EFFECT OF SOIL ACIDITY AND EXCHANGEABLE POTASSIUM ON ALFALFA YIELD

by

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INTRODUCTION

The efficient production of milk is enhanced when the dairy farmer includes alfalfa in his crop rotation. Experience and a limited number of critical studies have shown that the successful growing of alfalfa in the northeastern United States requires proper soil treatments to correct the acidity and low exchangeable potassium levels prevalent in the area. However, there appears to be little agreement among the various investigators as to the optimum soil pH and exchangeable potassium levels for alfalfa production or the amounts of added lime and/or potassium needed to obtain or maintain these optimum levels.

The objectives of this study then, were to determine the effects of various levels of soil pH and exchangeable potassium on the yield of alfalfa, to establish whether the effects of these two variables on yield are additive or interdependent, and to use the information obtained to develop an equation, based on soil tests for pH and exchangeable potassium, for predicting alfalfa yields. A secondary objective was to determine the sampling depth for which the soil test values would correlate best with crop response.

The established fertility plots on the Clark County farm were selected for this study. These plots exhibited a wide range in exchangeable potassium combined with a wide range in pH which assured the presence of all combinations of pH and potassium levels. The large number of plots (75 four year old and 105 five year old Cossack-Ladak alfalfa plots, plus 25 two year and 25 three year Vernal alfalfa plots) provided an excellent opportunity for the application of statistics to aid in the interpretations.

REVIEW OF LITERATURE

The literature was reviewed to obtain available information on the effect of pH and exchangeable K on the yield of alfalfa, the optimum ranges for these factors, and the experimental conditions that may have influenced the interpretations.

Effect of Soil pH on Alfalfa Yield

The availability of nutrients to plants, according to Truog and Engelbert (1954), is affected by the forms of the nutrients, soil pH, supply of organic matter and water, and the feeding ability of the plants.

Soil pH affects the solubility of many of the nutrients and, therefore, may determine whether the plant obtains sufficient or excessive amounts of those nutrients (Truog and Engelbert, 1954; Schmehl, et al., 1950; Wang, et al., 1953; Moschler, et al., 1960). It also influences the kind and amount of microbiological action in the soil and thus nitrification, nitrogen fixation and the amount of organically-bound nutrients released to the plant.

Field studies. Surprisingly few workers have attempted to show the effect of pH on the yield of alfalfa by field studies.

Moschler, Jones, and Thomas (1960), in a three year study on a soil initially at pH 4.9,grew alfalfa on plots at established pH values up to 6.9. They obtained significant yield increases up to pH 5.7 and concluded that reduction in the amount of exchangeable Al in the soil appeared to be one of the principle benefits of liming. However, the alfalfa suffered from drought in all three years, and lack of yield responses above pH 5.7 could have been caused by a lack of moisture. Also, the lime was applied just prior to seeding, and thus did not become equilibrated with the entire plow layer as evidenced by the presence of significant amounts of exchangeable Al at pH 6.5 and above.

Love, Peterson and Engelbert (1960) studied the effect of the method of lime and fertilizer application on the yield of alfalfa. The three year trial showed no differences in yield or average pH of the plow layer whether the lime was applied before plowing, after plowing, or $\frac{1}{2}$ before and $\frac{1}{2}$ after plowing as long as the lime was well mixed with the soil. However, there were treatment induced variations in pH at different depths within the plow layer.

A five year study on the effects of molybdenum and lime on alfalfa yield (Giddens and Perkins, 1960) showed that highly significant yield increases were obtained with increasing amounts of lime (0, 500 and 4000 pounds per acre) and resulting increases in soil pH from 5.5 to 6.3. Additions of molybdenum in addition to lime increased the yield significantly on 3 to 5 year old alfalfa stands.

Wang, Attoe and Truog (1953) concluded that soils with high lime applications (pH 6.5 and above) promote winter survival of alfalfa in Wisconsin. Moschler, Jones and Thomas (1960) also reported better winter survival with increasing soil pH values but considered pH 5.7 as optimum for Virginia. Wang et al. did not study the pH effects between 5.0 and 6.5.

Greenhouse studies. Some workers have attempted to show the effect of pH on the yield of alfalfa in the greenhouse, but, at best, this appears to be a poor substitute for field trials. Nimlos (1959) reported that no highly significant alfalfa yield increases were obtained in the greenhouse when various size fractions of dolomitic limestone were used, even though there were wide variations in the soil pH. There were yield responses to fertility variations which suggested that some of the previous greenhouse data on yield response of alfalfa to soil pH may have been complicated by release of nutrients such as N and P, especially where the fertility levels were not optimum for greenhouse work.

Meyer and Volk (1952) grew five crops of alfalfa on soils with a wide pH range and reported increased yields with increased soil pH. No initial or applied fertility data were given, however, so this response may have been caused, at least partially, by nutrient release.

Other workers (Haddock and Vandecaveye, 1946; Schmehl, Peech and Bradfield, 1950) obtained no increased alfalfa growth in the greenhouse above pH 5.6.

Studies by Fried and Peech (1946) showed yield increases of alfalfa with lime and yield decreases with gypsum, even when the gypsum supplied more calcium than the lime. They concluded that the gypsum may have depressed the pH low enough to cause toxic effects from Al, Fe, or Mn.

Conclusions. There appears to be general agreement that alfalfa grown on acid soils responds to lime applications. However, opinions on the optimum pH for alfalfa production range from 5.7 to over 6.5. Reasons given for the response to liming range from improvement of conditions for N fixation to release of Mo and precipitation of toxic Fe, Mn or Al.

The Effect of Exchangeable Potassium on Alfalfa Yield

Potassium is present in the plant in soluble form and does not constitute a part of the plant tissue (Truog and Engelbert, 1954). Its function in the metabolism of plants is considered to be primarily in the synthesis and translocation of carbohydrates, and possibly in the synthesis of proteins. A deficiency of exchangeable K in the soil, therefore, seriously affects the growth of alfalfa.

Field studies. Attoe and Truog (1950) reported increasing yields of red clover-alfalfa hay with increasing levels of available P and exchangeable K in plots with a soil pH 6.5. The exchangeable K level was three times as effective as the available P level when predicting the yield in this six year study. In the second year of hay, alfalfa survival increased as the exchangeable K level was increased.

Seay, Attoe and Truog (1949) found a high correlation between percent potassium in alfalfa tissue and the log of the lbs. of exchangeable K per acre. They suggested a minimum potassium content of 1.25% in the plant tissue, and an exchangeable K level of 180 lbs. per acre in the soil at harvest time (when the exchangeable K is the lowest) to resist winter kill.

Wang, Attoe and Truog (1953) reported that exchangeable K levels above 200 pounds per acre promoted the winter survival of alfalfa.

Stivers and Ohlrogge (1952) obtained large yield responses and better stands of alfalfa with the addition of 200 lbs. of K_2O per acre on soils with 0.13 to 0.19 me. of exchangeable K per 100 g. of soil (100 to 150 lbs. per acre).

Bear and Wallace (1950) concluded that the most limiting factor on alfalfa survival and growth was the lack of sufficient exchangeable K, 490 lbs. per acre being ideal. They also suggested a soil pH above 6.5.

MacLean and Langille (1958) checked "healthy" and "unhealthy" alfalfa plants to determine their nutrient status by the amounts of the nutrients found in the tissue. They concluded that a 1.0% potassium level in the tissue was needed to maintain "healthy" stands.

Other field studies have been concerned with correlation of soil test values in the plow layer with potassium uptake on various soil types (Baumgardner and Barber, 1956) and also correlation of yield with soil test values of both surface and subsoil horizons (Wells, 1959). Both reports showed highly significant correlations between exchangeable K values and potassium uptake, percent potassium in the tissue and/or yield of dry matter when alfalfa was used as the response crop.

Greenhouse studies. Most potassium studies in the greenhouse have been concerned with potassium fixation and release and potassium uptake with various grasses as the availability indicators (Wells, 1959; Bear, Prince and Malcolm, 1944; Baumgardner and Barber, 1956).

In a greenhouse study by Jung and Smith (1959), it was concluded that adequate potassium levels increased the cold resistance (and plant survival) of alfalfa.

Conclusions. There is general agreement that the potassium level in the soil is very critical for alfalfa production. However, the optimum recommended exchangeable K levels for alfalfa vary from 150 to 490 lbs. of exchangeable K per acre. Reasons given for yield response include increased winter survival and "healthier" plants.

Effect of the Interaction of Soil pH and Exchangeable Potassium on Alfalfa Yield

Frequently, yield responses to applications of individual plant nutrients are not additive. In these cases, the response to one nutrient may depend on the level of another. This has been shown to be the case by Rendig and McComb (1959) for the response by alfalfa to N applications at various S levels. No well defined pH - K interactions on the yield of alfalfa have been found in the literature, but various studies have indicated that this interaction does exist.

Field studies. Jackson, Evans, Attoe, Huber and Kaudy (1947) reported that alfalfa failed on the acid (pH below 5.5) silt loam soils of north-central Wisconsin regardless of the amount of K_2O applied (up to 300 lbs. per acre) and that well limed soils (pH 6.5 and above) needed an annual application of at least 150 lbs. of K_2O per acre to maintain the alfalfa stand. It was concluded that a potassium content in alfalfa tissue of 1.25% to 2.0% and a soil pH of 6.5 or above was needed for alfalfa survival. Actual soil test values and yields of alfalfa were not reported.

Wang, Attoe and Truog (1953) concluded that adding enough lime and potash to increase the soil pH to 6.5 and the exchangeable K level to 200 lbs. per acre promoted the winter survival of alfalfa.

Brown (1928) made a six year field study and reported that applying potassium as manure of muriate of potash was beneficial to the alfalfa stands. He included a table that showed the highest yields of alfalfa to be on plots with the highest soil pH (6.7) and the highest potash applications (200 lbs. of muriate of potash per acre), both factors contributing to the increasing yields. No mention was made of the significance of these data.

Bear and Wallace (1950) suggested liming sandy soils (low lime requirement) with 1000 lbs. of $CaCO_3$ per acre and supplying adequate potassium, with 0.5 me. exchangeable K per 100 g. of soil (490 lbs. per acre) being ideal. The authors reported that potash levels had the greatest effect on yield and that a pH of 6.5 and 80 lbs. of exchangeable K per acre were the "critical" levels.

Thomas and Coleman (1958) found that ladino clover yields were reduced when potash was applied to an acid soil, but the yields were increased when both lime and potash applications were made.

Conclusions. Although some workers have reported critical and optimum levels of pH and exchangeable K for alfalfa, there are no specific reports on the interaction of these two factors on the yield of alfalfa.

EXPERIMENTAL PROCEDURES

Field Methods

A field experiment was conducted to determine how the pH and exchangeable K levels as determined by soil analyses would affect alfalfa yields, and to determine what interaction might exist between these two soil factors in promoting alfalfa growth.

Site description. The Clark County fertility plots were selected for this study. These plots were located on Withee silt loam at the Clark County farm in the SE $\frac{1}{4}$ of Section 31, Township 29 North, Range 1 West.

Soil type.[1] The Withee series includes imperfectly drained Gray Brown Podzolic soils developed in a loess cap over slowly permeable reddish-brown clay loam glacial till. It resembles closely the Freer series. The latter however has a more permeable till. Withee is acid throughout and is associated with the Loyal, Granton, Withee, Auburndale and Adolph Catena.

I. Soil Profile. Withee silt loam

1.	A_p	0 - 7"	Brown (10YR 5/3 d) dark brown (10YR 3/3 m) very friable silt loam. Very fine moderate granular structure; abundant roots and root hairs; pH 5.6; 6 to 8 inches thick. This breaks abruptly and sharply into -
2.	A_2	7 - 12"	Very pale brown to pale brown (10YR 7/3, 6/3 d) dark yellowish brown to grayish brown (10YR 4/4, 5/2 m) with many distinct fine light brown to brown mottlings (7.5YR 6/4, 5/4) very friable silt loam with fine moderate platy structure. Roots plentiful; pH 5.0; 3 to 5 inches thick. This breaks abruptly and sharply into -

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[1] Description from Soil Conservation Service.

3.	B_1	12 - 16"	Dark brown to dark yellowish brown (10YR 4/3 m) silty clay loam with many distinct medium sized (7.5YR 4/4) dark brown mottlings. Angular, medium sized blocky structure of firm consistency; roots few; pH 5.0; 3 to 6 inches thick. Grades clearly with wavy boundary into -
4.	B_2	16 - 20"	Reddish brown (5YR 4/4 m) clay loam with reddish brown (5YR 4/2) coatings on the peds. Strong, coarse angular blocky structure of firm consistency; few roots; pH 5.0; 3 to 8 inches thick. Clear but wavy boundary to -
5.	C_1	20"+	Yellowish red (5YR 4/6 m) plastic clay loam with light brownish gray streaks. A small percentage of sand gives it a gritty feel. Strong coarse angular blocky structure, with a firm consistency. No roots observed in this layer. Stones ranging in size from $\frac{1}{4}$ inch to 2 or 3 inches in diameter are common in this layer. These are subangular and of granitic or basaltic composition. pH 5.5.

II. Variations: Mainly in depth to the underlying glacial till which may be from 18 to 26 inches. Surface texture in some localities may be a loam where silt deposits are very shallow.

III. Topography: Gently sloping upland. Slopes are typically long.

IV. Drainage: Imperfectly drained. Slow internal; medium to slow surface drainage.

V. Natural Vegetation: Most areas are cultivated. Natural vegetation consists of mainly oak and maple.

VI. Use: Cultivated areas grow grain and hay. Questionable for corn although some is grown.

VII. Distribution: Central Wisconsin

Type location: Taylor County, Wisconsin near Stetsonville

NW$\frac{1}{4}$, NW$\frac{1}{4}$, Sec. 19, T 30 N, R 2 E.

Series Proposed: Clark County, Wisconsin

Source of Name: Village in northern Clark County

Site History. (Jackson and Truog, 1944). The Clark County plots were started in 1944 on a field selected for its representation of conditions in the Spencer soil area (includes the Withee silt loam). The land had been cleared about 1900 and farmed thereafter with only manure being returned to the field. Prior to treatment, soil analyses showed 10 to 20 pounds per acre of available P, 70 to 80 pounds per acre of exchangeable K, and a pH of 5.0 to 5.2.

The plot area was divided into four fields, A, B, C and D (Figure 1), and each field received similar lime and fertilizer treatments with the exception of field A which received additional treatments described below.

Each field was divided into five blocks with block 0 receiving no lime and blocks 10, 20, 30 and 40 receiving, respectively, 2, 4½, 6 and 8 tons of <100 mesh dolomitic limestone per acre (Figure 1).

Each block was divided into five plots, except field A where P only and K only plots were added. Initial amounts of P and K carrying fertilizers were applied to plots 3, 4 and 5 of each block to obtain the soil test levels indicated in Figure 2a.

All plots received about 10 tons of fresh cow manure per acre (Figure 2a) previous to working the land for corn, and all plots, except plot 1, received 150 pounds of 3-12-12 fertilizer applied in the row on corn. Plot 2 received 300 lbs. of 0-20-20 fertilizer per acre with the grain (considered a common fertilizer practice in 1944) while plots 3, 4 and 5 received 400, 500 and 600 lbs. of 0-20-20 fertilizer per acre, which, it was hoped, would maintain the intended soil test values for each plot (Figure 2a). The "P" plots and "K" plots in field A received

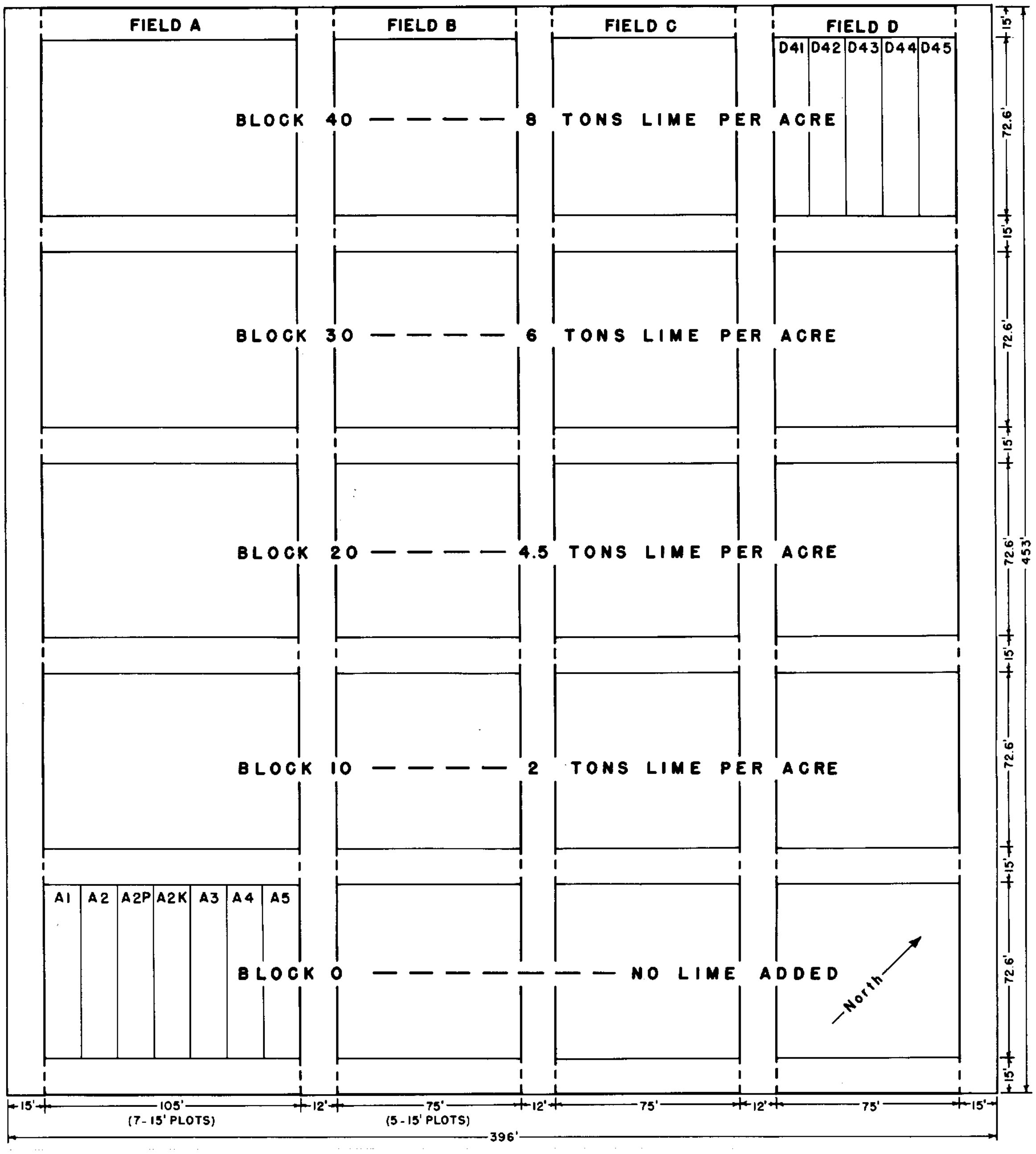
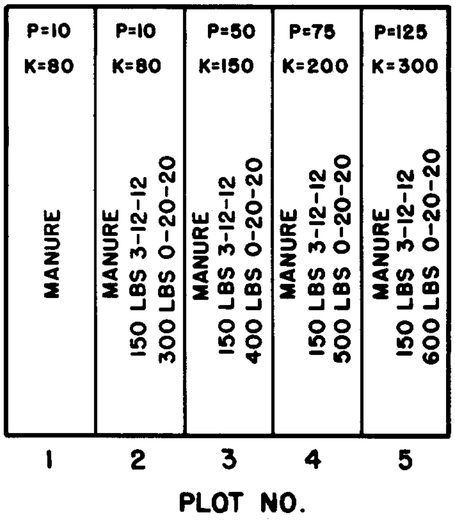
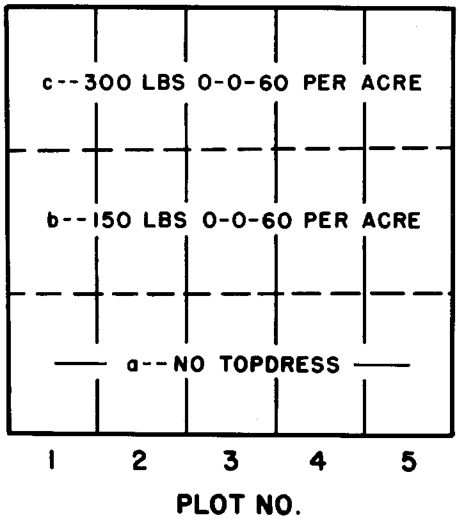


