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RESPONSE OF ALFALFA VARIETIES TO CUTTING TREATMENTS AND FERTILIZERS

by

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INTRODUCTION

The production of alfalfa in the United States has increased markedly in the past half-century. This increase has been accomplished through expanded acreage, in part, but yields per acre have risen also. In the past, much of the increased acreage has been a result of expansion in area devoted to hay production; more recently, some of the increase has been at the expense of other hay crops, viz., red clover in the Midwest. Higher yields are due to both better management of the crop and the more widespread use of new varieties.

Many new varieties have been released in the past two decades. Some of these have been bred for increased yield, more winterhardiness, greater wilt resistance, low-set crowns, spreading crowns and/or adaptation to more severe cutting practices. Most farmers now use the recommended methods of good alfalfa management. However, these recommendations have changed but little in the past twenty years. Cutting management for hay, based on stage of bloom and with regard to quality and stand persistence, was developed largely through research on the older varieties. The practice of making the last cutting early in the fall to permit storage of root reserves was recommended after studies on varieties then in wide use. But the advent of new varieties, with different adaptations and growth habits, impels the revaluation of these, and other, management practices. The possibility of a more flexible cutting or grazing program, especially with regard to some of the new varieties which have been developed with low, spreading crowns or more spreading roots, becomes apparent.

As alfalfa becomes more widely used, it begins to compete with crops of higher cash value. If alfalfa is to maintain its competitive position, greater efficiency must be developed in its culture. Fertilizer recommendations for alfalfa generally have been based on soil tests for a given field. If increased efficiency in the use of fertilizer is necessary, recommendations should be re-examined in terms of response of the newer varieties.

This study was undertaken to consider such problems. The single and combined effects of variety, fertilizer application and cutting management were examined. The effects were measured over two harvest-years; much of the alfalfa acreage, particularly that which replaced red clover, is left down for only two seasons. Yield has been used as the major criterion of effect, but consideration has also been given to the mineral constituents of the forage.

REVIEW OF LITERATURE

The literature contains many references to alfalfa culture in general and, to a lesser extent, specific problems of its management. Among these latter, the question of fertilization is a major one. Bear and Wallace (6) have attempted to specify exact conditions within the soil cation exchange complex which should be met for best alfalfa growth. They state that the ideal soil should contain, as millequivalents of the cation exchange complex, 65% Ca, 10% Mg, 5% K and 20% H, with a resultant pH of 6.5. Under these conditions, alfalfa should contain 2% K and 0.27% P. These authors have also proposed 1.4% K and 0.27% P as critical levels for alfalfa growth.

Tysdal and Westover (88) stated that most soils lying east of the 95th meridian need fertilization and that phosphorus and potassium are the nutrients most often required. Many publications from states within the prescribed area recommend varying levels of P and K fertilizers. As time passes, the areas in which fertilizers are needed for good growth move westward. A survey (31) has indicated that, according to last recommendations and, usually, based on soil tests, phosphorus fertilizer should be applied to some extent in all 42 states from which replies were received. Potassium was recommended, based on soil test, in 35 states.

Attoe and Truog (3) attempted to predict alfalfa hay yields by means of a regression equation. The equation contains terms for P, K and early summer rainfall. Of these, under their conditions, potassium had the greatest effect on predicted yield.

Thus, it would seem that fertilizer is becoming more critical each year as farmers attempt to stabilize yields at a relatively high level.

A recent report by the Fertilizer Work Group (23) indicated what might be expected in attainable hay yields if fertilizer use were increased. They estimated that the current consumption of P and K on hay fields is of the order of 5 and 3 pounds per acre, respectively, for the country as a whole, and 6 and 3 pounds per acre for the North Central region in particular. Projecting yield estimates with increased fertilizer use, the report suggested that a national increase of 100% in the use of each of these nutrients would raise hay yields about 8 and 4%, respectively, in the United States. The increase for the North Central region would approximate 8 and 3%. These estimates emphasize one of the pressing problems of forage management; *i.e.*, in many areas, relative returns from fertilizer applied to forage, as compared to those from cash grain, discourage its use.

Phosphorus Fertilization

Phosphorus is generally conceded to be the most frequently limiting fertilizer nutrient in alfalfa production. Response to P fertilizer probably is the most widespread phenomenon reported in the literature on alfalfa culture. The importance of phosphorus from the standpoint of forage quality and animal yields has been emphasized by many workers. Eckles _et al_. (21) mentioned the detection and diagnosis of P deficiency among cattle. They recommended the use of bonemeal in rations as a stopgap measure but pointed out the importance of phosphorus fertilization as the ultimate cure. Morrison (51) stated that P and Ca deficiencies are the most common in cattle because not only are they more deficient in the soil but also higher animal production makes for higher requirements. He and other investigators have suggested percentages of P in alfalfa and other forages adequate if they are to meet the nutritional requirements of cattle. These have been summarized in reports from the National Research Council (53, 54). A 1000-pound dairy animal requires approximately 10 gm. P daily for maintenance alone, and beef animals need between 10 and 12 gm. daily for maintenance during their growth from 5 to 40 months of age. These should be considered minimal requirements, for maintenance only. However, according to many published alfalfa analyses, they exceed the amounts which would be supplied by much of the alfalfa hay produced, if fed in normal quantities. If, for example, hay analyzed 0.22% P, it would take 10 pounds of hay to supply the 10 gm. daily minimum. Obviously these nutrient requirements need not be met by forage alone. However, if forage is to be accepted widely as a quality feedstuff, it must contribute a fair amount of this mineral.

Sandal and Garey (71) noted the effect of phosphorus fertilization in terms of direct beef gains. In Arkansas, beef yields were increased more than 600 pounds with the application of up to 600 pounds of superphosphate, top-dressed on Bermuda-legume pastures.

An Indiana study (4) has indicated the relative yield expectations indicated by the results of the Purdue soil test. If the available soil P is greater than 44 pounds per acre, no response may be anticipated; if soil tests indicate 22-44 pounds per acre, one may expect 88-95% of the maximum yield; if the tests run between 11 and 13 pounds per acre, 65-88% of the maximum is the limit expected; and if less than 11 pounds per acre, no greater than 65% of the maximum yield may be anticipated. A similar system was based on plant analysis, with 0.3% P indicated as the level above which no response to fertilizer may be expected.

The effects of phosphorus on alfalfa have been noted by numerous workers in many states. It may be stated rather broadly that alfalfa responds to P at most locations east of the Missouri river and in many areas in the states to the west. A survey (31) of the current status of alfalfa fertilizer recommendations indicated that P is recommended to some extent in 42 states, 14 of which are west of the Missouri river.

Responses to phosphorus have been reported in terms of yield increases (11, 15, 45, 52, 58, 71, 84), increased stand (11), increased P content in the forage (7, 42, 45, 57, 58, 84, 92), increased protein content (15, 92), enhanced mineral absorption (15, 37, 59, 84, 99) and a higher percentage of legumes in the stand (13, 82). In some cases, P fertilizer had no effect on stand (62, 84) or a depressing effect on nutrient uptake (82). Hanway _et al_. (33) have reported increased K absorption under P fertilization during one season and, on the same stand of alfalfa, a depressing effect of P fertilizer on K uptake during the next season.

The value of phosphorus in Iowa has been investigated with increasing interest in the past decade. Nelson _et al_. (55) conducted some 32 experiments over the state and noted P response in 67% of them. They state that the largest response could be expected on the glacial drift or thin loessial soils in the eastern two-thirds of the state. In north-central Iowa, on the Clarion-Webster associations, mid-season applications of P corrected the stunted condition noted in some fields. On these high-lime soils, some recovery was noted during the season of application, and the carryover effect was marked.

Other workers have reported on similar studies in different areas of the state. The value of topdressed P on established stands on the neutral to high-lime soils of north-central Iowa has been reported by Larson et al. (42) and Stanford et al. (81). The authors recommended early spring topdressing to avoid the drought which normally occurs after the first cutting. Hanway et al. (33) have indicated that the critical level suggested by Bear and Wallace (6) for P content of alfalfa, 0.27%, pertains to Iowa conditions. This critical level has been defined as the level below which a yield response may be expected, if fertilizer is applied, and above which no response may be expected. Hanway et al. (33) reported rather high rates of recovery of P fertilizer on Carrington silt loam, which served to confirm the value of topdressing. Smith (78) reported that, at rather high rates of application and during the seeding year, topdressing in the summer, after the removal of the companion crop, was equally as effective as in the spring before or at seeding time. Pesek (62) has investigated the relative value of two P carriers applied to established stands. He concluded that source of P has a smaller effect on recovery than does method of application. On the soils tested, in some cases, broadcast

P was more effective than drilled; this, the author concluded, was partly due to the mantle of organic matter which reduced fixation at the soil surface.

On another group of soil types, Stanford et al. (82) concluded that topdressing on established stands was more effective than broadcasting before planting, when measured in terms of yield and per cent recovery of applied phosphorus. The crops used were a mixture of oats, red clover and timothy.

It may be concluded from these reports, and from soil-test summaries, that P is limiting yields in many alfalfa fields in Iowa. Soil tests on farmer-drawn samples show that three-fourths of the fields sampled in Iowa need phosphorus (34). It has been estimated that Iowa farmers use one-fifth the P needed for top yields (78). Phosphorus should certainly be applied at seeding time, if the need is indicated, and will be effective if topdressed on established stands. The effectiveness of late-applied fertilizer is conditioned in large part by the amount of rainfall received.

Potassium Fertilization

The need for potassium is considerably more localized than is that for phosphorus. Many scattered areas of the country require K fertilizer, and most of the states east of the Mississippi recommend it for best alfalfa growth. This necessity was pointed out by Bear and Wallace (6) who stated that potassium is the most critical element for good alfalfa stands and yields. Others have concurred in this recommendation (59, 61). Turrentine (85) has pointed out that very little research has been done on the K requirements of animals. This has happened because, although K is of vital importance to animals, deficiencies are rare. Bear et al. (6) indicated that the critical level of K in the plant is 1.4% and the ideal would be 2.0%. These authors defined critical level as that below which yield responses could be expected upon fertilization and above which no response may be anticipated. This critical level has been confirmed by other workers (81, 91). Bear and Wallace (6) also proposed that the soil exchange complex should contain 5% K for best alfalfa growth.

Lawton and Cook (44) reported 1% as about the critical value for alfalfa K and stated that, for good yields, alfalfa requires 100-130 pounds available K per acre as shown by soil test. This critical percentage was substantiated by Nielson et al. (58).

Chandler et al. (13) reported that when the K content of the plant dropped below 1.25% they obtained yield responses of better than 20% by weight; if the available soil K were below 80 pounds per acre, they noted a response to fertilization of better than 20% in 44 out of 57 cases; and if more than 15% of the plants showed deficiency symptoms, a yield response could be expected. Seay et al. (74) have confirmed this critical value of 1.25% plant potassium. These authors stated that, when the K content of the alfalfa plants dropped below this level, the winter survival of a stand was greatly reduced.

Drake and Scarseth (17) proposed the theory that K is especially necessary for alfalfa because it is a relatively inefficient feeder for this nutrient. This has also been indicated by Hanway et al. (33).

The effects of K have been reported by many investigators. Some have mentioned increased K content (75, 77, 82), increased yield (55, 57, 65), both increased yield and K content (82, 84, 91), better winter survival (41, 92), decreased weed invasion (11, 65, 99), lower P content (7) and increased longevity (84).

The luxury consumption of K by alfalfa has been discussed by several workers (2, 5, 6). Macy (47) proposed the theory that luxury consumption is a natural characteristic of plant growth and may be attributed to all nutrients.

Barber (4) has outlined a predictive scheme for evaluating expected response to potassium fertilizers. In southern Indiana, more than 166 pounds available K per acre is needed for maximum yields. If the Purdue soil test indicates 124-166 pounds, one may expect 92.5-97.5% of the maximum yields;

if 83-104 pounds of K are indicated, yields run 80-92.5% of the maximum. On the basis of plant analysis, maximum yields require more than 2% potassium. If the plant contains 1.5-2.0%, the yield should be 90-95% of the maximum; if the content were below 1.5%, the yield will be less than 90% of the highest.

The status of K fertilization in Iowa has been investigated (8, 19, 33, 37, 55, 81, 82). The need for K is not as widespread as that for P, response having been greatest in the northeastern part of the state with little or no response in western Iowa. If soils test below 100-130 pounds available K per acre (low), yield responses to K are likely; or if plants analyze less than 1.4% K, a response would be expected. Stanford _et al_. (81) suggested annual topdressing on soils low in potassium.

Potassium deficiency may be accentuated by P fertilization. The future need for K may increase, therefore, as the use of P fertilizer increases. This point was illustrated by the data of Cloninger and Herman (14) which presented both old and recent analyses of some soils. The P content tended to increase, and the K to decrease, in the more recent samples. One reason for this might be the increased drain on native soil K as the use of phosphorus has become more widespread. In some cases, failure to obtain a response to P fertilizer may be due to a lack of potassium.

Combined Fertilization: Phosphorus and Potassium

The interaction of P and K fertilizers has been discussed by Dumenil and Nelson (19). These authors found that in 22 experiments on hay crops, a significant interaction was apparent in four cases. The data of Attoe and Truog (3) indicated that a positive interaction may have been detected, though it probably was not significant. Heady _et al_. (37) also indicated that interactions may be expected when P and K are applied to alfalfa; these interactions, however, were negative.

Conversely, Hanway _et al_. (33) and Stanford _et al_. (82) reported the absence of interaction in their experiments. Apparently, the type of response denoted as positive interaction has been detected only in those cases where the native soil fertility was relatively low in both P and K and where the experimental design was such that interactions could be evaluated.

Fertilizer and Variety Interaction

The interaction of forage varieties with fertilizers has rarely been reported in the literature. The absence of differential responses of varieties to different fertilizers have been reported by Brown (11), Gross _et al_. (30) and

Rossiter (68). Younge and Takahashi (101) have noted one of the few cases of significant interactions with alfalfa. In their test of 13 varieties in Hawaii, the two highest-yielding varieties, Narragansett and Rhizoma, gave the least response to applied molybdenum. Hairy Peruvian, Kansas Common and Atlantic, though intermediate in yield, showed considerable response. Hairy Peruvian advanced from a mediocre to one of the higher-yielding varieties upon the application of molybdenum. Harvey _et al_. (36) have reported a study of six alfalfa varieties at the Texas Station. The varieties included Texas Common, Kansas Common, Buffalo, Ranger, Chilean and Pilca Butta. A uniform application of phosphorus was applied prior to seeding time. In subsequent years, one half of each varietal plot was topdressed with 80 pounds of P_2O_5 per acre, just after the first spring clipping. For the 3-year test period, the varieties did not differ significantly with respect to average yield. However, the variety x fertilizer interaction was significant, due in part to the lower yield of Ranger when fertilized than when no fertilizer was topdressed. Buffalo responded markedly to the topdressed P fertilizer.

The interaction of varieties with fertilizers has been investigated considerably more on cash crops. The results vary, and a possible explanation of the variation has been proposed by Frey _et al_. (25). Their thesis is based on the relative regions of adaptation of the varieties; if large, no differential response is expected; if small, an interaction might be noted.

Hartwell (35) mentioned the importance of such differential responses and recommended that varieties used be stated whenever crop responses to fertilizer are cited. Hunter and Leake (39) emphasized the importance of the possibility of such differential responses in a plant-breeding program. They cited specific circumstances under which a new variety might or might not be accepted, if it were markedly responsive to specific fertility conditions.

Fergus (22) discussed some of the implications of differential responses and the breeding of crops or varieties that are adapted to poorer soils. He indicated that such a procedure might well do more harm than good. If these varieties were used in conjunction with a soil-building program, all would be well. If, on the other hand, poor-land varieties were used to obtain some sort of yield from soils too infertile to support "good-soil" crops, the evil would be compounded. By virtue of the fact that it is capable of producing on poorer soils, such a crop must be able to remove sufficient nutrients from such a soil to support its growth. If no fertilizer were added, the removal of forage or grain from a variety of this type tends, therefore, to make an already infertile soil more deficient in those nutrients which it needed for growth.

Cutting Management

The effects of different systems of cutting management have been considered by many workers. These effects have been studied in terms of yield, which tended to decrease with increased or early cutting (12, 16, 38, 40, 43, 46, 56, 89, 98); yields which increased to a point and then fell off (1, 70, 94); quality, which usually increased with increased cutting (1, 9, 16, 43, 60, 70, 98); survival, which decreased with increased cutting (1, 12, 26, 28, 56, 60, 63, 90), and increased winterkilling with decreased cutting interval (64, 92). Some investigators found no decrease in stand (40, 43). These latter studies were not conducted at the extremes of possible cutting systems or were carried on under conditions markedly unlike those of the experiments which resulted in decreased stands.

It may be stated that generally quality decreased with less frequent cutting, although yields of quality factors, *i.e.*, protein, may increase to a point, with increased cutting, and then drop off. Increased cutting rates, or clipping in early stages, resulted in decreased root reserves, depletion of stands and, ultimately, reduced quality and growth.

Cutting Management and Variety Interaction

The possibility of a variety-cutting treatment interaction has been considered by some authors. Brown and Munsell (12), Willard (94) and Law and Patterson (43) have found no evidence of interaction. Albert (1), Jackobs and Oldemeyer (40), Tysdal and Kiesselbach (87) and Zapata (102) have cited evidence indicative of a differential response of varieties to cutting treatments. Such a differential response might be due, in large part, to differences in varietal origin; varieties tracing to Common alfalfa might be expected to respond differently than those having Medicago falcata in their hybrid parentage.

