FERTILIZER AND LIME INFLUENCE ON ENGMO TIMOTHY YIELD AND MINERAL COMPOSITION ON THE LOWER KENAI PENINSULA OF ALASKA

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AGRICULTURAL EXPERIMENT STATION
School of Agriculture and Land Resources Management
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James V. Drew, Director

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NOTE

This report contains the results of a cooperative investigation between Agricultural Reseach, Science and Education Administration, United States Department of Agriculture, and the Palmer Research Center, Agricultural Experiment Station, University of Alaska.

ABSTRACT

Another forage to supplement the native bluejoint (*Calamagrostis canadensis*) in the Caribou Hills area on Alaska's lower Kenai Peninsula is needed. Domestic grass growth has seldom been successful, although timothy (*Phleum pratense*) is more tolerant of the acid conditions found in this area than are many other grasses suited for use in Alaska.

This report summarizes the results of three separate experiments evaluating the effects of lime and fertilizers on forage production and chemical composition of Engmo timothy on Kachemak silt loam (*Typic Cryandept*). A 3-year study showed that lime markedly improved growth and yield of timothy in an area where domestic grasses had seldom survived. Ammonium phosphate nitrate, calcium metaphosphate, and treblesuperphosphate were equally effective as a source of phosphorus (P).

In an adjacent 6-year study, each lime increment over 1 ton per acre increased the soil pH, forage yield, and nitrogen (N) uptake, and tended to reduce the crude-protein concentration in forage. Increasing N applications increased yields, crude-protein percentage, and N uptake. Native bluejoint gradually replaced the timothy on plots receiving less than 2 tons lime per acre, responded to the high N rate, and thrived with two cuttings per growing season.

In a 5-year study, oven-dry yields of both cuttings increased with N rates up to 120 lb N per acre with no further increase at 180 lb N per acre. Each increasing N rate each year increased the crude protein and nitrate (NO_3-N) concentrations of both cuttings. Nitrogen rates exceeding 60 lb N per acre increased the mean seasonal P uptake and tended to increase the P concentration. Mean seasonal potassium (K) uptake varied with N rate as follows: $120>180$ and $240>60$ lb N per acre. Each increasing N increment through 180 lb N per acre increased the mean seasonal calcium (Ca) and magnesium (Mg) uptake. Increasing P rates from 75 to 150 lb per acre had no effect on forage yield. Increasing the P rate from 75 to 150 lb per acre increased the P concentration of both cuttings and the mean seasonal P and sulfur (S) uptake and depressed the mean seasonal Ca and Mg uptake. Increasing the K rate from 83 to 166 lb per acre increased the K concentration and depressed the crude-protein concentration of both cuttings as well as increasing the mean seasonal K and total N uptake. The higher K rate increased oven-dry yields of both cuttings and the mean seasonal NO_3-N uptake at the higher N rates.

The soil became more acid from 1972 to 1976 with September pH values generally lower than those of the preceding June, particularly in the top 2 inches. The highest N application (240 lb/A) produced the greatest pH reduction. The NO_3-N in the soil increased with each increasing N rate. Available P increased over time, accumulated in the top 2 inches, and was greater with the heavier P application. Available K also accumulated in the top 2 inches, was greater in September than in June, and was greater where 166 lb K per acre had been used than with 83 lb.

These experiments demonstrated that Engmo timothy can be grown successfully on the more acid Kachemak silt loam with lime application and proper fertilization.

INTRODUCTION

Ranchers in the Caribou Hills area east of Anchor Point and north of Homer on Alaska's Kenai Peninsula require considerable supplemental forage for winter feeding. Much of the native vegetation in this area consists of open grassland alternating with evergreen and deciduous tree stands. The dominant species in the grasslands is the tall-growing perennial bluejoint reedgrass (*Calamagrostis canadensis*), commonly referred to as bluejoint. Without fertilization, annual harvest drastically reduces yields of the native bluejoint. Some ranchers have planted domestic grasses but found that they rarely survive beyond the year of planting at some locations on this strongly acid soil (Klebesadel and Laughlin, 1964).

The areas of Kachemak silt loam (Typic Cryandept) selected for our studies were on a ranch where spring planting of timothy (*Phleum pratense*) barely survived the season; and oats (*Avena sativa*) produced short, spindly, unproductive growth, even with moderate fertilization. The soil pH here ranged from 3.8 to 4.4, somewhat less than average for the Kachemak series. The first two experiments were conducted in a fenced area on a south-facing slope formerly used as a garden. The third experiment was located on a uniform stand of Engmo timothy planted in 1970 after 2.5 tons of dolomitic limestone per acre was mixed into the soil by rototilling.

EXPERIMENTAL PROCEDURE

Experiment 1

The first experiment, a 3 by 2 factorial with three phosphorus sources (ammonium phosphate nitrate, calcium metaphosphate, and treblesuperphosphate) and no lime vs. 4 tons lime per acre, was arranged in a Latin square. The lime applications were mixed into the top 6 inches of soil with a rototiller 24 June 1964. All plots received 300, 132, and 249 lb of N, P, K per acre, respectively, stirred into the top 1 inch of soil by hand raking. Engmo timothy was planted in rows 6 inches apart with a Planet Jr. seeder on 24 June 1964.

In 1965 and 1966, the fertilizer treatments were repeated by top dressing near mid-June after removal of the dried debris of the previous season's growth. On 5 Aug. and 6 Oct. 1964 and on 17 June 1966 each plot was placed by visual inspection into one of four classes depending on vigor. A 6-inch snow on 29 September, which remained on the ground until spring, prevented harvest in 1965. On 27 July 1966, each plot (6 by 3 feet) was cut with a hand sickle leaving a 2-inch stubble, and green and dry weights of timothy forage were obtained.

Experiment 2

On 26 June 1966 an experiment based on a randomized block design was initiated adjacent to Experiment 1 with five lime rates (0, .5, 1, 2, and 3 tons per acre) and two N rates (120 and 240 lbs per acre) with five replications; lime applications were mixed into the top 6 inches of soil with a rototiller June 26. The entire area was top dressed uniformly·immediately afterward with 10-20-10 commercial fertilizer at 600 lb per acre, and Engmo timothy was seeded immediately at about 2.5 lb per acre with a Cyclone broadcast seeder making several trips perpendicular to each other for uniform seed idstribution. After seeding, the seedbed was packed with the wheels of a tractor.

All plots received 100 lb each of P and K per acre on 13 June 1967, 11 June 1968, 29 May 1969, 8 June 1970, 23 June 1971, and 6 June 1972. Half of the N was applied with these P and K treatments; the other half was applied immediately after the first harvest each year. All fertilizer was hand broadcast on the soil surface. Soil samples were collected each spring from each plot before fertilization and after the September harvest to a 6-inch depth. Samples in 1971 and 1972 were taken at 2-inch increments to a 6-inch depth. All were analyzed using a modified Morgan's procedure with sodium acetate buffered at pH 4.8 (Martin, 1970).

Forage from all plots was harvested twice per growing season, except in 1967 when inadvertently cattle grazing prevented a second cutting. All grass was cut with a small, sickle-equipped, power mower leaving a 2-inch stubble. The first cutting was made just before or at the time of emergence of seed heads in early July and the second cutting in September. The harvested area consisted of a swath, 2.5 ft wide by 25 ft long, cut from the center of plots. Green weights were recorded and dry weights calculated after drying representative forage samples from each plot harvest at 140^0 F in a forage dryer. These dried forage samples from each plot were ground to pass a 40-mesh, stainless-steel screen for chemical analysis. Nitrogen was determined using a modification of the Kjeldahl method by collecting the distillate in boric acid (AOAC, 1970). The percentage of grass growth on each plot represented by the invasion of native bluejoint was estimated visually on 28 May 1969, 8 June 1970, 23 June 1971, and 6 June 1972.

Experiment 3

On 7 June 1972, a 4 by 2^2 factorial-design experiment (60, 120, 180, and 240 lb N per acre; 76 and 152 lb P per acre; 83 and 166 lb K per acre) was initiated on a 2-year-old uniform stand of Engmo timothy which had previously received 2.5 tons lime per acre. Half of the N was applied in the spring with the P and K treatments; the other half was applied immediately after the first harvest each year. Plots were 6 by 15 feet. Spring fertilizer treatments were hand broadcast annually on 7 June 1972, 11 June 1973, 4 June 1974, 16 June 1975, and 7 June 1976. Soil samples were collected twice yearly at 2-inch increments to a 6-inch depth from each plot before spring fertilization and again immediately after the September harvest. These samples were analyzed as described for Experiment 2.

