AN ABSTRACT OF THE THESIS OF

Steven Edwin Petrie for the degree of Master of Science

in Soil Science presented on January 24, 1980

Title: SEASONAL DISTRIBUTION OF FORAGE PRODUCTION, N CONCENTRATION, AND Mo CONCENTRATION IN SUBTERRANEAN CLOVER

Abstract approved: Redacted for privacy

Dr. Thomas L. Jackson

Fall and winter forage availability is a major factor limiting animal production on subterranean clover pastures in western Oregon. Seasonal distribution of forage production, N concentration or crude protein content, N uptake and Mo concentration were measured in an experiment established in September 1977 near Sutherlin, Oregon on a Veneta soil (Typic haploxeralf, fine, mixed, mesic) that had received limited annual fertilizer application. To study the seasonal distribution of forage production, a factorial combination of three rates of lime (0, 4.5, and 9.0 metric tons of lime per ha) and two rates of each P (0 and 57 kg/ha) and K (0 and 186 kg/ha) was arranged in a split-plot design with lime rates as main plots and fertilizer rates as subplots. All plots received adequate S, B, and Mo. An incomplete factorial of the same three rates of lime, three rates of P (0, 19 and 57 kg P/ha), and two rates of Mo (0 and 0.45 kg Mo/ha) were applied to study the seasonal distribution of Mo concentration. All plots received adequate K, S, and B. The second rate of lime was applied to determine if any adverse effects resulted from raising the pH above 6.0.

Application of P, K, and lime increased the yield from 5380 to 7100 kg/ha and increased N uptake from 67 to 119 kg/ha in the 1976-77

growing season. Lime x P and lime x K interactions were evident.

Application of P, K, and lime increased fall forage production during the 1977-78 growing season from 170 to 650 kg/ha and increased N uptake from 4.5 to 20.4 kg/ha. Fall forage production was significantly correlated ($r^2 = 0.76$) with N uptake in the forage for the 1976-77 growing season. Fertilization with P and K increased winter forage production from 1908 to 2750 kg/ha and N uptake was increased from 44 to 64 kg/ha. Forage production during the spring was increased from 2440 to 4300 kg/ha by application of P, K, and 9.0 metric tons of lime/ha. Liming increased N uptake from 43 to 55 kg/ha. Lime x P and Lime x K interactions were evident during the 1977-78 growing season.

Fertilizer and lime application increased the percentage of forage production and N uptake occurring in the fall from 2% to 9% and from 3% to 14%, respectively. Total forage production and N uptake in the 1977-78 growing season were increased 41% and 40%, respectively, by liming and fertilization with P and K.

A separate phase of this experiment was designed to determine the effects of lime, P, and Mo application on the Mo concentration in subclover leaflets and petioles as well as in the total forage. The Mo concentration was increased from 1.5 µg/g to over 25 µg/g by application of lime, P, and Mo in subclover samples collected 18 March and 12 April 1977. The Mo concentration decreased to less than 15 µg/g by 12 May 1977. Application of lime, P, and Mo increased the Mo concentration in the forage from approximately 1 µg/g to over 5 µg/g and decreased the Cu:Mo ratio to below 2 which is potentially toxic to livestock.

The highest Mo concentration was less than 10 µg/g in subclover samples collected the second growing season and the Mo concentration in the forage was less than 5 µg/g for all treatments except one. The

Mo concentration was below 2 $\mu g/g$ in all samples collected during the third growing season.

Seasonal Distribution of Forage Production, N Concentration, and Mo Concentration in Subterranean Clover

by

Steven Edwin Petrie

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

June 1980

APPROVED:

Redacted for privacy

Professor of Soil Science
in charge of major

Redacted for privacy

Head of Department of Soil Science

Redacted for privacy

Dean of Graduate School

Date thesis is presented January 24, 1980

Typed by Margi Wolski for Steven Edwin Petrie

ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation and thanks to the following people:

Dr. T. L. Jackson for advise and counsel throughout the research and writing of this thesis,

Drs. Hugh Gardner and Rod Frakes for their constructive criticism of the manuscript,

Wayne Mosher, Douglas Co. Extension Agent, for assistance and enthusiasm in the field,

Dean Hanson and Linda Serbus for assistance with chemical assistance,

Gary Kiemnec and Dianne Drlica for assistance in fieldwork, and,

Donna Batch, my wife, for invaluable support and patience throughout the entire process.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

List of Tables, continued

SEASONAL DISTRIBUTION OF FORAGE PRODUCTION N CONCENTRATION, AND Mo CONCENTRATION IN SUBTERRANEAN CLOVER

INTRODUCTION

This thesis will be presented in two sections. Part 1 is a manuscript discussing the effects of lime, P, and Mo application on the Mo concentration in both the subclover leaflets and petioles and in the total forage. Part 1 is being submitted to the Agronomy Journal for publication. Part 2 discusses the effects of lime, P, and K application on the seasonal distribution of forage production and N concentration in both subclover leaflets and petioles and in the total forage.

Subterranean clover (*Trifolium subterraneum* L.), commonly called subclover, is a winter annual legume well adapted to the cool, wet winters and hot, dry summers of western Oregon. The unique seed-burying ability of subclover (Murphy et al., 1973) make it an ideal forage crop for use in the steep hill pastures of western Oregon where frequent pasture renovation or lime application would be difficult and expensive. Aerial application of fertilizers is often practiced on the steepest hillsides. Seed from the previous crop germinates when the rain begins in the fall and the subclover grows slowly through the fall and winter. As the weather warms and light intensity increases in late winter and spring, subclover makes rapid growth and yields of over 7000 kg/ha are possible.

Responses to lime, P, K, S, B, and Mo are common in western Oregon (Jackson et al., 1964; Jackson, 1972) but most yield measurements have been made in one harvest taken in the spring. The seasonal distribution of forage production is important because forage availability is at a minimum in the fall and winter and this is a major factor limiting animal production. The seasonal distribution of forage production has been examined (Rickard and Radcliffe, 1976) but not under climatic conditions similar to western Oregon.

Molybdenum is essential for nitrogen fixation and nitrate reductase activity (Anderson and Spencer, 1949) and would be applied to all acid legume pastures and hay fields if the potential did not exist (James et al., 1968; Kubota et al., 1967) for Mo to interfere with copper utilization by livestock.

The objectives of this research were to evaluate the effects of lime, P, and Mo application on:

1. the Mo concentration and Cu/Mo ratio in both the subclover leaflets and petioles and the total forage and
2. the longevity of the Mo effect;

and to evaluate the effects of lime, P, and K application on:

3. the seasonal distribution of forage production and
4. the N concentration in the subclover and the total forage.

MANUSCRIPT FOR SUBMISSION TO AGRONOMY JOURNAL

Subterranean clover (subclover) is a winter annual legume commonly grown on non-irrigated hill pastures in western Oregon. The soils are acid (pH 4.5 to 5.5) and deficient in phosphorus (P), potassium (K), sulfur (S), molybdenum (Mo), and boron (B). Although subclover is tolerant of soil acidity (Pearson and Hoveland, 1974) liming is often necessary to achieve maximum nitrogen fixation and forage production. Lime and Mo both increase legume yields on acid western Oregon soils (James et al., 1968; Jackson et al., 1964) and in some cases Mo reduces or eliminates the lime requirement of some soils (James et al., 1968). Molybdenum is essential for nitrogen fixation and nitrate reductase activity (Anderson and Spencer, 1949) and would be applied to all acid legume pastures and hay fields if the potential did not exist (James et al., 1968; Kubota et al., 1967) for Mo to interfere with copper utilization by livestock.

The toxic effect of excess Mo in the diet of ruminants has been known for over 40 years (Ferguson et al., 1938; Ferguson et al., 1943). Molybdenosis, a Mo-induced copper (Cu) deficiency, is caused by Mo concentrations above 10 μg/g (Ferguson et al., 1943) or an imbalance of the Cu:Mo ratio in the diet. Miltmore and Mason (1971) state a safe minimum Cu:Mo ratio of 2.0 while Alloway (1973) suggests a critical value of 4.0. Sheep are less susceptible to molybdenosis than are cattle (Underwood, 1977) and this partly accounts for the discrepancy in the values. The excess Mo interferes with sulfide oxidase (Halvorson et al., 1960) causing sulfide levels in the animal to increase which decreases Cu availability to the animal (Wynne and McClymont, 1955). Untreated molybdenosis can lead to unthriftiness, bone disorders, scouring, and, in some cases, death (Underwood, 1977).

The range between nutritional deficiency for the crop and potential toxicity to ruminants is small; from 0.5 to 10 μg/g. Therefore, it is important to evaluate the effects of Mo application not only on pasture yields but also on the Mo concentration in forage which affects the ruminants consuming the forage.

The objectives of these experiments were to determine the effects of lime, P, and Mo application on (1) the Mo concentration and Cu:Mo ratio of the clover and of the total forage, (2) the Mo content of the clover during the growing season, and (3) the longevity of the Mo effect.

MATERIALS AND METHODS

The experiment was established in September 1976 on the Murphy farm near Sutherlin, Oregon on a Veneta soil (typic haploxeralf, fine, mixed, mesic) where subclover is known to respond to P. Prior to establishment applications of about 10 kg P/ha/yr had been made by the grower. The soil analysis values at establishment were: P, 10 μg/g; K, 36 μg/g; Cu, 1.9 meq/100 gm; and Mg, 0.59 meq/100 gm with the procedures used by the Oregon State University Soil Testing Laboratory (Berg and Gardner, 1978).

Before seeding the area was plowed and either 0, 4.50, or 9.0 metric tons of lime/ha was applied (L_0, L_1, L_2) and disced into the soil resulting in a pH of 5.3, 5.9, or 6.2, respectively, the following March. Phosphorus as concentrated super phosphate was broadcast at 0, 19, or 57 kg P/ha (P_0, P_1, P_2) and Mo was spray applied as $Na_2MoO_4 \cdot 4H_2O$ at 0 or 0.5 kg Mo/ha (Mo_0, Mo_1). All plots received 186 kg K/ha as KCl, 45 kg S/ha as gypsum, and 1 kg B/ha as borax. The P, K, and S were reapplied each fall. Individual plots were 2.3 m by 7.6 m replicated 4 times in a split-plot design with lime rates as main plots and fertilizer rates as subplots. _Trifolium subterraneum_ L. var. "Nangeela" and _Lolium perenne_ L. var. "Linn" were seeded at 22.5 and 11.2 kg/ha, respectively. The plots were fenced to exclude livestock during the growing season. After harvesting the area was grazed intensively to remove material not harvested.

