THE EFFECT OF PHOSPHORUS, POTASSIUM AND MAGNESIUM ON THE YIELD AND CHEMICAL COMPOSITION OF SUBTERRANEAN CLOVER

by

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INTRODUCTION

The production of forage legumes on foothill pastures in Western Oregon is one of the major soil fertility problems of this area. It is generally recognized that inherent soil factors, including plant nutrient deficiencies and soil acidity, are limiting legume production on these pastures. Previous studies indicate that many of the soils in the northern part of the Willamette Valley have a low potassium supplying power in comparison with other Willamette Valley soils (23, p. 75-79). It is recognized that many Western Oregon soils are low in available phosphorus (29, p. 379), and recent soil tests from farmers' samples have raised a question as to the supply of magnesium in some of the upland soils in the northern part of the Willamette Valley.

Considerable information is available to show the production that can be obtained from nitrogen fertilizer on grasses grown in Oregon (4, p. 7-9). However, there is very little information available concerning the fertility treatments that will give maximum production of legumes. Subterranean clover (Trifolium subterraneum), the legume used for this study, is produced in combination with alta fescue (Festuca elatior) and other grasses on a large acreage of Western Oregon hill soils[1]. It is recognized that subclover requires fertilization to maintain high production and a general

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[1]The term "hill soil" refers to the residual soils developed on sandstone and basalt parent material above the main valley floor. In Columbia County the upland soils are developed from a mixture of loess and these parent materials.

recommendation for Western Oregon has been yearly applications of superphosphate at 200 to 300 pounds per acre (25, p. 8).

In order for the soil testing program to function properly in providing a basis for making accurate fertilizer recommendations, soil tests must be calibrated with results from field experiments in the area being served. This involves measuring the amount of the available nutrient in the soil and allowing the plant to indicate the significance of that amount in terms of yield response to added nutrients and the amount of the nutrient taken up by the plant.

The purposes of this study were to:

1. Determine the effect of phosphorus, potassium and magnesium fertilizer treatments on the production of subterranean clover on selected hill soils in Western Oregon.
2. Evaluate the relationships between the response from applications of potassium, phosphorus, and magnesium and soil tests, and the content of these nutrients found in the plant.

REVIEW OF LITERATURE

Very few fertility investigations on subclover have been reported in the literature. Australian and New Zealand publications have reported some information on subclover. However, publications from the United States concerning nutrition relationships for this plant are not available. For this reason the literature review is composed primarily of investigations on similar legumes.

There is considerable evidence to show that growing forages, particularly legumes, requires a relatively high amount of available plant nutrients (43, p. 24-25). Soils of relatively low fertility are frequently used for pasture and forage production, resulting in an increasing need for the addition of plant nutrients to pastures. Generally, legumes respond more readily to additions of phosphorus, potassium, calcium, and magnesium while grasses show a marked response to nitrogen with lesser response to other plant nutrients.

Potassium

The relatively high potassium requirements of legumes has been reported by a number of workers. Baver (2, p. 123-124) pointed out that growing legumes and removing the entire crop as hay or pasture results in large potash removal from the soil. This will accentuate potash needs for the succeeding crop. Strivers and Ohlrogge (36, p. 618-621) found that potassium fertilization resulted in large yield increases of alfalfa. Differences in yield between no potash and the highest rate of potash fertilization became greater each year that cropping continued. Maintenance of alfalfa stand was found to be closely related to both potash fertilization and the potassium content of the alfalfa.

When legumes are grown in association with grasses the potash requirements of the legumes appear to increase. Rossiter and Kipps (28, p. 379) found that potassium deficiency symptoms in subclover pot culture experiments appeared more rapidly in the presence of grass than when grass was absent. Blaser and Brady (3, p. 128-135) reported that potassium fertilization stimulated the growth of ladino clover but did not directly affect the productivity of non-leguminous plants grown in association with ladino clover.

Gray, et al, (13, p. 235-239) studying this phenomenon, concluded that grasses are capable of absorbing potassium to a far greater extent than clovers due to the higher cation exchange capacity of clover (dicotyledonous plants) roots. Plant roots with a high cation exchange capacity were observed to absorb more divalent cations and take up less monovalent cations, such as K^+, than roots with a low exchange capacity. Grass roots (monocotyledenous plants) possess a low cation exchange capacity and preferentially absorbed monovalent cations.

Rich and Odland (26, p. 423-426) found that reducing the potash applications on a grass-legume mixture from 100 to 50 pounds per acre lowered the proportion of legumes from 50 to 3 percent and the hay yield from 3.08 to 1.63 tons per acre. A further reduction in potash to 25 pounds per acre resulted in less than 2 percent legumes and a hay yield of only 1.7 tons per acre. During three crop years, Parsons, et al, (21, p. 42-46) noted that ladino clover grown with grasses showed a marked response to potassium applications. Split applications of 150 pounds of K_2O per acre annually (50 pounds after each of three cuttings) gave maximum yields of hay and increased clover yields 28 percent.

Phosphorus

Nowosad (18, p. 67-69) studied the effect of fertilizer phosphorus on the botanical composition and yield of permanent pastures. He found that phosphorus fertilizer increased growth and the percentage of clover in all plots studied. Brown (5, p. 145) found that the proportion of phosphorus in the forage of clover-grass pastures was markedly increased by the application of superphosphate; the average increase for two years was 60 percent. The addition of potash to the superphosphate treatment was responsible for further small increases.

Stanford and McAuliffe (33, p. 423-436) used radiophosphorus to determine the extent to which surface-applied superphosphate is utilized by alfalfa and ladino clover. A large proportion of the phosphorus in plants was derived from the fertilizer. At the 200 pound per acre rate approximately 20 percent of the phosphorus in both alfalfa and ladino clover was derived from the fertilizer. With a 1,000 pound per acre rate approximately 50 percent of the phosphorus in the alfalfa and ladino plants was derived from the fertilizer. Average total yield increases due to phosphorus ranges up to 1.5 tons per acre.

Magnesium

Magnesium generally is present in most soils in sufficient abundance to supply the needs of plants (8, p. 107). Some soils, however, have been shown to be magnesium deficient. Results reported by Truog, et al, (37, p. 19-25) support the theory that magnesium functions as a carrier of phosphorus. They indicated that there is a need for giving increased attention to the supplies of available magnesium in soils in order that the phosphorus may be used effectively. The failure to obtain crops of high phosphorus content was attributed to lack of available magnesium in many cases. The phosphorus content of peas was increased more by increasing the supplies of available magnesium than by increasing supplies of available phosphorus.

Multiple Nutrient Relationships

Millikan, (17, p. 26-28) using subclover in pot culture experiments, found that potash deficiency symptoms occurred only in the presence of added phosphorus. Plant growth was greater when phosphorus and potassium were both deficient than when potassium alone was deficient, indicating that a proper balance between potassium and phosphorus is necessary for optimum growth. Millikan suggested that where potassium alone was deficient the reduction in growth was due partly to an excess of phosphorus in plants.

Similarly, Rossiter and Kipps (29, p. 379-388) noted a decrease in the relative potassium content in subclover when phosphorus was applied. Wrenshall and Marcello (47, p. 448-458) noted that where phosphate and potash fertilizers were applied together the amount of exchangeable potash found in the soil after cropping was less than where potash was applied alone. They attributed this partly to the increased yield and greater uptake of potassium on the phosphate treated plots, but suggested that soluble phosphates may promote the fixation of potash in an unavailable form.

Seay and Weeks (32, p. 458-461) found that with alfalfa potash fertilization did not affect the phosphorus uptake from the soil. Similarly phosphorus fertilization did not significantly affect potassium uptake although trends were more suggestive than the effect of potash fertilization on phosphorus uptake. Fine (11, p. 2-22) used labeled superphosphate in measuring the recovery of added phosphorus and found that an increase in available potassium in the soil had little effect on the utilization of fertilizer phosphorus by crops.

Giddens and Toth (12, p. 213) found that potassium exerted the greatest effect upon the uptake of the other cations in a greenhouse experiment using ladino clover. Millikan (17, p. 30) observed less reduction in growth of subclover when potassium and magnesium were both deficient than when potassium alone was deficient. The effect of magnesium deficiency in the presence of potassium deficiency was considerably less than that of simple magnesium deficiency indicating that the presence of excess potassium induces magnesium deficiency in plants. This relationship has been noted by a number of other workers (9, p. 201-204).

Giddens and Toth (12, p. 213) also observed that low phosphorus content of forage occurred in the presence of low magnesium. In agreement with this Millikan (17, p. 31-32) obtained more growth with subclover when phosphorus alone was deficient than when both phosphorus and magnesium were deficient. Truog, et al (37, p. 19-25) found a similar positive relationship between the phosphorus and magnesium contents in the plant.

Chemical Plant Analysis

In order to use chemical plant analysis successfully for assessing fertility requirements, Steenbjerg (34, p. 99-100) emphasized that it is important to recognize the influence exerted by the following factors:

> " (1) soil factors, (2) the nature of the crop, (3) climatic conditions and (4) the time during the growing season at which the plants are sampled."