Forage from all plots was harvested twice per growing season as described for the second experiment, except in 1972 when grazing animals intruded, precluding a second cutting. The first cuttings were made in July and the second cuttings in September. Dry weights were obtained as before and, in addition to the determination of N, NO_3-N was determined with the nitrate electrode (Smith, 1975); K, Ca, and Mg using an atomic absorption spectrophotometer following a perchloric-acid digestion (Perkin-Elmer, 1973); and P colorimetrically using the same perchloric extract (Jackson, 1958).

RESULTS AND DISCUSSION

Experiment 1

This study was to test P sources with and without liming when adequate N and K were applied. All three sources of P were equally effective as shown by the visual ratings in 1964 and 1965 and 1966 yields (Table 1). The application of 4 tons of lime per acre markedly improved the growth and yield of the timothy. Plots without lime contained little timothy in 1966 and yielded less than half as much as plots that had received lime. The 4 tons of lime per acre increased the soil reaction from pH 4.1 to pH 5.2 (water) over the 3-year period.

Table 1. Effects of Phosphorus Source and Lime Application on Engmo Timothy as Measured by Visual Rating[1] in 1964 and 1965 and on Oven-dry Forage Yield in 1966.

	Visual rating[1]			Tons/acre
	5 Aug. 1964	6 Oct. 1964	17 June 1965	27 July 1966
---------- Effects of P source (means of 12 measurements) ----------				
P source (132 lb/A/year)				
Ammonium phosphate nitrate	1.9a[2]	1.5a	1.8a	2.74a
Treblesuperphosphate	1.8a	1.4a	1.7a	2.42a
Calcium metaphosphate	1.8a	1.2a	1.6a	2.90a
---------- Effects of lime (means of 18 measurements) ----------				
Tons lime per acre[3]				
None	0.8b	0.1b	0.5b	1.50b
4	2.9a	2.7a	2.8a	3.88a
C. V. (%)	20.1	24.0	32.9	25.3

[1] Rating of vigor: 0, Very poor; 1, Poor; 2, Good; 3, Very good.
[2] Means followed by the same letter within columns are not significantly different at the 5% level of probability according to Duncan's Multiple Range Test.
[3] Lime applied once only on 24 June, 1964.

Experiment 2

Soil Reaction and Available NO_3-N, P, and K

When all 6 years of data were considered, each lime increment increased the soil reaction (Table 2); however, the pH increase from .5 to 1 ton per acre was not large enough in June to be statistically significant. The pH in June and September 1971 and 1972 was increased significantly by each increment of lime added (Table 3). Available NO_3-N, P, or K were not influenced significantly by the different rates of lime applied.

Table 2. Effects of Lime Rates Applied in June 1966 and N Rates Applied Annually on Soil pH and Available NO_3-N, P, and K on Kachemak Silt Loam Sampled Beneath a Timothy Stand (Means of Values for Six Years 1967 to 1972).

	pH (water)		NO_3-N		P		K	
	June	Sept.	June	Sept.	June	Sept.	June	Sept.
			lb/A available					
---------- Effects of lime (means of 60 measurements) ----------								
T lime/A[1]								
0	4.41d[2]	4.29e	32a	41a	52a	55a	229a	249a
.5	4.58c	4.46d	33a	45a	52a	57a	222a	233a
1	4.65c	4.57c	32a	39a	54a	56a	219a	227a
2	4.84b	4.80b	33a	41a	53a	56a	218a	218a
3	5.02a	5.01a	32a	39a	52a	54a	209a	229a
---------- Effects of nitrogen (means of 150 measurements) ----------								
Lb N/A/yr								
120	4.72a	4.70a	32a	38a	53a	55a	219a	234a
240	4.68a	4.56b	33a	44a	52a	55a	220a	229a
C. V. (%)	4.2	4.3	22.3	22.4	19.5	18.2	14.2	14.9

[1] Lime applied once only on 26 June 1966.
[2] Means followed by the same letter within columns are not significantly different at the 5% level of probability according to Duncan's Multiple Range Test.

The heavier N application over this 6-year period significantly reduced the soil reaction as measured in the September samplings (Table 2) and in both June and September 1971 and 1972. (Table 3). The higher N rate increased the NO_3-N in the soil as sampled in September (Table 3). Available P and K were not influenced significantly by the amount of N applied over either the 6- or 2-year period.

At each 2-inch increase in sampling depth (1971 and 1972), both the soil pH and NO_3-N increased (Table 3). This increase in NO_3-N (Table 3) in soil samples taken at 2–4-and 4–6-inch depths is similar to that reported under grass by Puscaru et al. (1970) in Rumania. Also, available P in the top 2 inches was less than at the other two, deeper sampling depths. The amounts of available K were similar at all three sampling depths and on both sampling dates.

Bluejoint Invasion

The 1966 Engmo timothy seeding resulted in a uniform and dense stand through 1967 and 1968. However, grass on plots that received no lime or .5 ton per acre grew very slowly and was chlorotic throughout 1967. Native bluejoint invaded these two treatments in 1968 and competed vigorously with the timothy. Table 4 shows increasing proportions of bluejoint on those treatments from 1968 through 1972. Although timothy grew vigorously on plots that received 1 ton lime per year, by 1972 the percentage of bluejoint was greater than that of timothy. Despite rodents concentrating their feeding on timothy corms on plots that received 2 and 3 tons lime per acre, a good timothy stand was maintained and successfully withstood bluejoint invasion on those plots.

The native bluejoint that invaded plots from 1969 to 1972 responded well to the higher N rate and increased in vigor each year with the two annual harvests. The plots that were predominantly bluejoint produced forage yields and N concentrations in the herbage as high as those with timothy alone. These results agree with those of Klebesadel (1965) which showed native bluejoint stands remained undiminished with two harvests per season if surface organic debris was removed and N, P, and K were topdressed annually. Earlier observations and studies had suggested that bluejoint in unmodified native stands was rapidly reduced in vigor by successive annual mowings or by continuous grazing (Klebesadel and Laughlin, 1964).

Yield

When data from all 6 years were combined, each lime increment exceeding 1 ton per acre increased the oven-dry timothy yields, although increases were not always statistically significant (Figure 1). The higher N rate, when all lime rates were combined, produced significantly more forage than the lower N rate. From 1967 through 1970, more than 1 ton lime per acre generally increased yields with few significant differences between the 2 and 3 tons per acre applications. This is similar to the conclusions of Reith and Robertson in Scotland (1971). They reported increased grass growth over a 5-year period on an acidic organic soil with 220 and 450 lb lime per acre but no further increases from applications of 1000 to 4000 lb per acre. In our study, no significant yield differences were found between 0 and .5 ton lime per acre in 1967, nor between 2 and 3 tons per acre in 1968 through 1970. The increased bluejoint growth on plots that received less than 2 tons lime per acre in 1971 and 1972 resulted in no significant yield differences related to lime rate.

Doubling the N application rate from 60 to 120 lb per acre increased forage yields from 1968 through 1970 and reduced them in 1972. In 1967 and 1971, the higher N rate did not significantly affect yields. The 1971 and 1972 results reflect heavy rodent feeding concentrated on plots that received the higher N rate.

Mean yearly forage yields (tons per acre) over all lime and N rates ranked as follows: 1970 (5.3)>1968 (3.83)>1969 (3.12)>1972 (2.41)>1971 (1.98)>1967 (1.41) with each year's yields being significantly different from the others.

