

THE EFFECT OF PHOSPHORUS AND POTASSIUM
ON THE BOTANICAL AND CHEMICAL COMPOSITION
YIELD, AND PERSISTENCE OF ALFALFA AND
CERTAIN GRASSES GROWN IN COMBINATION

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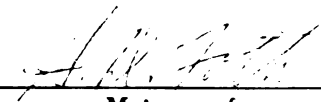
The Effect of Phosphorus and Potassium on the Botanical
and Chemical Composition, Yield, and Persistence of
Alfalfa and Certain Grasses Grown in Combination

presented by

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By

Joseph Neal Pratt

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A handwritten signature in dark ink, appearing to be "J. A. H. H.", is written over a horizontal line.

ABSTRACT

THE EFFECT OF PHOSPHORUS AND POTASSIUM ON THE BOTANICAL AND CHEMICAL COMPOSITION, YIELD, AND PERSISTENCE OF ALFALFA AND CERTAIN GRASSES GROWN IN COMBINATION

by Joseph Neal Pratt

The effect of phosphorus and potassium on the botanical and chemical composition, yield, and persistence of alfalfa when grown in association with certain grasses was studied under field and greenhouse conditions. Field plots established in 1954 were used to study the persistence of unfertilized alfalfa.

The botanical composition, yield, and chemical composition of forage for the fourth harvest year, 1958, were determined. Five soil profiles were sampled and analyzed for reserve phosphorus and potassium by horizons.

Fertilizer subtreatments resulted in yield differences which were highly significant for all eight cuttings over a four year period from 1954 to 1958. The highest amount of alfalfa in the forage occurred in the treatment and subtreatment receiving no fertilization at the time of establishment or as a topdressing. A significant negative correlation existed between the percentage of alfalfa in the forage and the amount of phosphorus in the soil. Increased phosphate applications increased the amount of

phosphorus extracted from soil samples, but increased potash applications resulted in little influence on the amounts of potassium extracted from soil samples.

In the 1959 field experiment, significant differences in yield existed as a result of five fertilizer treatments applied in the fall of 1958. Only treatments receiving the potash yielded significantly higher amounts of forage than the original check plots established in 1954 and which were check plots in 1959.

A tendency for decreased yield with phosphorus fertilization and increased yield with potash fertilization was shown by alfalfa with a reverse tendency shown by bromegrass. No radical change in the percentage of alfalfa in the forage during one growing season was noticed as a result of fertilizer treatment.

Phosphate fertilization increased the phosphorus content while decreasing the potassium content of both alfalfa and bromegrass tissue.

Potash fertilization increased the yields of both alfalfa and bromegrass. It caused little to no change in the phosphorus content while increasing the potassium content of both alfalfa and bromegrass.

Removal of soil phosphorus was increased as a result of both phosphate and potash fertilization. Removal of soil potassium was increased by potash fertilization and unchanged by phosphate fertilization.

In all three greenhouse experiments, striking similarities of yield resulted from phosphate and potash fertilization. High levels of phosphate fertilization increased the yields of grasses and had little influence on the yields of alfalfa. High levels of potash fertilization resulted in higher yields of alfalfa and lower yields of grasses.

The botanical composition of the alfalfa-bromegrass association showed significant differences as a result of both phosphate and potash fertilization. The lowest amount of applied phosphate produced the highest percentage of alfalfa in the forage, with the highest amount of phosphate producing the lowest percentage of alfalfa in the forage. Potash fertilization increased the percentage of alfalfa at low levels of added phosphate, but not at high levels of added phosphate.

The percentage of phosphorus and potassium in the tissue of alfalfa and the associated grass was increased as the applications of these nutrients were increased.

In all three greenhouse experiments, alfalfa contained a higher percentage of phosphorus in the tissue than the grass grown in association. The phosphorus content of bromegrass was higher than the phosphorus content of timothy and ryegrass.

Negative associations were found in all three greenhouse experiments between the percentage of alfalfa in the forage and the phosphorus content of the soil.

The persistence of alfalfa when grown with an associated grass without phosphorus or potassium fertilization was attributed to the subsoil furnishing phosphorus in sufficient amount to enable alfalfa to compete with a shallow rooted grass plant. The restricted growth of grass, in turn, enabled the soil to supply sufficient potassium to maintain the alfalfa in association with a grass. The pH of the surface and subsurface horizons may have proved a disadvantage in phosphorus uptake by the grass.

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I. INTRODUCTION

Alfalfa-grass mixtures (especially brome-grass) have been grown on considerable acreage in Michigan for several years. As early as 1943, alfalfa and smooth brome-grass had proved their value in a mixture for both pasturage and hay purposes. Although there have been exceptions, the general reports have indicated that compatible mixtures of grasses and legumes are higher yielding than any single component grown in a pure stand. Mixtures are more efficient than pure legumes in the control of soil erosion and in the prevention of bloat in cattle.

Maintenance of the desired portion of alfalfa growing in association with brome-grass has been a major problem in Michigan as well as many other regions. Increased competition from brome-grass, resulting from insufficient potash fertilization, has often been cited as the cause for decreased alfalfa percentages in stands with time.

A study of the establishment and fertilization of legume-brome-grass hay at the University Farm showed that plots receiving no fertilization contained a higher percentage of alfalfa at the end of a four year experiment than plots fertilized with phosphorus and potassium (26).

The purpose of this study was to determine how phosphorus and potassium fertilization affected the growth of the alfalfa and brome grass to provide an explanation for the persistence of alfalfa in the alfalfa-grass association. It was hoped that the information obtained would make possible a more efficient fertilization program for alfalfa-brome grass hay fields and pastures.

II. REVIEW OF LITERATURE

The growing of legumes and non-legumes together has been an important factor in agriculture from the earliest days, and an interesting historical review has been made by Wilson (74).

Frequently the treatment that would be best for any one of the component species of a mixture is not best for the mixture as a whole. There is less basic information on the responses of various forage species to management when two or more are grown in association than on the responses of individual species in pure stands.

One of the earliest workers to study the effect of fertilizers on maintaining stands of alfalfa was Brown (7) in Connecticut. He reported that: (a) nitrogenous fertilizers increased yields, but tended to increase the grasses and weeds and reduce the percentage of alfalfa in the stands, (b) carriers of phosphoric acid gave slightly better stands of alfalfa than no fertilizer treatment, and (c) potash was very beneficial in maintaining stands of alfalfa. The experiment was conducted on a Gloucester fine sandy loam, and all of the plots received lime.

Rich and Odland (53), studying the effect of various fertilizers on the botanical composition and yield of

grass-legume hay, used a standard application of 20 pounds of nitrogen, 80 pounds of phosphate, and 100 pounds of potash per acre. Reducing the nitrogen or phosphorus had no significant effect on either the yield or percentage of legumes in the hay. Reducing potash applications from 100 to 50 pounds per acre lowered the proportion of legumes from 50 to 39 per cent and the hay yield from 3.08 to 1.63 tons per acre. A further reduction in potash to 25 pounds resulted in less than two per cent legumes and a hay yield of only 1.17 tons per acre.

Chiasson (13) found in Canada that applications of nitrogen, phosphorus, and potassium to an area grazed and unfertilized for over 30 years resulted in some immediate and marked improvements in yield and botanical composition. Phosphorus at rates up to 80 pounds per acre brought about the most marked improvement, being responsible for highly significant increases in yield. Phosphorus increased wild white clover and useful grasses, and decreased weeds and bare ground. Potassium up to 60 pounds per acre also gave highly significant increases in yield. Potassium had little effect on the prevalence of species at first, but by the fourth year had maintained white clover better than phosphorus. The effect of nitrogen on botanical composition was largely to decrease the percentage of white clover with a corresponding increase in grasses.

Haskell (33) and Beaumont et al. (2) in Massachusetts reported that the clover and grass plots which received

high amounts of potassium showed a superior type of vegetation with respect to clovers.

Jackson et al. (34) found that on well limed and phosphated soils in Wisconsin 500 pounds of muriate of potash increased the total legumes from practically none to 50 to 70 per cent. Originally, 250 pounds of muriate of potash maintained alfalfa at only 10 per cent of the forage.

Parsons et al. (49) conducted field studies on Ladino clover, orchardgrass, smooth brome grass and timothy in Ohio. Each specie was planted in a pure stand. By the third crop year, Ladino clover comprised less than five per cent of the vegetation on the plots receiving low amounts of potash.

Stivers and Ohlrogge (61) found that the stand maintenance of alfalfa was closely related to both potassium fertilization and potassium content of alfalfa on two soil types in Indiana. The higher rates of potassium fertilization maintained stands better than the lower rates. There was no relationship between stand maintainence and phosphorus fertilization or phosphorus content.

Dodd (18) reported that lime, phosphate, and weather were the major factors responsible for the fluctuation in the white clover content of permanent sod areas in Ohio.

Sears (56) in New Zealand found that without dung and urine, grass-clover mixtures were dominated by clovers,

but where dung and urine were returned to the soil, the grasses were dominant. He also found that superphosphate gave responses in growth only on the mixture not receiving dung and urine.

Wang et al. (71) obtained results which they said left no question but that high levels of lime and available phosphorus and potassium markedly promote winter-survival of alfalfa in Wisconsin.

Determining the effect of different fertilizer levels on the yield, persistence, and chemical composition of alfalfa, Gerwig and Ahlgren (30) found in Wisconsin that potassium was the most important factor in maintaining high yields and persistence of an alfalfa stand. Potassium deficiency decreased the stand by as much as 80 per cent on the plots not receiving potassium. They found that nitrogen applications resulted in lower yields, reduced stands, and increased weeds. Phosphorus fertilization was found to have no significant beneficial effect.

Brown and Munsell (9) made a study in Connecticut of clovers in permanent grasslands as influenced by fertilization. They found that 30 to 40 pounds of nitrogen annually, even with lime, phosphorus, and potassium, increased the growth of grasses and depressed clover stands, and that omission, as well as large applications of phosphorus, depressed clover first.

In a study of the influence of association upon the forage yield of legume-grass mixtures, McCloud and Mott (42)

found that brome grass was higher yielding for the first two years, but that alfalfa led in the third year. The shift was apparently caused by a depletion of soil nitrogen favoring legume production.

In grass-legume associations, interspecific competition for nutrients is apparently a considerable factor in determining legume production. Blackman (5) showed that nitrogen fertilizers added to grass-clover associations may lead to marked suppression of the clover, due to the effects on nodule formation and increased competition from the grasses which are greatly stimulated.

The available nitrogen has a remarkable effect on the grass-clover balance. Although frequently explained by increased competition for light by nitrogen treated grasses, there is evidence to suggest a direct increase in nutrient competition. Mouat and Walker (44) studied the competition for nutrients between three grass species and white clover for phosphorus and potassium. Nitrogen application was shown to increase competition for nutrients by grasses in clover association without postulating an indirect mechanism acting through competition for light.

Willoughby (73) determined earlier that under appropriate conditions, grass development may be considerably reduced by competition for nitrogen by the associated clover.

Walker et al. (69) reported that grasses take up 95 per cent of the mineral nitrogen utilized by a grass-

clover association. Hence, an increase in the supply of combined nitrogen will thus automatically intensify the competition offered by grasses for other nutrients.