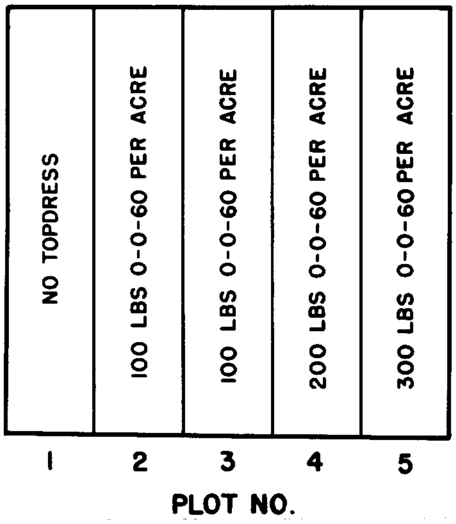
FIGURE 1. GENERAL LAYOUT OF CLARK COUNTY PLOTS WITH FIELDS, BLOCKS, PLOTS AND LIME LEVELS DESIGNATED. FIELD A HAS TWO EXTRA PLOTS RECEIVING PHOSPHORUS ONLY AND POTASSIUM ONLY.



a. ENLARGED BLOCK SHOWING PLOTS AND FERTILITY LEVELS TO BE MAINTAINED.



b. ENLARGED BLOCK SHOWING PLOTS AND ANNUAL TOPDRESS TREATMENTS OF FIELDS A AND B.



c. ENLARGED BLOCK SHOWING PLOTS AND ANNUAL TOPDRESS TREATMENTS OF FIELDS C AND D.

FIGURE 2. ENLARGED BLOCKS FROM CLARK COUNTY PLOTS SHOWING FERTILITY TREATMENTS.

no 0-20-20, but they did receive straight P or K applications equivalent to the P or K applications on plot 4. A four year rotation of corn, oats seeded to an alfalfa-clover-timothy mixture, and two years of hay was followed on these fields. In order to obtain data for each crop each year, the initiation of the rotation was staggered so that field A went into oats seeded in 1945, field B in 1946, field C in 1947, and field D in 1948.

In 1955, it was decided (Peterson, Olsen and Attoe, 1957) to discontinue the rotations, but to maintain each field as it came into forage production (the seeding mixture had been changed to alfalfa-brome) with superimposed potash topdressing treatments. The plots in fields A and B were split into three subplots receiving (a) no topdressing, (b) 150 lbs. of 0-0-60, and (c) 300 lbs. of 0-0-60 per acre topdressed in the fall of each hay year (Figure 2b). On fields C and D the 0-0-60 was applied uniformly on each plot at the following rates: plot (1) none, (2) 100 lbs., (3) 100 lbs., (4) 200 lbs. and (5) 300 lbs. per acre (Figure 2c). Field A was in its second hay year in 1955 when it was decided to topdress the hay fields. Therefore, it did not receive a fall topdress treatment its first hay year.

Soil sampling. It was desired to determine the sampling depth (in the A_p) at which the soil test values best correlated with alfalfa yield. Therefore, preliminary soil sampling involved taking paired cores to a depth of 8 inches. The paired cores were taken within 3 inches of each other. One core was composited with cores from four other pairs for analysis, while the other core was divided into four 2-inch increments, each increment being composited with similar increments from the mates to the individual cores. Soil test values were determined on each composite sample, and the average soil test values of the 2-inch increments were compared with those of the 0 - 8 inch cores. The results of triplicate analyses of ten samples are shown in Table 1.

The close agreement between the two methods indicated that averages of 2-inch increments could be used in place of single core samples taken to the same depth. This method was then used in the subsequent work.

In May of 1958, before there was any alfalfa growth, each plot at the Clark County fertility plots was sampled by taking twenty 0 to 8 inch (plow depth) soil cores from a strip, 38 inches by 22 feet, in the center of each plot from which subsequent harvests were made. Each core was divided into 2-inch increments and the twenty increments from similar depths were composited for analysis.

Forage sampling. The forage was harvested on July 2 and August 13, 1958. A 38-inch swath, 22 feet long, was cut with a Jari mower and the green forage was weighed in the field. Samples for moisture determination were dried at 55° C, weighed, and the pounds of dry matter per acre calculated.

Analytical Methods

Soil pH, available P and exchangeable K were determined by the methods used in the Wisconsin State Soils Laboratories.

Soil preparation. The soil samples were dried at 45° C for 48 hours. They were then ground to pass through a 12-mesh sieve with a mechanical soil grinder.

Table 1. Comparison of the averages of pH and exchangeable potassium analyses of 2-inch increments of soil to 8-inch depth with analyses of 0 to 8 inch soil cores.

	Soil analyses*			
Sample number	Ave. pH of 2" increments to 8" depth	pH of 0 - 8" cores	Ave. exch. K of 2" increments to 8" depth	Exch. K of 0 - 8" cores
			pp2m	pp2m
1	5.98	6.05	229	238
2	5.80	5.73	181	180
3	6.30	6.22	150	155
4	6.23	6.15	128	130
5	6.36	6.30	225	220
6	6.70	6.92	246	255
7	6.23	6.18	184	187
8	5.93	5.85	190	190
9	6.60	6.50	179	180
10	5.94	6.00	218	222
Ave.	6.21	6.19	193	196

* Averages of 3 analyses for each sample.

Determination of soil pH. Approximately 15 g. of soil was wet to a thin paste with distilled water. After 30 minutes of equilibration, the pH was determined with a line operated, model 18A, Coleman pH Electrometer.

Determination of available phosphorus. A measured volume of soil, equivalent to 6.5 g. of light colored silt loam soil, was placed in a 50-ml Erlenmeyer flask. Two grams of P-free activated charcoal was added to eliminate the organic color in the extract. Fifteen ml of 0.3 N HCl and 0.1 N NH_4NO_3 extracting solution was added and the sample shaken for 5 minutes on an oscillating shaker at 160 excursions per minute. The suspension was filtered through Whatman No. 2, 9-cm filter paper into a 15-ml funnel tube. A 3-ml aliquot of the filtrate was dispensed into a 20-ml colorimeter tube, and 3 ml of vanadomolybdate reagent was added and mixed. After 15 minutes, the available phosphorus determination was made on a Coleman, model 8 photo-electric colorimeter using the 8-203 (430 mu) filter.

Determination of exchangeable potassium. The exchangeable potassium determination was made with a Perkin-Elmer, model 52C flame photometer using the filtrate from which the phosphorus aliquot was taken.

Statistical Methods

Correlation analyses were run on the IBM 650 computer of the Agricultural Records Cooperative by the routines of Beaton, Baker and Kelly (mimeo of routine furnished by Professor E. Corley of the Dairy Husbandry Department of the University of Wisconsin). The simple correlation routine computes means, standard deviations, simple correlation coefficients, sums, sums of squares and cross products, etc. The multiple correlation routine computes normalized Beta coefficients and their standard errors, partial correlation coefficients, B coefficients and their standard errors, multiple correlation coefficients, standard error of estimate, the constant terms in the regression equations, the coefficients of determination and unexplained variance, and rectangular matrix of the Beta coefficients and the inverse of the correlation matrix of the independent variables.

The coefficients of determination were corrected for degrees of freedom by means of the following formula:

$$\bar{R}^2 = 1 - (1-R^2)\frac{n-1}{n-m}$$

where $\bar{R}^2$ is the corrected coefficient of determination, R^2 the uncorrected coefficient of determination, n the number of observations, and m the total number of variables considered.

RESULTS AND DISCUSSION

Soil samples and forage yields were taken in 1958 from the established Clark County fertility plots. These plots were selected because they exhibited wide ranges in pH and exchangeable K, well established alfalfa stands, a large number of plots, well known fertilizing history, and because the lime was well mixed and equilibrated with the entire plow layer.

The soil samples were analyzed for pH, available P and exchangeable K by the Wisconsin State Soil Testing Laboratory methods, and the yield of forage was computed on a dry weight basis. Correlation analysis was used to evaluate the fertility management practices and the pH, exchangeable K and available P content of samples taken to varying depths in the plow layer for their importance in predicting the yield of dry matter.

The four and five year old Cossack-Ladak plots were selected for the main discussion because there were 75 plots in field B with fourth year alfalfa and 105 plots in field A with fifth year alfalfa. This gave enough observations on older stands for reliable interpretation of statistical results. The two and three year old Vernal alfalfa plots (fields D and C) had only 25 observations for each field and a crop varietal difference which made them a different population from the four and five year old alfalfa stands.

Soil Analyses and Crop Yields

Four and five year old Cossack-Ladak alfalfa. Results of the soil analyses and corresponding crop yields for the four and five year old

Cossack-Ladak alfalfa plots are shown in Tables 2 and 3, respectively. The analyses show a wide range in pH (5.1 - 7.3) and exchangeable K (70 - 310 pp2m). The lime apparently was well mixed and equilibrated with the entire plow layer as evidenced by the uniform pH at various depths. Especially noteworthy is the fact that the sampling depth has a tremendous effect on the reported soil test value for exchangeable K because of the high K concentration in the top increment.

There is a lower level of exchangeable K in the five year old alfalfa plots than in the four year old alfalfa plots with similar original (1944; Figure 2a) K treatments. This is because the topdressing treatments in each hay year were not started until 1955 when the five year old alfalfa plots were in their second year of hay production. The effect of the annual topdressing treatments of (a) none, (b) 150 lbs., and (c) 300 lbs. of 0-0-60 per acre is reflected in the exchangeable K values and the corresponding yields.

Alfalfa failed to survive and was replaced by grasses and weeds on the low pH or low exchangeable K plots. Increases in soil pH and exchangeable K levels resulted in increasing amounts of alfalfa contributing to the yield. On the best yielding plots, alfalfa was estimated to contribute more than 95 percent of the dry matter. There were no reductions in alfalfa stands due to "over" liming or "over" fertilizing.

Two and three year old Vernal alfalfa. Results of the soil analyses and corresponding crop yields for the three and two year old Vernal alfalfa plots (Tables 4 and 5, respectively) vary considerably from the data on the four and five year old alfalfa plots. The three year old alfalfa plots have a good range in exchangeable K but show a pH range

Table 2. Yield of dry matter and analyses of 2-inch increments of soil to 8-inch depth for pH, available phosphorus and exchangeable potassium -- Four year old Cossack and Ladak alfalfa.

Plot no.	Yield of dry matter	Soil analyses of indicated depths													
		0" - 2"			2" - 4"			4" - 6"			6" - 8"			0" - 8"*	
		pH	P	K	pH	P	K	pH	P	K	pH	P	K	pH	K
	lbs./A		pp2m	pp2m		pp2m	pp2m		pp2m	pp2m		pp2m	pp2m		pp2m
B 1 a	1900	5.4	18	120	5.3	13	75	5.3	14	75	5.2	14	60	5.3	80
B 1 b	2520	5.3	15	290	5.4	12	100	5.3	13	100	5.4	11	70	5.4	130
B 1 c	1880	5.2	11	750	5.4	9	280	5.4	9	125	5.4	9	85	5.4	310
B 2 a	2300	5.4	31	105	5.4	21	65	5.4	18	60	5.4	19	60	5.4	70
B 2 b	2820	5.4	26	355	5.5	19	100	5.6	16	80	5.5	17	85	5.5	155
B 2 c	2420	5.4	22	820	5.4	15	235	5.4	14	95	5.4	13	85	5.4	310
B 3 a	2020	5.4	50	100	5.4	36	70	5.4	26	65	5.5	26	65	5.4	75
B 3 b	2600	5.3	37	315	5.4	28	120	5.4	30	80	5.3	27	75	5.4	145
B 3 c	1840	5.1	20	480	5.1	25	190	5.3	24	95	5.2	21	80	5.2	210
B 4 a	2200	5.5	50	130	5.4	35	85	5.4	30	80	5.4	31	80	5.4	95
B 4 b	2200	5.1	42	400	5.2	24	155	5.2	34	100	5.2	37	90	5.2	185
B 4 c	2260	5.1	24	490	5.1	18	220	5.1	19	95	5.2	24	90	5.1	225
B 5 a	2440	5.3	58	150	5.2	45	95	5.3	48	85	5.2	36	80	5.3	100
B 5 b	2640	5.1	57	365	5.2	45	150	5.2	35	95	5.3	35	95	5.2	180
B 5 c	2440	5.2	39	720	5.2	30	255	5.3	30	120	5.3	30	110	5.3	300
B 11 a	1820	5.7	15	150	5.9	11	75	6.0	10	75	6.1	10	65	5.9	90
B 11 b	2520	5.8	19	400	5.8	11	135	5.9	11	90	5.8	10	80	5.8	175
B 11 c	3060	5.7	17	720	5.9	12	300	5.9	11	125	5.9	11	100	5.9	310
B 12 a	2840	6.0	20	140	6.1	12	85	6.1	10	75	6.0	10	60	5.9	90
B 12 b	3860	5.7	20	265	5.9	12	100	5.9	13	75	5.9	15	75	5.8	130
B 12 c	2920	5.6	20	485	5.7	18	170	5.8	14	85	5.8	12	85	5.7	205

(Continued on next page.)

Table 2. Continued.

Plot no.	Yield of dry matter	Soil analyses of indicated depths													
		0" - 2"			2" - 4"			4" - 6"			6" - 8"			0" - 8"*	
		pH	P	K	pH	P	K	pH	P	K	pH	P	K	pH	K
	lbs./A		pp2m	pp2m		pp2m	pp2m		pp2m	pp2m		pp2m	pp2m		pp2m
B 13 a	3120	5.9	31	130	6.1	19	85	6.1	16	80	6.1	17	80	6.1	95
B 13 b	3900	5.7	38	350	5.9	31	130	5.9	22	85	5.9	31	55	5.9	155
B 13 c	3220	5.7	35	720	5.9	22	200	5.9	25	110	6.0	19	90	5.9	285
B 14 a	2440	5.9	42	160	6.0	31	85	6.0	26	75	6.0	22	95	6.0	105
B 14 b	4300	5.9	37	380	5.9	26	135	6.0	22	85	6.0	23	85	6.0	170
B 14 c	4640	5.8	39	780	5.9	30	165	6.0	29	110	5.9	26	95	5.9	290
B 15 a	3260	5.9	58	145	5.9	53	90	6.0	34	80	5.9	32	75	5.9	95
B 15 b	3780	5.8	55	300	5.9	47	110	6.0	33	95	6.0	32	85	5.9	145
B 15 c	4160	5.9	47	480	5.9	26	265	6.0	24	110	6.0	20	95	6.0	235
B 21 a	2520	6.5	22	120	6.8	18	75	6.8	10	75	6.6	11	75	6.7	85
B 21 b	4480	6.5	18	290	6.8	16	110	6.9	16	85	6.9	16	95	6.8	145
B 21 c	5060	6.5	18	550	6.7	14	190	6.8	14	110	6.9	14	95	6.7	235
B 22 a	2840	6.6	18	110	6.6	15	85	6.7	13	85	6.8	14	85	6.7	90
B 22 b	4840	6.4	26	260	6.6	20	100	6.8	19	85	6.8	21	85	6.7	130
B 22 c	5320	6.3	21	450	6.6	16	130	6.7	15	90	6.8	14	85	6.6	190
B 23 a	3100	6.5	50	140	6.6	32	110	6.7	28	90	6.7	24	100	6.6	110
B 23 b	4740	6.3	48	335	6.5	49	130	6.6	30	110	6.6	60	90	6.5	165
B 23 c	5120	6.3	38	720	6.5	28	160	6.6	23	105	6.6	26	90	6.5	270
B 24 a	2860	6.4	42	140	6.5	42	90	6.6	38	90	6.5	22	85	6.5	100
B 24 b	4640	6.3	40	270	6.5	29	110	6.6	24	95	6.7	22	85	6.5	140
B 24 c	5520	6.3	40	480	6.5	35	150	6.7	30	120	6.6	27	100	6.5	210

(Continued on next page.)

Table 2. Continued.

