To the Graduate Council:

I am submitting herewith a thesis written by Ghanem Saddalah Hassawy entitled "Lime-Fertilizer Placement Experiment on Alfalfa." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science with a major in Agronomy.

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LIME-FERTILIZER PLACEMENT EXPERIMENT ON ALFALFA

A Thesis

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

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by

Ghanem Saddalah Hassawy

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CHAPTER I

INTRODUCTION

Many greenhouse and field experiments have been conducted to investigate the effects on yield and nutrient content of different crops when lime and/or fertilizer are mixed in the surface layer of acid, infertile soils. Much less is known about the effects of incorporations of these nutrients in the subsoil.

Nutrients can be absorbed by plant roots at deep soil levels if they are available and can result in a pronounced effect both upon the quantity and quality of the crop. Hence, information concerning the nature of the subsoil and the pattern of root distribution in it can add materially to our understanding of crop production.

Root development and activity in the lower soil horizons has been investigated. Low crop production on soils with a hardpan or a tight subsoil is a common problem. The explanation frequently given for this low production centers around limited root development due to (a) the low fertility of the subsoil, (b) poor aeration, (c) the presence of a physical barrier preventing root penetration, or a combination of these factors.

Many investigations on the possibility of increasing crop yields by deep plowing or by subsoiling have shown no improvement in yield over that obtained by conventional tillage. Some recent studies in humid regions, however, have shown some benefits derived from deep tillage when lime and fertilizer were incorporated to greater depths. For example,

cotton and alfalfa have been studied in Tennessee (20), corn and oats in Iowa (12), corn in Illinois (9), and corn and sweet clover in Missouri (47).

The use of lime, and large amounts of phosphate and potash fertilizers is essential for satisfactory forage production on many of the highly acid soils of the southeastern United States.

Lime is generally credited with a dual role in acid soils. Its direct function is to correct soil acidity and improve soil structure, and thus create an environment suitable to the growth and development of the roots. At the same time it performs several indirect functions. It stimulates microbiological activity in the soil, thereby increasing the availability of nitrogen, phosphorus, and sulfur to plants. It reduces phosphorus fixation by precipitating aluminum and manganese from the soil solution. In some soils at least, lime is responsible for enhancing the availability of potassium. Within the plant, lime performs several important functions. Calcium is essential for the growth of the meristems, especially in the development and functioning of the root tips. It is also believed that calcium is concerned with certain enzymes involved in respiration.

The influence of lime on acid soils in promoting the growth, yield, and uptake of nutrients is of fundamental importance and immediate concern to agronomists. Therefore, experiments to investigate the effects of lime and/or fertilizer placement are very important in providing information on the wise use of these materials.

CHAPTER II

LITERATURE REVIEW

Despite the fact that liming of the soil is generally practiced in the humid section of the United States, most investigations on soil acidity and liming have been concerned with the plow layer only. Some investigators have attempted to correct subsoil acidity (8, 21, 29). For example, Pohlman (29) in West Virginia found that liming the 16-24 inch layer to approximate neutrality more than tripled the yield of alfalfa when the surface 0-8 inches had a pH of about 5.6. Approximately the same increases in crop yields were obtained when either the 0-8 or 8-16 inch layer was similarly limed. Root distribution was markedly affected by liming the subsurface horizons. The nodules on the roots were largely concentrated in the layer receiving the high lime treatment, irrespective of whether this was the 8- to 16-inch or the 16- to 24-inch layer. Pohlman observed a marked downward movement of lime not only from one layer to another, but also within the layer receiving lime.

Longenecker and Merkle (21) have reported that liming the top 6 inches gave the highest yields of sweet clover. However, there was not a marked yield response from placement of lime deeper than 3 inches, though the deeper and better root development resulting from 6-inch liming would undoubtedly have enabled the crop to endure drought and utilize more soil nutrients under field conditions. They concluded that for reasonably rapid results, lime compounds should be thoroughly mixed in the entire soil zone in which roots are expected to develop.

In recent field studies in humid regions, deep liming and fertilizing in addition to deep tillage resulted in much deeper root penetration and greater yields in most cases (8, 9, 20, 46, 47). For example, Fehrenbacher et al. (9) found in a 2-year study that fertilizer including limestone at the minimum rate increased corn yields an average of 40 bushels per acre over the check plots which were tilled to the same depth. There was no indication of a significant increase from higher fertilizer rates, greater depths of tillage, or fertilizer placement over that obtained with the first rate mixed in the upper 9 inches.

Woodruff and Smith (47), in Missouri, showed that mixing lime in the plow layer of a Mexico silt loam soil (claypan soil with an acid B horizon) improved growth and increased corn yields. Subsoil shattering alone appeared to have little effect on the growth of oats and sweet clover. They concluded that subsoil shattering with deep placement of lime and fertilizer offered a solution to the problem of growing corn on claypan soils.

In Wisconsin, Engelbert and Truog (8) compared the effect of deep plowing, subsoiling, and deep incorporation of lime and fertilizer over a 5-year period on a strongly acid and tight subsoil. They showed that deeper root penetration of alfalfa was promoted by subsoil liming and fertilizing, but not by subsoiling alone. Subsoil liming and fertilizing helped materially in establishing alfalfa during a dry year. Hay yields appeared to be increased by these treatments, but were not increased by subsoil treatment where the fertilizer was omitted. Yields of corn and oats appeared to be unaffected by any of the subsoil treatments.

Long (20), in Tennessee, has shown the importance of deep in-

corporation of lime and fertilizer on the growth and yield of cotton and alfalfa. He found that depth of rooting, weight of roots, total above-ground growth, and yield of seed cotton from deep incorporations exceeded the yields obtained from shallow incorporations at three locations. He pointed out that for a long time after stand establishment there was no observable difference in plant growth on the two treatments. It was late July or early August, when the soil had become very dry, before better growth was observed on the deep treatment. Alfalfa yields were decidedly better on the deep placement as the soil moisture stress increased. There was no consistent difference in the composition of the hay (N, P, K, Ca, and Mg) produced on the deep and shallow treatments.

Jamison, et al. (12) reviewed investigations in the Midwest on subsoiling, accompanied by liming and fertilizing. Corn, oats, sweet clover, and alfalfa were used as the test crops for many years. The results showed that the benefits from deep tillage and deep fertilization, when they occurred with corn, alfalfa, or other forage crops, were variable and relatively small. Considering the expense, the workers concluded it was doubtful that subsoiling could be justified, particularly when compared with the use of good fertility and management practices of the plow layer.

In some early investigations, deep tillage accompanied by fertilization frequently resulted in increases in crop yields (1, 7, 11, 16, 31). For example, Robertson, et al. (31), in Florida, found that in dry years, the deeper placements produced significantly more corn than the shallow placements when the surface soil had residual fertilizer. In wet years the crop was able to get enough phosphorus from the residual

fertilizer to promote root penetration, and subsoiling alone was as effective as applied phosphorus in increasing the yield. These investigators concluded that the higher corn yield from deep placement may have been the result of the deeper root system, which permitted the crop to extract nutrients and water at greater depths.

Bertrand and Kohnke (1) have pointed out that a combination of loose subsoil, high moisture, and subsoil fertilization produced the greatest top and root growth of corn.

Dennis et al. (7) obtained a highly significant increase in the yields of alfalfa hay due to phosphorus treatment of all horizons (A, B, C, D) in four eastern Nebraska soils. The root yield also increased, but not as much as aboveground growth.

Kohnke and Bertrand (16), in Indiana, reported that the growth of corn roots greatly increased as a result of subsoil fertilization and that the subsoiled areas generally contained more moisture than the untreated plots. Yield increases from subsoil fertilization were substantial in many cases, but not consistent.

However, deep fertilizing has not always been accompanied by greater yields (3, 9, 19, 26, 40). Wahhab and Azim (40), in West Pakistan, have pointed out that placement of exchangeable ammonium-nitrogen 2 inches below the soil surface gave highest yields of paddy grains and total dry matter. Deeper placements induced vegetative growth more than grain formation. The total root yields were determined for each placement depth (0, 2, 4, 6, 9, 15 and 20 inches); it was found that no relation existed between grain yield and root yield.

Subsoiling as a means of increasing crop yields has been widely investigated over the past 15 to 20 years in many parts of the United States. Some yield increases have been obtained with deep tillage where a tight subsoil or hardpan limited root development in the deeper horizons. Little or no crop increases resulted from deep tillage where the subsoils were strongly acid and low in plant nutrients (8).

Results obtained by Moschler et al. (24) showed that lime was indispensable to yield and longevity of alfalfa. Increases in the rate of lime applied were accompanied by gradual increases in soil pH, exchangeable bases, and percentage base saturation. They also found that depth of root penetration did not appear to be a factor contributing to the benefits from liming.

Chin et al. (4) reported that alfalfa yields generally increased with an increase in the rate of liming. Liming had no apparent effect on total phosphorus content.

Lawton and Davis (17) showed that the phosphorus content of plants was progressively depressed by successive increments of $CaCO_3$, and that the percent of plant phosphorus derived from fertilizer was generally progressively reduced by increasing amounts of lime.

Thorp and Hobbs (39), in Kansas, found that lime applications significantly increased the calcium percentage in the alfalfa plant, but there was no significant change in magnesium uptake. Applications of lime had no apparent effect on the phosphorus content of the plant, but the uptake of phosphorus was greater from the limed than from the unlimed soil. Potash uptake was also increased by lime applications.

Results obtained by Lawton et al. (18) indicated that as the

rate of superphosphate was increased, the percentage of plant phosphorus derived from fertilizer also was increased, but the percentage recovery of applied phosphorus decreased. The percentage of phosphorus derived from superphosphate placed at various depths was related to depth of fertilizer placement. Absorption of fertilizer phosphorus was highest at the surface or 3-inch depth, intermediate at the 6-inch depth, and low for the 12-, 24-, and 36-inch placements.

Results by Robertson et al. (30) showed that calcium on peanuts gave significant yield responses three out of four years. Three tons per acre of dolomitic lime was better than one. One ton per acre of lime raised the pH from 5.3 to 5.6, while 3 tons raised the pH to 6.2. Their results also showed that phosphorus interacted with lime; less fertilizer phosphorus was necessary to give maximum yields on limed than on unlimed soil.

Jones et al. (14) found that the calcium in white clover was increased by additional increments of lime. There was a progressive increase in soil pH and exchangeable calcium at all locations as the rates of lime were increased.

Sewell and Latshaw (33) found that the effect of lime in changing soil reaction did not extend below the surface soil. Chemical analysis of the alfalfa showed that applications of superphosphate alone did not result in an increase in the percentage of phosphorus in the plant, but applications of both superphosphate and lime did result in an increase. However, their results showed that the potassium content of the plant decreased as the rate of liming was increased.

Dawson (6), in Oregon, reported that growth and yield response

of alfalfa generally increased with increasing base saturation levels in four contrasting soils, which he attributed to direct or indirect effects of lime. He found that soil pH readings at the same base saturation levels varied considerably with different soils, and that the pattern of alfalfa response to lime varied. He also pointed out that additional calcium supplied to isolated root sections independent of the soil, increased alfalfa yields significantly, while it decreased the manganese content of the foliage.

Mehlich et al. (23), in North Carolina, found that the availability of calcium increased with increasing degree of calcium saturation of clays. The type of colloid in the fruiting medium had a pronounced effect on the Ca level required for production of high quality peanuts.

Since the plant roots absorb water and nutrients from the different soil horizons, a knowledge of their development, extent, and activities, and how these are modified by changes in the soil environment are necessary for an understanding of plant production. Results obtained by Weaver et al. (44) and others (5, 25) have shown that corn and barley obtained at least as much and sometimes more of their nutrients from the subsoil as from the plow layer. Other studies were concentrated mainly on root distribution throughout the various soil horizons (20, 22, 43).

A considerable number of studies have dealt with the influence of different soil conditions (profile, depth, structure, aeration, moisture, reaction, and fertility) on the development of some field crops (10, 13, 20, 42). Fox et al. (10), in Nebraska, reported that during the first season roots of alfalfa penetrated more than 5 feet

into the limed soil, while those of unlimed alfalfa reached a maximum depth of only 36 inches. The unlimed alfalfa was very unproductive during the first year. They concluded that heavy subsoils which have an adequate supply of nutrient cations may be more important to legume nutrition than horizons near the surface which have more favorable physical properties but are less abundantly supplied with nutrients.

Watenpaugh (42), in Pennsylvania, found that the pH values of the lower layers were influenced materially by the calcium carbonate additions to the layers above. Root development was correlated definitely with the pH and with the replaceable calcium of the various soil layers. Under the conditions of his experiment, depth of root penetration was positively correlated with the yield of alfalfa.

CHAPTER III

MATERIALS AND METHODS

Nature of the Study

An experiment involving lime-fertilizer placement on alfalfa at 3 base saturation levels and at 2 rates of fertilization at 2 depths of incorporation was initiated at the University of Tennessee, Blount Farm in Blount County, Tennessee in midsummer of 1960. This study was designed with the following objectives:

1. To determine the optimum pH and base saturation levels for alfalfa.
2. To determine the effect of deeper-than-normal incorporation of lime and/or fertilizer on above and below-ground yields.

Alfalfa (Medicago sativa), was selected for the study because:

1. On acid soils it responds well to liming.
2. Its high requirements for nutrients.
3. Its relatively deep root system.

The experiment was laid out in 3 x 2 x 2 factorial design plus six extra treatments, each treatment being replicated three times. Plot size was 8 feet by 20 feet or 1/275.25 acre.

There were 3 lime treatments: (1) no lime, (2) liming of the soil to a calculated 100 percent base saturation, and (3) liming of the soil to a calculated 150 percent base saturation. Hydrated lime ($Ca(OH)_2$) was the liming material used. The amount of lime applied to the surface layer (0-6") and to the subsoil (6-12") differed due to

differences in the cation exchange capacity (C.E.C.) and the original percent base saturation of each layer. In terms of calcium carbonate ($CaCO_3$) applications of slightly over 2 tons per acre in the plow layer (0-6"), and slightly over 2 1/2 tons in the subsoil (6-12") were required for the calculated 100 percent base saturation level and about 4 1/4 tons per acre in the plow layer, and 4 3/4 tons in the subsoil were required for the calculated 150 percent base saturation level. In some treatments, both topsoil and subsoil were limed; in other treatments only the topsoil was limed. There were four unlimed treatments.

Phosphate and potash were applied at 2 rates: 0-87-166 and 0-174-332 (N-P-K) pounds per acre. Concentrated superphosphate (CSP) was used as a source of P, and muriate of potash as a source of K, except in one treatment (treatment 12A). Here, coarse potassium calcium pyrophosphate was used, supplemented with enough muriate of potash to match the required K fertilization. In some treatments these materials were incorporated only to a 6-inch depth. In other treatments they were incorporated both in the surface layer and in the subsoil. In one treatment (treatment 13), Florida rock phosphate and muriate of potash were applied in the unlimed subsoil at a rate of 262 pounds of P and 166 pounds of K per acre, while CSP and muriate of potash were applied in the limed surface soil.

Nitrogen and boron fertilization was constant at a rate of 30 pounds of nitrogen and 20 pounds of borax per acre. These materials were mixed in the surface layer only. Ammonium nitrate was used as a source of N and borax as a source of B. A list of all the treatments is given in Table 1.

Table 1.--List of treatments in lime-fertilizer experiment on alfalfa

Tmt. No.	Limed to base saturation of:	Depth of tillage	Depth of lime and/or PK incorporation	Rate of fertilization (Lb./acre)
		Inches	Inches	
1	Unlimed	12	6	30-87-166
2	"	12	12	30-87-166
3	"	12	6	30-174-332
4	"	12	12	30-174-332
5	100%	12	6	30-87-166
6	100%	12	12	30-87-166
7	100%	12	6	30-174-332
8	100%	12	12	30-174-332
9	150%	12	6	30-87-166
10	150%	12	12	30-87-166
11	150%	12	6	30-174-332
12	150%	12	12	30-174-332
3A	Unlimed	6	6	30-174-332
7A	100%	6	6	30-174-332
11A	150%	6	6	30-174-332
12A	150%	12	12	30-174-332*
13	150% 0-6" Unlimed 6-12"	12	Lime 0-6" PK 0-12"	30-87-166 (0-6") 0-262**-166 (6-12")
14	150%	12	Lime 0-12" PK 0-6"	30-174-332

*Using coarse potassium calcium pyrophosphate.

**Using Florida rock phosphate.

Soil Characteristics

The experiment was conducted on Alcoa loam, a soil formed from old local alluvium, derived chiefly from sandy limestone and calcareous shale. It is dark reddish-brown both in the plow layer and in the subsoil, but somewhat lighter in color in the subsoil and is well drained (profile 4). Its particle-size distribution is presented in Table 2. Its subsoil is a clay loam in texture. Some of the chemical characteristics of this soil are given in Table 3. It was slightly acid (pH 6.0) in the plow layer, and strongly acid (pH 5.2) in the subsoil.

Field Studies

Subsoil incorporation and surface application of lime and fertilizer. The experimental area had been seeded to Korean lespedeza (Lespedeza stipulacea) in the spring of 1960, but had made rather poor growth at the time the subsoil incorporation of lime and fertilizer was made on August 30, 1960. The required amounts of fertilizer and lime were placed on the bottom of the turned furrow made by a moldboard plow and was incorporated into the subsoil (6-to 12-inch depth) by means of a "rototiller-type" device (Figure 1). This process was repeated one furrow at a time until the entire area had been treated. A disk harrow was used to level the soil for the surface application. On September 2 (3 days after the subsoil incorporation), fertilizer and lime were applied on the soil surface followed by a disk harrow in order to mix these materials into the surface layer (0- to 6-inch depth). Alfalfa (DuPuits variety) was seeded on September 10 at a rate of 20 pounds per acre.