McLean (43) found that plants grown under variable nitrogen levels produced increased top growth with higher nitrogen levels than plants with low nitrogen levels. However, root growth did not increase in proportion to top growth. Contents of phosphorus and potassium were generally decreased with greater nitrogen content of the medium.

The use of nitrogen fertilizer on grass-legume meadows and pastures has received considerable attention from research workers in recent years. There have been several studies of the effect of fertilizer nitrogen on the botanical composition using clover as the legume. Ridgman et al. (54) in England obtained increases in the grass portion of an alfalfa-orchardgrass association using as much as 60 pounds of nitrogen per acre with no change in the alfalfa portion of the matter. Lewis (40) obtained total forage increases with nitrogen, but grasses increased at the expense of legumes. Rouse et al. (55) in Colorado found an increase in grass and a reduction of clovers. In a study by Sprague and Garber (59), nitrogen fertilization stimulated the grass to such an extent that Ladino clover was almost entirely crowded out.

In a study of nitrogen fertilization of alfalfa-grass mixtures on a Wooster silt loam soil in Ohio,

Parsons (48) found that nitrogen fertilizer of an alfalfa-orchardgrass sod produced more hay but increased the grass at the expense of the alfalfa. However, the yields and botanical compositions of alfalfa-bromegrass and alfalfa-timothy sods were not affected by nitrogen.

Carter and Foth (12) found that nitrogen fertilization increased yields of alfalfa in the greenhouse, but did not increase yields of alfalfa in the field when applied either at time of establishment or to established stands in Michigan.

How atmospheric nitrogen, symbiotically fixed by legumes, becomes available to associated plants has been investigated. It is remarkable how few experiments have demonstrated any increase in nitrogen uptake by the non-legumes during the period of vegetative growth of the legumes. A remarkable exception has been Virtanen's and von Hausen's (68) pot-culture trials. Virtanen and von Hausen (67) attributed this benefit from legumes to the excretion of nitrogenous compounds from the legume roots. Wilson and Burton (75), and Wilson and Wyss (76) have confirmed Virtanen's and von Hausen's (68) findings that direct excretion of nitrogen by legumes does occur, with a consequent increase in nitrogen uptake by the non-legumes. Subsequently, these workers (75, 76) confirmed that temperature, shade, and length of day affected excretion of nitrogen, and Strong and Trumble (62) also

found that shading may induce nitrogen excretion by legumes. Wilson (74) advanced a hypothesis that the beneficial effect is due to the sloughing-off of the roots and nodules. Black (4) concluded that the grasses may obtain nitrogen from legumes by both processes, namely, the excretion and sloughing-off. Walker and associates (70) held the opinion that the transference of nitrogen from the legumes to the grasses should probably increase as the proportion of legumes in the mixture increases. They concluded that: (a) in some cases, clovers seemed to transfer to grasses half the nitrogen fixed, in a form readily absorbed by grasses, (b) in a high producing association, almost all of the nitrogen under certain conditions could be contributed by the clovers, and (c) management should be directed toward a high production from clovers, which in turn should lead to high production from grasses if given the correct species and management.

Ramage (51) concluded that alfalfa-grass mixtures grown on Duchess and associated soil types in New Jersey without added nitrogen and adequately fertilized with phosphorus and potassium will produce yields of forage about equivalent to the yields of pure grass fertilized with 150 to 200 pounds of nitrogen per acre.

Blaser and Brady (6) conducted experiments in New York to ascertain the effects of nitrogen and potassium

fertilization on the productivity and botanical and chemical compositions of Ladino clover and non-legumes when grown in a mixture. They found that potassium fertilization stimulated the growth of Ladino clover, but did not directly affect the productivity of the non-leguminous plants in the association, and that nitrogen fertilization increased the growth of grasses and decreased the growth of the leguminous plants in a mixed association.

Vandecaveye and Baker (66) reported that the general effect of mixed phosphorus and potassium fertilizer was to increase the amount of clover in mixed grass hay. The chemical composition of alfalfa at harvest stage was less influenced by fertilization than was the chemical composition of grasses.

Forage yields of alfalfa and legume-grass mixtures were higher the first year after heavy initial broadcast application of phosphorus than after smaller broadcast or topdress applications according to Terman et al. (63) in Kentucky. In the following years, yields after the initial application only became progressively poorer, as compared to yields after smaller annual topdressings. Time of application affected yields much more than method of application or source of phosphorus.

Brown (8) found that smaller, frequent applications of muriate of potash were much more effective in maintaining

the stands and yields of a Ladino clover-orchardgrass seeding than larger, less frequent applications.

Doll et al. (19) reported a yield response from phosphorus, but not from potassium. Also, there was no movement of phosphorus below three inches, nor potassium below six inches in the soil.

In an alfalfa-bromegrass meadow where the fertilizer was broadcasted, the bromegrass obtained a greater percentage of its phosphorus from the fertilizer than did the alfalfa, according to Lawton et al. (39). However, at three and six inch depths, the alfalfa absorbed two to three times as much phosphorus as did the bromegrass.

Hanway et al. (32) topdressed alfalfa-timothy meadows with phosphorus and potassium fertilizers on a soil very low in these nutrients. They found competition between these species for both phosphorus and potassium, with alfalfa being the more dominant competitor for phosphorus and timothy more dominant for potassium. There was very efficient recovery of phosphorus and as much as 100 per cent recovery of potassium from several treatments.

Differences in ability of plant species to use potassium from the soil have long been observed. Drake et al. (21) contributed this ability largely to the cation-exchange capacity of the plant root and the valence of the cation. Cation-exchange capacity of roots of the

dicotyledonous plants investigated were roughly double the value for monocotyledons. Hence, they claimed that in grass-legume associations at low levels of soil potassium, because of the lower exchange capacity of the root surface, grasses were able to obtain much more potassium than legumes, which eventually reduce the yields and longevity of legume stands.

Gray et al. (31) in Massachusetts studied the competition for potassium when Ladino clover was grown alone and in association with each of three grasses. Their objective was to explain the disappearance of legumes from pasture mixes as a result of plant competition for potassium. The relative competitiveness for potassium was smooth brome grass (best), Kentucky bluegrass (intermediate), and bentgrass (poorest). They found that maintaining an adequate potassium supply for Ladino clover when in association with bentgrass was almost impossible.

Through greenhouse and laboratory investigation, Brown and Rouse (10) determined that the persistence of clover in white clover-Dallisgrass associations on Sumter clay in Alabama was highly dependent on potash and minor element fertilization. They reported that Dallisgrass had a greater ability than white clover to absorb potassium from the soil, either as a result of greater soil coverage by its fibrous root system or because it is able to absorb potassium from sources that are less available to clover.

Gray et al. (31) studied the relative uptake of potassium by Ladino clover, smooth brome grass, Kentucky bluegrass, and bentgrass when grown separately. They found that potassium uptake by plant species at low levels of soil potassium was closely correlated with root cation-exchange capacity.

Fried (27) compared certain plant species as to their feeding power for both monocalcium phosphate and rock phosphate. The species differed in their ability to absorb phosphorus from basic calcium phosphates. The phosphorus of rock phosphate was more available to legumes than to grasses. He suggested that the differences among species in their capacity to absorb phosphorus from basic calcium phosphate were due not only to differences in root size and extensiveness but also to differences in species-source interactions.

Seay and Weeks (58) reported that topdressed phosphorus was taken up by alfalfa even in the winter or dormant season.

Chin et al. (14) reported that the uptake of phosphorus by alfalfa from monocalcium phosphate on Minnesota soils in greenhouse studies was increased by lime application.

Finn et al. (24) found that rock phosphate resulted in higher yields of alfalfa hay and roots on three podzolized soils of eastern Canada than did superphosphate.

Lime did not greatly reduce the effect of rock phosphate except on one soil when the pH was raised to 8.0.

MacLean and Cook (41) reported that the greatest uptake of phosphorus and highest phosphorus content of alfalfa plants occurred at a pH of about 7.5. Also, the yields were either similar to or higher than at any lower pH.

Thorp and Hobbs (65) applied lime to some acid soils from the south-central part of Kansas. Both phosphorus and potassium uptake were increased by lime applications.

A linear relation was found by Seay et al. (57) to exist between the percentage of potassium contained in alfalfa and the logarithm of the number of pounds or exchangeable potassium per acre in the soil on which the crop was grown. Lawton and Tesar (38) found that potassium absorption by both alfalfa and brome grass was significantly increased as applied potassium increased in greenhouse treatments.

Attoe and Truog (1) in Wisconsin found the yields of alfalfa and clover hay to be significantly correlated with the levels of available phosphorus and potassium in the soil.

A prediction when legume hays will respond to added fertilizer, according to Lawton et al. (37), can be benefited by rapid soil tests. They found general relation

between response to fertilizers and the amount of phosphorus and potassium extracted by the rapid tests.

Nelson and MacGregor (45) reported that significant yield increases of alfalfa were associated with high potassium content and to a lesser degree with high phosphorus content of the plant. Soil samples from the top six inches showed almost no correlation between the phosphorus and potassium in the soil and that found in the alfalfa plants.

Cutting management is an important factor influencing productivity and maintenance of stands of grasses and legumes. The ultimate in management assures the continued survival of the seeded species in desirable proportion and the most effective production possible.

Gervais (29) studied the chemical composition of Ladino clover grown alone and in mixture with grasses as influenced by cutting treatments. He found that: (a) brome grass had a higher content of phosphorus and potassium than timothy, (b) the height at cutting failed to modify the chemical composition of the grasses, and (c) in both forage fractions, the phosphorus and potassium content were higher with four or six cuttings than with two cuttings.

As early as 1897, Crozier (16) showed that hay cut every seven days yielded much less than hay cut only once during the season. Ellett and Carrier (23) reported that

the total yield of hay varied inversely with the number of times it was cut. This has been reported by Nowosad and Stevenson (47).

In a study of the stage of cutting of grasses, using pure species alone, Bird (3) found that brome grass was the highest yielding of the group of four grasses which included brome grass, timothy, red-top and Kentucky blue-grass.

Burger et al. (11) reported that smooth brome grass was less persistent than tall fescue when in mixture with legumes and there was a higher percentage of legumes and more weed encroachment in the brome grass-legume mixture.

Kalton and Wilsie (35) studied the effect of six brome grass varieties sown broadcast with ranger alfalfa. They evaluated the forage yield and mixture composition for a four year period and found no difference in the yield of two cuttings per year among the varieties. They also found no difference in yield or composition due to the rate of alfalfa seeded.

In a study of the productivity and botanical composition of Ladino clover grown alone and in mixture with timothy and smooth brome grass, Gervais (28) found that: (a) the mixtures yielded more clover but less grass and total production when cut four times than when cut twice, and (b) the mixed swards contained the most clover when cut four times and the least when cut only twice. Because

of the slow establishment of brome grass, it produced a small amount of grass the first year in comparison with timothy, but outyielded timothy the second year.

Comstock and Law (15) reported that grass species were better able to compete with alfalfa when frequently clipped than when the clipping was less severe.