Plot no.	Yield of dry matter	Soil analyses of indicated depths													
		0" - 2"			2" - 4"			4" - 6"			6" - 8"			0" - 8"*	
		pH	P	K	pH	P	K	pH	P	K	pH	P	K	pH	K
	lbs./A		pp2m	pp2m		pp2m	pp2m		pp2m	pp2m		pp2m	pp2m		pp2m
B 25 a	2920	6.4	60	150	6.5	32	100	6.6	42	90	6.6	30	90	6.5	105
B 25 b	5800	6.3	38	370	6.6	36	140	6.7	23	110	6.7	31	110	6.6	180
B 25 c	6600	6.3	80	630	6.5	75	190	6.6	55	110	6.7	55	105	6.5	260
B 31 a	2380	6.6	17	150	6.8	13	90	6.9	13	85	6.7	13	85	6.8	100
B 31 b	4180	6.5	17	250	6.7	14	110	6.8	16	95	6.8	15	85	6.7	135
B 31 c	5240	6.6	15	420	6.9	13	140	6.9	12	95	6.8	13	110	6.8	190
B 32 a	2740	6.7	27	130	6.8	16	90	6.9	15	85	6.9	15	75	6.8	95
B 32 b	5240	6.4	25	300	6.6	20	120	6.7	17	95	6.7	18	95	6.6	150
B 32 c	5960	6.3	28	810	6.6	21	230	6.7	20	110	6.7	17	95	6.6	310
B 33 a	3120	6.7	45	140	6.8	32	85	6.8	30	80	6.8	26	80	6.8	95
B 33 b	5420	6.5	40	250	6.7	28	105	6.8	27	100	6.8	27	95	6.7	135
B 33 c	7200	6.4	38	600	6.6	26	145	6.8	22	95	6.8	19	95	6.7	235
B 34 a	2580	6.2	42	160	6.8	34	90	6.9	25	80	6.9	20	80	6.7	100
B 34 b	5820	6.3	47	325	6.6	36	120	6.7	25	95	6.7	27	85	6.6	155
B 34 c	6440	6.4	35	720	6.7	38	200	6.8	31	130	6.8	29	120	6.7	290
B 35 a	3680	6.5	68	170	6.7	68	100	6.8	50	85	6.8	29	75	6.7	105
B 35 b	6160	6.4	57	340	6.7	58	120	6.8	40	70	6.8	40	95	6.7	160
B 35 c	7380	6.6	52	615	6.8	44	140	6.8	40	95	6.9	36	95	6.8	235
B 41 a	2440	6.8	17	115	7.1	17	75	7.1	18	70	7.0	14	70	7.0	80
B 41 b	5240	6.7	15	300	6.9	13	110	7.0	15	85	6.9	12	85	6.9	145
B 41 c	5080	6.6	12	460	6.9	11	160	6.9	10	95	6.9	11	95	6.8	200

(Continued on next page.)

Table 2. Continued.

Plot no.	Yield of dry matter	Soil analyses of indicated depths													
		0" - 2"			2" - 4"			4" - 6"			6" - 8"			0" - 8"*	
		pH	P	K	pH	P	K	pH	P	K	pH	P	K	pH	K
	lbs./A		pp2m	pp2m		pp2m	pp2m		pp2m	pp2m		pp2m	pp2m		pp2m
B 42 a	3200	6.8	30	130	7.0	16	80	7.1	15	75	7.1	14	75	7.0	90
B 42 b	5960	6.7	24	280	6.9	16	110	7.0	15	85	7.0	15	80	6.9	140
B 42 c	6360	6.6	23	780	6.8	16	180	6.9	15	95	6.9	16	90	6.8	285
B 43 a	2880	6.8	31	120	6.9	26	75	7.0	18	75	7.0	16	75	6.9	85
B 43 b	6040	6.6	26	325	6.8	18	110	6.9	16	85	6.9	16	85	6.8	150
B 43 c	5880	6.6	30	630	6.8	20	170	6.9	17	95	6.9	21	110	6.8	250
B 44 a	2880	6.9	41	120	7.0	22	85	7.0	21	85	6.9	17	80	7.0	90
B 44 b	5020	6.7	63	440	6.9	28	110	7.0	24	100	7.0	25	90	6.9	185
B 44 c	5000	6.5	36	405	6.7	32	140	6.8	24	95	6.8	22	95	6.7	185
B 45 a	3660	6.8	60	135	6.9	40	100	7.0	38	90	6.9	32	110	6.9	110
B 45 b	5480	6.6	50	285	6.8	45	110	6.9	36	95	6.9	36	95	6.8	145
B 45 c	6820	6.5	68	660	6.7	50	170	6.8	42	120	6.8	45	110	6.7	265

* 0 to 8 inch depth values are averages of the two-inch increments.

Table 3. Yield of dry matter and analyses of 2-inch increments of soil to 8-inch depth for pH, available phosphorus and exchangeable potassium -- Five year old Cossack and Ladak alfalfa.

Plot no.	Yield of dry matter	Soil analyses of indicated depths													
		0" - 2"			2" - 4"			4" - 6"			6" - 8"			0" - 8"*	
		pH	P	K	pH	P	K	pH	P	K	pH	P	K	pH	K
	lbs./A		pp2m	pp2m		pp2m	pp2m		pp2m	pp2m		pp2m	pp2m		pp2m
A 1 a	1960	5.5	18	130	5.4	14	80	5.4	16	80	5.3	14	75	5.4	90
A 1 b	1980	5.3	18	330	5.4	9	90	5.3	9	80	5.2	9	70	5.3	145
A 1 c	1920	5.3	14	630	5.3	11	180	5.3	10	95	5.1	10	75	5.2	245
A 2 a	1960	5.6	23	120	5.5	16	80	5.5	14	80	5.5	11	75	5.5	90
A 2 b	2300	5.6	24	315	5.4	13	90	5.4	15	75	5.4	10	70	5.5	135
A 2 c	2880	5.3	26	510	5.4	19	140	5.3	17	100	5.2	14	75	5.3	205
A 2 Pa	1800	5.6	45	110	5.6	45	80	5.6	40	75	5.4	16	65	5.6	80
A 2 Pb	2060	5.4	40	310	5.4	25	95	5.4	25	75	5.3	14	70	5.4	135
A 2 Pc	2500	5.6	32	430	5.6	18	135	5.6	21	85	5.3	15	180	5.6	180
A 2 Ka	2100	5.3	15	180	5.3	12	105	5.3	12	85	5.3	10	85	5.3	115
A 2 Kb	2200	5.1	13	380	5.2	10	130	5.2	10	95	5.2	9	85	5.2	170
A 2 Kc	1780	5.1	14	420	5.0	10	155	5.1	10	120	5.0	9	110	5.1	200
A 3 a	1800	5.5	28	120	5.4	16	75	5.5	14	50	5.4	12	55	5.5	75
A 3 b	2100	5.2	30	400	5.2	17	150	5.2	14	75	5.0	12	75	5.2	175
A 3 c	2200	5.1	30	465	5.2	25	120	5.2	15	75	5.1	12	55	5.2	180
A 4 a	2100	5.3	45	140	5.3	31	75	5.3	25	85	5.2	21	75	5.3	95
A 4 b	2380	5.0	50	400	5.1	32	150	5.1	30	95	5.1	23	90	5.1	185
A 4 c	3000	5.2	45	600	5.1	28	190	5.1	75	95	5.1	22	85	5.1	240
A 5 a	2440	5.3	60	140	5.2	42	95	5.2	40	85	5.2	32	85	5.2	100
A 5 b	2160	5.2	70	480	5.2	52	170	5.2	36	110	5.2	26	100	5.2	215
A 5 c	2340	5.2	58	750	5.2	40	270	5.1	45	130	5.1	28	85	5.2	285

(Continued on next page.)

Table 3. Continued.

Plot no.	Yield of dry matter	Soil analyses of indicated depths													
		0" - 2"			2" - 4"			4" - 6"			6" - 8"			0" - 8"*	
		pH	P	K	pH	P	K	pH	P	K	pH	P	K	pH	K
	lbs./A		pp2m	pp2m		pp2m	pp2m		pp2m	pp2m		pp2m	pp2m		pp2m
A 11 a	2300	6.2	12	140	6.2	9	85	6.3	10	75	6.3	7	75	6.2	95
A 11 b	2960	6.0	10	315	6.1	8	120	6.0	8	80	5.5	9	75	5.9	150
A 11 c	3220	5.8	12	750	6.0	8	190	5.9	8	105	5.6	8	85	5.8	280
A 12 a	2520	6.1	17	125	6.1	13	95	6.2	10	80	6.0	9	75	6.1	95
A 12 b	4540	5.9	18	315	6.0	11	110	6.0	11	90	5.9	10	90	6.0	150
A 12 c	3640	5.8	20	580	6.0	12	135	6.0	10	95	5.8	9	85	5.9	225
A 12 Pa	2420	6.2	33	130	6.2	19	80	6.2	16	75	6.1	13	70	6.2	90
A 12 Pb	3440	5.9	34	310	6.0	19	125	6.0	22	85	5.8	10	75	5.9	150
A 12 Pc	3760	5.9	42	620	6.2	28	150	6.2	26	110	6.0	20	110	6.1	250
A 12 Ka	2420	5.9	10	95	6.0	9	75	5.9	9	70	5.4	10	70	5.9	100
A 12 Kb	3120	5.7	17	335	5.8	12	130	5.8	11	85	5.8	10	85	5.8	160
A 12 Kc	3700	5.7	15	690	5.8	12	160	5.9	11	95	5.6	10	75	5.8	255
A 13 a	2400	5.8	32	130	5.8	17	75	5.9	15	75	5.7	16	85	5.8	90
A 13 b	2640	5.7	29	315	5.8	19	105	5.9	16	85	5.7	15	85	5.8	150
A 13 c	3140	5.8	25	600	5.9	15	160	6.0	12	90	5.7	11	85	5.9	230
A 14 a	2380	5.8	47	130	5.9	25	95	6.0	22	75	5.9	15	80	5.9	95
A 14 b	3920	5.7	42	295	5.8	28	90	5.8	22	80	5.7	19	80	5.8	135
A 14 c	5580	5.7	40	585	5.9	26	150	5.9	20	85	5.8	29	135	5.8	235
A 15 a	2520	5.8	45	135	5.9	38	85	5.9	30	75	5.8	22	75	5.9	90
A 15 b	3960	5.7	95	360	5.7	50	115	5.7	38	95	5.7	38	85	5.7	165
A 15 c	5580	5.8	76	585	5.9	50	165	5.9	42	110	5.8	36	95	5.9	215

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Table 3. Continued.

Plot no.	Yield of dry matter	Soil analyses of indicated depths														
		0" - 2"			2" - 4"			4" - 6"			6" - 8"			0" - 8"*	
		pH	P	K	pH	P	K	pH	P	K	pH	P	K	ph	K
	lbs./A		pp2m	pp2m		pp2m	pp2m		pp2m	pp2m		pp2m	pp2m		pp2m
A 21 a	2020	6.5	12	125	6.7	9	75	6.6	10	70	6.2	8	60	6.5	80
A 21 b	3620	6.1	13	280	6.2	12	110	6.2	12	85	5.9	12	85	6.1	140
A 21 c	3800	5.9	12	585	6.1	9	150	6.1	7	95	5.8	7	85	6.0	230
A 22 a	1940	6.4	24	125	6.5	14	85	6.5	13	80	6.5	11	80	6.5	90
A 22 b	3120	6.2	19	295	6.4	11	95	6.5	10	85	6.4	9	80	6.4	140
A 22 c	4300	6.2	17	600	6.4	10	160	6.4	9	110	6.1	8	95	6.3	240
A 22 Pa	1700	6.4	46	120	6.6	36	85	6.7	24	80	6.6	17	70	6.6	90
A 22 Pb	3940	6.6	48	285	6.5	34	110	6.6	25	90	6.5	25	85	6.6	145
A 22 Pc	4840	6.5	31	555	6.8	20	145	6.8	16	90	6.6	12	85	6.7	220
A 22 Ka	2520	6.4	15	170	6.4	12	95	6.6	10	85	6.5	10	80	6.5	105
A 22 Kb	4540	6.2	10	285	6.4	7	105	6.5	7	95	6.4	6	85	6.4	140
A 22 Kc	5440	6.4	10	600	6.6	8	170	6.7	6	100	6.6	7	95	6.6	240
A 23 a	1880	6.4	28	130	6.5	14	90	6.5	12	80	6.4	11	80	6.5	95
A 23 b	4660	6.3	21	305	6.6	15	110	6.6	11	90	6.6	10	95	6.5	150
A 23 c	5040	6.2	21	510	6.4	9	190	6.5	12	120	6.3	13	85	6.4	225
A 24 a	2760	6.4	46	135	6.5	25	95	6.6	19	85	6.4	19	90	6.5	100
A 24 b	5540	6.4	42	280	6.6	43	120	6.6	28	100	6.4	16	85	6.5	145
A 24 c	6320	6.2	32	455	6.4	28	150	6.6	42	220	6.4	33	170	6.4	250
A 25 a	3120	6.6	80	185	6.7	45	110	6.8	38	95	6.8	42	95	6.7	120
A 25 b	4280	6.2	72	315	6.4	54	120	6.5	42	105	6.4	32	90	6.4	155
A 25 c	5540	6.3	67	490	6.5	52	220	6.5	34	120	6.5	45	100	6.5	230

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Table 3. Continued.

Plot no.	Yield of dry matter	Soil analyses of indicated depths													
		0" - 2"			2" - 4"			4" - 6"			6" - 8"			0" - 8"*	
		pH	P	K	pH	P	K	pH	P	K	pH	P	K	pH	K
	lbs./A		pp2m	pp2m		pp2m	pp2m		pp2m	pp2m		pp2m	pp2m		pp2m
A 31 a	2880	6.8	11	145	6.9	8	95	6.9	11	85	6.4	10	80	6.8	100
A 31 b	3480	6.5	12	290	6.9	13	110	6.9	9	80	6.6	11	80	6.7	140
A 31 c	4260	6.5	9	580	6.8	9	180	6.8	8	110	6.5	8	80	6.7	240
A 32 a	2360	6.9	22	105	6.9	13	80	7.0	11	75	7.0	10	75	7.0	85
A 32 b	4360	6.7	20	260	6.9	12	90	7.0	11	85	6.8	10	75	6.9	130
A 32 c	5400	6.7	22	585	7.0	14	150	7.0	14	90	6.8	11	85	6.9	230
A 32 Pa	2100	6.9	49	110	7.0	30	75	7.1	25	70	7.0	24	75	7.0	80
A 32 Pb	3800	6.7	41	330	6.9	31	100	7.0	23	90	6.9	20	90	6.9	150
A 32 Pc	5400	6.9	52	455	7.0	37	140	7.1	27	85	7.0	25	95	7.0	195
A 32 Ka	2240	6.8	15	140	6.9	11	95	6.9	10	85	6.8	9	80	6.9	100
A 32 Kb	4040	6.7	14	290	6.9	11	110	7.0	9	85	6.9	9	85	6.9	140
A 32 Kc	6380	6.9	17	585	7.1	13	155	7.1	13	95	7.0	14	95	7.0	230
A 33 a	2100	6.9	41	140	7.0	24	95	7.1	20	80	7.0	18	85	7.0	100
A 33 b	4040	6.8	28	285	7.0	18	110	7.1	16	90	6.9	13	80	7.0	140
A 33 c	5640	6.8	34	600	7.0	21	150	7.1	16	90	7.0	16	85	7.0	230
A 34 a	2720	6.8	53	145	7.1	58	100	7.1	34	100	7.0	25	85	7.0	105
A 34 b	5280	6.8	51	280	6.9	30	110	6.9	28	120	6.9	19	90	6.9	150
A 34 c	6760	6.7	40	580	6.9	26	140	7.0	20	110	6.9	17	100	6.9	230
A 35 a	3260	6.9	75	145	7.0	52	105	7.1	40	85	7.0	28	85	7.0	105
A 35 b	5020	6.7	73	270	6.8	55	120	6.9	42	95	6.8	41	95	6.8	145
A 35 c	7260	6.8	83	490	6.9	52	150	6.9	38	110	6.9	38	120	6.9	220

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Table 3. Continued.

Plot no.	Yield of dry matter	Soil analyses of indicated depths													
		0" - 2"			2" - 4"			4" - 6"			6" - 8"			0" - 8"*	
		pH	P	K	pH	P	K	pH	P	K	pH	P	K	pH	K
	lbs./A		pp2m	pp2m		pp2m	pp2m		pp2m	pp2m		pp2m	pp2m		pp2m
A 41 a	1960	7.2	12	100	7.2	9	80	7.2	9	80	6.8	8	75	7.1	85
A 41 b	4780	6.9	12	260	7.1	10	100	7.1	9	85	6.9	8	80	7.0	130
A 41 c	4560	6.8	14	480	7.1	9	145	7.1	9	90	6.7	8	80	6.9	200
A 42 a	2300	7.3	25	95	7.3	14	75	7.4	13	75	7.2	9	70	7.3	80
A 42 b	4760	7.1	23	280	7.2	15	95	7.3	15	80	7.2	11	75	7.2	135
A 42 c	5720	6.8	23	420	7.1	15	130	7.0	16	85	6.9	12	85	7.0	180
A 42 Pa	2380	7.1	62	95	7.2	42	80	7.2	34	75	7.1	25	75	7.1	80
A 42 Pb	5060	7.0	55	240	7.2	40	95	7.2	34	85	7.1	30	75	7.1	125
A 42 Pc	6620	6.9	58	460	7.1	36	130	7.1	36	85	7.0	45	80	7.0	190
A 42 Ka	2560	7.2	16	130	7.3	11	85	7.1	11	85	7.1	10	75	7.2	95
A 42 Kb	6000	6.8	17	290	6.9	13	110	7.0	11	85	7.0	11	85	6.9	140
A 42 Kc	6480	6.8	19	390	7.0	15	100	7.0	14	80	6.9	13	75	6.9	160
A 43 a	2080	7.1	36	105	7.1	19	75	7.1	17	75	7.1	15	65	7.1	80
A 43 b	5200	6.9	32	235	7.0	19	90	7.0	16	75	6.9	13	80	7.0	120
A 43 c	6420	6.7	27	400	6.8	16	120	6.9	14	90	6.9	10	75	6.8	170
A 44 a	2340	7.0	65	120	7.1	37	85	7.1	35	75	7.0	30	75	7.1	90
A 44 b	6100	6.9	43	280	7.0	25	85	7.0	26	85	7.1	20	80	7.0	130
A 44 c	7020	6.8	48	510	6.9	31	170	7.0	26	95	6.8	24	85	6.9	215
A 45 a	3100	6.9	100	140	7.0	63	95	7.1	52	95	7.0	40	85	7.0	105
A 45 b	6280	6.9	80	340	7.0	48	120	7.1	36	95	6.9	28	90	7.0	160
A 45 c	7620	6.9	70	490	7.0	45	160	7.0	39	100	6.9	29	85	7.0	210

* 0 to 8 inch depth values are averages of the two-inch increments.