Alfalfa cutting and plant sampling. Four cuttings were made in

Table 2.--Particle-size distribution and texture of Alcoa loam

Depth	Sand	Coarse Silt	Fine Silt	Total Silt	Clay	Texture
Inches	%	%	%	%	%	
0-6	33.4	14.7	28.4	43.1	23.5	Loam
6-12	27.8	14.5	26.5	41.0	31.2	Clay loam

Table 3.--Some chemical properties of Alcoa loam

Soil layer	pH	Organic Matter Content	P	Exchangeable, m.e./100 gm.			
				K	Ca	Mg	C.E.C.
Inches		%	Lb./A.				
0-6	6.0	1.66	14	0.35	3.39	0.95	8.80
6-12	5.2	0.50	4	0.14	1.90	1.23	8.50



Figure 1.--"Rototiller-type" device used to incorporate lime and/or fertilizer in the subsoil.

1961: May 17, June 27, August 1, and September 12. The first cutting was made when the alfalfa was about one-half in bloom; this cutting was delayed because of rainy weather. The other three cuttings were made when the alfalfa was about one-tenth in bloom. The green weight of each cutting was recorded, then converted to tons of hay per acre on the basis of water loss by air drying several 5-pound green samples. The entire plot was harvested for the yield determinations.

Plant tissue samples (about 1/2-pound green weight) were taken from each plot before each cutting for plant analysis. Stems of from twelve to fifteen representative plants were cut from each plot and transferred to paper bags.

Soil sampling. Soil samples were taken from each plot on July 18-21, 1961 and determinations made for pH, available P and exchangeable K. The sampling was done with a soil sampling tube. The 0- to 6-inch and the 6- to 12-inch layers were sampled separately. Twelve to fifteen cores were obtained from the two layers of each plot and placed in paper bags.

Root studies. Alfalfa root studies were started on September 18, 1961 when the alfalfa stand was one year old (one year and eight days to be exact).

Depth of penetration by alfalfa roots was determined by digging a pit at the sampling site to a depth slightly below the deepest observed root. These pits were about 2 1/2 feet wide and 5 feet long--large enough to provide working space in digging. The soil containing roots was removed in successive layers beginning at the surface. These blocks

of soil were 6 inches wide and 18 inches long, an area of 0.75 square foot. The depth of these layers varied from 6 to 8 inches, but was usually 6 inches. Thus, in a 6-inch layer the dimensions of the soil block were 18 x 6 x 6 inches. The soil layers containing alfalfa roots were removed with a sharp knife (machete) and placed in containers.

These pits were dug along an 8-inch path that separated the plots from each other so that blocks of soil could be removed from each side of the pit. This provided the sampling of two plots for each pit dug. Three pits were dug, thus permitting a study of the root system in six treatments.

The soil containing roots was transported to a source of water where the roots were extricated from the soil in a washing barrel by a procedure described by Long (20).

Soil samples were taken from the various layers of soil throughout the entire depth of rooting and determinations made on particle-size distribution, organic matter content, pH, available P and exchangeable K.

Laboratory Studies

Particle-size distribution and organic matter determination.

Percentages sand, silt, and clay (Table 2), were determined by a modification of the pipette method as described by Kilmer and Alexander (15). Sedimentation times for the clay fraction were calculated using the nomograph of Tanner and Jackson (38). The initial soil organic matter content in the topsoil and subsoil (Table 3), was determined by the chromic acid oxidation method of Walkley and Black (41). Soil samples

collected in March 1959, were used for these two determinations.

Plant analysis. The plant tissue samples were oven dried (at 70° C for 24 hours), ground in a Wiley mill, and analyzed for their Ca, Mg, K, and P contents. Ca, Mg, and K were determined with the flame photometer by the method as described by Shaw and Veal (34); P was determined on the Fisher electrophotometer, using the method as described by Sterges et al. (36).

Soil tests. The soil samples collected in June 1961 were air dried and crushed to pass through a 2 mm. sieve. Soil pH, available P and exchangeable K were determined to observe the changes brought about by liming and/or fertilizing. Soil reaction (pH) was measured potentiometrically with a Beckman Zeromatic glass electrode pH meter. Determinations for P and K were made on a soil solution after extracting with 0.05N H_2SO_4, containing 1 percent $(NH_4)_2SO_4$; the soil-solution ratio was 1:4. P was determined with the Model B Beckman spectrophotometer, and K with the Perkin-Elmer flame photometer.

Root studies. After being washed completely free of soil, the roots were transferred to the laboratory and placed in a pan of water where debris (troublesome only in the plow layer) was removed with tweezers. Then the roots were oven-dried at 70° C for 24 hours. In weighing, a balance was used which was sensitive to 1/100 of a gram.

CHAPTER IV

RESULTS AND DISCUSSION

Forage Yields

The calculated hay yields of each of the 4 cuttings as well as the total yield for the year are presented in Tables 4 to 8. These data were subjected to analyses of variance as outlined by Snedecor (35). Since most of the discussion is limited to treatments 1-12, only these analyses are presented and they are shown in the appendix; however, the data were first analyzed using all 18 treatments. Treatment means for base saturation levels, depth of lime and/or fertilizer incorporation, and fertility level for each cutting are shown in Table 9.

In each cutting the lowest yields of alfalfa were obtained on the unlimed treatments. The highest yield was obtained where the soil was limed to a calculated 150 percent base saturation. For the experiment as a whole the highest yields were obtained in the first cutting and the lowest in the fourth cutting. Average hay yields varied from 1.70 to 2.13, 1.50 to 2.40, 0.90 to 1.70, and 0.19 to 0.44 tons per acre in the first to the fourth cutting, respectively (Tables 4-7). The lowest total yield was 4.45 tons of hay per acre on treatment 3, where no lime was applied and where the fertilization was at a rate of 30-174-332 (N-P-K) pounds per acre, and the highest total yield was 6.96 tons on treatment 13 where the soil was limed to a calculated 150 percent base saturation and where Florida rock phosphate was applied in the subsoil and concentrated superphosphate in the surface soil. In this treatment

Table 4.---First cutting yields of alfalfa (May 17, 1961)
(Acre yields of hay)

Tmt. No.	Limed to base saturation of:	Depth of tillage	Depth of lime and/or PK incorporation	Rate of fertilization (Lb./acre)	Replication			Av. of 3 reps.
					1	2	3	
		Inches	Inches		Tons	Tons	Tons	Tons
1	Unlimed	12	6	30-87-166	2.61	1.85	0.63	1.70
2	"	12	12	30-87-166	2.56	1.84	1.00	1.80
3	"	12	6	30-174-332	2.42	2.05	0.92	1.80
4	"	12	12	30-174-332	2.50	2.15	0.49	1.71
5	100%	12	6	30-87-166	1.96	2.28	2.21	2.15
6	100%	12	12	30-87-166	2.76	2.30	2.58	2.55
7	100%	12	6	30-174-332	2.12	2.27	2.28	2.22
8	100%	12	12	30-174-332	2.41	1.68	2.33	2.14
9	150%	12	6	30-87-166	2.20	2.11	1.83	2.05
10	150%	12	12	30-87-166	2.12	1.96	1.94	2.00
11	150%	12	6	30-174-332	2.36	2.96	2.16	2.49
12	150%	12	12	30-174-332	2.51	2.88	2.23	2.54
3A	Unlimed	6	6	30-174-332	2.37	2.26	1.41	2.01
7A	100%	6	6	30-174-332	2.85	2.24	1.75	2.28
11A	150%	6	6	30-174-332	2.49	2.31	2.03	2.28
12A	150%	12	12	30-174-332*	2.23	2.51	2.26	2.33
13	150% 0-6" Unlimed 6-12"	12	Lime 0-6" PK 0-12"	30-87-166 (0-6") 0-262**-166 (6-12")	2.88	2.57	2.45	2.63
14	150%	12	Lime 0-12" PK 0-6"	30-174-332	2.25	2.36	2.34	2.32

*Using coarse potassium calcium pyrophosphate.

**Using Florida rock phosphate.

Table 5.--Second cutting yields of alfalfa (June 27, 1961)
(Acre yields of hay)

Tmt. No.	Limed to base saturation of:	Depth of tillage	Depth of lime and/or PK incorporation	Rate of fertilization (Lb./acre)	Replication 1	2	3	Av. of 3 reps.
		Inches	Inches		Tons	Tons	Tons	Tons
1	Unlimed	12	6	30-87-166	2.19	2.57	0.50	1.75
2	"	12	12	30-87-166	2.42	2.53	0.64	1.86
3	"	12	6	30-174-332	2.11	1.94	0.65	1.57
4	"	12	12	30-174-332	2.14	2.08	0.28	1.50
5	100%	12	6	30-87-166	1.87	2.31	1.96	2.05
6	100%	12	12	30-87-166	2.30	2.30	2.41	2.37
7	100%	12	6	30-174-332	2.05	1.96	1.84	1.95
8	100%	12	12	30-174-332	2.23	1.80	1.86	1.96
9	150%	12	6	30-87-166	2.17	2.20	1.67	2.01
10	150%	12	12	30-87-166	1.79	1.75	2.12	1.89
11	150%	12	6	30-174-332	2.30	2.49	2.23	2.34
12	150%	12	12	30-174-332	1.22	2.40	2.27	1.96
3A	Unlimed	6	6	30-174-332	2.12	2.08	1.14	1.78
7A	100%	6	6	30-174-332	1.84	1.83	2.10	1.92
11A	150%	6	6	30-174-332	2.34	2.53	2.26	2.38
12A	150%	12	12	30-174-332*	1.63	1.94	1.94	1.84
13	150% 0-6" Unlimed 6-12"	12	Lime 0-6" PK 0-12"	30-87-166 (0-6") 0-262**-166 (6-12")	2.24	2.37	2.60	2.40
14	150%	12	Lime 0-12" PK 0-6"	30-174-332	2.02	1.17	2.10	1.76

*Using coarse potassium calcium pyrophosphate.

**Using Florida rock phosphate.

Table 6.--Third cutting yields of alfalfa (August 1, 1961)
(Acre yields of hay)

Tmt. No.	Limed to base saturation of:	Depth of tillage	Depth of lime and/or PK incorporation	Rate of fertilization (Lb./acre)	Replication 1	Replication 2	Replication 3	Av. of 3 reps.
		Inches	Inches		Tons	Tons	Tons	Tons
1	Unlimed	12	6	30-87-166	1.83	1.12	0.42	1.12
2	"	12	12	30-87-166	1.43	1.13	0.51	1.02
3	"	12	6	30-174-332	1.01	1.35	0.34	0.90
4	"	12	12	30-174-332	1.65	1.21	0.37	1.08
5	100%	12	6	30-87-166	1.58	1.47	1.28	1.44
6	100%	12	12	30-87-166	1.89	1.40	1.64	1.64
7	100%	12	6	30-174-332	1.51	1.40	1.61	1.51
8	100%	12	12	30-174-332	1.48	1.39	1.77	1.54
9	150%	12	6	30-87-166	1.21	1.47	1.41	1.36
10	150%	12	12	30-87-166	1.33	1.35	1.71	1.46
11	150%	12	6	30-174-332	1.81	2.01	1.21	1.68
12	150%	12	12	30-174-332	1.99	1.84	1.30	1.70
3A	Unlimed	6	6	30-174-332	1.50	1.73	1.07	1.43
7A	100%	6	6	30-174-332	1.73	1.40	1.59	1.58
11A	150%	6	6	30-174-332	1.36	1.42	1.47	1.42
12A	150%	12	12	30-174-332*	1.30	1.96	1.54	1.60
13	150% 0-6" Unlimed 6-12"	12	Lime 0-6" PK 0-12"	30-87-166 (0-6") 0-262**-166 (6-12")	1.38	1.56	1.66	1.53
14	150%	12	Lime 0-12" PK 0-6"	30-174-332	1.58	1.56	1.59	1.58

*Using coarse potassium calcium pyrophosphate.

**Using Florida rock phosphate.

Table 7.--Fourth cutting yields of alfalfa (Sept. 12, 1961)
(Acre yields of hay)

Trt. No.	Limed to base saturation of:	Depth of Tillage	Depth of lime and/or PK incorporation	Rate of fertilization (Lb./acre)	Replication 1	2	3	Av. of 3 reps.
		Inches	Inches		Tons	Tons	Tons	Tons
1	Unlimed	12	6	30-87-166	0.36	0.44	0.00	0.26
2	"	12	12	30-87-166	0.33	0.36	0.00	0.23
3	"	12	6	30-174-332	0.25	0.31	0.00	0.19
4	"	12	12	30-174-332	0.31	0.31	0.00	0.21
5	100%	12	6	30-87-166	0.40	0.48	0.21	0.36
6	100%	12	12	30-87-166	0.36	0.47	0.39	0.41
7	100%	12	6	30-174-332	0.25	0.29	0.39	0.31
8	100%	12	12	30-174-332	0.38	0.31	0.35	0.35
9	150%	12	6	30-87-166	0.31	0.29	0.26	0.29
10	150%	12	12	30-87-166	0.29	0.29	0.29	0.29
11	150%	12	6	30-174-332	0.46	0.58	0.29	0.44
12	150%	12	12	30-174-332	0.39	0.57	0.29	0.42
3A	Unlimed	6	6	30-174-332	0.46	0.29	0.27	0.34
7A	100%	6	6	30-174-332	0.44	0.32	0.29	0.35
11A	150%	6	6	30-174-332	0.47	0.47	0.32	0.42
12A	150%	12	12	30-174-332*	0.24	0.53	0.44	0.40
13	150% 0-6" Unlimed 6-12"	12	Lime 0-6" PK 0-12"	30-87-166 (0-6") 0-262**-166 (6-12")	0.38	0.46	0.34	0.39
14	150%	12	Lime 0-12" PK 0-6"	30-174-332	0.35	0.42	0.33	0.37

*Using coarse potassium calcium pyrophosphate.

**Using Florida rock phosphate.

Table 8.--Alfalfa production in 1961 (total of 4 cuttings)
(Acre yields of hay)

Tmt. No.	Limed to base saturation of:	Depth of Tillage	Depth of lime and/or PK incorporation	Rate of fertilization (Lb./acre)	Replication 1	Replication 2	Replication 3	Av. of 3 reps.
		Inches	Inches		Tons	Tons	Tons	Tons
1	Unlimed	12	6	30-87-166	6.99	5.98	1.55	4.84
2	"	12	12	30-87-166	6.74	5.86	2.15	4.92
3	"	12	6	30-174-332	5.79	5.65	1.91	4.45
4	"	12	12	30-174-332	6.60	5.75	1.14	4.50
5	100%	12	6	30-87-166	5.81	6.54	5.66	6.00
6	100%	12	12	30-87-166	7.31	6.48	7.02	6.94
7	100%	12	6	30-174-332	5.93	5.92	6.12	5.99
8	100%	12	12	30-174-332	6.50	5.18	6.31	6.00
9	150%	12	6	30-87-166	5.81	6.07	5.17	5.71
10	150%	12	12	30-87-166	5.53	5.35	6.06	5.65
11	150%	12	6	30-174-332	6.93	8.04	5.89	6.95
12	150%	12	12	30-174-332	6.11	7.69	6.09	6.63
3A	Unlimed	6	6	30-174-332	6.45	6.36	3.89	5.57
7A	100%	6	6	30-174-332	6.87	5.79	5.74	6.13
11A	150%	6	6	30-174-332	6.67	6.73	6.08	6.49
12A	150%	12	12	30-174-332*	5.40	6.95	6.18	6.18
13	150% 0-6" Unlimed 6-12"	12	Lime 0-6" PK 0-12"	30-87-166 (0-6") 0-262**-166 (6-12")	6.88	6.96	7.05	6.96
14	150%	12	Lime 0-12" PK 0-6"	30-174-332	6.20	5.51	6.36	6.02

*Using coarse potassium calcium pyrophosphate.

**Using Florida rock phosphate.

Table 9.--Treatment means of alfalfa hay yields by cuttings
(Hay yields tons/acre)

Treatment	Cuttings				
	First	Second	Third	Fourth	4 cuttings combined
Base saturation					
Unlimed	1.75	1.67	1.04	0.22	4.68
100%	2.26	2.07	1.54	0.36	6.23
150%	2.27	2.05	1.55	0.36	6.24
L.S.D. (5%)	0.41	N.S.	0.30	0.08	1.30
(1%)	0.56	N.S.	0.40	0.11	1.53
Depth of lime and/or fertilizer incorporation (Inches)					
0-6	2.06	1.94	1.33	0.31	5.65
0-12	2.12	1.92	1.41	0.31	5.77
L.S.D. (5%)	N.S.	N.S.	N.S.	N.S.	N.S.
Fertility level (N, P, K/acre)					
30-87-166	2.04	1.98	1.34	0.31	5.67
30-174-332	2.15	1.88	1.40	0.32	5.75
L.S.D. (5%)	N.S.	N.S.	N.S.	N.S.	N.S.

lime was incorporated only in the surface layer (Table 8).

The statistical analyses of the first twelve treatments reveal significant differences in the yield between the unlimed and limed treatments in the first cutting, and in the total yield of all cuttings, and highly significant differences between the unlimed and limed treatments in the third and fourth cuttings (Table 9). The favorable effect of lime on the production of alfalfa on this soil may be attributed to its influence in correcting such unfavorable soil factors as acidity and Al toxicity. Schmehl et al. (32) found that an excessive concentration of Al in the soil solution in an unlimed acid soil was a major factor limiting alfalfa growth. It is believed that as the soil acidity increases the nodule bacteria fail to function properly.

The statistical analysis of yield, however, showed no significant differences between the two rates of liming. Moschler et al. (24) found that each addition of lime generally resulted in increased alfalfa yields, but the yields were not significantly higher with higher rates of lime.