Ulrich (39, p. 106-108) studied plant analysis as a diagnostic procedure and concluded that the part of the plant selected for analysis should reflect the general status of the plant with respect to the nutrient under consideration. The part of the plant selected should be of a definite physiological age taken from a definite position on the plant and it should be as uniform as possible.

Chandler, et al (6, p. 712-714) found that the potassium content of ladino clover decreased upon continuous cropping and that symptoms of potassium deficiency appeared on the clover leaves when the potassium content of the plants fell below 0.8 percent. Increases in yield were obtained from alfalfa by Wallace and Bear (41, p. 675-676) upon increasing the potassium content of the plant to 3 percent.

Soil Correlation

Workers have consistently reported large increases from fertilization for soils low in available plant nutrients (45, p. 166-167). The correlation between soil analysis and response from applications of plant nutrients depends in part on the methods used to determine the amount of available plant nutrients. Stewart and Volk (35, p. 125-129) found no close relationship between potassium removed by crops and the exchangeable potassium in the soil. Also, the exchange capacity of the soil and the percentage potassium-saturation did not show definite relationships to the amount of potassium extracted by plants. They concluded that the variability of the capacity of different soils to release potassium from non-exchangeable forms is the dominant factor in the potassium nutrition of plants and that the magnitude of this factor is difficult to measure through the use of chemical soil tests.

Reitemeier, et al (26, p. 158-162) found that ladino clover growth was correlated with soil potassium that is release by extraction with hot 1 N nitric acid. Pratt and Morse (24, p. 18-20) found that the potassium release by extraction with 1 N nitric acid was more characteristic of the soil series than exchangeable potassium.

Hood, et al (15, p. 228-231) showed that when the potassium content of ladino clover was below the critical level, water soluble potassium was more highly correlated with yield than was exchangeable potassium. The water soluble potassium also gave a higher correlation with the potassium absorbed by plants than did exchangeable potassium. A percolation procedure which consisted of leaching a soil with a large volume of dilute electrolyte was a better measure of the potassium supplying power of a soil than the initial level of exchangeable potassium.

PROCEDURE

Selection of Locations

A series of preliminary soil samples was taken at a depth of 0 to 8 inches from several established subclover pastures in Western Oregon. The information obtained from chemical analysis of these samples was used as a basis for selecting ten locations to represent a range of soil test values for available phosphorus, exchangeable potassium, and exchangeable magnesium. Experiments were established on these locations in the fall of 1955. In the fall of 1956 two locations were re-established, and experiments were established on three additional locations.

A description of the locations is given in table 1. The Cascade series is an acid, moderately well drained to imperfectly drained soil derived from loess (45, p. 226-228). The Aiken series is a well drained soil derived from basic igneous rock and is currently classified as a Reddish Brown Latosol. The E 10 series is an imperfectly drained soil derived from shale. This series is in the process of being renamed and further soil correlation studies are needed to decide the correct series name. The Laughlin series is a well drained soil and is derived from sandstone and shale. It is currently classified in the Noncalcic Brown great soil group.

Plan of Treatments

The plan of treatments for the two experimental designs used are shown in table 2 and symbolic analysis of variance is given in

Table 1

Description of Locations

Location No.	Farmer	County	Legal description	Soil Series*
1	W. Loyd	Columbia	T 5 N, R 2 W, Sec. 1, SE1/4, SW1/4	Cascade
2	H. Hadler	Columbia	T 7 N, R 4 W, Sec. 1 SE1/4	Cascade
3	A. Marshall	Clackamas	T 4 S, R 2 E, Sec. 26, NW1/4, SE1/4	Aiken
4	R. Dumdi	Yamhill	T 2 S, R 4 W, Sec. 26, NW1/4, SW1/4	E 10**
5	W. Fisher	Clackamas	T 3 S, R 2 E, Sec. 21, SW1/4, SW1/4	Aiken
6	W. Fisher	Clackamas	T 3 S, R 2 E, Sec. 21, SW1/4, SW1/4	Aiken
7	R. Franks	Douglas	T 26 S, R 4 W, Sec. 22, NE1/4, NE1/4	Laughlin
8	R. Doerner	Douglas	T 26 S, R 7 W, Sec. 24, SW1/4, NW1/4	Laughlin

* Identification of soils was made by the Soil Conservation Service and T. L. Jackson.

** This soil was previously mapped Melbourne but is in the process of being reclassified.

table 3. The treatments in plan 1 were used on the original locations established in 1955. Plan 1 was altered on one location because preliminary soil tests indicated relatively high amounts of exchangeable and acid extractable potassium in the soil and relatively low phosphorus values. Only the K_1 rate of potassium was used and an additional rate of 30 pounds of P_2O_5 per acre was added. Plan 2 was used for the three new experiments established in 1956. Fertilizers were thoroughly mixed and applied in the fall by hand broadcasting to each 8 by 30 foot plot.

Harvesting and Collecting Data

Plots were grazed through the winter and fenced before spring growth started. One harvest was taken when the forage was approaching maximum yield for that season. Dates of harvest ranged from May 31 to June 20 for the 1956 experiments and from May 20 to June 5 for the 1957 experiments. Plots were harvested with the small plot forage harvester which was developed at Oregon State College by Page, Jackson and Hunter (20, p. 56-57). A 3.5 foot by 26.5 foot area was harvested for yield from each plot. Moisture samples of approximately 2 pounds were taken from each plot to determine the dry weight and samples of legume were taken from each plot for chemical analysis.

Both subclover and grasses are included in the yield data. It was assumed that yield differences due to applications of phosphorus, potassium, and magnesium would largely reflect differences in clover growth since these treatments would have as much or more effect on the growth of clover than on the growth of grasses. Evidence

Table 2

Treatment Plans

Plan 1

Treatment	P	K	Mg
1. Check	0	0	0
2. P_2	2	0	0
3. K_2	0	2	0
4. P_2 K_2	2	2	0
5. Mg	0	0	1
6. P_2 Mg	2	0	1
7. K_2 Mg	0	2	1
8. P_2 K_2 Mg	2	2	1
9. P_1 K_2	1	2	0
10. P_1 K_2 Mg	1	2	1
11. P_2 K_1	2	1	0
12. P_2 K_1 Mg	2	1	1

Plan 2

Treatment	P	K
1. Check	0	0
2. P_1	1	0
3. P_2	2	0
4. K_1	0	1
5. K_2	0	2
6. P_1 K_1	1	1
7. P_2 K_1	2	1
8. P_1 K_2	1	2
9. P_2 K_2	2	2

Treatment level	Rate	Source
P_1	60 lbs P_2 O_5 per acre	concentrated superphosphate
P_2	120 lbs P_2 O_5 per acre	" "
K_1	60 lbs K_2 O per acre	muriate of potash
K_2	120 lbs K_2 O per acre	" " "
Mg	30 lbs Mg per acre	epsom salts

A constant rate of sulfur was maintained on all plots and a constant rate of boron at 3 pounds of boron per acre was applied to the 1957 experiments.

Table 3

Symbolic Analyses of Variance for Treatment Plans

Plan 1 Source of variation	d. f.		Plan 2 Source of variation	d.f.
Total	35		Total	26
Replication	2		Replication	2
Treatment	11		Treatment	8
P_2 vs. P_1	1		P_2 vs. P_0	(1)
K_2 vs. K_1	1		P_2 vs. P_1	(1)
Treatment (2 X 2 X 2 fact.)	7		K_2 vs. K_0	(1)
P_2 vs. P_0		(1)	K_2 vs. K_1	(1)
K_2 vs. K_0		(1)	P X K	(4)
Mg_1 vs. Mg_0		(1)	Rep. X Treatment	16
P X K		(1)		
P X Mg		(1)		
K X Mg		(1)		
P X K X Mg		(1)		
Rep. X Treatment	22			

supporting this assumption has been reported by Blaser and Brady (3, p. 128-135) and Rossiter (28, p. 389). It was considered more important to obtain data from a number of locations than to make separations and determine the effect of fertilizer on clover and grass separately on a smaller number of locations.

Of the 10 original locations established in 1955 only 5 were harvested. The winter and spring of 1955-56 was a relatively poor growing season for dry land pastures and normal spring growth was not obtained. This is attributed in part to the low rainfall during the spring of 1956. Rainfall for the month of April in the Willamette Valley was less than an inch, 1.5 to 2 inches below normal (38, p. 166). Another factor contributing to the loss of clover in the 1956 experiments was an early freeze when clover was in the seedling stage. On November 15, 1955 the temperature fell to 9° F. in this area (38, p. 166).

Laboratory

Chemical analysis of plants. Clover and grass were separated from plant samples taken from each plot at the time of harvesting. Subclover plant tops (leaves and petioles) were analyzed chemically. It is recognized that there may be an advantage to separating leaves from petioles for chemical analysis as described by Ulrich (39, p. 101-111). A separate analysis was made on leaves, petioles, and leaves plus petioles on samples from two replications to evaluate the most advantageous plant part to use for the final analysis. The results of this analysis indicated a slight advantage for using petioles to represent potassium content, and leaves to represent magnesium content. There was no apparent advantage to using leaves or petioles as compared to leaves plus petioles for phosphorus determinations. Since significant differences in the content of all three nutrients were obtained when leaves and petioles were analyzed together, no separation of plant parts was made. This eliminated the necessity of making two digestions and a separation of plant parts on each sample.

