AN ABSTRACT OF THE THESIS OF

Viroch Impithuksa for the Master of Science
(Name) (Degree)

in Soils presented on 1 October 1971
(Major) (Date)

Title: MANAGEMENT EFFECTS ON THE NITROGEN, PHOSPHORUS AND SULPHUR STATUS OF GRASS-LEGUME PASTURES

Redacted for Privacy

Abstract approved: M. D. Dawson

These studies were initiated to investigate the influence of previous superphosphate fertilizer practices and grazing stock history on nitrogen, phosphorus and sulphur status in soils from grass-legume pastures. Four Western Oregon soil series, Dixonville, Demint, Winema and Josephine, were included in the study. Laboratory experiments and greenhouse trials were conducted on surface soils sampled from fields subjected to varying past fertilizer and stocking practices. The oxidizable carbon, nitrogen, phosphorus and sulphur status of the soils was determined, and yield and composition of ryegrass grown in the sampled soils was also investigated.

Greenhouse studies with ryegrass as a bioassay revealed that the previous superphosphate fertilizer history as well as period of grazing and stocking intensity increased yield. Moreover, plant nutrient composition of the bioassay ryegrass tended to reflect residual effects

from superphosphate fertilizer and the returns of animal droppings on the surface 10 cm of soils.

Percent oxidizable carbon, total soil nitrogen, phosphorus and sulphur from top 10 cm of surface soil suggested that the trends in changes of the C:N:P:S ratios from unimproved to improved soils were consistent with the bioassay results obtained in the greenhouse ryegrass experiment.

Management Effects on the
Nitrogen, Phosphorus and Sulphur Status of
Grass-Legume Pastures

by

Viroch Impithuksa

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

June 1972

APPROVED:

Redacted for Privacy

Professor of Soils
in charge of major

Redacted for Privacy

Head of the Department of Soils

Redacted for Privacy

Dean of Graduate School

Date thesis is presented 1 October 1971

Typed by Cheryl E. Curb for Viroch Impithuksa

ACKNOWLEDGEMENTS

The author wishes to express sincerest appreciation to his major advisor, Dr. M. D. Dawson, for his gracious guidance and assistance throughout the study and preparation of the manuscript.

Acknowledgements are expressed to Dr. W. W. Chilcote and Dr. J. L. Young who served on the graduate committee. Appreciation and special thanks are also due to the Department of Soils Staff and graduate students for their help and suggestions during the course of study and experimentation.

Without encouragement and financial support from family and concerned friends in Thailand, completion of this study would have been impossible. The author therefore takes this opportunity to express his deepest gratitude to his family, Mr. Veera, Mrs. Sritong, Ratuay, Rapipan, Suchada, Virach and especially to Pimolvarn Netravisesh.

TABLE OF CONTENTS

	Page
INTRODUCTION	1
LITERATURE REVIEW	3
General Discussion	3
Effect of Superphosphate	4
Yield and Botanical Composition	4
Nitrogen Status	5
Sulphur Status	7
Phosphorus Status	8
Other Essential Elements	8
Animal Grazing and Nutrient Recycling	11
Nitrogen	12
Sulphur	16
Phosphorus	18
C:N:P:S Ratios in Soil	18
EXPERIMENTAL METHODS AND MATERIALS	21
Field Locations	21
Soil Sampling	23
Greenhouse Experiment	23
Experimental Design	26
Harvest and Analysis	28
Laboratory Studies	28
RESULTS	32
Location One Soils	32
Location Two Soils	32
Location Three Soils	36
Location Four Soils	43
Soil C:N:P:S Status	49
DISCUSSION	56
Greenhouse Study	56
Soil Chemical Analysis	70
SUMMARY AND CONCLUSIONS	73
BIBLIOGRAPHY	77
APPENDIX	86