During the first growing season subclover leaflet and petiole samples were collected from selected plots on 3-18, 4-12, and 5-12 and on 5-25-77 a 0.9 m by 6.7 m swath was harvested from all plots using a self-propelled plot harvester. Three harvests were taken during the second growing season to determine seasonal distribution of forage production. The plots were harvested on 11-19-77, 4-8-78, and 6-9-78. Subclover leaflet and petiole samples were taken from selected plots on 3-30 and 4-27-78. The plots were harvested on 4-3 and 6-11-79 during the third growing season and subclover leaflet and petiole samples were taken on 4-3-79.

The samples were dried at 70°C and ground to pass a 20 mesh sieve in a stainless steel Wily mill. One half gram samples were digested in HNO_3: $HClO_4$ and analyzed with a Perkin-Elmer model 260 atomic absorption spectrophotometer. Molybdenum was determined by flameless atomic absorption spectrophotometry using a Perkin-Elmer model 2100 graphite furnace and Cu determined by flame atomic absorption spectrophotometry.

RESULTS

The Mo concentration of subclover leaflets and petioles sampled on 18 March 1977 was increased from 1.5 to 14 μg/g when a lime variable was applied on treatments that had received Mo; P fertilization caused a further increase to 25 μg/g in the forage from these lime-Mo treatments (Fig. 1). These increases in Mo concentration were significant at the 1% probability level. The same pattern and range in concentration was observed in samples collected on 12 April 1977. However, by 12 March

1977 the Mo concentration had fallen to less than 15 μg/g. Application of lime still caused an increase in Mo concentration but with one exception application of P did not further increase the Mo concentration.

The plots were harvested on 26 May 1977 and samples of the forage mixture were analyzed (Table 1). Lime application increased the Mo concentration of the grass-clover mixture only when both P and Mo were applied. Application of lime and Mo reduced the Cu: Mo ratio to 2.3 or below.

During the second growing season the plots were sampled on 30 March 1978. The application of lime and Mo increased the Mo concentration from less than 0.5 μg/g to as much as 10.4 μg/g (Table 2) in the leaflets and petioles. The concentration of Mo was reduced from 25 to 30 μg/g in 1977 (Fig. 1) to 6 to 10 μg/g in 1978 (Table 2) at a comparable stage of growth. At L_1 and L_2 only treatment P_2Mo_0 was analyzed since these samples would show the largest "P effect" on increasing the Mo concentration. Conversely at L_2 treatment P_2Mo_1 was not analyzed since both P_0Mo_1 and P_1Mo_1 had high Mo concentrations.

The plots were harvested on 8 April 1978 and the regrowth material was sampled on 27 April 1978. The same general pattern of Mo concentration was observed in the samples taken 30 March (Table 2).

The plots were harvested on 9 June 1978 and the forage mixture analyzed (Table 3). Application of lime and Mo increased the Mo concentration from 1.1 to 5.5 μg/g. At L_1 and L_2, P application decreased the Mo concentration from 3.4 to 1.2 μg/g and from 5.5 to 3.5 μg/g, respectively. The Cu concentration was also decreased by application of P from 14.2 to 10.1 μg/g at L_1 and from 14.3 to 10.0 μg/g at L_2. The changes in Mo concentration and decreases in Cu concentration were significant at the 1% probability level. The Cu: Mo ratio was above 4 except at L_2 when Mo was applied it was below 3.0.

The plots were sampled and harvested on March 12, 1979 (Table 4).

The Mo concentration was below 2.0 μg/g in the clover leaflets and petioles for all treatments. There were no significant differences among treatments. When P was applied the Cu concentration was reduced from 15.9 to 11.2 μg/g at L_0 and from 15.1 to 9.9 μg/g at L_1. These reductions were significant at the 1% probability level.

Forage samples, grass plus clover, had less than 1.3 μg Mo/g (Table 4) with no significant differences between treatments. The Cu concentration was above 8.5 μg/g for all treatments with no significant differences between treatments.

The plots were harvested on 9 June 1979 (Table 5). The Mo concentration of the forage for this harvest was less than 2.0 μg/g for all treatments. The Cu concentration was reduced from 9.4 to 6.3 μg/g at L_0 when P was applied. The Cu:Mo ratio was above 9 in all cases except one.

DISCUSSION

The Mo concentrations of 25 to 30 μg/g found in subclover leaflet and petiole samples collected in March and April 1977 are well above the maximum safe concentration of 10 μg/g determined by Ferguson et al. (1943) and would probably cause molybdenosis in livestock. The increased Mo concentration when P was applied is in agreement with Stout et al. (1951) who found that P fertilization increased the Mo concentration in tomato leaves. By 12 May 1977 the maximum Mo concentration had decreased from 25 to 30 μg/g to a maximum of 14 μg/g. This reduction may be a dilution effect from the much greater growth during warmer weather. The Mo concentration was not affected by P fertilization at this sampling date.

During March and April the subclover was dominant and analysis of subclover leaflet and petiole samples closely approximated the diet of a grazing animal. By early summer the grass portion increased and the total forage (grass plus clover) was a better representation of the animal's diet. Grass has a lower Mo concentration and thus "dilutes" the Mo concentration in a total forage sample. Nonetheless, application of lime and Mo or lime, P, and Mo increased the Mo concentration and reduced the Cu: Mo ratio to 2.3 or less which is potential toxic to livestock (Miltmore and Mason, 1971; Alloway, 1973).

The potential for molybdenosis was greatly reduced the second year. The Mo concentration of samples taken in the spring of 1978 was 6 to 10 μg/g when lime, P, and Mo were applied. The same treatments sampled at a comparable growth stage the first year had a Mo concentration of 25 to 30 μg/g. Forage sampled on 9 June 1978 had approximately the same Mo concentration as forage sampled the first year at the same stage of growth. The Cu concentration was somewhat greater the second year and only when 4.5 metric tons of lime/ha was applied with Mo was the Cu: Mo ratio less than 3.0.

By the third year after establishment the potential for molybdenosis was virtually eliminated. None of the treatments sampled had more than 1.7 μg/g Mo and none of the forage had a Cu: Mo ratio less than 3.7.

The Cu concentration of forage samples collected on 9 June 1978 and 9 June 1979 and the subclover leaflet and petiole samples collected on 12 March 1979 was reduced when 51 kg P/ha was applied. Although Greenwood and Hallsworth (1960) have reported a Cu: P interaction this effect is more probably a dilution effect due to greater growth when P was applied. The combination of P increasing Mo concentration and decreasing Cu concentration can increase the potential for molybdenosis by decreasing the Cu: Mo ratio.

The Mo concentration was as low as 0.1 μg/g from treatments with Mo applied but no lime applied. This is below 0.5 μg/g critical level established by Reisenauer (1956) for alfalfa leaves. Subclover petioles have a lower Mo concentration (unpublished data, T. L. Jackson) than leaflets and a dilution of the Mo would occur. There was no yield or nitrogen fixation response from application of Mo, hence the critical level must be less than 0.1 μg/g.

CONCLUSION

The location of this experiment represents an environment with a very limited response from Mo and probably a greater potential for molybdenosis than would be found in many areas. The Mo concentration increased to toxic levels the first year, fell to marginally safe levels the second year, and further decreased to low levels the third year.

The rapid decrease in Mo uptake offers farmers a safety margin. Limited acreage would be renovated or planted in any one year, thus if high Mo forage was produced, it would represent a small portion of the diet. Growers could begin a monitering program on fields with a recent Mo application by having plant samples taken in March and April analyzed. Decisions could then be made concerning Mo fertilization for future years and forage utilization programs.

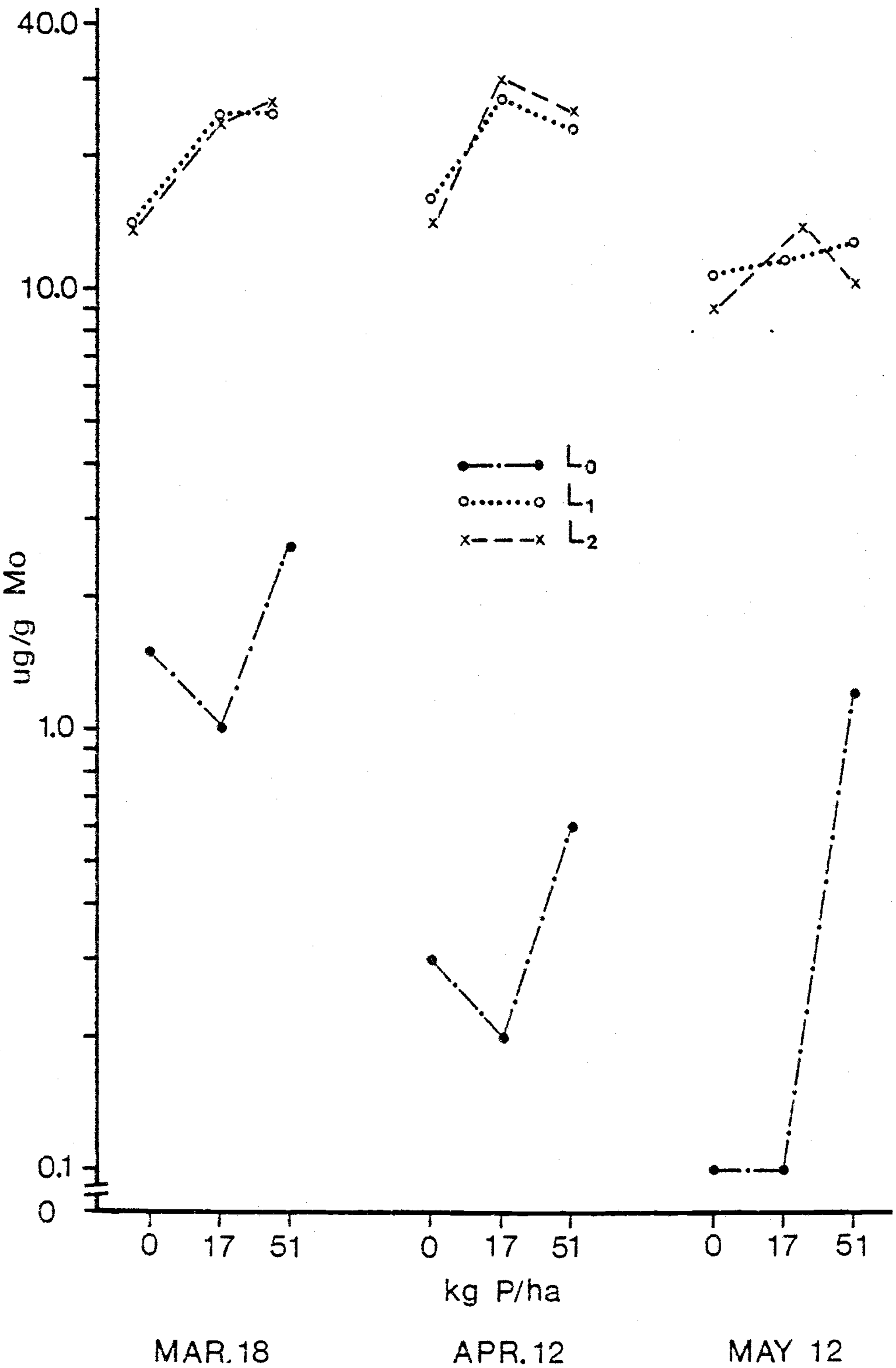

Fig. 1. The effects of lime and P on the Mo concentration in subclover leaflets and petioles.