The clover samples were dried in an oven at 65° C and ground in a Wiley mill to pass a 40 mesh screen. The percentage of phosphorus, potassium and magnesium in the sample was determined for each plot. One gram samples were weighed in 150 ml. beakers and wet ashed using nitric and perchloric acids as described by Piper (22, p. 272-274). Phosphorus was determined colorimetrically using a Klett colorimeter according to the method described by Kelly et al. (16, p. 319-322) and modified by Alban (1, p. 6-7). Potassium was determined flame photometrically at 768 mu on a Beckman DU Spectrophotometer with a photomultiplier. Magnesium was determined by the versenate titration method as described by Chang and Bray (7, p. 450-452). After the digested samples were made to volume, 10 ml. aliquots were taken for magnesium plus calcium determinations using Eriochrome black T dye as the indicator. Another 10 ml. aliquot was taken and calcium determined by using murexide dye as the indicator. Magnesium was determined by difference. Heavy metals of Cu, Ni, and Co which interfere with the titration were removed with a dilute solution of potassium cyanide.

Chemical analysis of soils. Soil samples were taken from each location just before fertilizer was applied. Surface samples (0-8 inches) from each replication and one composite sub-surface sample (8-16 inches) from each location were taken. Soil samples were analyzed by the Oregon Soil Testing Laboratory. Exchangeable cations of potassium, calcium, and magnesium were extracted with 1 N ammonium acetate and determined on a Model B Beckman Spectrophotometer with a flame attachment at wavelengths of 768, 554, and 383 mu respectively. Available phosphorus was determined using the sodium bicarbonate method as described by Olsen, et al. (19, p. 1-19) and modified by Alban (1, p. 2). Boron was determined using the carmine method as described by Hatcher and Wilcox (14, p. 567-569). Cation exchange capacity was determined using the ammonium acetate method as described by Schollenberger and Simon (31, p. 13-24), and percent base saturation was computed from the exchangeable cations. The pH was determined with a glass electrode pH meter on a 1:1 suspension and lime requirement was determined using Woodruff's method (46, p. 60-61). Acid extractable potassium was extracted with 1 N nitric acid in a constant temperature oil bath as described by Pratt and Morse (24, p. 4-5). Potassium in the extracts was determined on a Beckman DU Spectrophotometer with a flame attachment at 768 mu.

Results of the chemical analyses of the soil are shown in table 4. Values for the surface samples are the average of values for the three replications, except for the cation exchange capacity which was determined on composited surface samples.

Table 4

Results of Chemical Analyses of Soil Samples

Location	Sample depth	pH	Lime Req't T/A	P ppm	K*	m. e. per 100 grams Ex. K	Ex. Ca	Ex. Mg	Ex. Cap.	% Base satur.	B ppm
1	0-8	5.40	3.0	25.9	0.89	0.20	3.34	0.83	15.05	29.04	0.24
	8-16	5.55	3.0	5.0	0.84	0.19	4.35	1.37			0.34
2	0-8	5.32	4.0	8.1	0.77	0.16	3.37	0.51	13.47	29.99	0.31
	8-16	5.60	2.0	1.0	0.64	0.37	7.28	2.84			0.23
3	0-8	5.53	3.5	2.5	0.84	0.28	7.10	1.52	20.52	43.37	0.39
	8-16	5.30	2.5	1.7	0.51	0.23	4.20	1.78			0.36
4	0-8	5.50	2.0	2.6	2.18	0.54	9.65	3.75	15.88	98.79	0.25
	8-16	5.45	3.0	23.2	2.25	0.10	2.90	0.67			0.30
5	0-8	5.45	3.0	12.0	0.85	0.20	4.98	1.30	20.15	32.16	0.38
	8-16	5.15	3.5	5.0	0.84	0.09	1.20	0.33			0.27
6	0-8	5.75	3.5	21.9	0.86	0.30	5.64	1.52	22.89	32.59	0.10
7	0-8	5.90	1.5	1.8	0.83	0.24	7.03	1.95	12.69	72.65	0.24
	8-16	5.40	2.0	1.7	0.86	0.10	3.40	2.58			0.11
8	0-8	6.05	1.5	3.7	1.68	0.42	6.71	3.70	16.07	67.39	0.32
	8-16	5.65	2.0	0.7	1.79	0.27	5.85	3.25			0.29

*Potassium extracted with 1 N nitric acid as described by Pratt and Morse (24, p. 4-5)

RESULTS AND DISCUSSION

Yield data and the results of chemical analysis of plant samples from each location are presented in tables 5 through 14. The tables of F-values are the result of the subdivision of the analysis of variance into individual treatment comparisons. The first two comparisons of tables 5 through 11 were computed using individual degrees of freedom. The remaining seven comparisons are the variation due to treatments from the 2 X 2 X 2 factorial of plan 1 (table 3). Comparisons made in tables 12 through 14 are from the 3 X 3 factorial in plan 2 as shown in table 3.

The relationships between yield response, potassium and phosphorus contents of plants, and soil test values are shown in figures 1 through 8. The lines drawn between points are to clarify the relationships and do not represent calculated regression lines. Plant composition of phosphorus and potassium is on an oven dry basis, and subclover leaves and petioles were used for the determinations. Increases in yield are based on the K_2 and P_2 applications of potassium and phosphorus.

The botanical composition of locations 1, 2, 3, 5, and 6 was primarily subclover in combination with alta fescue. Locations 1, 3, 5, and 6 were approximately 60 percent clover and location 2 was only about 26 percent clover. Locations 4, 7 and 8 consisted of subclover with some winter annual weedy grasses. Location 4 was 70 to 75 percent clover and locations 7 and 8 were 75 to 85 percent clover.

The yields of the 1956 experiments were low in comparison with the 1957 experiments. This is attributed to the variation in growing seasons. As was previously pointed out, climatic conditions in 1956 were unfavorable for dry land pastures. Rainfall in the spring of 1957 was above average and favorable for the growth of dry land pastures. Relatively high yields were obtained on all locations except location 3. There was no apparent explanation for the poor growth obtained on location 3.

Effects of Potassium

Increases in yield resulted from the application of potassium fertilizer on all locations except 4 and 8 (tables 8, 11, and 14); however, differences were not significant on locations 2, 3, and 5 in 1956 (tables 6, 7, and 9). Potassium fertilizer increased yields up to 20 percent in 1956 and 40 percent in 1957 (locations 1 and 6; tables 5 and 12). The K2 application generally increased yields over the K_1 applications on locations where a response was obtained, but increases were not consistently significant.

A phosphorus x potassium interaction occurred where phosphorus soil test values were below 2.6 ppm (locations 3 and 7); tables 10 and 13). An increase in yield from potassium on these locations was obtained only on plots where phosphorus was added; there was no increase in yield from potassium alone but the combination of phosphorus and potassium increased yields over and above the increase that was obtained from comparable rates of phosphorus alone. Where phosphorus soil test values were above 2.6 ppm there was no phosphorus x potassium interaction except on location 2 (table 6) where a negative interaction occurred. On this location there was no increase in yield from potassium in the presence of phosphorus but applications of potassium alone increased yields. This relationship, however, was not evident at the P_1 and K_1 rates of phosphorus and potassium applications. The real effect of the treatments on growth of subclover at this location may have been obscurred by the vigorous growth and high percentage of alta fescue.

Soil test values indicated that a response was obtained from potassium when the exchangeable potassium in the soil was less than 0.30 me. per 100 gm. (figure 1). Failure of yield responses from potassium to be significant on locations 2, 3 and 5 (tables 6, 7 and 9) in 1956 where soil test values for exchangeable potassium were below this amount, is attributed to the poor growing season. The 1957 experiments with comparable soil test values consistantly gave significant increases in yield. The relationship between yield response to potassium and potassium content of the soil for the two seasons is shown in figure 1 for exchangeable potassium and figure 2 for 1 N HNO_3 extractable potassium.

