EFFECT OF RATE AND FREQUENCY OF POTASSIUM AND PHOSPHORUS APPLICATIONS ON THE YIELD AND THE POTASSIUM AND PHOSPHORUS CONTENTS OF ALFALFA

Thesis for the Degree of M. S.

MICHIGAN STATE UNIVERSITY

Tung - Ming Lai

1956

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By

TUNG-MING LAI

AN ABSTRACT

Submitted to the School of Graduate Studies of Michigan State University of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Department of Soil Science

1956

Approved R. L. Cook

Tung-Ming Lai

ABSTRACT

Greenhouse and field experiments were conducted to study the effect of rate and frequency of potassium and phosphorus applications on the yield and potassium and phosphorus contents of alfalfa. In the greenhouse, four rates of fertilizer, 0, 300, 600, and 1200 pounds per acre, were applied to three different soil types on which alfalfa was grown and cut nine times. The frequency of fertilizer treatment varied from a single application of fertilizer at planting time to two, three, and four cycle treatments. It was found that two or three cycle application of fertilizer at the rate of 1200 pounds of 0-20-20 per acre was more efficiently used by alfalfa than the same amount applied at the planting time. When the 600 pounds rate of fertilizer was used, higher yields were obtained with the same amount fertilizer by applying it all at planting time.

The correlation coefficients between total potassium or phosphorus uptake and the yield of nine cuttings of alfalfa were found to be very highly significant. The Ca/K equivalent ratio of alfalfa varied with different cuttings, different soils, and different treatments. Especially in the last three cuttings this ratio had a tendency to increase.

The data of chemical analysis of harvested alfalfa showed that the sum of cation-equivalents, including potassium, calcium, and magnesium, per unit dry matter of alfalfa tended to be a constant within the same cutting, but varied

from cutting to cutting. Alfalfa grown during the months of November to February contained the greatest quantity of cations on a weight basis.

A series of determinations of different forms of soil potassium was proposed to obtain the most reliable information on the need for potassium fertilization of alfalfa.

The field experiment was carried out on a Fox sandy loam using three rates of fertilizer amounting to 0, 80, and 160 pounds of K_2O and P_2O_5 per acre applied by broadcast and banded methods for comparison. The frequency of these fertilizer treatments included one, two, three, and five cycle applications. The preliminary results on the first two cuttings of alfalfa hay indicated little yield response to potash-phosphate fertilization. The potassium and phosphorus contents of alfalfa obtained from this field study were not strongly influenced by either the rate or frequency of fertilizer application. Lack of yield response to fertilization is believed to be due to a shortage of rainfall in the summer of 1956.

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ACKNOWLEDGMENTS

The author wishes to express his very sincere thanks to Dr. Kirk Lawton, under whose constant supervision and unfailing interest this investigation was undertaken, under whose kind guidance and valuable help this thesis was written, and to whom the results are herewith dedicated. He is also greatly indebted to Dr. J. F. Davis for his helpful suggestions and assistance in preparing this manuscript.

Grateful acknowledgment is also due to Dr. R. L. Cook who made it possible for the author to come to Michigan State University.

His sincere thanks are also extended to the graduate students of the Department of Soil Science for their assistance; especially to Mr. Clarence R. Carter for his help in the course of the field experiment phase of this study.

The writer deeply appreciates the financial support in the form of a special graduate research assistantship provided by Michigan State University.

Special appreciation is also extended to the author's wife, Chin-Yu, for her encouragement and support to him during his study.

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I. INTRODUCTION

Alfalfa is recognized as one of the most valuable of forage crops. It is high in minerals and digestible nutrients, especially protein. Under favorable conditions this crop exhibits a vigorous fixing power for atmospheric nitrogen. In many areas alfalfa alone or in combination with a grass is considered as the main soil improving crop within rotations. It is grown extensively on dairy farms of the East and Midwest of the United States.

Because alfalfa is a "heavy feeder," it has a very high mineral requirement for calcium, potassium, magnesium, and phosphorus. Potassium is often a limiting nutrient factor, especially on the sandy soils, which have a low reserve of available potassium. For this legume, phosphorus is most likely to be deficient on the finer textured soils. Thus, for many years there has been considerable interest in the most efficient methods of fertilizer application.

It is also well known that legumes such as alfalfa and clovers may absorb potassium and to some extent phosphorus far beyond plant nutritional requirements provided high levels of available potassium and phosphorus are present in the soil. This means that luxury consumption of nutrients may occur if large quantities of fertilizer are applied at one time. Soil management recommendations are beginning to emphasize the rather frequent application of potassium and phosphorus as yearly topdressings for maintenance of vigorous, high yielding stands of alfalfa.

With the above facts in mind, this study was designed to determine the efficiency of utilization of potassium and phosphorus applied at different rates and times by alfalfa grown continuously in both the greenhouse and field. In order to verify the efficiency of utilization of fertilizer, measurements of both yield and absorption of mineral nutrients, including potassium, phosphorus, calcium, and magnesium were made for each cutting of alfalfa.

II. LITERATURE REVIEW

The effect of fertilizer treatments on the yield and chemical composition of alfalfa has been studied by many workers. This crop has been found to respond greatly to applications of lime, phosphate, and potash where these nutrients were limiting factors in growth. The fact that alfalfa absorbs large quantities of mineral nutrients has been emphasized by many workers, including Washko (40) who showed that 3 tons of alfalfa hay removed 36 pounds of P_2O_5, 135 pounds of K_2O, 50 pounds of CaO, and 50 pounds of MgO per acre annually.

Bishop and Turner (6) in Tennessee suggested that 300 to 400 pounds of murate of potash and 20 pounds of fertilizer borate per acre be applied after the first cutting of alfalfa. According to Cooper (14), in Alabama even the best potassium-supplying soils are soon depleted by alfalfa unless liberal applications of potash are added. In his studies 120 and 240 pounds of K_2O per acre was applied annually to alfalfa as muriate of potash. Cotton yields were higher when grown on plots where alfalfa received the higher rate of potash. This was true even when the cotton crop was heavily fertilized with potassium. It is recommended that most alfalfa fields should be topdressed annually with 900 to 1000 pounds of 0-12-20 containing 20 to 25 pounds of borax after the first year in which the alfalfa was established. In the Northeast Washko (40) proposed that on soils low in available nitrogen, 700 - 800 pounds of a 2-12-12 fertilizer be applied at planting time. For those soils with ample nitrogen but which are low in boron, 400 - 500 pounds of an 0-19-19 with 5 per cent borax is recommended. When boron is not deficient the use of 0-20-20 is suggested. Early spring applications of 60 pounds of phosphate and 180 pounds of potash annually are considered desirable for maintenance of the legume stand.

In Michigan, Lawton et al. (22) showed that in 56 to 58 out of 66 topdressing experiments, a significant response was obtained from phosphate alone on established legume hay. Significant increases in yield were found for potassium in about one-half to two-thirds of the experiments conducted. Soils treated with 750 pounds of 0-20-20 per acre showed significant increase in yield in over 90 per cent of the trials. Work by Cook and Millar (12, 13, 29) showed the importance of potassium in the nutrition of alfalfa. They recommended the use of 300 to 400 pounds per acre of 0-12-12 for the better sandy loams and fertilizer of the ratio of 0-1-3 for lighter soils where seedlings are made without a nurse crop.

Stanford and Hanway (36), in a study of the methods and frequency of fertilizer application for alfalfa, suggested that a topdressing be used if soil tests show a need for phosphorus and potassium, but that this practice should not substitute for fertilization at time of seeding.

From a two year field experiment Prince et al. (31) found that applying all the phosphate and potash prior to seeding proved to be slightly superior to applying the same quantity of these materials in equal annual topdressings. However, they concluded that this point needs further study with larger amounts of material used over a greater length of time. In Wisconsin, Chapman (11) reported that field experimental data indicated that a fertilizer applied in the fall on established alfalfa gave higher yields than fertilizer applied the following spring. This Wisconsin worker recommended a topdressing by mid-September at rates from 300 to 500 pounds of 0-10-30 or 0-12-36 per acre.

Seay and Weeks (34) topdressed established alfalfa with radio-active superphosphate and ordinary potash at different times during the year. From the analyses of tops, crowns, and roots at various periods after topdressings, they concluded that phosphorus and potassium are translocated to the crowns from the roots and tops during autumn, whereas in spring a rapid translocation of phosphorus and potassium occurs from roots and crown to tops. They noted that topdressed phosphorus was taken up by alfalfa even in the winter. They also found that potassium fertilization did not

affect phosphorus uptake and phosphorus fertilization did not significantly affect absorption of potassium.

By the use of tagged fertilizer Lawton et al. (23) found that the percentage of phosphorus in alfalfa hay derived from superphosphate placed at various depths in two Michigan soils was related to depth of fertilizer placements. Absorption of fertilizer phosphorus was highest at the surface or 3-inch depth, intermediate at the 6-inch depth, and low for the 12-, 24-, and 30-inch placements. In contrast, Woodhouse (41) reported recently that placement of phosphate had surprisingly little effect on alfalfa performance, and the effect of placement of potash was almost nil on this legume grown on a Cecil sandy loam in North Carolina.

Recently, Martin et al. (26) published some results concerning methods of applying potash for alfalfa in California. Field tests were designed to compare surface application with corresponding rates of potassium sulfate placed approximately 7 inches deep during the dormant season. The results showed that for a soil of high potassium fixing capacity, yield and potassium uptake by alfalfa treated with 200 pounds of potassium sulfate drilled in the soil were significantly higher than when equivalent surface applications were made. At the 1000 pound fertilizer rate, yields were the same from each treatment, although the potash uptake was greater where the material was placed at depth in the sod. However, in another field trial broadcast application was more effective than drilling. It should be noted that the sod-placement applicator in this case was able to place fertilizer only 2 to 3 inches deep.

Many experimental results have shown the chemical composition of alfalfa is dependent to a large extent on soil factors. Upon analysis of alfalfa samples collected from good and poor alfalfa fields in Michigan, Lawton (21) showed that the average potash content of the leaves of alfalfa from poor fields was 0.86 per cent as compared with 1.82 per cent for plants from the normal fields. Likewise, the per cent of K_2O in the stems of deficient plants averaged about 0.87 in contrast to 1.92 in alfalfa stems of plants from good fields.

Using the results obtained from three experimental fields and 41 farm fields, Seay, Attoe, and Truog (33) found the relationship between potassium content of alfalfa and that available in soils to be as follows:

$$\text{Percentage of K in crop} = 1.81 \log \text{lbs. exchangeable K per acre} - 2.84$$

Attoe and Truog (2) also determined that the yield of alfalfa hay correlated with the level of available phosphorus and potassium in accordance with the following equation:

$$\text{Tons of hay per acre} = a \log \text{lb. available P} + b \log \text{lb. exchangeable K} + c$$

where the values of a, b, and c varied with weather conditions and the type of soil. On the basis of the coefficients of correlation, Hallock and Attoe (18) found that for acid soils, the phosphorus content of the alfalfa was correlated about equally with the acid soluble ($r = 0.48$) and alkali soluble ($r = 0.46$) inorganic phosphorus. A similar situation was found in the case of non-acid soils, except that the coefficients of correlation were much lower.

From a greenhouse study by Power, Swenson, and Cook (30) a high degree of correlation was found between soil phosphorus level and per cent of phosphorus in alfalfa, but the soil phosphorus level had only a slight effect on the calcium content of this legume. In contrast, a highly significant negative correlation was obtained between soil potassium level and calcium percentage of alfalfa.

In a field study conducted on extremely phosphorus-deficient soils in north-central Iowa, Larson et al. (20) found that during the first two years after the plots received phosphorus fertilizer, each increase in rate of phosphate applied resulted in a corresponding increase in plant phosphorus. After two years the phosphorus content of the alfalfa reached a minimum of from 0.15 to 0.17 per cent, first on the 0, 30-, and 60-pounds P_2O_5 per acre plots and later where 120 pounds P_2O_5 was applied. Alfalfa that received 240 pounds P_2O_5 per acre had not reached the minimum range, even after four years.

In a study of the effect of soil reaction on the availability of phosphorus for alfalfa in some Canadian soils, MacLean and Cook (25) showed that variation in soil reaction in the more acid range up to a pH of about 6.5 had but little effect on the phosphorus content of the alfalfa. However, as the soil pH was raised to about 7.0 some increase in the phosphorus content of alfalfa was noted regardless of whether or not supplemental phosphorus was used. The phosphorus content of plants grown on four of the six soils was highest at a pH above the neutral point. Baker and Brady (3) found a reciprocal relationship between calcium and potassium contents of alfalfa in experiments of the degree of reactivity of calcium carbonate with two acid soils. As the percentage of calcium carbonate reacted increased and the calcium content of the alfalfa increased, the potassium content of the plant decreased.

By the use of radioactive superphosphate Lawton et al. (23) showed that the recovery of fertilizer phosphorus by first-cutting hay from two of the five locations was low, but was as high as 15 per cent in hay from the other areas. As the rate of broadcast superphosphate increased, the percentage of recovery of applied phosphorus decreased.

Luxury consumption of nutrient elements by the plant is a well known phenomenon, and seems to be especially applicable to potassium. Stanford and Hanway (36) and Martin et al. (26) have shown the luxury uptake of potassium by alfalfa in field and greenhouse experiments. Consequently, for practical purpose some investigators have tried to determine the so-called "critical nutrients levels" for alfalfa. In New Jersey, Bear et al. (5) have set the following critical levels for alfalfa at early blossom stage:

K - 1.4%, P - 0.27%, Mg - 0.24%, Mn - 10 ppm, B - 20 ppm.

They also suggested the ideal values as follows:

K - 2%, Ca - 1.4%, Mg - 0.35%, N - 3%, P - 0.27%, S - 0.20%

From greenhouse and field experiments Martin et al. (26) concluded the critical level of middle stems was in the range of 0.65 to 0.75 per cent potassium, while for the entire top this value was found to be from 1.0 to 1.1 per cent potassium.

Since Bear and Prince (4) first concluded that the sum of the equivalents of calcium, magnesium, and potassium per unit dry weight of alfalfa tended to be a constant, other workers (42) have confirmed their results showing cation-equivalent constancy in alfalfa. The New Jersey workers (5) also showed that the ratio between the sum in milliequivalents of cations and the anions (NO_3, H_2PO_4, SO_4, Cl, and SiO_3) tended to be a constant at a value of about 0.54. This relationship suggests that a change in the supply of any one cation to a plant causes a change in the uptake of all the other cations in the plant tissues and the same is true for anions.

However, it has been observed that these relationships are not so simple, and that certain irregularities exist. Wallace et al. (38) have shown that cation constancy in the alfalfa plant is more pronounced in the active growing portions than in the stems and older leaves, indicating that this constancy may be secondary to other factors such as "carbohydrate dilution." The same authors (39) also found variations in cation and anion summation values as a function of successive harvests of forage crops. Such deviation was explained on the basis of the operation of a carbohydrate dilution factor. During periods of rapid formation of carbohydrates, usually in the summer, the cation and anion content per unit weight of tissue is diluted, resulting in a lower cation and anion summation value. Consequently, the nutrient content of alfalfa in terms of animal feeding is lower in the summer, as reported by Crampton and Forshaw (15). These workers found that forage crops have lower feeding value in summer than in spring or fall.

Wallace (37) conducted a series of experiments and showed that the cation and anion milliequivalent sums of alfalfa were highly correlated, the sums of each increasing with increasing concentrations of the medium in sand cultures. This same relationship was also observed for an increasing content of exchangeable bases in the soil. However, variations in the cation-anion ratio in the alfalfa were observed as well. In soil this ratio increased as the pH values of the soil increased. Wallace also pointed out that the accumulation of calcium and potassium by alfalfa, whether grown in the sand cultures or in the field, was more closely related to the ratios of the individual elements than to the absolute content of the individual element in the medium. This point was particularly noticeable when the total exchangeable cation content of the soil varied widely.

III. METHODS AND MATERIALS

I. Greenhouse Experiment

1. Soil Samples:

Three different surface soils, Brookston clay loam, Conover loam, and Hillsdale sandy loam, were used for greenhouse studies. Some of their chemical characteristics are shown in table 1. Methods used for soil analysis were as follows:

A. Texture: determined by Bouyoucos hydrometer method (7).

B. pH: determined by Beckman pH meter Model H using 1 : 1 soil to water ratio.

C. Acid soluble and adsorbed phosphorus : determined by Bray method (8).

D. Acid soluble potassium: determined by boiling 10 grams of soil with N nitric acid for 10 minutes, and analyzing the potassium in the filtrate using a Perkin-Elmer flame photometer Model 52A.

E. Exchangeable cations: determined in neutral ammonium acetate leachate, potassium by the Perkin-Elmer flame photometer Model 52A, calcium by the Beckman flame photometer Model DU, and magnesium by the thiazole yellow method (17).

Table 1. A partial chemical analysis of the surface soils used in the greenhouse study.

Soil type	Location	pH	Pounds per acre acid soluble and adsorbed P	Pounds per acre acid soluble K	M. e. cation exchange capacity per 100 g. soil	M.e.exchangeable K per 100 g. soil	Per cent K saturation	M.e.exchangeable Ca per 100 g. soil	M.e.exchangeable Mg per 100 g. soil
Brookston clay loam	Britton farm Lenawee county	6.8	66	670	22.3	0.27	1.21	22.9	1.04
Conover loam	Bobbit farm Gratiot county	7.3	65	446	14.5	0.15	1.04	17.9	0.42
Hillsdale sandy loam	University farm Ingham co.	6.7	71	388	4.4	0.14	3.15	6.0	0.43

F. Cation exchange capacity: determined by the neutral normal ammonium acetate method described by Peech (28).

The soil samples were air dried, passed through 1/4 inch screen and mixed thoroughly. Three gallon glazed porcelain pots were used as the containers. The soils were placed in each pot on a volume basis rather than on a weight basis since the surface soils were of widely different textures.

2. Treatments:

Different rates and different frequencies of application of phosphorus and potassium used for this study are listed as follows:

Treatment number	Description
	Series I. 1200 pounds 0-20-20 per acre.
1	1200 pounds 0-20-20 at planting time.
2	600 pounds 0-20-20 at planting time plus 600 pounds after 3rd cutting.
3	300 pounds 0-20-20 at planting time plus 450 pounds after 2nd and 4th cuttings.
4	300 pounds 0-20-20 at planting time plus 180 pounds after each cutting till the 5th cutting.
	Series II. 600 pounds 0-20-20 per acre.
5	600 pounds 0-20-20 at planting time.
6	300 pounds 0-20-20 at planting time plus 300 pounds after 3rd cutting.