In the course of this study, alfalfa showed no significant differences in yield at the two rates of fertilization. However, in general, the highest yields were obtained where the soil was limed and fertilized at the higher rate. This lack of response at the higher rate of fertilization may possibly be due to the fact that the lower rate of fertilization was adequate, at least for the first production year. Wells et al. (45) reported on alfalfa fertilization at various rates of annual fertilization over a 5-year period, and reported that significant differences in yield were obtained between 0- and the 100-pound-per-acre annual application of potash and between the 0- and the 60-pound-per-

acre annual application of phosphate. No significant yield response was obtained to higher rates of potash and phosphate.

No significant differences in yields were found between the 6-inch and 12-inch depth of lime and/or fertilizer incorporation. This failure to respond to subsoil incorporation could be expected for two reasons: (1) Alcoa loam is not a claypan soil; the clay content increases with depth (as will be shown later), and (2) there were no critical dry periods during the growing season of alfalfa in 1961. Woodruff et al. (47) have shown that deep liming and/or fertilizing resulted in deeper root penetration and increases in crop yields, especially on claypan soils, in dry years. Although the experiment reported here is only in its first year and must be considered as a beginning, it gives no encouragement to the belief that deeper-than-normal incorporation of lime and/or fertilizer on Alcoa loam will result in increased alfalfa yields under the two conditions just mentioned.

Treatments 3A, 7A, and 11A are the same as their counterparts, treatments 3, 7, and 11, except that in the former group the depth of tillage in preparing the area for seeding was 12 inches, while in the latter group the depth of tillage was 6 inches. A significant difference in yield between the two groups could have been attributed to depth of tillage. Since the yields on the 12-inch tillage treatments were less than those on the 6-inch tillage treatments in two out of three cases, it can be assumed that the deeper tillage was of no particular benefit. One explanation for the lack of response to deeper tillage is the acid reaction of the unlimed subsoil (pH 5.2). Deeper tillage without liming and fertilizing has seldom resulted in lasting advantages unless

the nature of the soil profile is radically changed. This occurs especially where a claypan layer is broken up. However, this was not the case in Alcoa loam.

The yields on treatments 13 and 14 (Table 8) are of some interest. In treatment 13 the soil was fertilized to a depth of 12 inches but limed to a depth of only 6 inches. Rock phosphate and muriate of potash were mixed with the acid subsoil (at rates of 262 pounds of P and 166 pounds of K per acre). As far as depth of tillage and depth of P and K incorporation are concerned, this treatment is like treatment 12. In treatment 14 the soil was limed to 150 percent base saturation to a depth of 12 inches, but P and K were mixed only in the surface 6 inches. While the highest total yield of alfalfa was obtained on treatment 13, its yield was essentially the same as the yields on treatments 6 and 11. On the basis of the performance of treatment 14 it can be concluded that there was no advantage in liming to full depth and fertilizing only the surface 6 inches.

Nitrogen fixation by legume is markedly influenced by soil reaction. In the present study, it was observed that the unlimed alfalfa had shorter and paler growth after the second cutting. In some plots, the alfalfa had almost completely disappeared at the time of the fourth cutting and these plots were composed largely of crabgrass and weeds. Where the soil was limed, the color of alfalfa was generally dark green. This was presumed to be related to the nitrogen nutrition of the plants, i.e., more nodulation and N fixation.

As an average of all treatments the hay yield obtained in the present study was 5.89 tons per acre. This is a high yield when com-

pared with Tennessee's average yield of 2 1/2 to 3 tons, but yields of 4 and 5 tons are not uncommon under proper fertilization and management.

Nutrient Content of Forage

Data showing the P, K, Ca, and Mg contents of the forage produced in each of the 4 cuttings on the various treatments are given in Tables 10-13, 15-18, 20-23, and 25-28, respectively. The data on P, K, and Ca were subjected to statistical analysis using the analysis of variance. Treatment means for P, K, and Ca contents at the three base saturation levels, at the two depths of lime and/or fertilizer incorporation, and at the two levels of fertility for each cutting are given in Tables 14, 19, and 24, respectively.

Phosphorus. The average P content of the forage varied from 0.22 to 0.26, 0.24 to 0.28, 0.25 to 0.29, and 0.23 to 0.27 percent in the first to the fourth cutting, respectively (Tables 10-13).

Statistical analyses of treatments 1-12 show that the higher rate of fertilization resulted in significant increases in P content in the second and fourth cuttings and highly significant increases in the first cutting (Table 14). The increase in the percentage of P in the alfalfa plant in this study was mainly due to the low level of available and reserve P in this soil (Table 3), and to the responsiveness of alfalfa to P fertilization.

Liming the soil, however, did not appear to affect the P content of the forage, there being about the same concentration of P in the forage produced on the unlimed soil as in that produced on the limed

Table 10.--Phosphorus (P) content of alfalfa forage on Alcoa loam, first cutting (Oven-dry basis)

Tmt. No.	Limed to base saturation of:	Depth of tillage	Depth of lime and/or PK incorporation	Rate of fertilization (Lb./acre)	Replication 1	Replication 2	Replication 3	Av. of 3 reps.
		Inches	Inches		%	%	%	%
1	Unlimed	12	6	30-87-166	0.23	0.20	0.31	0.25
2	"	12	12	30-87-166	0.22	0.18	0.29	0.23
3	"	12	6	30-174-332	0.25	0.24	0.29	0.26
4	"	12	12	30-174-332	0.24	0.24	0.31	0.26
5	100%	12	6	30-87-166	0.22	0.24	0.25	0.24
6	100%	12	12	30-87-166	0.20	0.23	0.23	0.22
7	100%	12	6	30-174-332	0.26	0.27	0.25	0.26
8	100%	12	12	30-174-332	0.25	0.25	0.27	0.26
9	150%	12	6	30-87-166	0.20	0.23	0.23	0.22
10	150%	12	12	30-87-166	0.22	0.23	0.23	0.23
11	150%	12	6	30-174-332	0.24	0.23	0.25	0.24
12	150%	12	12	30-174-332	0.24	0.26	0.25	0.25
3A	Unlimed	6	6	30-174-332	0.25	0.25	0.28	0.26
7A	100%	6	6	30-174-332	0.25	0.25	0.25	0.25
11A	150%	6	6	30-174-332	0.25	0.25	0.25	0.25
12A	150%	12	12	30-174-332*	0.22	0.25	0.26	0.24
13	150% 0-6" Unlimed 6-12"	12	Lime 0-6" PK 0-12"	30-87-166 (0-6") 0-262**-166 (6-12")	0.26	0.26	0.26	0.26
14	150%	12	Lime 0-12" PK 0-6"	30-174-332	0.24	0.26	0.24	0.25

*Using coarse potassium calcium pyrophosphate.

**Using Florida rock phosphate.

Table 11.--Phosphorus (P) content of alfalfa forage on Alcoa loam, second cutting
(Oven-dry basis)

Tmt. No.	Limed to base saturation of:	Depth of tillage	Depth of lime and/or PK incorporation	Rate of fertilization (Lb./acre)	Replication 1	Replication 2	Replication 3	Av. of 3 reps.
		Inches	Inches		%	%	%	%
1	Unlimed	12	6	30-87-166	0.26	0.22	0.30	0.26
2	"	12	12	30-87-166	0.24	0.23	0.27	0.25
3	"	12	6	30-174-332	0.27	0.26	0.28	0.27
4	"	12	12	30-174-332	0.27	0.29	0.26	0.27
5	100%	12	6	30-87-166	0.25	0.26	0.26	0.26
6	100%	12	12	30-87-166	0.25	0.25	0.25	0.25
7	100%	12	6	30-174-332	0.28	0.28	0.26	0.27
8	100%	12	12	30-174-332	0.27	0.27	0.27	0.27
9	150%	12	6	30-87-166	0.26	0.28	0.25	0.26
10	150%	12	12	30-87-166	0.26	0.25	0.28	0.26
11	150%	12	6	30-174-332	0.25	0.24	0.28	0.26
12	150%	12	12	30-174-332	0.26	0.28	0.26	0.27
3A	Unlimed	6	6	30-174-332	0.27	0.29	0.26	0.27
7A	100%	6	6	30-174-332	0.29	0.29	0.26	0.28
11A	150%	6	6	30-174-332	0.28	0.28	0.26	0.27
12A	150%	12	12	30-174-332*	0.24	0.23	0.26	0.24
13	150% 0-6" Unlimed 6-12"	12	Lime 0-6" PK 0-12"	30-87-166 (0-6") 0-262**-166 (6-12")	0.25	0.28	0.29	0.27
14	150%	12	Lime 0-12" PK 0-6"	30-174-332	0.27	0.26	0.25	0.26

*Using coarse potassium calcium pyrophosphate.

**Using Florida rock phosphate.

Table 12.--Phosphorus (P) content of alfalfa forage on Alcoa loam, third cutting (Oven-dry basis)

Tmt. No.	Limed to base saturation of:	Depth of tillage	Depth of lime and/or PK incorporation	Rate of fertilization (Lb./acre)	Replication 1	Replication 2	Replication 3	Av. of 3 reps.
		Inches	Inches		%	%	%	%
1	Unlimed	12	6	30-87-166	0.28	0.25	0.31	0.28
2	"	12	12	30-87-166	0.26	0.21	0.29	0.25
3	"	12	6	30-174-332	0.29	0.26	0.31	0.29
4	"	12	12	30-174-332	0.26	0.29	0.27	0.27
5	100%	12	6	30-87-166	0.26	0.27	0.28	0.27
6	100%	12	12	30-87-166	0.27	0.27	0.28	0.27
7	100%	12	6	30-174-332	0.27	0.28	0.28	0.28
8	100%	12	12	30-174-332	0.27	0.25	0.29	0.27
9	150%	12	6	30-87-166	0.26	0.27	0.27	0.27
10	150%	12	12	30-87-166	0.28	0.29	0.30	0.29
11	150%	12	6	30-174-332	0.25	0.27	0.30	0.27
12	150%	12	12	30-174-332	0.28	0.28	0.29	0.28
3A	Unlimed	6	6	30-174-332	0.25	0.31	0.31	0.29
7A	100%	6	6	30-174-332	0.29	0.29	0.30	0.29
11A	150%	6	6	30-174-332	0.27	0.28	0.29	0.28
12A	150%	12	12	30-174-332*	0.26	0.27	0.27	0.27
13	150% 0-6" Unlimed 6-12"	12	Lime 0-6" PK 0-12"	30-87-166 (0-6") 0-262**-166 (6-12")	0.26	0.27	0.28	0.27
14	150%	12	Lime 0-12" PK 0-6"	30-174-332	0.27	0.27	0.27	0.27

*Using coarse potassium calcium pyrophosphate.

**Using Florida rock phosphate.

Table 13.--Phosphorus (P) content of alfalfa forage on Alcoa loam, fourth cutting (Oven-dry basis)

Tmt. No.	Limed to base saturation of:	Depth of tillage	Depth of lime and/or PK incorporation	Rate of fertilization (Lb./acre)	Replication 1	Replication 2	Replication 3	Av. of 3 reps.
		Inches	Inches		%	%	%	%
1	Unlimed	12	6	30-87-166	0.25	0.23	----	0.24
2	"	12	12	30-87-166	0.24	0.22	----	0.23
3	"	12	6	30-174-332	0.27	0.27	----	0.27
4	"	12	12	30-174-332	0.25	0.25	----	0.25
5	100%	12	6	30-87-166	0.24	0.24	0.26	0.25
6	100%	12	12	30-87-166	0.25	0.24	0.24	0.24
7	100%	12	6	30-174-332	0.25	0.25	0.24	0.25
8	100%	12	12	30-174-332	0.25	0.24	0.26	0.25
9	150%	12	6	30-87-166	0.24	0.24	0.24	0.24
10	150%	12	12	30-87-166	0.25	0.23	0.27	0.25
11	150%	12	6	30-174-332	0.22	0.23	0.26	0.24
12	150%	12	12	30-174-332	0.25	0.27	0.28	0.27
3A	Unlimed	6	6	30-174-332	0.23	0.27	0.29	0.26
7A	100%	6	6	30-174-332	0.25	0.25	0.25	0.25
11A	150%	6	6	30-174-332	0.24	0.26	0.26	0.25
12A	150%	12	12	30-174-332*	0.23	0.23	0.22	0.23
13	150% 0-6" Unlimed 6-12"	12	Lime 0-6" PK 0-12"	30-87-166 (0-6") 0-262**-166 (6-12")	0.24	0.24	0.26	0.25
14	150%	12	Lime 0-12" PK 0-6"	30-174-332	0.24	0.26	0.22	0.24

*Using coarse potassium calcium pyrophosphate.

**Using Florida rock phosphate.

Table 14.--Treatment means of P content of alfalfa forage by cuttings
(P content, %)

Treatment	Cuttings			
	First	Second	Third	Fourth
Base saturation				
Unlimed	0.25	0.26	0.27	0.24
100%	0.24	0.26	0.27	0.24
150%	0.23	0.26	0.28	0.24
L.S.D. (5%)	N.S.	N.S.	N.S.	N.S.
Depth of lime and/or fertilizer incorporation (Inches)				
0-6	0.24	0.26	0.28	0.24
0-12	0.24	0.26	0.27	0.24
L.S.D. (5%)	N.S.	N.S.	N.S.	N.S.
Fertility level (N, P, K/acre)				
30-87-166	0.23	0.25	0.27	0.24
30-174-332	0.26	0.27	0.28	0.25
L.S.D. (5%)	0.02	0.01	N.S.	N.S.
(1%)	0.02	0.02		

Table 15.--Potassium (K) content of alfalfa forage on Alcoa loam, first cutting (Oven-dry basis)

Tmt. No.	Limed to base saturation of:	Depth of tillage	Depth of lime and/or PK incorporation	Rate of fertilization (Lb./acre)	Replication 1	2	3	Av. of 3 reps.
		Inches	Inches		%	%	%	%
1	Unlimed	12	6	30-87-166	2.10	2.75	3.15	2.66
2	"	12	12	30-87-166	2.20	2.60	2.80	2.53
3	"	12	6	30-174-332	2.60	2.10	3.20	2.63
4	"	12	12	30-174-332	2.65	2.60	3.20	2.82
5	100%	12	6	30-87-166	2.30	2.80	2.65	2.58
6	100%	12	12	30-87-166	2.05	2.40	2.60	2.35
7	100%	12	6	30-174-332	2.60	2.60	2.50	2.57
8	100%	12	12	30-174-332	2.45	2.25	2.55	2.42
9	150%	12	6	30-87-166	2.60	2.45	2.40	2.48
10	150%	12	12	30-87-166	2.25	2.00	2.35	2.20
11	150%	12	6	30-174-332	2.45	2.60	2.65	2.57
12	150%	12	12	30-174-332	2.40	2.60	2.65	2.55
3A	Unlimed	6	6	30-174-332	2.95	2.60	2.85	2.80
7A	100%	6	6	30-174-332	2.50	2.45	2.65	2.53
11A	150%	6	6	30-174-332	2.50	2.85	2.80	2.72
12A	150%	12	12	30-174-332*	2.00	2.75	2.85	2.53
13	150% 0-6" Unlimed 6-12"	12	Lime 0-6" PK 0-12"	30-87-166 (0-6") 0-262**-166 (6-12")	2.65	2.65	2.75	2.68
14	150%	12	Lime 0-12" PK 0-6"	30-174-332	2.25	2.80	2.80	2.62

*Using coarse potassium calcium pyrophosphate.

**Using Florida rock phosphate.

Table 16.--Potassium (K) content of alfalfa forage on Alcoa loam, second cutting (Oven-dry basis)

Tmt. No.	Limed to base saturation of:	Depth of tillage	Depth of lime and/or PK incorporation	Rate of fertilization (Lb./acre)	Replication 1	2	3	Av. of 3 reps.
		Inches	Inches		%	%	%	%
1	Unlimed	12	6	30-87-166	2.75	2.90	2.90	2.85
2	"	12	12	30-87-166	2.50	3.15	2.95	2.86
3	"	12	6	30-174-332	2.90	3.25	3.15	3.10
4	"	12	12	30-174-332	2.95	3.05	2.85	2.95
5	100%	12	6	30-87-166	2.85	2.85	2.85	2.85
6	100%	12	12	30-87-166	2.55	2.55	2.95	2.68
7	100%	12	6	30-174-332	2.95	2.75	2.90	2.86
8	100%	12	12	30-174-332	3.05	2.70	2.90	2.88
9	150%	12	6	30-87-166	2.60	2.35	2.30	2.41
10	150%	12	12	30-87-166	2.55	2.20	2.40	2.38
11	150%	12	6	30-174-332	2.85	3.15	2.90	2.96
12	150%	12	12	30-174-332	2.80	2.90	2.95	2.88
3A	Unlimed	6	6	30-174-332	3.35	2.95	3.25	3.18
7A	100%	6	6	30-174-332	2.90	2.95	3.30	3.05
11A	150%	6	6	30-174-332	2.80	2.85	3.25	2.96
12A	150%	12	12	30-174-332*	2.30	2.75	3.00	2.68
13	150% 0-6" Unlimed 6-12"	12	Lime 0-6" PK 0-12"	30-87-166 (0-6") 0-262**-166 (6-12")	2.80	2.95	3.00	2.91
14	150%	12	Lime 0-12" PK 0-6"	30-174-332	2.75	2.95	3.05	2.91

*Using coarse potassium calcium pyrophosphate.