Potassium fertilizer significantly increased the potassium content of subclover plants on all locations (figure 3 and 4). Applications of potassium significantly decreased the magnesium content of clover plants on locations 1, 3, and 4 (tables 5, 7, and 8), but had no consistent effect on phosphorus content of

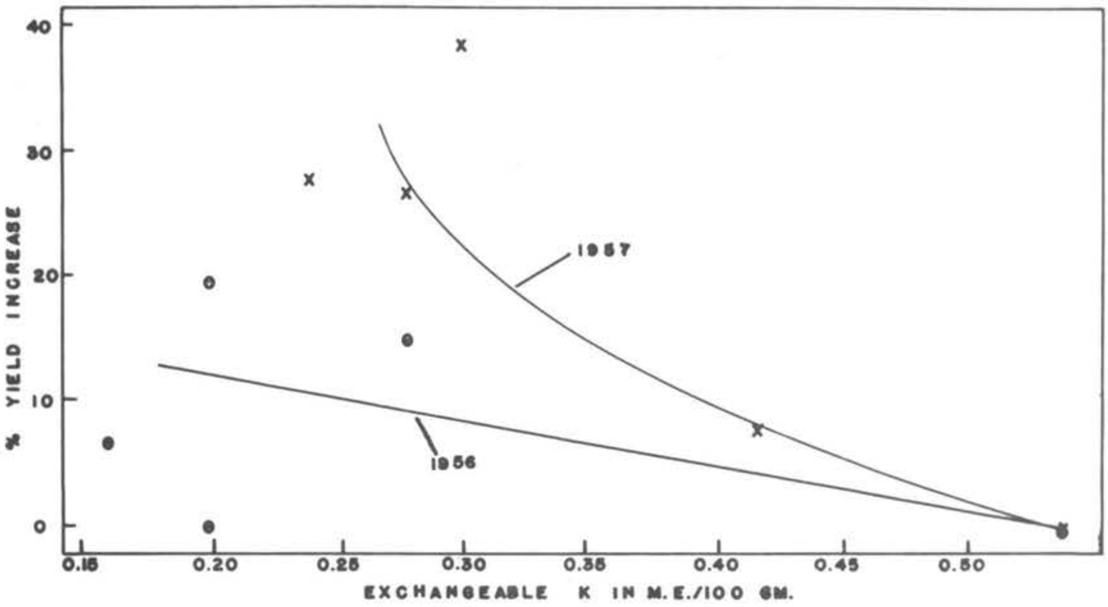

Figure 1. Relationship between yield response to potassium and exchangeable potassium in the soil (0-8 inches).

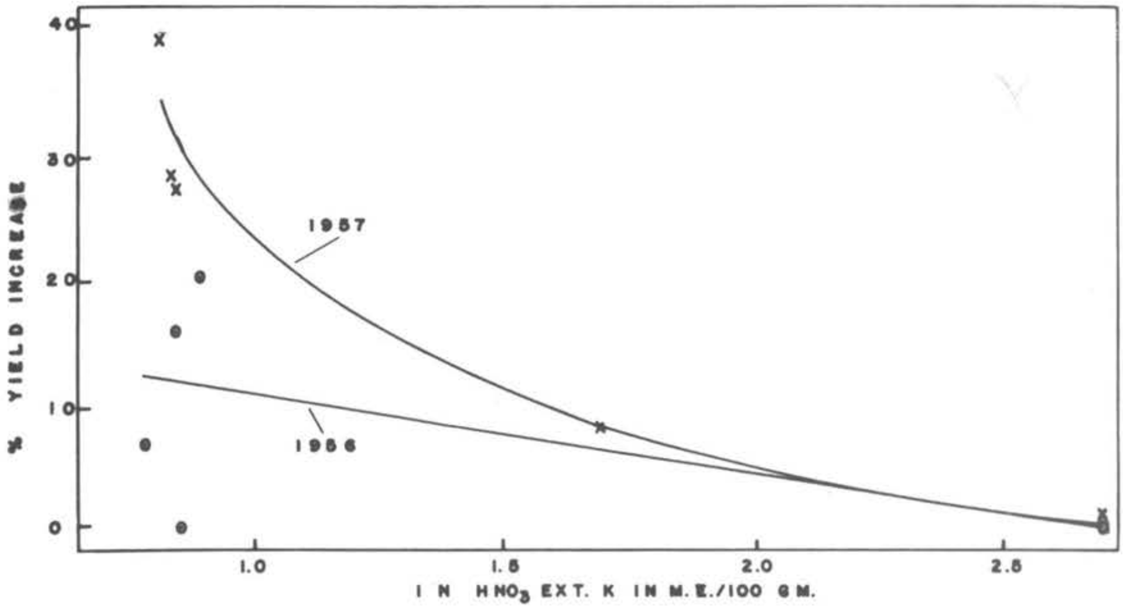

Figure 2. Relationship between yield response to potassium and 1 N nitric acid extractible potassium in the soil (0-8 inches).

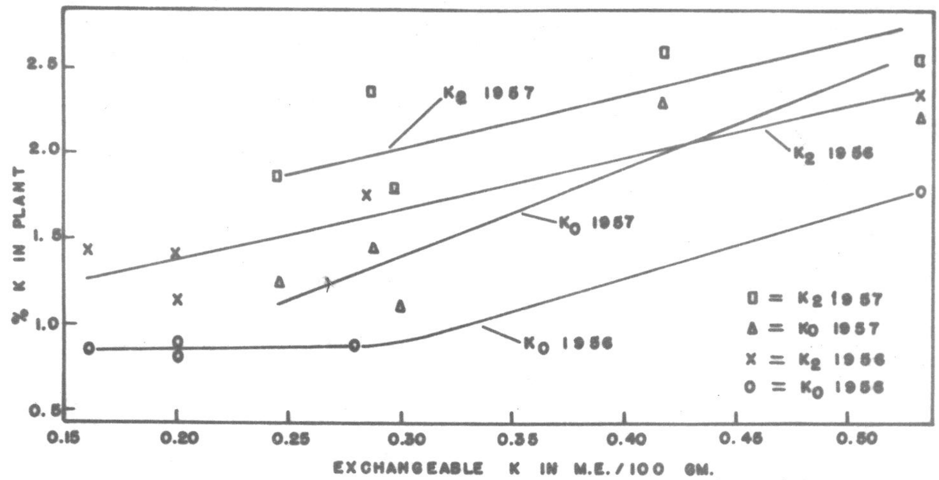

Figure 3. Effect of potassium fertilizer on the relationship between potassium content of plants and exchangeable potassium in the soil (0-8 inches).

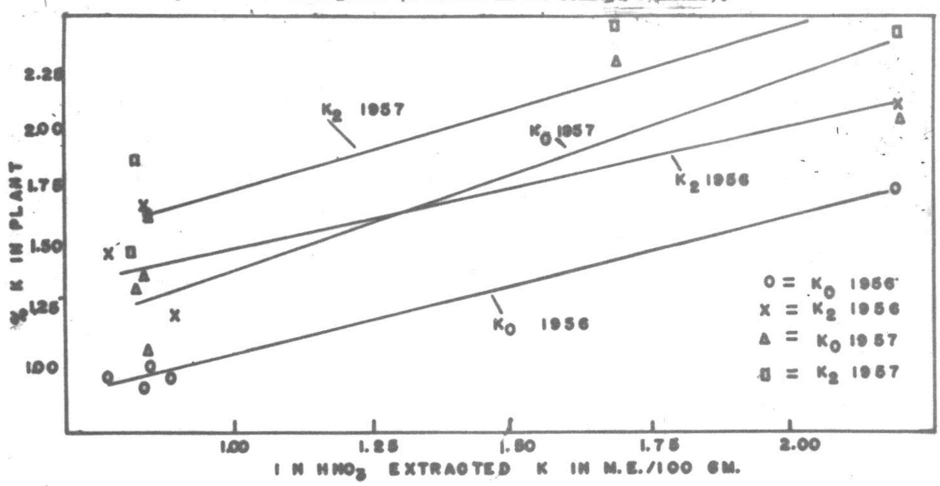

Figure 4. Effect of potassium fertilizer on the relationship between the potassium content of plants and 1 N nitric acid extractible potassium in the soil (0-8 inches).

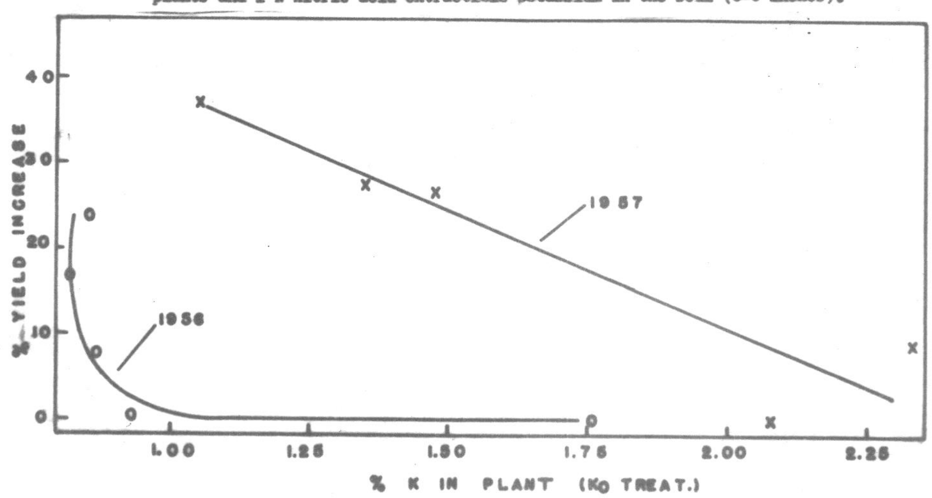

Figure 5. Relationship between yield response to potassium and potassium content of plants (K_0 treatment)

plants. This is in agreement with other evidence reported by Millikan (12, p. 30-31), and Seay and Weeks (32, p. 458-461).