Treatment number	Description
7	150 pounds 0-20-20 at planting time plus 225 pounds after 2nd and 4th cuttings.
8	150 pounds 0-20-20 at planting time plus 90 pounds after each cutting till the 5th cutting.
	Series III. Other treatments
9	300 pounds 0-20-20 at planting time.
10	No potash or phosphate added.
	Series IV. In order to determine the potassium and phosphorus supplying powers of the soils, the following treatments were carried out.
11	240 pounds K_2O at planting time.
12	240 pounds P_2O_5 at planting time.

Chemical pure salts in the form of mono-calcium phosphate and potassium chloride were used in the above treatments.

Other essential elements or so-called minor elements, were added in solution form at planting time to all pots at the same quantity as follows: (on the basis of pounds per acre)

100 pounds of $MgSO_4 \cdot 7H_2O$, 50 pounds of $MnSO_4 \cdot H_2O$, 20 pounds of $Na_2B_4O_7 \cdot 10\ H_2O$, 20 pounds of $CuSO_4 \cdot 5H_2O$, 10 pounds of $ZnSO_4 \cdot 2H_2O$, and 0.5 pounds of $(NH_4)_2Mo_7O_{24} \cdot 4H_2O$.

Three replicates were set up for all the treatments.

3. Culture Methods:

In order to get a uniform distribution of the minor elements in the soil, the minor elements compounds were dissolved in an amount of water equivalent to 125 per cent of the moisture equivalent of the soil and this solution reached the moisture equivalent point, the top two inches of soil in each pot was cultivated. Planting time applications of potassium and phosphorus were added in a band at the depth of one inch below the soil surface. About 30 seeds of alfalfa were planted 1/4 inch deep in each pot. After the seedlings had grown to the height of one inch, they were thinned to 12 per pot.

Other applications of potassium and phosphorus were made in solution to partially simulate topdressing immediately after alfalfa cuttings.

4. Harvesting and Preparation of Plant Material:

A total of nine cuttings were harvested, and each cutting was made when the alfalfa was in the half bloom stage. The cuttings were harvested on the following dates:

1st cutting on June 1, 1955; 2nd on July 1, 3rd on August 1, 4th on September 7, 5th on October 20, 6th on December 3, 7th on January 27, 1956, 8th on March 3, and 9th on April 10.

Due to poor germination or emergence in the Hillsdale soil, it was necessary to transplant the alfalfa to this soil in the pots. The dates of the first four cuttings for Hillsdale soil were as follows:

> 1st cutting on June 12, 2nd cutting on July 12, 3rd cutting on August 12, and 4th cutting on September 19.

Succeeding harvest dates were similar to those for alfalfa grown on other soils.

The plant material from each pot was harvested separately and dried at 70 degrees C., weighed, and ground separately. Each sample was thoroughly mixed before chemical analyses were made. Each replicate was separately analyzed and a mean value calculated.

II. Chemical Analysis of Plant Material

1. Digestion of Plant Material:

Wet digestion with nitric and perchloric acids, originally proposed by Piper (29), was used in this study to decompose organic material. Fifteen ml. of concentrated nitric acid was added to one gram of dried plant material in a 200 ml. tall form beaker. It was covered with a watch glass, and heated on a hot plate at low temperature till almost all plant material was oxidized. Then, the cover glass was taken off, 10 ml. of concentrated perchloric acid was added, and this solution heated at high temperature. Finally, the excess of perchloric acid was driven off and the solution was evaporated to near dryness, leaving a white residue. To the white residue was added 0.1 N hydrochloric acid and the solution was then transferred to a 100 ml. volumetric flask and made up to volume with distilled water. After standing over night, the clear solution was pipetted off and used as the stock solution for determinations of potassium, calcium, magnesium, and phosphorus.

2. Determination of Potassium, Calcium, Magnesium, and Phosphorus:

Potassium was determined on the Perkin-Elmer flame photometer Model 52A using a 300 p.p.m. potassium solution as the top standard.

Calcium and magnesium were determined on the Beckman flame photometer Model DU, and set up under the following conditions:

Conditions	Elements Determined	
	Calcium	Magnesium
Wave length, mu	422.7	285.2
Phototube	Blue	Blue
Phototube resister position	2	2
Selector	0.1	0.1
Slit width, mm.	0.01	0.06
Photomultiplier: Sensitivity	Full	Full
Zero Depression	1	1
Top standard solution, ppm.	500	[illegible]00

Phosphorus was determined by the ammonium molybdate method. One ml. of the stock solution was diluted to 10 ml. in a colorimeter tube. Six drops of ammonium molybdate reagent and 6 drops of F-S reducing reagent were added. After standing 20 minutes, the transmittancy of the blue solution was read on the Coleman Universal spectrophotometer Model 14 at 650 mu.

The ammonium molybdate reagent was prepared as follows: dissolved 100 gm. c.p. ammonium molybdate in 850 ml. water, added 160 ml. water to 1700 ml. concentration hydrochloric acid, cooled and added the molybdate solution slowly with stirring to the acid solution. The F-S reducing reagent was prepared by mixing 2.5 gm. 1-amino-2-naphthol-4-sulfonic acid, 5.0 gm. sodium sulfite, and 146.0 gm. sodium bisulfite, meta, thoroughly and grinding the mixture to a fine powder, dissolved 7.7 gm. of mixture in 50 ml. of warm water.

III. <u>Field Experiments</u>

1. Location: W. K. Kellogg Farm, Kalamazoo County.
2. Soil: Fox sandy loam, pH of 6.9, exchangeable potassium content of 176 pounds per acre, and acid soluble plus adsorbed phosphorus content of 98 pounds per acre.
3. Treatments: Eleven different treatments, as described in Table 2.
4. Size of plot: 10 x 30 feet.

Table 2. The rate, frequency, and method of application of fertilizer for alfalfa grown in the field on a Fox sandy loam soil.

Treatment number	Fertilizer	Pounds per Acre		Time
		Broadcast	Banded	
1	5-20-20	800	-	April, 1955
2	5-20-20	400	-	April, 1955
3	5-20-20	-	800	April, 1955
4	5-20-20	-	400	April, 1955
5	5-20-20	-	400	April, 1955
	0-20-20	400	-	April, 1956
6	5-20-20	-	400	April, 1955
	0-20-20	200	-	April, 1956
	0-20-20	200	-	April, 1957
7	5-20-20	-	267	April, 1955
	0-20-20	267	-	April, 1956
	0-20-20	267	-	April, 1957
8	5-20-20	-	160	April, 1955
	0-20-20	160	-	Sept., 1955
	0-20-20	160	-	April, 1956
	0-20-20	160	-	Sept., 1956
	0-20-20	160	-	April, 1957
9	5-20-20	-	160	April, 1955
	0-20-20	240	-	April, 1956
10	0-20-20	400	-	April, 1956
11	No fertilizer			

5. Experimental design: Randomized block with four replications per treatment.

6. Culture and harvest methods: Ranger alfalfa was band seeded on April 12, 1955, at 7 to 8 pounds per acre, and the nurse crop, Kent oats, was seeded at the same time at one bushel per acre. The field was cultipacked on April 14, 1955. The oat crop was harvested in July, 1955, but no attempt was made to evaluate yield of grain. However, at this time samples of oat plants and alfalfa were taken for chemical analysis. No harvest of alfalfa was made in 1955.

The first cutting of alfalfa was made on June 14, 1956, and the second cutting on August 10, 1956. Areas harvested for yield measurement were 7 x 30 feet. A moisture sample of the alfalfa was taken from each plot in order to calculate yields on an air dry basis. After drying and weighing, a composite plant sample was taken from each treatment for potassium and phosphorus analysis. These methods of analysis were the same as those used in the greenhouse studies.

IV. RESULTS AND DISCUSSION

Greenhouse Experiments

1. Yield

The total dry weights of alfalfa from nine cuttings are shown in Table 3. Since all the rates of potassium and phosphorus were applied at different times within a period of six cuttings, the total dry matter production from the nine cuttings included some residual effects of fertilizer treatments.

In each soil studied, yields of forage from pots receiving fertilizer were significantly higher than the yields from unfertilized pots. The highest dry matter production was found where the three cycle application of 1200 pounds of 0-20-20 per acre was applied to Brookston soil. This resulted in a 62 per cent increase in yield over that obtained from the unfertilized pots.

Although there was no statistical difference between frequencies of application when considering the same amount of applied fertilizer, nevertheless the efficiency in use of fertilizer was found to be different when the fertilizer was applied at different times on Brookston and Conover soils. It is evident from Table 3 that 1200 pounds of 0-20-20 applied in three cycles to Brookston soil increased yield significantly or very significantly over the lower

Table 3. The effect of rate and time of application of fertilizer on the yield of nine cuttings of alfalfa grown in the greenhouse on three soils.

Treatment number	Grams per pot (oven dry weight)	Increase over check (per cent)	1	2	3	4	5	6	7	8	9
			Difference in yield between treatments								
Brookston clay loam											
1	138.5	47.5									
2	146.1	55.5	-7.6								
3	152.1	62.0	-13.6	-6.0							
4	134.0	42.7	4.5	12.1	18.1*						
5	133.8	42.5	4.7	12.3	18.3*	0.2					
6	127.7	36.0	10.8	18.4*	24.4**	6.3	6.1				
7	128.2	36.5	10.3	17.9*	23.9**	5.8	5.6	-0.5			
8	133.5	42.2	5.0	12.6	18.6*	0.5	0.3	-5.8	-5.3		
9	123.5	31.6	15.0	22.6*	28.6**	10.5	10.3	4.2	4.7	-10.0	
10	93.9	-	44.6**	52.2**	58.2**	40.1**	39.9**	33.8**	34.3**	39.6**	29.6**
*L.S.D. (5 per cent level)			17.2								
**L.S.D. (1 per cent level)			23.6								
Conover loam											
1	129.7	48.4									
2	138.5	58.5	- 8.8								
3	135.1	54.6	- 5.4	3.4							
4	137.7	57.5	- 8.0	0.8	-2.6						
5	126.1	44.2	- 3.6	12.4*	9.0	11.6*					
6	122.8	40.5	6.9	15.7**	12.3*	14.9**	3.3				
7	123.9	41.7	5.8	14.6**	11.2*	13.8*	2.2	-1.1			
8	118.8	35.9	10.9*	19.7**	16.3**	18.9**	7.3	4.0	5.1		
9	115.4	32.0	14.3**	23.1**	19.7**	22.3**	10.7*	7.4	8.5	3.4	
10	87.4	-	42.3**	51.1**	47.7**	50.3**	38.7**	35.4**	36.5**	31.4**	28.0**
*L.S.D. (5 per cent level)			10.4								
**L.S.D. (1 per cent level)			14.3								

Table 3. Continued.

Treat- ment number	Grams per pot (oven dry weight)	Increase over check (per cent)	1	2	3	4	5	6	7	8	9
			Difference in yield between treatments								
			Hillsdale sandy loam								
1	122.4	24.5									
2	129.7	32.1	- 7.3								
3	135.9	38.2	13.5	-6.2							
4	128.8	31.1	6.4	0.9	7.1						
5	116.7	18.7	5.7	13.0	19.2*	12.1					
6	121.1	23.1	1.4	8.7	14.9	7.8	-4.3				
7	127.3	29.5	4.9	2.4	8.6	1.5	-10.6	-6.3			
8	124.3	26.4	1.9	5.4	11.6	4.5	-7.6	-3.3	3.0		
9	124.7	26.8	2.3	5.0	11.2	4.1	-8.0	-3.7	2.6	-0.4	
10	98.3	-	24.1*	31.4**	37.6**	30.5**	18.4*	22.7*	29.0**	26.0**	26.4**
*L.S.D. (5 per cent level)			17.1								
**L.S.D. (1 per cent level)			23.4								

Description

1 1200 lb. 0-20-20, one application at planting time.
2 1200 lb. 0-20-20, two applications, at planting time and after 3rd cutting.
3 1200 lb. 0-20-20, three applications, at planting time and after 2nd, 4th cuttings.
4 1200 lb. 0-20-20, four applications, at planting time and after each cutting till 5th cutting.
5 600 lb. 0-20-20, one application, same as number 1.
6 600 lb. 0-20-20, two applications, same as number 2.
7 600 lb. 0-20-20, three applications, same as number 3.
8 600 lb. 0-20-20, four applications, same as number 4.
9 300 lb. 0-20-20, one application, same as number 1.
10 Check, no fertilizer.

level fertilizer treatments. A significantly greater amount of dry matter was produced from soils where 1200 pounds of 0-20-20 was applied in a three cycle application than where a four cycle application was made. In the same soil when 1200 pounds of fertilizer was applied at planting time only, no statistical difference in yield was found when this rate was compared with the 600 or 300 pound applications. Two cycle application of 1200 pounds of 0-20-20 also increased the alfalfa yield significantly over the lower rates of fertilizer.

The highest yield of alfalfa from Conover soil was obtained from pots where a two cycle application of 1200 pounds per acre of 0-20-20 fertilizer was used. This represented a 58 per cent increase over yield from non-treated soils. The data in Table 3 also show that no statistical difference (five per cent level) was found between yields from soils which received a single application of 1200 pounds of fertilizer and those obtained when lower rates were used. It appears that 600 pounds of 0-20-20 applied at planting time was more efficient. Because of all the soils receiving the 600 pound rate, only this one resulted at five per cent level in significant increase in yield over the 300 pound rate.

In Hillsdale soil where the fertilizer was applied at planting time, the yield of alfalfa from pots receiving the highest fertilizer treatment was lower than from those

fertilized with 600 pound per acre of 0-20-20. According to these data, the potassium and phosphorus requirements of Hillsdale soil were lower than that of the other two soils.

When the yield of alfalfa of each cutting is compared in terms of yield curves as shown in figures 1, 4, 7, 10, 13, and 16, it is clear that the efficiency of the three cycle application of the 1200 pound per acre rate was higher than that of the same amount of fertilizer applied at planting time. A comparison of the data in figures 1 and 4, and figures 7 and 10 indicates that the yield curves for different fertilizer rates did not overlap in the three cycle application. Some slight overlap of yield is evident when all the fertilizer was applied at planting time, both in Brookston and Conover soils. An examination of figures 13 and 16 show that almost all the yield curves of treatments including various rates of fertilizer applied at one time to Hillsdale soil tended to cross one another. In the three cycle application of fertilizer to this soil the yield curves of two different rates overlapped only in the 6th and 7th cuttings.

As shown in Table 4, the response of alfalfa grown on Brookston and Conover soils to added phosphorus was found to be substantially greater than to potassium. The 240 pound P_2O_5 per acre treatment increased the yield by 37 per cent over that where 240 pounds of K_2O per acre was applied

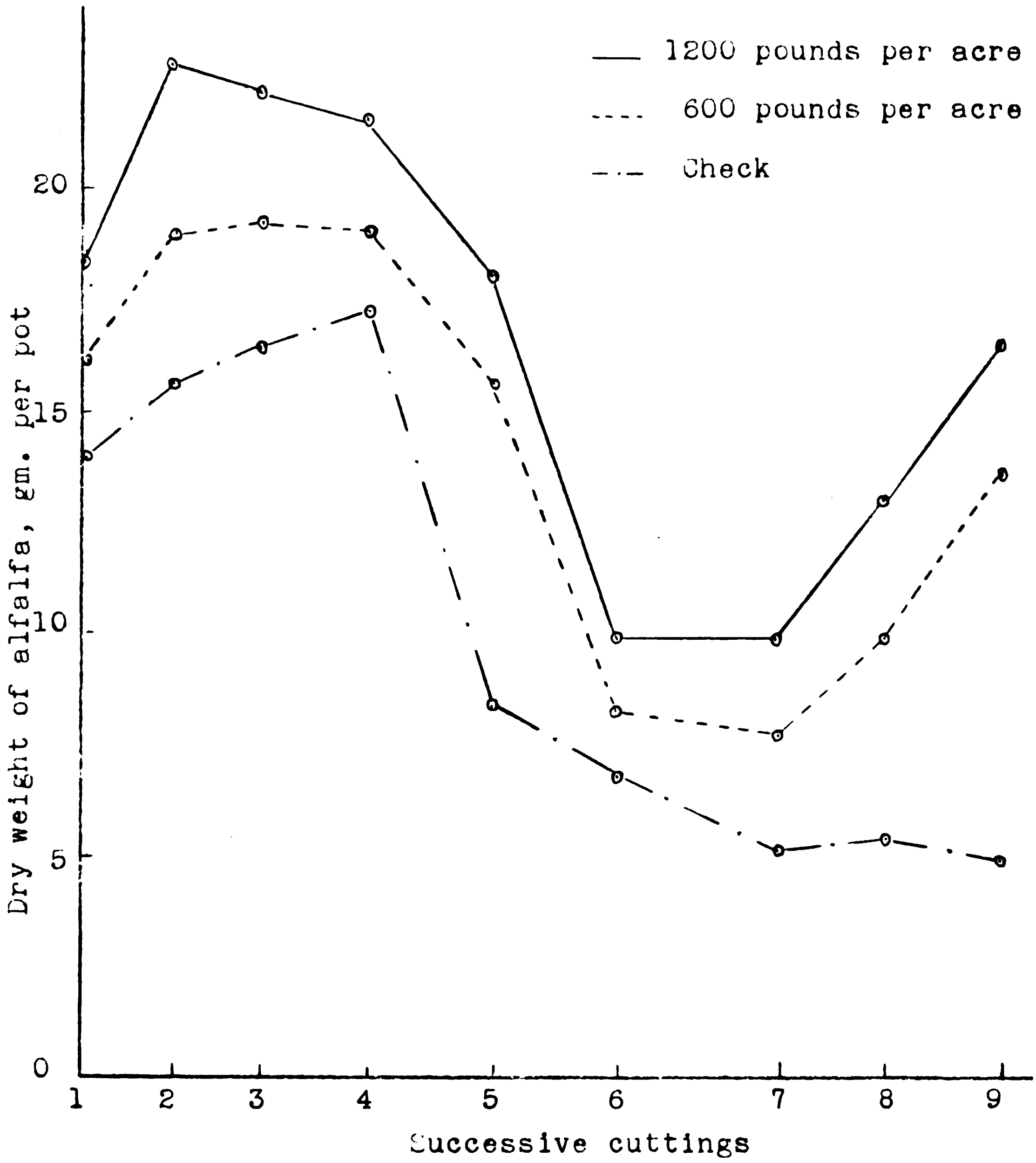

Fig. 1. Yield curves of alfalfa for a three cycle application of different rates of fertilizer applied to a Brookston clay loam.