Cutting Management and Fertilizer Interaction

The value of fertilization in offsetting the effects of cutting has been mentioned by Graber and Sprague (27). These authors found that high fertility reduced the damage done by clipping and stubble removal. The low-fertility treatments had fewer plants at the end of the second season than did the high. However, the high-fertility plots began to display decreased stands during the third season. Owens and Brown (61) reported that K fertilization does not offset the bad effects of early clipping of alfalfa.

Many of the main effects of these cultural aspects of alfalfa production have been exhaustively investigated. However, the interactions among these effects, as they might occur in the field, have not been studied as extensively. Some of these interactions will be discussed in this paper.

METHODS AND MATERIALS

General Plan of the Study

The primary objectives of this study were to evaluate some of the interactions which may occur among selected factors of field management and adapted alfalfa varieties. To this end, the test included phosphorus and potassium fertilizers, alfalfa varieties and different systems of cutting management. The interactions between alfalfa varieties and fertilizer treatments, between varieties and cutting management and between varieties as affected by cutting treatments and fertilizer application were of major interest.

Four fertilizer levels, eight alfalfa varieties and two systems of cutting management were combined in this study. The experimental design used was a randomized complete block in which the whole plots were divided into sub-sub-plots; a split-split plot design. Fertilizer treatments were assigned to the main (whole) plots and included a check (P_0K_0), phosphorus only (P_1K_0), potassium only (P_0K_1) and both phosphorus and potassium (P_1K_1). Eight varieties of alfalfa were included as sub-plots on these fertilizer treatments. The ultimate plot split into sub-sub-plots was used for two different cutting systems. The first of these was a normal hay management system, and the second simulated pasturing by means of frequent cutting at intervals based on plant height.

Fertilizer Management

The site chosen for this study was field 1000-C on the Agronomy Farm, Ames. This field had been in popcorn during the 1952 season and in forage-grass tests from 1949 until 1952. The field slopes slightly downward to the north. The area has been classified[1] as being primarily Webster silty clay loam, with a small area of Nicollet loam in the southeast corner. On this small Nicollet area were approximately six out of a total of 128 sub-plots.

Soil samples were taken on March 28, 1953. The soil was a bit too wet at this time to permit good sampling. The samples were analyzed by the Iowa State College Soil Testing Laboratory. The potassium samples were not conditioned (dried under controlled conditions of temperature and humidity) before analysis and, therefore, do not compare with subsequent potassium analyses. The field tested low in available phosphorus, i.e., between 3 and 7 pounds per acre is designated a "low" test for the Ames area. Under these conditions, 26 pounds P per acre would be recommended for

[1]Soil classified by Dr. W. D. Shrader. Ames, Iowa, Agronomy Department, Iowa State College. Sept. 1, 1955.

small grain with an underseeding. The test also indicated a low available potassium level, 100-130 pounds K per acre, on the unconditioned samples. Although no recommendation for K fertilization could be based on unconditioned samples, K was included in the experiment because other information had suggested a need for K on this soil type. The pH was 7.8.

The four fertilizer treatments were laid out in a randomized complete block design with four replicates. The materials used were 60% muriate of potash and 20% superphosphate. The treatments included no fertilizer (P_0K_0), phosphorus at 53 pounds (120 pounds P_2O_5) per acre (P_1K_0), potassium at 100 pounds[1] (120 pounds K_2O) per acre (P_0K_1) and both phosphorus and potassium at the stated rates (P_1K_1). The fertilizer treatments are, therefore, in a 2 x 2 factorial combination with two levels of each constituent in all possible combinations. The fertilizer schedule is shown in Table 1.

As indicated in Table 1, the pre-planting application was made on April 5, 1953. This application was at the full rate. In 1954, the fertilizer application was split in an attempt to reduce leaching and fixation. Part of the treatments was applied in the spring before growth had become pronounced, and the remainder was topdressed after the first

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[1]The initial pre-planting application of K was only 76 pounds per acre because of error in calibration of the fertilizer spreader.

Table 1. Schedule of fertilizer applications on eight varieties of alfalfa under two cutting systems, during 1953, 1954 and 1955

Year	Date of application	Rate of application (pounds per acre) P	K
1953[a]	April 5	53	76
1954[b]	March 28		66
	April 7	35	
	June 8[c]	9	
	June 12[c]		22
	June 15[d]	13	
	June 17[d]		15
1955	May 17[e]		100
	May 22[f]		105
	June 9[d]		100
	June 25[e]	53	
	July 1[g]	53	
	July 12[d]	53	

[a]Pre-planting application.

[b]Split application. First increment before rapid growth; second increment after first cutting removed.

[c]Plots cut on height basis.

[d]Plots cut on hay basis.

[e]P_1K_1 - frequently-cut plots (height basis).

[f]P_0K_1 - frequently-cut plots.

[g]P_1K_0 - frequently-cut plots.

cutting had been removed from the treatment plots. In 1955, full-rate applications were made. Potassium was applied at the full rate to overcome the K deficiency indicated by leaf symptoms; phosphorus was topdressed comparatively late in the spring, and for this reason, the full rate was applied.

In 1954, the first harvest-year, soil samples, taken on March 27, were analyzed in the Iowa State College Soil Testing Laboratory. The analyses indicated that, compared to 1953, the P-fertilized plots had increased a slight degree in available phosphorus. The K plots showed no apparent differences compared to the no-K plots, and there was no change in pH. The fertilization schedule for 1954 is shown in Table 1.

In the second harvest-year, 1955, soil samples were drawn on April 20. Cold soil prevented earlier sampling. The analyses indicated that the available P content had dropped in both the P_0 and P_1 plots. However, relative to 1953, the P_0-plots decreased 75% and the P_1-plots only 27%. The potassium contents of the K_0 and K_1 plots decreased about equally, as compared to the 1954 analyses. The pH remained much the same. The schedule of fertilizer applications in 1955 is shown in Table 1. Full-rate applications were made, both for P and K, but extremely rapid spring growth delayed the time of application. The phosphorus applications in particular were made late in the season, and this P was probably not effective during 1955.

Because of the marked discrepancy between the yields on Block I and those of Blocks II, III and IV, soil samples were taken between October 15 and October 19, 1955. Six-inch increments were drawn down to 36 inches. The surface 6-inch layer of all treatments was analyzed separately; the deeper layers were bulked for Blocks II, III and IV and kept separate for Block I. This system was in accord with the techniques outlined by the North Central Potassium Study Committee. The samples were analyzed by the Iowa State College Soil Testing Laboratory.

Alfalfa Management

The alfalfa was seeded on April 14, 1953. Varieties used were Atlantic, A-224, Buffalo, Grimm, Ladak, Narragansett, Ranger and Vernal, all of which are adapted to Iowa growing conditions (10, 97). They differ, however, in habit of growth, crown type, winter hardiness, wilt resistance, yield distribution throughout the season, recovery growth and tolerance to close cutting. Alfalfa varieties were sown as randomized sub-plots within the fertilizer whole plots. They were seeded with a Tysdal broadcast seeder at a rate of 13.0-13.5 pounds per acre. Cherokee oats, as a companion crop, was overseeded on April 17, 1953, at a rate of one bushel per acre. Cool, cloudy weather followed seeding and by May 4 both the oats and alfalfa had emerged satisfactorily. About May 21, heavy winds and rain occurred; the rain may have vitiated some of the fertilizer effects through sheet erosion. Stand estimates, made on May 29, indicated that emergence and establishment were not uniform. Differences were noted among varieties and among fertilizer treatments.

The oats were cut for hay on June 23, and all the straw was removed immediately. No yields were recorded for the oat crop. On August 13, the field was clipped for weed control. Insect damage was kept to a minimum by spraying whenever it seemed necessary. The insecticide spray schedule is shown in Table 2. Visual stand estimates were recorded on

Table 2. Schedule of insecticide applications on eight varieties of alfalfa under four rates of fertilization cut for hay and clipped frequently during 1953, 1954 and 1955.

Year	Date	Material	Rate (pounds per acre)
1953	August 14	DDT	1.0
1954	July 1	DDT	1.0
	July 13	DDT	1.0
		Toxaphene	1.5
	July 26	DDT	1.0
		Toxaphene	1.5
1955	July 13	DDT	1.5
		Aldrin	.25
	August 4	DDT	1.5
		Aldrin	.25

September 25, 1953. There were apparent differences among blocks, among fertilizers and among varieties.

Cutting treatments

In 1954, the cutting treatments were imposed as sub-sub-plots on the variety sub-plots. Each variety plot was divided in half; one half to be cut for hay, the other clipped to simulate grazing. The cutting treatments were assigned at random. Hay cuttings were made on a stage-of-growth basis; all harvests were taken when the plants in any treatment combination were in the one-tenth bloom stage. The second cutting system was a simulated grazing condition; the top growth was removed frequently to reproduce grazing effects. These plots were clipped on a height basis; the first clipping was made when the average height of the plants in any given variety-fertilizer combination was 12 inches, and subsequent clippings when the plants averaged 8 inches in height. Weed growth was estimated visually on the standing crop at the time of harvest. The area cut for yield was approximately 0.001 acre in size. The alfalfa was cut with a National mower at a height of about 1 1/2 inches.

Green weights were taken in the field, and a sample was saved from each plot for both dry weight determination and chemical analysis. A second sample was taken from several plots at random. These were hand-separated into "alfalfa" and "other species" and dried. These samples served as checks on the visual stand estimates made before each harvest. The harvesting schedule for 1954 and 1955 is shown in Table 3.

Table 3. Schedule of harvests of eight varieties of alfalfa under four fertilizer treatments during 1954 and 1955

Year	Harvest[a]	Period of harvest
1954	P-1	5/18-6/9
	H-1	6/11-6/17
	P-2	6/17-6/28
	H-2	7/7 -7/16
	P-3	7/7 -7/30
	P-4	7/30-9/1
	H-3	8/9 -8/30
	P-5	8/30-9/10
1955	P-1	5/11-5/24
	H-1	5/24-6/1
	P-2	6/11-6/30
	H-2	6/30-7/7
	P-3	6/30-7/18
	P-4	7/15-8/12
	H-3	7/25-8/8
	P-5	8/3 -9/8
	H-4	8/26-9/8
	P-6	9/8 (P_1K_1 Buffalo, only)

[a]P = frequent cutting to simulate pasture conditions.
H = hay cutting.
1, 2, 3, _etc_. = the number of the cutting.

All harvesting was discontinued on September 10, 1954. Therefore, some treatments were clipped four times for pasture, others five. All treatments were harvested three times for hay. An "aftermath" cut was made on all plots during the period October 28 to November 12. Yields were recorded and samples saved for analysis.

Stand observations made on April 14, 1955, after one harvest season, indicated no marked heaving. Some stand depletion was apparent, however, particularly on the P_1K_0 plots.

All plots under the frequent clipping system were cut four times, about 60% of the plots were cut five times and one (Buffalo P_1K_1) was cut six times. The first clipping was made when the plants were 10 inches tall and subsequent clippings were made at 8 inches. All hay plots were harvested at least three times. Samples were saved from each plot at each cutting for both moisture determination and chemical analysis. Cutting was discontinued on September 8, 1955. No aftermath cuttings were taken.

During the interval August 10 to September 20, when the plants had recovered from the last cutting, stand counts were made. Crowns per square foot were counted in each of three 1 square foot quadrats tossed at random along the length of the plot. Thus, for any given plot, three stand counts were made, making a total of 12 counts for any given variety-fertilizer-cutting treatment combination.

Weather Summary

A summary of the weather data covering the test period is presented in Table 4. The weather during the course of this field experiment was rather atypical. During the fall and winter of 1952-1953 there was a marked deficiency in rainfall. Subsoil moisture at the time the experiment was established was probably at a low level. Average temperatures during February and March, 1953, were above normal, but April, 1953, was colder than normal.

Subsequent to planting, the year 1953 was characterized by a rather severe drought. From June until January, precipitation was below normal, with a total deviation from normal of about -11 inches. Freezing temperatures came about October 7, 1953.

In 1954, May was cool and windy. At least two frosts in May checked growth considerably. The last freezing temperature was on May 7, 1954. June and August, 1954, were above average in precipitation. A considerable amount of this rain fell in intensive showers. These showers caused considerable surface wash, and in August, debris was piled around the alfalfa crowns to a depth, in some cases, of 3 inches. This, no doubt, moved some topsoil as well as ferti-

Table 4. Mean monthly temperatures and total monthly precipitation at the Ames weather station during the period September, 1952-November, 1955[a]

		Temperature (°F)		Precipitation (inches)	
Year	Month	Average monthly	Departure from normal	Total	Departure from normal
1952	Sept.	64.2	-0.2	0.19	-4.09
	Oct.	47.0	-5.6	0.03	-2.35
	Nov.	38.1	0.5	2.43	0.92
	Dec.	25.1	0.7	0.91	-0.14
1953	Jan.	22.0	2.1	0.69	-0.18
	Feb.	27.4	4.6	1.47	0.49
	Mar.	37.1	1.2	2.87	1.44
	Apr.[b]	43.9	-5.1	3.04	0.43
	May	60.0	-0.6	1.59	-2.59
	June	72.5	2.5	4.99	0.65
	July	74.5	-0.4	1.77	-1.65
	Aug.	72.5	0.1	2.11	-1.59
	Sept.	64.6	0.2	0.65	-3.63
	Oct.	57.7	5.1	0.27	-2.11
	Nov.	41.0	3.4	1.40	-0.11
	Dec.	29.2	4.8	0.76	-0.29
1954	Jan.	18.4	-1.5	0.17	-0.70
	Feb.	37.1	14.3	1.30	0.32
	Mar.	31.6	-4.3	1.55	0.12
	Apr.	52.8	3.8	2.73	0.12
	May	55.7	-4.9	4.68	0.50
	June	72.6	2.6	7.58	3.24
	July	77.6	2.7	0.69	-2.73
	Aug.	72.3	-0.1	14.67	10.97
	Sept.	66.4	2.0	2.63	-1.65
	Oct.	51.9	-0.7	4.80	2.42

[a]Taken from U. S. Weather Bureau Summary.

[b]Test planted.

Table 4. (Continued)

Year	Month	Temperature (°F) Average monthly	Temperature (°F) Departure from normal	Precipitation (inches) Total	Precipitation (inches) Departure from normal
1954	Nov.	41.5	3.9	0.23	-1.28
	Dec.	28.2	3.8	0.52	-0.53
1955	Jan.	20.0	0.1	0.50	-0.37
	Feb.	21.4	-1.4	1.14	0.16
	Mar.	34.2	-1.7	0.75	-0.68
	Apr.	56.0	7.0	3.76	1.15
	May	63.0	2.4	4.13	-0.05
	June	67.2	-2.8	2.46	-1.88
	July	79.1	4.2	3.83	0.41
	Aug.	76.4	4.0	1.47	-2.23
	Sept.	66.4	2.0	2.31	-1.97
	Oct.	53.1	0.5	0.77	-1.66
	Nov.	30.4	-7.2	0.14	-1.37

lizer from the treated plots. The first freezing temperature in the fall was on October 18, 1954.

The weather until November, 1955, was characterized by higher than normal temperatures and a rainfall deficit of approximately 7 inches. A report issued by the Agronomy Department, Iowa State College, (76) indicated that, at Ames, on Webster soil under permanent meadow, the surface 5 feet of soil contained 4.5 inches of available water in July. By October, this had dropped to 0.4 inches, all at the 4-5 foot level; no available moisture was measurable above this level. In 1955, the last freezing temperature in the spring came on April 8, and the first in the fall on October 15.

Plant Analyses

The plant samples taken from each plot were dried to approximately 4% moisture. After weighing for moisture determinations, they were ground in a Wiley mill and stored for analysis. The first cutting from all plots for both years was analyzed[1] for phosphorus and potassium. This cutting was chosen as being most typical of the stand, on the basis of previous experience. Phosphorus was determined by a colorimetric method, employing a nitric acid-ammonium molybdate-ammonium vanadate solution to develop the color. Potassium was determined in solution by means of the Perkin-Elmer flame photometer.

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[1]Courtesy of Dr. John J. Hanway. Agronomy Department, Iowa State College, Ames, Iowa.

EXPERIMENTAL RESULTS

The results of this study were measured as forage yield, phosphorus and potassium content of the forage and the number of surviving plants at the conclusion of the test. The complete data are presented in the Appendix (Table 69); mean yields are discussed in this section.

Yield Results

A summary of the analysis of variance of the yield data is presented in Table 5. The factorial nature of the fertilizer treatments permitted partitioning those variance terms attributable to fertilizers. Therefore, where possible, terms were partitioned into components for _P_, _K_ and _PK_.[1] Terms assigned as "Error" have been pooled in the instances where Bartlett's test (80) indicated that the partitioned variances were homogeneous.

The mean yields for the replicates are presented in Table 6. All yields are expressed as pure alfalfa, pounds

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[1] _P_, _K_ and _PK_ are symbols for the main effects due to phosphorus fertilization, potassium fertilization and the combined application, respectively. P, K and PK, as used in this paper, are the symbols for phosphorus, potassium and the combination of phosphorus and potassium as nutrient elements.

Table 5. Summary analysis of variance for total yields of alfalfa forage in pounds of dry matter per acre for 1954-1955

Source of variation	d.f.	Mean squares[a]
B (Blocks)	3	85,797,909**
F (Fertilizers)	3	
P	1	73,813,528
K	1	21,613,258
PK	1	2,071,503
Error (a)	9	11,392,501
P x B	3	20,401,468
K x B	3	3,979,973
PK x B	3	9,796,062
V (Varieties)	7	4,456,776**
V x F	21	
P x V	7	1,798,695**
K x V	7	618,736
PK x V	7	376,489
Error (b)[b]	84	536,752
C (Cutting treatments)	1	1,273,039,573**
C x V	7	3,061,593**
C x F	3	
P x C	1	37,523,243
K x C	1	2,878,050
PK x C	1	777,738
C x V x F	21	
P x C x V	7	1,735,263**
K x C x V	7	368,067
PK x C x V	7	619,202
C x B	3	2,901,649
C x F x B	9	
P x C x B	3	3,772,706
K x C x B	3	387,600
PK x C x B	3	91,827
Error (c)[b]	84	331,439

[a]The double asterisk (**) indicates F-test significant at the 1% level.