In a study of the effect of cutting treatments on the yield, botanical composition and chemical constituents of an alfalfa-brome grass mixture, Dotzenko and Ahlgren (20) reported that weed growth was generally greater under the treatments receiving earlier cuttings.

The results of Sprague and Garber (59) indicate that the time of removal of the first crop in the spring was an important factor in determining the persistence of Ladino clover. Removal of the first and subsequent crops when eight to ten inches in height provided good yields and maintained the clover better than later cuttings.

Nowosad and Stevenson (47), Newell and Keim (46), Koonce (36), and Rather and Harrison (52) have reported that more frequent cutting of alfalfa-grass mixtures favors the grass component as compared to cutting at the hay stage. Tesar and Ahlgren (64) conducted an experiment to determine the effect of two heights and three frequencies of cutting on the production and continued survival of Ladino clover grown alone and with smooth brome grass, timothy, or orchardgrass. They reported that the percentage

of surface area of soil occupied by Ladino clover was higher on the plots given the less severe cutting treatments than on plots given the more severe cutting treatments.

In a study of growth responses of alfalfa and Sudan-grass in relation to cutting practice and soil moisture, Dennis et al. (17) found that the yield was associated directly with the cutting interval. The more frequently plants were cut, the less productive they were.

III. METHODS AND MATERIALS

Field Experiments

Established field plots on the University Farm were used in an experiment to study the persistence of unfertilized alfalfa. The experiment was established in 1954 to study the effect of phosphate and potash fertilizer on the yield and stand maintenance of alfalfa-bromegrass hay (26).

A split-plot randomized block experimental design of the original experiment consisted of seven fertilizer treatments applied when the alfalfa-bromegrass was seeded, and six fertilizer subtreatments applied to the established stands. Eight pounds of Montana Grimm alfalfa and three pounds of Canadian bromegrass per acre were seeded with a standard grain drill without presswheels. The plots had been limed according to soil test. Oats was used as the companion crop.

In the spring of 1958, a definite change in the botanical composition of the forage was noticed. The plots which received no fertilizer at the time of establishment contained a larger percentage of alfalfa than the plots which received fertilizer. The same tendency had been observed at the end of a four year harvest period

in another experiment adjacently located. As a result of these observations, this study was initiated to try to explain the effect of phosphorus and potassium on the growth of alfalfa and brome grass when grown in association.

Just prior to harvest in June 1958, field estimates were made of the percentage of alfalfa. Forage samples, weighing approximately 1,000 grams, were collected for hand separation and determination of the botanical composition in the laboratory. They were sub-divided into four subsamples and the components in each were estimated. At first, the components were weighed, but as skill in estimating the percentages was obtained, only an occasional sample was weighed to check accuracy. Later the samples were ground in a Wiley mill in preparation for chemical analysis. Total forage yields were taken from areas of 7 by 40 feet and samples weighing approximately 1,000 grams were taken for determining the moisture content of the hay.

Samples of the top eight inches of soil were taken from all plots of main treatments 1, 6, and 7, and analyzed for reserve phosphorus and potassium and pH. These treatments represented the range of the percentage of alfalfa in the forage.

It was believed that information of the levels and location of nutrients in the soil might indicate a reason why alfalfa persisted without fertilization. Therefore,

five soil profiles were sampled and analyzed for reserve phosphorus and potassium by horizons.

In the fall of 1958, the fourth harvest year, the original experimental design was altered. The split-plot design consisting of seven main treatments and six sub-treatments was changed to a randomized block design consisting of seven main treatments. The plots which had received sub-treatment fertilization prior to 1958 received the fertilization of the main treatments in the fall of 1958. The fertilizers were applied as a topdressing in the fall. The treatments are given in Table 1.

TABLE 1.-Broadcast fertilizer treatments applied to the established field experiment in the fall of 1958

Original treatment ^a	Pounds P_2O_5 per acre	Pounds K_2O per acre
1. 0-0-0	Check	Check
2. 40-120-60	40	0
3. 20-120-60	200	0
4. 0-120-60	0	30
5. 40-120-60	0	150
6. 60-120-60	120	90
7. 60-240-120	Check	Check

^aPounds of N, P_2O_5 and K_2O per acre, respectively.

Just prior to harvest in 1959, field estimates were made of the percentage of alfalfa in the forage. The total forage yields were taken for each plot, and samples of approximately 1,000 grams were collected to determine the air-dry moisture content of the hay. The samples were later ground in a Wiley mill, oven dried, and analyzed for phosphorus and potassium.

A composite sample of the top eight inches of surface soil was taken from each plot at harvest time, 1959. The pH was determined with a glass electrode and reserve phosphorus and potassium were determined using 0.13 N HCl as the extracting solution.

The experiment was located on the University Farm at Forest and Harrison Roads in East Lansing, Michigan. The area includes a wide range of soil types from a well drained Brant loamy sand to a poorly drained Brookston clay loam.

Brant loamy sand is a light-colored, medium to slightly acid, well to moderately-well drained soil which developed on calcareous sands, gravels, and loamy sands, over calcareous loam to silty clay loam materials.

Dryden sandy loam is a moderately-well drained, fairly light colored, Gray-Brown Podzolic soil developed on a calcareous sandy loam till. The subsoil texture ranges from sandy clay loam to loam. Dryden is the moderately-well drained member of the catena which includes

the imperfectly drained Locke and poorly drained Barry series.

Conover loam is an imperfectly drained, moderately dark-colored Gray-Brown Podzolic soil which developed on highly calcareous loam till. It is slightly to medium acid throughout the solum and has a mottled clay loam subsoil.

Macomb fine sandy loam is an imperfectly drained soil which developed on gravelly loam and sandy loam materials overlying loam to clay loam calcareous till. The subsoil is a mottled sandy clay loam.

Barry sandy loam is a slightly acid to neutral, naturally poorly to very poorly drained soil developed on calcareous sandy loam till.

Brookston clay loam is a naturally poorly drained, dark-colored Humic Gley soil which developed on calcareous loam till. Brookston is the poorly drained member of the catena which includes the well drained Miami, the moderately-well drained Celina, and the imperfectly drained Conover.

Greenhouse Experiments

Three greenhouse experiments were initiated in the fall of 1958 to determine the influence of phosphorus and potassium fertilizer on the persistence of alfalfa when grown with different grasses.

The soil used for all three experiments was a Conover loam with a pH of 7.0, which was collected from an area adjacent to the field experiment. A brief description of this soil has been given earlier. The soil was dried, screened, weighed, mixed with fertilizer, and placed into four-gallon containers which had been lined with polyethylene bags. Grass and alfalfa seeds were planted in alternating semicircles near the outer edge of the pot.

The grass in association with alfalfa and the levels of phosphorus and potassium for the respective experiments are given in Table 2. Each pot received both phosphorus and potassium fertilization.

TABLE 2.-Grasses associated with alfalfa, and rates of phosphorus and potassium applied in three greenhouse experiments

	Exp. 1	Exp. 2	Exp. 3
Grass associated with alfalfa	Bromegrass	Perennial ryegrass	Timothy
Levels of phosphorus (pounds per acre)	50, 100, 200, 400	50, 400, 800	50, 400, 800
Levels of potassium (pounds per acre)	25, 50, 100, 200	25, 200, 400	25, 200, 400
Number of treatments	16	9	9
Replications	4	4	3

A few days after emerging, the plants were thinned to twelve alfalfa and twelve grass plants per pot. During

the course of the experiment the pots were weighed periodically and water was added to bring the soils to a uniform moisture content.

The forage was harvested when one-tenth to one-fourth of the alfalfa plants began to flower. A total of eight harvestings were made. The forage from each container was separated by hand immediately after cutting into the alfalfa and grass components. These components were dried in an oven at 70° C. and weighed. Due to insufficient weight of dry material for chemical analyses, replications for each treatment were combined. The combined samples of each treatment were ground in a Wiley mill and each cutting was analyzed separately for phosphorus and potassium.

Laboratory Techniques

Soils

Soil reaction was determined by a glass electrode using a 1:4 soil to water ratio. Available phosphorus and potassium were determined by the Spurway method (60) (0.13 N HCl, soil to acid dilution 1:4).

Plant Samples

The plant samples were wet-ashed by the perchloric acid method of Piper (50).

One gram sample was placed in a 180 ml. tall form beaker and 15 ml. of concentrated nitric acid were added.

The sample was digested on an electric hot plate until almost all of the organic matter was destroyed and a clear solution was obtained. After cooling, 6 ml. of 70 per cent perchloric acid were added to the solution and the digestion continued until the oxidation was complete and a clear, colorless solution was obtained. The solution was then evaporated almost to dryness, cooled, and the volume made up to 100 ml. with 0.1 N HCl. The solution was filtered through Whatman No. 2 filter paper.

The phosphorus in solution was determined by a molybdenum blue reduction method. One ml. of the solution was diluted to 10 ml. and 6 drops of ammonium molybdate-sulfuric acid reagent were added, followed by the same amount of Fiske-Subbarow (25) reagent. The solution was shaken, and after fifteen minutes the absorbance of blue color developed was measured in a Coleman spectrophotometer using a red filter (650 mμ).

The potassium in solution was determined using the Coleman Model 21 Flame Photometer. The source of fuel for the flame was natural gas burned in the presence of oxygen. Two ml. of the solution were diluted to 10 ml., shaken, and transferred to a 10 ml. beaker. The solution was vaporized and emission was measured using a red filter (771 mμ).

Computation

Analysis of variance and Duncan's Significant Studentized Range Test (22) were used to determine statistical significance. Any difference less than the L. S. D. value was considered not significant.

IV. RESULTS AND DISCUSSION

1958 Field Experiments

Yield

Table 3 shows the effect of fertilizer treatments and subtreatments on the yield of alfalfa-bromegrass hay in 1958 as reported by Foth et al. (26). There was no significant difference between the treatments, but there were highly significant differences between the subtreatments. The latter showed that by the fourth harvest year, plots receiving 60 pounds of potassium per acre annually were yielding significantly more forage than those receiving 30 pounds of potassium per acre. They also reported that fertilizer applications at the time of establishment caused significant yield differences for the first three cuttings, but not in the later cuttings. Also, fertilizer subtreatments resulted in highly significant yield differences for all eight cuttings over a four year period. Attention is directed to the fact that the check plots yielded approximately 85 per cent as much hay as the fertilizer plots.

Botanical Composition

The botanical composition of alfalfa-bromegrass forage at the time of the first cutting is presented in Table 4.

TABLE 3.--The effect of fertilizer treatment on the yield of alfalfa-bromegrass hay for the fourth harvest year, 1958

Treatments* at establishment (1954)	Tons per acre	
	1st cutting	2nd cutting
1. 0-0-0	1.54	.97
2. 40-120-60	1.66	.97
3. 20-120-60	1.72	.86
4. 0-120-60	1.64	1.05
5. 40-120-60	1.54	.82
6. 60-120-60	1.56	.83
7. 60-240-120	1.90	1.06
Mean	1.65	.94
L. S. D.	N.S.	N.S.
Subtreatments topdressed after establishment (1955-1958)		
A. 0-0-0	1.23 ^{d**}	.75 ^d
B. 0-60-30 spring of each year	1.70 ^b	.99 ^{ab}
C. 10-60-30 spring of each year	1.72 ^b	.89 ^{bc}
D. 0-120-60 spring of second harvest year	1.42 ^c	.78 ^c
E. 0-60-60 spring of each year	1.95 ^a	1.08 ^a
F. 0-60-60 after first cutting each year	1.92 ^a	1.13 ^a
Mean	1.66	.94
L. S. D.	1%	1%

* Pounds of N, P₂O₅ and K₂O per acre, respectively.