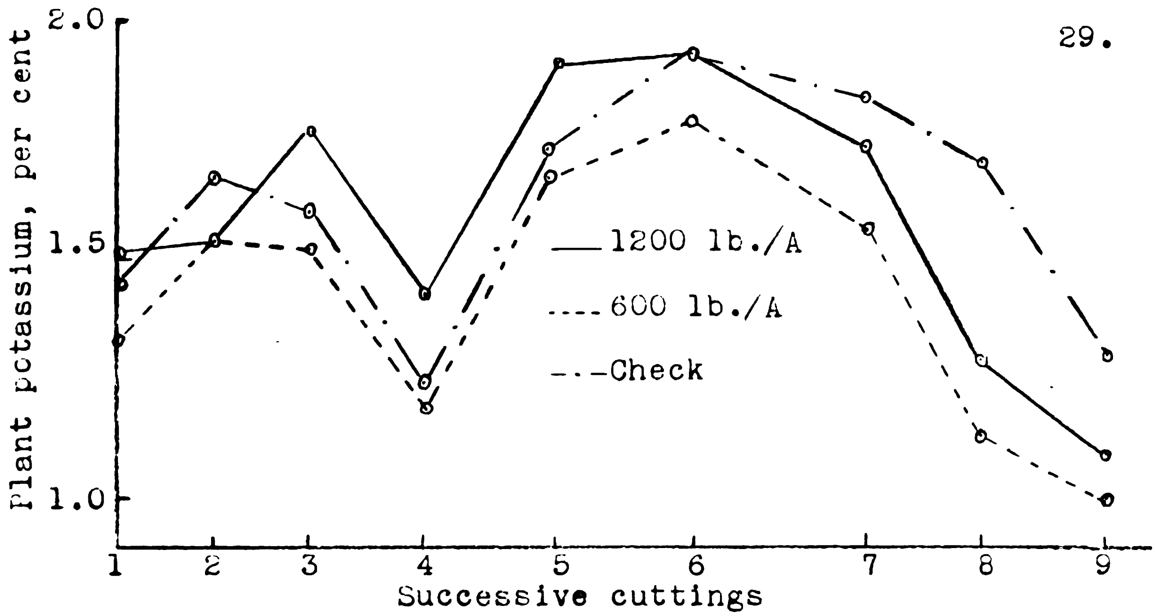

Fig. 2. The potassium content of nine successive cuttings of alfalfa for a three cycle application of different rates of fertilizer applied to a Brookston clay loam.

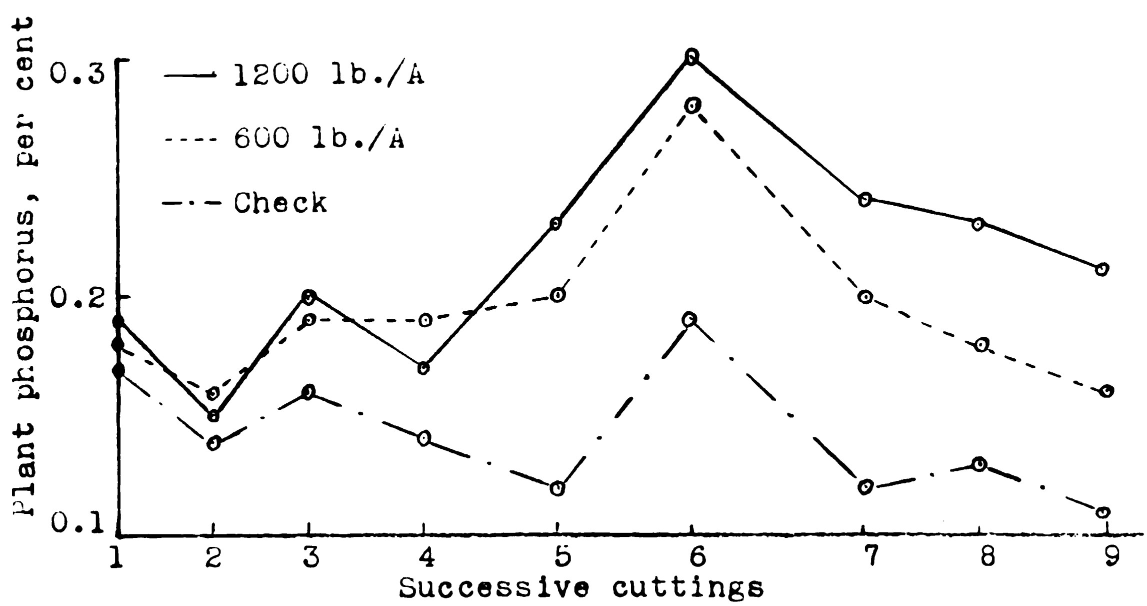

Fig. 3. The phosphorus content of nine successive cuttings of alfalfa for a three cycle application of different rates of fertilizer applied to a Brookston clay loam.

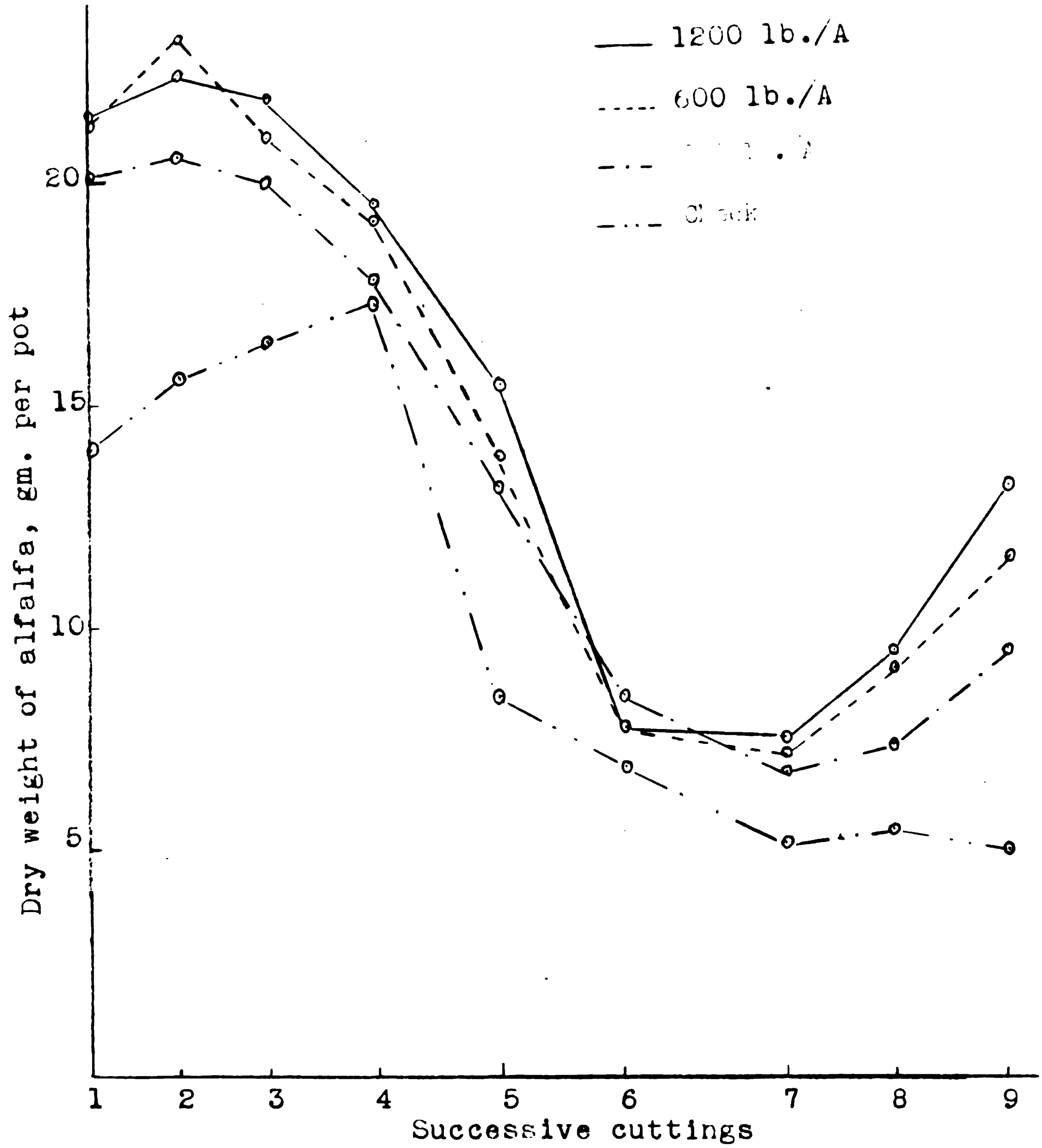

Fig. 4. Yield curves of alfalfa for a single application of different rates of fertilizer applied to a Brookston clay loam.

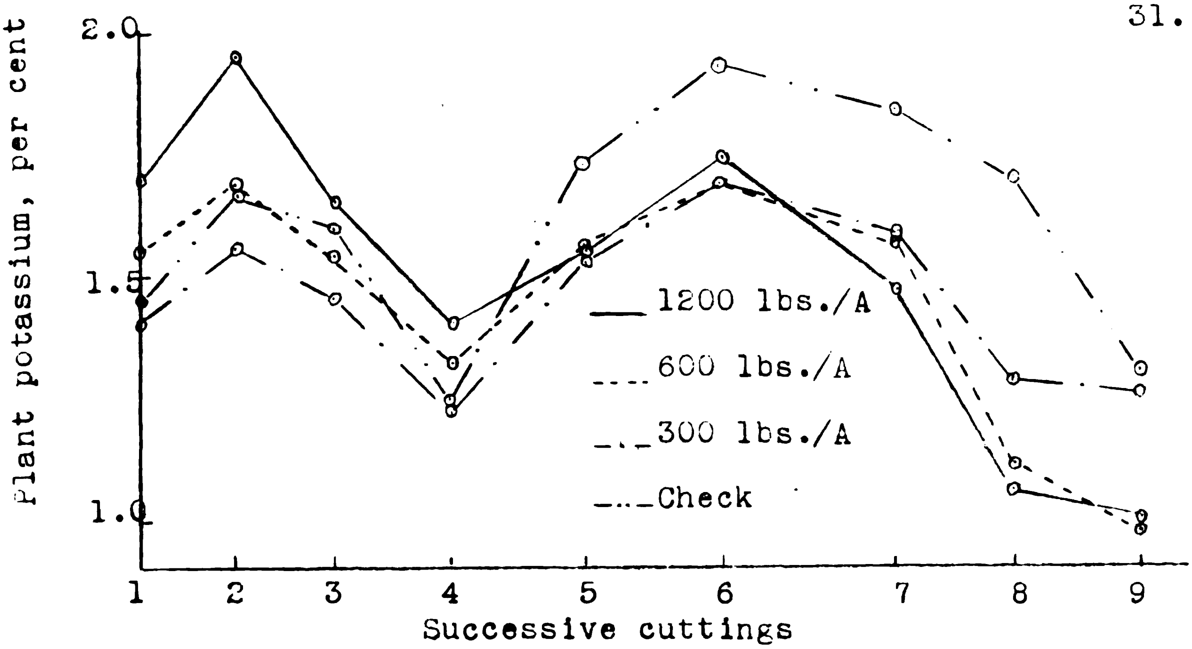

Fig. 5. The potassium content of nine successive cuttings of alfalfa for a single application of different rates of fertilizer applied to a Brookston clay loam.

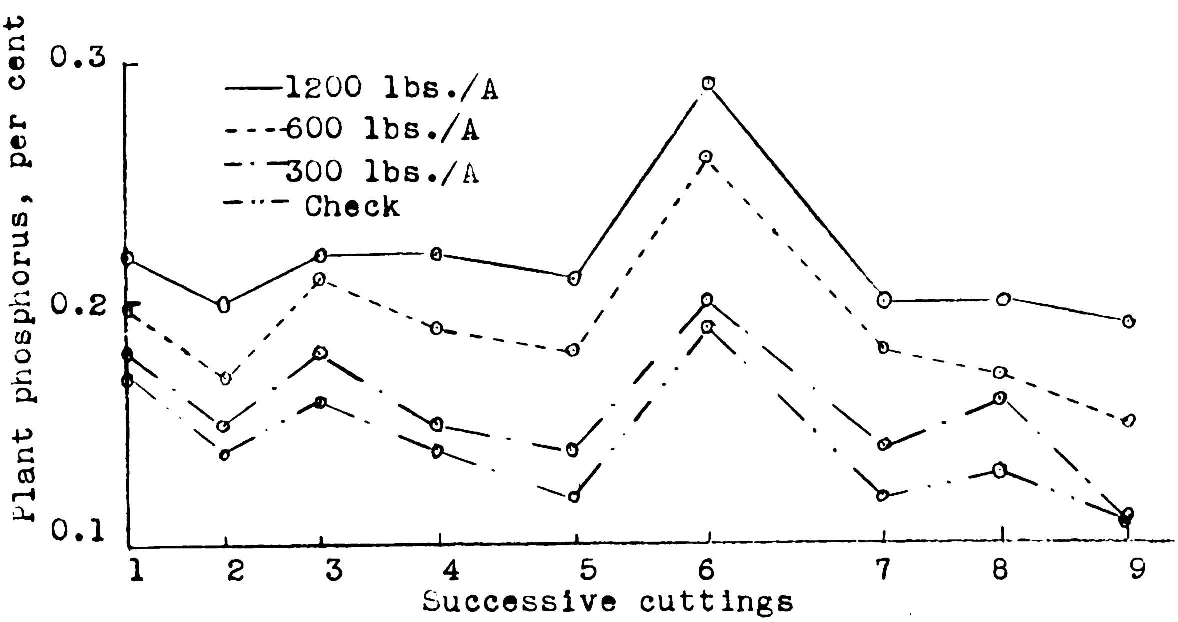

Fig. 6. The phosphorus content of nine successive cuttings of alfalfa for a single application of different rates of fertilizer to a Brookston clay loam.

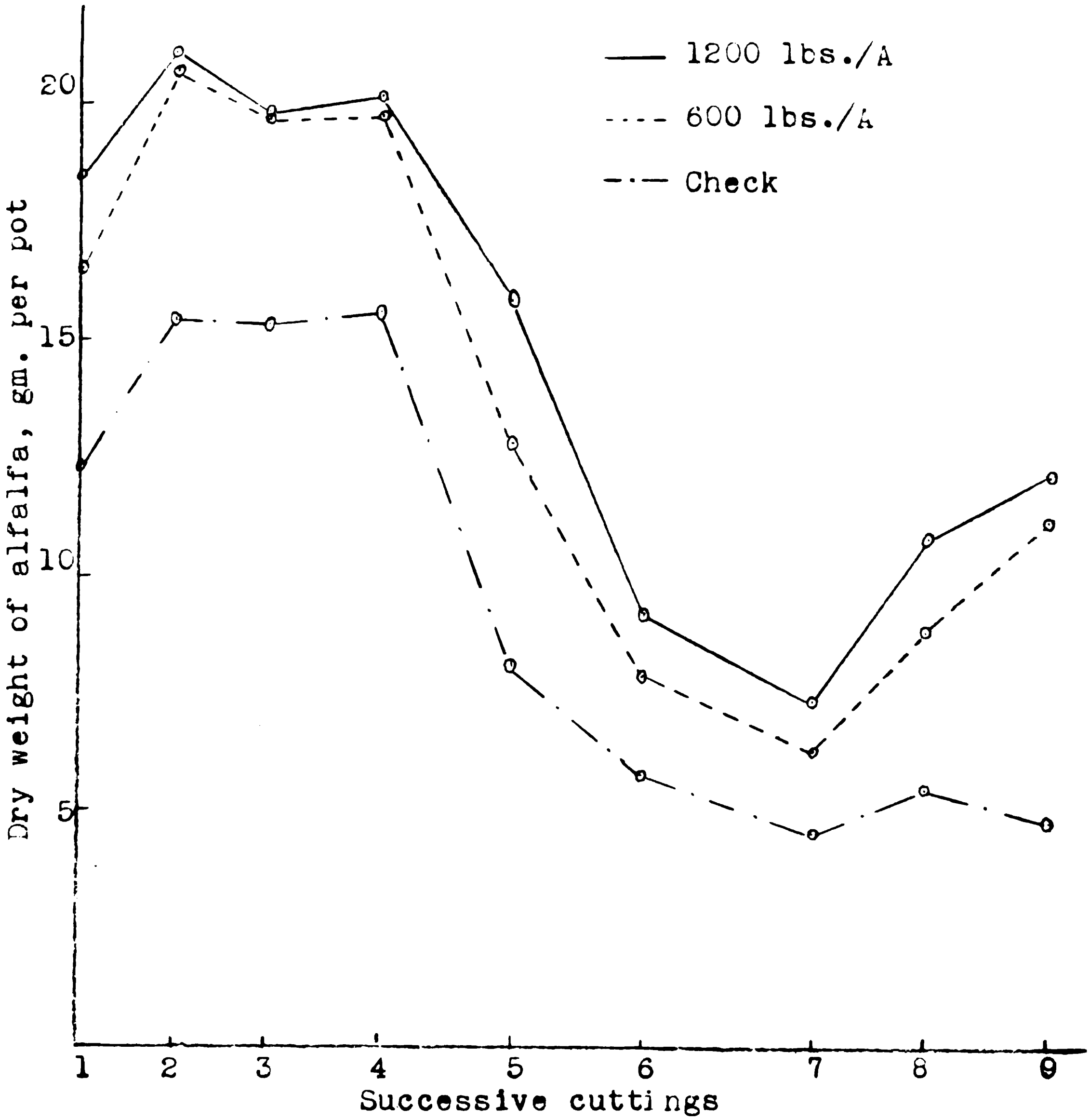

Fig. 7. Yield curves of alfalfa for a three cycle application of different rates of fertilizer applied to a Conover loam.