**Using Florida rock phosphate.

Table 17.--Potassium (K) content of alfalfa forage on Alcoa loam, third cutting
(Oven-dry basis)

Tmt. No.	Limed to base saturation of:	Depth of tillage	Depth of lime and/or PK incorporation	Rate of fertilization (Lb./acre)	Replication 1	Replication 2	Replication 3	Av. of 3 reps.
		Inches	Inches		%	%	%	%
1	Unlimed	12	6	30-87-166	2.45	2.10	3.05	2.50
2	"	12	12	30-87-166	2.05	2.25	2.75	2.35
3	"	12	6	30-174-332	2.75	2.60	2.95	2.80
4	"	12	12	30-174-332	2.75	2.50	2.85	2.70
5	100%	12	6	30-87-166	2.70	2.65	2.15	2.50
6	100%	12	12	30-87-166	2.45	2.35	2.35	2.38
7	100%	12	6	30-174-332	2.75	2.70	2.85	2.80
8	100%	12	12	30-174-332	2.60	2.55	2.60	2.58
9	150%	12	6	30-87-166	1.90	2.30	2.20	2.13
10	150%	12	12	30-87-166	2.30	2.10	2.20	2.20
11	150%	12	6	30-174-332	2.85	2.80	2.65	2.80
12	150%	12	12	30-174-332	2.80	2.60	2.45	2.62
3A	Unlimed	6	6	30-174-332	2.90	2.80	3.05	2.92
7A	100%	6	6	30-174-332	2.65	2.80	2.95	2.80
11A	150%	6	6	30-174-332	2.85	2.45	2.95	2.75
12A	150%	12	12	30-174-332*	2.70	2.55	3.10	2.78
13	150% 0-6" Unlimed 6-12"	12	Lime 0-6" PK 0-12"	30-87-166 (0-6") 0-262**-166 (6-12")	2.90	2.65	2.65	2.70
14	150%	12	Lime 0-12" PK 0-6"	30-174-332	2.60	2.50	2.75	2.62

*Using coarse potassium calcium pyrophosphate.

**Using Florida rock phosphate.

Table 18.--Potassium (K) content of alfalfa forage on Alcoa loam, fourth cutting (Oven-dry basis)

Tmt. No.	Limed to base saturation of:	Depth of tillage	Depth of lime and/or PK incorporation	Rate of fertilization (Lb./acre)	Replication 1	Replication 2	Replication 3	Av. of 3 reps.
		Inches	Inches		%	%	%	%
1	Unlimed	12	6	30-87-166	2.00	1.90	----	1.95
2	"	12	12	30-87-166	1.85	1.95	----	1.90
3	"	12	6	30-174-332	2.75	2.55	----	2.65
4	"	12	12	30-174-332	2.30	2.25	----	2.28
5	100%	12	6	30-87-166	2.45	2.40	2.00	2.28
6	100%	12	12	30-87-166	2.00	2.05	2.20	2.08
7	100%	12	6	30-174-332	2.65	2.55	2.95	2.72
8	100%	12	12	30-174-332	2.35	2.80	2.75	2.63
9	150%	12	6	30-87-166	1.75	2.05	2.65	2.15
10	150%	12	12	30-87-166	1.75	1.95	2.10	1.93
11	150%	12	6	30-174-332	3.00	2.75	2.45	2.73
12	150%	12	12	30-174-332	2.45	2.40	2.35	2.40
3A	Unlimed	6	6	30-174-332	3.10	2.65	2.90	2.88
7A	100%	6	6	30-174-332	2.85	2.85	2.90	2.87
11A	150%	6	6	30-174-332	2.85	2.50	2.96	2.77
12A	150%	12	12	30-174-332*	2.50	2.35	2.85	2.57
13	150% 0-6" Unlimed 6-12"	12	Lime 0-6" PK 0-12"	30-87-166 (0-6") 0-262**-166 (6-12")	2.85	2.55	2.60	2.67
14	150%	12	Lime 0-12" PK 0-6"	30-174-332	2.35	2.45	2.55	2.45

*Using coarse potassium calcium pyrophosphate.

**Using Florida rock phosphate.

Table 19.--Treatment means of K content of alfalfa forage by cuttings
(K content, %)

Treatment	Cuttings			
	First	Second	Third	Fourth
Base saturation				
Unlimed	2.75	2.94	2.58	2.40
100%	2.48	2.82	2.55	2.26
150%	2.45	2.66	2.43	2.19
L.S.D. (5%)	0.18	0.17	N.S.	0.16
(1%)	0.24	0.23		0.23
Depth of lime and/or fertilizer incorporation (Inches)				
0-6	2.64	2.84	2.58	2.40
0-12	2.48	2.77	2.47	2.17
L.S.D. (5%)	0.15	N.S.	N.S.	0.13
(1%)	N.S.			0.19
Fertility level (N, P, K/acre)				
30-87-166	2.47	2.67	2.35	2.00
30-174-332	2.65	2.94	2.70	2.56
L.S.D. (5%)	0.15	0.14	0.16	0.13
(1%)	N.S.	0.19	0.21	0.19

Table 20.--Calcium (Ca) content of alfalfa forage on Alcoa loam, first cutting
(Oven-dry basis)

Tmt. No.	Limed to base saturation of:	Depth of tillage	Depth of lime and/or PK incorporation	Rate of fertilization (Lb./acre)	Replication 1	2	3	Av. of 3 reps.
			...ches		%	%	%	%
			6	30-87-166	2.10	1.85	1.45	1.80
			12	30-87-166	2.25	1.60	1.55	1.80
			6	30-174-332	2.15	1.50	1.55	1.73
			12	30-174-332	2.15	1.65	1.45	1.75
			6	30-87-166	2.25	2.05	2.05	2.12
			12	30-87-166	2.40	2.30	2.25	2.32
			6	30-174-332	2.10	2.30	2.10	2.16
			12	30-174-332	2.40	2.55	1.95	2.30
			6	30-87-166	2.50	2.15	2.05	2.26
			12	30-87-166	2.75	2.60	2.15	2.50
			6	30-174-332	2.30	2.15	2.10	2.18
			12	30-174-332	2.15	2.30	2.15	2.20
			6	30-174-332	1.95	1.65	1.55	1.72
7A	100%	6	6	30-174-332	2.25	1.95	2.30	2.16
11A	150%	6	6	30-174-332	2.15	1.95	2.25	2.12
12A	150%	12	12	30-174-332*	2.70	2.15	2.25	2.36
13	150% 0-6" Unlimed 6-12"	12	Lime 0-6" PK 0-12"	30-87-166 (0-6") 0-262**-166 (6-12")	2.15	1.95	1.95	2.02
14	150%	12	Lime 0-12" PK 0-6"	30-174-332	2.30	2.20	2.20	2.26

*Using coarse potassium calcium pyrophosphate.

**Using Florida rock phosphate.

Table 21.--Calcium (Ca) content of alfalfa forage on Alcoa loam, second cutting (Oven-dry basis)

Tmt. No.	Limed to base saturation of:	Depth of tillage	Depth of lime and/or PK incorporation	Rate of fertilization (Lb./acre)	Replication 1	2	3	Av. of 3 reps.
		Inches	Inches		%	%	%	%
1	Unlimed	12	6	30-87-166	1.70	1.30	1.00	1.33
2	"	12	12	30-87-166	1.70	1.30	1.00	1.33
3	"	12	6	30-174-332	1.35	1.25	1.05	1.22
4	"	12	12	30-174-332	1.60	1.25	1.15	1.33
5	100%	12	6	30-87-166	1.75	1.70	1.55	1.66
6	100%	12	12	30-87-166	1.85	1.85	1.60	1.80
7	100%	12	6	30-174-332	1.85	1.75	1.60	1.70
8	100%	12	12	30-174-332	1.85	1.90	1.70	1.82
9	150%	12	6	30-87-166	1.95	1.95	1.80	1.90
10	150%	12	12	30-87-166	1.95	1.80	1.95	1.90
11	150%	12	6	30-174-332	1.80	1.45	1.50	1.58
12	150%	12	12	30-174-332	1.80	1.70	1.70	1.70
3A	Unlimed	6	6	30-174-332	1.25	1.60	0.95	1.27
7A	100%	6	6	30-174-332	1.55	1.60	1.45	1.50
11A	150%	6	6	30-174-332	1.70	1.60	1.55	1.62
12A	150%	12	12	30-174-332*	1.85	1.70	1.80	1.78
13	150% 0-6" Unlimed 6-12"	12	Lime 0-6" PK 0-12"	30-87-166 (0-6") 0-262**-166 (6-12")	1.60	1.45	1.45	1.50
14	150%	12	Lime 0-12" PK 0-6"	30-174-332	1.80	1.65	1.70	1.72

*Using coarse potassium calcium pyrophosphate.

**Using Florida rock phosphate.

Table 22.--Calcium (Ca) content of alfalfa forage on Alcoa loam, third cutting
(Oven-dry basis)

Tmt. No.	Limed to base saturation of:	Depth of tillage	Depth of lime and/or PK incorporation	Rate of fertilization (Lb./acre)	Replication 1	Replication 2	Replication 3	Av. of 3 reps.
		Inches	Inches		%	%	%	%
1	Unlimed	12	6	30-87-166	1.55	1.25	0.85	1.22
2	"	12	12	30-87-166	1.35	1.15	1.00	1.20
3	"	12	6	30-174-332	1.00	1.05	1.05	1.03
4	"	12	12	30-174-332	1.55	1.30	0.85	1.23
5	100%	12	6	30-87-166	1.80	1.65	1.50	1.65
6	100%	12	12	30-87-166	1.80	1.85	1.70	1.78
7	100%	12	6	30-174-332	1.55	1.95	1.45	1.65
8	100%	12	12	30-174-332	1.70	1.80	1.50	1.70
9	150%	12	6	30-87-166	2.00	1.95	1.95	1.97
10	150%	12	12	30-87-166	1.85	1.95	1.80	1.90
11	150%	12	6	30-174-332	1.55	1.65	1.60	1.60
12	150%	12	12	30-174-332	1.85	1.65	1.55	1.68
3A	Unlimed	6	6	30-174-332	1.30	1.35	0.95	1.20
7A	100%	6	6	30-174-332	1.70	1.65	1.30	1.55
11A	150%	6	6	30-174-332	1.10	1.55	1.40	1.35
12A	150%	12	12	30-174-332*	1.95	1.85	1.40	1.70
13	150% 0-6" Unlimed 6-12"	12	Lime 0-6" PK 0-12"	30-87-166 (0-6") 0-262**-166 (6-12")	1.30	1.95	1.50	1.58
14	150%	12	Lime 0-12" PK 0-6"	30-174-332	1.85	1.55	1.65	1.68

*Using coarse potassium calcium pyrophosphate.

**Using Florida rock phosphate.

Table 23.---Calcium (Ca) content of alfalfa forage on Alcoa loam, fourth cutting
(Oven-dry basis)

Tmt. No.	Limed to base saturation of:	Depth of tillage	Depth of lime and/or PK incorporation	Rate of fertilization (Lb./acre)	Replication 1	2	3	Av. of 3 reps.
		Inches	Inches		%	%	%	%
1	Unlimed	12	6	30-87-166	1.60	1.45	----	1.53
2	"	12	12	30-87-166	1.60	1.45	----	1.53
3	"	12	6	30-174-332	1.55	1.20	----	1.38
4	"	12	12	30-174-332	1.55	1.35	----	1.45
5	100%	12	6	30-87-166	1.65	1.60	1.45	1.57
6	100%	12	12	30-87-166	1.80	1.70	1.60	1.70
7	100%	12	6	30-174-332	1.60	1.45	1.45	1.50
8	100%	12	12	30-174-332	1.60	1.70	1.55	1.62
9	150%	12	6	30-87-166	1.80	1.60	1.65	1.68
10	150%	12	12	30-87-166	1.80	1.75	1.65	1.73
11	150%	12	6	30-174-332	1.60	1.55	1.60	1.58
12	150%	12	12	30-174-332	1.80	1.45	1.60	1.62
3A	Unlimed	6	6	30-174-332	1.45	1.40	1.10	1.32
7A	100%	6	6	30-174-332	1.60	1.35	1.40	1.45
11A	150%	6	6	30-174-332	1.55	1.60	1.35	1.50
12A	150%	12	12	30-174-332*	1.85	1.70	1.55	1.70
13	150% 0-6" Unlimed 6-12"	12	Lime 0-6" PK 0-12"	30-87-166 (0-6") 0-262**-166 (6-12")	1.60	1.65	1.40	1.55
14	150%	12	Lime 0-12" PK 0-6"	30-174-332	1.65	1.45	1.45	1.52

*Using coarse potassium calcium pyrophosphate.

**Using Florida rock phosphate.

Table 24.--Treatment means of Ca content of alfalfa forage by cuttings
(Ca content, %)

Treatment	Cuttings			
	First	Second	Third	Fourth
Base saturation				
Unlimed	1.77	1.30	1.17	1.47
100%	2.23	1.74	1.69	1.64
150%	2.28	1.77	1.78	1.67
L.S.D. (5%)	0.15	0.18	0.12	0.09
(1%)	0.21	0.24	0.17	0.13
Depth of lime and/or fertilizer incorporation (Inches)				
0-6	2.04	1.57	1.52	1.55
0-12	2.14	1.64	1.57	1.62
L.S.D. (5%)	N.S.	N.S.	N.S.	N.S.
Fertility level (N, P, K/acre)				
30-87-166	2.13	1.65	1.61	1.65
30-174-332	2.06	1.57	1.48	1.53
L.S.D. (5%)	N.S.	N.S.	0.10	0.08
(1%)			0.14	0.11

Table 25.--Magnesium (Mg) content of alfalfa forage on Alcoa loam, first cutting
(Oven-dry basis)

Tmt. No.	Limed to base saturation of:	Depth of tillage	Depth of lime and/or PK incorporation	Rate of fertilization (Lb./acre)	Replication 1	Replication 2	Replication 3	Av. of 3 reps.
		Inches	Inches		%	%	%	%
1	Unlimed	12	6	30-87-166	0.35	0.25	0.30	0.30
2	"	12	12	30-87-166	0.30	0.30	0.30	0.30
3	"	12	6	30-174-332	0.30	0.25	0.25	0.27
4	"	12	12	30-174-332	0.20	0.25	0.30	0.25
5	100%	12	6	30-87-166	0.20	0.20	0.25	0.22
6	100%	12	12	30-87-166	0.30	0.30	0.25	0.28
7	100%	12	6	30-174-332	0.25	0.30	0.20	0.25
8	100%	12	12	30-174-332	0.30	0.20	0.20	0.23
9	150%	12	6	30-87-166	0.25	0.20	0.25	0.23
10	150%	12	12	30-87-166	0.25	0.20	0.20	0.22
11	150%	12	6	30-174-332	0.20	0.20	0.25	0.22
12	150%	12	12	30-174-332	0.25	0.25	0.20	0.23
3A	Unlimed	6	6	30-174-332	0.20	0.20	0.20	0.20
7A	100%	6	6	30-174-332	0.20	0.25	0.20	0.22
11A	150%	6	6	30-174-332	0.20	0.25	0.25	0.23
12A	150%	12	12	30-174-332*	0.25	0.25	0.20	0.23
13	150% 0-6" Unlimed 6-12"	12	Lime 0-6" PK 0-12"	30-87-166 (0-6") 0-262**-166 (6-12")	0.25	0.25	0.25	0.25
14	150%	12	Lime 0-12" PK 0-6"	30-174-332	0.25	0.25	0.20	0.23

*Using coarse potassium calcium pyrophosphate.

**Using Florida rock phosphate.

Table 26.--Magnesium (Mg) content of alfalfa forage on Alcoa loam, second cutting (Oven-dry basis)

Tmt. No.	Limed to base saturation of:	Depth of tillage	Depth of lime and/or PK incorporation	Rate of fertilization (Lb./acre)	Replication 1	2	3	Av. of 3 reps.
		Inches	Inches		%	%	%	%
1	Unlimed	12	6	30-87-166	0.35	0.20	0.25	0.27
2	"	12	12	30-87-166	0.35	0.20	0.25	0.27
3	"	12	6	30-174-332	0.30	0.20	0.20	0.23
4	"	12	12	30-174-332	0.25	0.20	0.25	0.23
5	100%	12	6	30-87-166	0.30	0.25	0.15	0.23
6	100%	12	12	30-87-166	0.30	0.30	0.15	0.25
7	100%	12	6	30-174-332	0.35	0.25	0.20	0.27
8	100%	12	12	30-174-332	0.25	0.25	0.20	0.23
9	150%	12	6	30-87-166	0.20	0.35	0.20	0.25
10	150%	12	12	30-87-166	0.20	0.25	0.15	0.20
11	150%	12	6	30-174-332	0.15	0.15	0.15	0.15
12	150%	12	12	30-174-332	0.15	0.20	0.15	0.17
3A	Unlimed	6	6	30-174-332	0.25	0.20	0.20	0.22
7A	100%	6	6	30-174-332	0.25	0.20	0.15	0.20
11A	150%	6	6	30-174-332	0.20	0.20	0.15	0.18
12A	150%	12	12	30-174-332*	0.20	0.15	0.15	0.17
13	150% 0-6" Unlimed 6-12"	12	Lime 0-6" PK 0-12"	30-87-166 (0-6") 0-262**-166 (6-12")	0.20	0.35	0.15	0.23
14	150%	12	Lime 0-12" PK 0-6"	30-174-332	0.20	0.20	0.20	0.20

*Using coarse potassium calcium pyrophosphate.

**Using Florida rock phosphate.

Table 27.---Magnesium (Mg) content of alfalfa forage on Alcoa loam, third cutting
(Oven-dry basis)

Tmt. No.	Limed to base saturation of:	Depth of tillage	Depth of lime and/or PK incorporation	Rate of fertilization (Lb./acre)	Replication 1	2	3	Av. of 3 reps.
		Inches	Inches		%	%	%	%
1	Unlimed	12	6	30-87-166	0.35	0.40	0.30	0.35
2	"	12	12	30-87-166	0.30	0.30	0.25	0.28
3	"	12	6	30-174-332	0.25	0.35	0.25	0.28
4	"	12	12	30-174-332	0.25	0.30	0.25	0.27
5	100%	12	6	30-87-166	0.25	0.25	0.30	0.27
6	100%	12	12	30-87-166	0.30	0.25	0.25	0.27
7	100%	12	6	30-174-332	0.30	0.25	0.25	0.27
8	100%	12	12	30-174-332	0.30	0.30	0.15	0.25
9	150%	12	6	30-87-166	0.30	0.30	0.35	0.32
10	150%	12	12	30-87-166	0.25	0.30	0.30	0.28
11	150%	12	6	30-174-332	0.20	0.25	0.30	0.25
12	150%	12	12	30-174-332	0.25	0.25	0.30	0.27
3A	Unlimed	6	6	30-174-332	0.30	0.30	0.20	0.27
7A	100%	6	6	30-174-332	0.30	0.30	0.15	0.25
11A	150%	6	6	30-174-332	0.25	0.30	0.15	0.23
12A	150%	12	12	30-174-332*	0.30	0.30	0.20	0.27
13	150% 0-6" Unlimed 6-12"	12	Lime 0-6" PK 0-12"	30-87-166 (0-6") 0-262**-166 (6-12")	0.25	0.35	0.25	0.28
14	150%	12	Lime 0-12" PK 0-6"	30-174-332	0.25	0.25	0.20	0.23

*Using coarse potassium calcium pyrophosphate.