Table 3. Effects of Lime Rates Applied in June 1966 and N Rates Applied Annually on Soil pH and Available NO_3-N, P, and K at Three Sampling Depths on Kachemak Silt Loam Beneath a Timothy Stand (Means of Values for 1971 and 1972).

	pH				Lb/A available					
	water		0.01 M $CaCl_2$		NO_3-N		P		K	
	June	Sept.	June	Sept.	June	Sept.	June	Sept.	June	Sept.
---------- Effects of lime (means of 60 measurements) ----------										
T lime/A[1]										
0	4.32e[2]	4.24e	3.72e	3.88e	42a	53a	89a	87a	226a	226a
.5	4.45d	4.35d	3.86d	4.00d	45a	58a	91a	92a	226a	228a
1	4.56c	4.46c	3.95c	4.09c	43a	51a	94a	90a	226a	230a
2	4.70b	4.68b	4.08b	4.32b	46a	55a	92a	90a	226a	230a
3	4.81a	4.87a	4.21a	4.49a	44a	50a	89a	84a	222a	226a
---------- Effects of nitrogen (means of 225 measurements) ----------										
Lb N/A/yr										
120	4.62a	4.64a	4.00a	4.22a	43a	46b	91a	89a	226a	228a
240	4.52b	4.40b	3.92b	4.10b	45a	61a	91a	89a	225a	228a
---------- Effects of sampling depth (means of 150 measurements) ----------										
Sampling depth (in.)										
0-2	4.46c	4.42c	3.82c	3.98c	30c	38c	75b	75b	222a	224a
2-4	4.57b	4.54b	3.99b	4.21b	48b	59b	96a	94a	225a	229a
4-6	4.66a	4.60a	4.08a	4.28a	53a	63a	101a	98a	229a	231a
C. V. (%)	4.4	4.2	4.6	4.6	19.8	21.2	17.0	18.9	7.6	4.0

[1] Lime applied once only on 26 June 1966.

[2] Means followed by the same letter within columns are not significantly different at the 5% level of probability according to Duncan's Multiple Range Test.

Table 4. Effects of Lime Rates Applied in June 1966 and N Rates Applied Annually on the Invasion by Native Bluejoint into Engmo Timothy Plots Seeded in 1966 (Means of Values for Four Years 1969 to 1972).

	1969	1970	1971	1972
	% native bluejoint			
---------- Effects of lime (means of 10 measurements) ----------				
T lime/A[1]				
0	65a[2]	64a	90a	90a
.5	18b	32b	60ab	80b
1	15b	14c	40b	60b
2	1b	4c	0c	0d
3	0b	0c	0c	0d
---------- Effects of nitrogen (means of 25 measurements ----------				
Lb N/A/yr				
120	16a	20a	40a	48a
240	20a	24a	38a	45a
C. V. (%)	87	113	107	80

[1] Lime applied once only on 26 June 1966.

[2] Means followed by the same letter within colunns are not significantly different at the 5% level of probability according to Duncan's Multiple Range Test.

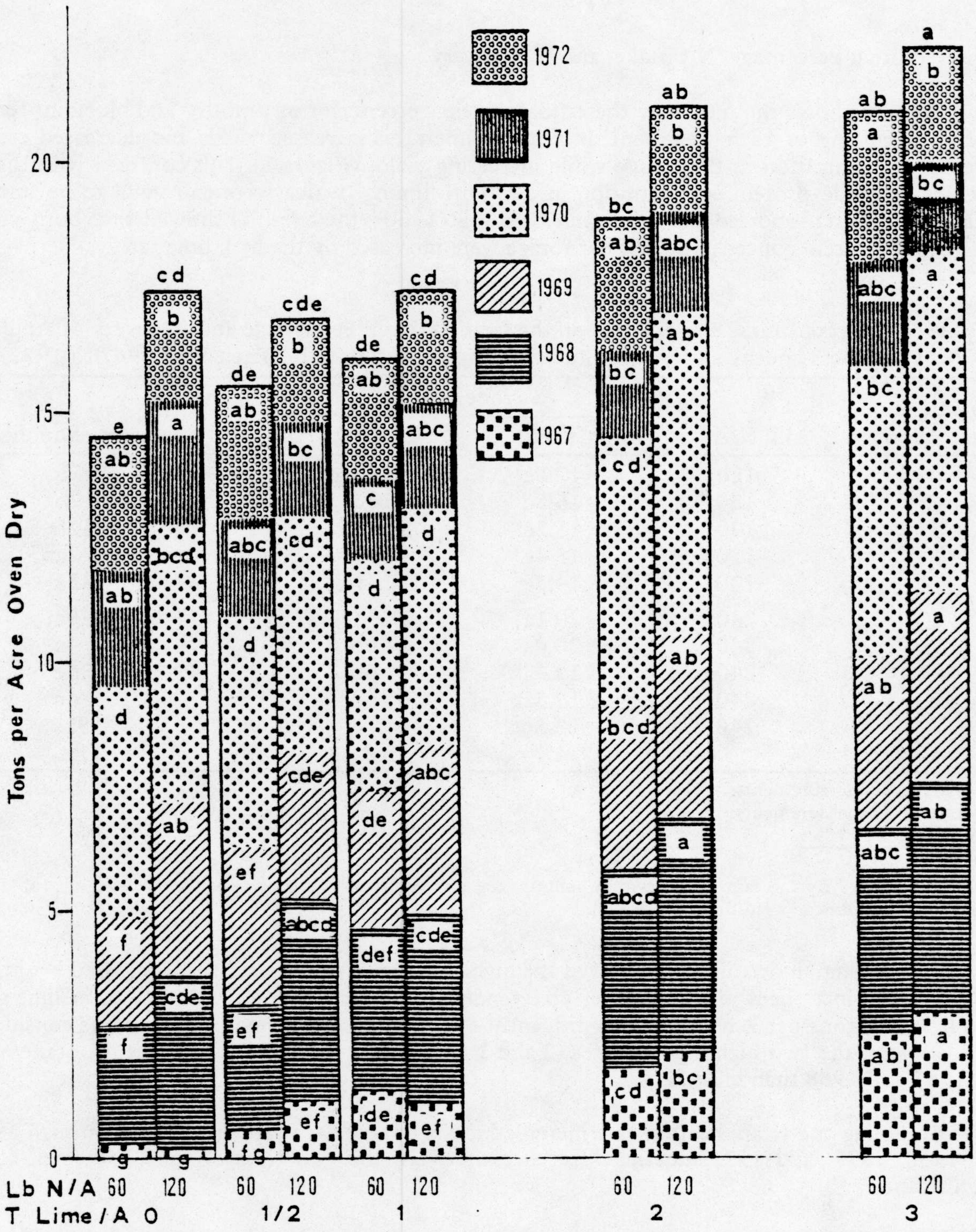

Figure 1. Effects of lime and nitrogen on Engmo timothy forage yields, 1967 to 1972. (Letters in each segment refer to Duncan's Mutliple Range Test. Segments for each year containing the same letter are not significantly different at the 5% level of probability).

Crude Protein Percentage, N Uptake, and N Recovery

Table 5 shows the means of the crude protein percentages in timothy and bluejoint forage for each cutting of each treatment. Increasing lime rates increased yields and decreased crude-protein concentration in the forage while increasing yields (Figure 1). This contrasts with the increases in crude-protein concentration in oats with liming (which were too small to be statistically significant) reported by Ogata and Caldwell (1960); their results showed that both yields and crude-protein concentration of oat forage were increased by the high lime rate.

Table 5. Effects of Lime and N Rates on the Crude Protein Percentage and Recovery of Applied N by Engmo Timothy and Native Bluejoint (Means of Values for Each Year 1967 to 1972).

T lime/A June 1966	Lb N/A/yr	% crude protein 1st cut[1]	% crude protein 2nd cut[2]	% recovery of applied N[3]
0	120	17.8e[4]	16.1bcd	117b
.5	120	16.5d	16.1cd	119b
1	120	15.2e	14.9de	112b
2	120	15.4e	12.9f	122ab
3	120	14.5e	12.4f	133a
0	240	20.1a	18.5a	78c
.5	240	20.0a	17.0bc	74c
1	240	19.4ab	17.3b	76c
2	240	19.5ab	15.6de	86c
3	240	18.8bc	14.7e	87c
C. V. (%)		4.1	5.8	11.1

[1] Means of 30 measurements.
[2] Means of 25 measurements.
[3] $\frac{\text{N uptake} \times 100}{\text{N applied}}$
[4] Means followed by the same letter within columns are not significantly different at the 5% level of probability according to Duncan's Multiple Range Test.

Combining all 6 years' data showed the higher N increment significantly increased N uptake, as each lime increment over 1 ton per acre tended to do also (Figure 2). Increases in lime rates from 2 to 3 tons per acre did not significantly affect N uptake. When each year was considered individually, the two highest lime rates (2 and 3 tons per acre) tended to increase N uptake more in 1967 and 1968 than in 1972.

Doubling the N application rate increased the N uptake each year from 1968 through 1970; in 1967, 1971, and 1972, uptake differences between the two N rates were too small to be significant.