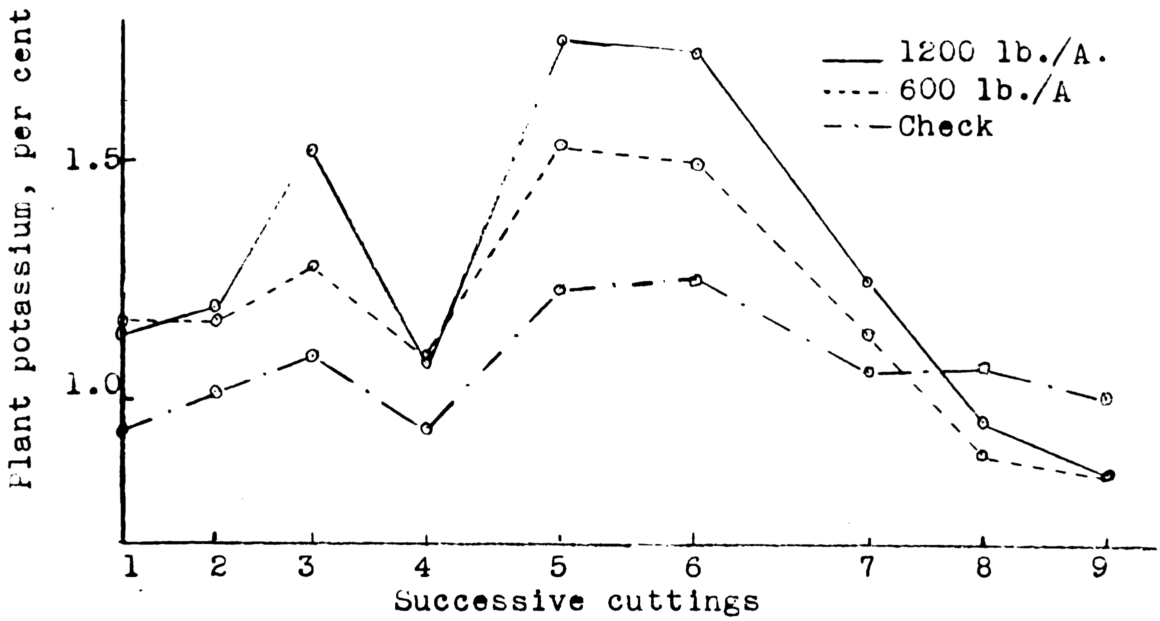

Fig. 8. The potassium content of nine successive cuttings of alfalfa for a three cycle application of different rates of fertilizer applied to a Conover loam.

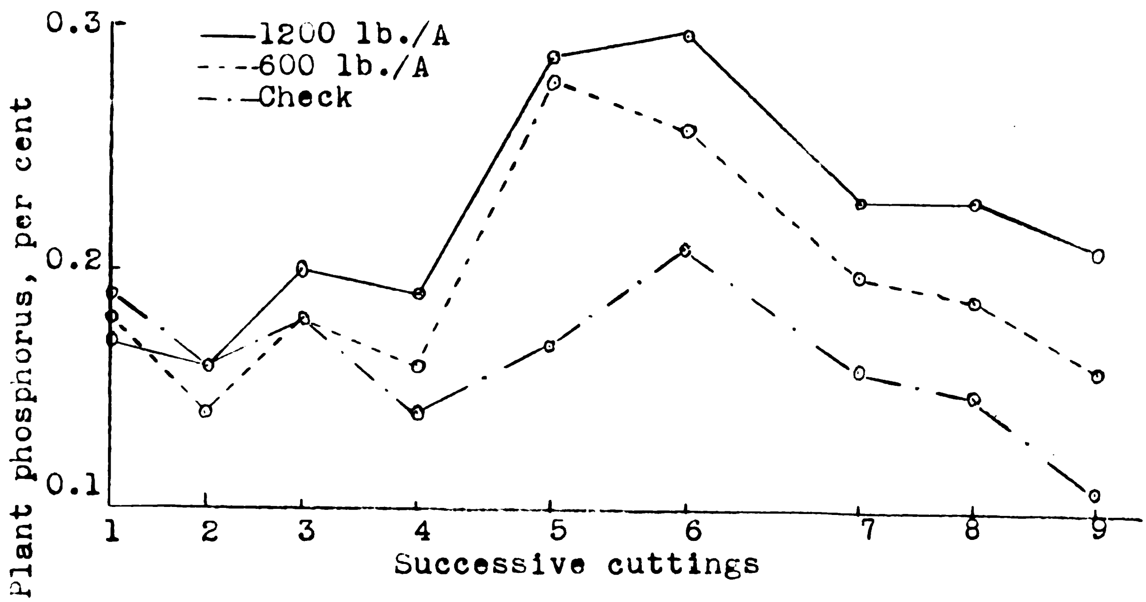

Fig. 9. The phosphorus content of nine successive cuttings of alfalfa for a three cycle application of different rates of fertilizer applied to a Conover loam.

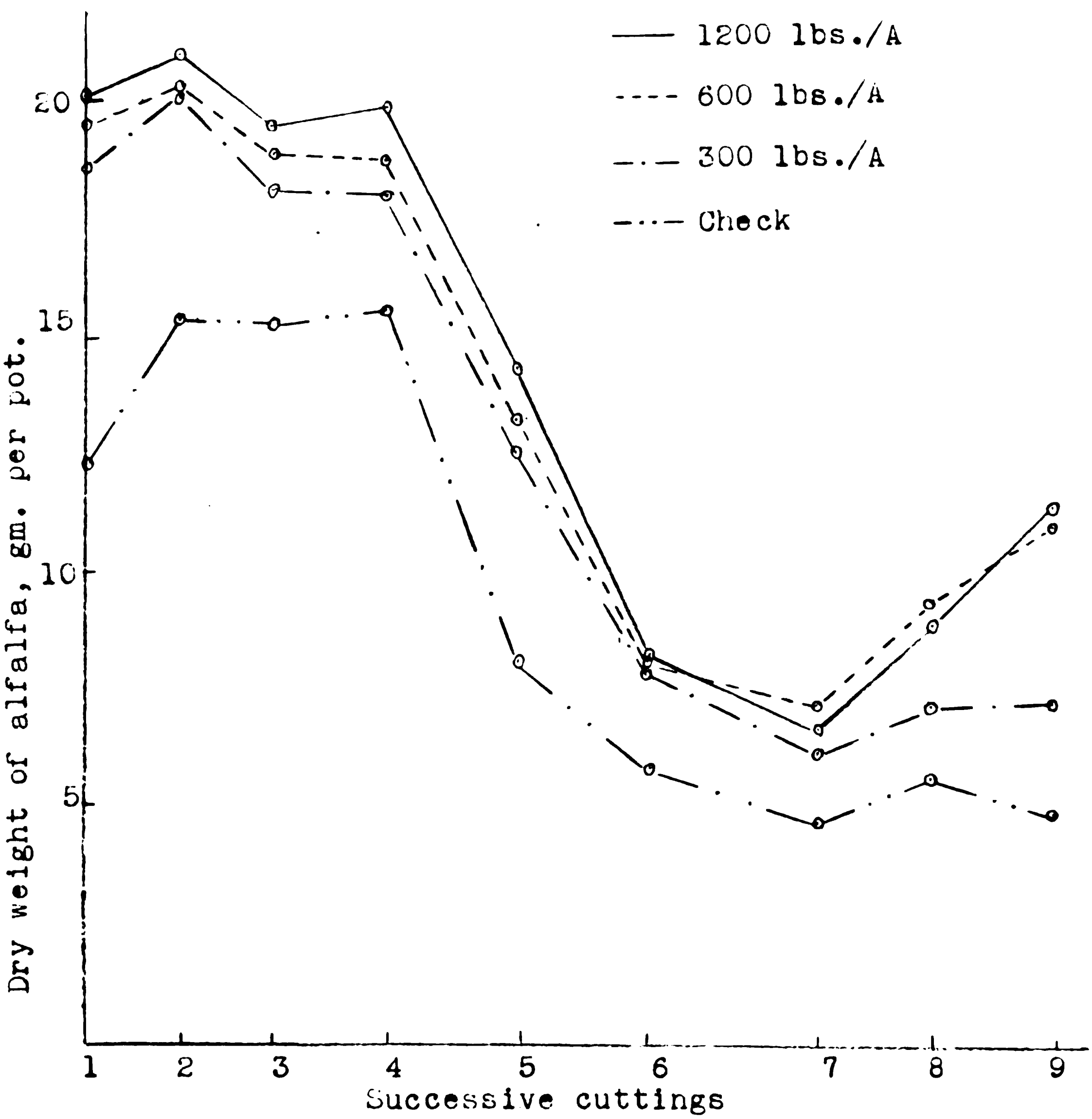

Fig. 10. Yield curves of alfalfa for a single application of different rates of fertilizer applied to a Conover loam.

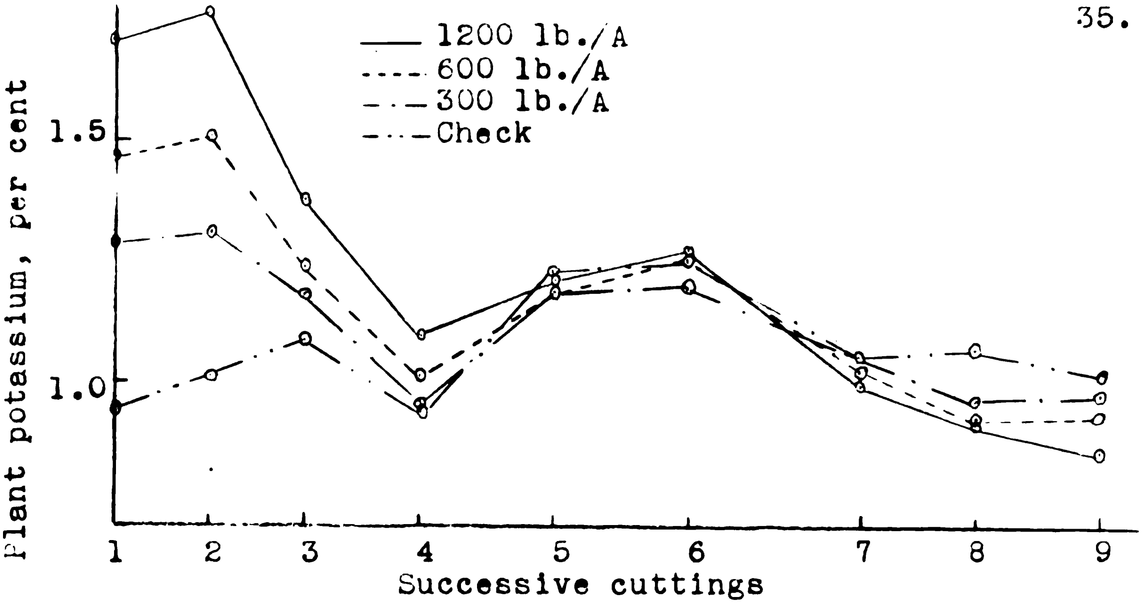

Fig. 11. The potassium content of nine successive cuttings of alfalfa for a single application of different rates of fertilizer applied to a Conover loam.

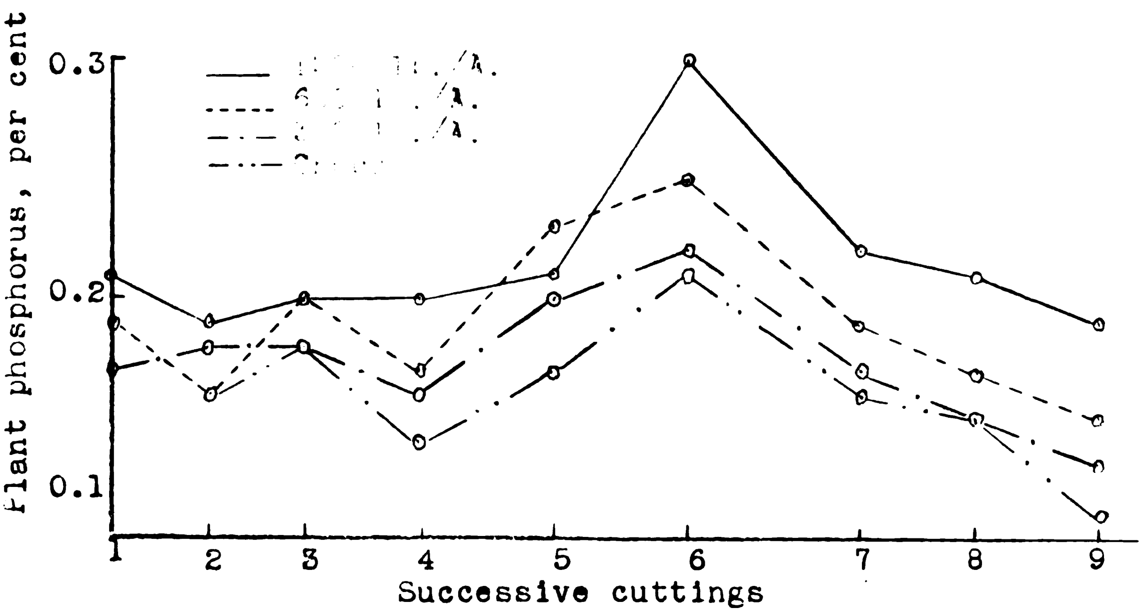

Fig. 12. The phosphorus content of nine successive cuttings of alfalfa for a single application of different rates of fertilizer applied to a Conover loam.

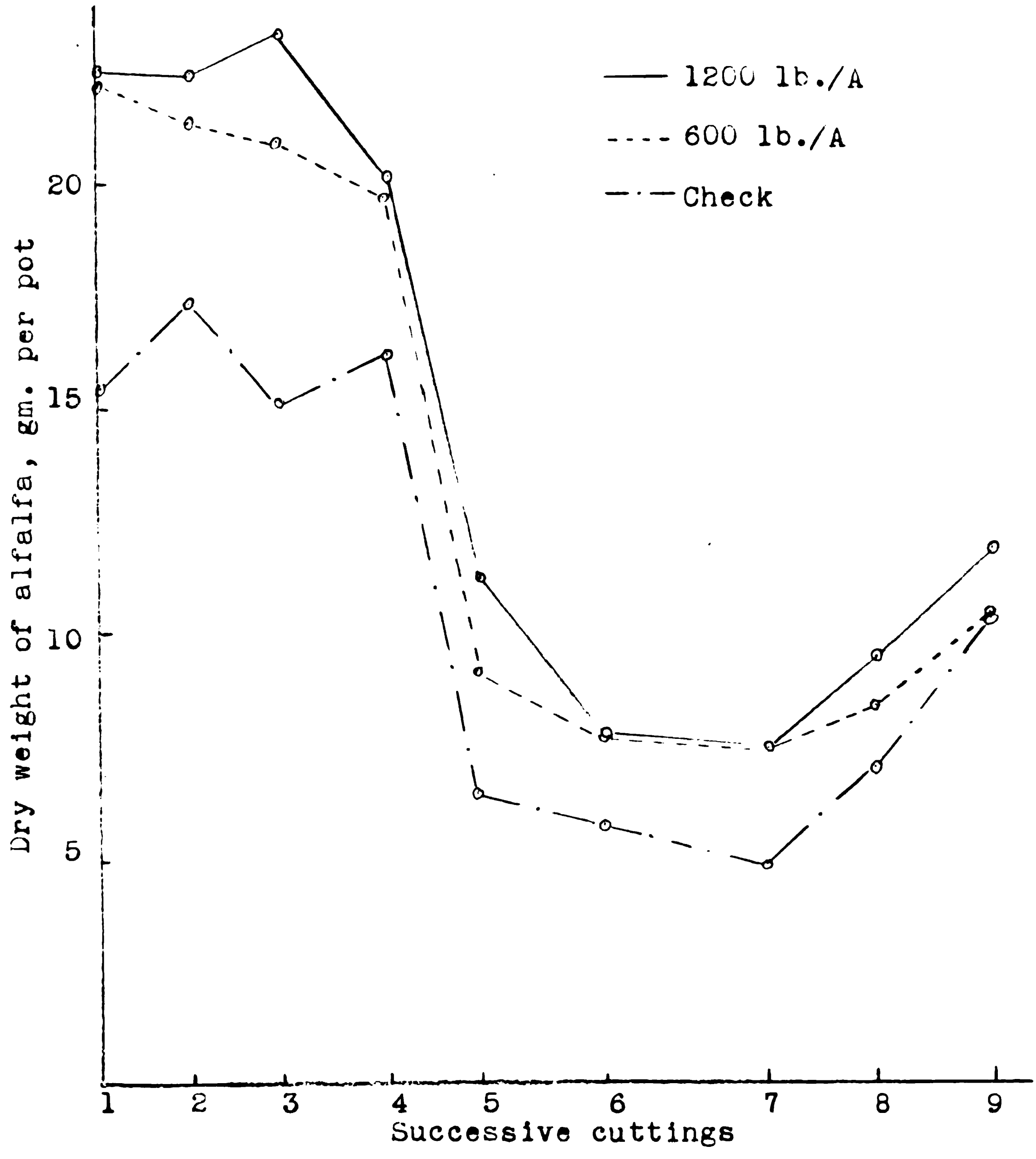

Fig. 13. Yield curves of alfalfa for a three cycle application of different rates of fertilizer applied to a Hillsdale sandy loam.

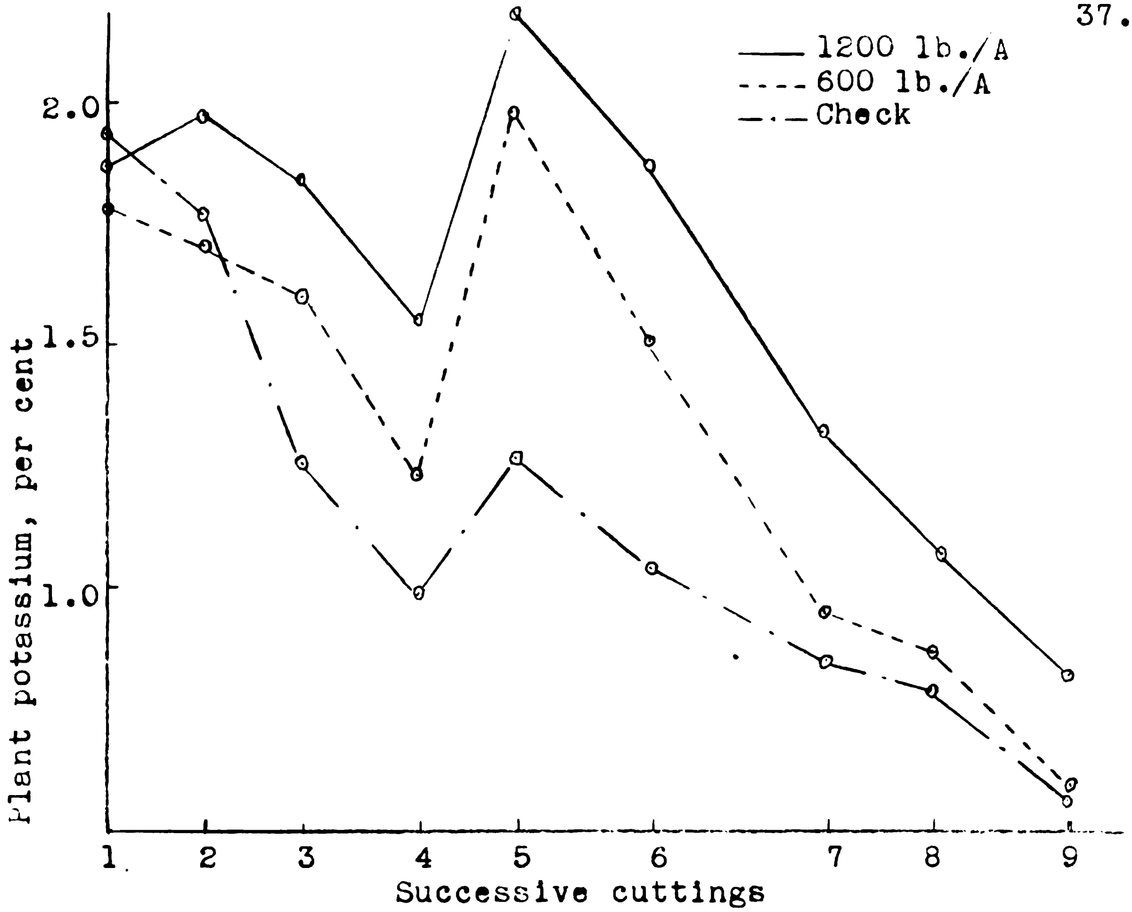

Fig. 14. The potassium content of nine successive cuttings of alfalfa for a three cycle application of different rates of fertilizer applied to a Hillsdale sandy loam.