** Any two means that do not have the same letter are significantly different and any two means having the same letter are not significantly different as calculated by Duncan's shortest significant range test.

TABLE 4.-Botanical composition of alfalfa-bromegrass forage at the time of the first cutting of the fourth harvest year, 1958

Treatments ^a at establishment (1954)	Per cent of components			
	Field estimate		Laboratory inspection	
	Alfalfa	Alfalfa	Bromegrass	Weeds
1. 0-0-0	87	63	26	11
2. 40-120-60	71	47	47	6
3. 20-120-60	77	56	39	5
4. 0-120-60	80	51	44	5
5. 40-120-60	81	45	48	7
6. 60-120-60	68	46	48	6
7. 60-240-120	81	53	39	8
Subtreatments topdressed after establishment (1955-1958)				
A. 0-0-0	83	61	33	6
B. 0-60-30 spring of each year	76	47	45	8
C. 10-60-30 spring of each year	77	48	42	10
D. 0-120-60 spring of second harvest year	76	53	43	4
E. 0-60-60 spring of each year	78	50	43	7
F. 0-60-60 after first cutting each year	76	50	43	7

^a Pounds of N, P₂O₅ and K₂O per acre respectively.

The highest percentage of alfalfa in the forage was observed in the treatment and subtreatments receiving no fertilization at the time of establishment or later as a topdressing. The botanical composition as determined both

by field estimate and by laboratory inspection showed the same trend, even though the percentages of the latter were consistently smaller.

Yields of the alfalfa and bromegrass components, as calculated from the laboratory inspection data, reveal that the fertilizers increased the yield of grass much more than the yield of alfalfa, relatively speaking, and is consistent with the finding that the highest percentage of alfalfa existed on unfertilized plots in 1958.

Foth et al. (26) reported similar findings in another adjacently located bromegrass experiment for the first cutting of the fourth harvest year, 1956. The unfertilized forage contained 58 per cent alfalfa while the average for three fertilizer treatments, each containing phosphorus and potassium, was 35 per cent.

From the range of the percentage of alfalfa in the forage, fertilizer treatments 1, 6, and 7 were selected to determine if a relationship existed between soil nutrients and the percentage of alfalfa in the forage.

The results of soil analyses for reserve phosphorus and potassium in the top eight inches of soil of the selected treatments are shown in Table 5.

Correlation analysis of all plots of treatments 1, 6, and 7 revealed a significant negative correlation between the percentage of alfalfa in the forage and the amount of phosphorus in the soil.

TABLE 5.--Soil phosphorus and potassium of selected treatments, 1958

Treatments ^a at establishment (1954)	Pounds per acre		Per cent alfalfa
	Phosphorus	Potassium	
1. 0-0-0	32	47	63
6. 60-120-60	109	62	46
7. 60-240-120	55	56	53
Subtreatments topdressed after establishment (1955-1958)			
A. 0-0-0	52	55	61
B. 0-60-30 spring of each year	65	55	47
C. 10-60-30 spring of each year	72	55	48
D. 0-120-60 spring of second harvest year	64	52	53
E. 0-60-60 spring of each year	67	56	50
F. 0-60-60 after first cutting each year	72	56	50

^aPounds of N, P₂O₅ and K₂O per acre, respectively.

There was no significant correlation found between the percentage of alfalfa in the forage and the amount of potassium in the soil. However, the trend was similar to that for the phosphorus.

For the subtreatments, the highest percentage of alfalfa was again associated with the lowest soil test for phosphorus. No association existed between the percentage of alfalfa in the forage and the potassium revealed by soil test of the subtreatments.

Tissue Analyses

The percentages of phosphorus and potassium in alfalfa and brome grass tissue as determined by chemical analyses of selected treatments are shown in Table 6.

TABLE 6.-The phosphorus and potassium content of alfalfa and brome grass as influenced by selected fertilizer treatments, 1958

Treatments ^a at establishment (1954)	Alfalfa		Brome grass	
	Per cent P	Per cent K	Per cent P	Per cent K
1. 0-0-0	.21	1.02	.20	1.66
6. 60-120-60	.22	.89	.23	1.73
7. 60-240-120	.24	1.06	.23	1.64
L. S. D. 5%	N.S.	N.S.	N.S.	N.S.
Subtreatments topdressed after establishment (1955-1958)				
A. 0-0-0	.18	.89	.18	1.49
B. 0-60-30 spring of each year	.21	.94	.23	1.72
C. 10-60-30 spring of each year	.25	1.03	.24	1.61
D. 0-120-60 spring of second harvest year	.17	.78	.19	1.75
E. 0-60-60 spring of each year	.25	1.13	.25	1.66
F. 0-60-60 after first cutting each year	.24	1.00	.20	1.69
L. S. D. 5%	.03	N.S.	.03	N.S.
1%	.04	N.S.	.04	N.S.

^a Pounds of N, P₂O₅ and K₂O per acre, respectively.

Analysis of variance revealed no significant differences between the main treatments in the percentage of phosphorus and potassium.

The subtreatments, however, showed highly significant differences between the percentages of phosphorus in both alfalfa and brome grass tissue. The subtreatments receiving phosphorus each year contained significantly greater amounts of phosphorus in the tissue than the subtreatments receiving no phosphorus and those receiving phosphorus in the second harvest year. This condition existed for both alfalfa and brome grass tissue.

There were no significant differences between the subtreatments with respect to the percentages of potassium in either alfalfa or brome grass tissue. The subtreatment receiving potash only in the second harvest year contained the lowest percentage of potassium in alfalfa tissue and the highest percentage in brome grass tissue.

Highly significant correlations were found between the phosphorus in alfalfa and brome grass tissue and the phosphorus revealed by soil test. A similar association was not present between the potassium in plant tissue and the potassium revealed by soil test.

Soil Analyses of Profile Samples

The pH, phosphorus and potassium content by soil horizons of five soil profiles taken in 1958 are shown in

Table 7. The table shows that the lower soil horizons tended to have more phosphorus than the upper soil horizons. The reverse tendency is shown for soil potassium. Average values for all five soils revealed an increasing amount of phosphorus and a decreasing amount of potassium with soil depth.

These findings are in agreement with Whiteside (72). He grouped some Michigan soils with similar profile characteristics, similar management requirements, and similar potential productivities. The groups of soils that included the soils in this experiment contained more available phosphorus in the subsurface horizons than in the surface horizons. Available potassium was less in the subsurface horizons than in the surface horizons.

The pH appears satisfactory for the growth of alfalfa in all cases.

1959 Field Experiments

As was mentioned earlier, the experimental design was altered in the fall of 1958. The subtreatments were grouped into one treatment, making seven treatments, each consisting of six plots of the original experiment. The fertilizer treatments applied in the fall of 1958 were given in Table 1.

Drainage tile was installed in part of the experiment in the spring of 1959. Therefore, only two of the original four replications were harvested for a total of 84 plots.

TABLE 7.--Soil pH, phosphorus and potassium content by horizons of five profiles taken at selected locations on experimental plots, 1958

Horizon	Depth in inches	Pounds per acre		pH
		Phosphorus	Potassium	
<u>Celina sandy loam</u>				
A _p	0-6	11	55	6.4
A ₂	9-15	10	55	6.2
B ₂	18-22	72	55	6.8
C ₁	28-32	6	34	8.3
<u>Celina sandy loam</u>				
A _p	0-6	10	27	7.3
A ₂	9-15	4	69	6.7
B ₂	18-22	24	34	6.9
C ₁	28-32	187	34	8.0
<u>Brookston clay loam</u>				
A _p	0-6	121	82	7.0
A ₂	9-15	198	21	7.4
B ₂	18-22	209	27	7.8
C ₁	28-32	9	14	7.8
<u>Locke fine sandy loam</u>				
A _p	0-6	19	62	7.2
A ₂	9-15	84	41	7.1
B ₂	18-24	55	41	6.4
C ₁	26-30	198	41	7.8
<u>Conover loam</u>				
A _p	0-6	11	62	7.3
A ₂	9-15	27	76	6.8
B ₂	18-22	42	34	7.0
C ₁	23-26	10	21	8.3

Yield

Table 8 shows the yield in tons per acre of alfalfa-bromegrass hay as influenced by fertilizer treatments.

TABLE 8.-The effect of fertilizer treatment on the yield and botanical composition of the first cutting of alfalfa-bromegrass hay, 1959

Treatment ^a	Tons of hay per acre	Per cent alfalfa in forage	Tons per acre	
			Yield Alfalfa	Grass ^b
1. 0-0-0	1.51	64	.97	.54
2. 0-40-0	1.55	60	.93	.62
3. 0-200-0	1.60	48	.77	.83
4. 0-0-30	1.77	56	.99	.78
5. 0-0-150	2.03	66	1.34	.69
6. 0-120-90	1.83	64	1.17	.66
7. 0-0-0	1.69	62	1.05	.64
L. S. D. 5%	.21			
1%	.29			

^a Pounds of N, P₂O₅ and K₂O per acre, respectively.

^b All forage other than alfalfa.

Analysis of variance showed a significant difference between fertilizer treatments.

The lowest yielding treatment was one of the checks (treatment number 1), while the highest yielding treatment was the one receiving the highest amount of potash (treatment number 5).

Only treatments receiving potash yielded significantly higher amounts of forage than the original check plots established in 1954, and which were check plots (treatment number 1) in 1959.

The calculated yield of alfalfa (Table 8) showed a tendency for decreased yield with phosphorus fertilization and increased yield with potash fertilization. The yield of grass showed a reverse trend. As was the case in the 1958 data, fertilization increased the production of grass more than the production of alfalfa.

The results of Rich and Odland (53) were similar. They found that reducing the amount of potassium applied to grass-legume stands from 100 to 50 pounds per acre reduced the total hay yield from 3.08 to 1.63 tons per acre.

Comparison of the total yields of hay in 1959 with the yields of hay of subtreatments B, C, E and F in 1958 reveals striking similarity of the effect of potash fertilization.

Botanical Composition

The estimated percentage of alfalfa in the forage at the time of cutting in 1959 is shown in Table 8. Although there was no significant difference, treatment number 3 (high phosphate) contained the lowest percentage of alfalfa. The treatments receiving potash and the treatments receiving no fertilization showed very similar trends in their composition.

The works of Haskell (33) and Beaumont et al. (2) might be considered at this point. They reported that

clover and grass plots in Massachusetts which received high amounts of potassium showed a superior type of vegetation with respect to clovers. Rich and Odland (53) reported that reducing potassium applications from 100 to 50 pounds per acre reduced the proportion of legumes from 50 to 39 per cent.