Table 4. Yield of dry matter and analyses of 2-inch increments of soil to 8-inch depth for pH, available phosphorus and exchangeable potassium -- Three year old Vernal alfalfa.

Plot no.	Yield of dry matter	Soil Analysis														
		0" - 2"			2" - 4"			4" - 6"			6" - 8"			0" - 8"*	
		pH	P	K	pH	P	K	pH	P	K	pH	P	K	pH	K
	lbs./A		pp2m	pp2m		pp2m	pp2m		pp2m	pp2m		pp2m	pp2m		pp2m
C 1	1700	5.7	16	120	5.7	13	75	5.7	14	75	5.7	14	75	5.7	85
C 2	2060	5.4	33	170	5.5	23	80	5.6	20	80	5.5	23	75	5.5	100
C 3	3920	5.6	34	280	5.7	20	90	5.7	20	90	5.6	16	85	5.7	135
C 4	4820	5.8	60	370	5.9	33	120	5.9	24	95	5.8	26	95	5.9	170
C 5	6420	6.0	85	660	6.2	50	160	6.2	43	100	6.0	43	110	6.1	260
C 11	1980	6.0	11	100	6.1	9	75	6.1	8	75	6.0	9	75	6.1	80
C 12	3300	6.0	22	200	6.1	22	80	6.1	16	75	6.0	17	85	6.1	110
C 13	4720	6.1	27	210	6.3	20	90	6.3	19	75	6.3	18	85	6.3	115
C 14	6300	6.3	55	340	6.4	34	120	6.4	30	100	6.4	30	95	6.4	165
C 15	6960	6.5	120	480	6.7	75	160	6.6	68	130	6.6	60	125	6.6	225
C 21	2640	6.7	11	110	6.7	9	80	6.6	9	80	6.4	8	80	6.6	85
C 22	4120	6.5	19	170	6.7	10	85	6.7	14	75	6.7	14	80	6.6	100
C 23	6800	6.6	35	190	6.7	23	95	6.8	19	95	6.8	18	90	6.7	115
C 24	7160	6.4	53	445	6.6	36	125	6.6	26	95	6.5	24	95	6.5	190
C 25	7200	6.6	70	870	6.8	50	180	6.8	50	120	6.8	45	125	6.8	325
C 31	1800	6.7	15	120	6.8	11	85	6.8	11	85	6.8	11	85	6.8	95
C 32	4600	6.7	22	230	6.8	17	105	6.8	17	95	6.8	16	95	6.8	130
C 33	4680	6.8	25	180	6.9	17	95	6.9	16	95	6.9	18	90	6.9	115
C 34	6400	6.5	42	360	6.7	32	140	6.8	22	120	6.8	24	110	6.7	185
C 35	7200	6.7	80	480	6.8	50	160	6.9	35	120	6.8	36	110	6.7	220
C 41	2280	6.8	15	125	6.9	12	85	7.0	12	85	6.8	12	85	6.9	95
C 42	3720	6.9	24	170	7.0	22	85	7.0	18	85	7.0	18	95	7.0	110
C 43	5280	6.9	45	250	7.0	27	100	7.0	24	100	7.0	24	95	7.0	135
C 44	6080	6.8	50	460	7.0	38	150	7.0	30	120	7.0	24	100	7.0	210
C 45	6460	6.8	75	615	6.9	56	150	6.9	46	120	6.9	29	110	7.0	250

* 0 to 8 inch depth values are averages of the two-inch increments.

Table 5. Yield of dry matter and analyses of soil from the 0 to 8 inch depth for pH and exchangeable potassium -- Two year old Vernal alfalfa.

		0" -- 8"	
Plot No.	Yield of Dry Matter lbs/A.	pH	Exch. K pp2m
D 1	2540	5.5	95
D 2	4380	5.6	140
D 3	4240	5.4	140
D 4	4880	5.3	200
D 5	3940	5.2	200
D 11	2760	6.0	120
D 12	4600	5.9	120
D 13	5420	5.8	140
D 14	5320	5.8	170
D 15	5840	5.8	190
D 21	3240	6.5	95
D 22	6080	6.4	110
D 23	5480	6.3	120
D 24	6860	6.3	150
D 25	6900	6.2	180
D 31	3180	6.8	95
D 32	6200	6.9	125
D 33	6520	6.7	115
D 34	7220	6.6	125
D 35	7040	6.7	160
D 41	3100	6.9	95
D 42	5960	7.0	105
D 43	6420	7.0	105
D 44	8500	7.0	145
D 45	7200	6.9	170

of only 5.5 to 7.0 compared to a 5.1 to 7.3 for the four and five year old alfalfa. The two year old alfalfa plots, on the other hand, have a wide pH range, but the exchangeable K range is only 90 to 200 pp2m compared to a range of 70 to 310 pp2m for the four and five year old alfalfa plots. Furthermore, the two year old alfalfa yields are much higher than the four and five year old alfalfa yields for corresponding soil test values. This could be caused partially by the difference in alfalfa varieties. Vernal alfalfa is considered to be a higher yielder, more acid tolerant, and more cold resistant than Cossack and Ladak alfalfa. The age of the stand may also be a contributing factor.

Simple Correlation of Soil Test Values with Yield as Affected by Sampling Depth

Statistical analyses for the correlation of soil test values with yield as affected by sampling depth (Tables 6 and 8) showed that the 0 to 8 inch soil sampling depth correlated as well or better than any other depth except for the exchangeable K and log K with the four year old alfalfa. In addition to correlating well, the 0 to 8 inch depth represents the complete plow layer and is less subject to sampling error when considering the high concentration of exchangeable K in the 0 to 2 inch depth. Sampling to plow depth is especially important on fields that do not have a complete mixing of the applied lime, have had topdress or plow down applications of any nutrient being determined, or are being sampled after plowing. Therefore, the soil test values for the 0 to 8 inch depth were selected for all further studies.

orrelation coefficients for the four and five year old Cossack-Ladak alfalfa, for the relationship between yield and ertility factors.

Simple correlation coefficients*														
Exch. K				Log. K				pH				Initial K	Topdress K	Initial lime
0-2"	0-4"	0-6"	0-8"	0-2"	0-4"	0-6"	0-8"	0-2"	0-4"	0-6"	0-8"			
.438	.397	.404	.414	.516	---	.480	---	.555	.574	.586	.601	.215	.512	.610
xxx	.995	.994	.992	.963	---	.973	---	-.156	-.131	-.110	-.103	.020	.916	-.047
.997	xxx	.999	.998	.959	---	.976	---	-.189	-.165	-.145	-.137	.022	.916	-.078
.992	.997	xxx	.999	.959	---	.977	---	-.179	-.155	-.135	-.128	.028	.915	-.070
.988	.992	.996	xxx	.959	---	.978	---	-.165	-.142	-.121	-.114	.041	.915	-.057
.969	.962	.960	.961	xxx	---	.994	---	-.157	-.128	-.103	-.094	.045	.959	-.029
.937	.936	.934	.935	.962	xxx	---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	xxx	---	-.164	-.137	-.114	-.105	.062	.954	-.042
.972	.973	.977	.983	.981	.953	---	xxx	---	---	---	---	---	---	---
-.247	-.254	-.249	-.233	-.244	-.247	---	-.230	xxx	.996	.998	.990	-.045	-.127	.946
-.209	-.217	-.213	-.195	-.205	-.209	---	-.193	.995	xxx	.993	.998	-.057	-.101	.952
-.201	-.209	-.204	-.186	-.195	-.200	---	-.183	.995	.995	xxx	.992	-.075	-.072	.948
-.204	-.212	-.206	-.187	-.195	-.202	---	-.182	.994	.994	.999	xxx	-.049	-.069	.952
.032	.054	.075	.080	.059	.032	---	.111	-.068	-.068	-.068	-.045	xxx	---	---
.939	.930	.926	.930	.958	.921	---	.946	-.126	-.126	-.082	-.082	---	xxx	---
-.139	-.146	-.140	-.125	-.119	-.118	---	-.112	.958	.958	.963	.963	---	---	xxx

ove diagonal. Significant correlation coefficients: 1% level, 0.296; 5% level, 0.227; 10% level, 0.191. N = 75.

low diagonal. Significant correlation coefficients: 1% level, 0.251; 5% level, 0.193; 10% level, 0.162. N = 105.

Table 6. Simple correlation coefficients for the four and five year old Cossack-Ladak alfal various fertility factors.

Variable			Simple correlation coefficient								
		Yield	Exch. K				Log. K				
			0-2"	0-4"	0-6"	0-8"	0-2"	0-4"	0-6"	0-8"	0-2"
Yield		xxx	.438	.397	.404	.414	.516	---	.480	---	.555
Exch. K	0-2"	.484	xxx	.995	.994	.992	.963	---	.973	---	-.156
	0-4"	.472	.997	xxx	.999	.998	.959	---	.976	---	-.189
	0-6"	.485	.992	.997	xxx	.999	.959	---	.977	---	-.179
	0-8"	.509	.988	.992	.996	xxx	.959	---	.978	---	-.165
Log. K	0-2"	.577	.969	.962	.960	.961	xxx	---	.994	---	-.157
	0-4"	.522	.937	.936	.934	.935	.962	xxx	---	---	---
	0-6"	---	---	---	---	---	---	---	xxx	---	-.164
	0-8"	.557	.972	.973	.977	.983	.981	.953	---	xxx	---
pH	0-2"	.445	-.247	-.254	-.249	-.233	-.244	-.247	---	-.230	xxx
	0-4"	.469	-.209	-.217	-.213	-.195	-.205	-.209	---	-.193	.995
	0-6"	.478	-.201	-.209	-.204	-.186	-.195	-.200	---	-.183	.995
	0-8"	.486	-.204	-.212	-.206	-.187	-.195	-.202	---	-.182	.994
Initial K		.223	.032	.054	.075	.080	.059	.032	---	.111	-.068
Topdress K		.631	.939	.930	.926	.930	.958	.921	---	.946	-.126
Initial lime		.537	-.139	-.146	-.140	-.125	-.119	-.118	---	-.112	.958

* Four year data above diagonal. Significant correlation coefficients: 1% level, 0.296; 5%

Five year data below diagonal. Significant correlation coefficients: 1% level, 0.251; 5%

Simple Correlations of Yield with Various Fertility Factors

Statistical analyses were made to evaluate the effect on alfalfa yield of the soil test values for pH and exchangeable K and soil amendment factors of lbs. of K_2O applied at seeding time in the last rotation (initial K), lbs. of 0-0-60 applied as an annual fall topdressing (topdress K) and lbs. of limestone applied at the original establishment of the plots (initial lime). The factor of exchangeable K at seeding time was not available, but it undoubtedly varied in the same relative order as the intended (Figure 2a) exchangeable K levels.

Available P was not included in the statistical analyses because there was no apparent yield response to P. It is possible that some of the yield response attributed to initial K was actually a response to P applied at seeding time. This information could not be sorted under the conditions of this experiment.

Four and five year old Cossack-Ladak alfalfa. The simple correlation data for the four and five year old Cossack-Ladak alfalfa plots are shown in Table 6. Soil pH, exchangeable K and log exchangeable K (log K) at all soil sampling depths, the topdress applications of 0-0-60 and the lime applications made during the original establishment of the plots are highly significant predictors of the yield of dry matter at the 1% level. The initial K_2O applied at seeding time in the last rotation is less significant (at the 5% level), having been effectively masked by the cross-imposed topdress K treatments (Figures 2a and 2b).

That the topdressing treatments influence the exchangeable K levels to a much greater extent than the initial K applications can be shown by comparing the correlation coefficient for exchangeable K, 0 - 8, vs. topdress K with that for exchangeable K, 0 - 8, vs. initial K for the four year old alfalfa plots (Table 6). The correlation coefficients of 0.915 and 0.041, respectively, clearly show that the influence of the initial K level on exchangeable K has been almost completely masked by crop uptake and by topdressed K.

The pH and the log K values for the 0 to 8 inch depth were selected for further correlation studies. The K_2O applied at seeding, the topdress applications of 0-0-60 and the lime that had been applied were also considered. Simple correlation coefficients were then determined for the combined four and five year old Cossack-Ladak alfalfa data.

Table 7 compares the effect of the selected predictors on the yield of four, five, and combined four and five year old alfalfa. All correlation coefficients for each predictor are quite similar between groups, and are highly significant (1% level) on the combined group. Therefore, for further work, the four and five year old alfalfa plots were considered as one population. Because the lime applied is a very erratic predictor, depending on amount, calcium carbonate equivalent, and fineness of the particles of the lime, the lime requirement and initial pH of the soil, the lime distribution in the soil, and the time of equilibration with the soil, pH was selected in preference to the initial lime applied as the more dependable and practical predictor. There is a very high correlation ($r > 0.925$; Tables 6 and 8) between initial lime and pH under the conditions of this study.

Two and three year old Vernal alfalfa. Simple correlation coefficients for the two and three year old Vernal alfalfa are presented in

Table 7. Comparison of simple correlation coefficients for the relationship between selected fertility factors and the yield of four year old, five year old and combined four and five year old Cossack and Ladak alfalfa.

Independent variable used with yield	Age of alfalfa stand		
	4 years (N = 75)	5 years (N = 105)	4 and 5 years (N = 180)
Log K	0.457***	0.557***	0.523***
pH	0.601***	0.486***	0.530***
Initial K	0.215*	0.223**	0.219***
Topdress K	0.512***	0.631***	0.581***
Initial lime	0.610***	0.537***	0.570***

* Significant at the 10% level
** " " " 5% "
*** " " " 1% "

Table 8. The initial K (which also reflects the amount of exchangeable K in the soil at seeding time) and the topdress K are significant predictors of the yield of dry matter at the 1% level. The correlation coefficients for yield vs. exchangeable K or log K were significant at the 1% level on only the three year old plots, while the effect of pH on yield is significant at the 5% level on only the two year old plots. All other soil test values shown, except for exchangeable K on the two year old plots, were significant predictors of the yield at the 10% level. The highly significant r values between log K, initial K and topdress K reflect the fact that the original intended soil test values were in the same relative order as the amounts of potassium fertilizer subsequently applied to these plots (Figures 2a and 2c).

Multiple Correlation of Yield with Various Fertility Factors

In a previous section it was noted that soil test values of samples taken to the 8-inch depth correlated as well or better with yield than those of samples taken to a lesser depth, and that a deeper sampling depth has certain advantages when fertilizers are not uniformly distributed throughout the plow layer. Therefore, soil test values for the 8-inch depth have been used in the multiple correlation analyses described in this section.

The simple correlation data presented in the previous section showed that soil pH, logarithm of the exchangeable K (log K), annual topdress applications of K_2O (topdress K) and initial applications of K_2O at time

orrelation coefficients, for the two and three year old Vernal alfalfa, for the relationship between yield and various
factors.

Simple correlation coefficients*														
Exch. K				Log. K				pH				Initial K	Topdress K	Initial lime
0-2"	0-4"	0-6"	0-8"	0-2"	0-4"	0-6"	0-8"	0-2"	0-4"	0-6"	0-8"			
			.328				.387				.452	.747	.654	.502
.999														
.996	.999													
.994	.998	.999					.992				-.479			
.958	.962	.965	.964											
.967	.973	.977	.977	.996										
.966	.973	.979	.979	.994	.998									
.969	.977	.982	.983	.991	.996	.999					-.463	.801	.850	-.376
.123	.134	.154	.169	.097	.121	.157	.179							
.149	.170	.190	.205	.137	.161	.195	.216	.998						
.156	.177	.198	.212	.148	.171	.205	.226	.996	.999					
.155	.177	.198	.212	.149	.172	.206	.227	.993	.997	.999		-.114	-.115	.980
			.919				.886				.144		.933	
			.961				.960				.158	.934		
			.021				.085				.925			

e and three year data below diagonal. Significant correlation coefficients: 1% level, 0.506; 5% level, 0.396; 10%
25.

Table 8. Simple correlation coefficients, for the two and three year old Vernal alfalfa, for the fertility factors.

Variable		Simple correlation coefficients*										
		Yield	Exch. K				Log. K				p	
			0-2"	0-4"	0-6"	0-8"	0-2"	0-4"	0-6"	0-8"	0-2"	0-4"
Yield						.328				.387		
Exch. K	0-2"	.778										
	0-4"	.794	.999									
	0-6"	.807	.996	.999								
	0-8"	.812	.994	.998	.999					.992		
Log. K	0-2"	.865	.958	.962	.965	.964						
	0-4"	.868	.967	.973	.977	.977	.996					
	0-6"	.869	.966	.973	.979	.979	.994	.998				
	0-8"	.871	.969	.977	.982	.983	.991	.996	.999			
pH	0-2"	.336	.123	.134	.154	.169	.097	.121	.157	.179		
	0-4"	.372	.149	.170	.190	.205	.137	.161	.195	.216	.998	
	0-6"	.382	.156	.177	.198	.212	.148	.171	.205	.226	.996	.999
	0-8"	.386	.155	.177	.198	.212	.149	.172	.206	.227	.993	.997
Initial K		.912				.919				.886		
Topdress K		.875				.961				.960		
Initial lime		.186				.021				.085		

* Two year data above and three year data below diagonal. Significant correlation coefficients:
level, 0.337. N = 25.

of seeding (initial K) are highly significant predictors of dry matter yield.

The values for pH and log K are easily determined by chemical analyses, but accurate values for topdress K and initial K are not always obtainable. Therefore, multiple correlation analyses were made to evaluate the above predictors and determine which predictors were needed to calculate the yield of dry matter with a reasonable degree of accuracy.

Four and five year old Cossack-Ladak alfalfa. Soil pH and log K proved to be excellent yield predictors when considered together (Table 9), accounting for 64.1% of the yield variation in the 180 observations. They also showed a very marked interaction, increasing their partial correlation values from 0.530 and 0.523, respectively, when considered separately to 0.715 and 0.711, when considered together.