LIST OF TABLES

Table		Page
1	Soil Series, Location, Fertilizer and Grazing history for each location used in the study.	22
2	Results of Soil Tests from soils sampled at each location and at each level of management.	24
3	Amount, Kind and Form of nutrients applied in the greenhouse ryegrass fertilizer trials.	25
4	Fertilizer treatments used on soils sampled at three levels of past management from each location.	27
5	Summary of the methods used for soil chemical analyses.	30
6	Summary of the methods used for the routine plant chemical analyses.	31
7	Average dry matter yields (grams/pot) of ryegrass grown in the Barker soils as influenced by previous management.	32
8	Mean ryegrass yields (grams/pot) obtained from the application of nitrogen, phosphorus and sulphur to soils from location one.	33
9	Mean yields (grams/pot) of ryegrass grown in soils subjected to different previous management and fertilized with nitrogen and sulphur.	33
10	The percent nitrogen, phosphorus and sulphur of ryegrass as influenced by applied fertilizer on soils of different previous management.	35
11	Average dry matter yields (grams/pot) of ryegrass grown in the Gross soils as influenced by previous management.	37
12	Mean ryegrass yields (grams/pot) obtained from the application of nitrogen, phosphorus and sulphur to soils from location two.	37

LIST OF TABLES (Cont.)

Table		Page
13	Mean yields (grams/pot) of ryegrass grown in soils of different previous management and fertilized with nitrogen.	38
14	The percent nitrogen, phosphorus and sulphur of ryegrass as influenced by applied fertilizer on soils of different previous management.	40
15	Average dry matter yields (grams/pot) of ryegrass grown in the McKenzie soils as influenced by previous management.	41
16	Mean ryegrass yields (grams/pot) obtained from the application of nitrogen, phosphorus and sulphur to the soils from location three.	41
17	Mean yields (grams/pot) of ryegrass grown in soils subjected to different previous management and subsequently fertilized with nitrogen, phosphorus and sulphur in greenhouse trials.	42
18	The percent nitrogen, phosphorus and sulphur of ryegrass as influenced by applied fertilizer on soils of different previous management.	44
19	Average dry matter yields (grams/pot) of ryegrass grown in the Rydell soils as influenced by previous management.	45
20	Mean ryegrass yields (grams/pot) obtained from the application nitrogen, phosphorus and sulphur to the soils from location four.	45
21	Mean yields (grams/pot) of ryegrass grown in soils subjected to different previous management and fertilized with nitrogen and sulphur.	46
22	Mean yields (grams/pot) of ryegrass grown in soils subjected to different previous management and fertilized with nitrogen and phosphorus.	46

LIST OF TABLES (Cont.)

Table		Page
23	The percent nitrogen, phosphorus and sulphur of ryegrass as influenced by applied fertilizer on soils of different previous management.	48
24	Soil Test results from each location and for different previous management.	50
25	Carbon:nitrogen; Carbon:sulphur, Carbon: phosphorus and Nitrogen:sulphur ratios from soils sampled from each location.	55

LIST OF FIGURES

Figure		Page
1	The Urinary nitrogen cycle diagram.	14
2	Nitrogen cycle on grazed grass-legume pasture.	15
3	Sulphur cycle on grazed grass-legume pasture.	17
4	The relationship between oxidizable carbon and total soil nitrogen.	52
5	The relationship between soil total nitrogen and soil total phosphorus.	53
6	The relationship between soil total nitrogen and soil total sulphur.	54
7	Average yields (gm/pot) of ryegrass grown in variously fertilized soil from the Barker location as influenced by previous management.	59
8	Average yields (gm/pot) of ryegrass grown in variously fertilized soil from the Gross location as influenced by previous management.	59
9	Average yields (gm/pot) of ryegrass grown in variously fertilized soil from the McKenzie location as influenced by previous management.	61
10	Average yields (gm/pot) of ryegrass grown in variously fertilized soil from the Rydell location as influenced by previous management.	61
11	Average ryegrass yields (gm/pot) as influenced by previous soil management at each location.	63
12	Average nitrogen content (mg N/pot) of ryegrass as influenced by previous soil management at each location.	66
13	Average phosphorus content (mg P/pot) of ryegrass as influenced by previous soil management at each location.	67

LIST OF FIGURES (Cont.)