The omission of fertilizer in 1958 from the original check plots did not cause these plots to have a smaller percentage of alfalfa in 1959 than those fertilized each year for five years with phosphorus and potassium.

Tissue Analyses

The results of chemical analyses for phosphorus and potassium in plant tissues are given in Table 9.

TABLE 9.--The phosphorus and potassium content of alfalfa and bromegrass as influenced by fertilizer treatment in the 1959 field experiment

Treatment ^a	Alfalfa		Bromegrass	
	Per cent P	Per cent K	Per cent P	Per cent K
1. 0-0-0	.19	.74	.18	1.36
2. 0-40-0	.23	.68	.24	1.13
3. 0-200-0	.24	.67	.27	1.14
4. 0-0-30	.20	1.02	.19	1.66
5. 0-0-150	.19	1.22	.16	1.94
6. 0-120-90	.23	1.06	.24	1.71
7. 0-0-0	.24	.79	.23	1.17
L. S. D. 5%	.03	.17	.03	.35
1%	.05	.26	.05	.52

^a Pounds of N, P₂O₅ and K₂O per acre, respectively.

Phosphate fertilization increased significantly the amount of phosphorus in alfalfa tissue over the treatments which received potash fertilization. Similarly, treatments receiving potash fertilization contained significantly higher amounts of potassium in the tissue than the check treatments and treatments receiving phosphorus fertilization.

There is a striking similarity of results obtained from chemical analyses of bromegrass tissue. The tendencies are the same, although the percentages of these two nutrients are somewhat different. Bromegrass contained a higher percentage of potassium in the tissue than did alfalfa.

It might be mentioned at this point that the results from treatment number 7 (check) were similar to treatments receiving phosphate fertilization. Possibly there was some carry-over of phosphorus from the original experiment.

The removal of phosphorus and potassium from the soil by alfalfa and bromegrass is shown in Table 10.

Phosphorus fertilization increased the percentage of phosphorus while decreasing the percentage of potassium in both alfalfa and bromegrass tissue. The yield of alfalfa was decreased and the yield of bromegrass increased as a result of added phosphorus. At the same time, removal of potassium from the soil was decreased by alfalfa and increased by bromegrass.

TABLE 10.—The amount of phosphorus and potassium removed from the soil by alfalfa and bromegrass in the field, 1959

Treatment ^a	Pounds per acre removed by				Total pounds per acre removed	
	Alfalfa		Bromegrass			
	Phosphorus	Potassium	Phosphorus	Potassium		
1. 0-0-0	3.68	14.4	1.94	14.6	5.62	29.0
2. 0-40-0	4.26	12.6	2.96	14.0	7.22	26.6
3. 0-200-0	3.70	10.4	4.48	19.0	8.18	29.4
4. 0-0-30	3.96	20.2	2.96	25.8	6.92	49.8
5. 0-0-150	5.10	32.6	2.20	26.8	7.30	59.4
6. 0-120-90	5.38	24.8	3.16	22.6	8.54	47.4
7. 0-0-0	5.04	16.6	2.94	15.0	7.98	31.6

^a Pounds of N, P₂O₅ and K₂O per acre, respectively.

potash fertilization caused no change in the percentage of phosphorus in alfalfa and a slight decrease in the percentage of phosphorus in bromegrass. This was accompanied by an increase in the percentage of potassium in both alfalfa and bromegrass tissues. Potassium increased the yield of alfalfa. Removal of phosphorus from the soil by both alfalfa and bromegrass was slightly increased, whereas removal of potassium from the soil was greatly increased as a result of adding potash.

Phosphorus removal from the soil by alfalfa and bromegrass increased as a result of both phosphate and potash fertilization. Removal of potassium from the soil was unchanged as a result of phosphate fertilization, but increased by potash fertilization.

Soil Analyses

The results of analyses for reserve phosphorus and potassium of the soil samples taken after harvest are shown in Table 11.

The treatments receiving phosphate fertilization contained more phosphorus in the soil sample than the treatments not receiving phosphate fertilization. Similar results were obtained from treatments receiving potash fertilization.

TABLE 11.-The reserve phosphorus and potassium content of the soil as influenced by alfalfa-bromegrass under different fertilizer treatments, 1959

Treatment ^a	Pounds per acre	
	Phosphorus	Potassium
1. 0-0-0	22	37
2. 0-40-0	31	36
3. 0-200-0	56	31
4. 0-0-30	19	50
5. 0-0-150	26	57
6. 0-120-90	38	44
7. 0-0-0	47	37

^aPounds of N, P₂O₅ and K₂O per acre, respectively.

The results of soil analyses in 1958 and 1959 differ. Increased potash application showed little influence on the amount of potassium extracted from soil samples in 1958, while in 1959 soil samples from the treatments receiving potash fertilization showed a marked increase in the amount of potassium extracted, but the amount extracted was still low.

There was no significant correlation found between the percentage of alfalfa in the forage and the phosphorus or potassium extracted from the soil samples. This is in contrast with the findings in 1958 when a significant negative correlation existed between the percentage of alfalfa in the forage and the amount of phosphorus in the soil. However, treatment 3 had the highest rate of

phosphorus applied, the highest soil test for phosphorus after harvest and the lowest percentage of alfalfa in the forage.

There was a significant correlation found, however, between the percentage of phosphorus in both alfalfa and brome grass tissue and the phosphorus content of the soil. In addition, there was a highly significant correlation between the percentage of potassium in both alfalfa and brome grass tissue and the potassium content of the soil.

Blaser and Brady (6) found that potassium fertilization stimulated the growth of Ladino clover, but did not directly affect the productivity of the non-leguminous plants in the association.

Greenhouse Experiments

Attention is directed to Table 2 which lists the grasses grown in association with alfalfa, the rates of phosphorus and potassium fertilization, and the number of replications for each of the three greenhouse experiments. It might be recalled at this point that treatments 1 and 2 contained four replications, while treatment 3 contained three replications.

Yield

The effect of fertilizer treatments on the total yields of alfalfa and brome grass when grown in association is shown in Tables 12 and 13.

TABLE 12.-The effect of fertilizer treatment on the yield of alfalfa when grown with bromegrass in the greenhouse^a

Treat- ment	Cutting								Av.
	1	2	3	4	5	6	7	8	
P ₁ K ₁	15.3	56.7	40.3	47.4	27.9	29.6	27.0	20.2	33.0
P ₁ K ₂	13.9	61.1	42.2	51.5	28.3	32.2	25.2	20.6	34.4
P ₁ K ₃	17.6	61.7	47.8	51.9	32.9	40.6	28.6	24.0	38.1
P ₁ K ₄	21.8	62.3	54.6	64.4	41.5	48.4	32.8	25.8	44.0
P ₂ K ₁	11.1	45.9	34.8	42.2	26.6	33.4	14.8	12.0	27.6
P ₂ K ₂	3.6	36.7	25.2	26.6	14.1	19.4	11.2	8.6	18.2
P ₂ K ₃	14.2	59.8	38.6	52.0	25.8	34.0	21.0	22.8	33.5
P ₂ K ₄	19.6	60.6	49.6	57.0	33.2	43.8	23.6	25.4	39.1
P ₃ K ₁	12.9	54.9	37.8	44.4	23.4	32.0	18.4	12.0	29.5
P ₃ K ₂	12.3	52.0	37.2	39.3	21.8	28.0	17.0	12.0	27.5
P ₃ K ₃	16.3	53.6	38.8	40.5	27.0	34.2	25.2	20.8	32.1
P ₃ K ₄	16.1	50.3	42.4	47.3	30.4	34.4	24.6	22.6	33.5
P ₄ K ₁	15.4	45.4	33.0	39.0	28.7	34.2	21.8	15.8	29.2
P ₄ K ₂	17.0	51.3	40.6	42.9	25.1	31.6	20.8	15.6	30.6
P ₄ K ₃	18.4	61.9	45.4	55.2	31.2	39.6	28.4	21.6	37.7
P ₄ K ₄	10.2	58.9	42.2	51.7	23.7	33.6	22.2	17.6	32.5
L.S.D.									
5%	N.S.	3.3	2.7	3.1	2.5	3.4	2.7	2.0	
1%	N.S.	4.4	3.6	4.1	3.3	4.6	3.6	2.6	
P x K	N.S.	N.S.	N.S.	5%	N.S.	N.S.	N.S.	N.S.	

^aTotal yield in grams of four replications.

TABLE 13.-The effect of fertilizer treatment on the yield of bromegrass when grown with alfalfa in the greenhouse^a

Treat- ment	Cutting								Av.
	1	2	3	4	5	6	7	8	
P ₁ K ₁	3.7	4.7	4.6	7.6	7.5	10.4	7.6	2.6	6.1
P ₁ K ₂	3.6	3.1	3.8	7.2	6.9	10.2	6.8	1.6	5.4
P ₁ K ₃	5.9	3.2	3.4	4.6	5.5	7.4	3.6	.6	4.3
P ₁ K ₄	4.0	2.8	3.4	5.6	6.6	9.0	6.6	.6	4.8
P ₂ K ₁	5.9	7.3	7.4	13.8	8.1	12.8	8.6	5.2	8.6
P ₂ K ₂	4.9	8.0	8.0	10.6	9.3	11.8	10.8	6.4	8.7
P ₂ K ₃	4.1	4.2	4.2	7.8	7.9	10.2	6.8	2.2	5.9
P ₂ K ₄	2.8	4.1	4.2	6.4	6.8	9.0	6.0	1.0	5.0
P ₃ K ₁	3.4	4.7	4.0	6.2	6.0	9.2	5.6	1.0	5.0
P ₃ K ₂	5.7	5.5	5.6	10.0	7.9	11.8	8.6	4.0	7.4
P ₃ K ₃	3.4	7.2	4.8	10.6	7.7	9.8	8.0	1.4	6.6
P ₃ K ₄	4.3	7.1	5.2	9.8	7.5	10.2	7.4	1.2	6.6
P ₄ K ₁	6.7	10.7	9.0	11.2	8.7	12.2	8.0	1.6	8.5
P ₄ K ₂	4.0	7.3	6.2	9.8	8.6	12.2	6.2	2.0	7.0
P ₄ K ₃	4.2	6.8	5.2	10.2	10.2	11.6	5.6	1.8	7.0
P ₄ K ₄	4.0	4.9	5.4	9.8	9.4	10.8	7.8	3.8	7.0
L.S.D.									
5%	N.S.	.3	.1	1.3	.1	N.S.	N.S.	.9	
1%	N.S.	.4	.1	1.8	.1	N.S.	N.S.	1.1	
P x K	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	

^aTotal yield in grams of four replications.

The differences between cuttings were highly significant for both species, probably due to varied climatic conditions.

Analyses of variances also show highly significant differences due to both phosphate and potash fertilizations, with one significant phosphorus-potassium interaction.

Generally speaking, the higher rates of phosphate fertilization decreased the yields of alfalfa and increased the yields of bromegrass.

With one exception, the highest level of potash application gave significantly higher yields of alfalfa and significantly lower yields of bromegrass over the lowest level of potash fertilization.