[b]Pooled sums of squares and degrees of freedom do not differ significantly, as indicated by Bartlett's test (80).

Table 5. (Continued)

Source of variation	d.f.	Mean squares
Y (Years)	1	74,993,740
Y x B (Blocks)	3	1,407,336
Y x F (Fertilizers)	3	
P x Y	1	104,911
K x Y	1	5,022,271
PK x Y	1	4,354,385
Y x V (Varieties)	7	1,562,917**
Y x C (Cutting treatments)	1	274,524,918**
Y x V x F	21	
P x Y x V	7	1,836,845**
K x Y x V	7	820,141**
PK x Y x V	7	1,054,498**
Y x C x V	7	1,888,634**
Y x C x F	3	
P x Y x C	1	3,998,968**
K x Y x C	1	893,868
PK x Y x C	1	14,039
Y x V x B	21	143,376
Y x C x B	3	3,167,978
Y x F x B	9	1,050,978
Residual[d]	176	274,668
Total	510[c]	

[c]One degree of freedom lost through missing plot estimation.

[d]Coefficient of variation 7.3%.

Table 6. Yields of alfalfa forage (four replicates) in pounds of dry matter per acre; average of fertilizers, varieties, cutting treatments and years, 1954-1955[a]

Rep. I	Rep. IV	Rep. II	Rep. III
6045	7302	7356	8003

[a]Solid line joins those means which do not differ significantly, by Duncan's test (20), at the 5% level.

dry matter (4% moisture) per acre per year. The replicate mean yields are averages for fertilizers, varieties, cutting treatments and years and they have been arrayed in order of increasing yield. In order to establish significant differences between these ranked means, Duncan's new multiple range test (20) has been used, and his suggested form of presentation has been followed.

In Table 6, those mean yields which are underscored do not differ significantly from one another at the 5% level, and those means not so indicated are considered significantly different. The data indicate that replicates II, III and IV did not differ significantly from one another but replicate I yielded significantly less than the other three replicates.

The analysis of variance indicates that the mean *P*, *K* and *PK* effects were not significant. However, these data are of interest and, as shown in Table 7, indicate that yield responses to both phosphorus and potassium were established. The relatively high variation from block to block, as indicated by the respective error terms, precluded statistical significance at the 5% level. However, the average response to both P and K approached the 10% level of significance.

The mean yield increase, as shown in Table 7, is a mean of both treatment responses, *i.e.*, the mean yield increase due to phosphorus application is defined as:

Table 7. Mean yields and yield increases in pounds per acre for four fertilizer treatments - average of varieties, cutting systems and years, 1954-1955

Fertilizer treatment	Yield	Main effect	Mean yield increase[a]	Probability[b]
P_0K_0	6655			
P_0K_1	6938	K	410	$.2 > P > .1$
P_1K_0	7287	P	760	$.2 > P > .1$
P_1K_1	7825	PK	128	$> .5$

[a]Mean of increase due to fertilizer treatment as compared to no treatment with the same fertilizer.

[b]Probability that yield increase due to chance.

$$\frac{(P_1K_0) - (P_0K_0) + (P_1K_1) - (P_0K_1)}{2}$$

and has been used as such by some workers (19, 69). It is apparent that the greatest response was obtained where phosphorus was applied. The lack of significant PK interaction is also apparent in these data; the yield responses to P and K alone, if added together, total more than the response to PK. The expected yield response from the PK treatment would be 585 pounds, (760 + 410) ÷ 2, and the obtained response from the combined treatment was only 128 pounds per acre.

Forage yields among the eight varieties differed considerably. These data, shown in Table 8, indicate that

Table 8. Yields of eight alfalfa varieties in pounds of dry matter per acre - average of replicates, fertilizers, cutting systems and years, 1954-1955[a]

Ladak	Grimm	Atlantic	Ranger	Buffalo	A-224	Narragansett	Vernal
6864	6982	7021	7087	7099	7242	7459	7656

[a]Those means underscored do not differ significantly at the 5% level, Duncan's test (20).

Vernal and Narragansett were high-yielding varieties. At the 5% level of significance, Vernal did not differ significantly from Narragansett but did yield more than A-224, Buffalo, Ranger, Atlantic, Grimm and Ladak; Narragansett did not yield significantly more than A-224 but did yield more than Buffalo, Ranger, Atlantic, Grimm and Ladak; A-224 yielded significantly more than Ladak; and the yields of Buffalo, Ranger, Atlantic, Grimm and Ladak did not differ significantly.

The alfalfa varieties differed in their response to P fertilization as shown in Table 9. The data indicate that Buffalo and Grimm responded to a greater extent than Atlantic, Narragansett, Ranger and Vernal. The positive increases for all varieties indicated that the yields were higher when phosphorus was applied than when the plots received no phos-

Table 9. Mean yield and yield increases, in pounds of dry matter per acre, under phosphorus fertilizer applied to eight varieties of alfalfa - average of replicates, cutting systems and years, 1954-1955

Variety	Mean increase due to P	Mean yield
Atlantic	559	7021
A-224	843	7242
Buffalo	1233	7099
Grimm	1199	6982
Ladak	898	6864
Narragansett	362	7459
Ranger	490	7087
Vernal	490	7656
Standard error	130	92

phorus. The variety mean yields may be used to establish the yield-level at which the mean increases, due to P, are applicable. For example, Atlantic ranged in yield from 7301 pounds per acre, (7021 + 1/2 559), to 6742 pounds per acre, (7021 - 1/2 559). With the indicated standard errors, the significance of the differences between means may be evaluated. The rule of thumb is that a quantity is significant at the 5% level if it is twice its standard error; and the difference between two means with the same standard error is significant if it is greater than three times that standard error. Thus, all the mean increases, with the exception of Narragansett, were significant at the 5% level, and the difference between the mean increase of Narragansett and that of A-224 was significant. It is apparent that Vernal was relatively high-yielding, regardless of treatment, and Ladak was comparatively poor-yielding, despite fertilization.

The two cutting systems used in this study, one, cutting for hay, the other, clipping frequently to simulate grazing, resulted in markedly different yields, as shown in Table 10.

Table 10. Yields of alfalfa in pounds of dry matter per acre under two cutting systems - average of varieties, replicates and fertilizer treatments for the two-year period, 1954-1955

Cutting treatment	Yield
Hay	8753
Frequent clipping	5599

Under frequent cutting, with top growth removed when the plants reached a height of 8 inches, the plants were unable to produce the quantity of dry matter essential to high yields.

The interaction between cutting systems and varieties was highly significant. The reasons for this are apparent in the data presented in Table 11. As these data indicate, all varieties yielded more when cut for hay than they did when cut frequently. However, the change in rank within these two cutting systems is the feature which contributes to the interaction. Under the hay system, at the 5% level of significance, Vernal, Buffalo and Narragansett did not differ significantly in yield; when clipped frequently, Vernal and Narragansett were again high, but Buffalo yielded the lowest absolute value in the test. When cut for hay, the yields of Buffalo, Narragansett, Ranger and Atlantic did not differ significantly, but under frequent cutting, Narragansett yielded significantly more than Ranger, Atlantic or Buffalo. A-224, Grimm and Ladak did not differ significantly when cut for hay, but when clipped frequently, A-224 was significantly higher-yielding than either Grimm or Ladak.

Although not statistically significant, the interaction between cutting treatments and fertilizers is of interest. These mean yield increases, shown in Table 12, indicate that, when clipped frequently to simulate pasture, the effects _P_ and _K_ were not markedly different, but when cut for hay, the response to _P_ is considerably greater than that for potassium. In all cases, the probability is very close to the 5% level; _i.e._, the difference in response of the hay treatment, com-

Table 11. Yields of alfalfa varieties in pounds of dry matter per acre when cut for hay and when cut frequently - average of fertilizers, replicates and years, 1954-1955

Cutting treatment	Variety	Yield	Significant intervals[a]
Hay	Vernal	9199	
	Buffalo	9044	
	Narragansett	8856	
	Ranger	8822	
	Atlantic	8776	
	A-224	8514	
	Grimm	8470	
	Ladak	8345	
Frequent clipping	Vernal	6114	
	Narragansett	6061	
	A-224	5969	
	Grimm	5494	
	Ladak	5384	
	Ranger	5352	
	Atlantic	5267	
	Buffalo	5155	

[a]Solid line connects those means which do not differ significantly at the 5% level, Duncan's test (20).

Table 12. Mean forage yield increases in pounds of dry matter per acre obtained under two cutting systems, due to the main fertilizer effects, P, K and PK - average of replicates, varieties and years, 1954-1955

Treatment	Hay	Frequent clipping	Probability[a]
P	1301	218	$.1 > P > .05$
K	561	261	$.1 > P > .05$
PK	205	49	$.1 > P > .05$

[a]Probability that a given increase is due to chance.

pared to that of the plots cut frequently, is close to significance.

The second-order interaction, P x Varieties x Cutting Treatment, was significant at the 1% level. The mean yield increases for this term are presented in Table 13. The significance of this interaction indicates that the varieties responded differently to P fertilization when they were cut for hay than when they were clipped frequently. This is particularly true in the instances of Atlantic, Narragansett, Ranger and Vernal when clipped frequently; these varieties yielded less when fertilized than when no P was added. When cut for hay, all varieties yielded more when fertilized than when no phosphorus was used. Both Buffalo and Vernal responded to phosphorus when cut for hay, but when clipped on

Table 13. Mean yield increases, in pounds of dry matter per acre, for eight alfalfa varieties, when cut for hay and when clipped frequently, under phosphorus fertilizer - average of replicates and years, 1954-1955.

Variety	Cut for hay		Clipped frequently	
	Mean increase due to *P*	Mean yield	Mean increase due to *P*	Mean yield
Atlantic	1213	8776	-94	5267
A-224	1411	8514	275	5969
Buffalo	1506	9044	960	5155
Grimm	1338	8470	1061	5494
Ladak	1104	8345	693	5384
Narragansett	1272	8856	-548	6061
Ranger	1019	8822	-39	5352
Vernal	1544	9199	-564	6114
Standard error	144	102	144	102

a height basis, Buffalo responded markedly, and the yield of Vernal was depressed. A-224, Buffalo and Vernal responded to a significantly greater extent than Ranger, under the hay system; and the wide difference between Grimm and those varieties which had yield depressed when cut frequently is significant. All varieties cut for hay yielded significantly more than when clipped frequently.

The environmental differences between the two years, 1954 and 1955, were marked, and this was reflected in the yields. The average yield in 1954 was 7559 pounds per acre, for all fertilizers, replicates, varieties and cutting treatments, and the average in 1955 decreased to 6794 pounds per acre. Because the plot arrangement was not changed from year to year, no valid term exists against which the variance-source "Years" might be tested. However, this difference is an apparent one, reflected in most of the variance terms which involved "Years". An example is the difference in effect of fertilization from year to year, as shown in Table 14. With regard to P, the relative yields changed but little, but under K fertilizer the response was considerably greater in

Table 14. Yields of alfalfa, in pounds of dry matter per acre, for four fertilizer treatments and the mean yield increases due to the main fertilizer effects, P, K and PK - average of varieties, replicates and cutting systems

Fertilizer treatment	Yield 1954	Yield 1955	Main effect	Mean yield increase 1954	Mean yield increase 1955	Probability[a]
P_0K_0	7059	6251				
P_0K_1	7329	6548	K	213	609	$.1 > P > .05$
P_1K_0	7846	6727	P	730	788	$> .5$
P_1K_1	8002	7648	PK	-57	312	$.1 > P > .05$

[a]Probability that a given difference between years is due to chance.

1955 than in 1954. This difference approaches the 5% level of significance. And the reversal in effect of the combined treatment, PK, is apparent; from a yield depression in 1954 to a small increase in 1955.

The variety ranking changed from year to year as illustrated by the data in Table 15. It is apparent that Vernal, in 1954, yielded more than any other variety in either year. In 1954, A-224, Narragansett and Grimm did not differ significantly in yield, but in 1955, Narragansett yielded significantly more than A-224, which in turn yielded more than Grimm. Ladak also decreased relatively more in 1955, as compared to 1954, than did Narragansett or Grimm.

The changes in yield from year to year under the two systems of cutting were marked. These yields are shown in Table 16. The relatively greater decrease in the second-year yield under the frequent clipping system is obvious, but when cut for hay, the yields were better in the second season. The hay yields were significantly higher than simulated pasture yields in both years.

The response of the alfalfa varieties to P fertilizer changed from year to year as shown in Table 17. The increase in the response of Buffalo from 1954 to 1955 is apparent, and conversely, the decrease in response of Narragansett is marked. Atlantic, Ranger and Vernal also responded less to P fertilization in 1955 than they did in 1954. The tendency of all

Table 15. Forage yields, in pounds per acre, of eight alfalfa varieties in 1954 and 1955 - average of fertilizers, replicates and cutting treatments

Year	Variety	Yield	Significant intervals[a]				
1954	Vernal	8017					
	A-224	7736	x				
	Narragansett	7670	x	x			
	Grimm	7523	x	x	x		
	Ladak	7492		x	x		
	Ranger	7412			x	x	
	Atlantic	7324			x	x	
	Buffalo	7298			x	x	
1955	Vernal	7295			x	x	
	Narragansett	7248				x	
	Buffalo	6900					x
	Ranger	6762					x
	A-224	6748					x
	Atlantic	6719					x
	Grimm	6441					
	Ladak	6236					

[a]Solid line connects those yields which do not differ significantly at the 5% level, Duncan's test (20).

Table 16. Yields of alfalfa, in pounds dry matter per acre, under two cutting systems, in 1954 and 1955 - average of fertilizers, varieties and replicates[a]

Frequent clipping		Hay	
1955	1954	1954	1955
4484	6714	8404	9103

[a]Line connects those means which do not differ significantly at the 5% level, Duncan's test (20).

Table 17. Mean yield and yield response, in pounds per acre, of eight alfalfa varieties to phosphorus fertilizer in 1954 and 1955 - average of replicates and cutting systems

Variety	Mean P response		Mean yield	
	1954	1955	1954	1955
Atlantic	823	295	7324	6719
A-224	628	1059	7736	6748
Buffalo	634	1832	7298	6900
Grimm	1037	1362	7523	6441
Ladak	641	1156	7492	6236
Narragansett	772	-49	7670	7248
Ranger	755	226	7412	6762
Vernal	556	424	8017	7295
Standard error	126		90	

1954 yields to be higher than those of 1955 is not significant, except in the cases of the extremes; Vernal in 1954 was higher-yielding than any other variety, under any treatment, in either year, and Ladak and Grimm, in 1955, were considerably lower-ranking than the other varieties, in either year.

The response of the alfalfa varieties to K fertilization also varied from year to year. These mean responses are presented in Table 18. As was the case under P fertilizer, Buffalo increased markedly in response from 1954 to 1955.

Table 18. Mean yield and yield increase, in pounds of dry matter per acre, of eight alfalfa varieties to potassium fertilizer in 1954 and 1955 - average of replicates and cutting treatments

Variety	Mean K response		Mean yield	
	1954	1955	1954	1955
Atlantic	457	460	7324	6719
A-224	239	419	7736	6748
Buffalo	122	1390	7298	6900
Grimm	85	497	7523	6441
Ladak	28	382	7492	6236
Narragansett	478	659	7670	7248
Ranger	217	142	7412	6762
Vernal	76	924	8017	7295
Standard error	126		90	

The data in Table 15 indicated that, relative to 1954, Buffalo increased in rank considerably in 1955. Undoubtedly, the increases in forage yield, under P and K fertilizer, are responsible for this alteration of rank. Ranger alfalfa decreased in yield under K fertilizer in 1955, relative to 1954; this variety is the only one which had a lower mean response in 1955. Vernal, although relatively high-yielding in both years, responded considerably more to K fertilizer in 1955 than in 1954. As was true of the response to phosphorus, the tendency of 1955 mean responses to be higher than those of 1954 is apparent. However, the difference is not a significant one.

In response to the combined, PK, treatment, the varieties were markedly different in the yearly response. These data are shown in Table 19. In 1954, five varieties yielded less when fertilized with phosphorus and potassium as compared to phosphorus alone. In 1955, only one variety, Ladak, showed this tendency. In 1954, therefore, the effect of potassium on P-fertilized plots was a depressing one, in general; in 1955, the effect became an ameliorating one.

The varieties also varied in their response to cutting treatment in 1954, as compared to 1955. These data are presented in Table 20. All varieties, in both years, when cut for hay ranked significantly higher than when clipped frequently. Within the hay yields, the 1954 yields tended to be

Table 19. Mean yield response, in pounds of dry matter per acre, of eight alfalfa varieties to combined phosphorus and potassium fertilization, in 1954 and 1955 - average of replicates and cutting systems

Variety	Mean increase[a]			
	1954		1955	
	$\underline{P}k_0$	$\underline{P}k_1$	$\underline{P}k_0$	$\underline{P}k_1$
Atlantic	813	833	-247	837
A-224	635	620	758	1359
Buffalo	283	984	1572	2091
Grimm	1269	805	1034	1689
Ladak	543	739	1447	864
Narragansett	1031	513	-330	234
Ranger	1118	393	-740	1191
Vernal	611	501	316	531
Standard error	126		126	

[a]The magnitude and direction of response would be the same if considered as $\underline{K}p_0$ and $\underline{K}p_1$.

lower than those of 1955; Vernal, 1954, is the exception. With the exception of A-224 and Ladak, the 1955 yields of hay for any given variety were significantly higher than the 1954 yields for that variety. When cut frequently, 1954 yields of all varieties were significantly higher than the 1955 yields. The ranking of the simulated pasture yields changed markedly

Table 20. Yields of eight alfalfa varieties, in pounds per acre, cut for hay and clipped frequently, in 1954 and 1955 - average of fertilizers and replicates

Year	Variety	Yield	Significant intervals[a]
	Cut for hay		
1955	Buffalo	9507	
"	Vernal	9447	
"	Ranger	9428	
"	Narragansett	9388	
"	Atlantic	9232	
"	Grimm	8955	
1954	Vernal	8950	
1955	A-224	8631	
1954	Buffalo	8580	
"	Ladak	8454	
"	A-224	8398	
"	Narragansett	8325	
"	Atlantic	8320	
1955	Ladak	8234	
1954	Ranger	8217	
"	Grimm	7985	

[a]The solid line connects mean yields which do not differ significantly at the 5% level, Duncan's test (20).