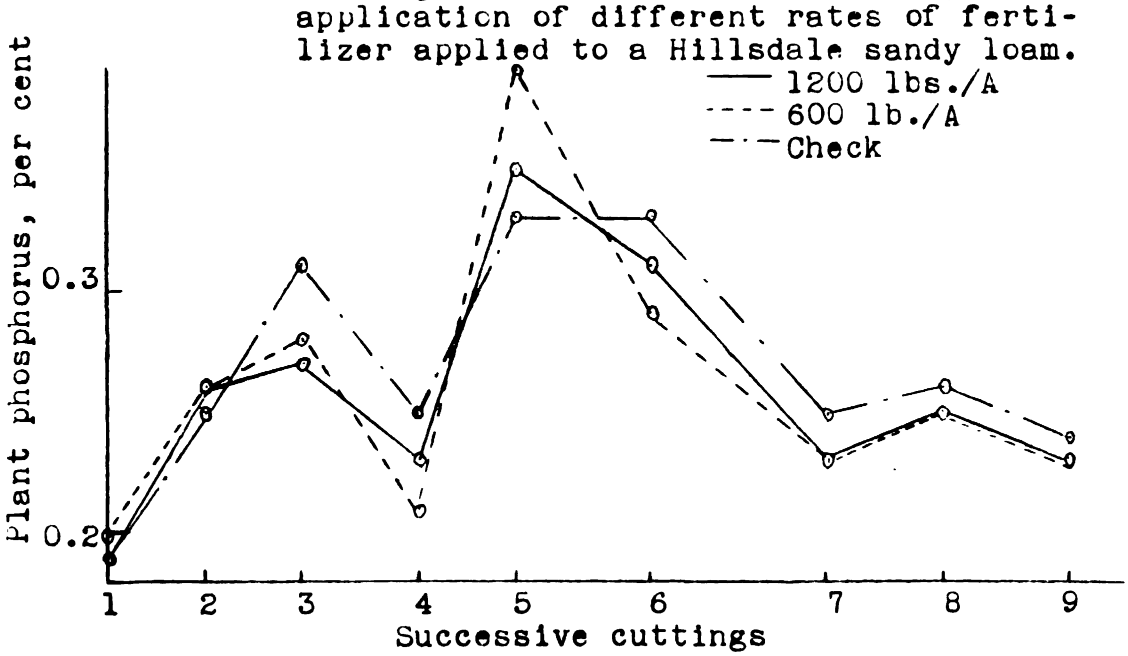

Fig. 15. The phosphorus content of nine successive cuttings of alfalfa for a three cycle application of different rates of fertilizer applied to a Hillsdale sandy loam.

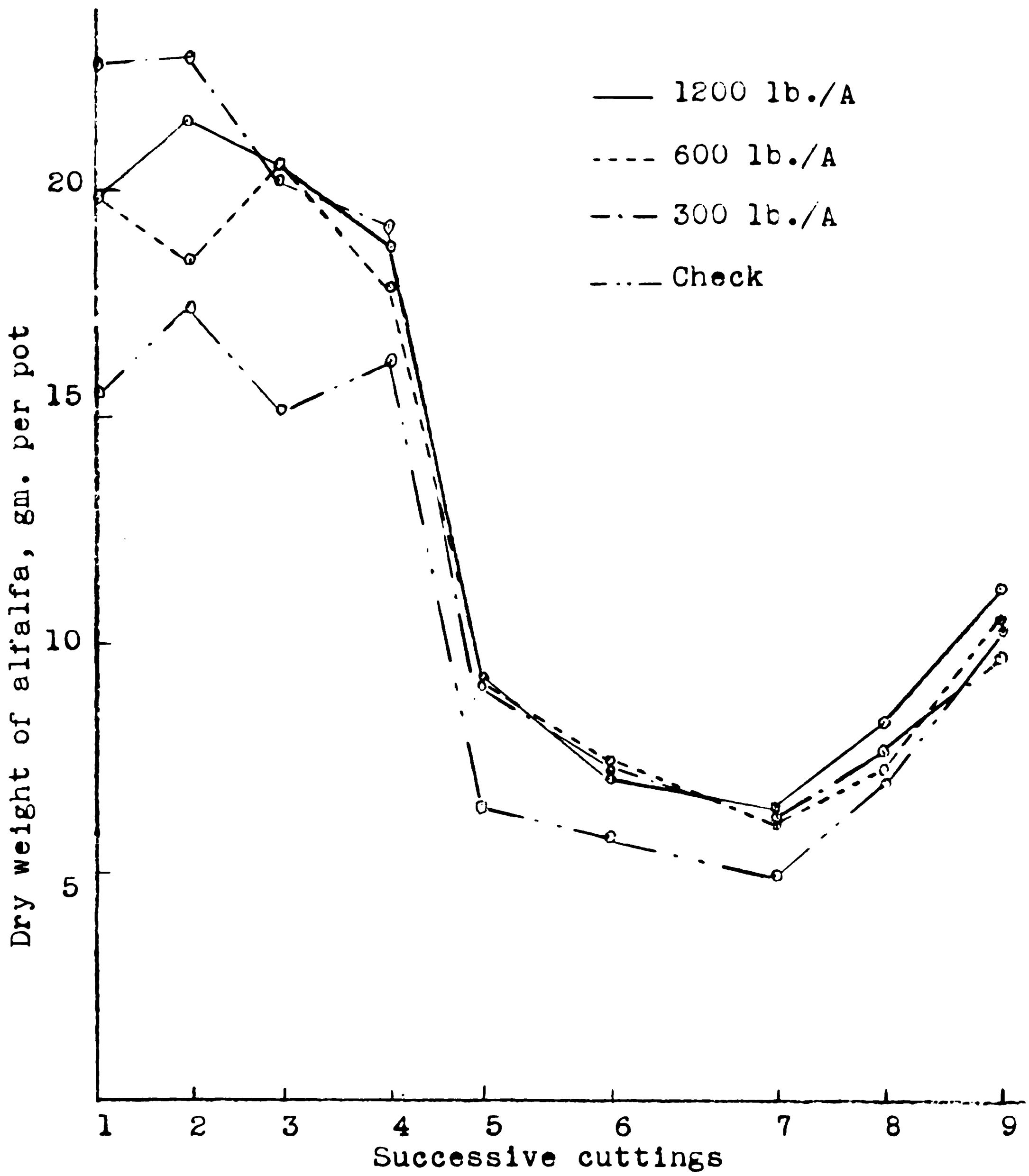

Fig. 16. Yield curves of alfalfa for a single application of different rates of fertilizer applied to a Hillsdale sandy loam.

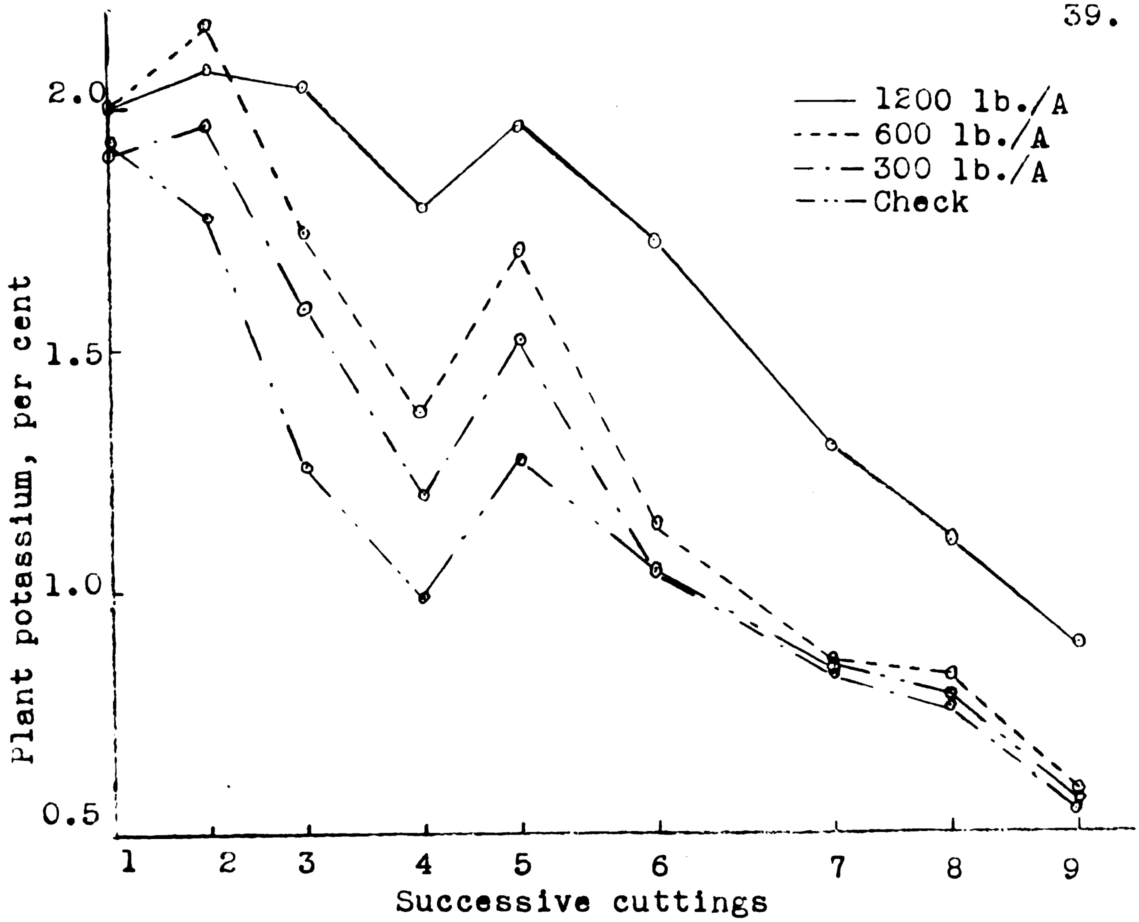

Fig. 17. The potassium content of nine successive cuttings of alfalfa for a single application of different rates of fertilizer applied to a Hillsdale sandy loam.

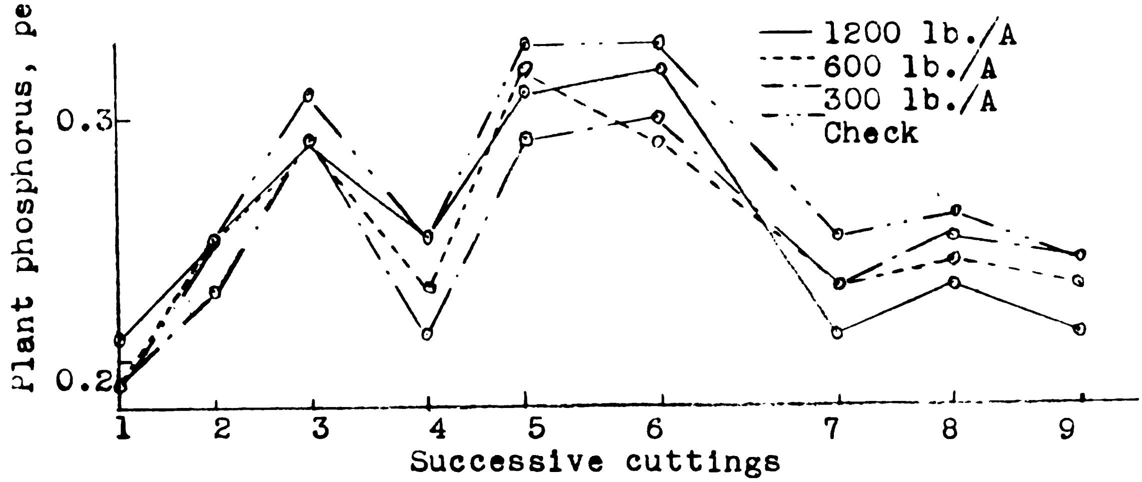

Fig. 18. The phosphorus content of nine successive cuttings of alfalfa for a single application of different rates of fertilizer applied to a Hillsdale sandy loam.

Table 4. Total yield of nine cuttings of alfalfa grown on three surface soils, which received separate applications of phosphate and potash fertilizers.

Treatment	Brookston clay loam		Conover loam		Hillsdale sandy loam	
	Grams per pot	Index per cent	Grams per pot	Index per cent	Grams per pot	Index per cent
240 lb. K_2O applied at planting time	87.4	100.0	79.6	100.0	91.2	100.0
240 lb. P_2O_5 applied at planting time	120.0	137.3	114.7	144.0	95.1	104.3

to the Brookston soil. In Conover soil the corresponding value was 44 per cent. There was not much difference between yield response to phosphate and to potash on Hillsdale soil. According to the results of a field survey by Lawton et al. (22), phosphorus was found to be a greater limiting growth factor than potassium for established alfalfa fields in Michigan.

From the above results it is evident that when higher rates of fertilizer are to be supplied for alfalfa, it is better to apply a given total amount on the basis of a two or three cycle application. In other words, a portion of the total amount should be applied at planting time to get a good stand, and then the remainder applied after every two or three cuttings. When the rate of fertilizer is lower, it is better to apply the entire amount at planting time.

2. Potassium Uptake

Potassium uptake was calculated from the average value of dry weight of alfalfa of each cutting and its corresponding potassium percentage value. The summation values for nine cuttings are given in Table 5.

The relationships between the total dry weight of nine cuttings of alfalfa and potassium uptake for the three soils are shown in figures 19, 20, and 21. The correlation coefficients between these two factors for alfalfa grown on

Table 5. Total amount of potassium and phosphorus absorbed by nine cuttings of alfalfa grown on three surface soils which received different fertilizer

Treatment number	Brookston clay loam		Conover loam		Hillsdale sandy loam	
	Grams K per pot	Grams P per pot	Grams K per pot	Grams P per pot	Grams K per pot	Grams P per pot
1	2.126	0.293	1.677	0.264	2.184	0.308
2	2.246	0.306	1.872	0.283	2.224	0.333
3	2.381	0.309	1.714	0.284	2.287	0.341
4	1.998	0.279	1.879	0.277	2.101	0.322
5	1.981	0.253	1.534	0.236	1.187	0.292
6	1.779	0.238	1.570	0.222	1.884	0.310
7	1.799	0.201	1.439	0.230	1.839	0.320
8	1.913	0.249	1.350	0.222	1.787	0.308
9	1.778	0.196	1.347	0.201	1.805	0.299
10	1.471	0.138	0.915	0.145	1.251	0.255

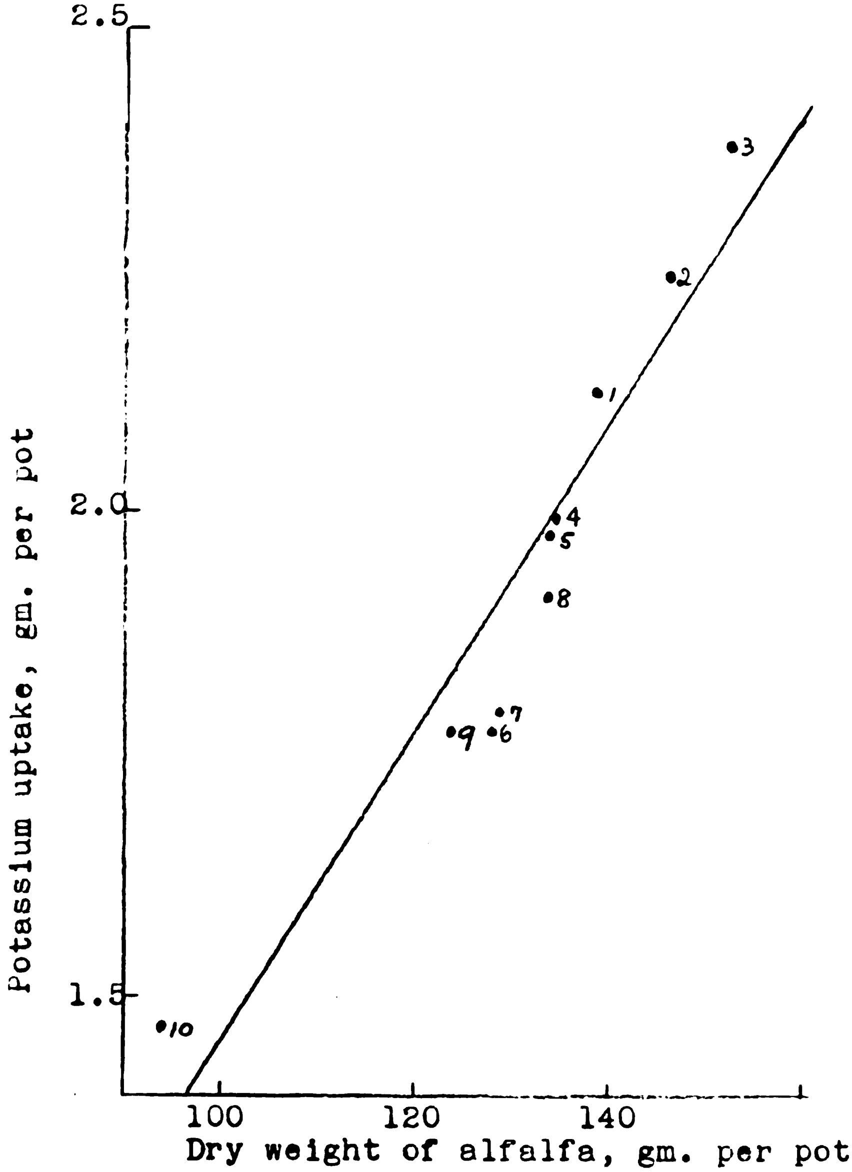

Fig. 19. Relationship between total amount of potassium absorbed by and yield of nine cuttings of alfalfa from a Brookston clay loam which received various fertilizer treatments.