Figure		Page
14	Average sulphur content (mg S/pot) of ryegrass as influenced by previous soil management at each location.	69
15	Ryegrass response to past management practices or to applied nutrients.	76

LIST OF APPENDIX TABLES

Table		Page
1	Average yields (grams dry matter/pot) for combined first and second harvest of ryegrass from greenhouse trials.	86
2	Total nitrogen content (milligrams N/pot) of ryegrass from greenhouse experiment.	87
3	Total phosphorus content (milligrams P/pot) of ryegrass samples from greenhouse experiment.	88
4	Total sulphur content (milligrams S/pot) of ryegrass samples from greenhouse experiment.	89
5	Average yield, nitrogen, phosphorus and sulphur content in ryegrass from combined first and second harvest.	90
6	ANOV for Barker location.	91
7	ANOV for Gross location.	92
8	ANOV for McKenzie location.	93
9	ANOV for Rydell location.	94

MANAGEMENT EFFECTS ON THE NITROGEN, PHOSPHORUS AND SULPHUR STATUS OF GRASS-LEGUME PASTURES

INTRODUCTION

Soil - plant - animal relationships in a grass-legume pasture ecosystem are complex. One of the interesting interrelationships of this ecosystem involves the recycling of plant nutrients, nitrogen, phosphorus and sulphur, when pastures are heavily stocked. Often the first limiting nutrient in pastures production is nitrogen. Even in the presence of a legume symbiotic nitrogen fixation is often insufficient to supply enough available nitrogen to the grass grown in association with clover. The role of both phosphorus and sulphur in favoring vigorous clover growth is well known. Since nitrogen and sulphur are needed by the pasture in large amounts the capacity of these nutrients to remain in adequate supply depends considerably upon dung and urine returns by the grazing animal.

In recent years the average subterranean clover pasture land in Oregon has greatly increased. Since soil management practices both influence and are influenced by the stocking practices, it is both economically and ecologically sound to consider recycling of nutrients on this land. In one instance, to ensure high producing pastures at lowest cost and in the other, to conserve nutrients against loss. The role of soil management and conservation practices assumes importance in monitoring the nutrient balance of the pasture ecosystem.

The following investigation was initiated in an attempt to determine the effect of previous superphosphate application and stocking practices on soils supporting grass-legume pastures. Specific objectives of this study were:

1. To evaluate nitrogen, phosphorus and sulphur availability by means of plant yield and compostion as a basis for predicting potential nutrient deficiency.
2. To determine carbon, nitrogen, phosphorus and sulphur status in the surface soil of superphosphate fertilized and intensively grazed subterranean clover pastures.
3. To examine the evidence of nitrogen, phosphorus and sulphur recycling in a pasture ecosystem subjected to different previous managements.

LITERATURE REVIEW

The application of superphosphate fertilizer followed by intensively grazed grass-legume pastures results in an interesting complex soil-plant-animal relationship that includes changes in the soil fertility status, and plant mineral content. That superphosphate applications resulted in increased yields from subterranean clover pastures has been reported by several workers (Anderson and McLachlan, 1951; Willoughby, 1953; Donald and Williams, 1954; McLachlan and Norman, 1962; and Jones, Lawler and Ruckman, 1970).

Moreover, it would appear that such grass-legume responses have sometimes resulted from added phosphorus, sometimes added sulphur, often from both phosphorus and sulphur (Doak, 1929; Anderson and Spencer, 1950; McLachlan, 1955, 1968; Sears, 1953; Hilder, 1954; Donald and Williams, 1954; Jones and Ruckman, 1969; and Dawson and Bhella, 1971).

In some instances other fertility requirements must be ameliorated to ensure maximum symbiotic nitrogen fixation for high producing pasture (Virtanen, Hausen and Tauno, 1937; Wilson, 1940; Anderson, 1946; Walker, Adams, and Orchiston, 1955a; Anderson, 1956; McNaught, 1957; Dawson and Bhella, 1971; and Brockman, Shaw and Wolton, 1970).