Table 20. (Continued)

Year	Variety	Yield	Significant intervals[a]
	Clipped frequently		
1954	Vernal	7084	
"	A-224	7074	
"	Grimm	7060	
"	Narragansett	7014	
"	Ranger	6607	
"	Ladak	6530	
"	Atlantic	6328	
"	Buffalo	6017	
1955	Vernal	5143	
"	Narragansett	5108	
"	A-224	4864	
"	Buffalo	4292	
"	Ladak	4237	
"	Atlantic	4206	
"	Ranger	4098	
"	Grimm	3928	

from 1954 to 1955. Vernal, A-224 and Narragansett tended to yield well in both years, but Grimm, which yielded well in 1954, was the lowest-yielding variety in 1955. Buffalo, which ranked among the lower-yielding varieties in 1954, was above the median-yielding varieties in 1955.

Phosphorus fertilization altered the yields of alfalfa under the two cutting systems in 1955, as compared to 1954. These data are shown in Table 21. It is apparent that a

Table 21. Mean response of alfalfa, in pounds per acre, to phosphorus fertilizer, when cut as hay, in 1954 and 1955 - average of varieties and replicates

1954		1955	
Hay	Cut frequently	Hay	Cut frequently
1095	366	1506	70
Standard error 63			

considerable part of the response noted for P fertilizer in both years, was due to the hay cutting system. In 1954, the frequently-clipped plots responded significantly to P fertilization, but in 1955 the response was not as great. The opposite trend is apparent when hay yields are considered. The 1954 response, under the hay system, was significantly lower than that of 1955.

Though the differences are not significant, the data for potassium fertilization for each cutting system, in 1954 and 1955, are presented in Table 22 for comparison. It is apparent that K was becoming more limiting in 1955 than in

Table 22. Mean response of alfalfa, in pounds per acre, to potassium fertilizer under hay cutting system in 1954 and 1955 - average of varieties and replicates

1954		1955	
Hay	Cut frequently	Hay	Cut frequently
279	146	842	375

1954. When cut for hay, with consequent greater drain on the soil nutrient supply, the response to K fertilizer, in 1955, was marked. A similar trend is noted in the 1955 yields of those plots clipped frequently. Under both cutting systems, in 1954, the mean increase to K fertilization was considerably more limited.

Plant Analysis Results

Phosphorus analysis

The forage from the first cutting on each plot in the years 1954 and 1955 was analyzed for phosphorus content. The results of these analyses are presented in complete form in the Appendix (Table 70). A summary of the analysis of variance for these data is shown in Table 23.

The phosphorus content of the alfalfa forage from the four replicates differed significantly, as indicated in Tables 23 and 24. The replicates ranked in the same order for phosphorus content as they did for average yields (Table 6), and replicate I was significantly lower than replicates IV, II and III in terms of per cent phosphorus, as it was in forage yield. The data indicate that replicate III was significantly higher than replicates I, IV and II in per cent P and replicates II and IV did not differ in phosphorus content, but both were higher than replicate I. The critical level proposed by Bear and Wallace (6) was 0.27% phosphorus. These authors defined this critical percentage as that below which a yield response could be expected, and above which no response might be anticipated. The average per cent P in this study, as indicated in Table 24, was .243, indicating that this element might be considered a limiting factor.

When fertilized with P, the per cent phosphorus in the alfalfa forage was increased considerably. The data, shown in Table 25, indicate that the mean response, in phosphorus content, was .062% when P fertilizer was used. The average P content without fertilization was considerably below the

Table 23. Summary analysis of variance for per cent phosphorus of first-cutting alfalfa forage for 1954-1955

Source of variation	d.f.	Mean squares[a]
B (Blocks)	3	.041057*
F (Fertilizers)	3	
P[b]	1	.493894*
K	1	.001219
PK	1	.001755
Error (a)[c]	9	.009064
V (Varieties)	7	.003045**
V x F	21	
P x V	7	.000548
K x V	7	.000942*
PK x V	7	.000835
V x B	21	.000116
Error (b)	63	
P x V x B	21	.000770
K x V x B	21	.000272
PK x V x B	21	.000588
C (Cutting treatments)	1	.112753*
C x F	3	
P x C	1	.001624
K x C	1	.003719*
PK x C	1	.001372
C x V	7	.000773
C x V x F	21	
P x C x V	7	.000177
K x C x V	7	.000518
PK x C x V	7	.000625
C x B	3	.003750
Error (c)[c]	93	.000613
Y (Years)	1	.254719
Y x B	3	.000858

[a]The single (*) and double (**) asterisks indicate F-tests significant at the 5% and 1% levels, respectively.

[b]*P*, *K* and *PK* are symbols for the main effects due to phosphorus fertilizer, potassium fertilizer and the combined application, respectively.

[c]Pooled error terms and degrees of freedom do not differ significantly, Bartlett's test (80).

Table 23. (Continued)

Source of variation	d.f.	Mean squares
Y x F (Fertilizers)	3	
P x Y	1	.001807*
K x Y	1	.000794
PK x Y	1	.000072
Y x F x B (Blocks)[c]	9	.000201
Y x V (Varieties)	7	.000901
Y x V x B	21	.000392
Y x V x F	21	
P x Y x V	7	.000349
K x Y x V	7	.000699**
PK x Y x V	7	.000376
Y x V x F x B	63	
P x V x Y x B	21	.000278
K x V x Y x B	21	.000049
PK x V x Y x B	21	.000187
Y x C (Cutting treatments)	1	.101870**
Y x C x F	3	
P x Y x C	1	.000059
K x Y x C	1	.000832
PK x Y x C	1	.004687*
Y x C x V	7	.000867
Residual[d]	117	.001059
Total	511	

[c]Pooled error terms and degrees of freedom do not differ significantly, Bartlett's test (80).

[d]Coefficient of variation 13.4%.

Table 24. Per cent phosphorus in dried, first-cutting alfalfa from each of four replicates - average of fertilizers, varieties, cutting treatments and the years 1954-1955[a]

Rep. I	Rep. IV	Rep. II	Rep. III
.220	.243	.244	.264

[a]Means underscored do not differ significantly at the 5% level, Duncan's test (20).

Table 25. Mean per cent phosphorus in alfalfa forage and percentage-point increases for four fertilizer treatments - average of replicates, varieties, cutting systems and years, 1954-1955

Fertilizer treatment	Per cent P	Main effect	Mean per cent increase[a]
P_0K_0	.215		
P_0K_1	.208	K	-.003
P_1K_0	.274	P	.062*
P_1K_1	.274	PK	.004

[a]Mean of increase due to fertilizer treatment as compared to no treatment with that same fertilizer.

*Significant at the 5% level.

critical percentage, and when phosphorus was applied, was slightly above the critical percentage. The data also indicate that K fertilization tended to depress the phosphorus content. The mean increase was significant only under the P main effect.

The alfalfa varieties differed considerably in phosphorus content as shown in Table 26, Narragansett being higher than any other variety. Ladak and A-224 did not differ in P content but were significantly higher than Grimm, Buffalo, Ranger, Atlantic and Vernal. Atlantic, Ranger, Buffalo and Grimm did not differ in per cent P, but Grimm

Table 26. Mean phosphorus content, in per cent, of eight alfalfa varieties, first-cutting forage - average of fertilizers, replicates, cutting treatments and years, 1954-1955[a]

Vernal	Atlantic	Ranger	Buffalo	Grimm	Ladak	A-224	Narragansett
.234	.238	.238	.238	.242	.249	.249	.254

[a]Means underscored do not differ significantly at the 5% level, Duncan's test (20).

was significantly higher than Vernal. The phosphorus contents of Vernal, Atlantic, Ranger and Buffalo did not differ significantly.

When fertilized with potassium, a differential effect on the phosphorus content of the forage of the eight varieties was observed. As presented in Table 27, the average effect of K treatment was to decrease the phosphorus content. The varieties Ladak and A-224, which had the same average P content, responded similarly under K fertilization; a slight depression in per cent phosphorus is evident. Atlantic, Ranger and Buffalo, with the same phosphorus content, responded quite differently when fertilized with potassium. This change in response, particularly with respect to Atlantic and Buffalo, was the major factor in this interaction.

Table 27. Per cent phosphorus in eight alfalfa varieties and mean effect on phosphorus content under potassium fertilization - average of replicates, cutting treatments and years, 1954-1955

Variety	Mean effect of K on per cent P	Mean per cent P
Atlantic	-.010	.238
A-224	-.001	.249
Buffalo	.014	.238
Grimm	-.006	.242
Ladak	-.002	.249
Narragansett	-.007	.254
Ranger	-.006	.238
Vernal	-.007	.234
Standard error	.004	

Buffalo alfalfa was unique in that forage from plots fertilized with K also showed an increase in phosphorus content. This increase was significant at the 5% level. Atlantic, when fertilized with K, was depressed in per cent P to a significant degree.

When cut frequently, to simulate pasture conditions, the forage was significantly higher in per cent P than when cut for hay. The average per cent P in alfalfa hay was .228, and the frequently-cut forage contained an average of .258% phosphorus. The main effects of the fertilizer treatments, P, K and PK, were different under the two cutting systems as shown in Table 28. Of these, only the effect of potassium

Table 28. Mean effects of the main fertilizer treatments, P, K and PK, expressed as percentage-points of average phosphorus content, in alfalfa cut under two different systems - average of varieties, replicates and the years, 1954-1955

Main effect	Hay	Cut frequently	Probability[a]
P	.058	.066	$.2 > P > .1$
K	-.008	.002	$.05 > P > .01$
PK	.000	.007	$.2 > P > .1$

[a]Probability that increase due to chance.

was significant. It is apparent that the depressing effect of K fertilization upon phosphorus content was confined to the hay forage. When clipped frequently, topdressing with K resulted in an increase in the per cent of P in the alfalfa. The difference in effects, P and PK, though not significant, indicates that the frequently-cut alfalfa was higher in P, when fertilized with either P alone or P and K, than was the hay.

It is not valid to test the "Years" term against its "error variance", but the difference in phosphorus content of the first-cutting forage between the two years was considerable. In 1954, the average content was .265% P; in 1955, the percentage dropped to .221. These average percentages are indicated in the data shown in Table 29. Both

Table 29. Per cent phosphorus and mean response to phosphorus and potassium treatments in 1954 and 1955 - average of varieties, replicates and cutting treatments

Year	Per cent P	Mean increase for main effect P	Mean increase for main effect K
1954	.265	.058	-.000
1955	.221	.066	-.006
Probability[a]		.05 > P > .01	.1 > P > .05

[a]Probability that an increase due to chance alone.

P and K fertilization had some effect on the per cent phosphorus in the forage in either year. The change in mean response, under the main effect <u>P</u>, was a significant one; the effect <u>K</u> approached significance. It is apparent that, in 1955, under P fertilizer the percentage of phosphorus in the forage did not equal the critical percentage of .27%. In 1954, the P-fertilized plots were well above this critical point. When fertilized with K, the phosphorus content of the forage, in 1954, decreased to a slight degree. In 1955, this tendency was more marked.

Potassium fertilization affected the P content of the varieties to a different degree in 1954 than in 1955. These data are shown in Table 30. The mean decrease in phosphorus percentage under K fertilization was, in most cases, consistent in both 1954 and 1955. A-224 and Vernal, however, changed from an increase in phosphorus content, under K ferti-

Table 30. Mean phosphorus content of eight alfalfa varieties, and mean effect of phosphorus content, of potassium fertilization in the years 1954 and 1955 - average of replicates and cutting treatments

Variety	Mean treatment effect in per cent P		Varietal mean P per cent	
	1954	1955	1954	1955
Atlantic	-.012	-.007	.258	.218
A-224	.006	-.007	.279	.220
Buffalo	.021	.008	.262	.215
Grimm	-.003	-.008	.266	.218
Ladak	-.002	-.002	.269	.229
Narragansett	-.017	.002	.274	.233
Ranger	-.001	-.012	.260	.216
Vernal	.004	-.018	.252	.217
Standard error	.002			

lization in 1954, to a decreased content in 1955. Both Atlantic and Narragansett showed less decrease in 1955 than in 1954. Buffalo consistently had a higher P content when fertilized with potassium than when no K was applied.

The average P content of the forage from the two cutting systems varied from year to year. These data, shown in Table 31, indicate that in 1954 there was little difference in P

Table 31. Mean per cent phosphorus in dried, first-cutting alfalfa forage as affected by cutting treatments in the years 1954 and 1955 - average of fertilizers, replicates and varieties

Cutting treatment	Year 1954	1955
Hay	.264	.192
Clipped frequently	.266	.250
Standard error	.003	

content between hay and the forage from the frequently-cut plots; in 1955, this difference was considerably greater. The first cutting in 1954 on the frequently-cut plots was taken when the average plant height was 12 inches, and in 1955, these plots were cut at an average height of 10 inches. This fact may explain part of the difference shown in Table 31.

The effect of K fertilization on the phosphorus content of the forage varied for the two cutting systems in 1954 and 1955. As shown in Table 32, the forage from the frequently-cut plots was affected to the same degree in both years. The

Table 32. Mean effect of potassium fertilization on the phosphorus content of the forage of two cutting systems in 1954 and 1955 - average of alfalfa varieties and replicates

Cutting treatment	1954	1955
	(%)	(%)
Hay	-.003	-.013
Cut frequently	.002	.002
Probability[a]	.2 > P > .1	

[a]Probability that mean effect due to chance.

hay-cut forage, in 1954, when fertilized with K, had a decreased phosphorus content, as compared to the increased P content in the material from the frequently-cut plots. In 1955, this decrease was considerably larger.

When both P and K were applied, the phosphorus percentage of the forage, under the two cutting systems was affected differently in each year. This significant difference, presented in Table 33, is apparent in the reversal in mean effect on the hay-cut forage, as compared to that cut more fre-

Table 33. Mean effect of the combined phosphorus-potassium application on the phosphorus content of first-cutting alfalfa forage under two cutting systems in 1954 and 1955 - average of replicates and varieties

Cutting treatment	1954	1955
	(%)	(%)
Hay	.006	-.005
Cut frequently	.000	.014
Standard error	.006	

quently. In 1954, the mean effect of the combined PK treatment was an increase in the phosphorus content of the forage cut for hay and no apparent change in the frequently-clipped material. In 1955, this tendency was markedly reversed. The frequently-cut forage had a higher average P content under the combined fertilizer treatment, but the P content of the hay was decreased to a considerable degree. The difference between the phosphorus effects on the two cutting systems, in 1954, was not significant; the difference in 1955 was a significant one.

Phosphorus analysis of selected varieties

Because Vernal was a high-yielding variety but had a relatively low phosphorus content in 1954, it seemed desirable

Vernal

to investigate further the comparative phosphorus status of several varieties. Vernal, Buffalo and Grimm were chosen because they are well adapted to Iowa conditions and represent a range in type and yield. The three hay cuttings, and the three frequent-clippings which were cut at approximately the same time as the hay cuttings, were analyzed for P; these are referred to as "Samples" in the following section. All replicates of each variety-fertilizer treatment were analyzed. The data are shown in the Appendix (Table 71), and a summary of the analysis of variance of these data is shown in Table 34.

The analysis of variance of the chemical composition data indicated that the P content of the three varieties varied with P fertilization. The average phosphorus content of these varieties for the season, based on the cuttings analyzed, was .269%. The average response under P fertilization was .048%. The phosphorus content of the forage from the four replicates differed considerably and ranked in the same order as the forage yields and P content of the first-cutting forage. Replicate I was significantly lower than replicates IV, II and III, and the latter three were not significantly different.

The three varieties differed in their mean P content. Buffalo contained an average of .262% P for the season, Vernal contained .270 and Grimm .276% P for the samples selected; each of these means is significantly different from the others.

Table 34. Summary analysis of variance for per cent phosphorus in the forage of three alfalfa varieties, for three selected cuttings in 1954

Source of variation	d.f.	Mean squares[a]
B (Blocks)	3	.022475*
F (Fertilizers)	3	
P[b]	1	.164738*
K	1	.000042
PK	1	.000847
Error (a)	9	
P x B	3	.014920
K x B	3	.000919
PK x B	3	.000771
V (Varieties)	2	.005118*
V x F[c]	6	.001462
Error (b)[c]	24	.001037
C (Cutting treatments)	1	.012377**
C x F	3	
P x C	1	.001184**
K x C	1	.003055**
PK x C	1	.000679*
C x V	2	.001507**
C x V x F	6	
P x C x V	2	.002815**
K x C x V	2	.000466
PK x C x V	2	.000667*
Error (c)	36	.000143

[a]The asterisk (*) and double asterisk (**) indicate F-tests significant at the 5% and 1% levels, respectively.

[b]P, K and PK are the symbols for the main effects due to phosphorus fertilization, potassium fertilization and the combined application of phosphorus and potassium, respectively.

[c]Pooled mean squares and degrees of freedom do not differ significantly, Bartlett's test (80).