**Using Florida rock phosphate.

Table 28.--Magnesium (Mg) content of alfalfa forage on Alcoa loam, fourth cutting (Oven-dry basis)

Tmt. No.	Limed to base saturation of:	Depth of tillage	Depth of lime and/or PK incorporation	Rate of fertilization (Lb./acre)	Replication 1	Replication 2	Replication 3	Av. of 3 reps.
		Inches	Inches		%	%	%	%
1	Unlimed	12	6	30-87-166	0.45	0.50	----	0.48
2	"	12	12	30-87-166	0.45	0.55	----	0.50
3	"	12	6	30-174-332	0.40	0.40	----	0.40
4	"	12	12	30-174-332	0.40	0.45	----	0.43
5	100%	12	6	30-87-166	0.40	0.35	0.40	0.38
6	100%	12	12	30-87-166	0.40	0.40	0.40	0.40
7	100%	12	6	30-174-332	0.40	0.35	0.25	0.33
8	100%	12	12	30-174-332	0.35	0.40	0.25	0.33
9	150%	12	6	30-87-166	0.45	0.35	0.45	0.42
10	150%	12	12	30-87-166	0.45	0.40	0.40	0.42
11	150%	12	6	30-174-332	0.30	0.30	0.35	0.32
12	150%	12	12	30-174-332	0.40	0.30	0.35	0.35
3A	Unlimed	6	6	30-174-332	0.40	0.35	0.30	0.35
7A	100%	6	6	30-174-332	0.40	0.25	0.30	0.32
11A	150%	6	6	30-174-332	0.35	0.30	0.30	0.32
12A	150%	12	12	30-174-332*	0.40	0.30	0.30	0.33
13	150% 0-6" Unlimed 6-12"	12	Lime 0-6" PK 0-12"	30-87-166 (0-6") 0-262**-166 (6-12")	0.35	0.40	0.35	0.37
14	150%	12	Lime 0-12" PK 0-6"	30-174-332	0.40	0.30	0.30	0.33

*Using coarse potassium calcium pyrophosphate.

**Using Florida rock phosphate.

soil. None of the P-limed treatments brought about any significant increase in yield over P alone. However, P uptake (yield x percent P) by alfalfa plants was higher for the limed treatments, since a significant yield increase was obtained on the limed treatments. Thorp et al. (39) have pointed out that increased yields of alfalfa on limed soil are probably due to increased P uptake, since the P content of the plant material was almost constant for all cuttings. Stubblefield and Deturk (37) have pointed out that P is converted into living tissues and becomes a part of the organic body, and since the absorption of increasing amounts of P is accompanied by a corresponding increase in growth, the percentage of P in the plant tissues generally tends to be a constant. This was the case in the present study, since the P content of the plant was not increased by liming.

Depth of lime and/or fertilizer incorporation did not appear to have any influence on the P content of the forage. This lack of advantage in the deeper placement may be due to the somewhat high P rate even at the lower rate of fertilization. On the other hand, incorporation of P to the 12-inch depth could result in more P fixation than would be obtained with incorporation to the 6-inch depth due to more points of soil-P contact with the deeper incorporation. According to Woodhouse (46), this might well be balanced by the increase in root-phosphate contact afforded by mixing the phosphate with the plow layer. This might be another explanation for this lack of response to deeper incorporation of P fertilizer.

Potassium. The K content of the forage ranged from 2.20 to

2.82, 2.38 to 3.18, 2.13 to 2.92 and 1.90 to 2.88 percent in the first to the fourth cutting (Tables 15-18).

As an average of all 18 treatments, the K content of the forage was highest in the second cutting (2.85 percent) and lowest in the fourth cutting (2.44 percent). Limiting the discussion to the first 12 treatments, the K content declined with an increase in degree of base saturation and also with greater depth of lime and/or fertilizer incorporation. For example, as an average of all cuttings the K content of the forage was 2.60 percent where the soil was unlimed and 2.57 percent and 2.46 percent where the soil was limed to 100 percent and 150 percent base saturation, respectively. However, no significant differences in K content were found between liming treatments (Table 19). It is believed that the percentage K in the crop is often decreased by liming through some replacement of K by Ca in the plant, or simply through the dilution effect, when yield increases faster than uptake. This finding is supported by those of Pearson (28).

Where lime and/or fertilizer were incorporated to a depth of 6 inches the K content was 2.61 percent, compared to 2.48 percent where these materials were incorporated to a depth of 12 inches. This result could be explained by the fact that alfalfa roots are mainly concentrated at the depth of 0-6 inches (as will be shown later), where the K uptake might be at a maximum (5). Moreover, there were no critical dry periods in the 1961 growing season to limit surface root activity. Furthermore, the K fertilizer rate might be adequate at this depth for adequate K utilization, at least for this production year.

On the other hand, the K content of the forage was 2.38 percent at the lower rate of fertilization (30-87-166), and 2.70 percent at the higher rate of fertilization (30-174-332). Boswell et al. (2) found that the K content of the corn plant increased with increased rates of K fertilization. It has been suggested, however, that K can accumulate in large quantities, be translocated, and re-utilized. The K ion is generally absorbed in larger quantities than any other mineral element and absorption takes place at a high rate throughout the life of the plant.

Many of the differences in K content of the forage are significant or highly significant, as shown in Table 19.

Calcium. The average percent Ca in the forage varied from 1.72 to 2.50, 1.22 to 1.90, 1.03 to 1.97 and 1.32 to 1.73 in the first to the fourth cutting, respectively (Tables 20-23).

As an average of all 18 treatments the Ca content of the forage was highest in the first cutting (2.10 percent) and lowest in the third cutting (1.54 percent), although there was little difference in the percentage of Ca in the last three cuttings. Limiting the discussion to the first twelve treatments, the Ca content increased with an increase in percent base saturation and also with greater depth of lime and/or fertilizer incorporation. For example, as an average of all cuttings, the Ca content of the forage was 1.43 percent where the soil was unlimed and 1.82 percent and 1.87 percent where the soil was limed to 100 and 150 percent base saturation, respectively. There was a significant difference in the Ca content between the unlimed and

limed treatments in all 4 cuttings, but no significant difference between the two limed treatments (Table 24), despite the fact that in all 4 cuttings the concentration was higher at the 150 percent base saturation level than it was at the 100 percent level. Thus, while percent Ca increased with increase in base saturation due to Ca additions, K decreased. The increased Ca content of the alfalfa forage by soil liming can be explained by the higher Ca content of the soil. This higher Ca content of the soil depressed the Mg content of the plants, as will be shown later. The differences in Ca content of the forage due to lime applications paralleled very closely the differences in yield between the limed and unlimed treatments. Thorp et al. (39) have reported that the rate of absorption of Ca by alfalfa was markedly reduced in the presence of the Al ion and to a lesser degree by Mn and H ions in the nutrient solution. The low Ca content of the forage observed on the unlimed plots might be partly due to the antagonistic effect of Al, Mn, and H on the absorption of Ca rather than to the low Ca supply in the soil.

Where lime and/or fertilizer were incorporated to a depth of 6 inches, the Ca content was 1.67 percent compared to 1.75 percent where these materials were incorporated to a depth of 12 inches. However, differences in Ca content at the two depths of incorporation were not great enough to be statistically significant in any of the 4 cuttings. On the other hand, the Ca content of the forage declined with an increase in the rate of fertilization, averaging 1.76 percent at the 30-87-166 rate and 1.65 percent at the 30-174-332 rate. The decline in Ca content at the higher rate of K fertilization is ex-

plained by the increase in K content of the forage at the higher rate of fertilization. A high concentration of K in the soil solution can depress plant uptake of Ca, even though Ca is present in adequate amounts. This behavior is often referred to as Ca-K antagonism and is the result of an unbalance between K and other cations. In most cases higher levels of K have been found to be associated with lower levels of Ca in plants, (28).

Magnesium. The Mg content of the alfalfa forage varied from 0.20 to 0.30, 0.15 to 0.27, 0.23 to 0.35, and 0.32 to 0.50 percent in the first to the fourth cutting, respectively (Tables 25-28).

The Mg contents were not subjected to an analysis of variance as was done with the P, K, and Ca contents. Therefore, only a few general trends will be discussed. In general, the Mg content was highest on unlimed alfalfa, averaging 0.32 percent for all cuttings on the four unlimed treatments (treatments 1-4). This compares with 0.28 percent on the four treatments limed to 100 percent base saturation (treatments 5-8), and 0.27 percent on the four treatments limed to 150 percent base saturation. This decline in Mg content can be explained by the fact that the chemical properties of Mg and Ca are so closely related that an increase in the Ca content presumably could have been accompanied by a decrease in the Mg content. Mg content appeared to be unaffected by depth of lime and/or fertilizer incorporation, averaging 0.29 percent for both incorporation depths. Mg was like Ca in this respect. The higher rate of fertilization (30-174-332) appeared to depress the Mg content slightly, averaging 0.27 percent

at this fertilization rate as compared to 0.31 percent at the lower rate of fertilization (30-87-166). This result could be expected, since the K content of the forage had increased and the Ca content decreased at the higher rate of K fertilization.

As can be seen from the nutrient content of the forage (Tables 10-13, 15-18, 20-23, and 25-28), alfalfa has a high mineral content and the high yields obtained in this experiment resulted in the removal of large amounts of nutrients.

Chemical Properties of the Soil

Soil samples were collected on July 18-21, 1961 (about 11 months after this experiment was started) at depths of 0-6 inches and 6-12 inches and were analyzed for P, K and pH.

Phosphorus and potassium levels of the soil. P values expressed in pounds per acre of available P are shown in Table 29. K values expressed in pounds per acre of exchangeable K are shown in Table 30. Data on the two soil layers are shown separately.

As an average of all treatments, there were marked differences in the P and K levels of the two soil layers.

The P level of the surface soil (0-6") at the higher rate of fertilization was on the average about twice that obtained with the lower rate of fertilization (25 pounds of P per acre vs 12). The higher rate of fertilization was also reflected in the nutrient level of the 6- to 12-inch layer, with one exception. For example, where the incorporation of lime and/or fertilizer was made to full depth (12 inches), P averaged 9 pounds per acre for the lower rate of

Table 29.--Available phosphorus content of Alcoa loam resulting from different lime and fertilizer treatments

Tmt. No.	Limed to base saturation of:	Depth of tillage	Depth of Lime and/or PK incorporation	Rate of fertilization (Lb./acre)	0-6" layer				6-12" layer			
					Replication 1	2	3	Av. of 3 reps.	Replication 1	2	3	Av. of 3 reps.
		Inches	Inches		Pounds Per Acre				Pounds Per Acre			
1	Unlimed	12	6	30-87-166	6	11	21	13	2	5	7	5
2	"	12	12	30-87-166	5	9	12	9	4	6	12	7
3	"	12	6	30-174-332	34	42	29	35	5	7	7	6
4	"	12	12	30-174-332	18	11	15	15	7	10	15	11
5	100%	12	6	30-87-166	25	16	17	19	3	6	6	5
6	100%	12	12	30-87-166	13	9	15	12	17	9	12	13
7	100%	12	6	30-174-332	29	38	29	32	3	4	6	4
8	100%	12	12	30-174-332	20	14	21	18	6	32	10	16
9	150%	12	6	30-87-166	8	12	11	10	3	6	5	5
10	150%	12	12	30-87-166	1	6	11	6	5	6	8	6
11	150%	12	6	30-174-332	49	29	38	39	3	6	7	5
12	150%	12	12	30-174-332	7	19	14	13	5	9	17	10
3A	Unlimed	6	6	30-174-332	23	27	29	26	3	6	6	5
7A	100%	6	6	30-174-332	58	55	34	49	4	7	6	6
11A	150%	6	6	30-174-332	34	31	35	33	4	5	8	6
12A	150%	12	12	30-174-332*	<1	5	5	3	1	2	4	2
13	150% 0-6" Unlimed 6-12"	12	Lime 0-6" PK 0-12"	30-87-166 (0-6") 0-262**-166 (6-12")	17	12	20	16	100	42	67	70
14	150%	12	Lime 0-12" PK 0-6"	30-174-332	32	63	28	41	3	5	6	5

*Using coarse potassium calcium pyrophosphate. **Using Florida rock phosphate.

Table 30.--Exchangeable potassium content of Alcoa loam resulting from different lime and fertilizer treatments

Tmt. No.	Limed to base saturation of	Depth of tillage	Depth of lime and/or PK incorporation	Rate of fertilization (Lb./acre)	0-6" layer				6-12" layer			
					Replication 1	2	3	Av. of 3 reps.	Replication 1	2	3	Av. of 3 reps.
		Inches	Inches		Pounds Per Acre				Pounds Per Acre			
1	Unlimed	12	6	30-87-166	184	184	456	275	98	130	274	167
2	"	12	12	30-87-166	157	181	317	218	109	119	313	180
3	"	12	6	30-174-332	353	375	536	421	160	188	326	225
4	"	12	12	30-174-332	270	211	384	288	160	146	366	224
5	100%	12	6	30-87-166	199	274	203	225	90	177	134	134
6	100%	12	12	30-87-166	184	251	214	216	130	196	157	161
7	100%	12	6	30-174-332	260	335	251	282	113	177	138	143
8	100%	12	12	30-174-332	214	218	242	225	134	211	181	175
9	150%	12	6	30-87-166	157	196	188	180	119	142	123	128
10	150%	12	12	30-87-166	157	153	174	161	119	123	130	124
11	150%	12	6	30-174-332	344	326	255	308	174	169	150	164
12	150%	12	12	30-174-332	211	278	265	251	142	188	199	176
3A	Unlimed	6	6	30-174-332	326	282	253	287	181	150	222	184
7A	100%	6	6	30-174-332	313	358	353	341	199	181	278	219
11A	150%	6	6	30-174-332	286	251	320	286	160	134	214	166
12A	150%	12	12	30-174-332*	211	188	286	228	142	138	230	170
13	150% 0-6" Unlimed 6-12"	12	Lime 0-6" PK 0-12"	30-87-166 (0-6") 0-262**-166 (6-12")	255	211	251	236	192	166	207	188
14	150%	12	Lime 0-12" PK 0-6"		295	255	344	298	146	134	222	167

*Using coarse potassium calcium pyrophosphate. **Using Florida rock phosphate.

fertilization and 12 pounds for the higher rate.

The one exception was the P level of the soil where the incorporation of lime and fertilizer was made in only the surface layer. Here there was no difference in the P levels of the 6- to 12-inch layer at the two rates of fertilization. This finding indicates little or no downward movement of P.

The low P level of treatment 12A can be explained by the fact that the potassium calcium pyrophosphate used in this treatment was a very coarse vitreous material (-3/8" + 1/4" mesh); therefore, it is unlikely that very much of it was solubilized. The high P level of the 6- to 12-inch layer of treatment 13 is explained by the fact that a large amount of rock phosphate was incorporated in this layer.

The application of lime resulted in no consistent variation in soil P level. For example, where no lime was applied in the 0- to 6-inch layer the average available P was 18 pounds per acre compared to 20 pounds per acre and 17 pounds per acre where the soil was limed to 100 percent and 150 percent base saturation, respectively. In the 6- to 12-inch layer, the average available P was 7 pounds per acre where the soil was unlimed compared to 10 pounds per acre and 6 pounds per acre where the soil was limed to 100 percent and 150 percent base saturation, respectively.

Most noticeable in these results are the wide differences in the P levels of the soil for the two depths of lime-fertilizer incorporation. Where the incorporation was made only in the surface layer (0 to 6 inches) the average level of this layer was 25 pounds of P per acre, but where the incorporation was made in both the surface and sub-

soil layers the average level of the surface layer was only 12 pounds of P per acre. This can be explained as a dilution effect. This relationship was reversed, however, in the 6- to 12-inch layer. Here, where the lime-fertilizer incorporation was confined to the surface layer the average level of the subsoil layer was 5 pounds of P, compared to 11 pounds where the incorporation was made to a depth of 12 inches. In the above comparisons both rates of fertilization are combined and the average values as given are for treatments 1 to 12.

The K level of the surface soil at the higher rate of fertilization was on the average higher than that obtained with the lower rate of fertilization (296 pounds of K per acre vs 213). The higher rate of fertilization was also reflected in the nutrient level of the 6- to 12-inch layer. Here, the exchangeable K was 185 pounds per acre for the higher rate of fertilization and 149 pounds for the lower rate.

Unlike P, soil levels of K in the limed treatments were markedly less than those in the unlimed treatments. For example, where the soil was unlimed, the exchangeable K averaged 250 pounds per acre for both soil layers, as compared to 194 pounds per acre and 184 pounds per acre where the soil was limed to 100 percent and 150 percent base saturation, respectively. Although the K content of the forage was significantly decreased by liming, these exchangeable K values indicate that total K uptake (yield x percent K) was greater where lime was applied. As an average of the two lime rates, total K uptake was 26 percent greater on the limed than on the unlimed treatment. This result is supported by Pearson (28). The idea that the liming of acid soils has often caused certain amounts of exchangeable K to become fixed in non-

exchangeable form might not be true in this study, since the K uptake was greater on the limed than on the unlimed soil.