Table 1. The effects of lime and fertilizers on the Mo and Cu concentration in forage harvested 26 May 1977.

Lime* Rates	Fertilizer Treatments		Mo and Cu Concentration		
	P	Mo	Mo	Cu	Cu/Mo
	- kg/ha -		---- μg/g ------		
0	0	0.5	1.5	9.5	6.3
0	57	0	0.5	7.7	15.4
0	57	0.5	2.7	10.9	4.0
1	0	0.5	3.5	7.3	2.1
1	57	0	1.3	6.8	5.2
1	57	0.5	7.1	11.8	1.6
2	0	0.5	3.1	7.3	2.3
2	57	0	2.1	7.3	3.5
2	57	0.5	5.2	8.1	1.6
		$LSD_{(0.01)}$	2.4	NS	5.7

* L_0, L_1, L_2 = 0, 4.5, 9.0 metric tons of lime/ha, respectively

Table 2. The effects of lime and fertilizers on the Mo concentration in subclover leaflets and petioles sampled 30 March and 27 April 1978

Fertilizer Treatments		Lime Treatments*					
		30 March			27 April		
P	Mo	L_0	L_1	L_2	L_0	L_1	L_2
-- kg/ha -		----------------		μg Mo/g	----------------		
0	0.5	0.1	6.5	9.7	0.3	6.4	7.3
19	0.5	0.4	8.2	10.4	0.3	8.2	7.9
57	0.5	0.4	6.2		0.2	9.3	
19	0	0.3			0.2		
57	0	0.1	0.4	1.0	0.3	0.5	0.5
	$LSD_{(0.05)}$	0.3	1.7	3.0	0.1	3.7	2.6

*L_0, L_1, L_2 = 0, 4.5, 9.0 metric tons of lime/ha, respectively

Table 3. The effects of lime and fertilizers on the Mo and Cu concentration in forage harvested 9 June 1978.

Lime* Rates	Fertilizer Treatments		Mo and Cu Concentration		
	P	Mo	Mo	Cu	Cu/Mo
	- kg/ha --		---- µg/g -----		
0	0	0.5	1.1	10.8	9.8
0	57	0	0.8	9.3	11.6
0	57	0.5	1.5	9.7	6.5
1	0	0.5	3.4	14.2	4.2
1	57	0	3.0	12.1	4.0
1	57	0.5	1.2	10.1	8.4
2	0	0.5	5.5	14.3	2.6
2	57	0	1.5	12.3	8.2
2	57	0.5	3.5	10.0	2.9
		$LSD_{(0.01)}$	2.1	3.4	2.8

* L_0, L_1, L_2 = 0, 4.5, 9.0 metric tons of lime/ha, respectively

Table 4. The effects of lime and fertilizers on the Mo and Cu concentration in subclover leaflets and petioles and forage on 12 March 1979.

Treatments			Mo and Cu Concentration					
			Subclover leaflets and petioles			Forage		
Lime*	P	Mo	Mo	Cu	Cu/Mo	Mo	Cu	Cu/Mo
-----kg/ha-----			------ μg/g --------			----- μg/g --------		
0	0	0.5	0.4	15.9	39.7	0.6	10.1	16.8
0	57	0	0.3	12.5	41.7	0.5	8.3	16.6
0	57	0.5	0.5	11.2	22.4	0.5	9.2	18.4
1	0	0.5	1.5	15.1	10.1	0.9	10.3	11.4
1	57	0	0.7	9.2	13.4	0.7	8.6	12.3
1	57	0.5	1.7	9.9	5.8	1.2	8.6	7.2
		$LSD_{(0.01)}$	NS	3.4	16.7	NS	NS	10.5

* L_0, L_1 = 0, 4.5 metric tons of lime/ha, respectively

Table 5. The effects of lime and fertilizers on the Mo and Cu concentration in forage harvested 9 June 1979.

Lime* Rates	Fertilizer Treatments		Mo and Cu Concentration		
	P	Mo	Mo	Cu	Cu/Mo
	- kg/ha -		---- μg/g ------		
0	0	0.5	0.6	9.4	15.7
0	57	0	0.4	7.1	17.7
0	57	0.5	0.6	6.3	10.5
1	0	0.5	1.0	7.7	7.7
1	57	0	0.8	7.4	9.3
1	57	0.5	1.6	5.9	3.7
		$LSD_{(0.05)}$	0.8	2.4	8.4

*L_0, L_1 = 0, 4.5 metric tons of lime/ha, respectively

BIBLIOGRAPHY

Alloway, B. J. 1973. Copper and molybdenum in swayback pastures. J. Agric. Soc. 80:521-524.

Anderson, A. J., and D. Spencer. 1949. Molybdenum and sulfur in symbiotic nitrogen fixation. Nature. 164:273-274.

Berg, M. G., and E. H. Gardner. 1978. Methods of soil analysis used in the soil testing laboratory at Oregon State University. Oreg. Agric. Exp. Stn. Spec. Rep. 321.

Ferguson, W. S., A. H. Lewis, and S. J. Watson. 1938. Action of molybdenum in nutrition of milking cattle. Nature. 141:553.

Ferguson, W. S., A. H. Lewis, and S. J. Watson. 1943. The teart pastures of Somerset. 1. The cause and cure of teartness. J. Agric. Sci. 33:44-51.

Greenwood, E. A. N., and E. G. Hallsworth. 1960. Studies on the nutrition of forage legumes. II. Some interactions of calcium, phosphorus, copper, and molybdenum on the growth and chemical composition of _Trifolium subterraneum_ L. Plant Soil. 12:97-127.

Halverson, A. W., J. H. Phifer, and K. J. Monty. 1960. A mechanism for the copper-molybdenum interrelationship. J. Nutr. 71:95-100.

Jackson, T. L., H. H. Rampton, and J. McDermid. 1964. The effects of lime and phosphorus on the yield and phosphorus content of legumes in western Oregon. Oreg. Agric. Exp. Stn. Tech. Bul. 83.

James, D. E., T. L. Jackson, and M. E. Harward. 1968. Effects of molybdenum and lime treatments on the growth and molybdenum content of alfalfa grown on acid soils. Soil Sci. 105:397-402.

Kubota, Joe, Victor A. Lazar, G. H. Simonson, and W. W. Hill. 1967. The relationship of soils to molybdenum toxicity in grazing animals in Oregon. Soil Sci. Soc. Am. Proc. 31:667-671.

Miltmore, J. E., and J. L. Mason. 1971. Copper to molybdenum ratios and molybdenum and copper concentrations on ruminant feeds. Can. J. Ani. Sci. 51:193-200.

Murphy, A. H., M. B. Jones, J. W. Clawson, and J. E. Street. 1973. Management of clovers on California annual grasslands. Calif. Agric. Exp. Stn. Circ. 564.

Pearson, R. W., and C. S. Hoveland. 1974. Lime needs of forage crops. In D. A. Mays (ed). Forage fertilization. Am. Soc. of Agron., Madison, Wisc.

Reisenauer, H. M. 1956. Molybdenum content of alfalfa in relation to deficiency symptoms and response to molybdenum fertilization. Soil Sci. 81:237-242.

Stout, P. R., W. R. Meagher, G. A. Pearson, and C. M. Johnson. 1951. Molybdenum nutrition of crop plants. I. The influence of phosphate and sulfate on the absorption of molybdenum from soils and solution culture. Plant Soil. 3:51-87.

Underwood, E. J. 1977. Trace elements in human and animal nutrition. Academic Press. New York.

Wynne, K. N., and G. L. McClymont. 1955. Copper-molybdenum-sulfur interaction in induction of hypocuprosis. Nature. 175:471-472.

INTRODUCTION

This section discusses the effects of lime, P, and K on the seasonal distribution of forage production and N concentration. The objectives for this research, as stated on page 2, were to evaluate the effects of lime, P, and K application on the seasonal distribution of forage production and the N concentration in the subclover and the total forage.

LITERATURE REVIEW

Phosphorus

Phosphorus is essential for energy exchange within the plant as well as many other biochemical reactions; it exists in the plant in a variety of compounds (Tisdale and Nelson, 1965; Mengel and Kirkby, 1978). The "red hill" soils of western Oregon are commonly deficient in P and yield responses to P fertilization are common (Jackson et al., 1964; Drlica and Jackson, 1979). Phosphorus fertilization of subclover results in increased P concentration in the plants (Jackson et al., 1964; Jones et al., 1970; Jones and Ruckman, 1973; Drlica and Jackson, 1979), increased levels of soil N (Watson, 1969), and increased nodulation (Osman et al., 1977).

Ozanne et al. (1976a) found that dry matter intake and body weight gains by sheep were increased by feeding dry subclover forage with increased P concentration due to P fertilization. A comparable rate of gain was not achieved when forage with lower P was supplemented with inorganic P. They found that maximum dry matter intake and body weight gains occurred at P fertilization levels about three times that required for maximum forage production and P concentration in the forage was also greater than required for optimum yield.