Table 34. (Continued)

Source of variation	d.f.	Mean squares[a]
S (Samples)	2	.008544**
S x F (Fertilizers)	6	
P x S	2	.004996**
K x S	2	.001425**
PK x S	2	.000516
S x V (Varieties)	4	.003718**
S x C (Cutting treatments)	2	.004515**
S x F x V[c]	12	.000496
S x F x C	6	
P x S x C	2	.003358**
K x S x C	2	.002680**
PK x S x C	2	.000580
S x V x C	4	.003544**
Residual[e]	153	.000246
Total	284[d]	

[c]Pooled mean squares and degrees of freedom do not differ significantly, Bartlett's test (80).

[d]Three degrees of freedom lost through missing-plot estimation.

[e]Coefficient of variation 5.8%.

The variety means for the first cutting in 1954, as shown in Table 30, were Buffalo .262, Vernal .252 and Grimm .276% phosphorus. It is apparent that, for the seasonal average percentage, Vernal recovered enough phosphorus in subsequent cuttings, to markedly raise its ranking as of the first cutting. Grimm maintained its top-ranking position; Buffalo decreased in relative rank though its mean P percentage was the same as that in the first-cutting analysis.

The interaction, varieties and fertilizers, was not significant for the seasonal total per cent phosphorus. In the first-cutting analysis, Buffalo, under K fertilization, had an increased phosphorus content, and the other varieties had decreased percentages of P when fertilized with potassium (Table 27). In 1954 (Table 30), both Buffalo and Vernal, when fertilized with K, had higher phosphorus contents than when no K was used, but Grimm had a slightly lower content.

The cutting treatments, hay and frequent clipping, differed significantly in average P content for 1954. The forage cut as hay averaged .263% P, and that cut frequently had an average of .276%. The interaction of fertilizers and cutting treatments was highly significant. The mean response, under P fertilization, when cut for hay was .052%, and when cut frequently was .044%. Phosphorus fertilization raised the average P content of the forage under either cutting system.

When fertilized with K, the phosphorus content of the forage was affected to a significant degree. The mean response for the forage cut as hay was -.006 and for that cut frequently was .003. The hay, when fertilized with K, had a decreased phosphorus uptake, but the forage cut more frequently increased in P content when fertilized with potassium.

When both P and K were applied, the phosphorus content was affected in both the hay and frequently-cut forage. This interaction is shown in the data of Table 35. It is apparent that the addition of K to P-fertilized plots had no effect

Table 35. Phosphorus percentage of alfalfa under combined phosphorus and potassium fertilization as affected by cutting treatment in 1954 - average of replicates, varieties and samples

	Mean effect in	
	Hay	Frequently-cut
$\underline{P}$ at k_0	.052	.037
$\underline{P}$ at k_1	.052	.050
Standard error	.001	

when those plots were cut for hay, but when clipped frequently the addition of K increased the phosphorus content to a significant degree.

The varieties varied in the P content with different cutting treatments. The percentage of P in Grimm did not differ under either cutting system, but both Vernal and Buffalo had a significantly higher P content when cut frequently than when cut for hay. These data are presented in Table 36.

The varieties varied in their phosphorus contents under P fertilization, when cut for hay or clipped frequently. These data, in Table 37, indicate that P fertilizer did not markedly affect the phosphorus content of the varieties when cut for hay, but that under frequent cutting, the mean effect of P fertilization was marked. The increase was greatest on

Table 36. Phosphorus content of three alfalfa varieties as influenced by cutting treatment in 1954 - average of replicates, fertilizers and samples[a]

Hay			Cut frequently		
Buffalo	Vernal	Grimm	Buffalo	Vernal	Grimm
(%)	(%)	(%)	(%)	(%)	(%)
.251	.264	.272	.273	.277	.279

[a]The means connected with a solid line do not differ significantly, Duncan's test (20).

Table 37. Influence of phosphorus fertilization on phosphorus percentage of three alfalfa varieties, under different cutting systems in 1954 - average of replicates and samples

Variety	Mean effect under Hay	Mean effect under Frequently-cut
	(%)	(%)
Buffalo	.050	.060
Vernal	.053	.020
Grimm	.053	.050
Standard error	.002	

Buffalo, which had a mean content of .272 per cent P, and least on Vernal, mean content .277, when cut for pasture. Grimm, under frequent clipping, showed an intermediate increase and had a mean P percentage of .279. The mean contents are fairly similar, but the ability to utilize applied P is, apparently, quite different. The tendency of Buffalo to respond markedly to fertilization was apparent throughout the test.

The uptake of phosphorus in the three varieties was affected by combined PK fertilization to a different degree with the two cutting systems. This difference is illustrated by the data in Table 38. Vernal, cut for hay, was not affected

Table 38. Influence of PK fertilizer on phosphorus uptake of three varieties when cut for hay or clipped frequently in 1954 - average of replicates and samples

	Hay: Mean effect of		Frequent cutting: Mean effect of	
	P_{K_0}	P_{K_1}	P_{K_0}	P_{K_1}
	(%)	(%)	(%)	(%)
Vernal	.054	.052	.007	.035
Buffalo	.030	.041	.058	.062
Grimm	.044	.063	.046	.054
Standard error			.002	

whether K was added or not. Buffalo and Grimm, however, had significantly increased phosphorus contents when PK was applied to the hay plots. When cut frequently, Vernal and Grimm contained higher percentages of phosphorus when both P and K were applied, but Buffalo did not respond to a significant degree. Thus, not only do the varieties differ in their abilities to use applied fertilizer, but also they vary in the degree to which uptake may be influenced by the addition of other nutrients.

The three samplings across the season - H-1 and P-1, H-2 and P-3, and H-3 and P-4 - differed in their phosphorus content. The first sampling, H-1 and P-1, averaged .260% phosphorus, the second, H-2 and P-3, averaged .279% and the third, H-3 and P-4, contained an average of .269% phosphorus.

The uptake of phosphorus by the three samples was affected by P fertilization. The mean increase in P content, for the first sample was .059; for the second sampling it was .053; and for the third, the average increase under P fertilization was .032 (standard error .003). This decreasing influence with advance in season may have been due to exhaustion of the available phosphorus.

Potassium also influenced the P uptake of the three samples to a differing degree. The increase, under K fertilization, in the first sampling group was .013; in the second, the average increase was -.002; and the average increase in the third sampling was -.008. It might be postulated that, with phosphorus availability decreasing, K had a greater effect on suppressing the uptake of that phosphorus.

The varieties differed in the per cent P in the forage within the different sampling groups. This was to be expected if Vernal overtook Buffalo in seasonal total per cent phosphorus. The data, in Table 39, show that, within the first sampling group, Grimm and Buffalo were higher than Vernal; within the second sample, Grimm had a higher average P percentage than Buffalo; and, within the third sampling, both Grimm and Vernal were significantly higher in P percentage than Buffalo. Vernal increased in average per cent P with

Table 39. Mean phosphorus content of successive samples of alfalfa varieties in 1954 - average of fertilizers, replicates and cutting treatments

Cutting (Sampling)	Variety	Mean per cent P	Significant intervals[a]
H-2(P-3)	Grimm	.285	
H-3(P-4)	Vernal	.281	
H-2(P-3)	Vernal	.278	
H-3(P-4)	Grimm	.277	
H-2(P-3)	Buffalo	.274	
H-1(P-1)	Grimm	.266	
H-1(P-1)	Buffalo	.262	
H-1(P-1)	Vernal	.252	
H-3(P-4)	Buffalo	.249	

[a]Lines connect means which do not differ significantly, Duncan's test (20).

advancing season, and both Buffalo and Grimm increased through the second sampling but decreased in the third. In the case of Buffalo, this decrease was a significant one.

The sample and cutting treatment interaction was a significant one. At all samplings, the frequently-cut plots contained a higher percentage of P, but the mean difference between the two systems of cutting advanced with the season; from .001% at the first sampling to .014% P for the second sample group to .004% P in the third sampling (standard error .002). Therefore, the difference between the hay and pasture forage was greatest at the time of greatest P uptake. The character of the plants under the two harvest systems may explain some of this difference.

The percentage of phosphorus in the forage of the two cutting systems varied with samplings and with fertilization. The mean effects for P fertilizer are shown in Table 40. The data indicate that, with advancing season, the phosphorus uptake of the frequently-cut plots was increased to a lesser extent by P fertilizer. When cut for hay, the P content of the forage was increased through the second cutting, but the content of the third harvest decreased to the lowest effect under this cutting system.

The effect of potassium on P uptake under the two cutting systems is shown in Table 41. When cut for hay, K applications always depressed the phosphorus content, but to a sig-

Table 40. Mean effect of phosphorus fertilizer upon phosphorus percentage as influenced by cutting treatment and samplings during 1954 - average of varieties and replicates

Cutting treatment	Sampling group		
	H-1(P-1)	H-2(P-3)	H-3(P-4)
	(%)	(%)	(%)
Hay	.052	.065	.049
Cut frequently	.066	.051	.014
Standard error	.003		

Table 41. Phosphorus percentage of alfalfa forage under two cutting systems as influenced by potassium fertilization and samplings through the season of 1954 - average of varieties and replicates

Cutting treatment	Sampling group		
	H-1(P-1)	H-2(P-3)	H-3(P-4)
	(%)	(%)	(%)
Hay	-.004	-.016	-.003
Cut frequently	.018	.012	-.014
Standard error	.003		

nificant degree only at the time of the second cutting. When cut frequently, K enhanced the uptake of phosphorus in the first two samplings and decreased P uptake in the third. The effect of K, in increasing phosphorus content of the forage, decreased with advancing season.

The interaction of samples and cutting treatments with varieties was a significant one. Table 42 shows the mean P percentages for this interaction. The tendency of the frequently-cut forage to be high in P content is apparent. The first-cutting percentages of P did not differ appreciably whether cut for hay or clipped frequently, with the exception of Vernal, cut for hay. Grimm and Vernal appeared to be higher in P content than Buffalo, as was apparent in data presented previously. The marked discrepancy of Buffalo, at the time of the second sampling, when cut for hay, as compared to frequent clipping, is apparent.

Potassium analysis

Forage from the first cutting from all plots, in 1954 and 1955, was analyzed for potassium content. The complete data are presented in the Appendix (Table 72), and a summary of the analysis of variance of these data is shown in Table 43.

The K content of the forage harvested from the four replicates differed considerably, as shown in Table 44. Unlike the forage yield results, or the results of the phosphorus analyses, replicate I was not the lowest-ranking for potassium content. As indicated in Table 44, replicate III

Table 42. Percentage of phosphorus in alfalfa forage as influenced by variety, cutting treatment and sampling group during 1954 - average of replicates

Variety	Cutting treatment	Sampling group	Mean per cent P	Significant intervals[a]
Buffalo	Frequent	H-2(P-3)	.306	
Vernal	"	"	.288	
"	"	H-3(P-4)	.287	
Grimm	"	H-2(P-3)	.286	
"	"	H-3(P-4)	.284	
"	Hay	H-2(P-3)	.284	
Vernal	"	H-3(P-4)	.276	
Grimm	"	"	.270	
Vernal	"	H-2(P-3)	.267	
Grimm	"	H-1(P-1)	.266	
"	Frequent	"	.266	
Buffalo	"	"	.262	
"	Hay	"	.261	
Vernal	Frequent	"	.255	
"	Hay	"	.249	
Buffalo	"	H-3(P-4)	.249	
"	Frequent	"	.249	
"	Hay	H-2(P-3)	.242	

[a]Line connects those means which do not differ significantly, Duncan's test (20).

Table 43. Summary analysis of variance for per cent potassium of first-cutting alfalfa forage for 1954-1955

Source of variation	d.f.	Mean squares[a]
B (Blocks)	3	.7643*
F (Fertilizers)	3	
P[b]	1	.0047
K	1	9.6443**
PK	1	.1475
Error (a)[c]	9	.1941
V (Varieties)	7	.1660**
V x F	21	.0239
Error (b)	84	.0198
C (Cutting treatments)	1	.4821**
C x F	3	
P x C	1	.0933
K x C	1	.0687
PK x C	1	.0015
C x V	7	.0173*
C x V x F	21	
P x C x V	7	.0051
K x C x V	7	.0079
PK x C x V	7	.0131
C x B	3	.0107
C x F x B	9	.0198
Error (c)	84	.0076
Y (Years)	1	11.4930
Y x B	3	.2017

[a]The asterisk (*) and double asterisk (**) indicate F-tests significant at the 5% and 1% levels, respectively.

[b]P, K and PK are symbols for the main effects due to phosphorus fertilization, potassium fertilizer and the combined phosphorus-potassium application, respectively.

[c]Mean squares and degrees of freedom, when pooled, do not differ significantly, Bartlett's test (80).

Table 43. (Continued)

Source of variation	d.f.	Mean squares
Y x F	3	
P x Y	1	.8970**
K x Y	1	.6735**
PK x Y	1	.0146
Y x F x B	9	.0308
Y x V (Varieties)	7	.0218**
Y x V x F (Fertilizers)	21	
P x Y x V	7	.0199**
K x Y x V	7	.0106
PK x Y x V	7	.0344**
Y x C (Cutting treatments)	1	.6434
Y x C x F	3	
P x C x Y	1	.0001
K x C x Y	1	.0960**
PK x C x Y	1	.0003
Y x C x V	7	.0138
Y x V x B (Blocks)	21	.0054
Y x V x F x B[c]	63	.0055
Y x C x B	3	.1342
Y x C x F x B	9	
P x Y x C x B	3	.0192
K x Y x C x B	3	.0013
PK x Y x C x B	3	.0135
Residual[d]	105	.0138
Total	511	

[c]Mean squares and degrees of freedom, when pooled, do not differ significantly, Bartlett's test (80).

[d]Coefficient of variation 6.4%.

was not significantly higher than replicate II but was higher than replicates I and IV. Replicates IV, I and II did not differ significantly in terms of K content of the forage. The average K percentage, as indicated by the data, was 1.39, which is slightly below the critical percentage of Bear and

Table 44. Potassium content of the forage from four replicates - average of fertilizers, alfalfa varieties, cutting treatments and the years 1954-1955[a]

Rep. IV	Rep. I	Rep. II	Rep. III
(%)	(%)	(%)	(%)
1.31	1.35	1.40	1.49

[a]Means underscored do not differ significantly at the 5% level, Duncan's test (20).

Wallace (6), 1.4% K, and well below their ideal content of 2.0% potassium.

As indicated in Table 43, the forage under K fertilization was significantly higher in potassium content than that which received no potassium. The average content of the unfertilized alfalfa was 1.25% K, and that which was fertilized with K contained an average of 1.52% potassium.

The potassium content of the varieties differed to a marked degree. As presented in Table 45, Narragansett and Grimm ranked high in K content. Reference to Table 26 indicates that Narragansett also contained the highest per cent phosphorus in the first-cutting forage. As shown in Table 45, Narragansett did not contain significantly more K than Grimm but did rank significantly higher than Vernal, Ledak, Ranger, Buffalo, A-224 and Atlantic. Grimm and Vernal did

Table 45. Per cent potassium in dried, first-cutting alfalfa forage of eight varieties - average of fertilizers, replicates, cutting treatments and years, 1954-1955[a]

Atlantic	A-224	Buffalo	Ranger	Ladak	Vernal	Grimm	Narragansett
1.34	1.34	1.35	1.35	1.39	1.40	1.46	1.47

[a]Means underlined do not differ significantly at the 5% level, Duncan's test (20).

not differ significantly in per cent K, but Grimm did have a significantly higher potassium content than Ladak, Ranger, Buffalo, A-224 and Atlantic. The potassium content of Vernal, Ladak, Ranger and Buffalo did not differ significantly, but Vernal ranked significantly higher than A-224 and Atlantic. The per cent K in Atlantic, A-224, Buffalo, Ranger and Ladak was not significantly different.

When cut frequently, to simulate pasture conditions, the forage was considerably higher in K than when cut for hay. These values were 1.36% K for hay forage and 1.42% in the forage clipped frequently, and the difference is significant at the 1% level.

Although not significant at the 5% level, the interaction between cutting treatment and fertilizer is of some interest.

The data, presented in Table 46, show that, when cut for hay, the application of P caused a decrease in the potassium content of the forage, but when clipped frequently, P fertilization tended to increase the uptake of potassium. Under both harvest systems, K fertilization caused a marked increase in potassium content of the forage.

Table 46. Mean effect of phosphorus and potassium fertilization on the potassium content of alfalfa forage under two cutting systems - average of replicates, varieties and years 1954-1955

Main effect[a]	Cutting treatment: Hay	Cutting treatment: Clipped frequently	Probability[b]
	(%)	(%)	
P	-.03	.02	.1 > P > .05
K	.25	.30	.1 > P > .05

[a]Effect under a fertilizer treatment as compared to the content of the forage without that treatment.

[b]Probability that an effect due to chance.

The alfalfa varieties differed in the potassium content of the forage under the two cutting systems. In all cases, the forage from the frequently-cut plots was higher in per cent K than that from the plots cut for hay. As shown in Table 47, the K content in the varieties A-224, Buffalo and

Table 47. Mean increase in potassium content of eight varieties of alfalfa when clipped frequently, as compared to when cut for hay - average of fertilizers, replicates and years, 1954-1955

Variety	Increase in K content	Mean per cent K
	(%)	
Atlantic	.06	1.34
A-224	.04	1.34
Buffalo	.03	1.35
Grimm	.01	1.46
Ladak	.08	1.39
Narragansett	.09	1.47
Ranger	.07	1.35
Vernal	.11	1.40
Standard error	.01	

Grimm was not changed markedly under either cutting treatment, but the varieties Atlantic, Ladak, Narragansett, Ranger and Vernal had significantly higher K percentages when clipped frequently than when cut for hay.