With 120 lb N per acre, 121% as much N as that applied during the 6-year period was recovered in the harvested forage as compared with 80% N recovery with the 240 lb N rate (Table 5). The two higher lime rates also tended to increase the per cent recovery of applied N at both N rates. This higher recovery of applied N probably indicates that fertilization and liming increased the soil biological activity, releasing N in the decomposition of the organic material. This recovery of applied N compared favorably with the 83 to 121% N recovery by Engmo timothy on Mutnala silt loam (Typic Cryorthod) receiving 150 lb N per acre (Laughlin, 1965). These high crop recoveries of applied N indicate efficient utilization and certainly justify the use of 100 to 150 lb N per acre annually in combination with some P and K.

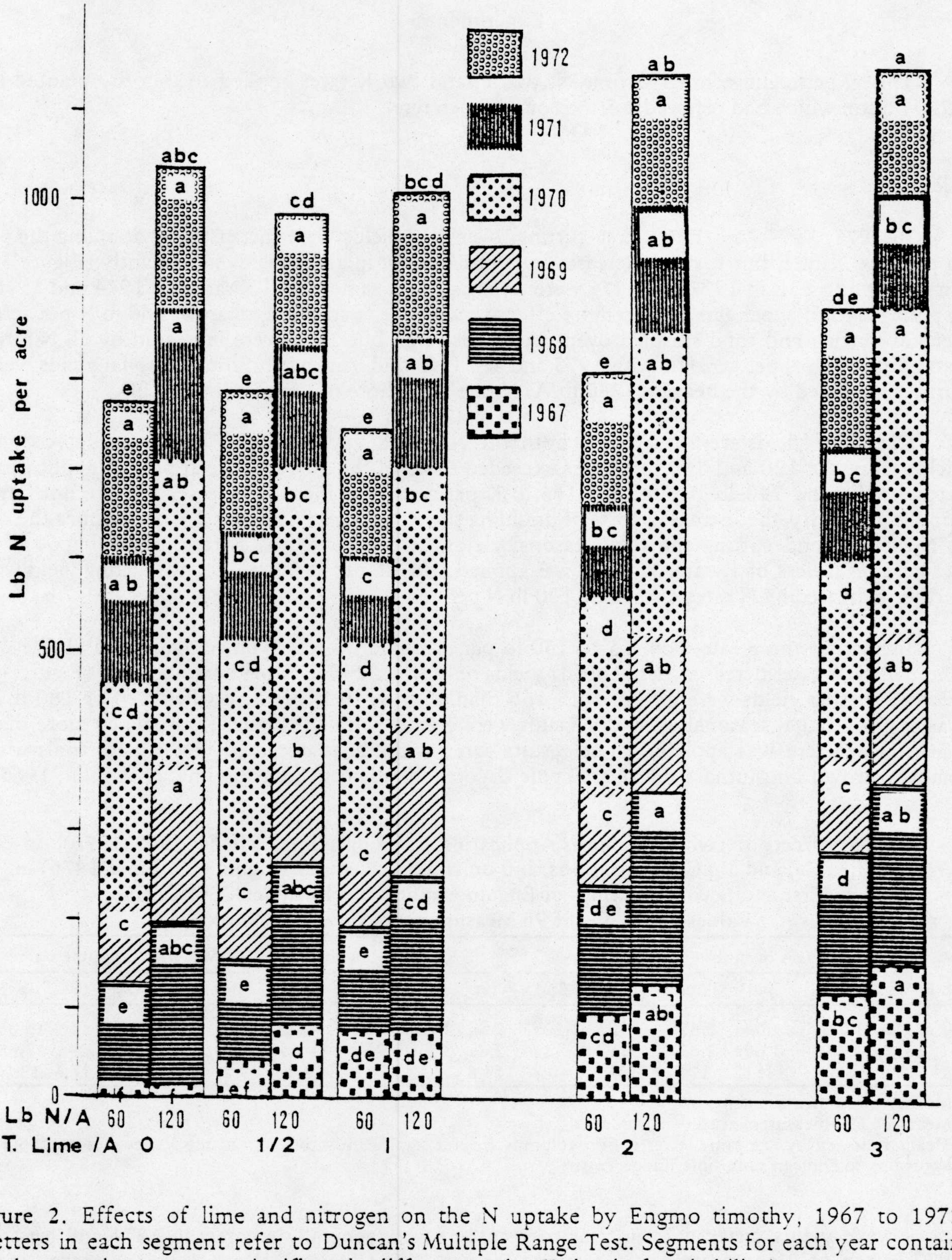

Figure 2. Effects of lime and nitrogen on the N uptake by Engmo timothy, 1967 to 1972. (Letters in each segment refer to Duncan's Multiple Range Test. Segments for each year containing the same letter are not significantly different at the 5% level of probability).

Experiment 3

This experiment compared four N, two P, and two K rates applied to timothy planted in 1970 on soil which had received 2.5 tons of lime per acre.

Yield

In 1973, 1974, and 1976, first-cutting, oven-dry yields were increased by doubling the 60 lb per acre N rate, but further increases in N rate did not increase yields significantly (Figure 3). First-cutting yields in 1972 and 1975 were essentially the same for all N rates. In 1974 and 1976, applying 240 lb N per acre was no more effective with the first cutting than was 60 lb N per acre. Second-cutting and total seasonal oven-dry yields in all but 1972 were increased by all N rates exceeding 60 lb N per acre. In both 1973 and 1974, second-cutting and total seasonal yields were further increased by the heaviest (240 lb/A) N rate over those obtained with 120 lb.

Oven-dry yields were related to both the N and K applications (Figure 4). First-cutting yields from the 120 and 180 lb N rates exceeded those of the 60-lb N rate at both K application rates, as did the 240-lb N rate with 166 lb K per acre. The increases, however, were not large enough to justify the increased costs of doubling the K rate or in applying 2, 3, or 4 times the 60 lb N rate. Second-cutting and total seasonal yields were increased by N rates exceeding 60 lb N per acre regardless of K rate. When K was applied at 83 lb per acre, the second-cutting yield was further increased by N rates exceeding 120 lb N per acre.

Increasing the P rate from 75 to 150 lb per acre had no effect on forage yields (Table 6). The higher K rate increased first-cutting yields only when 240 lb N per acre was used (Figure 4). Second-cutting yields were greater with 166 than with 83 lb K per acre when 120 or 180 lb N was applied. Total seasonal oven-dry yields were greater with the higher K rate when more than 60 lb N per acre was applied. These results agree with those obtained in fertilizer trials with timothy grown on Mutnala silt loam (Typic Cryorthod) adjacent to Cook Inlet (Laughlin, 1965).

Table 6. Effects of Two Phosphorus Application Rates on Forage Yields (1972-1976), on NO_3-N, K, Ca, and Mg Concentrations, and on NO_3-N, P, and S Uptake (1975 and 1976) in First and Second Cuttings of Engmo Timothy on Kachemak Silt Loam. Values are Means of 96 Measurements Except as Noted.

	T/A oven-dry			% NO_3-N		% K		% Ca		% Mg		Lb uptake/acre		
Lb P/A/yr	1st[1]	2nd[2]	Total[1]	1st	2nd	1st	2nd	1st	2nd	1st	2nd	NO_3-N	P	S
75	1.78a[3]	1.04a	2.61a	.13a	.12a	2.8a	2.2a	.42a	.42a	.20a	.19a	7.0a	21b	15.0b
150	1.78a	1.09a	2.65a	.12a	.11a	2.8a	2.2a	.45a	.44a	.21a	.20a	6.8a	24a	15.6a
C. V. (%)	12.6	38.2	11.5	35.0	46.8	13.8	17.8	25.1	18.8	19.2	17.0	38.0	37.4	13.7

[1] Means of 240 measurements.
[2] Means of 192 measurements.
[3] Means followed by the same letter within columns are not significantly different at the 5% level of probability according to Duncan's Multiple Range Test.

Forage yields differed from year to year, but were generally greatest in 1974 and least in 1972 (when only one cutting was obtained) and in 1976 (Figure 3). From June to September in 1974, the mean temperature was 51.8^{0}F with a total of 7.62 inches of precipitation (NOAA, 1964-76). The 1976 oven-dry yields with two cuttings were only slightly more than those in 1972 with one cutting. This relatively lower yield coincided with the highest average temperature (52.6^{0}F) but the least precipitation (3.48 inches) from July through September during this 5-year study (Table 7).