Phosphorus also affects the botanical composition of pastures. Greenhouse studies have shown that young grass roots are more efficient at taking up P than are clover roots (Barrow, 1975; Keay et al., 1971). Also, subclover has a higher P critical level than ryegrass at either 29 or 92 days after germination (Ozanne et al., 1969). Biddiscombe et al. (1969) grew subclover and ryegrass in a greenhouse and studied the effect of P on both yield and relative growth rate (RGR = $\frac{dW}{WdT}$; W = weight, T = time). At low P rates ryegrass had a higher yield than subclover but at high P rates the yields were almost equal. On day 29, the ryegrass had an RGR of 14.2 as opposed to an RGR of 5.3 for the sublcover when grown at a low P level. However, at high rates of P the ryegrass had an RGR of 14.3 and the subclover had an RGE of 10.4. Thus, the young subclover plants were much more responsive to added P than were young ryegrass plants. At low P rates the sub-clover had a smaller percentage of total P in the tops than did the ryegrass.

The results of field studies, where N is a limiting nutrient, have not always been consistent with greenhouse studies. Ryegrass is not able to compete with subclover for low concentrations of available P when growing in N-deficient soil. However, at high P levels more N fixation occurs (Ozanne et al., 1976b) and because subclover readily transfers N to associated grasses (Simpson, 1976) this would result in better ryegrass growth and more efficient competition for P.

Low or medium levels of P tend to favor clover dominance of pastures where N is not applied while high P levels tend to favor grass dominance of pastures (Willoughby, 1953; Morley, 1961; Watson, 1969). Phosphorus fertilization or high levels of soil P increases N fixation by subclover (Drlica and Jackson, 1979). The resulting increase in soil N (Watson, 1969) encourages rapid early growth of grasses in the fall and winter (Baylor, 1974) and can lead to grass dominance of the pasture. A subclover and ryegrass pasture responded to higher levels of P fertilization than ryegrass grown alone (Ozanne et al., 1976).

Potassium

Potassium is required for many physiological functions in plants including carbohydrate metabolism, nitrogen metabolism, and the formation, transport, and breakdown of starches. Adequate K fertilization helps ensure maximum clover growth and vigor, and therefore maximum N fixation (Tisdale and Nelson, 1965). Fertilization of K deficient soils increases subclover and overall pasture yields (Paton, 1956; McNaught, 1958) and is essential to maintain clover in a grass-clover forage system (Meissner and Clarke, 1977). Meissner and Clarke (1977) also found that clover was more responsive to K fertilization than was grass.

Lime

Soil acidity causes reduced plant growth mainly because of increased concentrations of Al and Mn and reduced availability of P and Mo (Jackson, 1967). Subclover is able to tolerate soil acidity, at least in part, because it is not as sensitive to Mn toxicity as some other legumes (Munns, 1965). However, yield responses of subclover to liming have been reported. Jackson et al. (1974) found that 6.7 metric tons of lime per ha increased the yield and P uptake of subclover as much as 30 or 60 kg of P/ha with no additional effect from 13.4 metric tons of lime per ha. Philpotts (1976) found that two metric tons of lime per ha increased the yield of subclover 27% but had no effect on the nodulation percentage which was above 85% in all cases. Munns and Fox (1977) found that lime doubled the yield of subclover but that it was among the least responsive of 18 legume species studied. Munns et al. (1977) attributed the yield response to increased nodule number and improved nodule effectiveness.

MATERIALS AND METHODS

The procedures followed in carrying out this experiment are the same as those described on page 4, Part I with the exception that all plots received Mo and only P_0 and P_2 will be discussed. Potassium was broadcast at 0 or 186 kg K/ha as KCl (K_0 and K_2, respectively).

Total N was determined by a Kjeldahl procedure (Jackson, 1958) and nitrogen uptake was used as an index of the N fixation that occurred.

Analysis of variance were completed on the dry matter yields, N concentration, and N uptake but not on the relative yield and N uptake comparisons.

RESULTS

1976-1977 Growing Season

To ensure good establishment the experiment was harvested only once the first growing season, on 26 May 1977, with the yield data given in Table 1. In this and following tables the "within lime rates" LSD is valid for comparisons within any one lime rate. The "between lime rates" LSD is valid for comparisons between lime rates both at the same fertilizer rate and across fertilizer rates.

Table 1. The effects of lime and fertilizers on the yield of forage harvested 26 May 1977.

Fertilizer Treatments			Lime Rates*		
P	K		L_0	L_1	L_2
- kg/ha -				kg/ha	
0	0		5380	5910	5380
0	186		5110	6380	6340
57	0		5820	6470	5910
57	186		6320	6520	7100
		avg	5660	6320	6210

* L_0, L_1, L_2 = 0, 4.5, 9.0 metric tons of lime/ha, respectively
$LSD_{(.05)}$ within lime rates = 1010
$LSD_{(.05)}$ between lime rates = 1100

The yields from lime rates, averaged across fertilizer treatments, were 5660, 6320, and 6210 kg/ha at L_0, L_1, and L_2, respectively; these yield differences were not significant. Also, yield differences were not significant when P was applied without K. The application of P or lime with an application of K produced similar and significant yield increases. Lime treatments $P_0K_2L_1$ and $P_0K_2L_2$ produced 6380 and 6340 kg/ha, respectively, compared to 5110 kg/ha for the $P_0K_2L_0$ treatment. Application of P and K at L_0 resulted in a yield of 6320 kg/ha. This data indicates a typical lime x P interaction with lime increasing the availability or uptake of P.

Application of both P and K (P_2K_2 vs. P_0K_0) resulted in a yield increase of 1720 kg/ha at L_2. Application of K alone (P_0K_2 vs. P_0K_0) increased the yield 960 kg/ha at L_2; this increase was significant at the 10% probability level. No significant fertilizer interactions were evident.

The N concentration in the forage was not affected by lime application nor was there a significant lime x fertilizer interaction. The N concentration in the forage, averaged across lime rates, was 1.29%, 1.50%, 1.43%, and 1.71% for the P_0K_0, P_0K_2, P_2K_0, and P_2K_2, treatments, respectively. Application of P or K alone did not significantly affect N concentration but the increase due to application of both P and K was significant at the 5% probability level.

The combination of P and K increased the N uptake by 52 kg/ha; the N uptake was 67 and 119 kg/ha at P_0K_0 and P_2K_2, respectively. The P_0K_2 and P_2K_0 treatments each had 87 kg N uptake/ha. Both increases were significant at the 1% probability level.

The relative yield and N uptake are shown in Table 2. Fertilizer and lime application had more impact on N uptake than on total yield. The P_0K_0 treatment, averaged across lime treatments, had 78% of the maximum yield but only 51% of the maximum N uptake. Application of P alone (P_2K_0 vs. P_0K_0) increased relative yield 6% and increased relative N uptake 15%. Application of K alone (P_0K_2 vs. P_0K_0)

increased relative yield 8% and relative N uptake 15%. The combined effect of P and K (P_2K_2 vs. P_0K_0) was to increase yield 16% while increasing N uptake 39%.

Table 2. The effects of lime and fertilizers on the relative yield and N uptake of forage harvested 26 May 1977.

Fertilizer Treatments		Lime Rates*		
P	K	L_0	L_1	L_2
- kg/ha -		--------- % of Maximum ------------		
0	0	76[1] (53)[2]	83 (47)	76 (52)
0	186	72 (72)	90 (61)	89 (65)
57	0	82 (64)	91 (66)	85 (67)
57	186	89 (86)	92 (100)	100 (85)

*L_0, L_1, L_2 = 0, 4.5, 9.0 metric tons of lime/ha, respectively

[1] Relative yield

[2] Relative N uptake

In these relative yield comparisons the response from P without lime or lime without P was significant ($P < 0.05$) when K was added but not without K. The response from K was not significant ($P < 0.05$).

1977-1978 Growing Season

The plots were harvested on 19 November, 8 April, and 9 June for this growing season. It is difficult to measure the absolute forage production for the fall growth; a large proportion of the forage is less than 3 to 5 cm tall, the cutting height of our harvester. Visual inspection revealed that the density of the unharvested material was proportional to the harvested material. Therefore, the total yield data should be proportional to the forage available to a grazing animal.

Yield data and N uptake that occurred in the fall are shown in Table 3. The yield of forage, averaged across fertilizer rates, was 310 kg/ha at L_0 and 460 kg/ha at L_1 and L_2. This increase was significant at the 1% probability level.

Table 3. The effects of lime and fertilizers on the yield and N uptake of forage harvested 19 November 1977.

Fertilizer Treatments			Lime Rates*		
P	K		L_0	L_1	L_2
- kg/ha -			kg/ha		
0	0		170[1] (4.5)[2]	320 (9.6)	340 (9.1)
0	186		170 (4.6)	490 (14.1)	440 (13.3)
57	0		340 (11.3)	400 (10.8)	420 (11.8)
57	186		580 (18.7)	640 (20.4)	650 (16.9)
		avg	310 (10.0)	460 (14.0)	460 (13.0)

* L_0, L_1, L_2 = 0, 4.5, 9.0 metric tons of lime/ha, respectively

[1]Yield ; [2]N uptake

$LSD_{(.01)}$ within lime rates; yield = 160, N uptake = 5.7

$LSD_{(.01)}$ between lime rates; yield = 170, N uptake = 5.7

Application of P alone (P_0K_0 vs. P_2K_0) increased the yield by 170 kg/ha at L_0 while application of P with K present (P_2K_2 vs. P_0K_2)

increased the yield by 410, 150, and 210 kg/ha at L_0, L_1, and L_2, respectively. A 150 kg/ha yield increase resulted from liming the P_0K_0 treatment and a 170 kg/ha yield increase resulted from P application at L_0. This indicates a lime and P interaction similar to that observed for yield data from the 1976-77 growing season.

Application of K alone (P_0K_0 vs. P_0K_2) resulted in a 170 kg/ha yield increase at L_1 while application of K with P present (P_2K_0 vs. P_2K_2) resulted in a 240 kg/ha yield increase at L_0 and 230 kg/ha yield increase at L_1. At L_0 a P x K interaction was evident. Application of K alone did not affect yield and application of P alone increased yield 170 kg/ha; however, application of both P and K resulted in 410 kg/ha yield increase.

The application of fertilizers did not significantly affect the N concentration in the forage; therefore, the data was averaged across fertilizer treatments. The average N concentration in the forage was 2.97% at L_0, 3.00% at L_1, and 2.70% at L_2; the reduction in N concentration at L_2 was significant at the 1% probability level.