Soil pH and topdress K show a similar interaction and are slightly better yield predictors than pH and log K. However, log K is more easily measured and actually is a reflection of the topdress K. As was noted previously, the simple correlation study showed a very high correlation coefficient (0.930; Table 6) for the relationship between exchangeable K and topdress K. Further evidence that log K reflects topdress K is noted in the four predictor correlation of pH, log K, initial K and topdress K. The addition of topdress K as a fourth predictor reduced the correlation coefficient for log K from 0.523 to -0.050 and for topdress K from 0.581 to 0.392, indicating that log K and topdress K were interdependent. Since log K can be measured by soil test and since it correlates nearly as well with yield as does topdress K, it is the logi-

Table 9. Simple, partial and multiple correlation coefficients for the relationship between selected fertility factors and yield of four and five year old Cossack and Ladak alfalfa.

Dependent variable	Independent variables	Simple correlation coefficient	Partial correlation coefficient*	Multiple correlation coefficient	Coefficient of multiple determination	Corrected coefficient of multiple determination
Yield	pH Log K	0.530 0.523	0.715 0.711	0.803	0.645	0.641
"	pH Topdress K	0.530 0.581	0.705 0.732	0.816	0.667	0.663
"	pH Initial K	0.530 0.219	0.553 0.285	0.582	0.339	0.335
"	pH Log K Initial K	0.530 0.523 0.219	0.736 0.719 0.318	0.825	0.681	0.676
"	pH Log K Initial K Topdress K	0.530 0.523 0.219 0.581	0.736 -0.050 0.428 0.392	0.854	0.730	0.724

* Significant correlation coefficients: 1% level, 0.193, 5% level, 0.147, 10% level, 0.123. N = 180.

cal soil K factor to use for yield predictions, especially when the fertilizing history is unknown.

The paired factors of pH and initial K have only one-half (33.5%) of the ability that pH and log K or pH and topdress K have to predict the yield. When initial K is considered with pH and log K the coefficient of multiple determination is increased but correlation coefficients for all three predictors are increased only slightly. This indicates an additive rather than an interaction effect of initial K in predicting yield.

Two and three year old Vernal alfalfa. The partial and multiple correlation coefficients in Table 10 show that pH and log K are very good two year old Vernal yield predictors accounting for 62.6% of the yield variation in the 25 observations. They also have a very good interaction, increasing the r values from 0.452 and 0.387 respectively, when considered separately, to 0.772 and 0.754, when considered together. The three year old Vernal alfalfa (25 observations) does not appear to respond in this manner (Table 11). The r value for log K vs. yield is very high (0.870) and little or no interaction between pH and log K is apparent. Previous data (Figure 10) show that the three year old Vernal has a restricted pH range with only 4 observations below pH 6.1. Little or no interaction of pH and log K can be expected under the conditions of a limited pH range and wide log K range, but the high yield vs. log K correlation value of 0.870 compares favorably with that for the Cossack-Ladak alfalfa (Figure 3) at pH values over 6.0.

Soil pH and initial K appear to be excellent Vernal alfalfa yield predictors. The addition of log K as a third predictor and topdress K

Table 10. Simple, partial and multiple correlation coefficients for the relationship between selected fertility factors and yield of two year old Vernal alfalfa.

Dependent variable	Independent variables	Simple correlation coefficient	Partial correlation coefficient*	Multiple correlation coefficient	Coefficient of multiple determination	Corrected coefficient of multiple determination
Yield	pH	0.452	0.772	0.810	0.657	0.626
	Log K	0.387	0.754			
"	pH	0.452	0.812	0.922	0.850	0.836
	Initial K	0.747	0.901			
"	pH	0.452	0.727	0.922	0.850	0.829
	Log K	0.387	-0.049			
	Initial K	0.747	0.750			
"	pH	0.452	0.754	0.930	0.864	0.837
	Log K	0.387	0.146			
	Initial K	0.747	0.724			
	Topdress K	0.654	-0.306			

* Significant correlation coefficients: 1% level, 0.506; 5% level, 0.396; 10% level, 0.337. N = 25.

Table 11. Simple, partial and multiple correlation coefficients for the relationship between selected fertility factors and yield of three year old Vernal alfalfa.

Dependent variable	Independent variables	Simple correlation coefficient	Partial correlation coefficient*	Multiple correlation coefficient	Coefficient of multiple determination	Corrected coefficient determination
Yield	pH Log K	0.386 0.870	0.394 0.871	0.892	0.795	0.776
"	pH Initial K	0.386 0.912	0.627 0.938	0.948	0.898	0.889
"	pH Log K Initial K	0.386 0.870 0.912	0.604 0.253 0.730	0.951	0.904	0.890
"	pH Log K Initial K Topdress K	0.386 0.870 0.912 0.875	0.591 0.221 0.664 -0.087	0.951	0.905	0.886

* Significant correlation coefficients: 1% level, 0.506; 5% level, 0.396; 10% level, 0.337. N = 25.

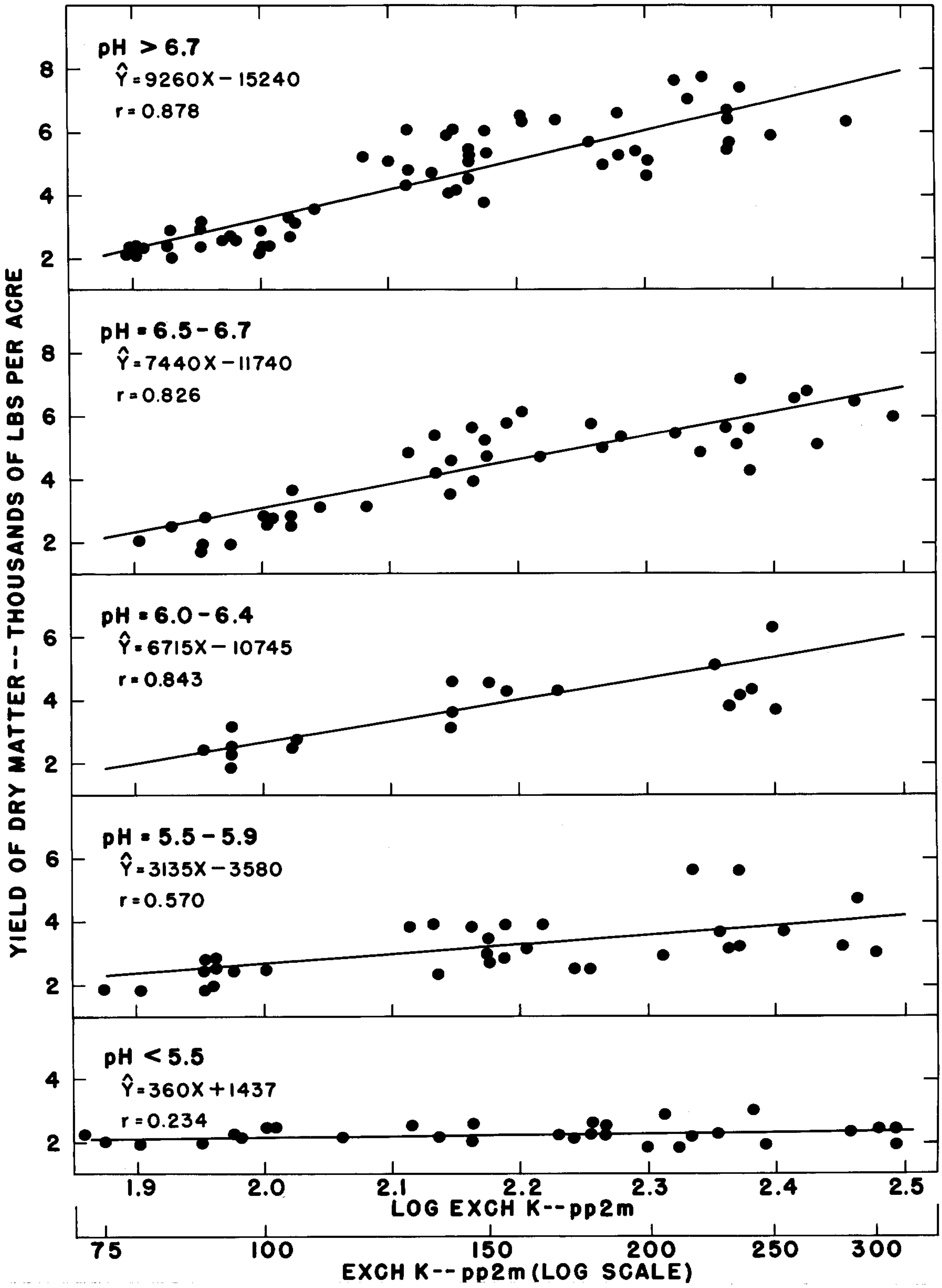

FIGURE 3. EFFECT OF SOIL pH ON THE RELATIONSHIP BETWEEN EXCHANGEABLE POTASSIUM AND ALFALFA-BROME YIELDS -- FOUR AND FIVE YEAR OLD COSSACK AND LADAK ALFALFA.

as a fourth predictor in the analysis lowers the r value for log K as was noted in the Cossack-Ladak four predictor analysis. Inspection of the K treatments (Figures 2a and 2c) shows that initial K and topdress K values are similar; therefore, both K treatments are reflected in the log K values. The large increase in the prediction value from 62.6% for pH and log K to 82.9% for pH, log K and initial K, indicates a marked effect of initial K on Vernal alfalfa yield. This is supported by the data in tables 4 and 5 where the yield of the no-initial K plots are substantially lower than those which received some initial K. Since subsequent topdress K applications were roughly proportional to initial treatments, it is difficult to determine whether the low yields are caused by low exchangeable K or lack of initial K, but calculations presented later in this thesis confirm a marked yield response to initial K.

Conclusions. It is concluded from the multiple correlation data that soil pH and log K values for the 8-inch depth are excellent predictors of alfalfa yield, that there is a very significant interaction between these predictors, and that initial K has an additive effect upon the prediction of this yield. Topdress K is highly correlated with log K and is a slightly better yield predictor in a multiple correlation. However, the fact that log K can be determined by soil test while use of topdress K requires fertilizing histories which frequently are not available makes log K a more practical yield predictor.

Development of an Equation for Predicting Yield of Four and Five Year Old Cossack-Ladak Alfalfa

The multiple correlation analyses presented in the previous section definitely showed that soil pH and the logarithm of the exchangeable K (log K) were good predictors of alfalfa yield and that there was a strong interaction between them, that is, the yield response to one apparently depended on the level of the other. In order to study this interaction further, the data from the four and five year old alfalfa were divided into 5 pH groupings and 3 log K groupings. This made it possible to study the yield response to log K as a function of pH and the yield response to pH as a function of log K, all soil tests being based on a 0 to 8 inch sampling depth. The results of this study, when combined with the apparently independent response to initial K, were used to develop a formula for predicting the yield of alfalfa from a knowledge of the pH, log K and initial K values. This equation proved highly successful in predicting the yields of the four and five year old Cossack-Ladak alfalfa.

Yield response to exchangeable potassium at various pH levels. The data from the Cossack-Ladak alfalfa plots were grouped into five pH ranges, <5.5, 5.5 - 5.9, 6.0 - 6.4, 6.5 - 6.8 and >6.8. Yields were plotted against log K for each of the groups (Figure 3), and the regression lines were determined. The increasing slopes of the regression lines with increasing pH (Figures 3 and 4) show increasing yield response to K with increasing pH.

When the slopes (change in yield per unit increase in log K) of the regression lines for the various pH ranges are plotted against pH (Figure

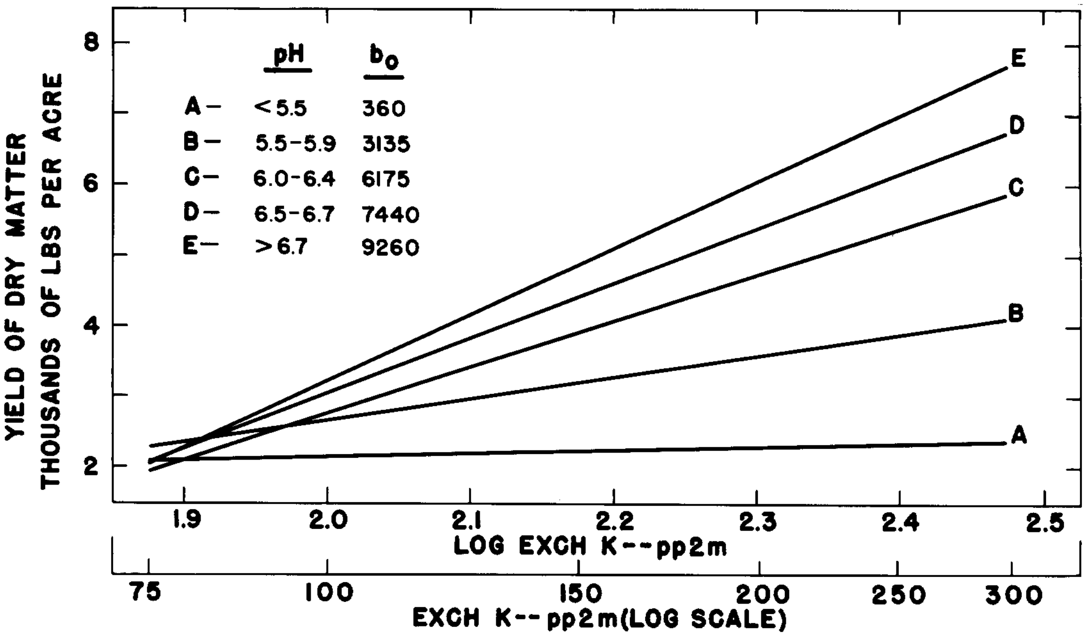

FIGURE 4. REGRESSION LINES SHOWING EFFECT OF SOIL pH ON THE RELATIONSHIP BETWEEN EXCHANGEABLE POTASSIUM AND ALFALFA-BROME YIELDS — FOUR AND FIVE YEAR OLD COSSACK AND LADAK ALFALFA.

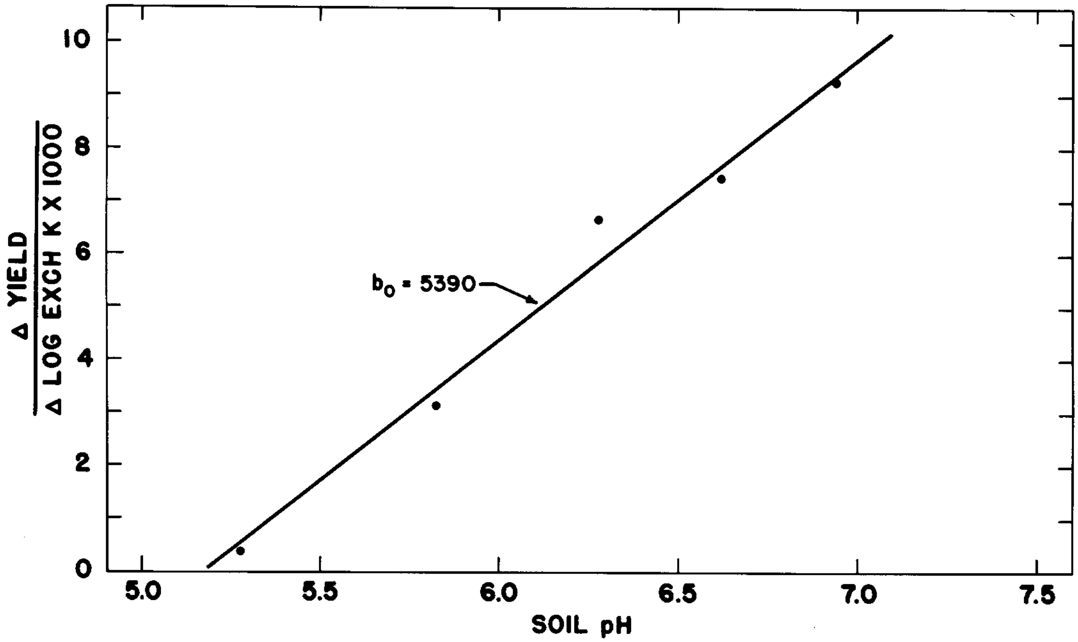

FIGURE 5. RELATIONSHIP BETWEEN SOIL pH AND CHANGE IN YIELD OF ALFALFA-BROME PER UNIT CHANGE IN LOG K — FOUR AND FIVE YEAR OLD COSSACK AND LADAK ALFALFA.

5) a straight line is obtained. This indicates that the yield response to log K is a linear function of pH from pH 5.2 to the upper limit of pH used in this study (approximately pH 7.0). The slope value of 5390 indicates that each additional unit of pH increases the yield response per unit change in log K by 5390 lbs. per acre.

Later studies on yield response to pH as a function of log K indicated a maximum yield response to K at log K = 2.25 (180 pp2m). Close inspection of Figure 3 supports this contention. If this response limit were taken into account, all of the points representing log K values greater than 2.25 would have to be shifted back to this value, and the regression lines would have to be recalculated. The slopes obtained would be greater (more in line with values obtained for response to pH as a function of log K), but the linear nature of the slope vs. pH plot should be unchanged. The regression lines will be recalculated prior to publication of this material.

Yield response to pH at various exchangeable potassium levels. The data from the Cossack-Ladak alfalfa plots were regrouped into three exchangeable K ranges (70 - 125, 130 - 200 and 205 - 310 pp2m). Yields were plotted against pH for each of the groups (Figures 6 and 7), and the regression lines were determined. The increasing slopes of the regression lines with increasing K levels show that the yield response to pH increases with an increase in exchangeable K.