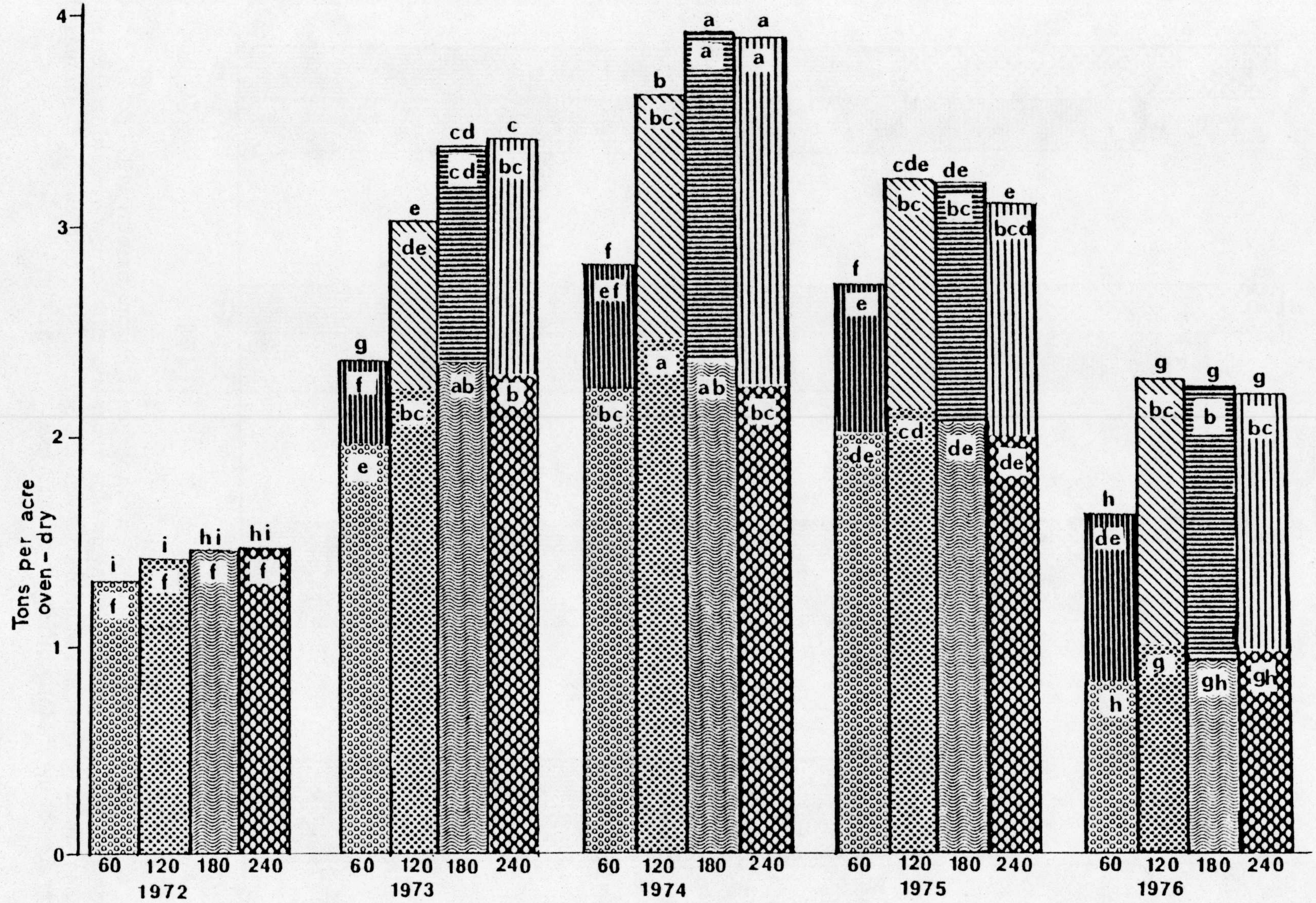

Figure 3. Effects of nitrogen on the oven-dry yield of Engmo timothy, 1972 to 1976. The lower segments represent the first cutting and the upper segments the second cutting. (Letters in each segment refer to Duncan's Multiple Range Test. Segments for each cutting containing the same letter are not significantly different at the 5% level of probability).

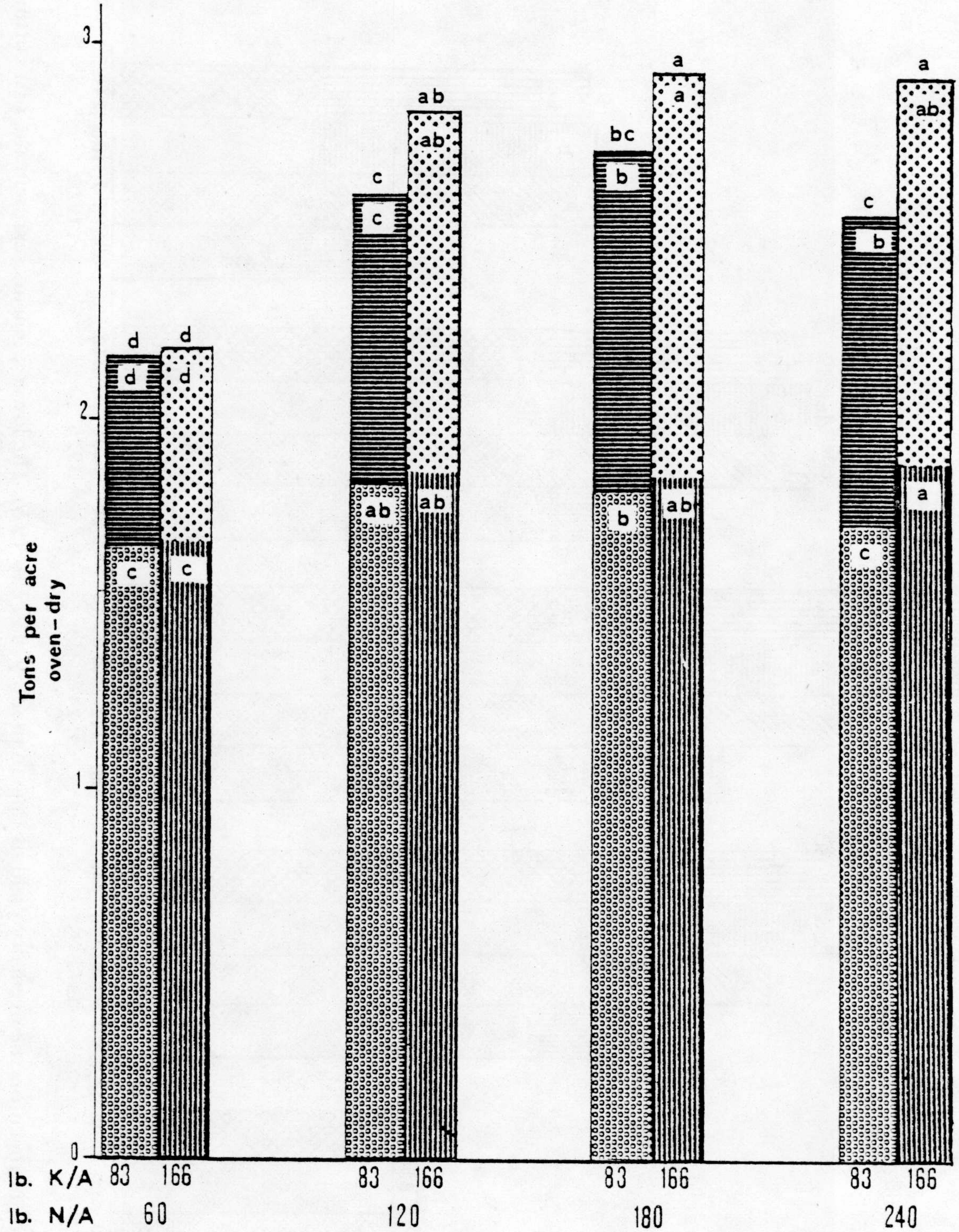

Figure 4. Effects of N and K on oven-dry mean yields of Engmo timothy, 1972 to 1976. The lower segments represent the first cutting and the upper segments the second cutting. (Letters in each segment refer to Duncan's Multiple Range Test. Segments for each cutting containing the same letter are not significantly different at the 5% level of probability).

Table 7. Mean Temperatures and Total Precipitation June through September, 1964-1976. (Means of Homer 5NW and Homer FAA; These Weather Stations are About 5 Miles Apart and Both are Located About 10 Mi. From Experimental Site. National Oceanic and Atmospheric Administration Environmental Data).