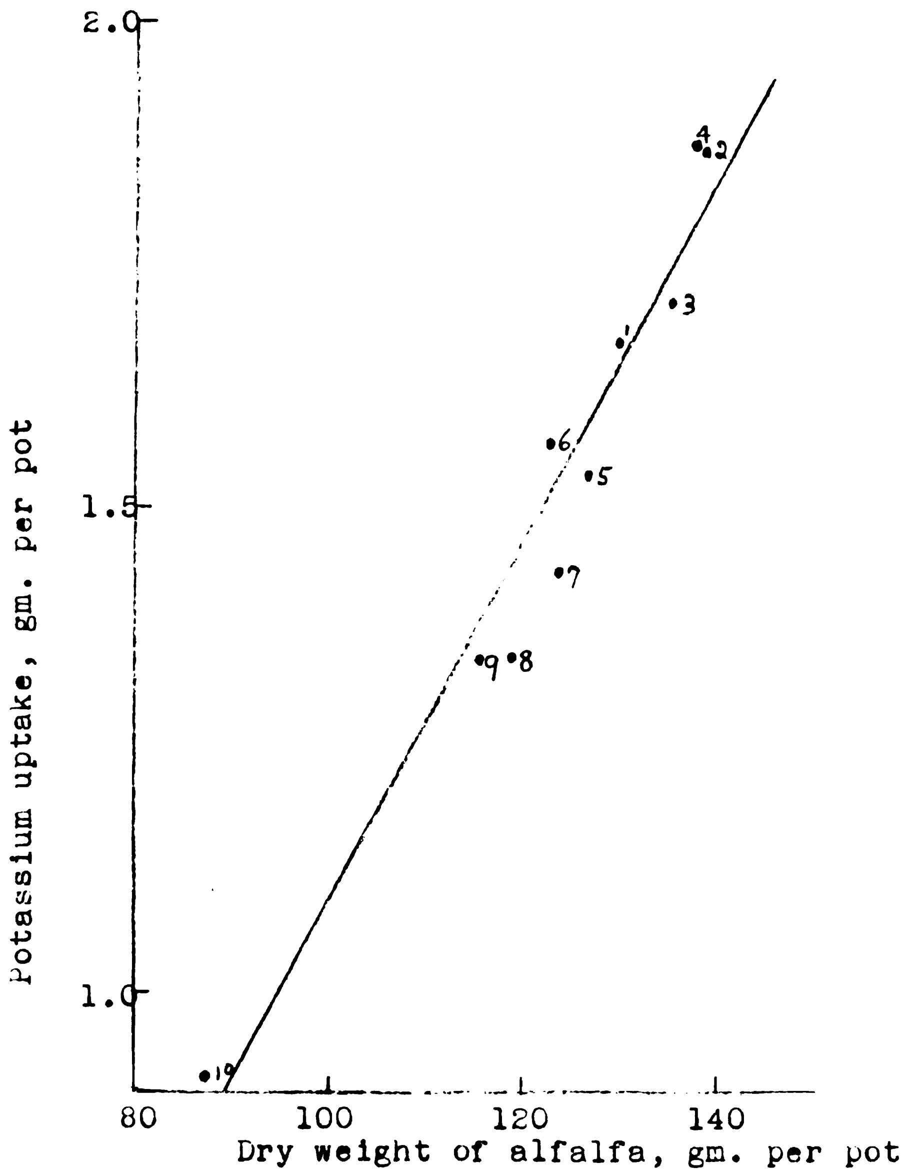

Fig. 20. Relationship between total amount of potassium absorbed by and yield of nine cuttings of alfalfa from a Conover loam which received various fertilizer treatments.

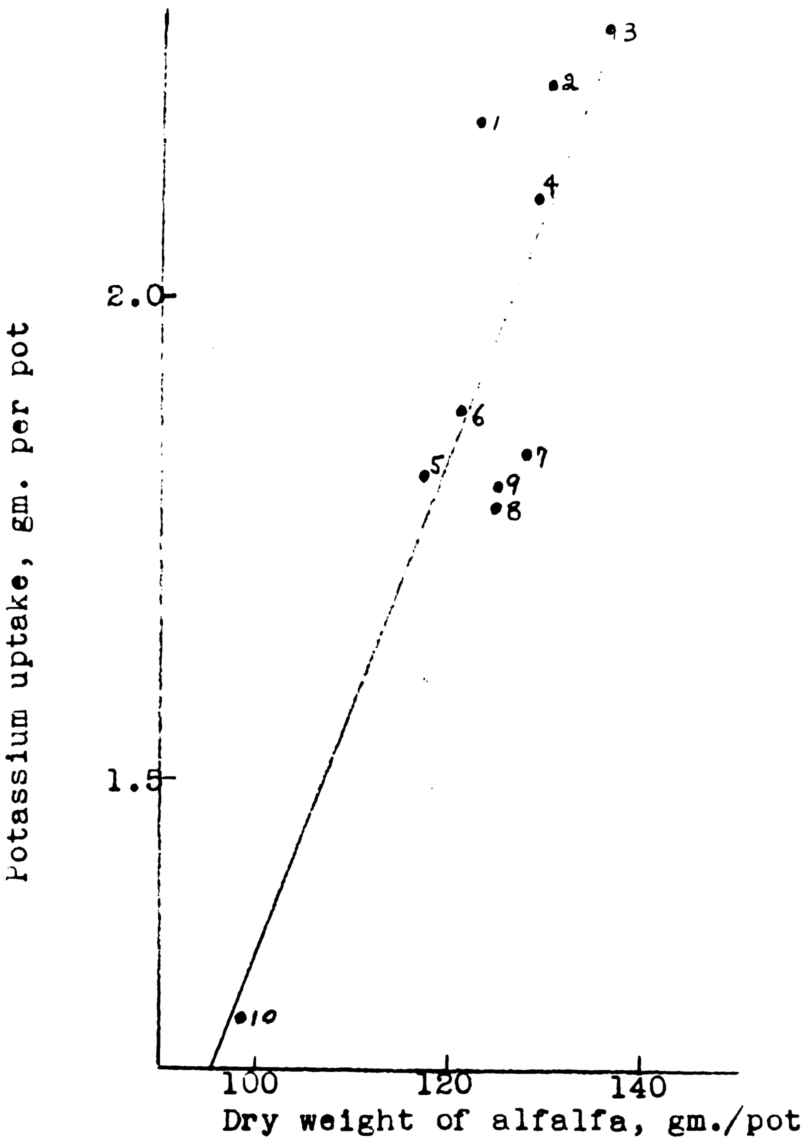

Fig. 21. Relationship between total amount of potassium absorbed by and yield of nine cuttings of alfalfa from a Hillsdale sandy loam which received various fertilizer treatments.

Brookston, Conover, and Hillsdale soils are 0.95, 0.97, and 0.87 respectively. The corresponding "t" test values are 8.67, 11.93, and 5.13 respectively. Since the "t" value at the one per cent level is 3.71, all three correlation co-efficients are highly significant. For a better comparison, the regression equation for each soil was calculated as follows:

$Y = 0.016X - 0.145$ (Brookston soil)

$Y = 0.019X - 0.777$ (Conover soil)

$Y = 0.026X - 1.275$ (Hillsdale soil)

Y equals potassium uptake of nine cuttings of alfalfa in grams per pot and X equals the dry weight of the nine cuttings of alfalfa in grams per pot. It should be noted that the above equations were calculated using the dry weight of the nine cuttings of alfalfa ranging from 80 to 160 grams per pot. Therefore, the above equations are true only within these limitations. Using the above equations, calculations show that 100 grams of dried alfalfa of nine cuttings would absorb 1.45 gm. of potassium from Brookston soil, 1.09 gm. from Conover soil, and 1.32 gm. from Hillsdale soil. The regression coefficient values for the three soils are in the order of Hillsdale Conover Brookston. This relationship indicates that for each unit increase in dry weight of alfalfa, the increase in potassium uptake is

of the order Hillsdale Conover Brookston. For an increase of 10 grams of dried alfalfa, within the range from 80 to 160 grams per pot, the increasing potassium uptake values of Brookston, Conover, and Hillsdale soils are 0.16, 0.19, and 0.26 grams per pot respectively.

The accumulation of potassium in nine successive cuttings where 240 pounds phosphate per acre was applied at planting time, is shown in figure 22. This value may be used as an index of potassium supplying power of the soil.

It is of interest to compare the total dry weight of alfalfa, potassium uptake, and the chemical analysis of several potassium fractions of the three soils. Comparing the acid soluble potassium and exchangeable potassium contents, the order was Brookston Conover Hillsdale. This trend does not check too satisfactorily with the yield response, potassium uptake, and supplying power. However, taking the percentage saturation of exchangeable potassium into consideration, the relationship appears to be more reliable. Even though both the acid soluble and exchangeable potassium contents of the Hillsdale soil were the lowest, its exchangeable potassium saturation value was 3.15 per cent (see Table 1), which is substantially higher than the value of 1.21 per cent for Brookston soil and 1.04 per cent for Conover soil.

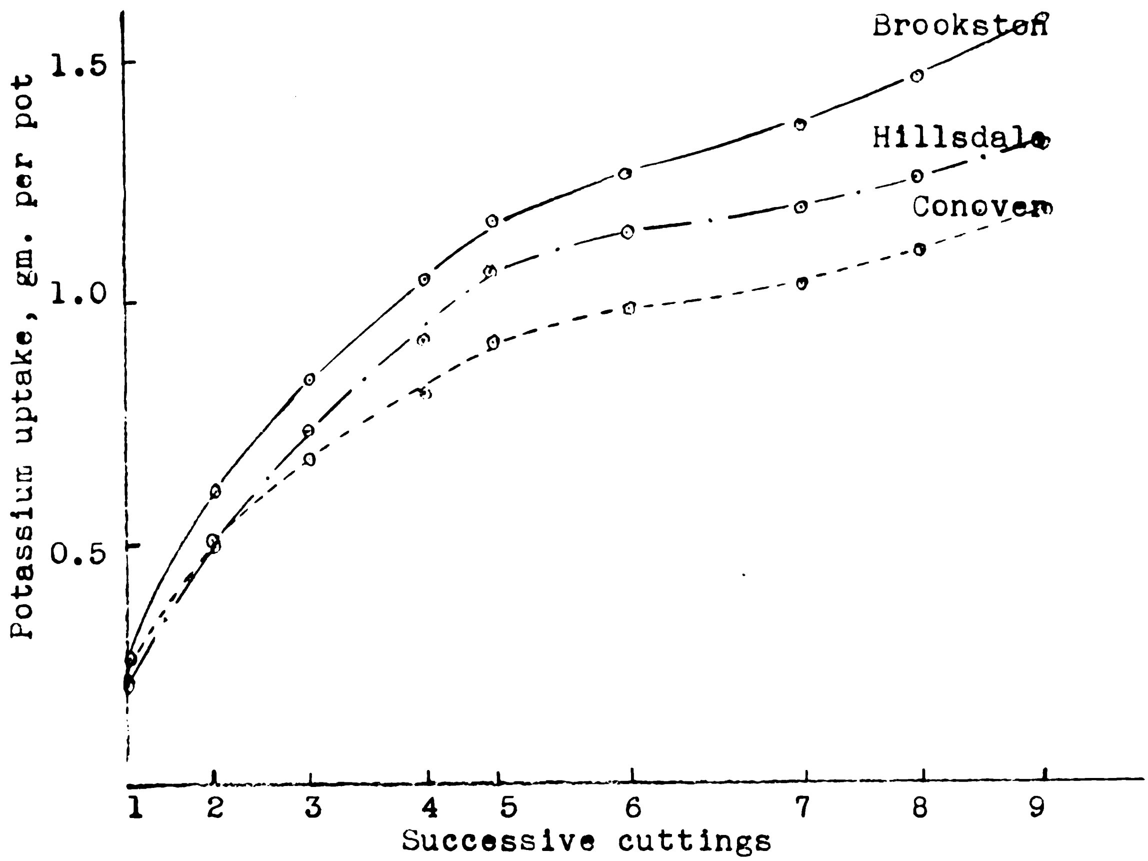

Fig. 22. The accumulative uptake of potassium by nine successive cuttings of alfalfa grown on three surface soils.

It is likely for this reason that the regression coefficient of potassium uptake for Hillsdale soil was highest, and also, that the potassium uptake value and potassium supplying power of Hillsdale soil was greater than that of Conover soil.

These results suggest that when the difference in acid soluble potassium or exchangeable potassium content between two soils is small, such as for Conover and Hillsdale soils in this study, the percentage saturation of exchangeable potassium is important as far as fertility is concerned. If this difference is large, as for Brookston compared with the other two soils, the acid soluble or exchangeable potassium value is still a very good index of the potassium fertility level.

3. Phosphorus Uptake

Phosphorus uptake by alfalfa was calculated in the same manner as that for potassium absorption. These results are also shown in Table 5.

In figures 23, 24, and 25 the relationship between phosphorus uptake and dry weight of alfalfa are presented for each soil. The correlation coefficients of these two factors for Brookston, Conover, and Hillsdale soils are 0.96, 0.97, and 0.96 respectively. These values were similar to those representing the potassium yield relationships for Brookston or Conover soil, and was higher than that for

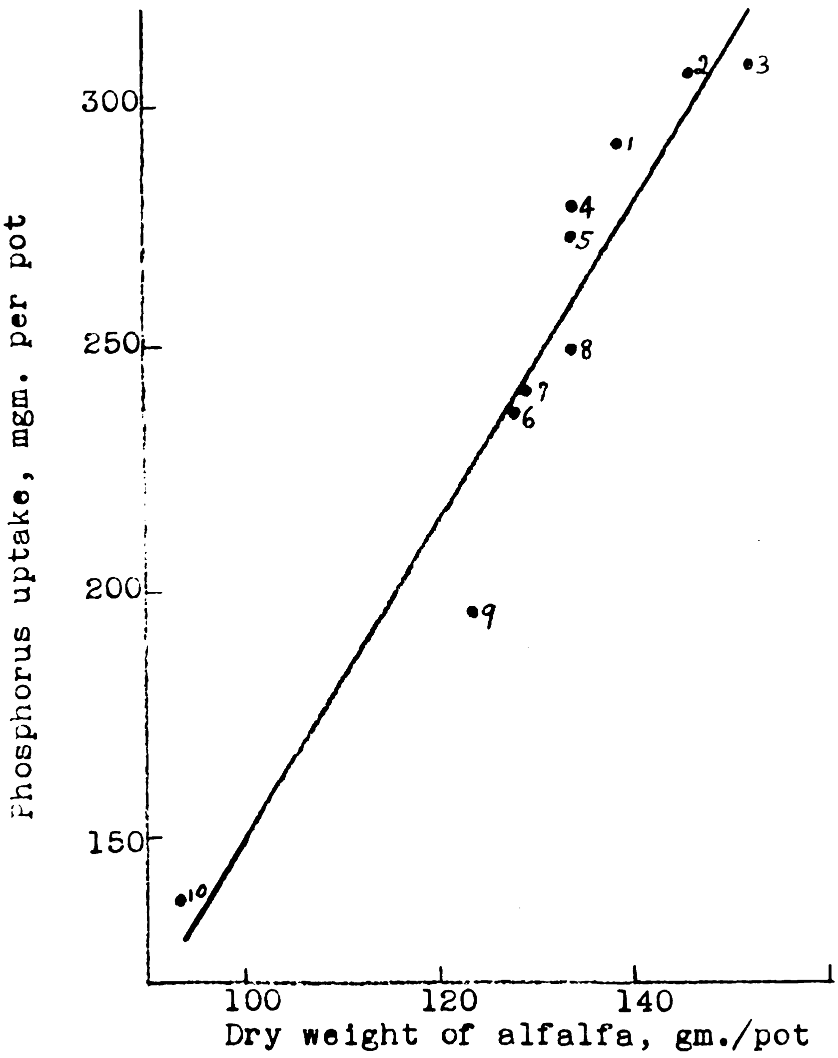

Fig. 23. Relationship between total amount of phosphorus absorbed by and yield of nine cuttings of alfalfa from a Brookston clay loam which received various fertilizer treatments.

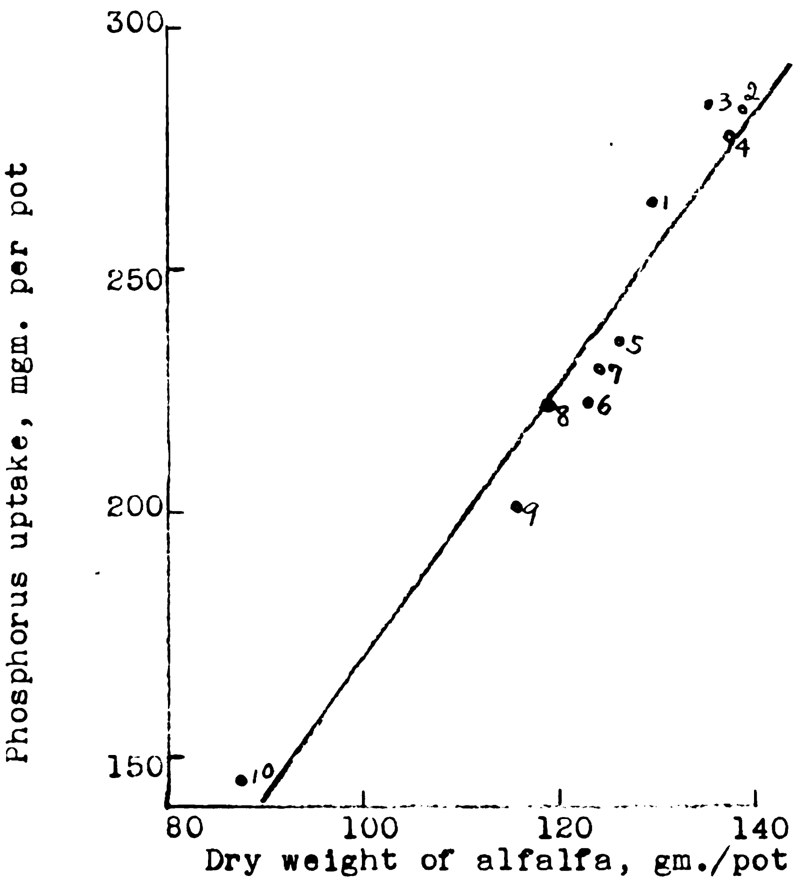

Fig. 24. Relationship between total amount of phosphorus absorbed by and yield of nine cuttings of alfalfa from a Conover loam which received various fertilizer treatments.