The slope values (b_o = change in yield per unit change in pH) for each exchangeable K level are plotted against exchangeable K in Figure 8. The yield response to pH does not appear to be a linear function of log

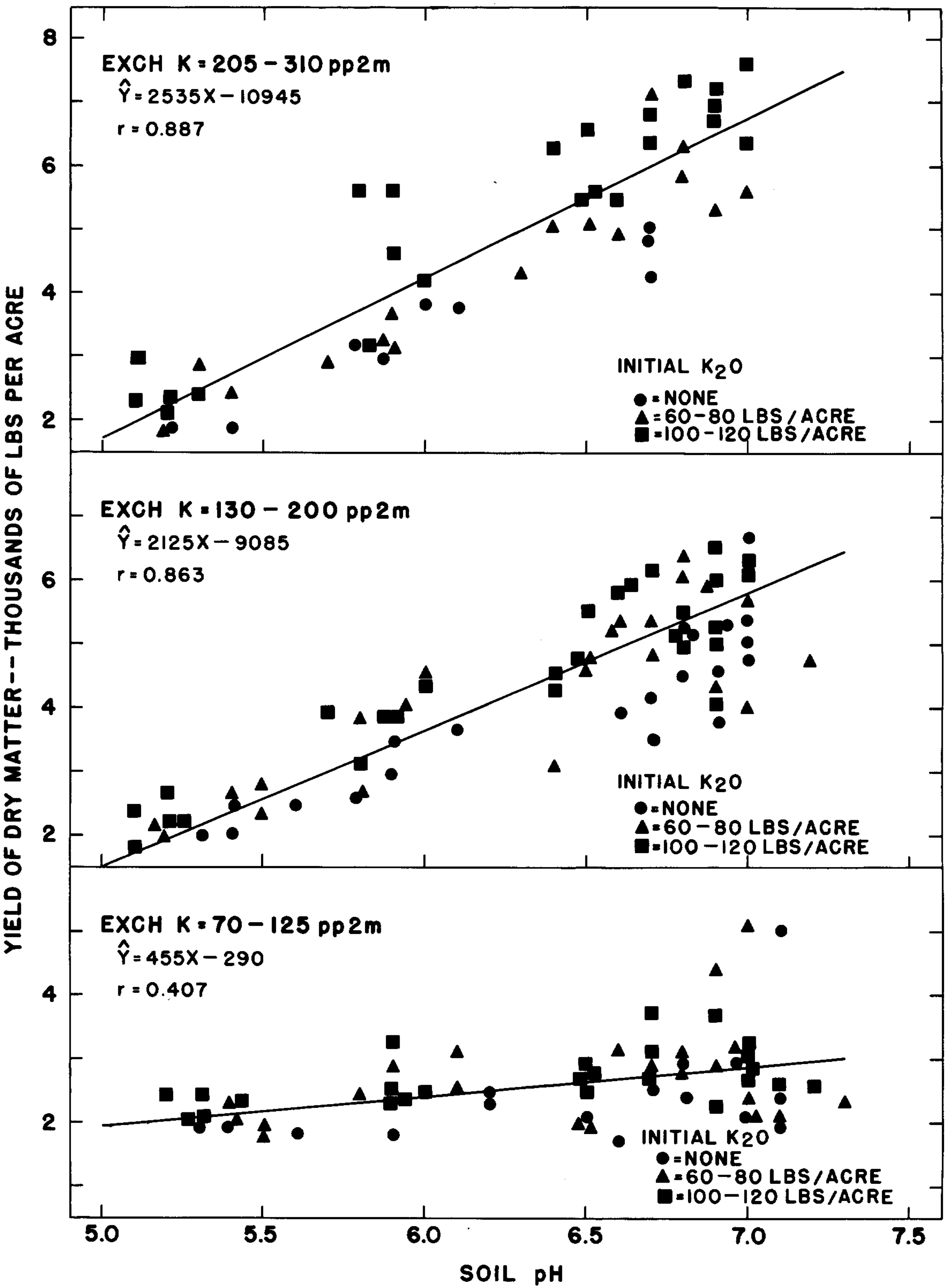

FIGURE 6. EFFECT OF EXCHANGEABLE POTASSIUM AND POTASSIUM APPLIED AT TIME OF SEEDING ON THE RELATIONSHIP BETWEEN SOIL pH AND ALFALFA-BROME YIELDS -- FOUR AND FIVE YEAR OLD COSSACK AND LADAK ALFALFA.

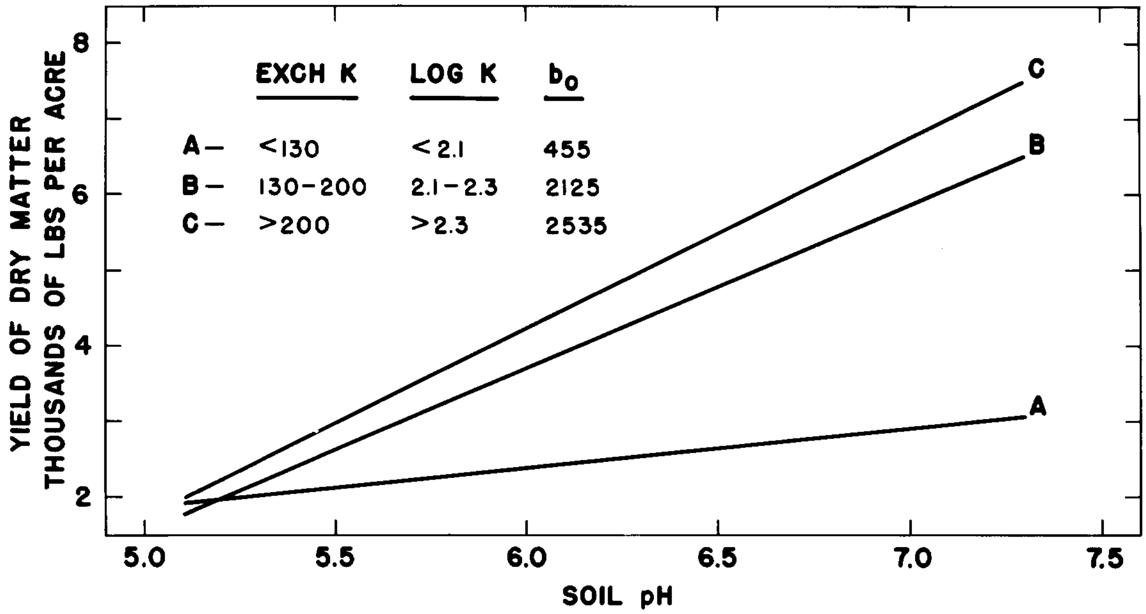

FIGURE 7. REGRESSION LINES SHOWING THE EFFECT OF EXCHANGEABLE POTASSIUM ON THE RELATIONSHIP BETWEEN SOIL pH AND ALFALFA-BROME YIELDS -- FOUR AND FIVE YEAR OLD COSSACK AND LADAK ALFALFA.

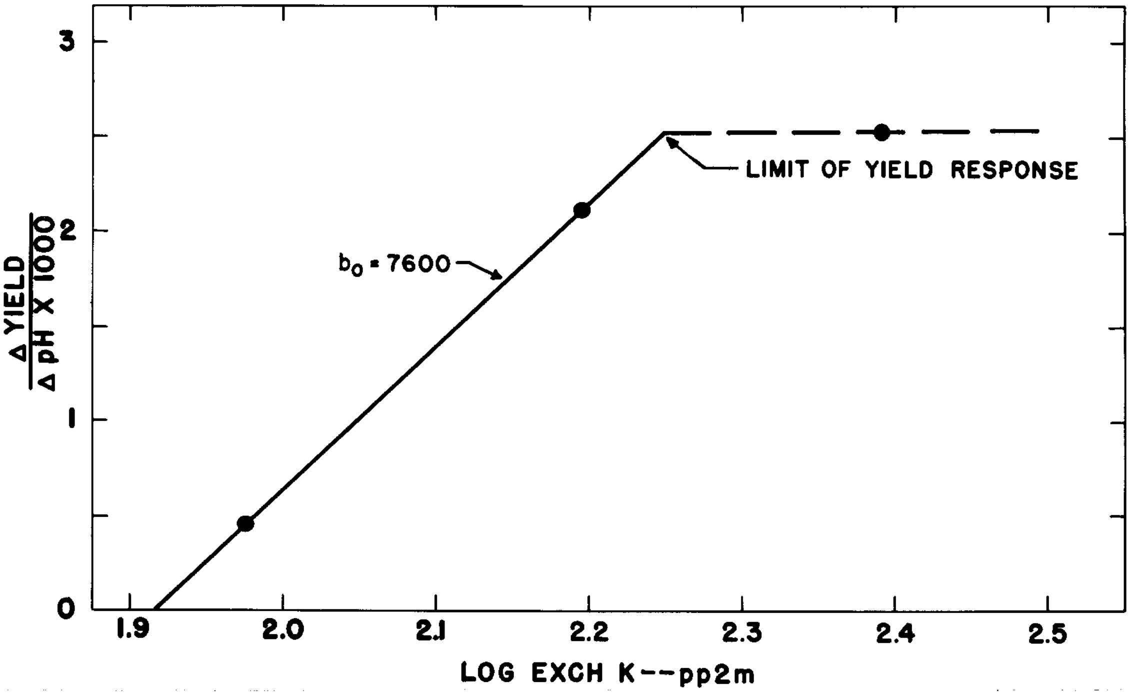

FIGURE 8. RELATIONSHIP BETWEEN LOG K AND CHANGE IN YIELD OF ALFALFA-BROME PER UNIT CHANGE IN SOIL pH -- FOUR AND FIVE YEAR OLD COSSACK AND LADAK ALFALFA.

K throughout the entire K range, but does appear linear in the lower end of the range.

By inspection of Figure 3, it is assumed that a log K value of 1.92 is the threshold level of response. This point plus the values for the two lower K levels give three points in Figure 9 that fall in a straight line which is intercepted by a horizontal line through the fourth point which is assumed to represent K levels above the limit of further yield response. These lines intercept at a log K value of 2.25, the value beyond which no yield increase is noted in Figure 3. The yield response slope (b_o = 7600) should compare closely with the yield response slope (b_o = 5390) obtained in Figure 5. It is assumed that yield response to the log K and pH interaction is expressed best by the slope in Figure 8 (b_o = 7600) because of the factors discussed in the preceding section.

Yield response to potassium applied at time of seeding. According to the correlation data, the Cossack-Ladak yield response to initial K (measured for this study as the amount of K_2O applied at time of establishment of the alfalfa) is 800 lbs. of dry matter per 100 lbs. of K_2O applied. Therefore, the yield response is 960 lbs. of dry matter per acre for the initial K range of 0 to 120 lbs. of K_2O per acre, or 8 lbs. of dry matter per lb. of K_2O.

Calculation of "base" yields. Inspection of Figures 4 and 8 shows that the average yield below pH 5.2 or log K 1.92 (85 pp2m) is about 2000 lbs. per acre. If it were assumed that this yield represents that obtained at the average initial K application (60 lbs. of K_2O per acre) the yield at the highest initial K application (120 lbs. of K_2O per acre) would be about 2500 lbs. per acre if the calculated yield increase of 8 lbs. per acre per lb. of K_2O were obtained. This value is used as the "base" yield, that is, the yield obtained when the soil test values for pH and log K are below the threshold response levels, but where the initial K applications were high enough to assure good establishment. Yield responses due to the pH - log K interaction are added to this base yield and yield reductions due to lack of initial K are subtracted from it.

Equation for predicting Cossack-Ladak alfalfa yields. If the above data and assumptions are correct, the following equation should predict the yield of Cossack and Ladak alfalfa grown on Withee silt loam with known pH, exchangeable K, and initial K levels:

$$Y = b_o \, (\log K - 1.92) \, (pH - 5.2) + a - c,$$

where Y is the predicted annual yield of dry matter in lbs. per acre, b_o is the change in yield per unit change in the log K - pH interaction within the response ranges of both predictors, a is the maximum yield obtained without a response to the log K - pH interaction ("base" yield) and c is the reduction in yield caused by lack of sufficient initial K. Cossack-Ladak alfalfa yields were calculated by substituting the following previously determined values in the above formula: b_o is 7600, a is 2500, c is 8(120 - initial K), and the log K function is limited to 0.33 (log K 1.92 or less is treated as 1.92, and a log K greater than 2.25 is assigned a value of 2.25). The possible calculated yield range is 1500 lbs. to approximately 7000 lbs. of dry matter per acre.

Correlation of predicted yield with actual yield. These calculated yields correlate very highly with the actual yields ($r = 0.920$), and the calculated regression line ($b_o = 0.954$) compares very favorably with the theoretical regression line ($b_o = 1.000$; Figure 9).

Development of an Equation for Predicting Yield of Two and Three Year Old Vernal Alfalfa

The highly successful equation for predicting yields of Cossack-Ladak alfalfa and the apparently similar pH - log K interactions for Cossack-Ladak and Vernal alfalfa suggested a similar equation for predicting yields of Vernal alfalfa. The development of a highly successful equation for predicting Vernal alfalfa yields is discussed below.

<u>Yield response to exchangeable potassium at various pH levels</u>. The two year old Vernal alfalfa had a wide pH range (Figure 11) and the yield response to exchangeable K was highly dependent on the pH level (coded; Figure 10). The three year old Vernal, on the other hand, has a limited pH range (Figure 11) and, therefore, the yield response does not appear to be dependent on the pH level (Figure 10). However, the correlation data showed that the mean pH was 6.48 for the three year old alfalfa. This information, coupled with the fact that later calculations showed the upper limit for Vernal yield response to pH to be pH 6.3, produces conditions similar to that found with Cossack-Ladak alfalfa (Figure 3), namely, an effective pH range above pH 6.0, a wide exchangeable K range and a high correlation value for yields vs. exchangeable K.

The limited number of observations (N = 25 for each year) and the limited pH or exchangeable K ranges could lead to erroneous interpretations of the Vernal alfalfa data if there were no data from the more complete Cossack-Ladak study to use as a guide.

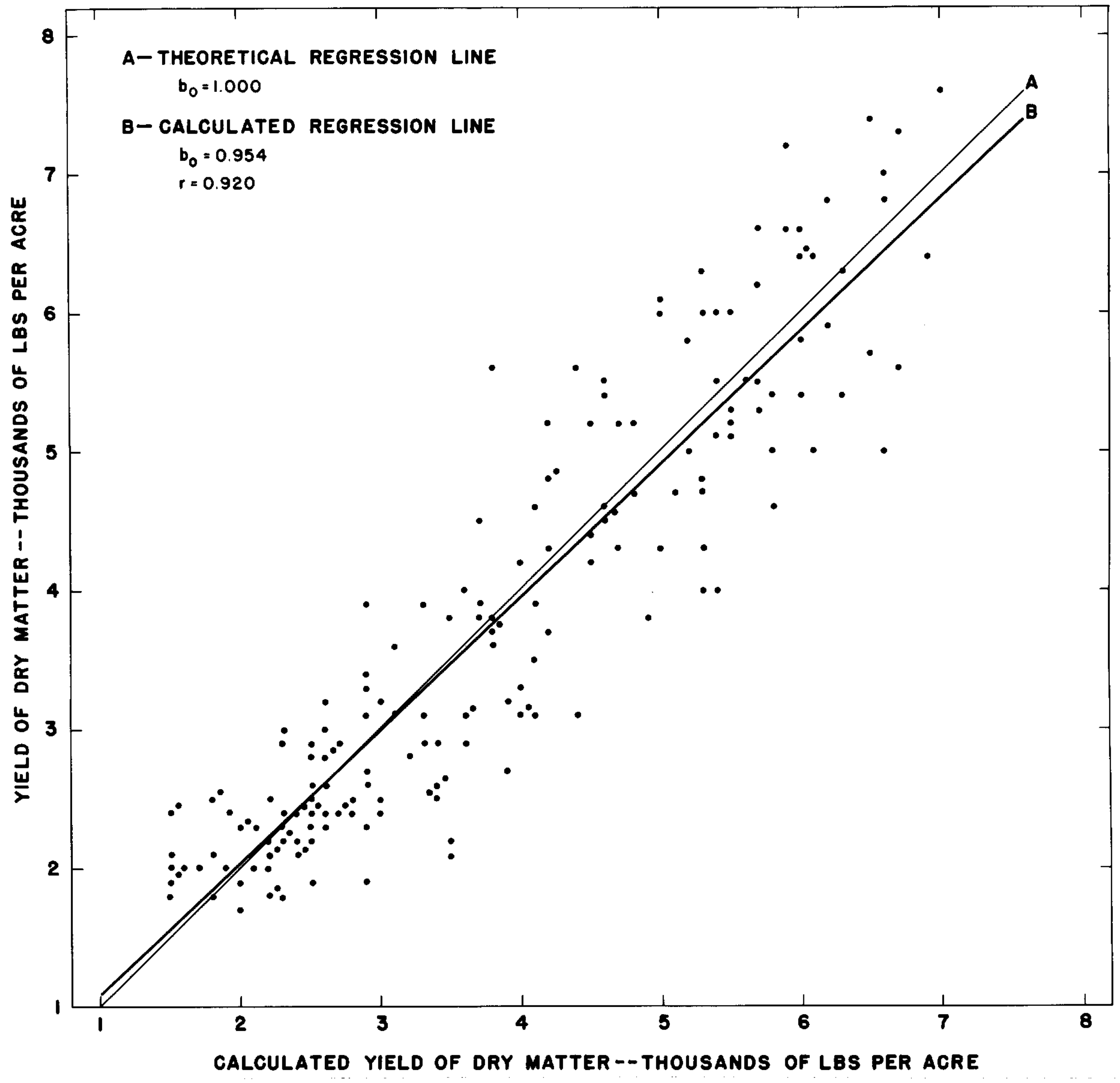

FIGURE 9. COMPARISON OF CALCULATED YIELDS WITH ACTUAL YIELDS -- FOUR AND FIVE YEAR OLD COSSACK AND LADAK ALFALFA.