Effect of Superphosphate

Yield and Botanical Composition

The influence of superphosphate and subterranean clover on the fertility status of podzolic soils was indicated by Donald and Williams (1954). The mean analyses of the untreated soils was 0.076 percent nitrogen, 0.012 percent phosphorus, and 0.010 percent sulphur. After subterranean clover where superphosphate had been applied for about 30 years at the rate of 80-120 pounds per acre, the values increased to 0.184 percent nitrogen, 0.028 percent phosphorus, and 0.024 percent sulphur. Plant growth was also improved as fertility was restored from superphosphate applications.

Anderson and McLachlan (1951) have shown that heavy and infrequent dressings of superphosphate were as effective in terms of total subterranean clover yields over a four-year period as fertilizer applied in regular annual top-dressings. Further, they concluded that the total pasture yield and dominance of either grass or clover depended on the amount of superphosphate applied. High fertility build-up caused from annual dressings of superphosphate in the early years resulted in grass dominance, but lighter annual dressings resulted in clover dominance.

Both stocking practices and superphosphate applications significantly influence pasture and animal production. A marked influence on the botanical composition follows. McLachlan and Norman (1962) noted that the maximum fertilizer requirement for optimum production on unimproved pastures was greater than for improved pastures. Jones, Lawler and Ruckman (1970) have pointed out that the application of superphosphate on California's annual grasslands has not only increased forage production, but also has changed the botanical composition. The increased soil nitrogen from symbiotic nitrogen fixation, and phosphorus increased the amount of grasses, and decreased the legumes, but the application of sulphur increased the growth of legume. Ellis (1967) reported studies on subterranean clover in New Zealand in which sulphur alone gave an annual yield response of 930 pounds dry matter per acre, and phosphorus alone had a yield response of 970 pounds. When both sulphur and phosphorus were applied together, a combined annual yield response of 4,680 pounds dry matter per acre was obtained.

Nitrogen Status

Walker, Orchiston and Adams (1954) concluded that the productivity of grassland depends primarily on the amount of nitrogen. Moreover the main source of nitrogen in the pasture came from symbiotic nitrogen fixation by legumes. Anderson and McLachlan (1951) recorded that with heavy dressing of superphosphate alone, subterranean clover became dominant in the early years, but in later years grass became dominant because of the enhanced soil nitrogen.

The nodulation of subterranean clover was markedly better on the areas receiving superphosphate (Hilder, 1934). Melville and Sears (1953) showed that the total amount of nitrogen fixed by clover will depend markedly on the amount of sulphur. Dawson and McGuire (1971) showed that inoculated seed plus superphosphate resulted in good effective nodulation and increased plant nitrogen content of subterranean clover (table below).

Table of percent effective nodulation of subterranean clover and plant nitrogen content.

Treatment	Percent effective modulation 4 weeks after planting Polk Co.	Washington Co.	Coos Co.	Average plant nitrogen content
Uninoculated	14	2	3	1.29
Inoculated	14	2	44	-
Inoculated + Superphosphate	72	96	79	3.54

Andrew (1962) reported that although sulphur was important in nitrogen metabolism, there was no evidence that it had a direct role in the symbiotic nitrogen fixation. He also reported that in some instances, sulphur increased the size of nodules and efficiency of fixation.

Most research suggests that symbiotic nitrogen fixation in legumes tends to increase when either or both phosphorus and sulphur are added to deficient soils. Moreover, a deficiency of phosphorus or sulphur will inhibit the number of nodules as well as fixation capacity of legumes (Wilson, 1939).

Sulphur Status

In the State of Oregon, sulphur deficiencies have long been recognized and have been reported by Powers et al. for various crops. Dawson (1968) concluded that widespread sulphur deficiency exists on grass-legume pasture in western Oregon. Soils with sulphur fertilizer responses were noted within one mile of the Pacific Ocean. Jones (1964) reported that in California, 40 pounds of sulphur per acre every two years applied to subterranean clover was required for near maximum yield.

In New Zealand, Doak (1929) showed that lucerne responded to applications of sulphur or sulphate. Sears (1953) obtained grass-legume pasture response attributed to sulphur in superphosphate on a soil high in available phosphate. Walker, Adams and Orchiston (1955a) noted response to gypsum on establishment and growth of clovers in grassland.