The average potassium content of the forage was 0.30% lower in 1955 than in 1954. This difference is manifest in many of the interactions involving the two seasons. The effect of both P and K fertilization on the potassium content of the forage varied from year to year. These differences, significant at the 1% level, are presented in Table 58. Under P fertilization, in 1954, the potassium content of the forage was increased, but in 1955 a considerable decrease was

Table 48. Mean effects of phosphorus and potassium fertilizers on the potassium content of alfalfa forage in 1954 and 1955 - average of replicates, varieties and cutting treatments

Main effect	Mean effect on per cent K	
	1954	1955
_P_	.08	-.10
_K_	.35	.20
Standard error	.07	

evident. When fertilized with potassium, in both years the K content was increased, but the increase in 1954 was higher than that in 1955. This trend, _i.e._, lower average nutrient content in 1955 as compared to 1954, has been apparent throughout the study.

The alfalfa varieties differed markedly in their potassium content in the years 1954 and 1955. As shown in Table 49, all varieties contained significantly higher amounts of potassium in 1954 than in 1955, but within each season, the ranking changed considerably. The extreme instances are

Table 49. Potassium content (two-year average) of eight alfalfa varieties and decrease in content from 1954 to 1955 - average of fertilizers, replicates and cutting treatments

Variety	Mean per cent K	Mean decrease 1954-1955
Atlantic	1.34	-.26
A-224	1.34	-.34
Buffalo	1.35	-.33
Grimm	1.46	-.35
Ladak	1.39	-.30
Narragansett	1.47	-.27
Ranger	1.35	-.29
Vernal	1.40	-.27
Standard error		.01

represented by Atlantic and Grimm. Atlantic, with a low mean K content, decreased from 1.47% K in 1954 to 1.21% K in 1955, and Grimm, with a K content of 1.63% in 1954, dropped to 1.28% in 1955.

As the data in Table 50 show, the potassium content of the alfalfa varieties was altered to a different degree by P fertilization in 1954 than in 1955. The difference between the mean effects for any given variety is significant in every case. Grimm was the only variety which did not have a

Table 50. Mean effect of phosphorus fertilizer on the potassium content of eight alfalfa varieties in 1954 and 1955 - average of replicates and cutting treatments

Variety	Mean treatment effect of P in per cent K	
	1954	1955
Atlantic	.02	-.16
A-224	.08	-.04
Buffalo	.15	-.08
Grimm	.10	.00
Ladak	.05	-.06
Narragansett	.06	-.15
Ranger	.02	-.08
Vernal	.13	-.10
Standard error	.03	

decrease in potassium content under P fertilization in 1955, and Grimm and A-224 were the only varieties in which the decrease in 1955 was not a significant one. In 1954, Atlantic, Ladak and Ranger did not show a significant increase in potassium content when fertilized with phosphorus.

The varieties responded differently to the combined PK fertilization in each year. These data, presented in Table 51, indicate that, in both years, the addition of K to the phosphorus fertilization caused an increase in the K content

Table 51. Mean effect of combined phosphorus and potassium fertilization on the potassium content of eight alfalfa varieties in 1954 and 1955 - average of replicates and cutting treatments

Variety	Mean treatment effect of PK in per cent K	
	1954	1955
Atlantic	.32	.18
A-224	.48	.22
Buffalo	.35	.23
Grimm	.36	.18
Ladak	.31	.25
Narragansett	.30	.18
Ranger	.36	.17
Vernal	.35	.21
Standard error	.03	

of the forage. The difference in increase between the two years is apparent. Only in the case of Ladak is the difference non-significant. In both years, the increase in per cent K, when potassium and phosphorus were topdressed, as compared to P alone, was a significant one.

The effect of potassium fertilization in increasing the potassium content of the forage under the different cutting systems varied from year to year. In 1954, the hay forage, fertilized with K, had an average increase of 0.35% K, as compared to an increase of 0.34% in the frequently-clipped forage. In 1955, the forage cut for hay increased an average of 0.15% K over that not fertilized, and the frequently-clipped forage increased 0.25% in potassium content. The difference between the two cutting treatments was significant only in 1955. Within each cutting system, the differences from year to year were significant.

Potassium analysis of selected varieties

In 1954, the three varieties, Buffalo, Grimm and Vernal, selected for further study of phosphorus content (Table 34 *et seq.*) were analyzed also for potassium content. The three hay cuts, during 1954, were selected for analysis, and also the three frequent clippings which were cut at approximately the same time as those cut for hay. These three cutting-groups will be referred to as "Samples" in the following section. The results of the chemical analysis are presented in the Appendix (Table 73), and an analysis of variance of these data is shown in Table 52.

As indicated in the analysis of variance summary, the change in potassium content of the three varieties, when fertilized with K, was a significant one. The average potassium content of these samples was 1.47%. When no K was

Table 52. Summary analysis of variance of the per cent potassium in three selected cuttings from three alfalfa varieties during 1954

Source of variation	d.f.	Mean squares[a]
B (Blocks)	3	.2573
F (Fertilizers)	3	
P[b]	1	.1517
K	1	4.9586**
PK	1	.1085
Error (a)[c]	9	.1333
V (Varieties)	2	.0456
V x F	6	.0178
Error (b)	24	.0140
C (Cutting treatments)	1	.0879**
C x F	3	
P x C	1	.0306
K x C	1	.0008
PK x C	1	.0205
C x V	2	.1729**
C x V x F	6	
P x C x V	2	.0208
K x C x V	2	.0074
PK x C x V	2	.0578*
Error (c)	36	
S (Samples)	2	.7841**
S x F	6	
P x S	2	.3584**
K x S	2	.2255**
PK x S	2	.0690**
S x V	4	.0967**
S x C	2	.1542**

[a]The asterisk (*) and double asterisk (**) indicate F-tests significant at the 5% and 1% levels, respectively.

[b]P, K and PK are symbols for the main effects under phosphorus fertilization, potassium fertilizer and the combined phosphorus-potassium application.

[c]Pooled degrees of freedom and variances do not differ significantly, Bartlett's test (80).

Table 52. (Continued)

Source of variation	d.f.	Mean squares
S x V x F	12	
P x S x V	4	.0248**
K x S x V	4	.0061
PK x S x V	4	.0124*
S x F x C	6	
P x S x C	2	.1094**
K x S x C	2	.0128*
PK x S x C	2	.0189**
S x V x C	4	.2546**
Residual[d]	129	.0028
Total	284	

[d]Coefficient of variation 3.5%.

applied, the average percentage was 1.34, and when K was topdressed, the average content was 1.60% potassium. The critical percentage proposed by Bear and Wallace (6) was 1.4% K, and the average content in these varieties slightly exceeded this percentage.

The varieties did not differ in their seasonal average K content, nor was there any interaction of a variety with the fertilizer treatments. When cut for hay, the average potassium content of the three varieties was 1.45%, and when clipped frequently, the average percentage was 1.49, a difference significant at the 5% level.

The individual varieties, Buffalo, Grimm and Vernal, differed slightly in per cent K when cut for hay, as compared to per cent K when clipped frequently. These data, in Table

53, show that the varieties Buffalo and Vernal had a higher potassium content when clipped frequently than when cut for hay. Grimm, however, was slightly higher in potassium under the hay system of cutting.

Table 53. Per cent potassium in three selected varieties when cut for hay or clipped frequently - average of samples, replicates and fertilizer treatments in 1954

Variety	Cutting treatment	
	Hay	Frequent clipping
Buffalo	1.40	1.51
Grimm	1.52	1.47
Vernal	1.44	1.49
Standard error	.02	

The effect of the combined fertilization PK was different when the varieties were clipped frequently than when they were cut for hay. With the exception of Vernal, clipped frequently, the effect of the combined fertilizer was to decrease the K content of the forage. As presented in Table 54, the data indicate that this decrease was significant only in the case of Grimm, cut frequently. This effect might, in part, account for the relatively low K content of the forage from the frequently-clipped Grimm plots, indicated in Table 53.

Table 54. Mean effect upon the per cent potassium in alfalfa forage of the combined phosphorus-potassium fertilization, under two cutting systems - average of replicates and samples during 1954

Main PK effect on:	Cutting treatment	
	Hay	Clipped frequently
	(per cent potassium)	
Buffalo	-.02	-.04
Grimm	-.00	-.14
Vernal	-.05	.01
Standard error	.03	

Vernal, when clipped frequently, exhibited a trend toward an increased K content, but the increase was not a significant one.

Three samples groups were used in this analysis: H-1 and P-1, H-2 and P-2 and H-3 and P-4. These combinations were chosen because they were harvested during comparable periods in 1954. The difference in average K content among these samples was significant. The first group, H-1 and P-1, contained an average of 1.56% potassium; the second, H-2 and P-3, averaged 1.47% K; and the third sampling, H-3 and P-4, contained an average of 1.38% potassium. Each of these means is significantly different from the other two.

The fertilizer effects, P, K and PK, varied considerably in their effect on the potassium content of the forage from the successive samples. As indicated in Table 55, the general trend under all fertilizer treatments was a decline in K percentage as the season progressed. Under phosphorus, or the combined PK, fertilization, the potassium content of the

Table 55. Mean effect, in per cent, of three main fertilizer treatments on the potassium content of three successive cuttings of alfalfa forage in 1954 - average of replicates, varieties and cutting treatments[a]

Main effect	Sample group		
	H-1(P-1)	H-2(P-3)	H-3(P-4)
	(per cent potassium)		
P	.13	.10	-.09
K	.35	.28	.16
PK	.02	-.07	-.07

[a]Underscoring connects those means which do not differ significantly at the 5% level, Duncan's test (20).

later samplings had decreased below the average content of the forage without treatment. As was indicated by the phosphorus analyses (p. 75), as the season advances, and nutrients presumably become more limiting, the tendency for mutual suppression of P uptake by K, or *vice versa*, becomes more marked.

The potassium content of the three varieties varied among sampling-groups. As indicated in Table 56, the last

Table 56. Per cent potassium in three alfalfa varieties from three sample-groups during 1954 - average of replicates, fertilizers and cutting treatments[a]

Buffalo	Grimm	Vernal	Vernal	Grimm	Buffalo	Buffalo	Vernal	Grimm
				Sample-group				
3	3	2	3	2	2	1	1	1
1.34	1.37	1.43	1.43	1.48	1.51	1.51	1.54	1.63

[a]Means underlined do not differ significantly at the 5% level, Duncan's test (20).

sampling tended to be lower in potassium than the second sample group, with the exception of Vernal, in which sampling-groups 2 and 3 were alike. The K content of the samples from 1 or 2, Buffalo, did not differ significantly, unlike those of Grimm and Vernal, in which cases sample-group 1 had a significantly higher potassium content than group 2.

The two cutting systems, hay and frequent-clipping, varied in their K content among the three samples. Under the hay management system, as presented in Table 57, the per cent K in the forage decreased from 1.57, in the first sampling, to 1.32% K in the third. When clipped frequently, the potassium content decreased from 1.55, in the first sample-group, to 1.44, in the third. It is apparent that the decline in K

Table 57. Per cent potassium in alfalfa forage when cut for hay, or cut frequently, in three samplings during 1954 - average of fertilizers, replicates and varieties

Cutting treatment	Sample group		
	H-1(P-1)	H-2(P-3)	H-3(P-4)
Hay	1.57	1.48	1.32
Cut frequently	1.55	1.47	1.44
Standard error	.01		

content was considerably greater under the hay-cutting system than when the plots were clipped frequently.

The mean effect of treatment P upon the per cent potassium of the three varieties also varied with sample-groups. As shown in Table 58, P fertilizer had a greater effect on Vernal alfalfa than it did on either Grimm or Buffalo. Grimm was unique in that the K content, under phosphorus fertilization, increased at the time of the second sampling, and in Buffalo and Vernal, the potassium content decreased steadily through the season.

The PK treatment had a depressing effect on the potassium content of the three varieties in all but the first cutting. These data, presented in Table 59, indicate a progressive decrease in the K content of the varieties as the season advanced. Under PK fertilization, the potassium

Table 58. Mean effect of phosphorus fertilization upon the potassium content of three alfalfa varieties sampled three times during 1954 - average of replicates and cutting treatments

Variety	Mean effect in sample-group:		
	H-1(P-1)	H-2(P-3)	H-3(P-4)
	(%)	(%)	(%)
Buffalo	.15	.05	-.08
Grimm	.10	.18	-.03
Vernal	.13	.08	-.17
Standard error		.02	

Table 59. Mean effect of the combined phosphorus-potassium fertilization upon the potassium content of three alfalfa varieties sampled three times during 1954 - average of replicates and cutting treatments

Variety	Mean effect in sample group:		
	H-1(P-1)	H-2(P-3)	H-3(P-4)
	(%)	(%)	(%)
Buffalo	.08	-.10	-.06
Grimm	-.02	-.08	-.11
Vernal	.01	-.03	-.03
Standard error		.02	

content of Grimm was decreased in all sample-groups. The tendency toward lower potassium contents, under PK fertilizer, in Vernal was not a significant one. Buffalo alfalfa decreased in K content across the season, but the absolute low potassium content was detected in the second sampling, rather than the third.

All fertilizer main effects, P, K and PK, showed varying influences upon the potassium content of the forage when cut for hay or clipped frequently. These effects, shown in Table 60, indicate a considerable decrease in K content when the forage, fertilized with P, was clipped frequently and a lesser decrease when cut for hay. The same tendency was true in the K-fertilized forage; the decline was greater in the frequently clipped forage than it was in the hay-cut material. The PK average effect exhibited the same general trend. When fertilized with both phosphorus and potassium, the decrease in potassium content of the material cut for hay was non-significant, but the frequently-cut forage showed a significant decline in potassium content. These data are in marked contrast to the average effect of the cutting systems across the season, as indicated in Table 57.

When cut for hay or clipped frequently, the alfalfa varieties varied considerably in potassium content among the three sample-groups. The reversal in position in the second sample-group of Vernal is apparent in Table 61; at

Table 60. Mean effects of the main fertilizer treatments, P, K and PK, upon the per cent potassium in forage from two cutting systems at three times of sampling during 1954 - average of replicates and varieties

Cutting treatment	Sample-group H-1(P-1)	H-2(P-3)	H-3(P-4)
	(% K)	(% K)	(% K)
		Effect of P	
Hay	.08	.04	-.04
Frequent clipping	.18	.17	-.15
		Effect of K	
Hay	.32	.28	.18
Frequent clipping	.38	.27	.14
		Effect of PK	
Hay	.01	-.03	-.04
Frequent clipping	.04	-.11	-.10
Standard error .03			

the time of first and third hay cuts, the frequently-cut plots had a higher K content; the second hay-cutting had a higher content than did the frequently-cut material. Similar reversals may be noted among the other variety means. A partial explanation of these reversals may be provided by the fact that these cuttings were not exactly comparable, i.e., the third frequently-cut forage is compared with the second hay-cut, and the fourth clipping from the frequently-cut plots is compared with the third harvest as hay.

Table 61. Per cent potassium in the forage of three alfalfa varieties, sampled at three times during 1954, when cut for hay or clipped frequently - average of replicates and fertilizers

Sample-group	Cutting treatment	Variety Buffalo	Grimm	Vernal
H-1(P-1)	Hay	1.54	1.64	1.52
	Cut frequently	1.49	1.63	1.55
H-2(P-3)	Hay	1.36	1.61	1.47
	Cut frequently	1.66	1.36	1.38
H-3(P-4)	Hay	1.30	1.33	1.32
	Cut frequently	1.38	1.41	1.54
Standard error	.01			

Effects on Alfalfa Stand

In the fall of 1955, stand counts were made on all plots. Three individual 1 square foot quadrats in each variety-fertilizer-cutting treatment plot for each replicate were counted. These data are presented in the Appendix (Table 74), and a summary of the analysis of variance of the data is shown in Table 62. The average stand, for 768 quadrats counted, was 10 plants per square foot, with extremes, under the haying system, of five and 18 plants and, under the frequent-clipping management, two to 20 plants per quadrat.

As indicated in Table 63, the number of plants per

Table 62. Summary analysis of variance of alfalfa stand counts, in 1955, on all variety-fertilizer-cutting treatment-replicate combinations - three quadrats counted per plot

Source of variation	d.f.	Mean squares[a]
B (Blocks)	3	95*
F (Fertilizers)	3	
P[b]	1	300**
K	1	000
PK	1	18
Error (a)[c]	9	22
V (Varieties)	7	61**
V x F	21	
P x V	7	14
K x V	7	22*
PK x V	7	15
Error (b)	84	8
C (Cutting treatments)	1	6
C x F	3	
P x C	1	61**
K x C	1	10
PK x C	1	00
C x V	7	22**
C x V x F	21	
P x C x V	7	28**
K x C x V	7	8
PK x C x V	7	24**
Residual	96	6
Sampling error[d]	512	4
Total	767	

[a]The asterisk (*) and double asterisk (**) indicate F-tests significant at the 5% and 1% levels, respectively.

[b]P, K and PK are symbols for the main effects due to phosphorus fertilization, potassium fertilizer and the combined application, respectively.

[c]Pooled variances and degrees of freedom do not differ significantly, Bartlett's test (80).

[d]Coefficient of variation 19.0%.

Table 63. Alfalfa plants per square foot for four replicates - average of fertilizers, varieties, cutting treatments and quadrats in 1955[a]

Rep. III	Rep. II	Rep. IV	Rep. I
8.8	9.7	10.1	10.6

[a]Means underscored do not differ at the 5% level, Duncan's test (20).

square foot differed for the replicates. It is noteworthy that the replicate rankings are exactly opposite of the rankings according to yield (Table 6). The data in Table 63 show that replicates I, IV and II did not differ significantly in stand count, but replicates I and IV were significantly higher than replicate III. Replicates II and III did not differ significantly.