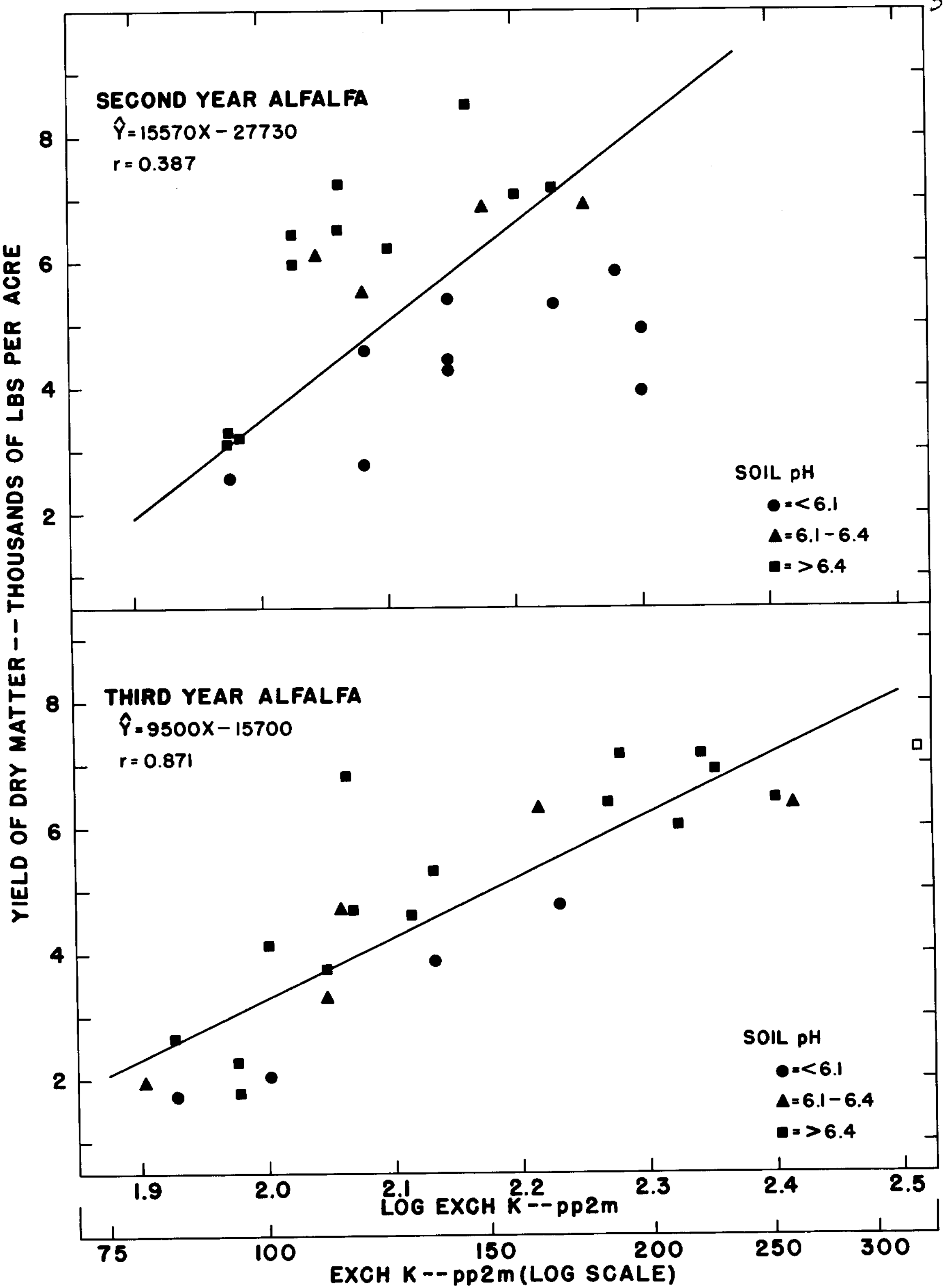

FIGURE 10. EFFECT OF SOIL pH ON THE RELATIONSHIP BETWEEN EXCHANGEABLE POTASSIUM AND ALFALFA-BROME YIELDS -- TWO AND THREE YEAR OLD VERNAL ALFALFA.

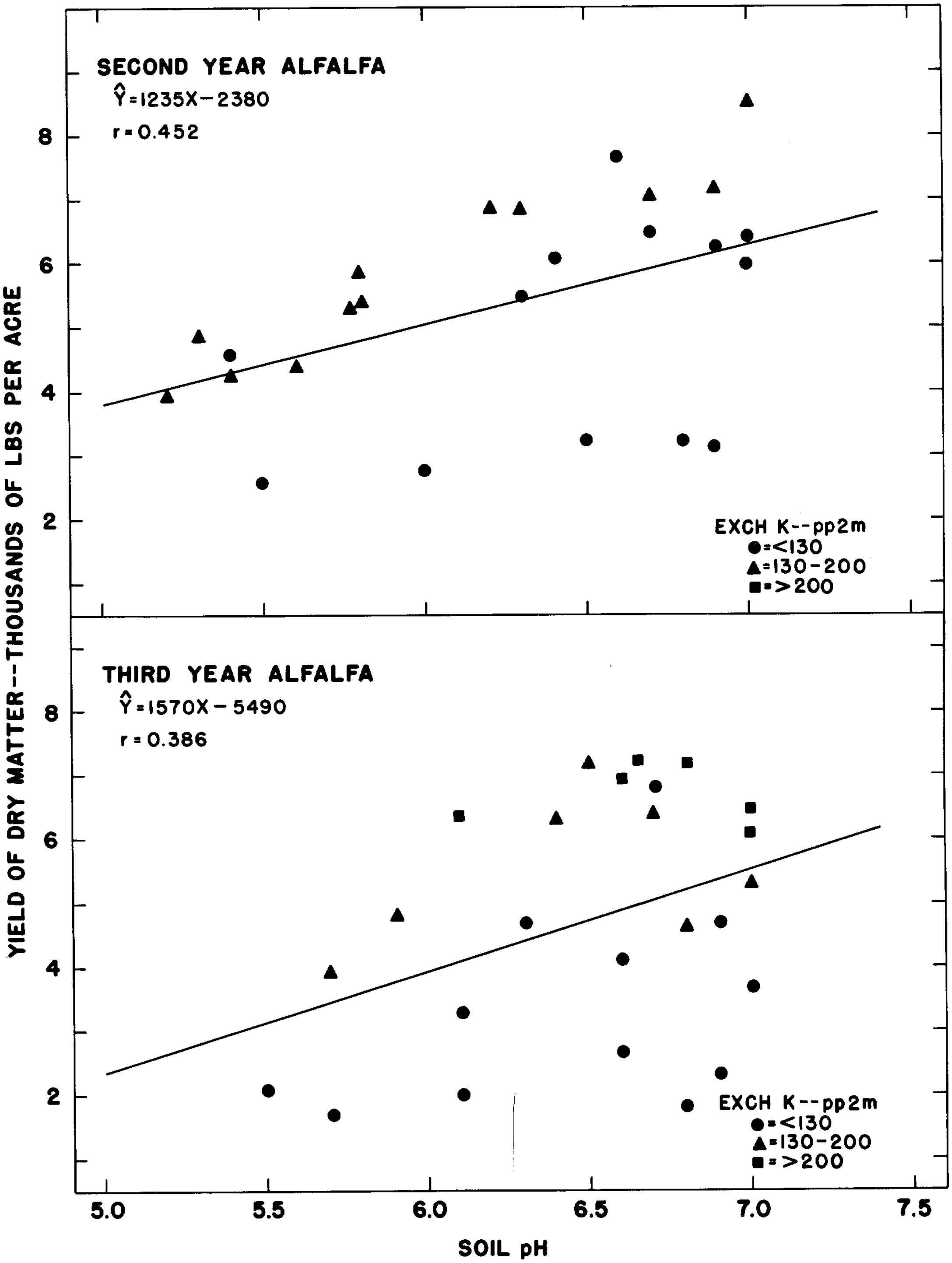

FIGURE 11. EFFECT OF EXCHANGEABLE POTASSIUM ON THE RELATIONSHIP BETWEEN SOIL pH AND ALFALFA-BROME YIELDS -- TWO AND THREE YEAR OLD VERNAL ALFALFA.

Yield response to pH at various exchangeable potassium levels. The Vernal alfalfa yield response to pH appears to be dependent on exchangeable K at low and medium soil test levels (coded; Figure 11), but, as was the case with the Cossack-Ladak alfalfa, there appears to be little or no additional yield response to exchangeable K levels above 200 pp2m.

Yield response as a function of pH and exchangeable potassium. Because of the apparent similarity of the Vernal alfalfa data and the Cossack-Ladak alfalfa data it was first assumed that the Vernal yield response to the log K - pH interaction was similar to the Cossack-Ladak yield response (log K range of 1.92 to 2.25 and pH range 5.2 to over 7.0).

When the log K - pH function for each observation was plotted against the actual yield, it was noted that the yields from the higher pH plots (above pH 6.3) did not exceed the yields of the pH 6.3 plots. The yield response to change in pH was then limited to 1.1 (pH 6.3 less pH 5.2). The recalculated values (coded for each year) are shown plotted against actual yield in Figure 12. It can be noted that lack of initial K limited the total yield response; therefore, the no-initial K observations were not included in subsequent regression line determinations. (Another three year old Vernal observation, obviously erroneous, was also omitted.)

The calculated regression line slope values (b_o = 9450 for the two year old Vernal and b_o = 11,900 for the three year old Vernal) were used to obtain the average slope value of 10,700 lbs. per acre yield response per unit change in the log K - pH interaction used for the Vernal alfalfa yield predictions.

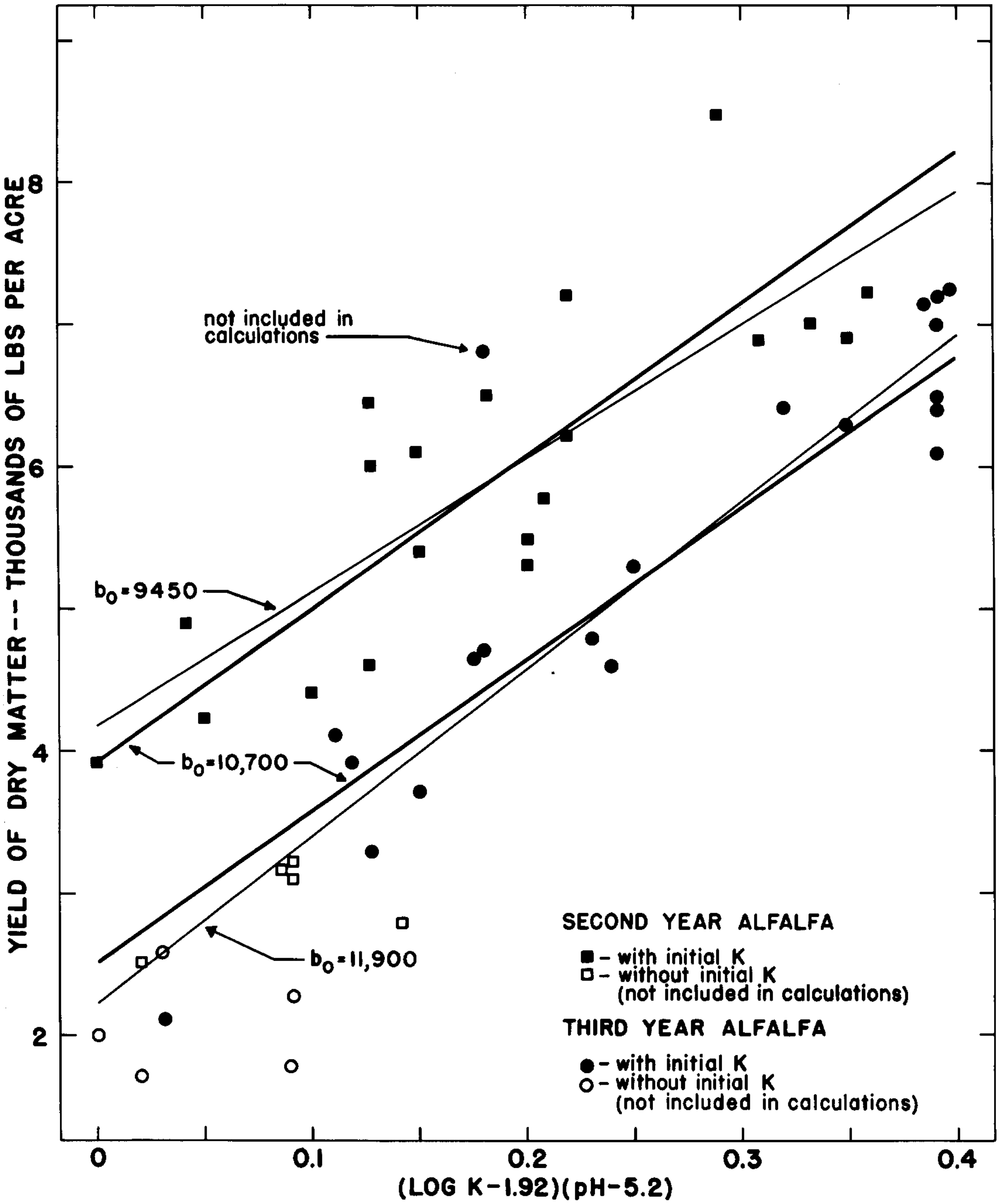

FIGURE 12. RELATIONSHIP BETWEEN THE LOG K-pH FUNCTION AND ALFALFA-BROME YIELDS — TWO AND THREE YEAR OLD VERNAL ALFALFA.

Determination of "base" yields and response to potassium applied at time of seeding. The "base" yield of 3900 lbs. per acre for the two year old Vernal and 2500 lbs. per acre for the three year old Vernal were determined by the yield level at which the average regression line slope ($b_o = 10,700$) intercepted the zero point for the pH - log K function (Figure 12).

Since the plots receiving no initial K were not included in the regression line calculation, it was assumed that the difference between the "base" yield and the yield of those plots receiving no initial K was the yield response attributable to the initial K application. No additional yield response was noted for initial K applications greater than 60 lbs. of K_2O per acre.

Equation for predicting Vernal alfalfa yields. The following equation similar to that developed for Cossack-Ladak was used to predict Vernal alfalfa yields.

$$Y = b_o (\log K - 1.92) (pH - 5.2) + a - c,$$

The following derived values were used in the formula: b_o is 10,700; a is 3900 for the two year old and 2500 for the three year old Vernal; c is 1900 (1 - initial K) and 900 (1 - initial K) with initial K equal to 0 or 1 (none or some) for the two and three year old Vernal, respectively; change in log K is limited to 0.33 (log K values of less than 1.92 are treated as 1.92, and log K values greater than 2.25 are treated as 2.25); and the change in pH is limited to 1.1 (pH values less than 5.2 are treated as 5.2 and values greater than 6.3 are treated as pH 6.3).

Correlation of predicted yields with actual yields. The possible calculated yield range is 2000 lbs. to 7800 lbs. of dry matter per acre for the two year old Vernal, and 1400 lbs. to 6400 lbs. of dry matter for the three year old Vernal. These yields correlate very highly with the actual yields ($r = 0.954$) and the calculated regression line ($b_o = 1.004$) is practically identical with the theoretical regression line ($b_o = 1.000$; Figure 13). It is assumed that some undetermined condition during the year of establishment must have seriously reduced the "base" yield, and thereby the total yield obtainable, for the three year old Vernal alfalfa stand.

Alfalfa Yield Response as a Function of the Log K - pH Interaction

The linear alfalfa yield response to the log K - pH interaction appears to be a function dependent upon the variety of alfalfa and is additive to the "base" yield which is affected by the previous management practices, previous weather conditions and/or age of stand.

A comparison of the Vernal and Cossack-Ladak yield responses to the log K - pH interaction, shown in Figure 14, indicates some possible reasons for the apparent variance in conclusions noted in the literature. The four and five year old Cossack-Ladak alfalfa yield response to the log K - pH interaction extends over a wider range than it does for Vernal alfalfa. This is caused by the variation in the limits of the yield response range for pH (pH 5.2 to at least 7.0 and pH 5.2 to 6.3, respectively, for Cossack-Ladak and Vernal).

The yield response to the log K - pH interaction is additive to the base yield; therefore, a low base yield can seriously limit the total possible yield. This is the case for the lower maximum yields with

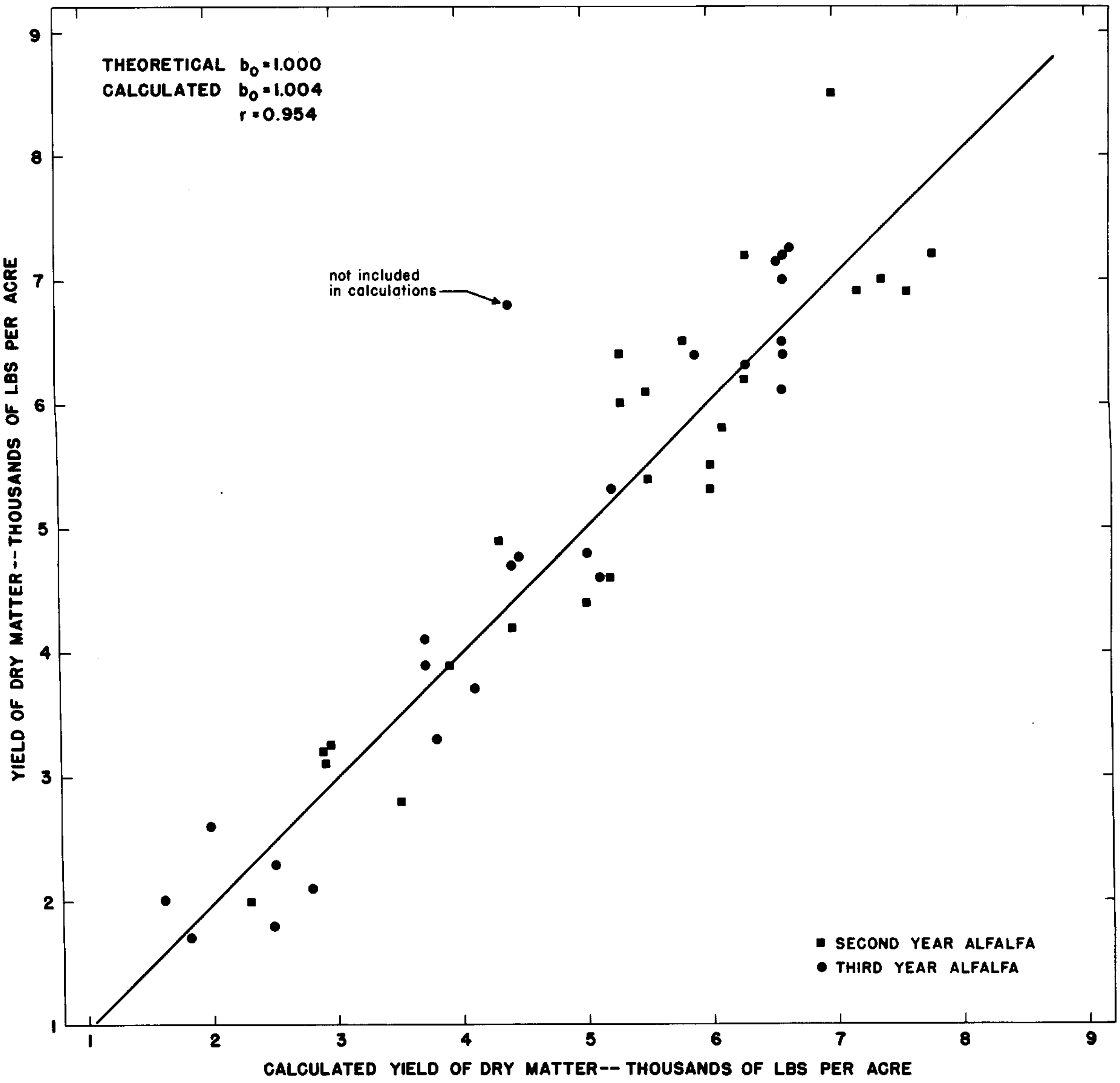

FIGURE 13. COMPARISON OF CALCULATED YIELDS WITH ACTUAL YIELDS — TWO AND THREE YEAR OLD VERNAL ALFALFA.