In Australia, sulphur deficiency has been widespread, particularly for legumes in many parts of Australia (Anderson and Spencer, 1950; Anderson and Molye, 1952; Hilder, 1954; and Donald and Williams, 1954).

Response from sulphur on improved grass-clover pastures appears related to the past history of superphosphate top-dressing. Hilder (1954) found rapid development of sulphur deficiency in pastures on the Northern Tablelands of New South Wales when superphosphate applications were discontinued.

Phosphorus Status

Anderson and Spencer (1950) demonstrated that 20 percent superphosphate successfully supplied both phosphorus and sulphur elements. Donald and Williams (1954) pointed out that phosphorus levels in the soil increased concurrently with sulphur increases, based on the ratio of S:P in the superphosphate applied, and under average stocking practices each hundredweight of superphosphate applied per acre resulted in an increase of 10. 3 pounds phosphorus and 13. 9 pounds sulphur. McLachlan and Norman (1962) indicated that the residual value of phosphorus was greater than sulphur in superphosphate.

Other Essential Elements

In the case of clover fertilizer, nutrient response other than applied nitrogen is dependent upon effective nodulation. Besides the agronomic problems encountered in establishing nodulated clover, oftimes the strain of Rhizobium used can be critical. Inoculation responses with introduced legumes have been reported throughout

Australia and New Zealand.

Greenwood (1961) reported that with inoculated field sowings, good nodulation occurred with red and white clover, but with subterranean clover most of the nodules were found to be ineffective. Furthermore, in higher rainfall areas white clover was effective, but subterranean clover and crimson were ineffective. Jenkins, Vincent and Walters (1954), in field experiments with crimson and subterranean clover, confirmed the importance of successful inoculation with an effective strain of a root-nodule bacterium. Yield was directly related to the proportion of plants effectively nodulated.

Occasionally nutrients other than phosphorus and sulphur are required for vigorous grass-legume pastures (Anderson, 1942; Rossiter and Kipps, 1947; Rossiter, 1947; Rossiter, 1952; McNaught, 1957, Andrew, 1962). Rossiter (1947) reported that yields of subterranean clover were increased by application of potassium, in the presence of phosphate on Crawley sand. Newman (1948) reported that a marked response of subterranean clover to applications of potash fertilizers at the rate of 1/4 cwt per acre. Positive potassium, molybdenum interactions with respect to the growth of subterranean clover have been obtained in pot culture trials on South Australian soils. Most pasture species require an average content of at least 0.5 percent potassium for healthy growth. In spite of the high plant requirements for potassium, however, actual losses of potassium from the soil under grazing conditions are quite low because of the recycling of this nutrient via urine and dung. Williams and Donald (1957) showed that exchangeable potassium increased in podzolic soils (Crookwell district of New South Wales) when put in subterranean clover pastures and fertilized with superphosphate.

A micronutrient now widely recognized as helping increase nitrogen content is molybdenum (Anderson and Spencer, 1950a; Evans, Purvis and Bear, 1950; McLachlan, 1955; Anderson and Moye, 1952; Anderson, 1946). Anderson (1942) found that clover grew better in the ash from burned trees. Further research indicated that molybdenum was one of the factors responsible for the increased growth. Over a seven-year period, as little as 1/32 of an ounce of $Na_2MoO_4 \cdot 2H_2O$ per acre produced 9,000 pounds more dry matter than the check plot (During, 1967).

Molybdenum deficiencies of legumes in the United States are known to occur in New Jersey, South Carolina, Texas, Idaho, Wisconsin, Indiana, California, Washington, Georgia and New York (Rubins, 1956; Kliewer and Kennedy, 1960; Parker and Harris, 1962; Lavy and Barber, 1963; Stout et al., 1951). Dawson and Bhella (1971) obtained increased yields of subterranean clover in Oregon resulting from an application of 1/4 pound of sodium molybdate per acre.