Depth of incorporation resulted in no wide variation in soil K level. For example, where the incorporation of K fertilizer was made to full depth (12 inches) the average exchangeable K was 200 pounds per acre as compared to 221 pounds found in the surface soil (0-6"). However, incorporation of K fertilizer to a depth of 6 inches was more efficient than incorporation to a depth of 12 inches. This was reflected in the K content of the forage, where a significant increase in K content was obtained in the first and fourth cuttings where K fertilizer was incorporated to a depth of 6 inches over that obtained where the incorporation was made to full depth (12 inches).

Liming and soil reaction. pH values of each treatment for the three replications at both soil depths are shown in Table 31. These values may be compared with values of pH 6.0 for the 0- to 6-inch layer and pH 5.2 for the 6- to 12-inch layer, shown in Table 3, which are for single composite samples taken from the experimental area before the experiment was started. There was a wide variation in soil reaction among the samples taken in July 1961. This is illustrated in the unlimed treatments (1, 2, 3, 4, and 3A), where the soil pH was as low as 3.7 and as high as 7.4 in the plow layer and as low as 3.9 and as high as 7.1 in the subsoil.

The highest pH value was recorded where the soil was limed to 150 percent base saturation to a depth of 12 inches. Treatments limed to 150 percent base saturation generally showed higher pH values than

Table 31.--Soil reaction (pH) of Alcoa loam resulting from different lime and fertilizer treatments

Tmt. No.	Limed to base saturation of:	Depth of tillage	Depth of lime and/or PK incorporation	Rate of fertilization (Lb./acre)	0-6" layer Replication 1	0-6" layer Replication 2	0-6" layer Replication 3	6-12" layer Replication 1	6-12" layer Replication 2	6-12" layer Replication 3
		Inches	Inches							
1	Unlimed	12	6	30-87-166	7.4	5.0	4.7	7.1	5.3	4.7
2	"	12	12	30-87-166	6.5	5.1	4.7	6.4	5.6	4.2
3	"	12	6	30-174-332	5.9	4.8	3.7	6.1	5.5	4.5
4	"	12	12	30-174-332	6.0	5.1	4.7	6.2	5.6	3.9
5	100%	12	6	30-87-166	7.2	5.7	6.5	6.6	6.0	5.2
6	100%	12	12	30-87-166	7.2	7.1	6.0	7.3	6.9	6.0
7	100%	12	6	30-174-332	7.6	7.3	6.9	7.1	6.5	5.2
8	100%	12	12	30-174-332	7.3	7.5	6.5	7.0	7.4	5.5
9	150%	12	6	30-87-166	7.7	7.6	7.1	6.5	6.7	6.0
10	150%	12	12	30-87-166	7.8	7.7	7.4	7.5	7.2	6.8
11	150%	12	6	30-174-332	7.5	6.8	7.2	6.0	6.6	5.2
12	150%	12	12	30-174-332	7.7	7.5	7.5	7.3	7.0	6.7
3A	Unlimed	6	6	30-174-332	5.7	6.1	4.8	5.8	5.2	4.3
7A	100%	6	6	30-174-332	7.1	6.9	5.9	6.0	6.2	4.9
11A	150%	6	6	30-174-332	7.5	7.4	6.5	6.7	6.0	3.8
12A	150%	12	12	30-174-332*	7.7	7.8	7.1	7.5	7.7	6.6
13	150% 0-6" Unlimed 6-12"	12	Lime 0-6" PK 0-12"	30-87-166 (0-6") 0-262**-166 (6-12")	7.4	7.7	6.9	5.8	6.7	5.0
14	150%	12	Lime 0-12" PK 0-6"	30-174-332	7.7	7.6	7.3	7.5	7.5	6.3

*Using coarse potassium calcium pyrophosphate. **Using Florida rock phosphate.

those limed to 100 percent base saturation.

Where no lime was applied, the average soil reaction at the conclusion of the experiment was about the same in both layers as it was in the subsoil when this study was started, i.e., approximately pH 5.3 (treatments 1, 2, 3, 4, and 3A).

Where lime was mixed with the soil at a rate calculated to attain a base saturation of 100 percent, the average pH of the surface layer was 6.9, as compared to an average pH of 7.5 where this layer was limed to a calculated 150 percent base saturation. In the 6- to 12-inch layer, where limed to 100 percent base saturation to the full depth of 12 inches, the average pH was 6.7, compared to an average pH of 7.1 where limed to 150 percent base saturation.

An average pH value of 6.0 of the subsoil layer, where the lime incorporations had been confined to the surface layer (treatments 5, 7, 7A, 9, 11, 11A, and 13), indicates some movement of lime from the surface layer into the subsoil or contamination of the subsoil layer by the surface layer in collecting the soil samples. Of the two possibilities, the latter is considered to be the most likely, even though an effort was made to prevent it.

In the fertilized-unlimed treatments, no discernible change in the soil reaction was caused by fertilizer applications, a finding which is supported by the results of Wells et al. (45), and Sewell et al. (33).

The results obtained in this study, however, did not show the exact manner in which lime functions in acid soils. According to Peech and Bradfield (27), the yield responses of crops to application

of lime on acid soils are complex and involve many contributing factors, such as Ca deficiency and the toxicity of H, Al, Fe, and Mn ions, the relative importance of which vary with different crops and soils. However, low yield and the poor growth of alfalfa plants obtained on the unlimed plots might be partly attributed to the low Ca supply in the soil, since there were significant differences in the Ca content between the unlimed and limed treatments in all 4 cuttings. Schmehl et al. (32) found that toxic quantities of Mn and Al greatly inhibited the growth of alfalfa in an acid soil until it was adequately limed.

Root Yields

Six measurements were made on the depth of root penetration and yield of alfalfa roots. Depth of root penetration and root yields by 6-inch layers are shown in Figures 2 to 7.

The taproot of alfalfa found in these six observations, tapered gradually and was largely unbranched. Long (20) found this same type of taproot on well-drained soils.

Figure 2 represents the root system of alfalfa on one plot of treatment 3 (plot 3), where the soil was unlimed, tilled to a depth of 12 inches, and fertilized to a depth of 6 inches at the higher rate of fertilization (30-174-332). The maximum depth of root penetration was 31 inches. The total yield of roots (oven-dry basis) was 1787 pounds per acre. About 65 percent (1168 pounds) of the total weight of roots was found in the surface six inches and about 84 percent in the first twelve inches. The total hay yield on this plot was 5.79 tons per acre. This is a shoot-root ratio of about 6.5.

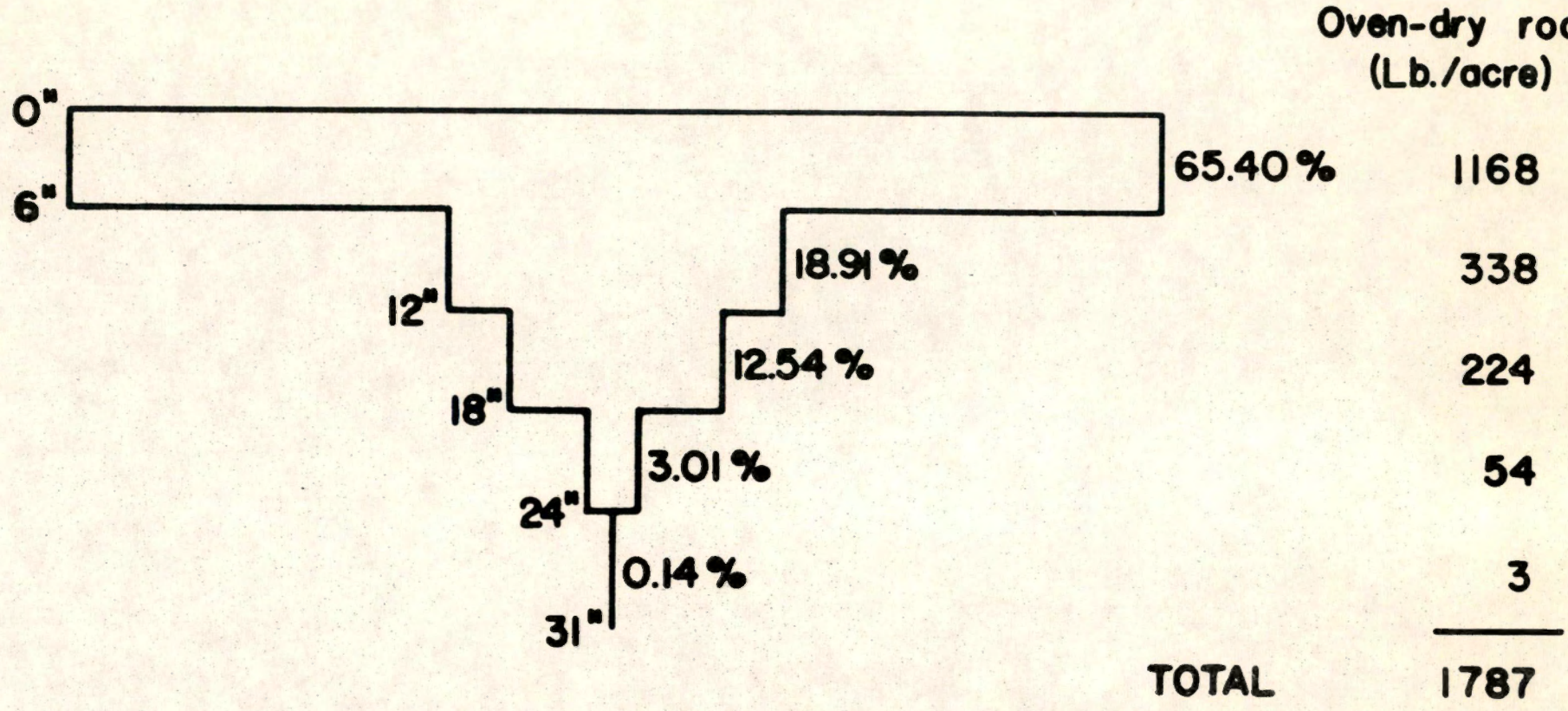


Figure 2.--Root distribution of alfalfa (by weight) to a 31-inch depth where soil was unlimed and fertilizer was incorporated to a depth of 6 inches (treatment 3).

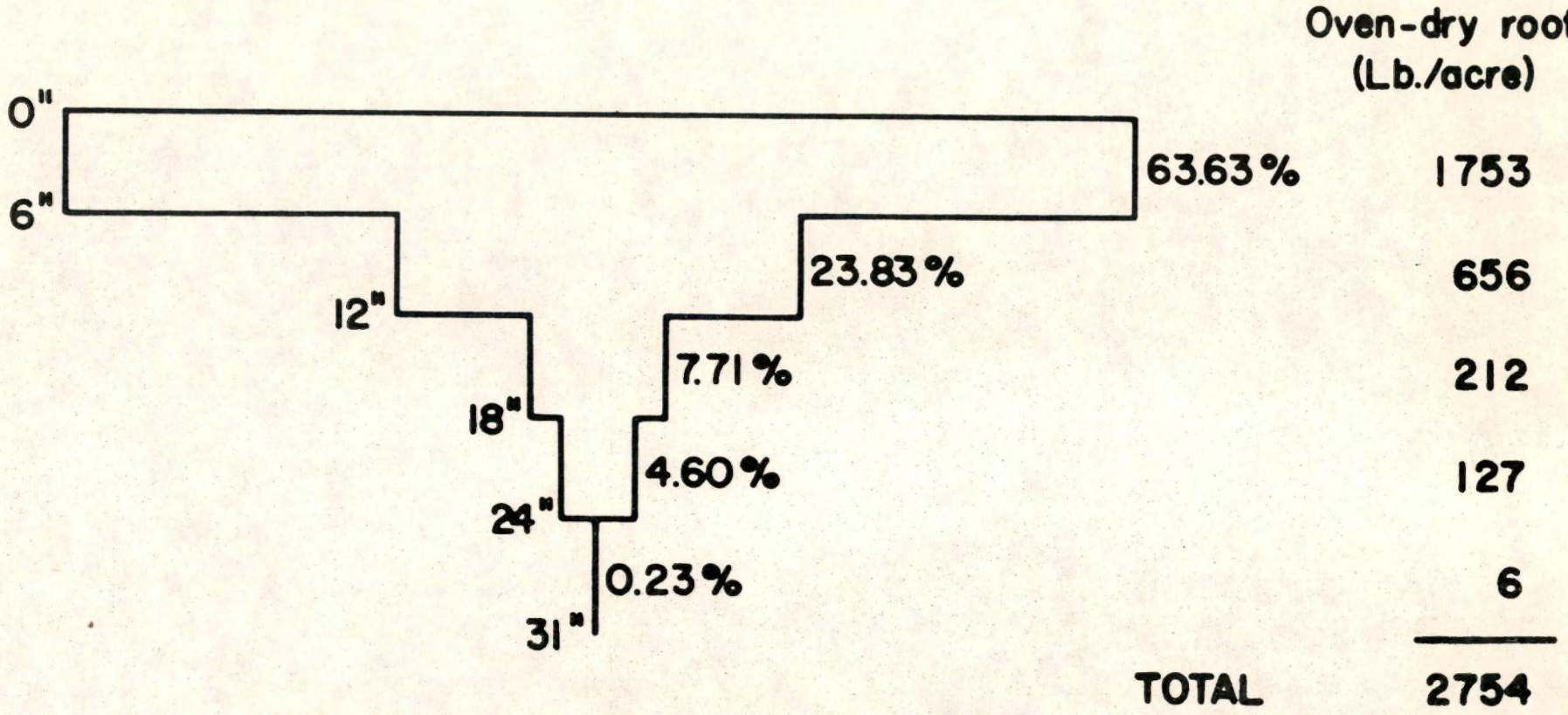


Figure 3.--Root distribution of alfalfa (by weight) to a 31-inch depth where soil was unlimed and fertilizer was incorporated to a depth of 12 inches (treatment 4).

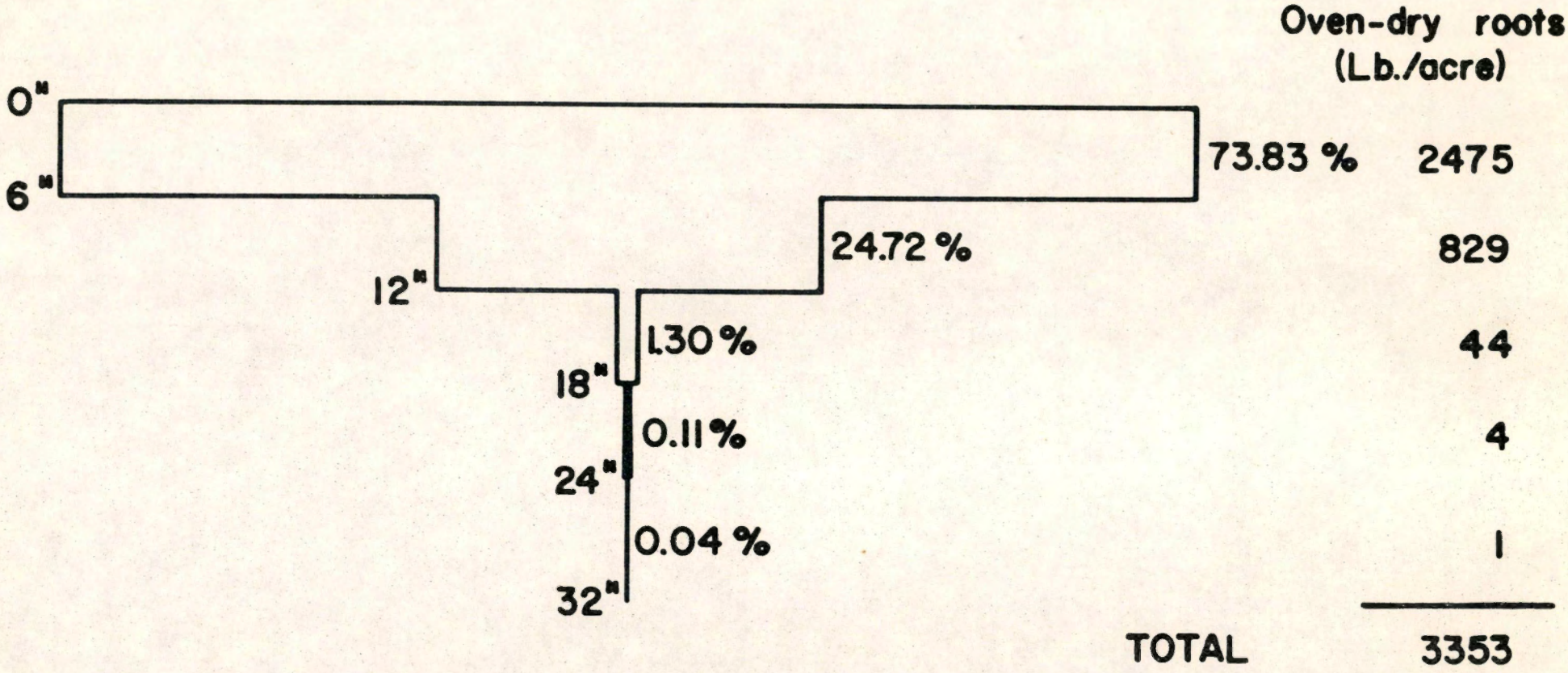


Figure 4.--Root distribution of alfalfa (by weight) to a 32-inch depth where soil was limed to 100% base saturation and where lime and fertilizer were incorporated to a depth of 6 inches (treatment 7).