	Mean Temp. (F^0)	Precipitation			Mean Temp. (F^0)	Precipitation	
		Total (inches)	Departure from normal			Total (inches)	Departure from normal
1964	50.6	7.05	-1.34	1970	48.6	7.19	-1.20
1965	51.8	11.43	+3.04	1971	49.2	7.76	-0.63
1966	50.2	13.95	+5.56	1972	49.0	4.99	-3.40
1967	51.5	13.23	+4.84	1973	49.7	10.12	+1.73
1968	50.9	3.94	-4.45	1974	51.8	7.62	-0.77
1969	50.6	3.46	-4.93	1975	50.2	6.12	-2.27
				1976	52.6	3.48	-4.91

Crude Protein and NO_3-N Percentages and Nitrogen Uptake

The crude protein and NO_3-N concentrations in both cuttings were increased by each increasing N rate each year, although not all of the increases were large enough to be statistically significant (Table 8). Each increasing N rate increased the NO_3-N concentration in both cuttings and the mean NO_3-N uptake at both K rates, except that the increase with 240 lb N per acre was not large enough to be significant when 83 lb K per acre was applied; the increases in second-cutting NO_3-N concentration and in the seasonal NO_3-N uptake were not large enough to be significant at the two highest N rates (Table 9).

Increasing the P from 75 to 150 lb per acre had no significant effect on the NO_3-N or crude-protein concentrations in either cutting or on the seasonal NO_3-N or total N uptake (Tables 6 and 10).

Increasing the K application from 83 to 166 lb per acre increased the first-cutting NO_3-N concentration when the highest N rate (240 lb per acre) was used, and increased the second-cutting NO_3-N concentration and the mean seasonal NO_3-N uptake when more than 120 lb N per acre was used (Table 9). The higher K rate decreased the crude-protein concentration in both cuttings, but, with higher yields, increased the mean seasonal total N uptake (Table 10); this effect was similar to the depression in crude-protein concentration with increasing K rates in timothy grown near Anchor Point (Laughlin, 1965).

Table 8. Effects of Four N Rates on Nutrient Concentrations in First and Second Cuttings of Engmo Timothy Grown On Kachemak Silt Loam (Means of 24 Measurements).

		% NO_3-N		% crude protein		% P		% K		% Ca		% Mg		% S	
Lb N/A	Year	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
60	1972	—	—	16.9e[1]	—	—	—	—	—	—	—	—	—	—	—
60	1973	—	—	10.9i	17.6g	—	—	—	—	—	—	—	—	—	—
60	1974	—	—	9.4j	12.6j	—	—	—	—	—	—	—	—	—	—
60	1975	.02e	.02d	12.4h	14.3hi	.380c	.394c	3.02a	2.70a	.308e	.394c	.140d	.160c	.34bc	.24c
60	1976	.04e	.02d	15.9f	13.9i	.420b	.361d	2.96a	1.96c	.578a	.379cd	.261a	.133d	.49a	.35a
120	1972	—	—	19.8c	—	—	—	—	—	—	—	—	—	—	—
120	1973	—	—	13.5g	19.8def	—	—	—	—	—	—	—	—	—	—
120	1974	—	—	11.8hi	15.6h	—	—	—	—	—	—	—	—	—	—
120	1975	.10d	.06c	15.6f	18.7f	.415b	.473b	2.92a	2.45b	.356de	.475b	.162cd	.232b	.30de	.24c
120	1976	.09d	.08c	18.2d	17.0g	.410bc	.392c	2.60bc	2.04c	.500b	.322e	.237b	.145cd	.37b	.27bc
180	1972	—	—	22.5b	—	—	—	—	—	—	—	—	—	—	—
180	1973	—	—	15.4f	22.2c	—	—	—	—	—	—	—	—	—	—
180	1974	—	—	14.2g	19.1f	—	—	—	—	—	—	—	—	—	—
180	1975	.20b	.20a	18.2d	23.9b	.462a	.542a	2.80ab	2.33b	.364de	.587a	.173c	.290a	.28e	.28bc
180	1976	.13c	.15b	19.6c	19.6f	.414bc	.432b	2.52c	1.87c	.503b	.343cde	.239b	.158c	.34bc	.27bc
240	1972	—	—	23.8a	—	—	—	—	—	—	—	—	—	—	—
240	1973	—	—	18.3d	22.6c	—	—	—	—	—	—	—	—	—	—
240	1974	—	—	16.3ef	20.9d	—	—	—	—	—	—	—	—	—	—
240	1975	.28a	.22a	19.9c	25.8a	.470a	.562a	3.00a	2.29b	.414cd	.608a	.186c	.278a	.29e	.29b
240	1976	.15c	.16b	20.2c	20.8de	.426b	.430b	2.44c	1.88c	.481bc	.333de	.231b	.159c	.33cd	.27bc
C. V. (%)		35.0	46.8	8.3	9.5	12.6	9.8	13.8	17.8	25.1	18.8	19.2	17.0	17.3	26.2

[1] Means followed by the same letter within columns are not significantly different at the 5% level of probability according to Duncan's Multiple Range Test.

Table 9. Effects of N and K on the NO_3-N Concentration and Uptake in Engmo Timothy Grown On Kachemak Silt Loam, 1975 and 1976 (Means of 24 Measurements).

Lb N/A/yr	Lb K/A/yr	% NO_3-N 1st cut	% NO_3-N 2nd cut	Lb NO_3-N yearly uptake per acre[1]
60	83	.03e[2]	.02d	1.0e
60	166	.03e	.02d	1.2e
120	83	.09d	.06c	4.3d
120	166	.10d	.08c	5.5d
180	83	.16c	.15b	8.5c
180	166	.17bc	.20a	11.0b
240	83	.19b	.16b	9.8bc
240	166	.24a	.22a	13.8a
C. V. (%)		35.0	46.8	38.0

[1] Amount of N remaining in the plant in the NO_3 form.
[2] Means followed by the same letter within columns are not significantly different at the 5% level of probability according to Duncan's Multiple Range Test.

Table 10. Effects of P and K on the Total N (1972-1976), P and S Concentrations, and the Total N, Ca, and Mg Uptake (1975 and 1976) in First and Second Cuttings of Engmo Timothy Grown on Kachemak Silt Loam (Means of 96 Measurements Except as Noted).

Applied annually	% crude protein 1st[1]	% crude protein 2nd[2]	% P 1st	% P 2nd	% S 1st	% S 2nd	Lb yearly uptake/acre Total N	Lb yearly uptake/acre Ca	Lb yearly uptake/acre Mg
				Effect of phosphorus					
Lb P/A									
75	16.6a[3]	19.1a	.40b	.43b	.34a	.27a	144a	20b	9.4b
150	16.7a	18.9a	.45a	.47a	.35a	.28a	146a	22a	9.9a
				Effect of potassium					
Lb K/A									
83	16.8a	19.4a	.42a	.46a	.33b	.29a	142b	22a	10.5a
166	16.5b	18.6b	.43a	.44b	.36a	.26b	148a	19b	8.8b
C. V. (%)	8.3	9.5	12.6	9.8	17.3	26.2	13.8	15.5	14.0

[1] Means of 240 measurements.
[2] Means of 192 measurements.
[3] Means followed by the same letter within columns are not significantly different at the 5% level of probability according to Duncan's Multiple Range Test.

Phosphorus Concentration and Uptake

The P concentrations in both 1975 cuttings and in the second 1976 cutting were increased by each N increment through 180 lb N per acre (Table 8). Nitrogen rates of 120, 180, and 240 lb per acre increased the mean seasonal P uptake (Table 11).

Increasing the P rate from 75 to 150 lb per acre increased the P concentration of both cuttings (Table 10) and the mean seasonal P uptake (Table 6).

Increasing the K rate from 83 to 166 lb per acre decreased second-cutting P concentration (Table 10), but did not significantly influence first-cutting P concentration and the mean seasonal P uptake (Table 11). This behavior of P with increased K application again corresponds to results with timothy grown near Anchor Point (Laughlin, 1965).

Table 11. Effects of N and K Applications on the P and S Uptake by Engmo Timothy Grown on Kachemak Silt Loam, 1975 and 1976.