The N uptake for each lime rate, averaged across fertilizer treatments, was 10 kg/ha at L_0, 14 kg/ha at L_1, and 13 kg/ha at L_2 (Table 3). The increase at L_1 and L_2 was significant at the 1% probability level. Application of P without K (P_0K_0 vs. P_2K_0) increased the N uptake from 4.5 to 11.3 kg/ha at L_0. Application of P with K present (P_0K_2 vs. P_2K_2) increased the N uptake 14.1 kg/ha at L_0 and 6.3 kg/ha at L_1. The $P_0K_0L_0$, $P_0K_0L_1$, $P_2K_0L_0$, and $P_2K_0L_1$ treatments had an N uptake of 4.5, 9.6, 11.3, and 10.8 kg/ha, respectively, indicating a negative lime x P interaction (Table 3).

Application of K with P present (P_2K_0 vs. P_2K_2) increased N uptake 7.4 kg/ha at L_0 and 9.6 kg/ha at L_1. At L_0 and L_1 there was a positive P x K interaction. At L_0 the application of K alone increased the N uptake only 0.1 kg/ha and P alone increased the N uptake 6.8

kg/ha but P and K together increased N uptake 14.2 kg/ha. At L_2, K alone increased N uptake 4.5 kg/ha, P alone increased N uptake 1.2 kg/ha but P and K together increased N uptake 10.8 kg/ha.

The plots were sampled on 30 March 1978 to determine N concentration in the subclover leaflets and petioles. The N concentration was not affected by lime application; therefore, the data was averaged across lime rates. The N concentration in the P_0K_0, P_0K_2, P_2K_0, and P_2K_2 treatments was 4.57%, 4.55%, 5.02%, and 4.84%, respectively. The increase in N concentration resulting from P application was significant at the 5% probability level.

The experiment was harvested on 8 April 1978 to determine how much forage production and N uptake occurred in the winter. Liming did not significantly affect the yield; therefore, the data was averaged across lime rates. Yields from the P_0K_0, P_0K_2, P_2K_0, and P_2K_2 treatments were 1980, 2030, 2240, and 2750 kg/ha, respectively. Application of P or K alone did not significantly affect yield but the combination ot P and K resulted in a yield increase that was significant at the 1% probability level.

Fertilizer application did not significantly affect the N concentration in the forage harvested on 8 April; therefore, the data was averaged across fertilizer rates. The N concentration was 2.57% at L_0, 2.71% at L_1, and 2.44% at L_2. These differences were significant at the 1% probability level. Visual observation revealed that grass growth made up a large proportion of the forage production on the limed plots than on the unlimed plots.

The N uptake that occurred in the winter is shown in Table 4. The N uptake for the L_0, L_1, and L_2 treatments, averaged across fertilizer rates was 53, 56, and 45 kg/ha, respectively. The decreased N uptake at L_2 was significant at the 5% probability level. As the forage yield was not significantly affected by liming the reduced N uptake was due to the reduced N concentration in the forage. The application of P alone increased N uptake 17 kg/ha at L_0; the lime x P interaction was not significant.

Table 4. The effects of lime and fertilizers on the N uptake of forage harvested 8 April 1978.

Fertilizer Treatments			Lime Rates*		
P	K		L_0	L_1	L_2
- kg/ha -			---------- kg/ha ------------		
0	0		44	48	44
0	186		43	51	41
57	0		61	57	37
57	186		64	67	59
		avg	53	56	45

* L_0, L_1, L_2 = 0, 4.5, 9.0 metric tons of lime/ha, respectively

$LSD_{(.05)}$ within lime rates = 10.0

$LSD_{(.05)}$ between lime rates = 10.0

A lime x K interaction was evident in this data. The application of lime decreased N uptake on the P_2K_0 treatment from 61 kg/ha at L_0 to 37 kg/ha at L_2. Application of K with P (P_2K_0 vs. P_2K_2) increased the N uptake from 57 to 67 kg/ha at L_1 and from 37 to 59 kg/ha at L_2. Thus, K application overcame the depressive effects of 9.0 metric tons of lime/ha and restored the N uptake to levels that occurred at L_0.

Lime did not significantly affect the N concentration in subclover leaflets and petioles collected 27 April 1978; therefore the N concentration was averaged across lime rates. The N concentration of the P_0K_0, P_0K_2, P_2K_0, and P_2K_2 treatments was 4.15%, 4.12%, 4.75%, and 4.73%, respectively. The increased N concentration in treatments receiving P was significant at the 1% probability level.

The experiment was again harvested on 9 June 1978 to determine spring forage production (Table 5) and N uptake. The forage yield for the L_0, L_1, and L_2 treatments, averaged across fertilizer rates, was 2640, 3080, and 3310 kg/ha, respectively. Each of these yield increases was significant at the 1% probability level indicating a yield response to lime.

Table 5. The effects of lime and fertilizers on the yield of forage harvested 9 June 1978.

Fertilizer Treatments			Lime Rates*		
P	K		L_0	L_1	L_2
- kg/ha -			kg/ha		
0	0		2440	2980	2840
0	186		2250	3090	2940
57	0		2270	3120	3150
57	186		3590	3110	4300
		avg	2640	3080	3310

* L_1, L_2 = 4.5, 9.0 metric tons of lime/ha, respectively

$LSD_{(.05)}$ within lime rates = 740

$LSD_{(.05)}$ between lime rates = 660

Yield effects from the application of P, K, or from the lime x P or lime x K interactions were not significant. However, there was a significant P x K interaction at L_0 and L_2. At L_0, P application decreased yield 170 kg/ha and K application decreased yield 190 kg/ha; neither reduction was significant. However, application of P and K together increased yield 1150 kg/ha which was significant at the 1% level. At L_2, P application increased yield 310 kg/ha and K application increased 100 kg/ha while together they increased yield 1460 kg/ha.

The application of lime did not significantly affect the N concentration in the forage; therefore, the data was averaged across lime rates. The N concentration in the P_0K_0, P_0K_2, P_2K_0, and P_2K_2 treatments was 1.77%, 1.63%, 1.84%, and 1.62%, respectively. The decreased N concentration when K was applied was significant at the 5% probability level.

The fertilizer treatments did not significantly affect the N uptake; therefore, the data was averaged across fertilizer treatments. The N uptake was 43, 55, and 53 kg/ha at L_0, L_1, and L_2, respectively. The increased N uptake at L_1 and L_2 was significant at the 5% probability level.

Total forage production and N uptake during the 1977-78 growing season are shown in Table 6. The yield for the L_0, L_1, and L_2 treatments, averaged across the fertilizer treatments, was 5310, 5850, and 5860 kg/ha, respectively. The increase at L_1 and L_2 was significant at the 1% probability level.

The application of P or K alone did not significantly affect the forage yield at any lime rate nor was there a significant lime x P or lime x K interaction. However, application of P and K together increased yield 2150 kg/ha at L_0 and 2490 kg/ha at L_2.

The N uptake of L_0, L_1, and L_2, averaged across fertilizer rates, was 110, 130, and 120 kg/ha, respectively. The increase from

110 to 130 kg/ha was significant at the 5% probability level.

Table 6. The effects of lime and fertilizers on the total forage production and N uptake during the 1977-78 growing season.

Fertilizer Treatments P	K		Lime Rates* L_0	L_1	L_2
- kg/ha -			kg/ha		
0	0		4550[1] (95)[2]	5360 (120)	5130 (110)
0	186		4460 (90)	5670 (125)	5350 (105)
57	0		5170 (125)	5920 (135)	5330 (110)
57	186		7060 (140)	6440 (150)	7620 (145)
		avg	5310 (110)	5850 (130)	5860 (120)

* L_1, L_2 = 4.5, 9.0 metric tons of lime/ha, respectively

[1] Yield; [2] N uptake

$LSD_{(.01)}$ within lime rates; yield = 1150, N uptake = 19

$LSD_{(.01)}$ between lime rates; yield = 1020, N uptake = 18

The application of P without K (P_0K_0 vs. P_2K_0) increased N uptake 30 kg/ha at L_0. Application of P with K (P_0K_2 vs. P_2K_2) resulted in a 35 kg/ha increase at L_2. A lime x P interaction was evident; P application alone increased N uptake 30 kg/ha at L_0 and lime increased N uptake of the P_0K_0 treatment 25 kg/ha.

Application of K with P (P_2K_0 vs. P_2K_2) caused a 35 kg/ha increase at L_2. A P x K interaction was evident at L_0 and L_2. At L_0, P alone increased N uptake 30 kg/ha and K alone decreased N uptake

5 kg/ha but together they increased N uptake 45 kg/ha. At L_2, P did not affect N uptake and K decreased N uptake 5 kg/ha but together they increased it 35 kg/ha. The increase due to P and K application at L_0 and L_2 was significant at the 1% probability level.

DISCUSSION

The relationships between P fertilization, P critical level, and N concentration in subclover leaves and petioles for 1977 data from this experiment and a companion experiment in Douglas county were reported by Drlica and Jackson (1979). They found that when a P or S response was evident, those treatments had a marked effect on N fixation as measured by N concentration found in subclover leaflets and petioles.

A negative lime x P interaction was evident from 1976-77 yield data, yield and N uptake during the fall of 1977-78, and the total yield and total N uptake during the 1977-78 growing season. All treatments in the lime x P x K factorial received Mo; therefore, the lime or P response was probably not due to increased availability of Mo. There were additional treatments which showed that Mo application did not increase yield or N uptake at this location. The lime and P responses were probably not due to decreased Mn toxicity because the highest Mn concentration was less than 300 μg/g in the subclover leaflets and petioles. Therefore, the negative lime x P interaction was most probably due to lime increasing the availability of P.

At this location P limited forage production more than K as shown by the lack of response to K unless P or lime was applied. This effect was evident in yield data from the 1976-77 growing season, yield and N uptake during fall, yield and N uptake during winter, yield during spring, and total yield and total N uptake during the 1977-78 growing season.

The application of 9.0 metric tons of lime/ha accentuated or caused a K deficiency at certain times during the course of the experiment. This was probably due to K-Ca competition at the exchange sites in the soil as well as in the soil solution flowing to the root free space but not for uptake sites to cross the semi-permeable root membrane

(Mengal, 1974; Hiatt and Leggett, 1974). Since clover is more responsive to K fertilization than grass (Meissner and Clarke, 1977) the K deficiency would be expected to alter the species composition of the pasture. Application of lime without K did not significantly ($P < 0.05$) affect seasonal or total forage production but did reduce winter and total N uptake during the 1977-78 growing season. The reduced N uptake was probably due to relatively more grass and less clover on the heavily limed plots. Helyar and Anderson (1970) found that ryegrass was only marginally responsive to lime but markedly responsive to P; in their work lime did not increase the availability of P. Application of lime at this location did increase the availability of P. However, high rates of P fertilization of a legume are known to increase available N (Watson, 1969) and can increase the percentage of grass in pastures (Willoughby, 1953; Morley, 1961; Watson, 1969). Since grass has a lower N concentration than clover the increased proportion of grass would lower the N concentration of the forage; therefore, the same dry matter yield would result in less N uptake.