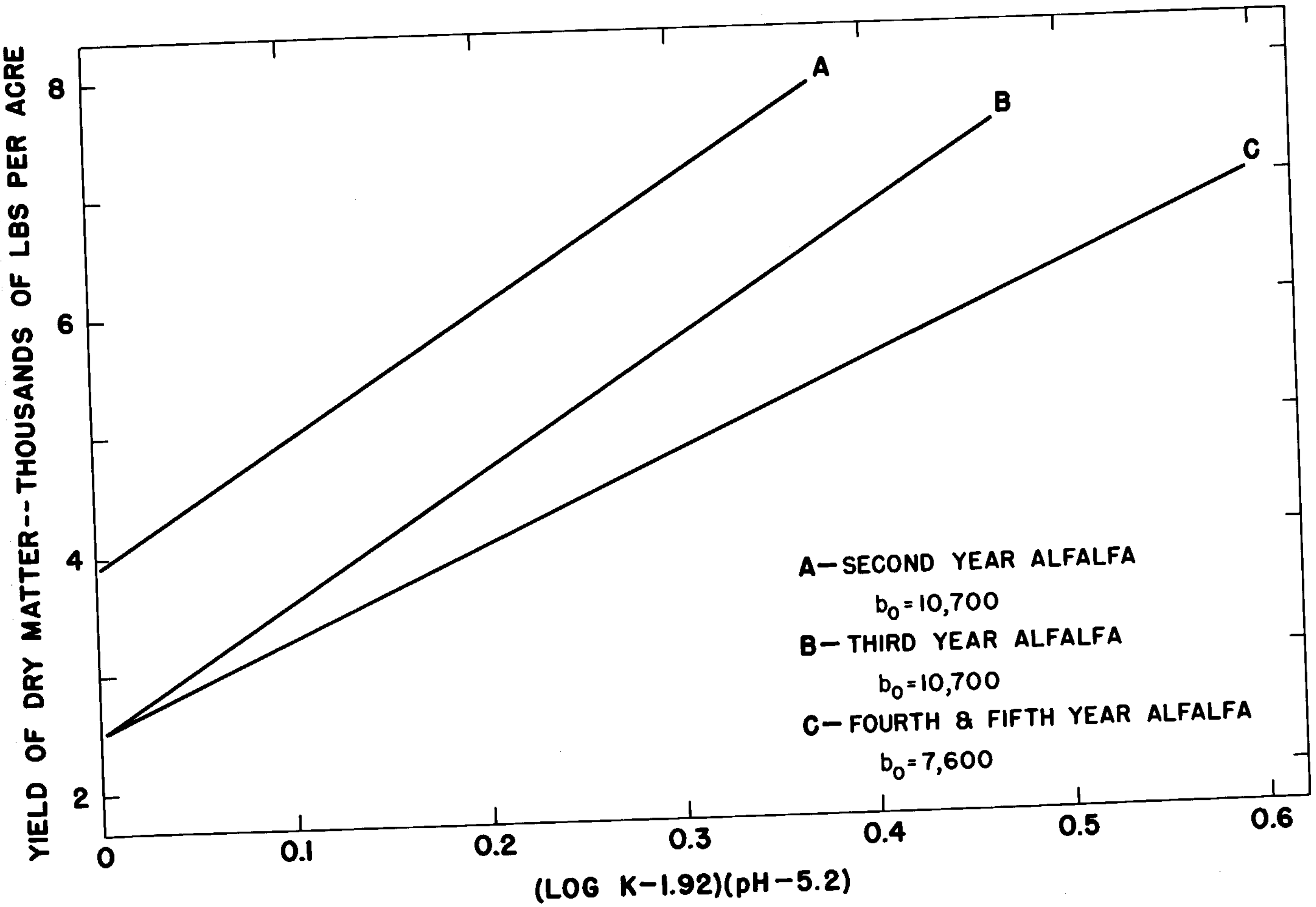

FIGURE 14. RELATIONSHIP BETWEEN THE LOG K-pH FUNCTION AND ALFALFA-BROME YIELDS FOR TWO YEAR OLD VERNAL, THREE YEAR OLD VERNAL AND FOUR AND FIVE YEAR OLD COSSACK AND LADAK ALFALFA.

three year old Vernal compared to two year old Vernal. It is assumed that this variation was the result of undetermined factors such as differences in previous management or previous weather conditions and/or factors associated with age of stand.

Conclusions

The results of this field study suggest the following conclusions with regard to the effect of soil pH and exchangeable K on alfalfa yields on Withee silt loam.

1. There was a high correlation of alfalfa yield with pH and exchangeable K for all sampling depths under the conditions of this study. However, samples taken to the 8-inch depth showed slightly better correlations of pH with yield and equally good correlations of exchangeable K with yield. The values for exchangeable K varied considerably with depth of the sampling because of the topdress K applications. This indicates that routine soil samples should be taken to plow depth to reduce possible errors in soil test interpretations caused by localized zones of high fertilizer concentration within the plow layer. These zones could be caused by topdressing or plowdown fertilizer applications, movement of K to surface horizons by plant uptake and subsequent leaching of K from the dead tissue, etc.
2. Alfalfa fails to survive or contributes very little to the yield of dry matter on soils with low pH (<5.2) or low exchangeable K (<85 pp2m), but is estimated to contribute more than 95% of the dry matter on plots with optimum pH and exchangeable K levels.

3. There is a linear increase in the yield of alfalfa with increase in pH (at any constant exchangeable K level above 85 pp2m) from pH 5.2 to pH 6.3 with Vernal and pH 5.2 to at least pH 7.0 (the upper pH limit for this study) with Cossack-Ladak as the response crop.
4. There is a linear increase in the yield of alfalfa with increase in log exchangeable K (at any constant pH level above 5.2) from log K of 1.92 (85 pp2m) to log K of 2.25 (180 pp2m) for either Vernal or Cossack-Ladak alfalfa.
5. The four and five year Cossack-Ladak yield response to initial K (K_2O applied at seeding time) averaged 8 lbs. of dry matter per lb. of K_2O under the conditions of this study (0 - 120 lbs. of K_2O per acre). The Vernal alfalfa yield response to initial K was limited to the 60 lbs. per acre rate of K_2O (the minimum added initial K rate). The difference in level of response may have been caused by varietal differences and/or differences associated with age of stand.
6. Alfalfa yield response is highly predictable with the following formula under the conditions of this study.

$$Y = b_o (\log K - 1.92) (pH - 5.2) + a - c,$$

where Y is the predicted annual yield of dry matter in lbs. per acre, b_o is the change in yield per unit change in the log K - pH interaction within the yield response range (log K of 1.92 to 2.25 and pH 5.2 to 6.3 for Vernal and pH 5.2 to at least 7.0 for Cossack-Ladak, a is the maximum yield obtained without a response to the log K - pH interaction, and c is the reduction in yield caused by lack of sufficient initial K (K_2O applied at seeding time).

The correlation values for the predicted yield with the actual yield are 0.920 for the four and five year old Cossack-Ladak alfalfa (N = 180) and 0.954 for the two and three year old Vernal alfalfa (N = 49).

Further Studies Contemplated

Because of time limitations on this study, some work remains to be done in improving the accuracy of some of the constants used in the equations and in obtaining additional information from the data already at hand. This work includes the following:

1. Alfalfa yield response limitations to exchangeable K (85 pp2m to 180 pp2m for the 8-inch sampling depth) can be more accurately determined by selecting narrower limits and more points for determining the yield response to pH at various exchangeable K levels.
2. The values above the exchangeable K response range should be corrected to equal the top exchangeable K value at which there is additional yield response, and regression lines then determined for the yield response to exchangeable K at various pH levels. The plotted regression line slope values for this study and the previous study should then approximate each other and give a very accurate determination of the log K - pH function.
3. The effect of initial K (K_2O applied at time of seeding) upon the yield of alfalfa appears to be partially limited by pH, therefore further study is needed to determine the possible interaction of pH and initial K.
4. It appears that annual fall topdress K applications of approximately

150 lbs. of K_2O per acre are needed to maintain the alfalfa yield response at the optimum level when other conditions of high level management are followed. Under the conditions of this study, the rate of 180 lbs. of K_2O per acre per year is slightly in excess of the amount required to maintain the exchangeable K level at the optimum 180 pp2m level, but the rate of 90 lbs. of K_2O per acre per year is not sufficient to maintain the exchangeable K level at 180 pp2m even on low yield plots. Further study of the data is needed to better evaluate topdressing rates.

5. The rate of lime applications needed on Withee silt loam to raise the pH of the plow layer to desired level within a few years after application (even when the best known practical lime and soil mixing techniques are used) appear to be sufficient to maintain that pH level for at least 15 years. The calculated reduction in pH caused by fertilizer acidity and loss of Ca and Mg by crop removal, erosion and leaching (negligible in this soil as evidenced by the low pH of the 8 - 10 inch soil sampling depth increment not reported as part of this study) is apparently compensated for by the remixing of the soil with small localized areas of unequilibrated limestone on further cultivation.

More information on this problem could undoubtedly be obtained by a critical study of the available data.

SUMMARY

Alfalfa is recognized as a very important crop in the efficient production of milk. Although it is generally agreed that alfalfa will either fail to survive or will yield poorly without adequate additions of lime and K, on the acid, K deficient soils of northeastern United States there appears to be little agreement as to the amount of these soil amendments needed for optimum yields of alfalfa. Therefore, the objectives of this field experiment were to determine alfalfa yield response as a function of soil pH and exchangeable K and to determine whether the contributions of these two factors to alfalfa yield are additive or interdependent.

The Clark County fertility plots (Withee silt loam) were selected for this study. There were 105 five year old and 75 four year old Cossack-Ladak alfalfa plots, and 25 three year old and 25 two year old Vernal alfalfa plots. Each stand had five rates of limestone (0, 2, 4½, 6 and 8 tons per acre) and each lime level had five rates of K at seeding time (0 to 120 lbs. initial K_2O per acre). The five year old stand had two extra fertility treatments. The four and five year old alfalfa plots had three topdress K treatments each fall (0, 150 and 300 lbs. of 0-0-60 per acre) superimposed across the initial fertility treatments while the two and three year old alfalfa topdress K treatments were approximately proportionate to the initial K treatments.

The soil was sampled in 1958 before the alfalfa made any visible growth. Twenty 2-inch increment cores to the 8-inch depth were taken from the harvest area of each plot and equivalent depth increments were composited. The soils were analyzed for pH, available P and exchangeable

K by the methods used in the Wisconsin State Soils Testing Laboratory. Yield of forage was calculated in lbs. of dry matter per acre. The data were subjected to simple and multiple correlation analyses at the Numerical Analysis Laboratory and the Dairy Records Cooperative at the University of Wisconsin.

Soil test values of the 0 to 8 inch depth were used for further study because they correlated with yield as well as those taken to a lesser depth and a deeper sampling depth has certain advantages when fertilizers are not uniformly distributed throughout the plow layer.

Simple correlation analyses indicated that the four and five year old Cossack-Ladak alfalfa stand data are very similar in characteristics, therefore, these stands were treated as one population.

The simple correlations of yield with pH, log K, initial K and topdress K are all highly significant at the 1% level. Multiple correlations show that a strong interaction exists between pH and both log K and topdress K and that the readily obtained values for pH and log K (topdress K values require a fertilizing history) are very good predictors of alfalfa yield.

The Cossack-Ladak alfalfa yield response to pH is linear, at any constant log K value, from pH 5.2 to at least pH 7.0. Similarly, the yield response to log K is linear, at any constant pH level, from log K 1.92 to log K 2.25. It was noted that alfalfa failed to survive or contributed very little to the yield of dry matter on low pH (below 5.2) or low exchangeable K (below 85 pp2m--log K 1.92) soils, but was estimated to contribute more than 95 percent of the dry matter on plots with optimum pH and exchangeable K levels.

There was a yield response to initial K applications, especially to the first increment of 60 lbs. of K_2O per acre, even though the initial K is not reflected in the exchangeable K determination.

The Cossack-Ladak alfalfa yields are highly predictable ($r = 0.920$ for 180 observations) when using the following formula and substituting the proper values determined by the statistical analysis.

$$Y = b_o (\log K - 1.92)(pH - 5.2) + a - c,$$

where Y is the predicted annual yield of dry matter in lbs. per acre, b_o is the change in yield per unit change in the log K - pH interaction within the yield response range (log K 1.92 to log K 2.25 and pH 5.2 to at least pH 7.0), a is the maximum yield obtained without a response to the log K - pH function, and c is the reduction in yield caused by lack of sufficient initial K.

The restricted exchangeable K range for the two year old Vernal and the restricted pH range for the three year old Vernal alfalfa made it difficult to observe the log K - pH interaction. Only by comparison with the Cossack-Ladak alfalfa data was it possible to derive an equation for calculating yield. High correlation ($r = 0.954$) of predicted yields with actual yields was obtained when the above equation for predicting alfalfa yields was modified by limiting the range of yield response to pH for Vernal to pH 5.2 to pH 6.3.

LITERATURE CITED

Attoe, O. J. and Truog, E. Correlation of yield and quality of alfalfa 1950 and clover hay with levels of available phosphorus and potassium. Soil Sci. Soc. Amer. Proc. 14:249-253.

Baumgardner, M. F. and Barber, S. A. Effect of soil type on correlation 1956 of soil test values with crop response. Soil Sci. 82:409-418.

Bear, F. E., Prince, A. L. and Malcolm, J. L. The potassium supplying 1944 power of 20 New Jersey soils. Soil Sci. 58:139-149.

Bear, F. E. and Wallace, A. Alfalfa, its mineral requirement and chemi- 1950 cal composition. New Jersey Agr. Exp. Sta. Bull. 748.

Brown, B. A. Effect of fertilizers on maintaining stands of alfalfa. 1928 Jour. Amer. Soc. Agron. 20:109-117.

Fried, M. and Peech, M. Comparative effects of lime and gypsum upon 1946 plants grown on acid soils. Jour. Amer. Soc. Agron. 38:614-623.

Giddins, Joel and Perkins, H. F. Influence of molybdenum on growth and 1960 composition of alfalfa and distribution of molybdenum in a Cecil-Lloyd soil. Soil Sci. Soc. Amer. Proc. 24:496-497.

Haddock, J. L. and Vandecaveye, S. C. Yield and chemical composition of 1946 alfalfa on two Western Washington soil types. Soil Sci. Soc. Amer. Proc. 10:129-133.

Jackson, M. L., Evans, C. E., Attoe, O. J., Huber, J. L. and Kaudy, J. C. 1947 Soil fertility level in relation to mineral and botanical composition of forage. Soil Sci. Soc. Amer. Proc. 12:282-288.

Jackson, M. L. and Truog, E. Clark County soil fertility experiments. 1944 Annual report, University of Wisconsin.

Jung, G. A. and Smith, Dale. Influence of soil potassium and phosphorus 1959 on cold resistance of alfalfa. Agron. Jour. 51:585-587.

Love, J. R., Peterson, A. E. and Engelbert, L. E. Lime and fertilizer 1960 incorporation for alfalfa production. Wis. Academy of Sciences, Arts and Letters 49:161-169.

MacLean, K. S. and Langill, W. M. Nutrient status of "healthy" and "un- 1958 healthy" alfalfa. Canada Jour. of Plant Sci. 38 (2):241-245.

Meyer, T. A. and Volk, G. W. Effect of particle size of limestones on 1952 soil reaction, exchangeable cations and plant growth. Soil Sci. 73:37-72.

Moschler, W. W., Jones, G. D. and Thomas, G. W. Lime and soil acidity
1960 effects on alfalfa growth in a Red-Yellow Podzolic soil. Soil Sci. Soc. Amer. Proc. 24:507-509.

Nimlos, T. J. Relative efficiencies of size fractions of dolomitic
1959 limestone. Ph.D. Thesis, University of Wisconsin.

Peterson, A. E., Olsen, C. C. and Attoe, O. J. Clark County soil ferti-
1957 lity experiments. Annual Report, University of Wisconsin.

Rendig, V. V. and McComb, E. A. Effect of nutritional stress on plant
1959 composition: I. The interaction of added nitrogen with varying sulfur supply. Soil Sci. Soc. Amer. Proc. 23:377-380.

Schmehl, W. R., Peech, M. and Bradfield, A. Causes of poor growth of
1950 plants on acid soils and beneficial effects of liming. Soil Sci. 70:393-410.

Seay, W. A., Attoe, O. J., and Truog, E. Correlation of the potassium
1956 content of alfalfa with that available in soils. Soil Sci. Soc. Amer. Proc. 14:245-259.

Stivers, Russell K. and Ohlrogge, A. J. Influence of phosphorus and
1952 potassium fertilization of two soil types on alfalfa yield, stand and content of these elements. Agron. Jour. 44:618-621.

Thomas, G. W. and Coleman, N. T. Lime helps potash. N. C. Agr. Exp.
1958 Sta., Research and Farming 17 (1):11.

Truog, E. and Engelbert, L. E. Soils - nature and management. College
1954 Typing Co., Madison, Wis.

Wang, L. C., Attoe, O. J. and Truog, E. Effects of lime and fertility
1953 levels on the chemical composition and winter survival of alfalfa. Agron. Jour. 45:381-384.

Wells, C. G. Potassium availability in surface and subsoil horizons as
1959 measured by plant uptake and chemical extraction. Ph.D. Thesis, University of Wisconsin.

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