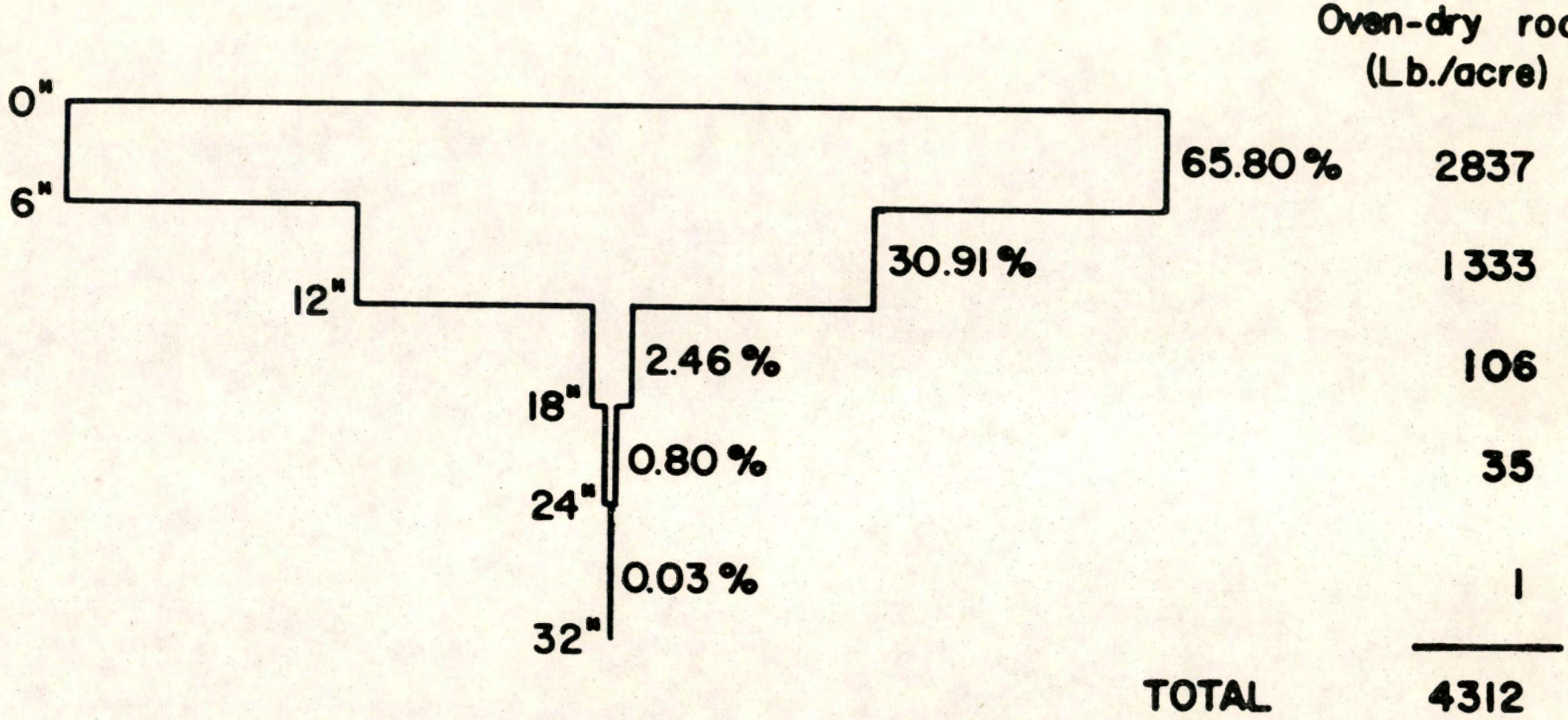


Figure 5.--Root distribution of alfalfa (by weight) to a 32-inch depth where soil was limed to 100% base saturation and where lime and fertilizer were incorporated to a depth of 12 inches (treatment 8).

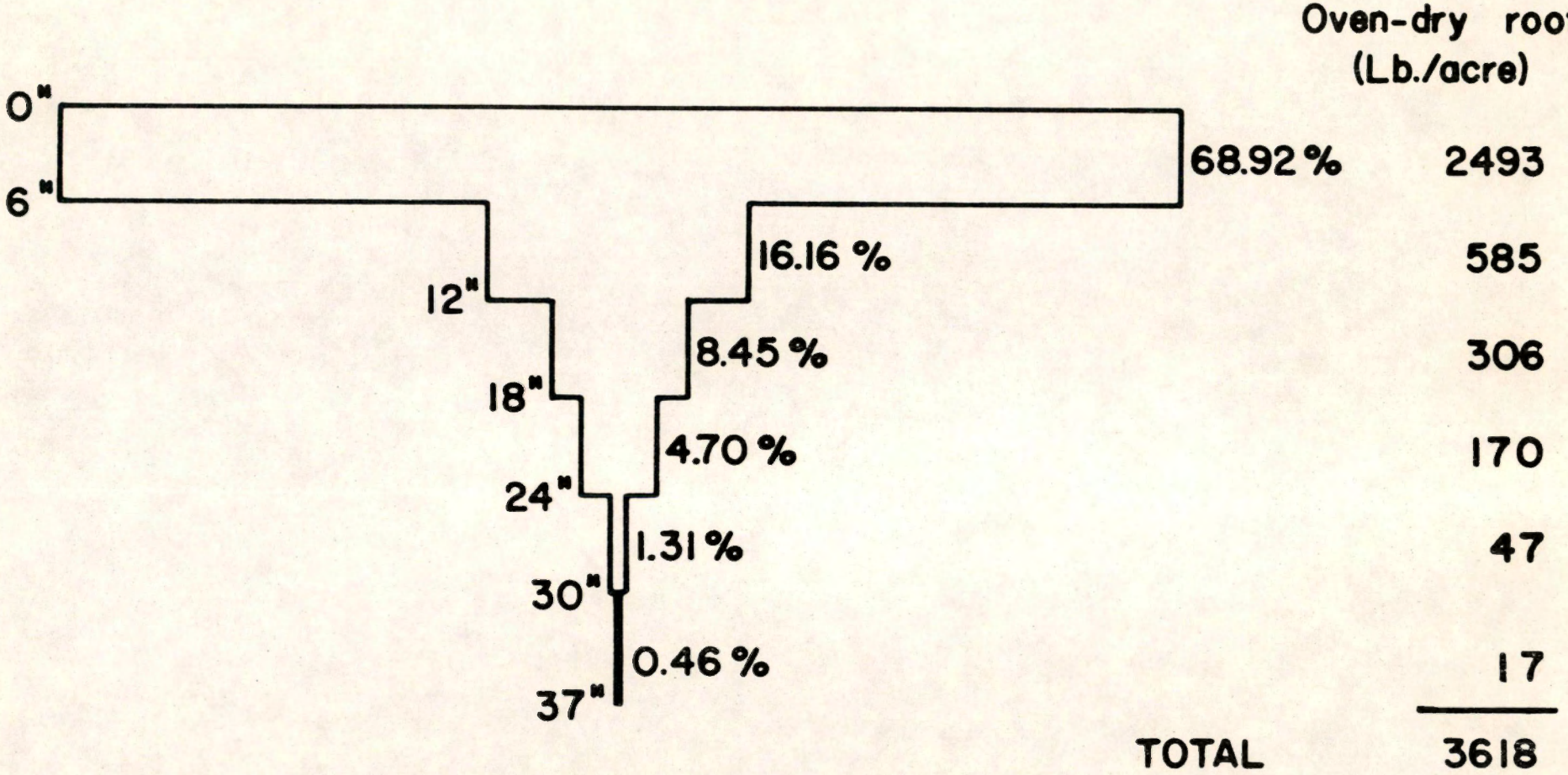


Figure 6.--Root distribution of alfalfa (by weight) to a 37-inch depth where soil was limed to 150% base saturation and where lime and fertilizer were incorporated to a depth of 6 inches (treatment 11).

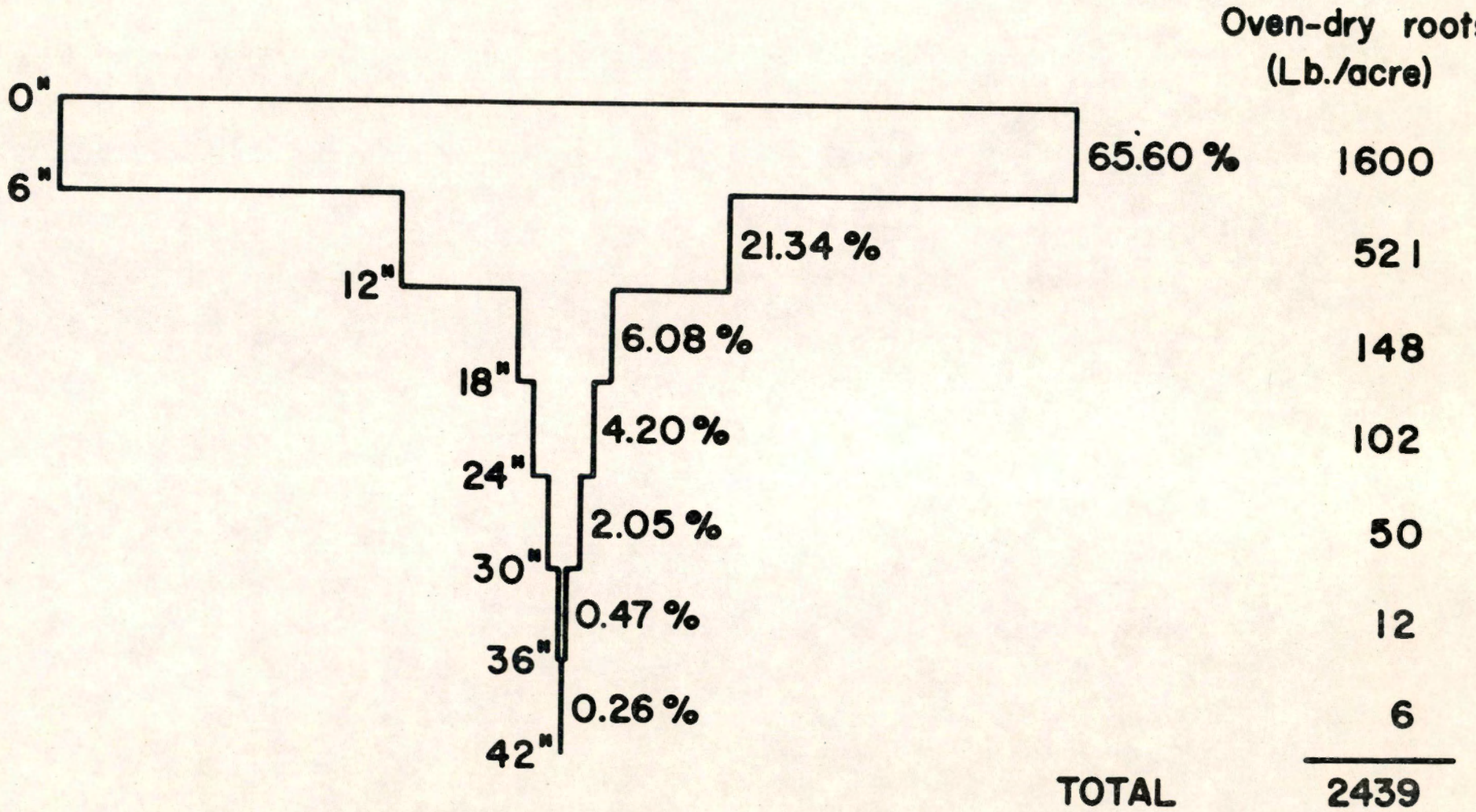


Figure 7.--Root distribution of alfalfa (by weight) to a 42-inch depth where soil was limed to 150% base saturation and where lime and fertilizer were incorporated to a depth of 12 inches (treatment 12).

Figure 3 represents the root system of alfalfa on one plot of treatment 4 (plot 4) which was the same as treatment 3, except that fertilizer was incorporated to a depth of 12 inches. Here, alfalfa roots had penetrated to the same depth as in treatment 3 (31 inches), but the oven-dry yield of roots was 2754 pounds per acre. The pattern of root distribution was essentially the same as that in treatment 3, except that a greater weight of roots was found in each soil layer of treatment 4. The total hay yield obtained on this plot was 6.60 tons per acre. This is a shoot-root ratio of about 4.8. As can be seen in these two figures, there was no difference in depth of root penetration, but a higher root yield was accompanied by a higher forage yield and a lower shoot-root ratio.

Two treatments were sampled where the soil was limed to 100 percent base saturation. One of these was treatment 7 (plot 43), where the depth of tillage was 12 inches, but where lime and fertilizer were incorporated to a depth of only 6 inches. The other was treatment 8 (plot 44) which was the same as treatment 7, except that the lime and fertilizer were incorporated to a depth of 12 inches. Root yields and pattern of root distribution are shown in Figures 4 and 5, respectively. Depth of root penetration was 32 inches in both treatments. The higher root yield was obtained where lime and fertilizer were incorporated to a depth of 12 inches (treatment 8). This root yield of 4312 pounds per acre was about 29 percent greater than the root yield of 3353 pounds where lime and fertilizer were incorporated to a depth of only 6 inches. Moreover, in treatment 8 a larger percentage of the total weight of roots was found at the lower depths. The total hay yield on the plot

representing treatment 7 was 6.12 tons per acre as compared to a hay yield of 6.31 tons on the plot representing treatment 8. Thus, where the lime-fertilizer incorporation was to a 6-inch depth the shoot-root ratio was about 3.6 as compared to a shoot-root ratio of about 2.9 where the lime-fertilizer incorporation was to a 12-inch depth.

Figures 6 and 7 show the rooting pattern of alfalfa on two treatments where the soil was limed to 150 percent base saturation. Figure 6 shows the pattern on one of the plots (plot 11) of treatment 11, where the depth of tillage was 12 inches but where lime and fertilizer were incorporated to a depth of only 6 inches. Figure 7 shows the pattern on one of the plots (plot 12) of treatment 12, which was like treatment 11, except that lime and fertilizer were incorporated to a depth of 12 inches. The maximum depth of root penetration was encountered in this pair of treatments, some roots being found at a depth of 42 inches in treatment 12. This pair of comparisons differs from the two pairs discussed previously in that maximum depth of root penetration was different and a much greater yield of roots was obtained where the lime-fertilizer incorporation was to the lesser depth. The hay yield was also higher on the plot limed and fertilized to a 6-inch depth. Depth of rooting was, however, 5 inches greater on the plot limed and fertilized to a 12-inch depth. Treatment 11 (plot 11) with a hay yield of 6.93 tons per acre and a root system reaching a maximum depth of 37 inches and a root yield of 3618 pounds indicates a shoot-root ratio of about 3.8. Treatment 12 (plot 12) with a hay yield of 6.11 tons per acre and a root system reaching a maximum depth of 42 inches and a root yield of 2439

pounds indicates a shoot-root ratio of about 5.0.

Considering the six observations, the average shoot-root ratio was about 4.2. The highest shoot-root ratio (about 5.5) was found where the soil was unlimed, whereas the lowest shoot-root ratio (about 3.8) was recorded where the soil was limed to 100 or 150 percent base saturation.

For the six plots on which this study was made, about 67 percent of the total root weight was found in the surface six inches. This was not surprising, since the large fleshy portion of the taproot was found in this layer.

As was the case in forage yields, the lowest yield of roots was obtained where no lime was applied. As an average of the two unlimed plots (Figures 2 and 3), the root yields were 2270 pounds per acre, as compared to an average of 3430 pounds per acre on the four limed plots (Figures 4 to 7). Pohlman (29), who grew alfalfa in greenhouse pots, showed that root development was concentrated in the limed area. Woodruff et al. (47) found lime to be important in root development. Where lime was mixed with the shattered subsoil, the plants developed a normal deep taproot without large lateral roots and the plants were not winterkilled. In the present study, alfalfa roots penetrated to a depth of about 3 feet in 1961, the first year of production. Generally, there was no great difference in the depth of root penetration between the limed and unlimed plots. Where alfalfa roots penetrated to depths of 37 and 42 inches (Figures 6 and 7), it was observed that the roots were very fine below the 30-inch depth and were largely following worm holes. For a better understanding of alfalfa root development soil

samples by 6-inch layers were collected where the deepest root penetration was found. Particle-size distribution as well as some of the chemical properties by 6-inch layers to a depth of 42 inches are given in Tables 32 and 33, respectively. As it can be seen, the clay content increased with depth. The soil became clay in texture below 18 inches. Exchangeable K increased with depth below 18 inches, whereas P declined sharply in the 6- and 12-inch layer and remained low throughout the rest of the profile. While the soil reaction (pH) of the surface twelve inches is considered satisfactory for alfalfa, it was very strongly acid in the lower soil horizons. The low yield of alfalfa roots at depths below 12 inches (only 13% of the total weight in Figure 7, for example) indicates some unfavorable chemical or physical characteristics of the lower soil horizons which limited root development not only because of their direct effect on root penetration but also because of lack of adequate aeration which might influence nutrient absorption (1, 5, 10, 16). Concentration of both oxygen and carbon dioxide have been shown to affect root growth and nutrient absorption. Field work by Bertrand et al. (1) has shown that corn root growth was encouraged by loosening, fertilizing, and liming the subsoil of certain Indiana soils. However, the low root yields obtained in this study at the lower soil horizons could be related to any of the poor chemical and physical soil conditions mentioned above or to a combination of these factors.