The K deficiency was not evident during the fall presumably because the young plants had not exhausted the available K. By spring the roots may have grown out of the zone of high Ca saturation reducing or eliminating the K deficiency.

There are few reports in the literature dealing specifically with seasonal distribution of forage production or N uptake in a pasture management system similar to this; only a limited number of references will be cited. Radcliffe and others (Radcliffe, 1975; Radcliffe and Rickard, 1974) have determined the seasonal distribution of forage production in New Zealand but the climatic patterns and species composition of pastures were different than for this experiment. Fertilizer rates were not included in their work and most locations were white clover (*Trifolium repens* L.) and perrenial ryegrass pastures.

Application of fertilizer and lime had a marked effect on the distribution of forage production throughout the growing season. Table 7 shows the relative yield during the fall, winter, spring, and the entire growing season. The application of lime increased the relative yield of the P_0K_0 treatment from 26% of the maximum yield occurring during fall (treatment $P_2K_2L_2$) at L_0 to 50% at L_1 and 52% at L_2. The $P_0K_2L_0$ treatment produced only 26% of the maximum fall yield but this was increased to 76% when 4.5 metric tons of lime/ha was applied. Application of P plus K together without lime increased yield to 90% of the maximum.

The percentage of the total forage production for a particular treatment occurring in the fall was also increased by lime and fertilizer application. Only 4% of the yield from the $P_0K_0L_0$ treatment occurred in the fall while 8% of the yield from the $P_2K_2L_0$ treatment occurred in the fall. Liming increased the percentage of forage production occurring during the fall for the P_0K_0 treatment from 4% at L_0 to 6% and 7% at L_1 and L_2, respectively. The application of K alone at L_0 did not increase the percentage of total forage production occurring in the fall. From this data it is clear that lime and fertilizer application not only quadrupled the absolute fall forage production, it also more than doubled the percentage of total forage production occurring in the fall. As Meissner and Clarke (1977) have pointed out, this has important implications for pasture management since fall and winter forage availability is more important than spring forage availability.

Visual observation revealed that fall forage production was mostly grass. It has been shown (Barrow, 1975; Keay et al., 1971) that young grass roots take up P more efficiently than clover roots; thus P fertilization or increased P availability due to liming would tend to favor grass more than clover. Biddiscombe et al. (1969) found that subclover had a lower RGR than ryegrass at both low and high P fertilization at 29 days

Table 7. The effect of lime and fertilizers on the relative forage production during the 1977-78 growing season.

Fertilizer Treatments		Lime Rates*					
P	K	L_0		L_1		L_2	
- kg/ha -		Relative Yield					
		Fall					
0	0	26[1]	(4)[2]	50	(6)	52	(7)
0	186	26	(4)	76	(9)	67	(8)
57	0	52	(6)	62	(8)	66	(8)
57	186	90	(8)	98	(10)	100	(9)
		Winter					
0	0	68[1]	(43)[2]	72	(38)	67	(38)
0	186	71	(46)	72	(37)	68	(37)
57	0	89	(50)	83	(40)	61	(33)
57	186	100	(41)	94	(42)	93	(35)
		Spring					
0	0	57[1]	(53)[2]	69	(56)	66	(55)
0	186	52	(50)	72	(54)	68	(55)
57	0	53	(44)	73	(52)	73	(59)
57	186	84	(51)	72	(48)	100	(56)
		Total					
0	0		(60)[1]		(70)		(67)
0	186		(58)		(74)		(70)
57	0		(68)		(78)		(70)
57	186		(93)		(85)		(100)

* L_0, L_1, L_2 = 0, 4.5, 9.0 metric tons of lime/ha, respectively

[1] Forage yield as a percentage of the maximum yield for that harvest.

[2] Forage yield as a percentage of the total for that treatment for the growing season.

after germination. However, application of P did reduce the difference between the RGR of subclover and ryegrass.

The relative yield during winter was less affected by lime and fertilizer application than the relative yield during the fall. The relative yield for the P_0K_0 treatment at L_0, L_1, and L_2 was 26%, 50%, and 52%, respectively, in the fall compared to 68%, 72%, and 67%, respectively, in the winter. The relative yield of the $P_0K_2L_0$ treatment was 26% in the fall and 71% in the winter. Meissner and Clarke (1977) also found that the yield responses to K were less frequent and smaller in the winter. With the exception of the P_2K_0 treatment the percentage of total production occurring in the winter ranged from 35% to 46%.

Kohn (1974) reported the forage availability throughout the growing season, as determined by a visual scoring system, in P x stocking rate experiment. He found, in contrast to these results, that fall and winter forage availability was either unaffected or reduced by P application but that total forage availability was increased. Biddiscombe et al. (1969) found the RGR of subclover, at either low or high P rates, to be greater than ryegrass at 78 days after germination; this is the reverse of the situation at 29 days after germination. Thus, the K deficiency, by causing relatively more grass production, would result in relatively less forage production during the winter.

The relative spring forage production was less affected by lime and fertilizer application than relative fall forage production. The relative spring forage production for the P_0K_0 treatment was 57%, 69%, and 66% at L_0, L_1, and L_2, respectively compared to 26%, 50%, and 52%, respectively for the relative fall forage production. The relative fall forage production for the $P_0K_2L_0$ treatment was 26% compared to 52% relative spring forage production. The percentage of forage production occurring during the spring was relatively constant, ranging from 48%

to 56%, with the exception of the P_2K_0 treatment. During the spring the application of lime increased the relative forage production as well as the percentage of total forage production occurring the spring for the P_2K_0 treatment. The relative forage production increased from 53% at L_0 to 73% at both L_1 and L_2.

Carter and Day (1970) reported that the percentage of subclover (by weight) in a pasture markedly increased between spring and summer. This, combined with the decreased K deficiency as the roots probably grew out of the zone of high Ca saturation would increase relative spring forage production. The increased spring forage production nearly offset the reduction in the relative amount of production that occurred in the winter; the relative total yield for the year was not significantly different for lime rates with 68%, 78%, and 70% for L_0, L_1 and L_2, respectively. A comparison of the relative fall production with the relative total production shows the importance of several harvests during the growing season to determine the effects of lime and fertilizers on forage production. The P_0K_0 treatment had relative total yield values of 60% at L_0, 70% at L_1, and 67% at L_2. However, the relative fall production was only 26% at L_0, 50% at L_1, and 52% at L_2. Thus the fall forage availability, which is one of the major factors limiting animal production on subclover pastures, was more reduced by lack of lime and fertilizer than was total yield for the growing season.

The effects of lime and fertilizer application on the relative N uptake during the growing season are shown in Table 8. The relative N uptake that occurred in fall for the P_0K_0 treatment was increased from 22% at L_0 to 47% at L_1 and 45% at L_2. The relative N uptake of the P_0K_2 treatment was 23% of the maximum N uptake, which was similar to the P_0K_0 treatment, but was increased to 76% by the application on 4.5 metric tons of lime/ha. Application of P and K without lime increased the relative N uptake from 22% to 92% of the maximum.

Table 8. The effects of lime and fertilizers on the relative N uptake during the 1977-78 growing season.

Fertilizer Treatments		Lime Rates*					
P	K	L_0		L_1		L_2	
- kg/ha -		Relative Yield					
				Fall			
0	0	22[1]	(5)[2]	47	(8)	45	(8)
0	186	23	(5)	76	(11)	65	(13)
57	0	55	(9)	53	(8)	58	(11)
57	186	92	(14)	100	(14)	83	(12)
				Winter			
0	0	66[1]	(51)[2]	71	(45)	66	(46)
0	186	64	(54)	76	(46)	61	(44)
57	0	91	(56)	84	(47)	55	(38)
57	186	95	(52)	100	(51)	87	(45)
				Spring			
0	0	68[1]	(44)[2]	89	(47)	81	(46)
0	186	59	(41)	85	(42)	75	(44)
57	0	71	(36)	97	(45)	90	(51)
57	186	77	(35)	85	(36)	100	(43)
				Total			
0	0		(65)[1]		(80)		(73)
0	186		(61)		(84)		(71)
57	0		(83)		(91)		(73)
57	186		(93)		(100)		(98)

* L_0, L_1, L_2 = 0, 4.5, 9.0 metric tons of lime/ha, respectively.

[1] N uptake as a percentage of the maximum N uptake for that harvest.

[2] N uptake as a percentage of the total N uptake for that treatment for the growing season.

The percentage of total N uptake, for a particular treatment, occurring in the fall was also increased by lime and fertilizer application. Liming increased the percentage of N uptake occurring in the fall for the P_0K_0 treatment from 5% at L_0 to 8% at L_1 and L_2; it increased the N uptake occurring in the fall on the P_0K_2 treatment from 5% at L_0 to 11% at L_1 and 13% at L_2. The maximum N uptake as well as largest percentage N uptake occurring in the fall occurred on the $P_2K_2L_1$ treatment. Thus, the application of lime and fertilizer not only quadrupled the absolute N uptake it also almost tripled the percentage of N uptake occurring in the fall.

The relative N uptake and percentage N uptake occurring in the winter were much less affected by lime and fertilizer application. The relative N uptake of the P_0K_0 treatment during the fall was 22%, 47%, and 45% at L_0, L_1, and L_2, respectively, while during the winter it was 66%, 71%, and 66%, respectively. The relative fall N uptake for the $P_0K_2L_0$ treatment was 23% compared with 64% relative N uptake in the winter. With the exception of the P_2K_0 treatment where a lime-induced or lime-accentuated K deficiency existed, the relative N uptake did not vary markedly within each fertilizer treatment. The relative N uptake of the P_2K_0 treatment was reduced from 91% at L_0 to 84% at L_1 and 55% at L_2.

The percentage of total N uptake occurring in winter was also relatively constant, with the exception of the P_2K_0 treatment, varying only from 45% to 54%; within each fertilizer treatment liming tended to decrease the percentage of total N uptake. The percentage of total N uptake occurring in the winter for the P_2K_0 treatment was reduced from 56% at L_0 to 47% at L_1 and 38% at L_2. This data emphasizes the lime-induced or lime-accentuated K deficiency that was noted earlier for N uptake occurring in the winter (Table 6). Observation showed that there was less clover on plots with lime and P but not K; thus the reduced N uptake is most likely due to a change in the species composition of the plots.