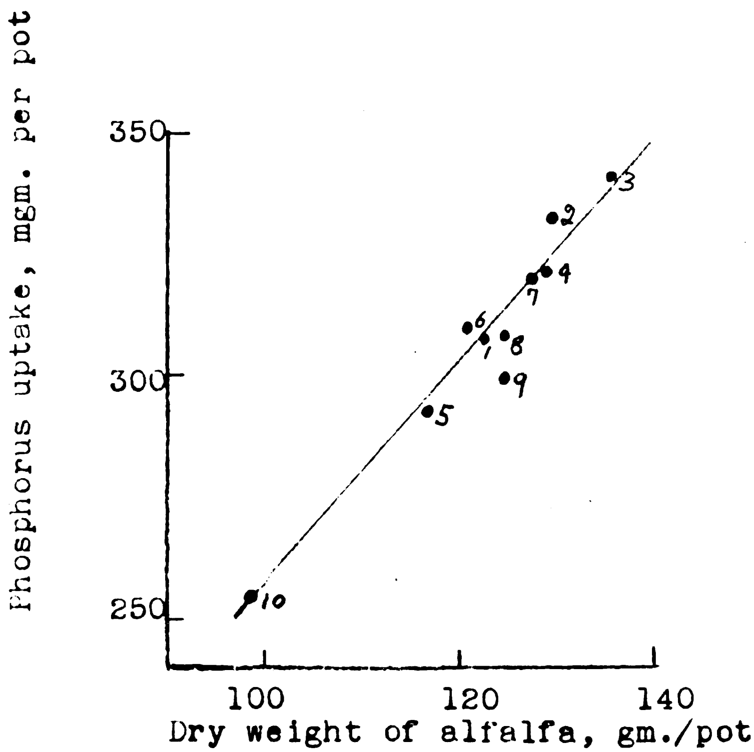

Fig. 25. Relationship between total amount of phosphorus absorbed by and yield of nine cuttings of alfalfa from a Hillsdale sandy loam which received various fertilizer treatments.

Hillsdale soil. All three values are highly significant as were those for potassium uptake and dry matter production. The calculated regression equations are as follows:

$$Y = 3.25X - 175.5 \quad \text{(Brookston soil)}$$

$$Y = 2.81X - 110.6 \quad \text{(Conover soil)}$$

$$Y = 2.27X - 29.8 \quad \text{(Hillsdale soil)}$$

Y equals phosphorus uptake of a total of nine cuttings of alfalfa in milligrams per pot, and X refers to the total dry weight of nine cuttings of alfalfa expressed as grams per pot. These equations hold only within the range of 80 to 160 grams per pot representing the total dry weight of nine cuttings of alfalfa.

The accumulation of phosphorus during the period of nine successive cuttings for the 240-pound per acre potash treatment applied at planting time may be used as an index of phosphorus supplying power as shown in figure 26.

Calculations from the above equations show that on the basis of all cuttings 100 grams of dried alfalfa absorbed 149 milligrams of phosphorus from Brookston soil, 170 milligrams from Conover soil, and 257 milligrams from Hillsdale soil. The difference in absorption of phosphorus by alfalfa from Hillsdale soil and Brookston or Conover soils was relatively large. This order of uptake was similar to the trend of phosphorus supplying power (see figure 26) and also similar to that for the acid soluble and adsorbed phosphorus

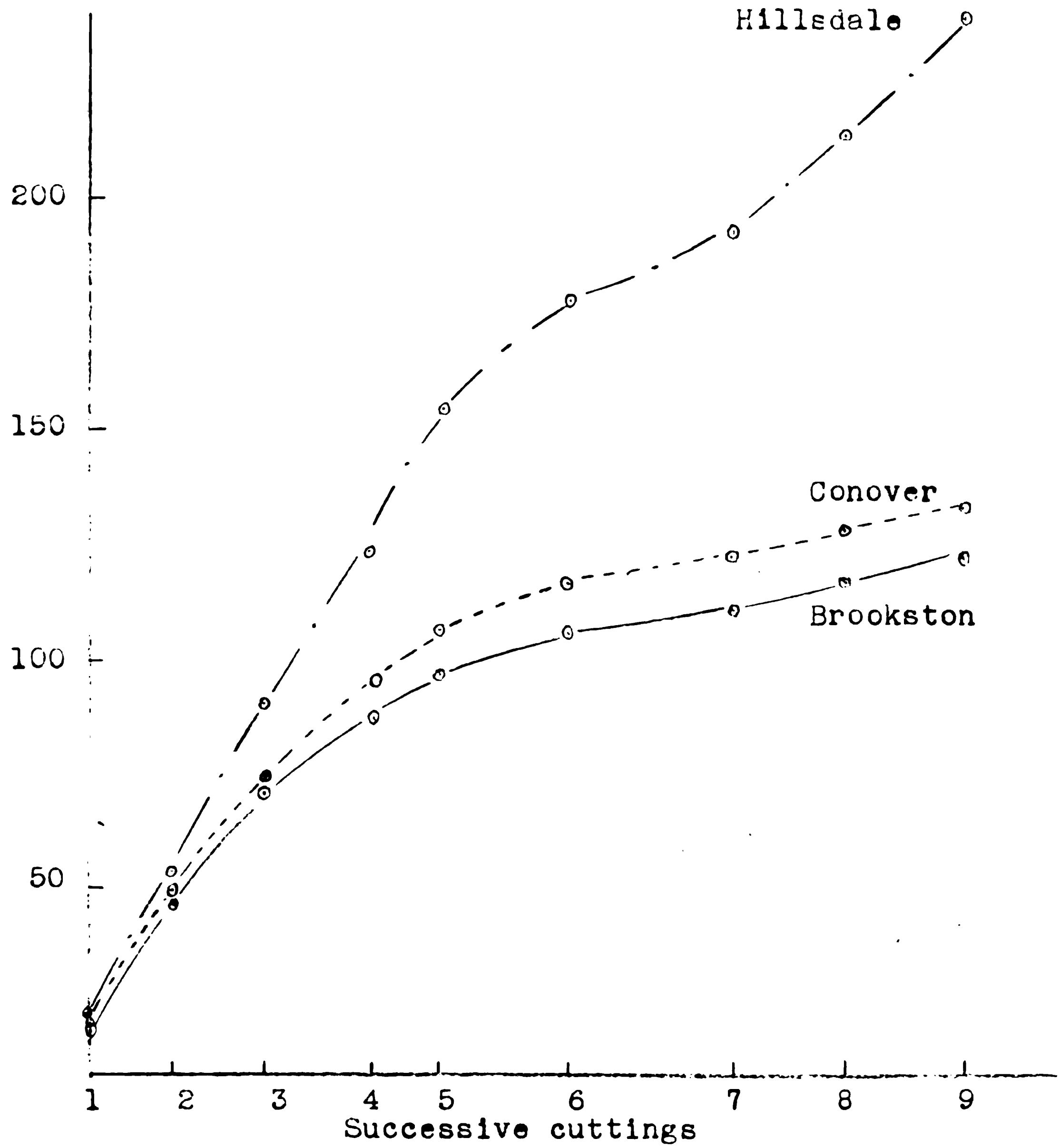

Fig. 26. The accumulative uptake of phosphorus by nine successive cuttings of alfalfa grown on three surface soils.

values of the three soils (see Table 1). It is noteworthy that the phosphorus supplying power of Hillsdale soil was far greater than the other two soils, whereas the content of acid soluble and adsorbed phosphorus of this soil was only slightly higher than the others.

4. Percentage Composition of Potassium and Phosphorus and Ca/K Ratio

As already pointed out, the correlation coefficients between the dry weight of alfalfa and the total amount of potassium and phosphorus absorbed were very significant. However, no definite relationship was found to exist between the percentage of potassium or phosphorus in the tissue and the yield of alfalfa. Nevertheless, the results of the percentage composition of potassium and phosphorus are of interest.

For the purpose of comparison, the percentage of potassium and phosphorus in alfalfa from the three cycle application treatments at two levels, from the single application at three rates, and from the no fertilizer treatment of each soil were plotted in curves as shown in figures 2, 3, 5, 6, 8, 9, 11, 12, 14, 15, 17, and 18.

When the curves of yield and percentage potassium values of each cutting from the Brookston soil (figures 1, 2, 4, and 5) are compared, only the curves representing the potassium content of alfalfa receiving the three cycle

treatments follow those of yield. This means that the value for potassium percentage increased with increasing yield. An interesting point is that the potassium content of alfalfa from the soil to which no fertilizer was added was higher than that of plant material from any other treatment at the last few cuttings. On the other hand, the curve representing the phosphorus content per cutting was different from that of potassium, being more similar to the yield curves. In the last few cuttings of the three cycle treatments especially, the percentage phosphorus curves varied widely according to the rate of fertilizer applied, as shown in figures 3 and 6.

The percentage composition of potassium and phosphorus of alfalfa grown on the Conover soil presented a slightly different trend than that of Brookston soil. When figures 7, 8, and 10, 11 are compared, the curves representing the potassium content of alfalfa for the 2nd to 7th cuttings in three cycle treatments and from 1st to 4th cuttings in the single application treatment are similar to yield curves. However, in the last few cuttings, just as for Brookston soil, alfalfa receiving no fertilizer contained the highest amount of potassium. The curves of percentage phosphorus for alfalfa from Conover soil (as represented in figures 9 and 12) are directly related to rate of phosphate fertilizer application, especially after the fourth cutting was made.

Absorption of the two mineral nutrients by the legume from the Hillsdale soil was quite different from that of the other soils. Data in figures 14 and 17 show that the potassium content of the forage was, in general, closely related to the rate of fertilizer used. In the last few cuttings alfalfa grown on soils receiving the highest rate of fertilizer contained the greatest amount of potassium. It should be pointed out that the downward slope of these curves was steeper than those of the other two soils. When figures 2, 5, 8, and 11 and 14 and 17 are compared, it suggests that luxury consumption of potassium occured using the single application of 1200 pounds 0-20-20 per acre. However, the potassium content of the alfalfa from this treatment was too low to indicate luxury consumption. In terms of phosphorus absorption the situation was the reverse. As shown in figures 15 and 18, no relation existed in the early cuttings between the phosphorus content of the tissue and the different phosphate applications. However, in the last few cuttings the phosphorus content of alfalfa from the check treatment was the highest of all treatments.

The above results indicate that when alfalfa yields were relatively low, the available potassium in the Brookston and Conover soils was not substantially reduced by cropping. Therefore, the percentage of potassium of unfertilized alfalfa did not drop too much. In fact, the 9th

cutting of the alfalfa from the check treatment of Brookston soil had 1.30 per cent of potassium. On the other hand, the available soil potassium was markedly reduced when certain treatments resulted in higher yields and a greater potassium uptake.

This may be the main reason that alfalfa from unfertilized pots of Brookston and Conover soils had the highest percentage value of potassium in the last few cuttings. The available potassium in Hillsdale soil was more easily exhausted by cropping. The potassium content of alfalfa grown on unfertilized pots dropped more rapidly than that produced in the other two soils. There are two important reasons why the available potassium was more easily exhausted in the Hillsdale soil. First, the percentage saturation of exchangeable potassium on the exchange complex of the Hillsdale soil was high and therefore this fraction was readily available to alfalfa. Secondly, the cation exchange capacity of this soil was low and thereby its ability to hold potassium was limited.

The above results are important in terms of the maintenance of soil fertility in areas where alfalfa is grown. It showed how important to take care the maintenance of fertility level after the high yield of alfalfa had been harvested. These results may help explain the results of Cooper (14) in Alabama showing that even the best

K-supplying soils are soon depleted by alfalfa unless liberal applications of potash are added.

In contrast to potassium, the phosphorus content of alfalfa from the highest yielding pots in Brookston and Conover soils did not drop much in the last few cuttings. However, the per cent of phosphorus of alfalfa grown in pots receiving no fertilizer became progressively lower as the number of cuttings increased. Consequently, in the last few cuttings it definitely appeared that the phosphorus percentage value increased with the increasing yield of alfalfa in these two soils. It is apparent that these two soils were much more responsive to phosphorus than to potassium. On this basis it is probable that in the ninth cutting the yield increase was due to phosphorus and not potassium; therefore, even though the yield was higher in the pots receiving the higher rate of fertilizer, the potassium content of the alfalfa from these pots was lower than that of plants from the check pots. In the Hillsdale soil the available phosphorus content was high and thus the phosphorus percentage value of the alfalfa from the no fertilizer treatment was not substantially reduced.

Based on the above results it was impossible to determine a single critical potassium or phosphorus percentage value of alfalfa grown on different soils and during different seasons. An evaluation of the critical percentage of potassium or phosphorus of alfalfa, should involve a more detailed study of the composition of different growth stages of the crop, different portions of the alfalfa plant, as well as different types of soils and weather conditions.

The Ca/K ratio of alfalfa varied with different cuttings, different soils, and different treatments. The Ca/K ratios of alfalfa from pots receiving a three cycle fertilizer application of 1200 and 600 pound per acre rates and the unfertilized pots for the three soils are shown in Table 6. From this table it is evident that this ratio was considerably different for the various cuttings from Hillsdale soil. The ratios varied from 0.91 to 6.86 in unfertilized plants, from 0.91 to 4.97 in alfalfa grown in pots receiving treatment number 3, and from 1.12 to 6.28 in alfalfa grown in pots receiving treatment number 7. In Brookston soil, however, the ratios ranged from 1.61 to 2.48 in alfalfa from the check soil, from 1.19 to 2.95 in plants from pots receiving treatment number 2, and from 1.40 to 3.78 where treatment number 7 was applied. In alfalfa from Conover soil the Ca/K ratios ranged from 2.35 to 4.30, from 1.34 to 4.07, and from 1.66 to 4.25 respectively. Usually the Ca/K ratio of the alfalfa was higher in the last few cuttings, especially for the Hillsdale soil. This increase may be explained by the adequate calcium

Table 6. Calcium/potassium milliequivalent ratio of individual cuttings of alfalfa grown on three surface soils which received different fertilizer treatments.

Treatment number	Cutting number								
	1	2	3	4	5	6	7	8	9
				Brookston clay loam					
3	2.17	1.63	1.28	1.55	1.19	1.71	2.19	2.48	2.95
7	2.64	1.86	1.46	2.23	1.40	1.86	2.81	2.99	3.78
10	2.12	1.75	1.75	1.98	1.61	2.07	2.48	2.01	2.47
				Conover loam					
3	4.07	2.54	1.45	2.39	1.34	1.91	3.74	3.51	4.02
7	3.48	2.60	1.77	2.82	1.66	3.41	3.50	3.76	4.25
10	3.55	3.63	2.49	3.18	2.35	3.15	4.30	3.75	3.54
				Hillsdale sandy loam					
3	1.30	0.99	0.91	1.62	1.09	1.79	3.09	3.57	4.97
7	1.49	1.12	1.18	2.05	1.20	2.36	4.40	4.07	6.28
10	1.16	0.91	1.58	2.49	2.13	3.60	5.40	4.52	6.86

contents of all three soils (Table 1). In contrast, the available soil potassium was more easily reduced, especially in the Hillsdale soil. Another point of interest is that the sum of the cation-equivalents tended to be a constant from the same cutting. Thus, if the supply of potassium is reduced, the Ca/K ratio of the alfalfa from the last few cuttings would be higher.

5. <u>Sum of the Cations Equivalent per Unit Dry Weight of Alfalfa</u>

The sum of the equivalents of potassium, calcium, and magnesium per 100 grams of dried alfalfa was calculated and reported in Table 7. The cation-equivalent sum tended to be a constant in the same cutting and same soil, but varied with different cuttings. In general, the highest values were found in the 6th and 7th cutting. These two cuttings were harvested on December 13, 1955, and January 27, 1956, respectively. These data agree with those of Wallace et al. (39) who showed that the cation contents were higher in the winter time than in the summer time due to carbohydrate dilution during the latter period.

The cation-equivalent sum of alfalfa from different soils also varied slightly. In general, alfalfa from Conover soil had the highest cation-equivalent values, varying from 121 to 214 milliequivalents per 100 grams of dry matter. In Brookston soil these values ranged from 115 to

Table 7. Sum of the individual cations* of nine successive cuttings of alfalfa grown on three surface soils which received different fertilizer treatments.

Treatment number	Cuttings 1	2	3	4	5	6	7	8	9
	M.e. cations per 100 gm. dry matter								
	Brookston clay loam								
1	159	124	115	133	137	159	153	137	133
2	162	131	116	132	139	161	166	141	133
3	154	125	130	122	128	161	175	135	119
4	166	140	129	120	132	159	170	142	120
5	149	127	126	127	133	170	178	141	137
6	140	131	122	128	133	168	182	142	142
7	168	142	119	136	131	161	189	137	133
8	157	136	121	126	138	161	182	146	131
9	144	133	128	135	135	173	193	168	138
10	152	142	143	131	142	181	200	160	124
	Conover loam								
1	170	144	125	137	123	174	155	141	135
2	165	139	136	139	132	175	158	131	125
3	178	139	132	130	133	180	165	140	126
4	163	138	133	143	130	184	150	134	124
5	166	136	128	138	138	181	135	132	144
6	171	144	146	145	138	201	140	146	138
7	171	141	142	139	137	202	144	143	133
8	177	148	145	133	129	214	152	148	151
9	162	147	138	141	137	194	173	145	141
10	154	165	146	153	146	198	159	162	138
	Hillsdale sandy loam								
1	124	105	104	119	130	174	161	154	142
2	130	122	108	135	141	185	155	167	154
3	122	113	108	138	145	188	147	165	150
4	131	115	109	135	139	193	146	163	142
5	133	120	108	127	135	197	140	156	142
6	134	111	112	144	136	198	153	143	145
7	126	107	116	127	139	199	142	138	143
8	132	109	128	128	135	190	154	127	152
9	121	102	109	128	139	191	156	150	155
10	118	103	108	124	139	190	150	145	158

*Cations include Ca - Mg - K

200 milliequivalents, and from 102 to 199 milliequivalents in Hillsdale soil.