	Pounds yearly uptake/A	
Applied annually	P	S
--------------- Effect of N (means of 48 measurements) ---------------		
Lb N per acre		
60	16.8b[1]	14.9b
120	23.2a	15.8a
180	25.0a	15.2ab
240	25.1a	15.2ab
--------------- Effect of K (means of 96 measurements) ---------------		
Lb K per acre		
83	21.9a	15.0b
166	23.2a	15.6a
--------------- Effect of year (means of 96 measurements) ---------------		
Year		
1975	28.0a	17.6a
1976	17.1b	12.9b
C. V. (%)	37.4	13.7

[1] Means followed by the same letter within columns are not significantly different at the 5% level of probability according to Duncan's Multiple Range Test.

Potassium Concentration and Uptake

No consistent relationship was demonstrated between K concentration in forage and N rates applied (Table 8). Concentrations in 1976 were lower than those for 1975, possibly reflecting differences in climatic factors. Total K uptake was influenced by N rates applied; K uptake was higher with 120 than with 180 or 240 lb N per acre, but K uptake at the latter two rates was higher than when N was applied at 60 lb per acre (Table 12).

The K concentrations in both cuttings and the mean seasonal K uptake were unchanged by the different P rates (Tables 6 and 12).

In both 1975 and 1976, increasing the K application from 83 to 166 lb per acre increased the K concentration in both cuttings as well as the mean seasonal K uptake (Table 13).

Table 12. Effects of N and P on the K, Ca, and Mg Uptake by Engmo Timothy Grown on Kachemak Silt Loam, 1975 and 1976.

	Pounds yearly uptake per acre		
Applied annually	K	Ca	Mg
Effect of N (means of 48 measurements)			
Lb N per acre			
60	120c[1]	16c	7.1c
120	142a	21b	10.0b
180	132b	23a	10.9a
240	133b	23a	10.7a
Effect of P (means of 96 measurements)			
Lb P per acre			
75	130a	20b	9.4b
150	133a	22a	9.9a
C. V. (%)	16.5	15.5	14.0

[1] Means followed by the same letter within columns are not significantly different at the 5% level of probability according to Duncan's Multiple Range Test.

Table 13. Effects of Two K Rates on the K, Ca, and Mg Concentrations in, and the K Uptake by First and Second Cuttings of Engmo Timothy Grown on the Kachemak Silt Loam, 1975 and 1976 (Means of 48 Measurements).

		% K		% Ca		% Mg		Lb K
Lb K/A/yr	Year	1st	2nd	1st	2nd	1st	2nd	yearly uptake per acre
83	1975	2.6c[1]	1.9c	.38c	.60a	.18c	.28a	142b
83	1976	2.2d	1.6d	.55a	.39c	.27a	.17c	77d
166	1975	3.3a	3.0a	.34c	.44b	.16d	.20f	200a
166	1976	3.0b	2.2b	.48b	.30d	.22b	.12d	109c
C. V. (%)		13.8	17.8	25.1	18.8	19.2	17.0	16.5

[1] Means followed by the same letter within columns are not significantly different at the 5% level of probability according to Duncan's Multiple Range Test.

Sulfur Concentration and Uptake

The S concentration of the first cutting tended to decrease with increasing N rates in both 1975 and 1976 (Table 8). The 1975 N had little effect on second-cutting S concentration; this was decreased by N rates exceeding 60 lb N per acre in 1976 (Table 8); total seasonal S uptake tended to be increased by N rates exceeding 60 lb per acre (Table 11).

Doubling the 75 lb per acre P application had no effect on the S concentration in either cutting (Table 10), but did increase the mean seasonal S uptake (Table 6).

Increasing the K application from 83 to 166 lb per acre increased the S concentration in the first cutting and the total seasonal S uptake, but decreased second-cutting S concentration (Tables 10 and 11).

Calcium and Magnesium Concentration and Uptake

The concentrations of Ca and Mg in timothy herbage were influenced by N application rate (Table 8). There was a trend toward increasing concentration of both Ca and Mg in both timothy cuttings in 1975 with increasing rates of N application, and in every case Ca and Mg concentrations were higher at the 240-lb-per-acre rate than at the 60-lb rate. However, in 1976, when only about half as much rainfall was received (June through September) as in the previous year, Ca and Mg concentrations tended to decrease in the first cutting with increasing N rates, whereas, in the second cutting, Ca remained unchanged but Mg showed a slight increase with increased N rates. In 1975, the wetter year, concentrations of both Ca and Mg were higher in the second cutting than in the first; conversely, in 1976, concentration of both elements was higher in first-cutting herbage. The mean seasonal Ca and Mg uptake were increased by each increasing N rate through 180 lb N per acre (Table 12).

Doubling the P application had no significant effect on the Ca or Mg concentrations in either cutting (Table 6), but increased the mean seasonal Ca and Mg uptake by the timothy (Table 10).

Increasing the K application from 83 to 166 lb per acre decreased the Ca and Mg concentrations in both cuttings in both years and also decreased the mean seasonal Ca and Mg uptake, except Ca concentration was unchanged in the first cutting of 1975 (Tables 10 and 13). The Ca/Mg ratio (molar basis) was approximately 1.3 for both cuttings. This value is much higher than the Ca/Mg ratio of 0.4 reported in 2 years of timothy harvests near Anchor Point (Laughlin, 1965), or the 0.2 ratio in bromegrass grown over three years near Fairbanks (Laughlin and Restad, 1964). The higher Ca/Mg ratio in this study, which is closer to that reported in most grasses grown elsewhere (Daniel, 1935; NAS, 1971), may have resulted from the additional Ca applied with liming.

Soil Reaction and Available NO_3-N, P, and K

The soil became more acidic from 1972 to 1976 (Figure 5A and B). September pH values in the top 2 inches generally were lower than in June; at the 2 – 4- and 4 – 6-inch depths, differences between June and September samplings were not consistent. The pH decrease with time was greatest with the highest N application (240 lb per acre). Each increasing N rate decreased the pH, although the decrease from 120 to 180 lb N per acre was significant only at the