When each cutting of alfalfa was analyzed separately, there were significant differences due to phosphorus in six of the eight cuttings; significant differences due to potassium in seven of the eight cuttings; but only one significant phosphorus-potassium interaction of the eight cuttings. Separate analyses for the cuttings of brome-grass, however, showed significant differences due to phosphorus in five of the eight cuttings, and a difference due to potassium in only one of the eight cuttings.

Tables 14 and 15 show the effect of fertilizer treatments on the yield of alfalfa and perennial ryegrass when grown in association.

TABLE 14.-The effect of fertilizer treatment on the yield of alfalfa when grown with perennial ryegrass in the greenhouse^a

Treat- ment	Cutting								
	1	2	3	4	5	6	7	8	Av.
P ₁ K ₁	10.3	53.7	38.8	56.1	32.6	67.4	35.4	29.8	40.5
P ₁ K ₂	15.5	65.5	43.8	61.4	37.2	62.4	33.2	32.4	43.9
P ₁ K ₃	18.6	57.8	47.2	64.9	43.9	67.2	40.2	34.6	46.8
P ₂ K ₁	17.7	61.3	41.8	52.9	44.4	69.6	36.0	35.0	44.8
P ₂ K ₂	20.6	66.6	41.0	55.6	42.9	63.6	28.2	32.8	43.9
P ₂ K ₃	20.9	55.5	47.0	60.1	46.3	83.6	49.8	35.4	49.8
P ₃ K ₁	13.5	59.4	41.8	51.4	43.4	65.2	30.0	24.0	41.1
P ₃ K ₂	24.6	66.3	42.2	60.1	45.9	73.6	50.0	34.0	49.6
P ₃ K ₃	22.6	73.7	48.8	62.2	50.9	76.0	47.2	36.8	53.4
L. S. D.									
5%	1.6	2.9	1.6	2.7	1.6	2.7	2.5	1.2	
1%	2.1	4.0	2.1	3.7	2.2	3.6	3.4	1.6	
P x K	N.S.	N.S.	N.S.	N.S.	N.S.	5%	1%	1%	

^aTotal yield in grams of four replications.

Analysis of variance of alfalfa yields revealed significant differences due to cuttings, phosphorus and potash fertilization, and phosphorus-potassium interaction. Analysis of variance of ryegrass yields, however, showed differences due only to cuttings and phosphorus fertilization.

TABLE 15.-The effect of fertilizer treatment on the yield of perennial ryegrass when grown with alfalfa in the greenhouse^a

Treat- ment	Cutting								Av.
	1	2	3	4	5	6	7	8	
P ₁ K ₁	15.6	14.2	2.2	4.0	. .	. .	3.0	1.2	6.7
P ₁ K ₂	14.2	12.1	3.8	3.6	. .	. .	7.0	2.0	7.1
P ₁ K ₃	13.6	10.0	3.2	2.6	. .	. .	2.6	1.2	5.5
P ₂ K ₁	12.5	13.4	3.6	4.2	. .	. .	6.6	2.4	7.1
P ₂ K ₂	13.7	12.3	6.4	7.8	. .	. .	11.2	4.4	9.3
P ₂ K ₃	12.3	10.9	4.6	4.4	. .	. .	3.4	.6	6.0
P ₃ K ₁	18.3	18.5	3.6	5.4	. .	. .	13.4	9.8	11.4
P ₃ K ₂	12.8	13.2	4.2	4.2	. .	. .	10.4	4.2	8.2
P ₃ K ₃	15.9	15.2	5.0	5.2	. .	. .	8.4	3.8	8.9
L.S.D.									
5%	N.S.	.6	.5	.6	. .	. .	.9	.5	
1%	N.S.	.8	.7	.8	. .	. .	1.3	.7	
P x K	N.S.	N.S.	N.S.	N.S.	. .	. .	5%	1%	

^aTotal yield in grams of four replications.

The higher rates of phosphate fertilization increased the yields of ryegrass, relatively speaking, more than the yields of alfalfa. In experiment 1, the yields of alfalfa were decreased with increased phosphate fertilization.

As in experiment 1, the yields of alfalfa were increased with increased potash fertilization, whereas the

yields of ryegrass were decreased with increased potash fertilization.

Analyses of individual cuttings of alfalfa revealed significant differences due to phosphorus fertilization in six of the eight cuttings; significant differences due to potash fertilization in all eight cuttings; and phosphorus-potassium interactions in three of the eight cuttings.

Growth of the grass in two of the eight cuttings was insufficient to be measured. The significant differences in the individual cuttings of ryegrass were due to phosphorus fertilization in five of the six cuttings, to potassium fertilization in four of the six cuttings, and to phosphorus-potassium interaction in only two of the six cuttings.

The yields of alfalfa and timothy in experiment 3 are reported in Tables 16 and 17.

There were highly significant differences in the yields of alfalfa due to cuttings, and phosphorus and potassium fertilization, while only cuttings showed differences in the grass yields.

Analysis of each cutting of alfalfa separately revealed differences in six of the eight cuttings due to phosphate fertilization and in four of the eight cuttings due to potash fertilization. One of the eight cuttings had significant phosphorus-potassium interaction.

TABLE 16.-The effect of fertilizer treatment on the yield of alfalfa when grown with timothy in the greenhouse^a

Treat- ment	Cutting								Av.
	1	2	3	4	5	6	7	8	
P ₁ K ₁	19.7	41.9	30.2	36.9	21.6	44.2	32.2	24.0	31.3
P ₁ K ₂	21.2	47.4	36.6	32.8	33.4	47.4	43.2	27.4	36.1
P ₁ K ₃	19.1	51.9	39.2	37.4	36.0	48.6	48.0	28.0	38.5
P ₂ K ₁	18.2	47.4	38.2	48.2	34.8	59.6	40.6	25.6	39.1
P ₂ K ₂	20.9	52.7	35.6	50.6	35.8	59.0	53.4	26.8	41.8
P ₂ K ₃	23.9	55.6	41.4	44.2	38.1	62.6	63.0	26.4	44.4
P ₃ K ₁	20.2	53.7	38.6	52.0	29.6	49.4	37.0	19.8	37.5
P ₃ K ₂	20.7	52.5	39.6	53.2	33.7	54.2	53.4	25.6	41.6
P ₃ K ₃	21.4	59.6	41.4	52.0	34.2	57.8	48.0	30.8	43.2
L.S.D.									
5%	N.S.	2.9	1.6	2.1	1.7	2.8	3.1	1.8	
1%	N.S.	4.0	2.1	2.8	2.4	3.8	4.2	2.5	
P x K	N.S.	N.S.	N.S.	N.S.	5%	N.S.	N.S.	N.S.	

^aTotal yield in grams of three replications.

Immeasurable amounts of grass were produced for the fourth, fifth, sixth, and eighth cuttings. Only one of the four cuttings showed any significant difference due to phosphorus and potassium fertilization.

As in experiments 1 and 2, increased potash applications increased the yields of alfalfa and decreased the yields of the grass.

TABLE 17.-The effect of fertilizer treatment on the yield of timothy when grown with alfalfa in the greenhouse^a

Treat- ment	Cutting								Av.
	1	2	3	4	5	6	7	8	
P ₁ K ₁	4.8	11.0	1.4	. .	. .	. .	3.0	. .	5.1
P ₁ K ₂	6.6	9.6	1.0	. .	. .	. .	2.0	. .	4.8
P ₁ K ₃	4.5	4.8	1.4	. .	. .	. .	2.2	. .	3.2
P ₂ K ₁	7.3	14.0	2.4	. .	. .	. .	4.2	. .	7.0
P ₂ K ₂	4.1	11.1	.6	. .	. .	. .	2.8	. .	4.7
P ₂ K ₃	3.9	8.7	1.4	. .	. .	. .	3.4	. .	4.4
P ₃ K ₁	6.2	13.9	1.2	. .	. .	. .	4.2	. .	6.4
P ₃ K ₂	4.2	12.4	.4	. .	. .	. .	3.2	. .	5.1
P ₃ K ₃	5.2	12.6	1.4	. .	. .	. .	4.2	. .	5.9
L.S.D.									
5% N.S.	N.S.	1.2	N.S.	. .	. .	. .	N.S.	. .	N.S.
1% N.S.	N.S.	1.6	N.S.	. .	. .	. .	N.S.	. .	N.S.
P x K	N.S.	N.S.	N.S.	. .	. .	. .	N.S.	. .	N.S.

^aTotal yield in grams of three replications.

Increased phosphate fertilization increased the yields of timothy, but had little effect on the yields of alfalfa. A similar tendency was observed in experiment 2.

The yields of alfalfa and the associated grass for all three greenhouse experiments have been summarized in Table 18. The higher rates of phosphate fertilization increased the yield of grasses in all three experiments,

TABLE 18.-A summary table of the yield of alfalfa and grass of three greenhouse experiments at different levels of phosphorus and potassium fertilization^a

Level of Nutrient	Alfalfa			Grass			Total		
	Experiment			Experiment			Experiment		
	1	2	3	1	2	3	1	2	3
P ₁	37.4	43.7	35.3	5.2	6.4	4.4	42.6	50.1	39.7
P ₂	29.6	46.1	41.8	7.1	7.7	5.4	36.7	55.8	47.2
P ₃	30.6	48.0	40.7	6.4	9.5	5.8	37.0	57.5	46.5
P ₄	32.5			7.4			39.9		
K ₁	29.8	42.1	35.9	7.1	8.4	6.2	36.9	50.5	42.1
K ₂	27.7	45.8	39.8	7.1	8.2	4.9	34.8	54.0	44.7
K ₃	35.4	45.0	42.0	5.9	6.8	4.5	41.3	51.8	46.5
K ₄	37.3			5.9			43.2		

^aAverage total yield in grams of four replicated pots for experiments 1 and 2, and average total yield in grams of three replicated pots for experiment 3.

while the yield of alfalfa was slightly decreased in one and increased in two of the experiments. Increasing potash resulted in increased yields of alfalfa and decreased yields of grasses in all three experiments.

These results are supported by the findings of several workers. Rich and Odland (53) found that phosphorus had no significant effect on the yield or percentage of legumes in grass-legume combinations. Reducing potassium applications from 100 to 50 pounds per acre reduced the hay yield from 3.08 to 1.63 tons per acre. Gerwig and Ahlgren (30) in Wisconsin found that potassium was the most important factor in maintaining high yields of alfalfa. Phosphorus fertilization was found to have no beneficial effect. Blaser and Brady (6) also found that potassium fertilization stimulated the growth of Ladino clover, but did not directly affect the productivity of the non-leguminous plants in the association.

Other factors beside phosphorus and potassium fertilization have definite influences on the yield of legume-grass mixtures. Cutting management is an important factor influencing the productivity of stands of grasses and legumes.

Several workers (17, 23, 28, 36, 46, 47, 52, 64) have reported that the total yield of hay varied inversely with the number of times it was cut during the season.

Botanical Composition

The effect of fertilizer treatments on the botanical composition of the forage is shown in Tables 19, 20, and 21. The percentages of alfalfa shown in the tables are the averages of all eight cuttings. When the growth of grass was immeasurable in certain cuttings, the forage was considered to consist entirely of alfalfa.