Significant increases in yield were obtained when the potassium content of plants was below 1.45 percent in 1957. For example, yields were increased 27 percent on location 3 in 1957 (table 10) where the potassium content of the K_0 treatments averaged 1.43 percent. The K_1 treatment on location 7 increased the potassium content of plants from 1.05 to 1.70 percent and there was no further increase in yield from the K_2 treatment. This suggests that, under the conditions prevailing in 1957, potassium contents of 1.70 percent or above are adequate while contents below 1.45 percent are deficient. The relationship between increase in yield from the K_2 application of potassium and the potassium content of plants from the K_0 treatments is shown in figure 5.

Effects of Phosphorus

Applications of phosphorus produced a significant increase in yield on all of the 1957 locations. Phosphorus increased yields as much as 47 percent in 1956 and 250 percent in 1957 (locations 3 and 7; tables 7 and 13). Only location 3 (table 7) of the 1956 experiments showed a significant increase in yield from phosphorus fertilizer. However, the data suggest a tendency toward increased yield with increased phosphorus on locations 2, 4, and 5. Location 1 showed no response to phosphorus fertilization.

Maximum yields were not obtained from the P_1 application where a response was obtained from phosphorus fertilizers. However, differences in yields between the P_1 and P_2 treatments were not significant on locations 4, 6, and 8.

The relationship between response to phosphorus and the available phosphorus in the soil is shown in figure 6. Location 1, which showed no response to phosphorus, had the highest soil test value. There was no response to phosphorus in 1956 with soil test values above 3 ppm. However, in 1957 a phosphorus response was obtained on all locations with soil test values up to 21.9 ppm. The phosphorus soil test values for locations 4, 6 and 8 where P_2 did not increase yields above P_1 applications ranged from 2.6 to 21.9. These locations represent the highest phosphorus soil test values for the 1957 locations.

Applications of phosphorus fertilizer significantly increased the phosphorus contents of subclover plants on all locations (figure 7). Phosphorus fertilizer treatments had no consistent effect on the potassium content of plants with the exception of location 6 (table 12) where added phosphorus increased the potassium content of plants from 1.49 to 1.72.

Increases in phosphorus content of plants was generally less for locations with relatively high phosphorus soil test values (figure 7). Critical levels for phosphorus content of plants cannot be proposed since increases in yield and phosphorus content were obtained from the application of phosphorus on all of the 1957 locations. Figure 8 shows the relationship between yield response to phosphorus from the P_2 application and the phosphorus content of plants from the P_0 treatments. The maximum phosphorus content of plants from the P_0 treatments was 0.23 percent for 1957. The P_1 application of phosphorus increased the phosphorus content of plants to an average of 0.25 percent on locations 4, 6, and 8 in 1957. There was no further yield increase from the P_2 application on these locations.

Added phosphorus increased the magnesium content of plants on all locations. Chang and Bray (7, p. 451) noted that the presence of excess phosphorus may interfere with the versenate titration of magnesium. This possibility was investigated and it was found that where phosphorus in the plant was greater than 0.20 percent the values given for magnesium content in the plant may be slightly higher than the true values. The extent of this error depends on the concentration of phosphorus in the digested plant solution. This discrepancy, however, does not account for all of the difference in magnesium contents resulting from the application of phosphorus.

Effects of Magnesium

Application of magnesium did not increase yields on any of the locations. A negative potassium x magnesium interaction was observed on location 1 (table 5). Potassium alone and in combination with phosphorus increased yields as much as 2000 pounds per acre, but potassium in combinations with magnesium had little effect on yield at this location.

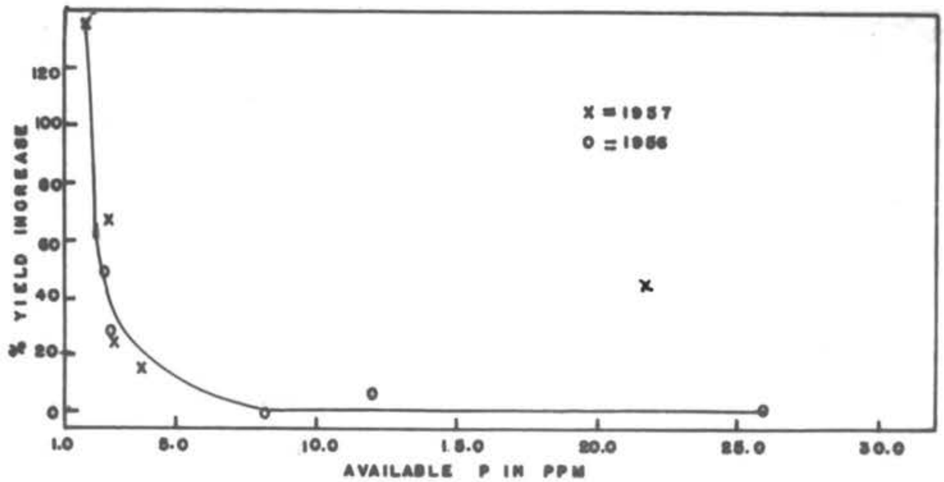

Figure. 6. Relationship between yield response to phosphorus and available phosphorus in the soil (0-8 inches).

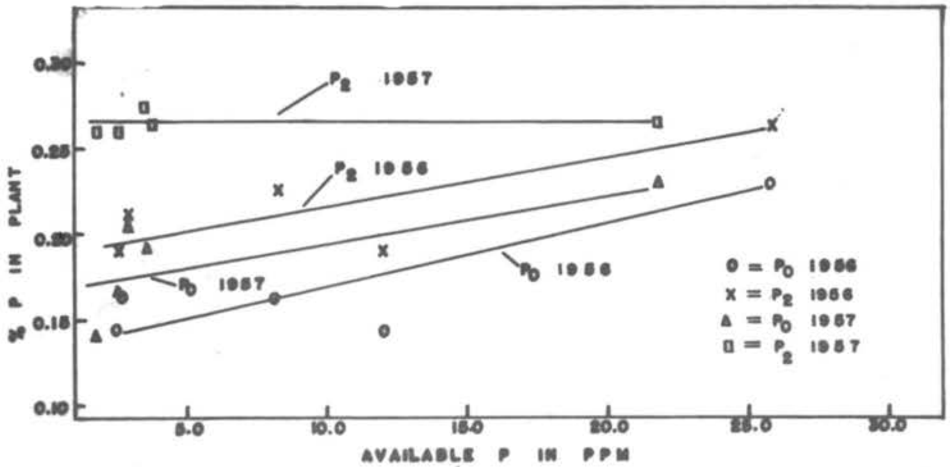

Figure 7. Effect of phosphorus fertilizer on the relationship between phosphorus content of plants and available phosphorus in the soil (0-8 inches).

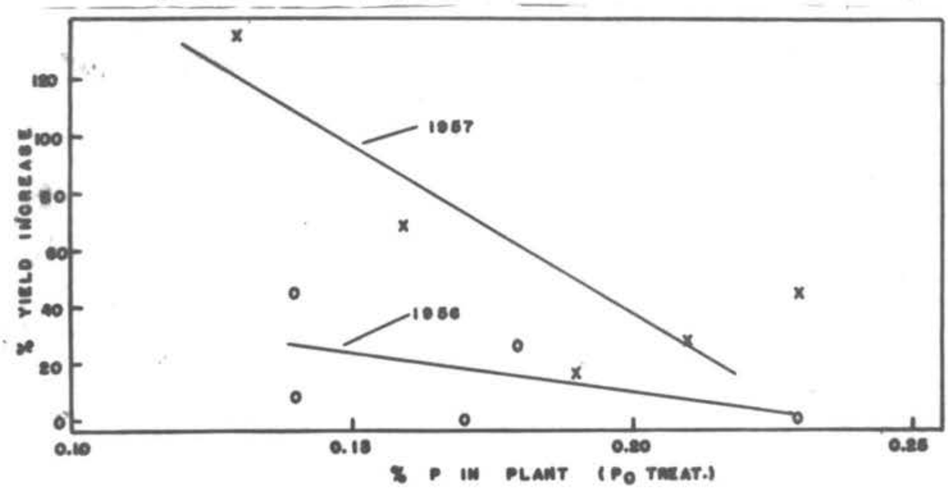

Figure 8. Relationship between yield response to phosphorus and phosphorus content of plants (P_0 treatment).