The relative spring N uptake was much less affected by lime and fertilizer application than was relative fall N uptake. The relative N uptake of the P_2K_0 treatment was increased from 71% at L_0 to 97% at L_1 and 90% at L_2; the percentage of N uptake occurring in the spring increased from 36% at L_0 to 45% at L_1 and 51% at L_2. This partially offset the decreased relative N uptake that occurred during the winter. The increased N uptake during the spring was due to increased growth of clover plots during the spring (Carter and Day, 1969).

A comparison of relative N uptake in the fall with relative N uptake for the entire growing season shows the importance of several harvests in measuring the effects of lime and fertilizers on N uptake.

The increased fall forage production was due to at least three factors. First, the reapplication of P, K, and S before the fall rains and subsequent increased forage growth. Second, carryover of P, K, and S from the initial application at seeding; the rainfall during the 1976-77 growing season was below average, thus resulting in less leaching loss of S and N than would normally occur. A third factor in the increased N carryover that would occur on plots which had more N uptake in the 1976-77 growing season.

Watson (1969) has shown that P fertilization increased soil N under subclover pastures which would result in more grass production; visual observation revealed that most of the fall forage production was grass. Jackson (1972) showed that applying 18 kg N/ha at seeding increased subclover seedling weight in January from 0.066 to 0.20 g/plant and increased yield from 550 to 970 kg/ha. Figure 1 shows the relationship between fall forage production and N uptake during the 1976-77 growing season.

The correlation between fall forage production in the 1977-78

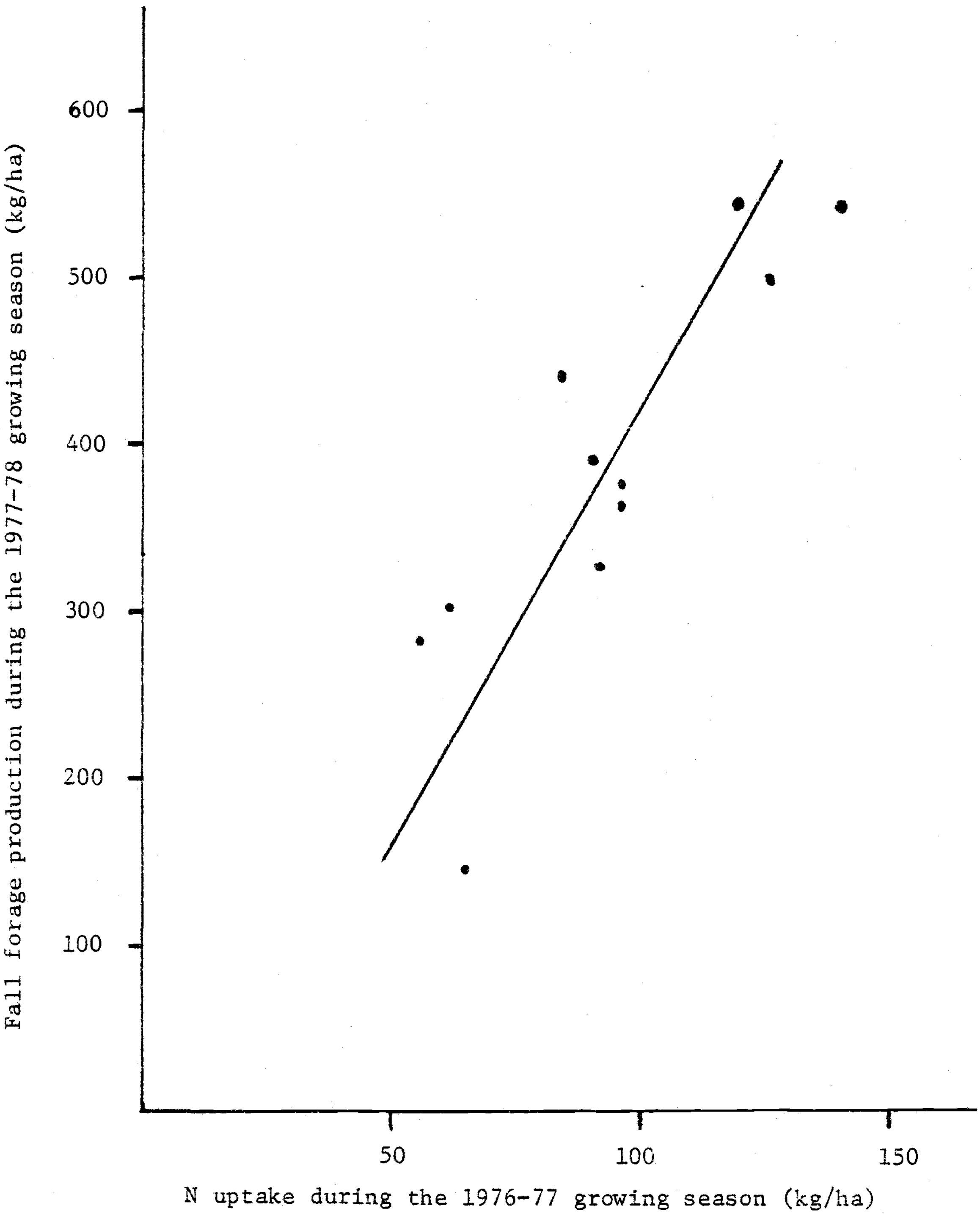

Fig. 1.. The relationship between N uptake in the 1976-77 growing season and fall forage production in the 1977-78 growing season.

growing season and N uptake during the 1976-77 growing season was significant at the 1% probability level ($r^2 = 0.76$). Application and carryover of K and S would undoubtedly affect forage production; however, since most of the forage produced was grass, N would probably be the most limiting nutrient. Therefore, N uptake and subsequent N carryover would have the most marked effect on fall forage production. Thus, the application of P, K, and lime not only increased total forage production and N uptake it also influenced, both directly and indirectly, the availability of fall forage.

SUMMARY

A field experiment was established in the fall of 1976 to determine the effects of lime and fertilizer application on the seasonal distribution of forage production and N uptake in subclover-grass pasture. To ensure good establishment a single harvest was taken the first growing season on 26 May 1977. Application of 51 kg P/ha, 183 kg K/ha and 9.0 metric tons of lime/ha increased yield from 5380 to 7100 kg/ha, N concentration from 1.29% to 1.71%, and N uptake from 67 to 119 kg/ha. All plots received adequate S, Mo, and B.

Three harvests were taken during the 1977-78 growing season to determine the forage production and N uptake during the fall, winter, and spring. The experiment was harvested on 19 November 1977 to determine fall forage production and N uptake. Lime and fertilizer application increased yield from 170 to 650 kg/ha and N uptake from 4.5 to 20.4 kg/ha. The percentage of total forage production occurring in the fall was increased from 4% to 10% and the percentage of N uptake occurring in the fall was increased from 5% to 14%. The correlation (r^2 = 0.76) between fall forage production and N uptake in the 1976-77 growing season was significant at 1% probability level.

Winter forage production and N uptake were measured by a harvest on 8 April 1978. Fertilization with P and K increased forage production from 1980 to 2750 kg/ha and increased N uptake from 44 to 67 kg/ha. The percentage of forage production occurring in winter ranged from 33% to 50%. The percentage N uptake occurring in winter ranged from 45% to 54% except for the P_2K_0 treatment which ranged from 38% at L_2 to 56% at L_0.

Spring forage production, measured by a harvest on 9 June 1978, was increased from 2440 to 4300 kg/ha by application of lime and fertilizer and N uptake was increased from 43 to 55 kg/ha. The percentage

of total forage production occurring in the spring ranged from 44% to 56% and the percentage of total N uptake occurring in the spring ranged from 36% to 51%.

Lime and fertilizer application increased relative fall yield more than winter, spring, or total relative yields. Thus, the application of lime and fertilizers had a greater impact on fall forage production, which is a major factor limiting animal production on subclover pastures, than on total forage production.

A negative lime x P interaction was evident in yield data from the 1976-77 growing season, yield and N uptake during the fall of the 1977-78 growing season, and the total yield and total N uptake during the 1977-78 growing season. The lime x P interaction was most probably due to lime increasing the availability or uptake of P.

A lime x K interaction was evident in yield data from the 1976-77 growing season, yield and N uptake data from the winter of the 1977-78 growing season, and total N uptake during the 1977-78 growing season. The lime x K interaction was most probably due to a lime-induced or lime-accentuated K deficiency.

BIBLIOGRAPHY

Barrow, N. J. 1975. The response to phosphate of two annual pasture species. II. The specific rate of uptake of phosphate, its distribution, and use for growth. Aust. J. Agric. Res. 26: 145-156.

Biddiscombe, E. F., P. G. Ozanne, N. J. Barrow, and J. Keay. 1969. A comparison of growth rates and phosphorus distribution in a range of pasture species. Aust. J. Agric. Res. 20: 1023-1033.

Carter, E. D., and H. R. Day. 1970. Interrelationships of stocking rate and superphosphate rate on pasture as determinants of animal production. Aust. J. Agric. Res. 21: 473-491.

Drlica, D. M., and T. L. Jackson. 1979. Effects of stage of maturity on P and S critical levels in subterranean clover. Agron. J. 71: 824-828.

Helyar, K. R., and A. J. Anderson. 1970. Responses of five pasture species to phosphorus, lime, and nitrogen on an infertile acid soil with a high phosphate sorption capacity. Aust. J. Agric. Res. 21: 677-692.

Hiatt, A. J., and James E. Leggett. 1974. Ionic interactions and antagonisms in plants. p. 101-134. In E. W. Carson (ed). The plant root and its environment. University Press of Virginia.

Jackson, T. L. 1972. Effects of fertilizers and lime on the establishment of subterranean clover. Oreg. Agric. Exp. Stn. Circ. Inf. 634.

Jackson, W. A. 1967. Physiological effects of soil acidity. In R. W. Pearson and F. Adams (ed). Soil acidity and liming. Agronomy 12: 43-124.

Jones, M. B., P. W. Lawler, and J. E. Ruckman. 1970. Differences in annual clover responses to phosphorus and sulfur. Agron J. 62: 439-442.

Jones, M. B., and J. E. Ruckman. 1973. Long term effects of phosphorus, sulfur, and molybdenum on a subterranean clover pasture. Soil Sci. 115: 343-348.