TABLE 19.—The effect of fertilizer treatment on the average botanical composition of eight cuttings of alfalfa-brome-grass mixture grown in the greenhouse

Treatment		Per cent alfalfa in forage
P ₁ K ₁		85
P ₁ K ₂		86
P ₁ K ₃		89
P ₁ K ₄		90
P ₂ K ₁		80
P ₂ K ₂		74
P ₂ K ₃		85
P ₂ K ₄		89
P ₃ K ₁		85
P ₃ K ₂		80
P ₃ K ₃		85
P ₃ K ₄		84
P ₄ K ₁		75
P ₄ K ₂		77
P ₄ K ₃		82
P ₄ K ₄		76
L. S. D. 5%		4
1%		5

TABLE 20.-The effect of fertilizer treatment on the average botanical composition of eight cuttings of an alfalfa-ryegrass mixture grown in the greenhouse

Treatment	Per cent alfalfa in forage
P ₁ K ₁	88
P ₁ K ₂	90
P ₁ K ₃	92
P ₂ K ₁	89
P ₂ K ₂	87
P ₂ K ₃	91
P ₃ K ₁	81
P ₃ K ₂	88
P ₃ K ₃	88
L. S. D. 5%	N.S.

TABLE 21.-The effect of fertilizer treatment on the average botanical composition of eight cuttings of an alfalfa-timothy mixture grown in the greenhouse

Treatment	Per cent alfalfa in forage
P ₁ K ₁	94
P ₁ K ₂	94
P ₁ K ₃	95
P ₂ K ₁	92
P ₂ K ₂	96
P ₂ K ₃	95
P ₃ K ₁	92
P ₃ K ₂	95
P ₃ K ₃	94
L. S. D. 5%	N.S.

Analysis of variance of the percentage of alfalfa in the forage in experiment 1 revealed significant differences due to both phosphate and potash fertilization. The lowest amount of applied phosphate produced the highest percentage of alfalfa in the forage, and the highest amount of phosphate produced the lowest percentage of alfalfa in the forage. The percentage of alfalfa in the forage was increased by potash fertilization at low levels of phosphate fertilization, but was not affected to such an extent at high levels of phosphate fertilization.

Analysis of variance of the percentage of alfalfa in the forage in experiments 2 and 3 reveal no significant differences in the percentages of alfalfa in the forage due to either phosphate or potash fertilization.

All three experiments (Table 22) indicated a trend of decreased alfalfa percentage as a result of high rates of phosphate, and increased alfalfa percentage with high rates of potash fertilization.

These results agree with the findings of several workers. Brown and Munsell (9) reported that omission, as well as large applications of phosphorus depressed clovers first in permanent grasslands in Connecticut. Rich and Odland (53) found, when using 80 pounds per acre of phosphate, that reducing potash reduced the proportion of legumes. Stivers and Ohlrogge (61) reported that stand maintenance of alfalfa was closely related to potash

fertilization, especially at high rates. They found no relationship between stand maintenance and phosphate fertilization. Brown (7) reported that potash was very beneficial in maintaining stands of alfalfa. Chiasson (13), on the other hand, reported that phosphorus increased clover and useful grasses at the beginning of the experiment, but that potash had maintained clover better by the fourth year than phosphorus.

TABLE 22.-Summary table of the botanical composition of three greenhouse experiments at different levels of phosphorus and potassium fertilization

Level of Nutrient	Per cent alfalfa in forage			Per cent grass in forage		
	Experiment			Experiment		
	1	2	3	1	2	3
P ₁	88	90	94	12	10	6
P ₂	82	89	94	18	11	6
P ₃	84	86	93	16	14	7
P ₄	78			22		
K ₁	81	86	93	19	14	7
K ₂	79	88	95	21	12	5
K ₃	85	90	95	15	10	5
K ₄	85			15		

Cutting management affects the botanical composition, as well as the yield, of grass-legume associations. Investigators (36, 46, 47, 52) have reported that more frequent

cutting of alfalfa-grass mixtures favors the grass component as compared to cutting at the hay stage. However, it should be recalled that the forage in these experiments was cut at what would be considered the hay stage.

The botanical composition of the greenhouse experiments compared favorably with those of the field experiments. In both instances, the treatments receiving the highest rate of phosphate fertilization contained the least amount of alfalfa.

Tissue Analyses

The effect of fertilizer treatments on the phosphorus and potassium contents of plant tissue is shown in Tables 23, 24, and 25.

Table 23 reveals that treatment effects reflected significant differences in the percentages of phosphorus and potassium in both alfalfa and bromegrass tissue. Increases in phosphate applications increased the content of phosphorus in the tissue of both the alfalfa and bromegrass, but to a greater extent in the bromegrass. Increased amounts of potash added to the soil increased the percentage of potassium in the tissues of alfalfa and bromegrass in comparable amounts.

There seemed to be a tendency for the higher amounts of potash fertilization to reduce the phosphorus content of alfalfa. This trend was not noticed in the bromegrass tissue.

TABLE 23.-The effect of fertilizer treatment on phosphorus and potassium contents of alfalfa and brome grass grown in the greenhouse

Treatment	Alfalfa ^a		Brome grass ^b	
	Per cent P	Per cent K	Per cent P	Per cent K
P ₁ K ₁	.37	.78	.26	1.05
P ₁ K ₂	.38	.88	.23	1.10
P ₁ K ₃	.38	1.06	.25	1.28
P ₁ K ₄	.38	1.40	.25	1.46
P ₂ K ₁	.45	.89	.25	.91
P ₂ K ₂	.42	.85	.28	.97
P ₂ K ₃	.38	1.11	.25	1.20
P ₂ K ₄	.32	1.51	.27	1.44
P ₃ K ₁	.48	.86	.29	.95
P ₃ K ₂	.48	.94	.33	1.07
P ₃ K ₃	.46	1.14	.31	1.23
P ₃ K ₄	.45	1.55	.29	1.52
P ₄ K ₁	.46	.98	.29	1.05
P ₄ K ₂	.43	.98	.33	1.13
P ₄ K ₃	.43	1.16	.33	1.30
P ₄ K ₄	.42	1.57	.33	1.49
L. S. D. 5%	.06	.22	.04	.11
1%	.07	.29	.05	.15

^aAverage of eight cuttings.

^bAverage of six cuttings.

TABLE 24.—The effect of fertilizer treatment on the phosphorus and potassium content of alfalfa and ryegrass grown in the greenhouse

Treatment	Alfalfa ^a		Ryegrass ^b	
	Per cent P	Per cent K	Per cent P	Per cent K
P ₁ K ₁	.27	.89	.13	.96
P ₁ K ₂	.23	1.68	.12	1.45
P ₁ K ₃	.22	2.06	.12	1.64
P ₂ K ₁	.45	.79	.20	1.01
P ₂ K ₂	.38	1.39	.23	1.41
P ₂ K ₃	.37	2.09	.20	1.77
P ₃ K ₁	.52	.88	.29	1.09
P ₃ K ₂	.46	1.41	.27	1.46
P ₃ K ₃	.39	2.28	.24	1.81
L. S. D. $5\frac{1}{2}$	.23	.28	.04	.17
1.0	.30	.38	.05	.23

^aAverage of eight cuttings.

^bAverage of five cuttings.

Different levels of phosphate fertilization showed no noticeable effect on the percentage of potassium in either alfalfa or bromegrass tissue.

As in experiment 1, Table 24 shows that increased amounts of phosphate and potash added to the pots increased the respective percentages in the tissue of both

alfalfa and ryegrass. Increasing potash fertilization reduced the percentage of phosphorus in alfalfa, while holding constant or slightly retarding the phosphorus content of ryegrass. This tendency is decidedly more pronounced in experiment 2 than in experiment 1.

TABLE 25.—The effect of fertilizer treatment on the phosphorus and potassium content of alfalfa and timothy grown in the greenhouse

Treatment	Alfalfa ^a		Timothy ^b	
	Per cent P	Per cent K	Per cent P	Per cent K
P ₁ K ₁	.26	.85	.11	.98
P ₁ K ₂	.22	1.67	.11	1.39
P ₁ K ₃	.22	2.38	.10	1.62
P ₂ K ₁	.46	.91	.20	1.19
P ₂ K ₂	.34	1.51	.19	1.49
P ₂ K ₃	.35	2.22	.19	1.67
P ₃ K ₁	.54	.83	.19	1.18
P ₃ K ₂	.45	1.39	.19	1.44
P ₃ K ₃	.42	2.17	.20	1.62
L. S. D. 5%	.09	.23	.02	.12
1%	.11	.30	.02	.17

^aAverage of eight cuttings.

^bAverage of three cuttings.

Increasing the amount of phosphate application, however, seemed to have very little, if any, effect on the phosphorus content of either alfalfa or ryegrass.

Table 25 reveals similar results for experiment 3 as Table 24 does for experiment 2. That is, increased phosphate and potash fertilizations increased the respective contents in both alfalfa and timothy. Also, as in Table 24, increasing the amount of potash application reduced the percentage of phosphorus in the tissue of alfalfa but not in timothy. Increasing the amount of phosphate had no effect on the percentage of potassium in either alfalfa or timothy.

In all three experiments, phosphorus and potassium in the tissue of both alfalfa and the associated grass were increased as the amount of the nutrient applied was increased. Lawton and Tesar (38) also obtained results from greenhouse experiments to the effect that potassium absorption by both alfalfa and bromegrass was significantly increased as applied potassium increased.

The results of chemical analyses of plant tissues of all three greenhouse experiments are outstandingly similar. Increasing the potash application at a constant level of phosphate reduced the phosphorus in alfalfa tissue, but not in the grass tissue. Conversely, increasing the phosphate application at a constant level of potash showed no effect on the potassium content of either the alfalfa or the grass tissue.

The phosphorus content of bromegrass was higher than the phosphorus content of timothy and ryegrass as shown in Table 26, which was basically the result obtained by Gervais (29). However, the potassium content of bromegrass was not higher than ryegrass or timothy, which is contrary to findings of Gervais (29). In all three experiments, the phosphorus content of alfalfa was higher than the phosphorus content of the grass grown in association.

Vandecaveye and Baker (66) reported that the chemical composition of alfalfa at harvest stage was less influenced by phosphate and potash fertilizations than was the chemical composition of grasses.

Soil Analyses

The results of soil analyses for phosphorus and potassium are given in Tables 27, 28, and 29.

Analysis of variance of each experiment revealed significant differences due to treatments. Generally, as the amount of each nutrient applied was increased, the amount of the respective nutrient extracted was increased.

Correlation analyses of the phosphorus in the soil and the percentage of phosphorus in plant tissue revealed a positive association in all three experiments. A highly significant correlation existed for both the alfalfa and the associated grass in experiments 2 and 3, and for bromegrass in experiment 1.