Table 5

The Effect of Phosphorus, Potassium and Magnesium Fertilizers on the Yield and Chemical Composition of Subclover
Location 1

Treatment	Yield lbs/A	Yield % inc.	% P in plant	% K in plant	% Mg in plant
P_0 K_0	3154	----	0.22	0.87	0.56
P_0 K_0 Mg	4499	22.8	0.25	0.97	0.80
P_2 K_0	3898	23.6	0.27	0.87	0.82
P_2 K_0 Mg	3937	24.8	0.26	0.72	0.78
P_0 K_2	5390	70.9	0.21	1.12	0.52
P_0 K_2 Mg	4106	30.2	0.24	1.25	0.67
P_2 K_2	4986	58.1	0.26	1.37	0.59
P_2 K_2 Mg	4147	41.5	0.26	1.04	0.65
P_1 K_2	5620	78.2	0.24	1.22	0.53
P_1 K_2 Mg	4460	41.4	0.29	1.04	0.70
P_2 K_1	4487	42.2	0.29	1.00	0.65
P_2 K_1 Mg	4008	27.0	0.29	0.92	0.78

Variation due to	F-values from analysis of variance Yield	% P	% K	% Mg
P_2 vs. P_1	(-)1.02	0.14	0.13	0.00
K_2 vs. K_1	0.46	(-)3.10	1.35	(-) 4.96*
P_2 vs. P_0	0.01	9.96**	0.46	6.75*
K_2 vs. K_0	5.61*	0.55	19.39**	(-)24.31**
Mg_1 vs. Mg_0	0.23	1.48	0.69	14.70**
P X K	0.00	0.00	0.93	2.93
P X Mg	0.31	2.58	(-) 5.70*	17.46**
K X Mg	(-)5.17*	0.00	0.25	0.00
P X K X Mg	1.41	0.37	0.90	0.00

*Significant at 5 percent level
**Significant at 1 percent level (-)Indicates decrease

Table 6

The Effect of Phosphorus, Potassium and Magnesium Fertilizers on the Yield and Chemical Composition of Subclover
Location 2

Treatment	Yield lbs/A	Yield % inc.	% P in plant	% K in plant	% Mg in plant
P_0 K_0	5075	----	0.18	0.97	0.47
P_0 K_0 Mg	5300	4.4	0.16	0.78	0.78
P_2 K_0	5691	12.1	0.24	0.63	0.36
P_2 K_0 Mg	5063	----	0.23	1.07	0.73
P_0 K_2	6023	18.7	0.18	1.54	0.62
P_0 K_2 Mg	6373	25.6	0.18	1.64	0.64
P_2 K_2	5572	9.8	0.20	1.22	0.55
P_2 K_2 Mg	4881	----	0.24	1.53	0.58
P_1 K_2	5473	8.2	0.16	1.39	0.42
P_1 K_2 Mg	5875	15.8	0.19	1.37	0.67
P_2 K_1	5342	5.3	0.21	1.18	0.49
P_2 K_1 Mg	5944	17.1	0.25	1.02	0.80

Variation due to	F-values from analysis of variance Yield	% P	% K	% Mg
P_2 vs. P_1	1.24	5.74*	0.00	0.25
K_2 vs. K_1	(-)1.12	0.34	5.40*	(-) 2.79
P_2 vs. P_0	3.76	17.34**	1.70	8.70**
K_2 vs. K_0	2.12	0.03	63.54**	0.21
Mg_1 vs. Mg_0	1.19	0.01	4.71*	60.54**
P X K	(-)7.40*	0.85	2.08	0.21
P X Mg	(-)5.19*	0.58	7.95*	0.45
K X Mg	0.67	1.20	0.27	45.12**
P X K X Mg	2.67	0.28	1.09	0.21

*Significant at 5 percent level
**Significant at 1 percent level (-)Indicates decrease

Table 7

The Effect of Phosphorus, Potassium and Magnesium Fertilizers on the Yield and Chemical Composition of Subclover
Location 3 (1956)

Treatment	Yield lbs/A	Yield % inc.	% P in plant	% K in plant	% Mg in plant
P_0 K_0	2212	----	0.13	0.78	0.39
P_0 K_0 Mg	1922	----	0.16	0.87	0.78
P_2 K_0	2270	2.6	0.19	0.95	0.57
P_2 K_0 Mg	2787	26.0	0.18	0.69	0.77
P_0 K_2	2261	2.2	0.15	1.70	0.43
P_0 K_2 Mg	1663	----	0.13	1.52	0.40
P_2 K_2	3397	53.6	0.18	1.68	0.35
P_2 K_2 Mg	3378	52.7	0.17	1.91	0.55
P_1 K_2	2290	3.5	0.17	1.62	0.55
P_1 K_2 Mg	1941	----	0.17	1.21	0.58
P_2 K_1	3302	49.3	0.19	1.52	0.44
P_2 K_1 Mg	2816	27.3	0.18	1.21	0.47

Variation due to	F-values from analysis of variance Yield	% P	% K	% Mg
P_2 vs. P_1	13.42**	1.08	6.06*	(-) 4.53*
K_2 vs. K_1	0.90	0.03	7.95**	0.00
P_2 vs. P_0	15.18**	24.98**	0.80	2.99
K_2 vs. K_0	2.42	0.59	79.90**	(-)31.99**
Mg_1 vs. Mg_0	0.16	0.21	0.09	31.99**
P X K	3.97	0.00	4.75*	0.49
P X Mg	2.04	0.23	0.12	0.06
K X Mg	0.76	2.80	0.03	(-)10.07**
P X K X Mg	0.06	1.12	0.00	8.59**

*Significant at 5 percent level
**Significant at 1 percent level (-)Indicates decrease

Table 8

The Effect of Phosphorus, Potassium and Magnesium Fertilizers on the Yield and Chemical Composition of Subclover Location 4 (1956)

Treatment	Yield lbs/A	Yield % inc.	% P in plant	% K in plant	% Mg in plant
P_0 K_0	1344	----	0.18	1.67	0.40
P_0 K_0 Mg	1872	30.5	0.20	1.74	0.52
P_2 K_0	2497	74.1	0.22	1.87	0.56
P_2 K_0 Mg	2043	42.4	0.22	1.74	0.60
P_0 K_1	1548	7.9	0.17	2.45	0.41
P_0 K_1 Mg	1520	6.0	0.16	2.21	0.44
P_2 K_1	1849	28.9	0.21	2.29	0.42
P_2 K_1 Mg	1733	20.8	0.23	2.12	0.52
P_1 K_1	1986	38.4	0.19	2.14	0.49
P_1 K_1 Mg	1841	28.3	0.22	2.03	0.62
$P_{\frac{1}{2}}$ K_1	1996	39.1	0.22	2.22	0.50
$P_{\frac{1}{2}}$ K_1 Mg	1841	28.3	0.19	2.10	0.58

Variation due to	F-values from analysis of variance Yield	% P	% K	% Mg
P_2 vs. P_1	0.01	5.29*	1.08	5.38*
P_1 vs. $P_{\frac{1}{2}}$	0.23	0.02	(-) 0.41	0.25
P_2 vs. P_0	4.03	38.55**	(-) 0.01	13.52**
K_1 vs. K_0	0.89	(-) 3.03	29.39**	(-) 9.84**
Mg_1 vs. Mg_0	0.03	1.43	(-) 1.52	11.78**
P X K	0.69	5.27*	(-) 2.94	(-) 2.54
P X Mg	1.30	0.93	0.01	0.01
K X Mg	0.02	0.01	(-) 1.14	0.09
P X K X Mg	0.82	4.48	0.64	2.56

*Significant at 5 percent level
**Significant at 1 percent level (-)Indicates decrease

Table 9

The Effect of Phosphorus, Potassium and Magnesium Fertilizers on the Yield and Chemical Composition of Subclover
Location 5

Treatment	Yield lbs/A	Yield % inc.	% P in plant	% K in plant	% Mg in plant
P_0 K_0	2824	----	0.15	0.85	0.41
P_0 K_0 Mg	3111	10.1	0.13	0.83	0.67
P_2 K_0	4145	46.8	0.21	0.98	0.63
P_2 K_0 Mg	3544	25.5	0.16	0.93	0.55
P_0 K_2	3178	12.5	0.14	1.61	0.29
P_0 K_2 Mg	3887	35.6	0.14	1.33	0.57
P_2 K_2	3306	17.1	0.17	1.45	0.52
P_2 K_2 Mg	3043	7.8	0.17	1.51	0.75
P_1 K_2	2998	6.9	0.16	1.39	0.44
P_1 K_2 Mg	4040	43.1	0.16	1.60	0.57
P_2 K_1	3200	13.3	0.14	1.05	0.41
P_2 K_1 Mg	3442	18.0	0.21	1.22	0.74

Variation due to	F-values from analysis of variance Yield	% P	% K	% Mg
P_2 vs. P_1	0.50	5.60*	0.01	3.34
K_2 vs. K_1	0.04	0.13	5.16*	0.72
P_2 vs. P_0	0.75	19.18**	0.14	5.45*
K_2 vs. K_0	0.03	0.33	27.46**	0.40
Mg_1 vs. Mg_0	0.01	4.09	0.84	10.11**
P X K	3.99	1.04	0.08	2.08
P X Mg	2.40	0.21	0.76	3.99
K X Mg	0.41	2.55	0.01	2.74
P X K X Mg	0.30	0.86	0.70	2.08

*Significant at 5 percent level
**Significant at 1 percent level (-)Indicates decrease

Table 10

The Effect of Phosphorus, Potassium and Magnesium Fertilizers on the Yield and Chemical Composition of Subclover
Location 3 (1957)

Treatment	Yield lbs/A	Yield % inc.	% P in plant	% K in plant	% Mg in plant
P_0 K_0	1582	----	0.16	1.53	0.43
P_0 K_0 Mg	1414	----	0.16	1.32	0.56
P_2 K_0	1969	24.4	0.25	1.68	0.53
P_2 K_0 Mg	1979	25.0	0.27	1.20	0.67
P_0 K_2	1644	3.9	0.15	2.17	0.31
P_0 K_2 Mg	1238	----	0.17	2.11	0.42
P_2 K_2	2791	76.4	0.26	2.52	0.44
P_2 K_2 Mg	3183	101.1	0.25	2.63	0.56
P_1 K_2	2035	28.6	0.20	2.47	0.43
P_1 K_2 Mg	1691	6.8	0.22	2.19	0.51
P_2 K_1	2151	35.9	0.26	1.98	0.45
P_2 K_1 Mg	2013	27.2	0.27	1.90	0.59