Keay, J., E. F. Biddiscombe, and P. G. Ozanne. 1970. The comparative rates of phosphate adsorption by eight annual pasture species. Aust. J. Agric. Res. 21:33-44.

Kohn, G. D. 1974. Superphosphate utilization in clover ley farming. I. Effects on pasture and sheep production. Aust. J. Agric. Res. 25:525-535.

McNaught, K. J. 1958. Potassium deficiency in pastures. I. Potassium content of legumes and grasses. N. Z. J. Agric. Res. 1:148-181.

Meissner, A. P., and A. L. Clarke. 1977. Response of mown pasture to potassium fertilization in south-eastern South Australia. Aust. J. Exp. Agric. Ani. Husb. 17:765-775.

Mengel, K. 1974. Ion uptake and translocation. p. 83-100. In E. W. Carson (ed). The plant root and its environment. University Press of Virginia.

Mengel, K., and E. A. Kirby. 1978. Principles of plant nutrition. DerBund, Bern, Switzerland.

Morley, F. H. W. 1961. Subterranean clover. Adv. Agron. 13:57-123.

Munns, D. N. 1965. Soil acidity and the growth of a legume. I. Interaction of lime with nitrogen and phosphate on growth of Medicago sativa L. and Trifolium subterraneum L. Aust. J. Agric. Res. 16:733-741.

Munns, D. N., and R. L. Fox. 1977. Comparative lime requirements of tropical and temperate legumes. Plant Soil. 46:533-548.

Munns, D. N., R. L. Fox, and B. L. Koch. 1977. Influence of lime on nitrogen fixation by tropical and temperate legumes. Plant Soil. 46:591-601.

Ozanne, P. G., D. B. Purser, K. M. W. Howes, and I. Southey. 1976. Influence of phosphorus content on feed intake and weight gains in sheep. Aust. J. Exp. Agric. Ani. Husb. 16:353-360.

Ozanne, P. G., K. M. W. Howes, and Ann Petch. 1976. The comparative phosphate requirements of four annual pastures and two crops. Aust. J. Agric. Res. 27:479-488.

Ozanne, P. G., J. Keay, and E. F. Biddiscombe. 1969. The comparative phosphate requirements of eight annual pasture species. Aust. J. Agric. Res. 20: 809-818.

Paton, D. F. 1956. The occurrence and significance of potassium deficiency in Tasmanian pastures. Tasmanian J. Agric. 27: 189-204.

Philpotts, H. 1976. Effect of lime on nodulation, growth, and nutrient content of Trifolium subterraneum L. on the Far North Coast of New South Wales. J. Aust. Inst. Agric. Res. 42:238-241.

Radcliffe, J. E. 1975. Seasonal distribution of pasture production in New Zealand. IV. Westport and Motueka. N. Z. J. Exp. Agric. 3:239-246.

Rickard, D. S., and J. E. Radcliffe. 1976. Seasonal distribution of pasture production in New Zealand. XII. Winchmore, Canterbury Plains dryland and irrigated pastures. N. Z. J. Exp. Agric. 4: 329-335.

Tisdale, S. L., and W. L. Nelson. 1965. Soil fertility and fertilizers. The Macmillan Co. New York.

Watson, E. R. 1969. The influence of subterranean clover pastures on soil fertility. III. The effect of applied phosphorus and sulfur. Aust. J. Agric. Res. 20: 447-456.

Willoughby, W. M. 1953. Some factors affecting grass-clover relationships. Aust. J. Agric. Res. 5: 157-180.

APPENDICES

Appendix Table 1. The effects of lime and fertilizers on the oven-dry forage yield of subclover.

Fertilizer Treatments					Harvest Dates			
P	K	Mo	B	Lime*	26 May 1977	19 Nov 1977	8 Apr 1978	1978
------lb/ac------					--------------lb/ac--------------			
0	166	0.5	1	0	4560	150	1820	2010
17	166	0	1	0	5360	260	2330	2540
51	166	0	1	0	5280	490	2700	2360
51	0	0.5	1	0	5200	300	2290	2030
51	83	0.5	1	0	6040	510	2340	2390
51	166	0.5	0	0	6080	490	2470	2260
0	0	0.5	1	0	4820	150	1740	2180
51	166	0.5	1	0	5640	520	2270	2760
17	166	0.5	1	0	5280	400	2100	3270
0	166	0.5	1	1	5700	440	1860	2760
17	166	0	1	1	6080	520	2800	2890
51	166	0	1	1	6680	700	2720	3530
51	0	0.5	1	1	5780	360	2140	2790
51	83	0.5	1	1	5880	600	2330	2980
51	166	0.5	0	1	6860	530	2650	3530
0	0	0.5	1	1	5280	290	1840	2660
51	166	0.5	1	1	5860	570	2400	2780
17	177	0.5	1	1	5860	570	1980	3270
0	166	0.5	1	2	5660	400	1760	2630
17	166	0	1	2	6080	540	2330	2920
51	166	0	1	2	5960	530	2440	3300
51	0	0.5	1	2	5400	380	1560	2810
51	83	0.5	1	2	6320	610	2380	2930
51	166	0.5	0	2	6540	650	2410	4110
0	0	0.5	1	2	4800	300	1730	2540
51	166	0.5	1	2	5140	580	2380	3430
17	166	0.5	1	2	5140	570	2540	3050
$LSD_{(.05)}$ within lime rates					1160	120	480	790
$LSD_{(.05)}$ between lime rates					1160	120	550	760

*0, 1, 2 = 0, 2, 4 tons of lime/acre, respectively

Appendix Table 2. The effects of lime and fertilizers on the N concentration in subclover/grass forage.

Fertilizer Treatments					Harvest Dates			
P	K	Mo	B	Lime*	26 May 1977	19 Nov 1977	8 Apr 1978	9 June 1978
------lb/ac-----					--------% N concentration---------			
0	166	0.5	1	0	1.79	2.83	2.49	1.64
17	166	0	1	0	1.59	2.88	2.57	1.52
51	166	0	1	0	1.61	2.89	2.64	1.81
51	0	0.5	1	0	1.48	3.25	2.68	1.82
51	83	0.5	1	0	1.68	3.23	2.90	1.72
51	166	0.5	0	0	1.83	3.27	2.64	1.63
0	0	0.5	1	0	1.33	2.64	2.59	1.73
51	166	0.5	1	0	1.81	3.16	2.52	1.55
17	166	0.5	1	0	1.74	3.27	2.58	1.80
0	166	0.5	1	1	1.32	2.79	2.77	1.66
17	166	0	1	1	1.45	3.06	2.47	1.73
51	166	0	1	1	1.44	2.97	2.84	1.85
51	0	0.5	1	1	1.34	2.73	2.65	1.92
51	83	0.5	1	1	1.30	2.98	2.78	2.03
51	166	0.5	0	1	1.12	3.26	2.73	1.81
0	0	0.5	1	1	1.26	2.95	2.59	1.83
51	166	0.5	1	1	1.75	3.26	2.85	1.70
17	166	0.5	1	1	1.30	3.16	3.08	1.69
0	166	0.5	1	2	1.37	2.99	2.33]	1.58
17	166	0	1	2	1.28	2.78	2.54	1.74
51	166	0	1	2	1.54	2.88	2.28	1.86
51	0	0.5	1	2	1.47	2.71	2.36	1.77
51	83	0.5	1	2	1.51	2.72	2.49	1.74
51	166	0.5	0	2	1.54	2.90	2.45	1.71
0	0	0.5	1	2	1.28	2.72	2.61	1.76
51	166	0.5	1	2	1.59	2.60	2.46	1.60
17	166	0.5	1	2	1.66	2.79	2.59	1.71
$LSD_{(.05)}$ within lime rates					0.34	0.30	0.31	0.23
$LSD_{(.05)}$ between lime rates					0.34	0.34	0.30	0.24

*0, 1, 2 = 0, 2, 4 tons of lime/acre, respectively

Appendix Table 3. The effects of lime and fertilizers on the chemical composition of subclover leaflets and petioles s.

Fertilizer Treatments					Chemical Composition					
P	K	Mo	B	Lime*	P	K	Ca	Mg	Mn	Zn
------lb/ac------					-%-	-%-	-%-	-%-	ug/g	ug/g
0	166	0.5	1	0	0.20	3.3	1.27	0.28	162	33
17	166	0	1	0	0.24	2.6	1.12	0.30	197	32
51	166	0 0	1	0	0.28	2.4	1.12	0.30	168	35
51	0	0.5	1	0	0.30	1.3	1.18	0.29	161	36
51	83	0.5	1	0	0.30	1.7	1.17	0.22	177	33
51	166	0.5	0	0	0.28	2.6	0.94	0.29	180	36
0	0	0.5	1	0	0.22	1.8	1.44	0.28	204	36
51	166	0.5	1	0	0.30	2.5	1.05	0.28	199	36
17	166	0.5	1	0	0.26	3.0	1.10	0.28	198	34
0	166	0.5	1	1	0.20	2.8	1.52	0.28	129	26
17	166	0	1	1	0.22	2.4	1.58	0.29	128	21
51	166	0	1	1	0.27	2.4	1.43	0.27	123	23
51	0	0.5	1	1	0.27	1.2	1.65	0.28	144	28
51	83	0.5	1	1	0.29	1.9	1.56	0.28	126	21
51	166	0.5	0	1	0.29	2.2	1.54	0.26	106	22
0	0	0.5	1	1	0.23	1.4	1.38	0.28	149	28
51	166	0.5	1	1	0.28	2.3	1.53	0.30	110	22
17	166	0.5	1	1	0.24	2.3	1.62	0.28	159	25
0	166	0.5	1	2	0.23	2.8	1.57	0.31	122	26
17	166	0	1	2	0.23	2.4	1.47	0.28	120	21
51	166	0	1	2	0.30	2.1	1.35	0.32	137	20
51	0	0.5	1	2	0.27	1.2	1.25	0.30	170	26
51	83	0.5	1	2	0.30	1.3	1.80	0.32	154	20
51	166	0.5	0	2	0.30	1.8	1.46	0.31	120	21
0	0	0.5	1	2	0.28	1.4	1.31	0.27	231	30
51	166	0.5	1	2	0.28	2.3	1.51	0.31	1.34	20
17	177	0.5	1	2	0.25	2.8	1.63	0.28	1.20	24

*0, 1, 2 = 0, 2, 4 tons of lime/ac, respectively