TABLE 26.--Summary table of the chemical composition of alfalfa and grass of three greenhouse experiments at different levels of phosphorus and potassium fertilization

Level of nutrient	Per cent phosphorus			Per cent potassium		
	Experiment			Experiment		
	1	2	3	1	2	3
Alfalfa						
P ₁	.38	.24	.23	1.03	1.53	1.63
P ₂	.39	.40	.38	1.09	1.09	1.55
P ₃	.47	.48	.47	1.12	1.19	1.46
P ₄	.44			1.17		
K ₁	.44	.41	.42	.88	.85	.86
K ₂	.43	.36	.37	.91	1.49	1.52
K ₃	.41	.33	.33	1.12	2.14	2.26
K ₄	.39			1.51		
Grass						
F ₁	.25	.12	.11	1.22	1.35	1.33
F ₂	.26	.21	.19	1.13	1.39	1.45
F ₃	.26	.27	.19	1.19	1.45	1.41
F ₄	.32			1.24		
K ₁	.26	.21	.17	.99	1.02	1.12
K ₂	.29	.21	.16	1.07	1.44	1.44
K ₃	.28	.19	.16	1.25	1.74	1.64
K ₄	.28			1.48		

TABLE 27.-The effect of alfalfa-bromegrass on the phosphorus and potassium content of the soil when grown under different fertilizer treatments in the greenhouse

Treatment	Pounds per acre	
	Phosphorus	Potassium
P ₁ K ₁	52	91
P ₁ K ₂	45	76
P ₁ K ₃	46	86
P ₁ K ₄	42	87
P ₂ K ₁	63	70
P ₂ K ₂	52	52
P ₂ K ₃	59	81
P ₂ K ₄	56	96
P ₃ K ₁	95	73
P ₃ K ₂	95	67
P ₃ K ₃	90	90
P ₃ K ₄	75	89
P ₄ K ₁	194	99
P ₄ K ₂	191	89
P ₄ K ₃	212	115
P ₄ K ₄	184	92
L. S. D. 5%	28	22
1%	37	30

TABLE 28.—The effect of alfalfa-ryegrass on the phosphorus and potassium content of the soil when grown under different fertilizer treatments in the greenhouse

Treatment	Pounds per acre	
	Phosphorus	Potassium
P ₁ K ₁	45	35
P ₁ K ₂	45	88
P ₁ K ₃	37	78
P ₂ K ₁	337	46
P ₂ K ₂	303	62
P ₂ K ₃	337	102
P ₃ K ₁	606	80
P ₃ K ₂	622	79
P ₃ K ₃	647	117
L. S. D. 5%	87	30
1%	118	40

Correlation analyses of the potassium in the soil and the percentage of potassium in plant tissue revealed also a positive association in all three experiments. Highly significant correlations existed for alfalfa in experiments 2 and 3, and for grass in experiments 1 and 2.

Negative associations were found in all three experiments from correlation analyses of the percentage of alfalfa in the forage and the phosphorus in the soil. A highly significant correlation existed for experiment 1, but not for experiments 2 and 3.

TABLE 29.—The effect of alfalfa-timothy on the phosphorus and potassium content of the soil when grown under different fertilizer treatments in the greenhouse.

Treatment	Pounds per acre	
	Phosphorus	Potassium
P ₁ K ₁	37	61
P ₁ K ₂	33	84
P ₁ K ₃	33	122
P ₂ K ₁	305	47
P ₂ K ₂	277	48
P ₂ K ₃	230	73
P ₃ K ₁	644	71
P ₃ K ₂	579	80
P ₃ K ₃	588	112
L. S. D. 5%	73	30
1%	100	43

No significant correlation was found between the potassium in the soil and the percentage of alfalfa in the forage. Table 30 combines the results of soil analyses for all three greenhouse experiments.

This is in contrast to the findings of Stivers and Ohlrogge (61). They found that stand maintenance of alfalfa was closely related to potash fertilization and potassium content of alfalfa.

Nelson and MacGregor (45) reported that soil samples showed almost no correlation between the phosphorus and potassium in the soil and that found in the alfalfa plants.

TABLE 30.--Available soil phosphorus and potassium at the completion of the greenhouse experiments

Level of nutrient	Pounds per acre					
	Phosphorus in soil			Potassium in soil		
	Experiment			Experiment		
	1	2	3	1	2	3
P ₁	46	42	34	85	67	89
P ₂	58	326	271	75	70	56
P ₃	89	625	604	80	92	88
P ₄	195			99		
K ₁	101	329	329	83	54	60
K ₂	96	323	296	71	76	71
K ₃	102	340	283	93	99	102
K ₄	89			91		

V. SUMMARY AND CONCLUSIONS

1958 Field Experiments

Fertilizer subtreatments resulted in yield differences which were highly significant for all eight cuttings over a four year period. Phosphate fertilization increased the yield of forage over the check treatments, with phosphate and potash fertilization yielding the highest amount of forage.

The highest proportion of alfalfa in the forage occurred in the treatment and subtreatment receiving no fertilization at the time of establishment or as a top-dressing.

The subtreatments receiving phosphorus each year contained significantly greater amounts of phosphorus in both alfalfa and bromegrass tissue than the subtreatments receiving no phosphorus as a topdressing and those receiving phosphorus in the second harvest year. There were no significant differences, however, between the subtreatments with respect to the content of potassium in either alfalfa or bromegrass tissue.

Increased phosphate applications resulted in increased amounts of phosphorus extracted from soil samples, but increased potash application resulted in little

influence on the amounts of potassium extracted from soil samples.

A significant negative correlation existed between the percentage of alfalfa in the forage and the amount of phosphorus in the soil.

Highly significant positive correlations existed between the percentage of phosphorus in alfalfa and bromegrass tissue and the phosphorus extracted from soil samples. Such was not the case for potassium.

Chemical analyses of soil profiles revealed that phosphorus content increased with depth while potassium content decreased with depth.

1959 Field Experiments

Significant differences in yield existed between fertilizer treatments. The lowest yielding treatment was one receiving no fertilization, while the highest yielding treatment was the one receiving the highest amount of potash. Only treatments receiving potash yielded significantly higher amounts of forage than the original check plots established in 1954, and which were check plots in 1959.

Alfalfa showed a tendency for decreased yield with phosphorus fertilization and increased yield with potash fertilization. Bromegrass showed a reverse tendency.

No radical change in the percentage of alfalfa in the forage during one growing season was noticed as a

result of fertilizer treatment, although the treatments receiving potash and the treatments receiving no fertilization showed very similar trends.

An increase in the amount of a nutrient applied to the soil increased significantly the percentage of that nutrient in the plant tissue. Bromegrass contained a higher percentage of potassium in the tissue than did alfalfa.

Significant positive correlations existed between the amount of a nutrient in the soil and the percentage of the respective nutrient in the plant tissue of both alfalfa and bromegrass.

Phosphorus fertilization decreased the yield of alfalfa and increased the yield of bromegrass; increased the phosphorus and decreased the potassium contents of both alfalfa and bromegrass tissue; and decreased the removal of soil potassium by alfalfa while increasing the removal of soil potassium by bromegrass.

Potash fertilization increased the yields of both alfalfa and bromegrass, caused little or no change in the phosphorus content while increasing the potassium content of both alfalfa and bromegrass, and increased slightly the removal of soil phosphorus while greatly increasing the removal of soil potassium.

Phosphorus removal from the soil was increased as a result of both phosphate and potash fertilization.

Removal of soil potassium was increased by potash fertilization, and unchanged by phosphate fertilization.

Greenhouse Experiments

Striking similarities of yield results of all three greenhouse experiments were noticed as influenced by phosphate and potash fertilization.

The higher rates of phosphate fertilization increased the yields of the grasses, while having little influence on the alfalfa yields. The higher rates of potash fertilization resulted in higher yields of alfalfa and lower yields of grasses.

Significant differences due to both phosphate and potash fertilization were found in the botanical composition of the alfalfa-bromegrass association. The lowest amount of applied phosphate produced the highest percentage of alfalfa, while the highest amount of applied phosphate produced the lowest percentage of alfalfa in the forage. The percentage of alfalfa in the forage was increased by potash fertilization at low levels of phosphate fertilization, but less affected at high levels of phosphate fertilization.

The percentages of phosphorus and potassium in the tissue of alfalfa and the associated grass were increased as the amount of the nutrient applied was increased.

Increasing the amount of potash at a constant level of phosphate reduced the percentage of phosphorus in

alfalfa tissue but not in grass tissue. Increasing the amount of phosphate at a constant level of potash showed no effect on the potassium content of either alfalfa or grass tissue.

The phosphorus content of bromegrass was higher than the phosphorus content of timothy and ryegrass. In all three experiments, alfalfa contained a higher percentage of phosphorus in the tissue than the grass grown in association.

Positive correlations were found in all three experiments between the amount of a nutrient in the soil and the percentage of the respective nutrient in plant tissue.

Negative associations were found in all three experiments between the percentage of alfalfa in the forage and the phosphorus content of the soil.

The explanation given for the persistence of alfalfa when grown with an associated grass in the field without phosphorus or potassium fertilization is that subsoil phosphorus is furnished in sufficient amount to the deep rooted alfalfa plant so that alfalfa is enabled to compete advantageously when grown in association with a shallow rooted grass plant. The restricted growth of the grass made it possible for the soil to supply sufficient potassium to maintain the alfalfa in association with bromegrass. In addition, the pH of the surface and sub-surface horizons may have proved a disadvantage in phosphorus uptake by the grass.

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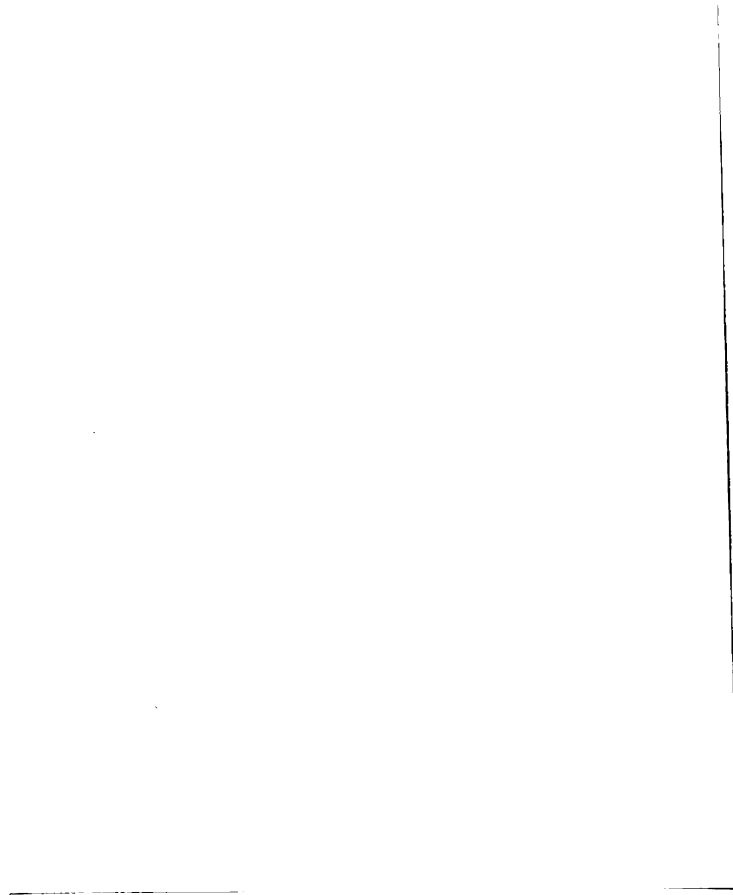
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