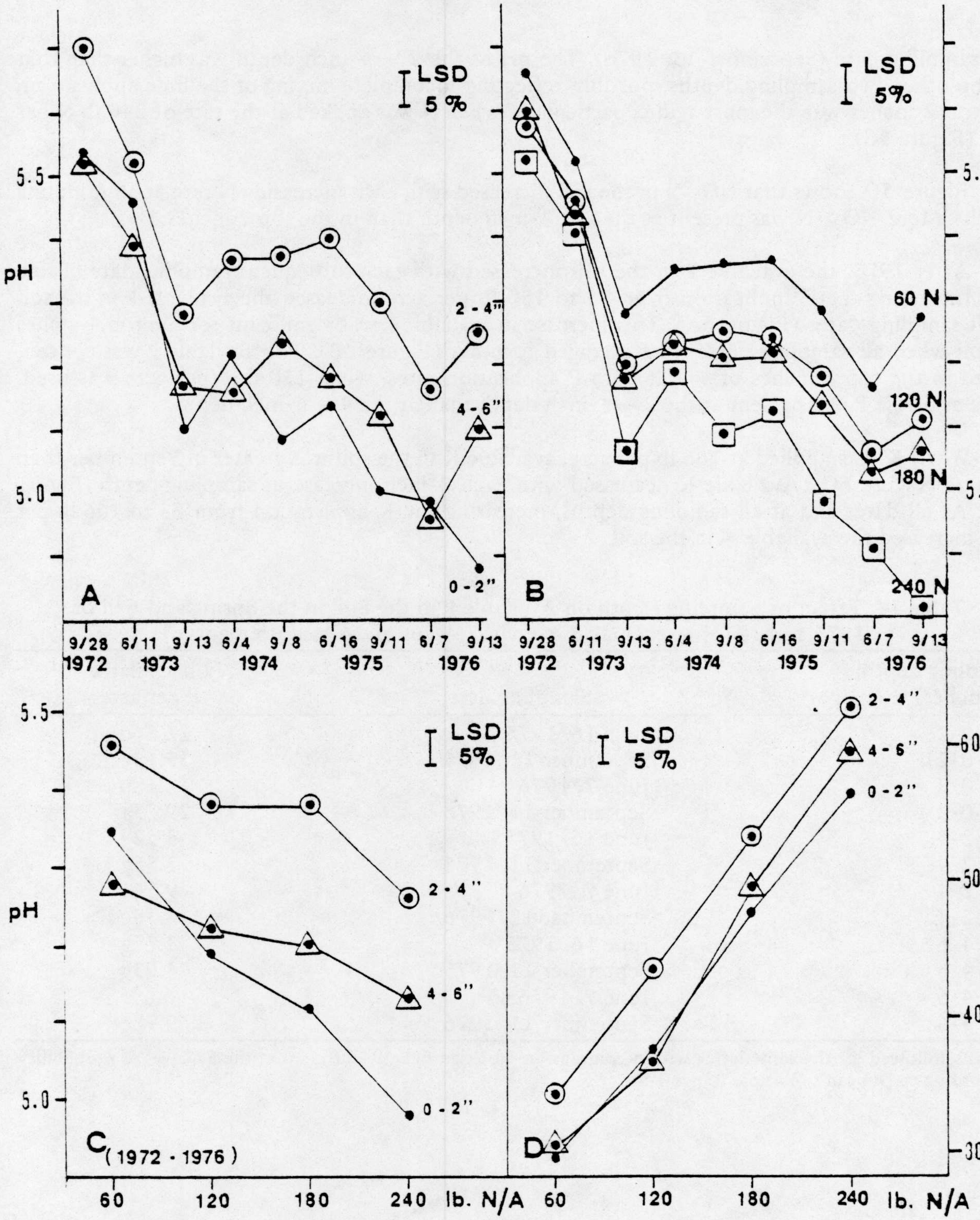

Figure 5. Effects of sampling date and depth (A), sampling date and nitrogen rate (B), and nitrogen rate and sampling depth (C), on the pH (water); and nitrogen rate and sampling depth on the NO_3-N in the soil (D), 1972 to 1976.

last sampling date (September 13, 1976). The pH at the 2 – 4-inch depth was higher than that of the other two sampling depths, possibly reflecting incomplete mixing of the lime application; the top 2 inches was the most acidic, particularly when N was applied at the rate of 240 lb N per acre (Figure 5C).

Figure 5D shows that NO_3-N in the soil increased with each increasing N rate at all sampling depths. More NO_3-N was present at the 2 – 4-inch depth than in the top 2 inches.

After 1975, the available P in the soil increased with each subsequent sampling date (Table 14). Increasing the P application from 75 to 150 lb per acre increased the available P in the soil at all sampling dates (Figure 6A). This increase in available P was significant for the top 4 inches of soil when all sampling dates were averaged together (Figure 6B). The available P was concentrated in the top 2 inches of soil at both P application rates; when 150 lb P per acre was used, more available P was present at the 2 – 4-inch depth than at the 4 – 6-inch depth.

When K was applied at 166 lb per acre, available K in the soil was greater in September than in June (Figure 6C). Available K decreased with each 2-inch increase in sampling depth (Figure 6D). At all dates and at all sampling depths, increasing the K application from 83 to 166 lb per acre increased the available K in the soil.

Table 14. Effect of Sampling Depth on Available P in the Soil in the Spring and Fall of 1975 and 1976. Kachemak Silt Loam (Means of 24 Measurements).

Sampling depth (inches)	Sampling date	Lb available P per acre
0-2	June 16, 1975	12.86d[1]
0-2	September 11, 1975	15.15c
0-2	June 7, 1976	18.68b
0-2	September 11, 1976	29.75a
2-4	June 16, 1975	3.52g
2-4	September 11, 1975	3.55g
2-4	June 7, 1976	9.54e
2-4	September 11, 1976	14.35cd
4-6	June 16, 1975	3.77g
4-6	September 11, 1975	4.03g
4-6	June 7, 1976	6.69f
4-6	September 11, 1976	9.98e

[1] Means followed by the same letter within columns are not significantly different at the 5% level of probability according to Duncan's Multiple Range Test.

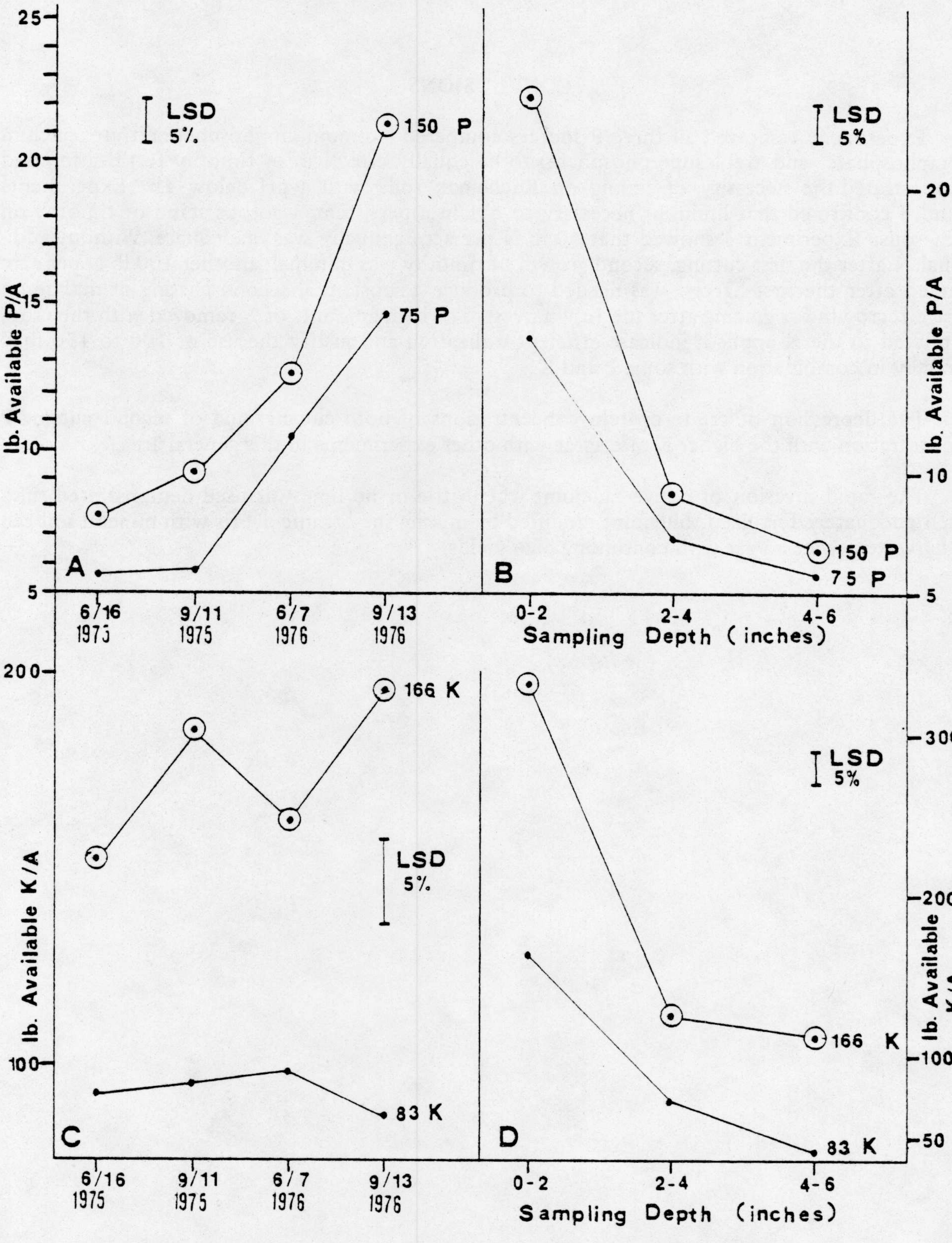

Figure 6. Effects of sampling date and phosphorus (A), sampling depth and phosphorus (B), sampling date and potassium (C), and sampling depth and potassium (D) on the available P and K, 1975 to 1976.

CONCLUSIONS

Experiment 1 showed all three P sources compared (ammonium phosphate nitrate, calcium metaphosphate, and treblesuperphosphate) to be equally effective for timothy fertilization and demonstrated the necessity of liming on Kachemak soils with a pH below 4.5. Experiments 2 and 3 confirmed that liming is necessary to obtain a persistent, vigorous stand of timothy on such soils. Experiment 3 showed that 60 lb N per acre annually was inadequate. Without additional N after the first cutting, second growth of timothy was minimal; another 100 lb N per acre applied after the first harvest was needed to produce a substantial second cutting or maximum forage regrowth for grazing after the July harvest. The high amounts of N removed with the crop, as related to the N applied, indicate efficient utilization and justify the use of 100 to 150 lb N annually in combination with some P and K.

The depression of crude-protein concentrations of both cuttings and of second-cutting P concentration with the higher K rate agree with other experiments in this general area.

The rapid invasion of native bluejoint when little or no lime was used demonstrated that, when adequately fertilized, bluejoint modified by mixing the organic debris with mineral soil can be harvested twice a year with continuing high yields.

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