Table 8 shows the range of the contents of the three cations in the alfalfa from this study.

6. General Relationships

In order to get the most efficient use of fertilizer for alfalfa in terms of both yield and nutrient uptake, the frequency of the application of fertilizer should be considered. Large amounts of fertilizer (1200 pounds 0-20-20 per acre) applied at planting time were not utilized to best advantage, especially in Hillsdale sandy loam soil. This condition is due mainly to the low cation-exchange capacity and potassium fixing power of such soils. The most efficient way of fertilization was found to be a two or three cycle application for high rates of fertilizer. For a lower rate of fertilizer (600 pounds 0-20-20 per acre) results indicated it was better to apply all fertilizer at planting time. It is suggested that a difference in frequency of application as related to rate may be explained mainly by the fixation phenomena. When a large amount of phosphorus or potassium was applied at one time, high levels of available forms of these nutrients were developed. Some potassium may be lost through leaching, whereas some phosphorus may revert to forms less available to plants. Luxury consumption by legumes of potassium and to a lesser extent

Table 8. Range of the potassium, calcium, and magnesium contents of alfalfa grown on three surface soils in the greenhouse.

Element	Brookston clay loam		Conover loam		Hillsdale sandy loam	
	Per cent	M.E. per 100 gm. dry matter	Per cent	M.e. per 100 gm. dry matter	Per cent	M.e. per 100 gm. dry matter
K	0.98-2.11	25-54	0.75-1.86	19-48	0.55-2.18	14-56
Ca	0.91-2.35	45-117	1.08-2.61	54-130	0.75-2.48	37-124
Mg	0.10-0.49	8-40	0.11-0.88	9-72	0.11-0.87	9-71

phosphorus is another reason why the application of a large amount of fertilizer at one time is not the most practical method. For example, an examination of the yield and potassium uptake of alfalfa grown on Conover soil receiving treatment number 1 (1200 pounds of 0-20-20 applied once at planting time) and treatment number 3 (three cycle application of 1200 pounds of 0-20-20) as presented in figure 27 indicates that the dry weight of the first four cuttings was not much different for these two treatments. After the 4th cutting the yield of alfalfa from the pot receiving treatment number 3 increased over that of number 1. However, up to the 7th cutting, the trend of potassium uptake was opposite that for dry matter production. This is evidence of some potassium luxury consumption in the early cuttings of the treatment with large amounts of fertilizer applied at one time as compared with the three cycle application treatment. Consequently, from data collected from six cuttings, large amounts of fertilizer would be better applied by split applications while low rates of fertilizer are better applied at one time. However, it should be mentioned that the availability of fixed phosphorus and fixed potassium is quite different. In general, the availability of fixed phosphorus is very low. Fixed potassium, as indicated by DeTurk, et al. (16), is available to plants. Therefore, it might be better to study the frequency of application for phosphorus and potassium separately as far as fixation is concerned.

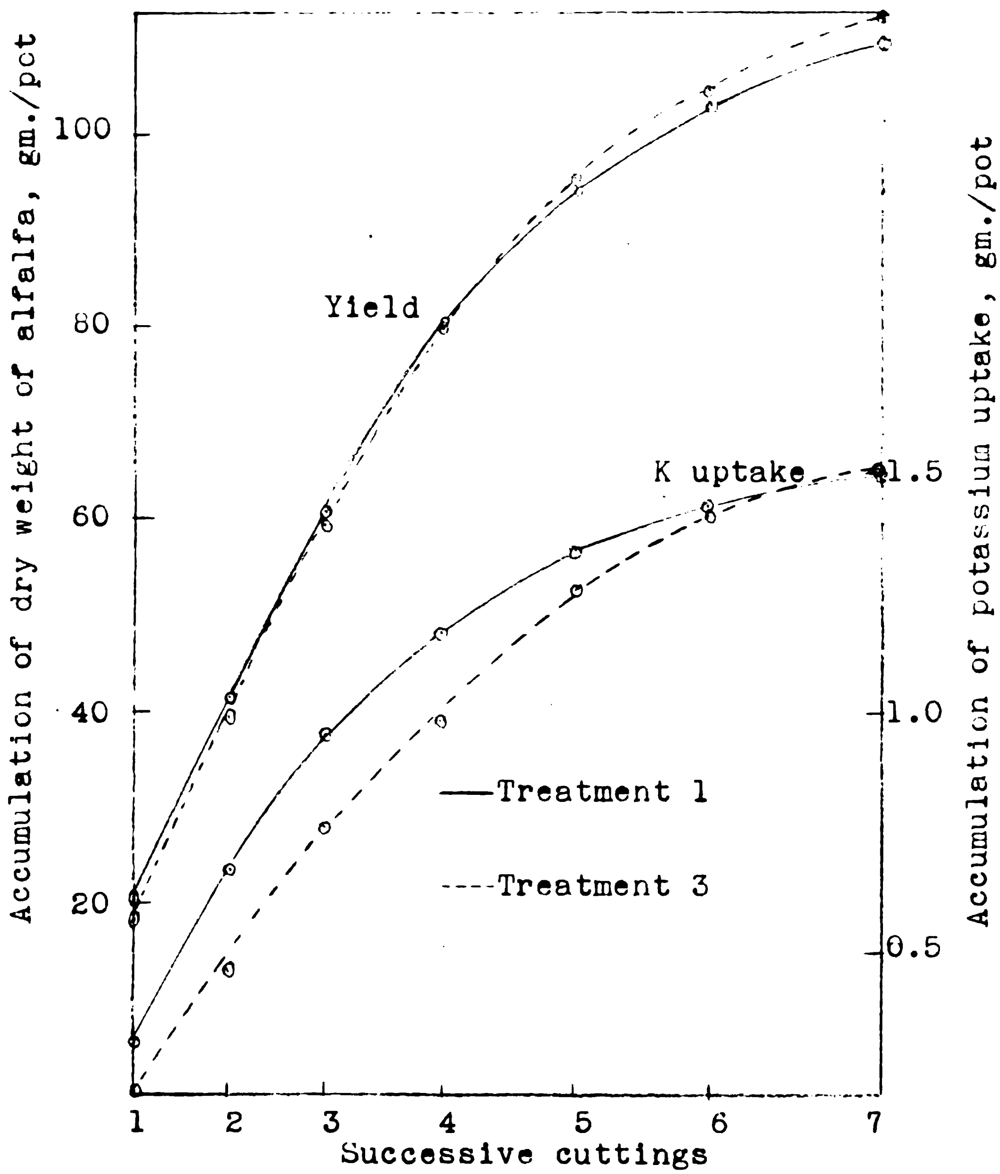

Fig. 27. Accumulation curves of yield and potassium uptake of alfalfa from two treatments in Conover loam showing some luxury consumption of potassium.

The correlation coefficient between both potassium and phosphorus uptake and the total yield of the nine cuttings of alfalfa were significant at the one per cent level. Consequently, for the entire cropping period of this study luxury consumption was not found to be a highly important factor.

In most cases the percentage of potassium and phosphorus as well as the sum of cations per unit weight of alfalfa was highest in the winter, while the yields during the winter months were the least. These opposite trends are mainly due to the low rate of photosynthesis resulting in reduced carbohydrates synthesis in winter. However, since the content of potassium and phosphorus changed with different cuttings, particularly during the last part of the cropping period, it is evident that the fertility level of the soil was reduced.

When large amounts of potash fertilizer were used, resulting in high yields, a large amount of potassium was absorbed. Consequently, the potassium content of alfalfa of the last cutting from the high fertilizer treated plots was less than that where no fertilizer was applied. Therefore, in order to maintain high yields of alfalfa, liberal applications of fertilizer should be continued in order to maintain a satisfactory soil fertility level. This management recommendation applies particularly to potassium fertilization of alfalfa. Even though the response of alfalfa to phosphorus was found to be greater than to potassium in Brookston and Conover soils, the problem of potassium fertilization of alfalfa grown on these soils needs more consideration.

It is believed that a series of determinations of acid soluble potassium, exchangeable potassium, cation exchange capacity, and percentage potassium saturation of the soil exchange complex will give the most reliable information on the potassium fertilization of alfalfa. The quantity of potassium extractable in acid will provide information on how much reserve potassium is available for use by alfalfa, and the percentage saturation of potassium and cation exchange capacity will give an idea of the availability of the exchangeable potassium to plants. On this basis a reasonable method of fertilization for potassium can then be worked out. Undoubtedly the main reason that alfalfa of the final cutting from Brookston soil still contained 1.30 per cent of potassium was the high reserve of acid soluble soil potassium. On the other hand, the potassium content of alfalfa was high in the first few cuttings from Hillsdale soil, but dropped markedly in the last few cuttings. Rapid removal in this case may be due to high percentage saturation of potassium and low cation exchange capacity of the Hillsdale soil,

as well as a low level of the acid soluble fraction. Since only three soils were used in this experiment, a more detailed study is needed to evaluate this hypothesis.

Field Experiment

1. Yield

The field experiment was designed for a duration of two and one-half years, beginning in April 1955 and ending in August 1957. Thus final conclusions as to the influence of various treatments can not be reached until the end of the experiment. However, some data have been collected up to August 1956.

The yield of alfalfa hay from first and second cuttings of 1956 are shown in Table 9. No yield response to applied fertilizer was observed in the first cutting. In the second cutting the yield of plants from soil receiving treatment number 3 (800 pounds 5-20-20 banded in 1955) and treatment number 10 (no fertilizer in 1955 - 400 pounds 0-20-20 broadcasted in 1956) were significantly higher than where no fertilizer was applied. From the present data, a comparison of banding versus broadcasting of 800 pounds of fertilizer at planting time shows that fertilizer applied in bands was more effective in terms of yield of alfalfa. The data also indicated that 400 pounds of fertilizer applied in April 1956 was of more benefit than either 400 or 800 pounds

Table 9. Yield of alfalfa hay from a Fox sandy loam soil which received different fertilizer treatments.

Treatment number	Date of fertilizer application				Cutting	
	April '55	Sept. '55	April '56	Total	1	2
	Pounds of fertilizer applied per acre				Pounds of hay per acre	
1	800[2]	-	-	800	3146	1428
2	400[2]	-	-	400	2815	1511
3	800[1]	-	-	800	3167	1966*
4	400[1]	-	-	400	2939	1532
5	400[1]	-	400[2]	800	2981	1552
6	400[1]	-	200[2]	600	3519	1842
7	267[1]	-	267[2]	534	2795[3]	1428[3]
8	160[1]	160[2]	160[2]	480	3291	1718
9	160[1]	-	240[2]	400	3022	1635
10	-	-	400[2]	400	3146	2070*
11	-	-	-	-	2898	1428
*L.S.D. (five per cent level)					-	484

Note: 5-20-20 used on April 1955, 0-20-20 used in September 1955 and April 1956.

[1] Fertilizer applied in band
[2] Fertilizer applied in broadcast
[3] Average of 3 replicates

applied broadcast in April 1955. Since treatment number 5 also involved 400 pounds of 0-20-20 broadcasted in April 1956 in addition to 400 pounds of 5-20-20 applied in 1955, and did not show a significant yield increase over treatments, the data seem inconclusive.

In general, no substantial yield response was obtained in this field experiment in 1956. A partial explanation for lack of response to fertilizer application may have been low precipitation at the critical period of growth of the alfalfa. The following values show the amount of rainfall from April 15 to August 10, 1956, at the Kellogg Farm:

April 15-22....0.14 in.	May 1-7.....0.93 in.
April 23-30....3.88 in.	May 8-14....0.27 in.
Total....4.02 in.	May 15-22...0.20 in.
	May 23-31...0.31 in.
	Total...3.71 in.
June 1-7.......No ppt.	July 1-7....0.01 in.
June 8-15......No ppt.	July 8-15...1.01 in.
June 14 ..1st cutting	July 16-22..0.95 in.
June 16-22.....2.65 in.	July 23-31..0.46 in.
June 23-31.....1.02 in.	Total..2.43 in.
Total.....3.67 in.	
	August 1-9..0.05 in.
	August 10..2nd cutting

According to these data only 0.51 inch moisture fell from May 15 to June 14, the day the first cutting was made, while the amount of rainfall was only 1.45 inches from July 16 to August 10, the day of the second cutting. The moisture holding capacity of this soil is low since the texture of the surface soil is a sandy loam. Consequently, it is believed that soil moisture was a limiting factor for growth of alfalfa during the final month of the first and second harvests and this may be the main reason that the alfalfa did not show much yield response to fertilization.

2. Percentage composition of potassium and phosphorus

The percentage of potassium and phosphorus in alfalfa and oat plants (nurse crop) collected in July 1955 and of alfalfa hay from two cuttings in 1956 are presented in Table 10.

In general the per cent of potassium in alfalfa from different treatments varied only slightly. In the first sampling, alfalfa from the plots which received the higher rate of fertilizer contained slightly more potassium. However, there was a greater difference among the oat samples of the several treatments. For example, a high of 1.15 per cent potassium was found in oats which received 800 pounds of 5-20-20 broadcast while the lowest value was only 0.81 per cent in plants from the no fertilizer plot. The difference in potassium percentage value of alfalfa hay from the first cutting in June 1956 for various treatments was very small. The potassium content of second cutting hay in 1956 was lower than that of the first cutting. The potassium content of the alfalfa hay from the check plot was 1.50 per cent potassium, which was lower than that from plots where fertilizer had been applied.

Table 10. The potassium and phosphorus content of alfalfa and oat plants grown on a Fox sandy loam which received different fertilizer treatments.

Treatment number	Alfalfa						Oats	
	1st Sampling 6/25/55		1st Cutting 6/14/56		2nd Cutting 8/10/56		7/10/55	
	Per cent K	Per cent P	Per cent K	Per cent P	Per cent K	Per cent P	Per cent K	Per cent P
1	2.19	0.21	2.11	0.21	1.72	0.17	1.15	0.28
2	2.23	0.19	1.96	0.19	1.62	0.18	0.99	0.27
3	2.31	0.21	2.14	0.23	1.67	0.18	1.07	0.31
4	2.16	0.22	1.94	0.22	1.67	0.21	0 0.98	0.25
5	2.14	0.23	2.14	0.23	1.66	0.21	0.94	0.26
6	2.15	0.21	2.01	0.20	1.65	0.19	1.04	0.25
7	2.11	0.21	2.06	0.22	1.76	0.18	0.95	0.24
8	2.09	0.21	2.09	0.23	1.66	0.18	0.86	0.26
9	2.09	0.20	1.94	0.21	1.65	0.19	0.90	0.25
10	2.14	0.22	2.05	0.25	1.74	0.19	0.81	0.26
11	2.02	0.22	2.04	0.23	1.50	0.19	0.84	0.25

No important differences between phosphorus contents of tissue were found between plants from the various treated plots at the same sampling date, except perhaps where the oat crop received 800 pounds of 5-20-20 banded near the seed. A point of interest here is that the per cent phosphorus of the first cutting of alfalfa in 1956 was slightly higher than that of plants sampled at the time of the second cutting.

V. SUMMARY

Greenhouse and field experiments were initiated to study the efficiency of utilization of applied potassium and phosphorus by alfalfa. The yield and per cent of potassium, phosphorus, calcium, and magnesium in alfalfa were obtained from plants grown on soils to which varying rates of fertilizer had been applied at different times.

In the greenhouse study, three soils, Brookston clay loam, Conover loam, and Hillsdale sandy loam, were cropped continuously to alfalfa for a period of approximately one year. To these soils were applied twelve fertilizer treatments, including four rates of application, 0, 300, 600, and 1200 pounds of 0-20-20 per acre. The frequency of fertilizer application varied from all nutrients applied at planting time to two, three, and four cycle treatments.

The field experiment, which was carried out on a Fox sandy loam at the Kellogg Farm in Kalamazoo county, included eleven fertilizer treatments replicated four times. Three rates of fertilizer amounting to 0, 80, and 160 pounds of K_2O and P_2O_5 per acre, applied by broadcast and banded methods, were compared. The frequency of these fertilizer treatments included one, two, three, and five cycle applications. This study was started in April 1955 and is to be terminated in the fall of 1957. The yield of alfalfa hay and the potassium and phosphorus contents of the oat nurse crop, the first sampling of alfalfa in 1955, and the two cuttings of hay in 1956 were obtained.

The results of these studies may be summarized as follows:

I. Greenhouse study

1. Two or three cycle application of fertilizer at the rate of 1200 pounds of 0-20-20 per acre was more efficiently used by alfalfa than the same amount applied at the planting time. When 600 pounds of 0-20-20 per acre was used, higher yield was obtained by applying it all at planting time, except in the Hillsdale soil. Little difference in yield was found between the 300, 600, and 1200 pounds fertilizer rates when all the fertilizer was applied at planting time. However, when applied as a two or three cycle application the highest fertilizer rate resulted in significantly higher yields than when lesser amounts of fertilizer were used.

2. Correlation coefficients between total potassium or phosphorus uptake and the yield of nine cuttings of alfalfa were found to be highly significant. In the case of potassium uptake, this value ranged from 0.87 to 0.97 for the three soils studied. Variation between correlation coefficients for phosphorus uptake was slight with all values falling between 0.96 to 0.97.

3. From the percentage of potassium or phosphorus in the alfalfa plants it was not possible to establish any minimum critical level for optimum growth.

4. Once maximum growth was established the potassium content in the alfalfa decreased gradually upon successive harvests to a point less than the plants from the check pots.

5. It is proposed that an evaluation of the acid soluble potassium, exchangeable potassium, cation exchange capacity, and per cent saturation of potassium of the exchange complex will give the most reliable information of the need for a specific soil for potassium fertilization of alfalfa.

6. The Ca/K equivalent ratio of alfalfa varied with different cuttings, different soils, and different treatments. Especially in the last three cuttings this ratio had a tendency to increase. This trend may be due to the fact that all three soils had adequate calcium content, but the available potassium was substantially reduced during the last three months of the growth period.

7. The sum of cation-equivalents per unit dry matter of alfalfa tended to be a constant within the same cutting, but varied from cutting to cutting. Alfalfa grown during the months of November to February contained the greatest quantity of cations on a weight basis.

II. Field study

The preliminary results on the first two cuttings of alfalfa hay indicated little yield response to phosphate-potash fertilization. Different rates and frequencies of fertilizer application to soil had little effect on the partial chemical composition of alfalfa in this study. It is believed that lack of yield response to fertilization was due mainly to a shortage of rainfall during the months of June, July, and August of 1956.

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