Variation due to	F-values from analysis of variance Yield	% P	% K	% Mg
P_2 vs. P_1	33.12**	19.63**	0.92	8.91**
K_2 vs. K_1	21.47**	0.00	9.48**	(-) 4.98*
P_2 vs. P_0	69.92**	188.56**	2.50	35.21**
K_2 vs. K_0	12.48**	0.07	42.57**	(-)30.31**
Mg_1 vs. Mg_0	0.31	1.14	1.23	36.97**
P X K	15.65**	0.09	2.28	1.07
P X Mg	3.25	1.04	0.00	0.02
K X Mg	0.07	0.01	1.72	0.57
P X K X Mg	1.42	2.65	0.61	0.00

*Significant at 5 percent level
**Significant at 1 percent level (-)Indicates decrease

Table 11

The Effect of Phosphorus, Potassium and Magnesium Fertilizers on the Yield and Chemical Composition of Subclover Location 4 (1957)

Treatment	Yield lbs/A	Yield % inc.	% P in plant	% K in plant	% Mg in plant
P_0 K_0	2654	----	0.20	2.17	0.75
P_0 K_0 Mg	2857	7.7	0.23	2.26	0.83
P_2 K_0	3618	36.3	0.27	1.90	0.83
P_2 K_0 Mg	3281	23.7	0.30	1.98	0.88
P_0 K_1	2777	4.7	0.20	2.32	0.77
P_0 K_1 Mg	2488	----	0.22	2.30	0.77
P_2 K_1	3186	20.1	0.28	2.46	0.84
P_2 K_1 Mg	3535	33.2	0.28	2.45	0.93
P_1 K_1	3297	24.2	0.25	2.15	0.84
P_1 K_1 Mg	3488	31.4	0.26	2.45	0.90
$P_{\frac{1}{2}}$ K_1	3449	29.9	0.26	2.46	0.87
$P_{\frac{1}{2}}$ K_1 Mg	3170	19.5	0.25	2.43	0.88

Variation due to	F-values from analysis of variance Yield	% P	% K	% Mg
P_2 vs. P_1	(-) 0.02	2.28	0.93	0.11
P_1 vs. $P_{\frac{1}{2}}$	0.11	0.14	0.83	0.03
P_2 vs. P_0	21.38**	82.22**	0.33	13.41**
K_1 vs. K_0	0.48	0.50	7.34*	0.05
Mg_1 vs. Mg_0	0.04	3.66	0.12	5.33*
P X K	0.01	0.00	3.47	0.91
P X Mg	0.00	0.60	0.00	0.56
K X Mg	0.07	1.30	0.21	0.24
P X K X Mg	3.71	0.36	0.00	1.51

*Significant at 5 percent level
**Significant at 1 percent level (-)Indicates decrease

Table 12

The Effect of Phosphorus and Potassium Fertilizers on the Yield and Chemical Composition of Subclover
Location 6 (1957)

Treatment	Yield lbs/A	Yield % inc.	% P in plant	% K in plant
P_0 K_0	2560	----	0.24	1.08
P_1 K_0	3058	19.5	0.26	0.93
P_2 K_0	3663	43.1	0.27	1.16
P_0 K_1	3651	42.6	0.23	1.42
P_0 K_2	3184	24.4	0.23	1.49
P_1 K_1	4387	71.4	0.25	1.42
P_1 K_2	4536	77.2	0.25	1.67
P_2 K_1	4848	89.4	0.27	1.68
P_2 K_2	5264	105.6	0.28	1.72

Variation due to	F-values from analysis of variance Yield	% P	% K
P_2 vs. P_0	9.66**	27.77**	7.36*
P_2 vs. P_1	1.60	5.70*	6.64*
K_2 vs. K_0	6.90*	0.00	61.41**
K_2 vs. K_1	0.00	0.18	2.81
P X K	0.34	0.59	1.00

*Significant at 5 percent level
**Significant at 1 percent level

Table 13

The Effect of Phosphorus and Potassium Fertilizers on the Yield and Chemical Composition of Subclover
Location 7 (1957)

Treatment	Yield lbs/A	Yield % inc.	% P in plant	% K in plant
P_0 K_0	1178	-----	0.13	1.48
P_1 K_0	3045	158.4	0.21	1.26
P_2 K_0	3230	174.1	0.28	1.34
P_0 K_1	1014	------	0.12	1.82
P_0 K_2	1218	3.4	0.12	2.13
P_1 K_1	3807	223.1	0.20	1.67
P_1 K_2	3645	209.3	0.26	1.64
P_2 K_1	4136	250.9	0.23	1.86
P_2 K_2	4686	297.6	0.27	1.85

Variation due to	F-values from analysis of variance Yield	% P	% K
P_2 vs. P_0	205.57**	135.88**	(-) 3.63
P_2 vs. P_1	6.66*	20.68**	0.02
K_2 vs. K_0	12.09**	0.03	31.01**
K_2 vs. K_1	0.96	1.45	5.09*
P X K	2.68	0.61	0.12
(P X K)†	7.24*	0.00	(-) 0.04

*Significant at 5 percent level
**Significant at 1 percent level (-)Indicates decrease
† Average increase due to potassium where phosphorus is absent compared to the average increase due to potassium where phosphorus is present.

Table 14

The Effect of Phosphorus and Potassium Fertilizers on the Yield and Chemical Composition of Subclover
Location 8 (1957)

Treatment	Yield lbs/A	Yield % inc.	% P in plant	% K in plant
P_0 K_0	3529	----	0.21	2.48
P_1 K_0	3865	9.5	0.25	2.29
P_2 K_0	4016	13.8	0.25	2.30
P_0 K_1	3767	6.5	0.18	2.70
P_0 K_2	3732	5.7	0.17	2.62
P_1 K_1	3995	13.2	0.27	2.73
P_1 K_2	4252	20.5	0.23	2.79
P_2 K_1	4570	29.5	0.28	2.31
P_2 K_2	4351	23.3	0.28	2.73

Variation due to	F-values from analysis of variance Yield	% P	% K
P_2 vs. P_0	9.54**	51.49**	(-)1.80
P_2 vs. P_1	1.90	1.90	(-)0.13
K_2 vs. K_0	2.40	0.84	8.82**
K_2 vs. K_1	0.00	(-)1.97	3.85
P X K	0.32	2.71	1.12

**Significant at 1 percent level (-)Indicates decrease

Magnesium fertilizer significantly increased the magnesium content of clover plants on all locations. Added magnesium had little effect on the phosphorus and potassium contents of subclover plants although the data suggest that magnesium fertilization had a positive effect on phosphorus content and a negative effect on potassium content. Similar relationships have been reported by Millikan (17, p. 30-32), Truog et al. (37, p. 19-25) and Wallace and Ashcroft (40, p. 219-222).

The magnesium content of plants from the Mg_0 treatments varied from 0.29 to 0.93. Since no response was observed from magnesium, there is reason to believe that the critical level of magnesium in subclover under these conditions is somewhere below 0.29 percent. The exchangeable magnesium content of the soil varied from 0.51 me. per 100 gm. to 3.75 me. per 100 gm., and the Ca:Mg ratios varied from 2.6:1 to 6.6:1. Results of other studies have indicated that a yield response to magnesium would not be expected within this range of Ca:Mg ratios (11, p. 209-214).

Effects of Seasonal Variations

As was previously pointed out the 1955-56 growing season was poor for growth of dry land pastures. This resulted in a lower response to fertilizer applications in 1955-56 than in the 1956-57 growing season which had a higher than average rainfall and was more favorable for the growth of dry land pastures. Weden et al. (42, p. 147-152) pointed out that ladino clover showed greater differences due to fertility treatments when the rainfall was above or close to normal during the growing season. The 1955-56 data, however, cannot be ignored because of an "abnormal" growing season since very few growing seasons can be considered normal.

Both yields and the chemical composition of plants were affected by the different growing seasons as can be seen in figures 1 through 8. The relationship between yield increase and the potassium content of plants from the K_0 treatments (figure 5) was greatly affected by the different growing seasons. The 1956 data indicate yield responses were observed where the potassium content of plants from the K_0 plots was below 0.80 to 0.90 percent. However, the 1957 data indicate responses were observed where the potassium content of plants was less than 1.45 percent. The average potassium content of the K_0 treatments was 0.82 percent for location 3, and 1.75 percent for location 4 in 1956. The average potassium content of the K_0 treatments for the same locations in 1957 increased to 1.43 and 2.03 respectively. The response to potassium was significant on location 3 in 1957 but failed to be significant in 1956.

The different growing seasons had a similar effect on the relationship between yield increase and the phosphorus content of plants from the P_0 treatments (figure 8). The average phosphorus content of the P_0 treatments was 0.14 percent for location 3 and 0.18 percent for location 4 in 1956. The average phosphorus content of the P_0 treatments for the same locations in 1957 increased to 0.16 and 0.22 percent respectively.