The analysis of variance data indicate that the main effect P had a significant effect on stand count. The average stand when no phosphorus fertilizer was applied was 10.6 plants per square foot; under P fertilization, the average decreased to 9.3 plants per square foot. This trend was apparent in all the data; under fertilization the stand count tended to decrease though yield data (Table 7) indicates a consistent increase under all fertilizer treatments.

The alfalfa varieties differed somewhat in stand in the fall of 1955. The data in Table 64 indicate that Ranger and Ladak, relatively low-yielding varieties (Table 8) had high stand counts. Vernal and Narragansett, high-yielding varieties, had intermediate stands at the conclusion of the study,

Table 64. Stand counts for eight alfalfa varieties in the fall of 1955 - plants per square foot averaged for replicates, fertilizers, cutting treatments and three quadrats per plot[a]

A-224	Atlantic	Buffalo	Grimm	Vernal	Narragansett	Ranger	Ladak
9.2	9.2	9.4	9.7	9.8	9.8	10.7	11.5

[a]Underlined means do not differ significantly at the 5% level, Duncan's test (20).

and A-224 and Atlantic, medium- and low-yielding respectively, had the lowest absolute number of plants per square foot.

Potassium fertilization had a significant effect on stand survival. The significance of the interaction between varieties and K was largely dependent on the effect of potassium on Narragansett. In most cases, the unfertilized alfalfa had a higher stand count than that fertilized with potassium. Narragansett, when fertilized with K, had a significantly higher count than when no K was applied. Grimm and Ranger also had higher stand counts under K fertilization, but the difference was not a significant one. All other varieties showed a non-significant increase in stand when no potassium was topdressed.

Stand counts did not differ significantly under the two cutting systems. The average stand under the hay system was 9.9 plants and the average count, when clipped frequently, was 10.0 plants per square foot. Phosphorus fertilization had a different effect on the hay-cut plots than on those clipped frequently. As shown in Table 65, when fertilized

Table 65. Alfalfa plants per square foot for two cutting systems under phosphorus fertilization - average of replicates, varieties and quadrats

Fertilization	Cutting system	
	Hay	Frequent clipping
P_0	10.2	10.9
P_1	9.5	9.1
Standard error	0.2	

with P, the stand count in both cutting systems tended to decrease. The reduction was considerably larger when the plants were clipped frequently than when they were harvested for hay.

It is apparent from the data in Table 66 that the three varieties, Atlantic, Grimm and Ladak, suffered greater stand depletion under the frequent-cutting system than they did when cut for hay. On the other hand, A-224, Narragansett and Vernal tended to have lower stand counts when cut for

Table 66. Stand counts, in plants per square foot, for eight alfalfa varieties when cut for hay or clipped frequently - average of replicates, fertilizers and quadrats

Variety	Hay-cut	Clipped frequently
Atlantic	9.5	9.0
A-224	8.8	9.7
Buffalo	9.3	9.5
Grimm	10.0	9.4
Ladak	12.2	10.8
Narragansett	9.2	10.5
Ranger	10.6	10.8
Vernal	9.1	10.5
Standard error	0.4	

hay than when clipped frequently. Differences in stand due to cutting system were significant, at the 5% level, for Ladak, Narragansett and Vernal.

The interaction between varieties, fertilizers and cutting treatments was significant under the main effects P and PK. These data are shown in Table 67 and indicate that, when fertilized with phosphorus, Grimm and Ladak, cut for hay, had markedly decreased stands under P fertilization, and this

Table 67. Number of plants per square foot, for eight alfalfa varieties, under two cutting systems, when fertilized with phosphorus or with the combination phosphorus-potassium application - average of replicates and quadrats

Variety	Cutting system: Hay		Cutting system: Clipped frequently	
	Main effect P			
	P_0	P_1	P_0	P_1
Atlantic	9.5	9.6	10.1	8.0
A-224	8.8	8.8	10.2	9.2
Buffalo	9.9	8.8	9.9	9.1
Grimm	11.2	8.8	10.1	8.6
Ladak	13.7	10.8	11.3	10.4
Narragansett	9.2	9.2	12.8	8.3
Ranger	10.6	10.7	12.3	9.3
Vernal	8.8	9.5	10.8	10.1
	Main effect PK			
	PK_0	PK_1	PK_0	PK_1
Atlantic	9.4	9.7	8.4	9.7
A-224	9.3	8.3	10.5	8.9
Buffalo	9.4	9.3	10.7	8.3
Grimm	10.0	10.0	9.6	9.2
Ladak	12.8	11.7	11.0	10.8
Narragansett	9.0	9.3	11.0	10.0
Ranger	11.2	10.0	9.3	12.3
Vernal	9.1	9.2	10.8	10.2
Standard error		0.7		

effect was not so striking under the frequent-clipping system. Conversely, Atlantic, Narragansett and Ranger, when cut frequently, had significantly lower stand counts when fertilized with phosphorus than when no P was applied. When cut for hay, these three varieties were, to all practical purposes, unaffected by fertilization.

When both phosphorus and potassium were applied, still different effects were noted. As indicated in Table 67, Buffalo, when clipped frequently, had a significantly lower stand count under fertilization than it did without fertilizer. Ranger, on the other hand, under frequent cutting, had significantly more plants per square foot under the combined PK fertilization than when no fertilizer was used. This is an unique instance among these data. When cut for hay, the varieties did not differ markedly in stand count in response to PK fertilization, as compared to no treatment.

Soil Profile Analysis

In the fall of 1955, after it became obvious that replicate I was markedly different than the other three replicates, soil samples were taken from each fertilizer treatment plot in each replicate and analyzed for available phosphorus and potassium content and pH. The results of these tests were analyzed statistically with the primary purpose of comparing replicate I, for each fertilizer treatment, with the other three replicates. The results of the analysis of variance for the available-phosphorus data indicated that potassium fertilization had a significant effect on the available P content of the soil. Where no K had been applied, the available phosphorus content was 1.2 pounds per acre, and where potassium had been topdressed, the available P was 1.8 pounds per acre. This difference, although statistically significant, probably is of no practical significance because both phosphorus analyses would be classed as "Very Low".

More interesting, under the circumstances, was the fact that the interaction, phosphorus and depth of sampling, was highly significant. These data are shown in Table 68, along with the average pH values, which also changed significantly with depth. The close relationship between available P and pH is evident. Though the differences in both pH and available phosphorus were small, apparently over the seasons, the cumulative effect of reduced phosphorus availability would, in part, account for the marked difference in yield and P content of the forage grown on such a soil. The correlation coefficient (r), in this test, between available P and pH was -0.462, significant at the 1% level with 54 degrees of freedom.

The potassium analyses for these samples were determined on both dried and undried soil. In reference to the fact

Table 68. Average available phosphorus, in pounds, per acre, and pH values for depth increments and replicates - average of fertilizers

Depth in inches	Pounds available P per acre		pH	
	Rep. I	Other reps.	Rep. I	Other reps.
6	1.2	5.5	7.8	7.4
12	0.8	1.9	7.9	7.6
18	1.4	0.6	8.0	7.8
24	1.2	1.6	8.1	7.9
30	0.8	0.6	8.2	8.0
36	1.2	1.0	8.3	8.2
Standard error	0.6		0.3	

that the initial tests were analyses on undried samples, the relationship between the two was of interest. Although not directly applicable to the analyses of 1953, in 1955 the correlation coefficient (r) between available potassium determined on dried and undried samples was 0.188, which was not significant at the 5% level with 54 degrees of freedom.

DISCUSSION

The results of this study must be considered preliminary in nature, and generalizations on the basis of data obtained probably cannot safely be made. It must be borne in mind that the test was conducted under a specific, and limiting, set of environmental conditions. The weather was somewhat adverse, and under any circumstances, two years' data are hardly an adequate sampling of climatological conditions, particularly for a perennial crop. The objectives regarding the fertility status of the soil were not achieved. However, some interesting implications may be derived from the data, and these should be discussed in the light of their potential for future, more intensive study.

The fertilizer rates used were not intended to establish a basis for recommendation. The levels of P and K applied were presumed merely to be high enough to keep these nutrients from becoming severely limiting. It is obvious that this end was not attained. The soil nutrient analyses were always at a low level, with an actual decrease in the 1955 season. It is not surprising that the nutrient level in the soil was not raised by these applications; other workers have reported similar results due, in large part, to fixation mechanisms (33, 73, 77, 82, 99). Both yield and plant analysis results indicated that the alfalfa was growing under conditions classed by Macy (47) as poverty adjustment; this is shown by the fact that both yield and forage nutrient content increased with fertilization.

The responses obtained under fertilization, though neither economical nor statistically significant, were of fair magnitude. And, as has been reported earlier (33), one limiting nutrient may limit crop responses to a second nutrient. It would, therefore, be difficult to draw conclusions from these data because no intermediate rate was used with which the results of the extreme rates could be compared. It would be valuable if a future study were to establish graduated rates of fertilization. From the data herein, one can not be sure that the full amount of phosphorus applied was necessary to obtain the 760-pound yield increase which was indicated.

The magnitude of actual crop nutrient removal could not be established on the basis of the data at hand. No so-called balance sheet was kept, though the data did indicate that topdressing was effective with both P and K; the increased nutrient content under each specific fertilizer treatment served to establish this fact. If a crop-removal value were to be established, the oat companion crop, as well as the forage from all cuttings from each plot, should have been analyzed for nutrient content.

The mechanics of fertilization were not ideal in this study. Water was definitely limiting at times during the test period, *viz*., the superphosphate which was topdressed in 1955 lay on the surface until after the third cutting of hay was removed. Under such circumstances, it would be difficult to draw definite conclusions about annual phosphate applications. In addition, some workers (50) have reported that, at low levels of potassium availability, potassium uptake is directly related to water availability. On the other hand, a few torrential showers occurred during 1954 and 1955. These rains moved considerable topsoil and plant debris. Such surface erosion would serve to eliminate fertility differences established by topdressing nutrient elements, which tend to remain near the surface (83, 95, 100). Another difficulty encountered was that the times of application were not constant, either for comparable hay and frequent-clipping treatments or for a given nutrient alone as compared to the combined PK treatment. Thus, the fertilizations were not equally subject to the vagaries of weather and are not exactly comparable (14, 66). Lastly, an experimental design, such as a Latin Square, might have been more efficient as regards evaluation of the main-plot effects.

The results of the variety yields are valuable particularly in that they are an intensive comparison of the potential yielding-ability of the varieties under two markedly different types of cutting management. It must be remembered that cutting on a plant-height basis would favor low-growing and/or low-crowned types such as A-224, Ladak, Vernal, and perhaps, Narragansett. Therefore, a comparison of these with erect-type varieties on the basis of yield or chemical composition might not be on the basis of equal plant-maturity. In addition, cutting such low-growing types on a height basis would tend to prolong the interval between cuttings, and therefore, stand depletion would not be expected to be as extreme as among the erect types. Finally, the inherent differences among varieties as regards such characteristics as stemminess and leaf-stem ratio would affect the results of the chemical analyses particularly.

The differential responses noted among varieties, in terms of both yield and chemical responses, are of interest. Earlier work (36) noted a differential response to superphosphate between varieties largely because of yield depression under fertilization. Such a response was not noted in this study; the interaction of varieties and fertilizers, in terms of yield, was due to magnitude of positive response. A factor which might indirectly affect the yield results of such a study has been reported by Nightingale (59); in a study such as this, where potassium was applied, bloom may be delayed because of enhanced nitrogen metabolism. This might have considerable effect on both yield and chemical composition (16, 24, 45, 57).

Not only were yield differences observed, but also significant variations in chemical composition were noted. It might be supposed that this was due to a dilution effect, *i.e.*, with a limited nutrient supply, a higher-yielding variety might have a low nutrient content and yet remove as much of that nutrient from the soil as a low-yielding, high-analysis variety. It does not seem that such was the case under all circumstances. To compare extremes, Ladak and Vernal represent varieties which gave low and high total yields, respectively. Based on first-cutting yields and first-cutting chemical analyses, Ladak yielded 106% and 94% as much dry matter as Vernal, in 1954 and 1955, respectively; in terms of per cent P, Ladak contained 107%, in 1954, and 106%, in 1955, as much P as Vernal; and in terms of pounds of P removed in the forage, Ladak yielded 114% and 101% as much P as Vernal in the two successive years. It would not seem that dilution explains the low P content of Vernal. Perhaps a different physiological mechanism, or a difference in protein quality, might explain the difference in apparent requirements of the two varieties. It was also of interest that Narragansett was the one variety which contained relatively high amounts of both phosphorus and potassium. Such a factor might be of considerable importance physiologically as well as nutritionally.

Another differential response may be noted in Table 9, regarding differential response to phosphate fertilization. From the data, A-224, Buffalo, Grimm and Ladak might be grouped as varieties which respond well to P fertilizer. This group seems to be composed of two sub-groups; the erect types, Buffalo and Grimm, and the lower-growing types, A-224 and Ladak. The yield responses fit this division quite well, but an explanation is less obvious. Differences in root systems might account for part of the grouping, but this has not been established by experiment. Differences in parentage and genetic potentiality might be postulated as a basis for the grouping; again, this would be entirely empirical. Drake _et al_. (18) have reported that alfalfa varieties, Atlantic and Kansas Common specifically, differ in their cation exchange capacities as measured on the roots. This might have considerable bearing on differences as noted in nutrient content.

Although the average nutrient content of the varieties was relatively high, differences were noted within varieties, under different treatments. It must be acknowledged that statistical significance and physiological, or practical, significance are not, necessarily, one and the same in this type of study. However, it is impossible to establish the difference from these data. In general, it may be concluded that many of the effects noted are due to dilution, _i.e._, in terms of average response, the P content of the forage under the main effect K showed a decrease of -.003%, which was not significant at the 5% level. In terms of yield of P, however, the amount of P contained in K fertilized forage was increased an average of 1.2 pounds per acre. Thus, the availability of the phosphorus was not affected, but that P which was taken up was diluted because of the yield increase which accompanied K fertilization. This trend may be detected in many of the data presented. Beeson (7) has noted that K fertilization may, in some cases, lower the P content of plant material.

The differences in varietal response to cutting management seem to follow a pattern. The erect-growing varieties such as Vernal, Buffalo and Narragansett were the higher-yielding when cut for hay. Under frequent clipping, the low- or spreading-crown types, Vernal, Narragansett and A-224 were higher-yielding. The apparent flexibility in management afforded by Vernal has been reported by other workers (10, 79).

The difference in response of the two varieties, Buffalo and Vernal, to cutting treatment under P fertilization (Table 13) is of some interest. When cut for hay, these two varieties responded similarly to phosphate fertilization and were alike when no P was applied. However, when clipped frequently, a marked difference was established; Vernal yielded well when no phosphorus was applied, but Buffalo yielded better under P fertilization, as compared to Buffalo without fertilizer. The difference in mean response of the two varieties was of the order of 4600 pounds per acre. The phosphorus content of the varieties did not show similar variation. One explanation of this phenomenon might be based on the differences in growth habit and parentage of the two varieties. However, a similar comparison may be made between Buffalo and Narragansett which would not bear this explanation. Perhaps one hypothesis will not serve to explain all observed differences; i.e., a dilution factor might operate in one case, a difference in parentage might explain another.

The depression in yield when P was applied to frequently-cut plots would seem to be of some importance. It has been variously estimated that alfalfa should have from 20 days (29) to one month (38, 63) to recover sufficiently after cutting for root reserves to be reestablished. It would seem that, in this study, the plots cut frequently were stimulated by P fertilization to grow more rapidly and, consequently, be cut more often. The root reserves might, thus, be more severely depleted, and subsequent growth less vigorous, though of sufficient height to be cut again. The low-growing varieties were not so affected (Table 13), or not affected to the same degree, perhaps because of the increased time for root accumulation engendered by their growth habit.

The differences between years, and the significance of those terms involving "Years", are of questionable value. The correlation coefficient (r) between plot yields of 1954 and those of 1955 was .826 for all plots, .833 for the hay-cut plots and .502 for the frequently-clipped plots; these are significant at the 1% level and compare favorably with the coefficient given by Tysdal (86) of .756 for the same plots in different years at three scattered locations. The effects of the two years are of some value in explaining, or reiterating, some of the anomalies in the literature, _viz_., Hanway _et al_. (33) reported increased uptake of K under P fertilization in one year, and decreased recovery during the next season on the same plots. The results, as regards low K content in 1955, of this test may be partially explained on the basis of the cold, wet soil in the spring of the season. It has been shown (32) that such conditions may retard potassium absorption by plants. Willard (93) has suggested that alfalfa uses relatively more nutrients for top growth in wet seasons than in dry years; this finding might serve to explain some of the results of this study.

The interaction involving varieties and potassium fertilization, in the two season, shown in Table 30, is of some interest. As availability decreased from 1954 to 1955, potassium fertilization might well result in a decrease in P uptake in the second season. Some investigators (100) have indicated that as K fertilizer was added, the available P in the soil tended to decrease. However, the reversal in this tendency, noted with the varieties Atlantic, Narragansett, and perhaps, Ladak, is noteworthy. In these varieties, the percentage of P in the plant, under K fertilization, increased from the first to the second season. The three varieties had comparable mean phosphorus yields and percentages from one year to another, so it seems unlikely that this was a dilution phenomenon or a matter of more available P in one case than another.

The average composition of the three varieties, Buffalo, Grimm and Vernal, which were sampled through the season, indicate that varieties may differ in their ability to absorb nutrients under varying climatological conditions. Vernal, for example, was low in per cent P at the time of the first cutting (Table 39 and p. 67) but by the end of the season ranked medially in this respect. The phosphorus percentage of Vernal forage increased through the season, which indicates that some relationship between time of cutting and relative availability may be operative.