Considering the six sampled plots as a whole, no consistent relationship between depth of rooting (or weight of roots) and hay yields was observed, although there was some agreement at the various base saturation levels. This indicates that there are factors other

Table 32.--Particle-size distribution and texture by 6-inch layers to a depth of 42-inches in Alcoa loam

Depth	Sand	Coarse Silt	Fine Silt	Total Silt	Clay	Texture
Inches	%	%	%	%	%	
0-6	33.2	11.1	28.8	39.9	26.9	Loam
6-12	28.3	13.7	26.8	40.5	32.2	Clay Loam
12-18	25.9	8.6	27.8	36.4	37.7	Clay Loam
18-24	23.8	6.2	26.2	32.4	43.8	Clay
24-30	26.5	9.4	16.1	25.5	48.0	Clay
30-36	30.2	3.8	17.9	21.7	48.1	Clay
36-42	28.2	3.4	18.9	22.3	49.5	Clay

Table 33.--Some chemical properties of Alcoa loam by 6-inch layers to a depth of 42-inches

Depth	Organic Matter Content	pH	P	K
Inches	%		Lb./A.	Lb./A.
0-6	1.12	7.7	6	174
6-12	0.49	7.8	0	113
12-18	0.30	5.2	3	105
18-24	0.25	5.0	3	113
24-30	0.20	4.7	3	138
30-36	0.16	4.4	4	157
36-42	0.14	4.6	4	192

than depth of rooting and weight of roots which influence aboveground growth. This result is supported by the findings of Long (20).

CHAPTER V

SUMMARY AND CONCLUSIONS

A field study on the influence of lime and fertilizer placement on the yield, composition, and root development of alfalfa on Alcoa loam was conducted in 1960-1961.

There were 3 lime treatments: (1) no lime, (2) liming of the soil to a calculated 100 percent base saturation, and (3) liming of the soil to 150 percent base saturation. Fertilizer was applied at 2 rates: 87 pounds of P and 166 pounds of K per acre, and twice this amount, or 174 and 332 pounds of P and K, respectively. Lime and/or fertilizer were incorporated to 2 depths: 0 to 6 inches and 0 to 12 inches. Nitrogen and boron fertilization was constant at a rate of 30 pounds of nitrogen and 20 pounds of borax per acre. These materials were mixed in the surface layer only. Hydrated lime ($Ca(OH)_2$), concentrated superphosphate, muriate of potash, and ammonium nitrate were the materials used.

Incorporation of lime and fertilizer in the 6- to 12-inch layer was accomplished by placing the required amounts of these materials on the bottom of each furrow as the soil was turned, and mixing them in this layer, using a "rototiller type" device. Incorporation in the surface layer (0 to 6 inches) was accomplished by broadcasting these materials on the plowed surface followed by disking.

Four cuttings were made in 1961 and yields expressed in terms of air-dry hay per acre. Plant tissue samples were taken from each

plot before each cutting and analyzed for P, K, Ca, and Mg contents.

Six measurements of depth of penetration and yield of alfalfa roots were made in 1961 when the alfalfa stand was about one year old.

The chief findings were as follows:

1. A significant yield response to lime was obtained. The lowest yield of alfalfa hay was obtained on the unlimed treatments. There were no significant differences in the yields at the two rates of liming; however, the highest yield was obtained where the soil was limed to 150 percent base saturation.

2. There was no significant difference in the yields of alfalfa obtained from the two rates of fertilization or from the two depths of lime-fertilizer incorporation.

3. The Ca content of the forage increased with increase in percent base saturation, while the K and Mg contents decreased. At the higher rate of fertilization the P and K contents increased, whereas the Ca and Mg contents decreased. With greater depth of incorporation of lime and/or fertilizer, the K content declined, while the P, Ca, and Mg contents appeared to be unaffected.

4. Tests on soil samples collected in 1961 indicated that the P and K levels of the 0- to 6-inch and the 6- to 12-inch layers were markedly less at the lower rate of fertilization than they were at the higher rate. Unlike P, soil levels of K in the limed treatments were markedly less than those of the unlimed soil. However, total K uptake (yield x percent K) was greater where lime was applied. There was a wide variation in soil reaction between and among the various treatments. However, liming of this acid soil to a calculated 100

percent base saturation raised the pH of the surface layer to an average of 6.9 and the pH of the 6- to 12-inch layer to an average of 6.7, while liming to 150 percent base saturation raised the pH of the surface layer to an average of about 7.5 and the pH of the 6- to 12-inch layer to an average of about 7.1.

5. Unlimed alfalfa showed shorter, paler growth in the third and fourth cuttings. In some unlimed plots, the alfalfa had completely disappeared by the fourth cutting.

6. Root studies made when the alfalfa stand was about one year old showed that depth of root penetration varied from 31 to 42 inches and root yields from 1787 to 4312 pounds per acre, oven-dry basis. The limed plots had deeper root systems and higher root yields than the unlimed plots. However, there was no consistent relationship between root development and aboveground yield.

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LITERATURE CITED

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APPENDIX

Analysis of Variance

First Cutting (May 17, 1961)

(Treatments 1-12)

Source of variation	D. F.	Sum of squares	Variance	F value
Base saturation (B.S.)	2	2.1358	1.0679	4.50*
Depth of incorporation (D)	1	0.0289	0.0289	0.12
Fertility level (F)	1	0.1089	0.1089	0.46
B.S. x D.	2	0.0451	0.0226	0.09
B.S. x F	2	0.6949	0.3474	1.46
D. x F.	1	0.0841	0.0841	0.35
B.S. x D. x F.	2	0.1204	0.0602	0.25
Replications	2	2.7933	1.3966	5.89**
Error	22	5.1027	0.2374	
Total	35	11.1141		

* Significant at the 5% level of probability.

** Significant at the 1% level of probability.

Analysis of Variance

Second Cutting (June 27, 1961)

(Treatments 1-12)

Source of variation	D. F.	Sum of squares	Variance	F value
Base saturation (B.S.)	2	1.2305	0.6152	2.03
Depth of incorporation (D)	1	0.0062	0.0062	0.02
Fertility level (F)	1	0.0951	0.0951	0.31
B.S. x D.	2	0.1773	0.0887	0.29
B.S. x F	2	0.4195	0.2098	0.69
D. x F.	1	0.1236	0.1236	0.40
B. S. x D. x F.	2	0.0810	0.0405	0.13
Replications	2	2.9231	1.4615	4.83*
Error	22	6.6455	0.3020	
Total	35			

* Significant at the 5% level of probability.

Analysis of Variance

Third Cutting (Aug. 1, 1961)

Treatments 1-12)

Source of variation	D. F.	Sum of squares	Variance	F value
Base saturation (B.S.)	2	2.1101	1.0550	8.75**
Depth of incorporation (D)	1	0.0507	0.0507	0.42
Fertility level (F)	1	0.0319	0.0319	0.26
B.S. x D.	2	0.0103	0.0051	0.04
B.S. x F.	2	0.2258	0.1129	0.94
D. x F.	1	0.0005	0.0005	0.00
B.S. x D. x F.	2	0.0794	0.0397	0.33
Replications	2	1.1601	0.5800	4.81*
Error	22	2.6540	0.1206	
Total	35	6.3228		

* Significant at the 5% level of probability.

** Significant at the 1% level of probability.

Analysis of Variance

Fourth Cutting (Sept. 12, 1961)

(Treatments 1-12)

Source of variation	D. F.	Sum of squares	Variance	F value
Base saturation (B.S.)	2	0.1468	0.0734	7.06**
Depth of incorporation (D)	1	0.0004	0.0004	0.04
Fertility level (F)	1	0.0011	0.0011	0.11
B.S. x D.	2	0.0050	0.0025	0.24
B.S. x F.	2	0.0767	0.0384	3.70*
D. x F.	1	0.0001	0.0001	0.01
B.S. x D. x F.	2	0.0031	0.0015	0.14
Replications	2	0.2214	0.1107	10.64**
Error	22	0.2282	0.0104	
Total	35	0.6828		

* Significant at the 5% level of probability.

** Significant at the 1% level of probability.

Analysis of Variance

Total Four Cuttings

(Treatments 1-12)

Source of variation	D. F.	Sum of squares	Variance	F value
Base saturation (B.S.)	2	19.4065	9.7032	5.44*
Depth of incorporation (D)	1	0.1144	0.1144	0.06
Fertility level (F)	1	0.0902	0.0902	0.05
B.S. x D.	2	0.6718	0.3359	0.18
B.S. x F.	2	4.8020	2.4010	1.34
D. x F.	1	0.3336	0.3336	0.18
B.S. x D. x F.	2	0.3619	0.1809	0.10
Replications	2	22.8906	11.4453	6.42**
Error	22	39.2395	1.7836	
Total	35	87.9105		

* Significant at the 5% level of probability.

** Significant at the 1% level of probability.

Analysis of Variance

Phosphorus (P) Content of Alfalfa Forage

First Cutting (May 17, 1961)

(Treatments 1-12)

Source of variation	D. F.	Sum of squares	Variance	F value
Base saturation (B.S.)	2	0.0015	0.0008	1.33
Depth of incorporation (D)	1	0.0000	0.0000	0.00
Fertility level (F)	1	0.0056	0.0056	9.33**
B.S. x D.	2	0.0006	0.0003	0.50
B.S. x F.	2	0.0001	0.0000	0.00
D. x F.	1	0.0004	0.0004	0.66
B.S. x D. x F.	2	0.0001	0.0000	0.00
Replications	2	0.0078	0.0039	6.50**
Error	22	0.0122	0.0006	
Total	35	0.0283		

** Significant at the 1% level of probability.

Analysis of Variance

Phosphorus (P) Content of Alfalfa Forage

Second Cutting (June 27, 1961)

(Treatments 1-12)

Source of variation	D. F.	Sum of squares	Variance	F value
Base saturation (B.S.)	2	0.0000	0.0000	0.00
Depth of incorporation (D)	1	0.0001	0.0001	0.33
Fertility level (F)	1	0.0013	0.0013	4.33*
B.S. x D.	2	0.0001	0.0000	0.00
B.S. x F.	2	0.0008	0.0004	1.33
D. x F.	1	0.0001	0.0001	0.33
B.S. x D. x F.	2	0.0002	0.0001	0.33
Replications	2	0.0006	0.0003	1.00
Error	22	0.0065	0.0003	
Total	35	0.0097		

*Significant at the 5% level of probability.

Analysis of Variance

Phosphorus (P) Content of Alfalfa Forage

Third Cutting (Aug. 1, 1961)

(Treatments 1-12)

Source of variation	D. F.	Sum of squares	Variance	F value
Base saturation (B.S.)	2	0.0002	0.0001	0.50
Depth of incorporation (D)	1	0.0000	0.0000	0.00
Fertility level (F)	1	0.0002	0.0002	1.00
B. S. x D.	2	0.0020	0.0010	5.00*
B. S. x F.	2	0.0003	0.0002	1.00
D. x F.	1	0.0000	0.0000	0.00
B.S. x D. x F.	2	0.0004	0.0002	1.00
Replications	2	0.0038	0.0019	9.50**
Error	22	0.0058	0.0002	
Total	35	0.0127		

* Significant at the 5% level of probability.

** Significant at the 1% level of probability.

Analysis of Variance

(Replications 1 and 2)

Phosphorus (P) Content of Alfalfa Forage

Fourth Cutting (Sept. 12, 1961)

(Treatments 1-12)

Source of variation	D.F.	Sum of squares	Variance	F value
Base saturation (B.S.)	2	0.0001	0.0000	0.00
Depth of incorporation (D)	1	0.0000	0.0000	0.00
Fertility level (F)	1	0.0007	0.0007	7.00*
B.S. x D.	2	0.0011	0.0005	5.00*
B.S. x F.	2	0.0007	0.0004	4.00
D. x F.	1	0.0000	0.0000	0.00
B.S. x D. x F.	2	0.0006	0.0003	3.00
Replications	1	0.0001	0.0001	1.00
Error	11	0.0009	0.0000	
Total	23	0.0042		

* Significant at the 5% level of probability.

Analysis of Variance

Potassium (K) Content of Alfalfa Forage

First Cutting (May 17, 1961)

(Treatments 1-12)

Source of variation	D.F.	Sum of squares	Variance	F value
Base saturation (B.S.)	2	0.6379	0.3189	7.18**
Depth of incorporation (D)	1	0.2336	0.2336	5.26*
Fertility level (F)	1	0.2844	0.2844	6.41*
B.S. x D.	2	0.0043	0.0022	0.05
B.S. x F.	2	0.1135	0.0568	1.28
D. x F.	1	0.0278	0.0278	0.62
B.S. x D. x F.	2	0.0310	0.0155	0.34
Replications	2	0.6837	0.3419	7.70**
Error	22	0.9763	0.0444	
Total	35	2.9925		

* Significant at the 5% level of probability.

** Significant at the 1% level of probability.

Analysis of Variance

Potassium (K) Content of Alfalfa Forage

Second Cutting (June 27, 1961)

(Treatments 1-12)

Source of variation	D. F.	Sum of squares	Variance	F value
Base saturation (B.S.)	2	0.4704	0.2352	5.75*
Depth of incorporation (D)	1	0.0400	0.0400	0.97
Fertility level (F)	1	0.6400	0.6400	15.65**
B.S. x D.	2	0.0004	0.0002	0.00
B.S. x F.	2	0.3054	0.1527	3.73*
D. x F.	1	0.0001	0.0001	0.00
B.S. x D. x F.	2	0.0478	0.0239	0.58
Replications	2	0.0216	0.0108	0.26
Error	22	0.9018	0.0409	
Total	35	2.4275		

* Significant at the 5% level of probability.

** Significant at the 1% level of probability.

Analysis of Variance

Potassium (K) Content of Alfalfa Forage

Third Cutting (Aug. 1, 1961)

(Treatments 1-12)

Source of variation	D. F.	Sum of squares	Variance	F value
Base saturation (B.S.)	2	0.1704	0.0852	1.64
Depth of incorporation (D)	1	0.1002	0.1002	1.93
Fertility level (F)	1	1.1025	1.1025	21.24**
B.S. x D.	2	0.0194	0.0097	0.18
B.S. x F.	2	0.1429	0.0714	1.37
D. x F.	1	0.0070	0.0070	0.13
B.S. x D. x F.	2	0.0417	0.0208	0.40
Replications	2	0.1004	0.0502	0.96
Error	22	1.1430	0.0519	
Total	35	2.8275		

** Significant at the 1% level of probability.

Analysis of Variance

(Replications 1 and 2)

Potassium (K) Content of Alfalfa Forage

Fourth Cutting (Sept. 12, 1961)

(Treatments 1-12)

Source of variation	D. F.	Sum of squares	Variance	F value
Base saturation (B.S.)	2	0.1881	0.0940	4.43*
Depth of incorporation (D)	1	0.3038	0.3038	14.33**
Fertility level (F)	1	1.8704	1.8704	88.23**
B.S. x D.	2	0.0019	0.0009	0.04
B.S. x F.	2	0.1715	0.0857	4.04
D. x F.	1	0.0204	0.0204	0.96
B.S. x D. x F.	2	0.1827	0.0913	4.31*
Replications	1	0.0037	0.0037	0.17
Error	11	0.2338	0.0212	
Total	23	2.9763		

* Significant at the 5% level of probability.

** Significant at the 1% level of probability.

Analysis of Variance

Calcium (Ca) Content of Alfalfa Forage

First Cutting (May 17, 1961)

(Treatments 1-12)

Source of variation	D. F.	Sum of squares	Variance	F value
Base saturation (B.S.)	2	1.8976	0.9488	29.10**
Depth of incorporation (D)	1	0.0900	0.0900	2.76
Fertility level (F)	1	0.0544	0.0544	1.67
B.S. x D.	2	0.0379	0.0190	0.58
B.S. x F.	2	0.0477	0.0239	0.73
D. x F.	1	0.0178	0.0178	0.54
B.S. x D. x F.	2	0.0301	0.0151	0.46
Replications	2	0.9622	0.4811	14.76**
Error	22	0.7162	0.0326	
Total	35	3.8539		

** Significant at the 1% level of probability.

Analysis of Variance

Calcium (Ca) Content of Alfalfa Forage

Second Cutting (June 27, 1961)

(Treatments 1-12)

Source of variation	D. F.	Sum of squares	Variance	F value
Base saturation (B.S.)	2	1.6872	0.8436	53.05**
Depth of incorporation (D)	1	0.0506	0.0506	3.18
Fertility level (F)	1	0.0584	0.0584	3.67
B.S. x D.	2	0.0017	0.0008	0.05
B.S. x F.	2	0.1450	0.0725	4.56*
D. x F.	1	0.0156	0.0156	0.98
B.S. x D. x F.	2	0.0039	0.0019	0.00
Replications	2	0.5268	0.2634	16.56**
Error	22	0.3499	0.0159	
Total	35	2.8391		

* Significant at the 5% level of probability.

** Significant at the 1% level of probability.

Analysis of Variance

Calcium (Ca) Content of Alfalfa Forage

Third Cutting (Aug. 1, 1961)

(Treatments 1-12)

Source of variation	D. F.	Sum of squares	Variance	F value
Base saturation (B.S.)	2	2.6572	1.3286	59.05**
Depth of incorporation (D)	1	0.0201	0.0201	0.89
Fertility level (F)	1	0.1534	0.1534	6.81*
B.S. x D.	2	0.0139	0.0069	0.30
B.S. x F.	2	0.0939	0.0469	2.08
D. x F.	1	0.0251	0.0251	1.11
B.S. x D. x F.	2	0.0572	0.0286	1.27
Replications	2	0.3735	0.1867	8.30**
Error	22	0.4965	0.0225	
Total	35	3.8908		

* Significant at the 5% level of probability.

** Significant at the 1% level of probability.

Analysis of Variance

(Replications 1 and 2)

Calcium (Ca) Content of Alfalfa Forage

Fourth Cutting (Sept. 12, 1961)

(Treatments 1-12)

Source of variation	D. F.	Sum of squares	Variance	F value
Base saturation (B.S.)	2	0.1852	0.0926	11.43**
Depth of incorporation (D)	1	0.0338	0.0338	4.17
Fertility level (F)	1	0.0817	0.0817	10.08**
B.S. x D.	2	0.0081	0.0040	0.50
B.S. x F.	2	0.0015	0.0002	0.02
D. x F.	1	0.0004	0.0004	0.05
B.S. x D. x F.	2	0.0027	0.0013	0.16
Replications	1	0.1204	0.1204	14.86**
Error	11	0.0896	0.0081	
Total	23	0.5234		

** Significant at the 1% level of probability.