The variation in growing seasons also had an effect on evaluating the relationship between phosphorus soil test values and response to added phosphorus. A response to phosphorus was obtained on all of the 1957 locations with phosphorus soil test values as high as 21.9 ppm. In 1956, however, the response to phosphorus was not significant on locations with soil test values ranging from 2.6 to 25.9 ppm.

These variations between growing seasons emphasize the importance of climatic factors in using chemical plant analysis and soil test values as diagnostic techniques. This factor was pointed out by Steenbjerg (34, p. 97-102).

Regression Analysis

The data from the field experiments and chemical analyses of plants and soils were incorporated into the following statistical model in order to determine the effects of soil and plant contents of phosphorus and potassium on yield response.

$$Y = b_0 + b_1P_p + b_2K_p + b_3P_s + b_4K_s + E$$

Where:

Y = the percent increase in yield over non-fertilized plots

b_0 = mean effect

b_1 = the effect of the phosphorus in the plant

P_p = the percent phosphorus in the plant

b_2 = the effect of the potassium content of subclover plants

K_p = the percent potassium in the plant

b_3 = the effect of phosphorus level in the soil

P_s = ppm of phosphorus in the soil before fertilization

b_4 = the effect of exchangeable potassium in the soil

K_s = ppm of exchangeable potassium in the soil before fertilization

E = random error. NID $(0, \sigma^2)$

It is recognized that differences in yield are affected by variables other than those included in the statistical model; however, from the information that was available, phosphorus and potassium content of plants and soil appeared to have the greatest effect on yield differences. Since there was no evidence of a response to magnesium on any of the locations, regression coefficients were not computed for plant and soil magnesium content. Variation due to fertilizer treatments of phosphorus and potassium were assumed to be reflected in the phosphorus and potassium content of plants and location differences are reflected in the soil test values.

The results of all ten field experiments during the two years were included in the regression analysis. The treatments that received no magnesium were not included for the locations where a magnesium variable was used. Yield increases, and the values for the potassium and phosphorus content of the soil used for the regression analysis were the mean values of the three replications.

The regression coefficients were computed using the abbreviated Doolittle method of solving simultaneous equations as described by Dwyer (10, p. 449-458). The following prediction equation resulted from the solution of the statistical model.

$$\hat{Y} = 81.34 + 669.62\ P_p + 18.10\ K_p - 3.496\ P_s - 0.819\ K_s$$

The solution of a second statistical model using 1 N nitric acid extractable potassium rather than exchangeable potassium as a measure of the potassium content of the soil is as follows:

$$\hat{Y} = 92.80 + 669.62\ P_p + 18.10\ K_p - 3.496\ P_s - 0.197\ K_s$$

The purpose of these equations was to determine the effect of the variables, P_p, K_p, P_s, and K_s, on yield response and is not necessarily a means of predicting yield response. A more complete equation would be necessary to predict yield response with any degree of accuracy.

The regression coefficients with their corresponding standard errors are shown in table 15. The F-values computed for the regression coefficients are shown in table 16, and correlation coefficients are shown in table 17. More variation was explained using acid extractable potassium than using exchangeable potassium. This is in agreement with the evidence reported by Pope and Cheney (23, p. 75-77) which showed that the amount of potassium extracted with nitric acid was a better index to the potassium removed by intensive greenhouse cropping with ladino clover than the amount of exchangeable potassium before cropping.

Table 15

Regression Coefficients and Standard Errors

Effect	Equation (1) Coefficient	Equation (1) Std. Error	Equation (2) Coefficient	Equation (2) Std. Error
Mean	81.34	±40.72	92.80	±36.55
P_p	669.62	±155.93	669.62	±148.51
K_p	18.10	±20.84	18.10	±19.84
P_s	-3.496	±1.060	-3.496	±1.010
K_s	-0.819	±0.191	-0.197	±0.042

Significant F-values, as are shown in table 16 for P_p, P_s, and K_s, indicate that these factors had a significant influence on the increase in yield. Potassium in the soil, by both methods of measurement, and levels of phosphorus in the soil were negatively correlated with yield increase. This verifies the observation that less response was obtained from phosphorus and potassium fertilizers where tests for these nutrients in the soil were relatively high than where soil tests were low (figures 1, 2, and 6). Larger yields were also associated with higher phosphorus content of plants (figure 7).

The regression analysis indicates the potassium content of plants was not necessarily associated with high yields or increases in yield. On locations 4 and 8 (tables 8, 11, and 14) the potassium content of plants increased from 1.75 to 2.66 percent with no increase in yield. The potassium content of the K_0 treatments on these locations was above the 1.45 critical level suggested previously from the 1957 data. These locations, in addition to locations 3 and 7 (tables 7, 10 and 13) where increased yield from potassium was limited to plots which received phosphorus, appear to be counteracting the positive relationship between yield increase and potassium content of plants which was evident on the remaining locations.

Table 16

Analysis of Variance Table Showing the Effects of Phosphorus and Potassium Content of Soil and Plants on the Percentage Increase in Yield

Variation due to	d. f.	Equation (1) Mean Square	F	Equation (2) Mean Square	F
Regression	4	23,709.59	8.89**	26,319.65	10.44**
P_p	1	50,950.61	18.32**	50,950.61	20.20**
K_p	1	2,120.10	0.76	2,120.10	0.84
P_s	1	30,215.90	10.86**	30,215.90	11.98**
K_s	1	51,270.33	18.44**	56,677.35	22.47**
Error	64	2,780.08		2,521.84	
Total	68				

**Significant at the 1 percent level

Table 17

Correlation Coefficients

	% Yield increase	% P in plant	% K in plant	P in soil	K (1) in soil
% P in plant	0.259*				
% K in plant	0.017	0.141			
P in soil	-0.427**	0.324**	-0.578**		
K (1) in soil	-0.251*	0.188	0.738**	-0.408	
K (2) in soil	-0.281*	0.178	0.719**	-0.390	0.925**

*Significant at the 5 percent level
**Significant at the 1 percent level

SUMMARY AND CONCLUSIONS

A study was made of the effects of phsophorus, potassium and magnesium on the yield and chemical composition of subterranean clover. Field experiments were conducted on five locations in 1956 and five locations in 1957. Variable levels of phosphorus, potassium and magnesium fertilizers were included in the experimental designs. Data collected from these experiments included yields, phosphorus, potassium, and magnesium content of subclover plants and soil test values for each location. The relationships between the response from phosphorus, potassium, and magnesium, and soil tests, and the content of these nutrients found in the plant were evaluated.

The 1957 results indicated that responses were obtained from applications of potassium on locations where soil test values were below 0.30 me. per 100 grams and where the potassium content of plants was 1.43 percent or below. The response to potassium in 1956 was not definite enough to suggest critical levels of soil and plant potassium.

Response to potassium was limited to plots receiving applications of phosphorus on locations with low phosphorus soil test values. Potassium applications increased the potassium content of plants on all locations and tended to decrease the magnesium content of plants. Increased potassium had no apparent effect on the phosphorus content of plants.

Applications of phosphorus increased yields on all locations where the level of phosphorus in the soil was below 22 ppm in

1957. The 1956 results showed no response to phosphorus on locations with phosphorus soil test values above 3.0 ppm. Increased phosphorus had no consistent effect on the potassium content of plants, but tended to increase the magnesium content of plants.

Applications of magnesium had no apparent effect on yield on any of the locations. Exchangeable magnesium in the soil varied from 0.51 to 3.75 me. per 100 gm. with Ca:Mg ratios varying from 2.6:1 to 6.6:1. The minimum magnesium content of plants from the Mg_0 treatments was 0.29 percent. The magnesium content of plants was increased by applications of magnesium. There was a tendency for added magnesium to increase the phosphorus content of plants and decrease the potassium content of plants.

The percentage increase in yield was assumed to be a function of the phosphorus and potassium content of plants and soil, and regression coefficientes were computed for these variables to determine their effect on yield increase. The following equation resulted from a regression analysis of the data; where Y is the predicted yield increase (percent), P_p is the phosphorus content of plants (percent), K_p is the potassium content of plants (percent), P_s is the available phosphorus in the soil (ppm), and K_s is the potassium extracted with 1 N nitric acid.

$$\hat{Y} = 92.80 + 669.62 P_p + 18.10 K_p - 3.496 P_s - 0.197 K_s$$

The percentage phosphorus in plants, available phosphorus in the soil, and exchangeable and/or 1 N nitric extractable potassium were found to have a significant effect on the increase in yield. These variables were also found to be correlated with yield increase. Soil test values for available phosphorus were statistically correlated with the phosphorus content of plants. Similarly both exchangeable and 1 N nitric acid extracted potassium were statistically correlated with the potassium content of plants.

The data for the two years show a wide variation between years. The 1957 experiments showed a greater response to phosphorus and potassium fertilizers than the 1956 experiments. The content of phosphorus and potassium plants was also greater for 1957 than for 1956. Results from one year, therefore, cannot be considered conclusive as a basis for making fertilizer recommendations, or for evaluating critical levels of the nutrient content of plants.

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