Reference to Table 36 emphasizes another interaction of some interest. Grimm alfalfa tended to accumulate the same percentage of both P and K (Table 53) regardless of cutting treatment. This tendency might be of considerable importance physiologically, but it is difficult of explanation. Grimm, when cut for hay, was among the earliest varieties, and several investigators have reported that potassium percentage decreases with maturity (16, 24). This tendency toward earlier maturity might tend to diminish differences between the two cutting systems as regards K content. In addition, it has been reported (45) that P content tends to increase with maturity; again, the early-blooming habit of Grimm might result in less disparity between the hay-cut and frequently-cut plots. On the other hand, Woodman _et al_. (98) pointed out that the first crop of alfalfa flowers more slowly than subsequent crops and, therefore, is harvested at a later stage, time-wise, than the second and third crops. This apparent contradiction may be resolved if it may be assumed that the first cutting was removed shortly after the first fertilization, and at this time, more P and K might have been in the available state than later in the season. Therefore, though the hay-cut plots may have been harvested at a relatively later stage than those cut frequently, the hay-cut forage might also have had a higher nutrient content in the early stages and, with maturity, the content decreased to a point comparable to that of the frequently-cut forage.

The differences noted in stand count again raise the question of statistical _vs_. practical significance. The correlation coefficient (r) between stand count and varietal yield was -.348 for all plots and -.546 for those plots cut for hay, as an average for the two-year period. These do not compare with the correlations reported by Ronningen (67), which were positive for all stands and yields. In either case, the correlation coefficients are not significant. The results of the counts indicate that the varieties reacted as might be expected as regards hardiness and persistence (96); Buffalo tended to reach a low level rather quickly under frequent clipping, and Ladak was among the varieties which persisted more strongly. The winter of 1954-1955 was not a particularly severe one, and stand depletion did not occur to the extent which might have been anticipated. There are many reports in the literature which indicate that the second winter is responsible for the largest decrease in stand (1, 27, 28). The relatively low stand of A-224 may be explained partially on the basis of seed of relatively low germinability and consequent initial poverty of stand. Seed of low germination and early observations indicated that thin stand might be expected in A-224, Buffalo and Atlantic. Conversely, Ranger had apparently good stands shortly after emergence. Another differential factor which might have operated to reduce stand counts was that those plots cut during the drought periods, with the consequent early bloom, may have had the root reserves depleted more thoroughly.

As has been shown by earlier work (70), plant quality may differ to a considerable, and more important, extent than plant quantity. It was apparent in this test that the plants cut frequently, though equal in number to those cut for hay, were of smaller crown and root diameter, had fewer stems per crown and were generally less thrifty than the hay-cut plants. As indicated by Garver (26), stand counts may be misleading because crown size is more dependent on available space than on varietal characteristics, among similar varieties. Also differential mortality will kill the smaller plants first, with consequent distortion of stand counts made in older leys.

Some of the stand counts bear further investigation. The varieties Ladak, Narragansett, Ranger and Vernal tended to have high stand counts. Empirical observation indicated that the varieties A-224, Atlantic and Buffalo were relatively thinner in stand at the outset, and the variety Grimm tended to have the lowest absolute stands in the group. Of course, part of the reduction in stand under fertilization and/or frequent-clipping may be attributed to stimulated growth and heavy cutting schedules. The response of Narragansett (p. 105) to K fertilization was unique among the observations; when fertilized with potassium, the Narragansett plant count increased from 8.9 plants to 10.7 plants per square foot. This was true of no other variety.

The comparatively high stands of A-224, Narragansett and Vernal when clipped frequently (Table 66) are probably a result of differential survival, not in that these stands were high, but that they did not decrease as rapidly as those of the other varieties under the same treatment.

The differential response manifested by the variety Ranger under the combined PK fertilization (Table 67) was unique. This difference, 3.0 plants per square foot, is large enough to be of practical, as well as statistical, significance. An explanation is not apparent from the data available in this study.

As a general conclusion, it might be stated that the interactions between varieties and the factors of fertilization and cutting management are manifold and diverse. It would seem that, in most cases, they are not of significance in that farm management would be little affected by the magnitude of the responses. However, in terms of nutritional or physiological significance there were many interesting and unexplained responses implicit in these data. It remains a problem of future intensive study to establish the importance of these differential responses.

SUMMARY AND CONCLUSIONS

The general objective of this study was to evaluate the responses of selected alfalfa varieties to the separate and combined effects of fertilizer treatments and cutting management.

During the years 1954 and 1955, eight alfalfa varieties, namely Atlantic, A-224, Buffalo, Grimm, Ladak, Narragansett, Ranger and Vernal, were grown under four specific fertilizer treatments and two systems of cutting management. Fertilizer treatments were used as follows: check (no fertilizer), 53 pounds of phosphorus per acre per year (120 pounds P_2O_5) and 100 pounds of potassium (120 pounds K_2O) per acre per year, alone and in all combinations. The cutting systems employed were a hay management, which was cut on a plant bloom basis, and a frequent-clipping, simulated-grazing system, which was clipped on an average plant-height basis. These factors of variety, fertilizer and cutting treatment occurred in all combinations with the purpose of measuring the differential responses of the selected varieties to the management-practice combinations available.

The responses were measured in terms of forage yield, nutrient (P and K) content and plant stand. Yield was determined as pounds per acre of dry (4% moisture) forage from plots cut according to bloom or height in four replicates of each variety-fertilizer combination. Hay-cut plots were harvested at least three times each season, and the frequently-clipped plots were cut at least four times each year. Nutrient content was measured as per cent P or K in the first-cutting forage from all plots in 1954 and 1955. Selected varieties were analyzed for P and K through the 1954 season. Stand counts were made at the conclusion of the study by counting three 1 square foot quadrats in each plot.

The results and conclusions of the study are summarized as follows:

1. The responses to fertilization were not economical nor were they statistically significant.
2. The alfalfa varieties differed considerably in their yield potential when harvested both for hay and when clipped frequently. Vernal and Narragansett showed the most flexibility in that they were relatively high-yielding under both systems.
3. The varieties differed in their response to phosphorus fertilization; A-224, Buffalo, Grimm and Ladak responded to the greatest degree, though they were not necessarily the highest-yielding varieties.
4. Frequent-cutting depressed the yield of all varieties, and Buffalo and Atlantic were most severely affected.
5. The varieties responded differently to P fertiliza-

tion when cut for hay or clipped frequently. The effect varied from a high positive response under both cutting systems, in the case of Grimm, to a positive response when cut for hay and a yield depression when clipped frequently, in the instances of Narragansett and Vernal.

6. Marked differences were apparent in the responses obtained in 1954 as compared to 1955, though these are of doubtful significance or importance.
7. The application of a given nutrient increased the percentage of that element in the forage and had a variable effect on the accessory nutrient.
8. The varieties differed in their ability to absorb and utilize applied P and/or K on the average, or when cut for hay or clipped frequently.
9. Alfalfa stand counts varied with fertilizer treatment, variety and combinations of these factors with cutting treatments. The stand counts were not reflected in the yield data and were of doubtful practical significance.
10. Many of the interactions which were statistically significant demand further investigation before their nutritional, physiological or practical application may be evaluated.

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APPENDIX

Table 69. Yields of alfalfa forage in pounds, of dry matter per acre, for all varieties, cutting treatments and fertilizers in 1954 and 1955, average of four replicates

Variety	Cutting treatment	Fertilizer treatment P_0K_0	P_0K_1	P_1K_0	P_1K_1
		1954			
Atlantic	Hay	7754	7896	8586	9041
	Cut frequently	5623	6375	6418	6897
A-224	Hay	7642	8034	8795	9120
	Cut frequently	6955	7056	7073	7210
Buffalo	Hay	8016	8161	8852	9292
	Cut frequently	6177	5574	5907	6410
Grimm	Hay	7386	7326	8607	8620
	Cut frequently	6304	7000	7622	7315
Ladak	Hay	8276	7840	8650	9052
	Cut frequently	6138	6435	6850	6700
Narragansett	Hay	7311	8343	8878	8769
	Cut frequently	6520	6961	7014	7562
Ranger	Hay	7336	7725	8658	9148
	Cut frequently	6152	6923	7066	6286
Vernal	Hay	8051	8599	9427	9726
	Cut frequently	7296	7012	7143	6886
		1955			
Atlantic	Hay	8068	8958	9295	10606
	Cut frequently	5157	4102	3435	4129
A-224	Hay	8104	7454	8655	10310
	Cut frequently	4214	5101	5180	4964
Buffalo	Hay	8054	8932	9549	11492
	Cut frequently	2783	4165	4432	5788
Grimm	Hay	8277	8216	9374	9954
	Cut frequently	3075	3475	4046	5115

Table 69. (Continued)

Variety	Cutting treatment	Fertilizer treatment			
		P_0K_0	P_0K_1	P_1K_0	P_1K_1
Ladak	Hay	6996	8060	8639	9244
	Cut frequently	3647	3930	4898	4474
Narragansett	Hay	8217	9012	9570	10752
	Cut frequently	5950	5910	3936	4637
Ranger	Hay	9029	9160	9259	10263
	Cut frequently	5094	3316	3384	4596
Vernal	Hay	8282	8775	9534	11195
	Cut frequently	5068	6207	4448	4849

Table 70. Per cent phosphorus in dried, first-cutting alfalfa forage, for all varieties, cutting treatments and fertilizers in 1954 and 1955 - average of four replicates

Variety	Cutting treatment	Fertilizer treatment			
		P_0K_0	P_0K_1	P_1K_0	P_1K_1
	1954				
Atlantic	Hay	.240	.228	.278	.277
	Cut frequently	.237	.239	.304	.263
A-224	Hay	.256	.236	.308	.320
	Cut frequently	.240	.256	.302	.317
Buffalo	Hay	.236	.236	.287	.286
	Cut frequently	.209	.241	.273	.326
Grimm	Hay	.251	.233	.288	.292
	Cut frequently	.237	.232	.296	.302
Ladak	Hay	.243	.250	.298	.301
	Cut frequently	.236	.242	.304	.280
Narrangansett	Hay	.240	.238	.305	.283
	Cut frequently	.260	.231	.324	.308
Ranger	Hay	.245	.224	.280	.305
	Cut frequently	.225	.218	.293	.295
Vernal	Hay	.224	.217	.279	.278
	Cut frequently	.226	.227	.272	.296
	1955				
Atlantic	Hay	.167	.160	.219	.196
	Cut frequently	.222	.202	.276	.298
A-224	Hay	.173	.145	.240	.225
	Cut frequently	.208	.198	.272	.294
Buffalo	Hay	.139	.153	.222	.202
	Cut frequently	.208	.227	.274	.292
Grimm	Hay	.169	.160	.240	.230
	Cut frequently	.220	.194	.260	.271

Table 70. (Continued)

Variety	Cutting treatment	Fertilizer treatment P_0K_0	P_0K_1	P_1K_0	P_1K_1
Ladak	Hay	.170	.166	.246	.227
	Cut frequently	.209	.228	.293	.292
Narragansett	Hay	.179	.184	.240	.222
	Cut frequently	.248	.221	.263	.310
Ranger	Hay	.160	.134	.219	.202
	Cut frequently	.226	.203	.281	.300
Vernal	Hay	.159	.144	.232	.207
	Cut frequently	.226	.202	.287	.278

Table 71. Phosphorus per cent of dried alfalfa forage from three selected alfalfa varieties, under two cutting systems and four fertilizer treatments, sampled three times during 1954 - average of four replicates

Variety	Cutting treatment	Fertilizer treatment P_0K_0	P_0K_1	P_1K_0	P_1K_1
	First sample group[a]				
Buffalo	Hay	.236	.236	.287	.286
	Cut frequently	.209	.241	.273	.326
Grimm	Hay	.251	.233	.288	.292
	Cut frequently	.237	.232	.296	.302
Vernal	Hay	.224	.217	.279	.278
	Cut frequently	.226	.227	.272	.296
	Second sample group[b]				
Buffalo	Hay	.222	.210	.278	.260
	Cut frequently	.251	.300	.335	.338
Grimm	Hay	.261	.244	.316	.316
	Cut frequently	.255	.260	.316	.311
Vernal	Hay	.250	.236	.306	.277
	Cut frequently	.274	.266	.292	.321
	Third sample group[c]				
Buffalo	Hay	.214	.241	.278	.264
	Cut frequently	.242	.212	.268	.274
Grimm	Hay	.248	.243	.288	.300
	Cut frequently	.274	.264	.293	.306
Vernal	Hay	.259	.240	.310	.294
	Cut frequently	.323	.282	.281	.263

[a]Forage from first hay cutting and first frequent-clipping.

[b]Forage from second hay-cut and third frequent-clipping.

[c]Forage from third hay-cut and fourth frequent-clipping.

Table 72. Per cent potassium in dried, first-cutting alfalfa forage, for all varieties, cutting treatments and fertilizers in 1954 and 1955 - average of four replicates

Variety	Cutting treatments	Fertilizer treatment P_0K_0	P_0K_1	P_1K_0	P_1K_1
	1954				
Atlantic	Hay	1.30	1.66	1.34	1.62
	Cut frequently	1.24	1.64	1.37	1.59
A-224	Hay	1.26	1.73	1.29	1.85
	Cut frequently	1.26	1.64	1.33	1.75
Buffalo	Hay	1.34	1.63	1.42	1.78
	Cut frequently	1.26	1.52	1.34	1.83
Grimm	Hay	1.45	1.79	1.48	1.82
	Cut frequently	1.32	1.76	1.54	1.88
Ladak	Hay	1.32	1.71	1.42	1.75
	Cut frequently	1.32	1.70	1.48	1.60
Narragansett	Hay	1.32	1.82	1.51	1.65
	Cut frequently	1.42	1.72	1.58	1.79
Ranger	Hay	1.32	1.66	1.36	1.68
	Cut frequently	1.28	1.70	1.32	1.67
Vernal	Hay	1.31	1.64	1.42	1.72
	Cut frequently	1.30	1.63	1.42	1.84
	1955				
Atlantic	Hay	1.12	1.34	1.01	1.10
	Cut frequently	1.28	1.42	1.06	1.36
A-224	Hay	1.09	1.24	0.96	1.18
	Cut frequently	1.08	1.35	1.12	1.37
Buffalo	Hay	1.06	1.32	1.04	1.08
	Cut frequently	1.06	1.46	1.12	1.33
Grimm	Hay	1.22	1.36	1.17	1.32
	Cut frequently	1.15	1.39	1.21	1.42

Table 72. (Continued)

Variety	Cutting treatments	Fertilizer treatment			
		P_0K_0	P_0K_1	P_1K_0	P_1K_1
Ladak	Hay	1.04	1.34	1.07	1.16
	Cut frequently	1.14	1.56	1.24	1.40
Narragansett	Hay	1.26	1.42	1.21	1.20
	Cut frequently	1.34	1.62	1.18	1.44
Ranger	Hay	1.12	1.27	0.98	1.14
	Cut frequently	1.24	1.36	1.15	1.39
Vernal	Hay	1.16	1.35	1.06	1.14
	Cut frequently	1.22	1.68	1.25	1.34

Table 73. Per cent potassium in dried alfalfa forage from three selected varieties, under two cutting systems and four fertilizer treatments, sampled three times during 1954 - average of four replicates

Variety	Cutting treatment	Fertilizer treatment P_0K_0	P_0K_1	P_1K_0	P_1K_1
	First sample group[a]				
Buffalo	Hay	1.34	1.63	1.42	1.78
	Cut frequently	1.26	1.62	1.34	1.83
Grimm	Hay	1.45	1.79	1.48	1.82
	Cut frequently	1.32	1.76	1.54	1.88
Vernal	Hay	1.31	1.64	1.42	1.72
	Cut frequently	1.30	1.63	1.42	1.84
	Second sample group[b]				
Buffalo	Hay	1.24	1.48	1.26	1.45
	Cut frequently	1.36	1.84	1.64	1.78
Grimm	Hay	1.38	1.73	1.49	1.83
	Cut frequently	1.03	1.44	1.43	1.54
Vernal	Hay	1.30	1.63	1.37	1.58
	Cut frequently	1.18	1.43	1.34	1.58
	Third sample group[c]				
Buffalo	Hay	1.19	1.46	1.20	1.35
	Cut frequently	1.30	1.57	1.26	1.40
Grimm	Hay	1.27	1.42	1.24	1.39
	Cut frequently	1.24	1.61	1.44	1.36
Vernal	Hay	1.22	1.45	1.26	1.36
	Cut frequently	1.65	1.73	1.34	1.42

[a]Forage from first hay cutting and first frequent-clipping.

[b]Forage from second hay-cut and third frequent-clipping.

[c]Forage from third hay-cut and fourth frequent-clipping.

Table 74. Number of alfalfa plants per square foot per eight varieties, under two cutting systems and four fertilizer treatments, in 1955 - average of 12 counts

Variety	Cutting treatment	Fertilizer treatment			
		P_0K_0	P_0K_1	P_1K_0	P_1K_1
Atlantic	Hay	10.0	9.0	9.8	9.3
	Cut frequently	11.2	9.0	7.8	8.2
A-224	Hay	8.7	9.0	9.7	8.0
	Cut frequently	9.4	11.0	10.0	8.3
Buffalo	Hay	10.3	9.4	9.3	8.3
	Cut frequently	8.4	11.3	10.0	8.2
Grimm	Hay	10.7	11.7	8.3	9.2
	Cut frequently	10.0	10.2	8.9	8.3
Ladak	Hay	13.5	13.9	11.7	9.8
	Cut frequently	12.2	10.4	11.6	9.3
Narragansett	Hay	8.8	9.5	8.6	9.8
	Cut frequently	10.9	14.6	7.5	9.1
Ranger	Hay	10.1	11.2	11.3	10.0
	Cut frequently	13.2	11.4	7.2	11.3
Vernal	Hay	9.2	8.3	9.8	9.2
	Cut frequently	10.3	11.3	10.2	10.0