Application of lime on grass-legume pasture apparently has both a direct and indirect role. Anderson (1942) observed that response from lime on molybdenum-deficient soils was in fact a response to molybdenum. Studies show that exchangeable molybdenum increases in the soil with increasing soil pH (Stout et al., 1951). On the other hand, response to lime occasionally is due to ameliorating the acidity and providing a more favorable environment for Rhizobium invasion and effective nodulation of the legume (Peterson and Goodding, 1941; Jensen, 1942; Vincent and Waters, 1954; Vincent, 1954a). Acid soil conditions result in complicated problems of nutrition including depressed molybdenum availability and possible toxicity from manganese and aluminum, but the functioning of the formed nodule appears not as sensitive to low pH as to the survival of Rhizobia. Jensen (1944) showed that when calcium and phosphorus were sufficient, the fixation of nitrogen by subterranean clover was as good in a soil with pH 5 as it was when the pH was raised by liming to 7-7.5.

Animal Grazing and Nutrient Recycling

The return of dung and urine on grazed grass-legume pastures is a significant factor in the recycling of nutrients (Melville and Sears, 1953; Sears, 1953a; Sears, 1953c; Sears and Evans, 1953; Sears and Thurston, 1953; Lodge, 1954; Watkin, 1954; Walker, Orchiston and Adams, 1954; Walker, 1956; Walker, 1957; Watkin, 1957; Wolton, 1963). Accumulated soil organic matter under a stocking regime slowly mineralized for subsequent plant uptake or alternatively the nutrients were directly taken up from the urine patch (Sears and Newbold, 1942). Intensively grazed grass-legume pastures accompanied by the application of superphosphate have resulted in increased plant content of nitrogen, phosphorus and sulphur (McNaught and Chrisstoffels, 1961; Jones, 1964; Bouma, Spencer and Dowling, 1969; Jones, Lawler, and Ruckman, 1970; Brockman, Shaw and Wolton, 1970).

A practical implication resulting from increased stocking rates resulted in a disproportionate increase in the rate of nutrient movement in the cycle, so that a steady state tended to exist. Such an intra system reduced the need for further fertilizer application (Anderson and McLachlan, 1951; Sears, 1953; McLachlan and Norman, 1966; Bromfield and Jones, 1970; Carter and Day, 1970). Peterson, Lucas and Mott (1965) suggested that the gain per ewe was constant as stocking rate was increased until the total amount of grazable forage per acre equalled the total amount of forage consumed per acre. Beyond this point gain per head was inversely related to stocking rate.

Nitrogen

The rate of nitrogen ingested by stock has been studied by Sears who emphasized that large quantities of plant nutrients, such as nitrogen and potassium, are returned to the sward by grazing animals on high-producing pastures. Walker, Orchiston and Adams (1954) also noted that as pasture was grazed, most of nitrogen contained in the grass and clover was returned to the pasture in the excreta. They found that the amount of nitrogen retained in animals varied with type of stock, but that some stock may excrete as much as 95 percent of the ingested nitrogen. They also calculated that rotational grazing of a pure grass-legume should yield 50 percent more nitrogen than cutting for conservation. Brockman, Shaw and Wolton (1970) indicated that grazed grass-legume pasture had higher nitrogen and phosphorus content than cut grass-legume stand.

Sears and Newbold (1942) observed that under grazing, the return of urine and dung resulted in a well-balanced grass and clover sward with optimum yield. These authors also noted that of the total excreted nitrogen, approximately 70 percent appeared in urine and 30 percent in the faeces. Doak (1952) has shown that urea and amino-acids constitute the major fraction of the nitrogen in the urine (see the Urinary nitrogen cycle diagram, Figure 1). Within the area affected by excreted urine, the nitrogen amounts to an application rate of about 200 pounds nitrogen per acre. Doak also indicated that about 90 percent of the urine-nitrogen was in the form of urea and amino-nitrogen, forms immediately available to the plant.

The nitrogen cycle as it pertains to stock grazing on grass-legume pasture, schematically presented by Walker (1956), and modified by Dawson (1971), appears in Figure 2.

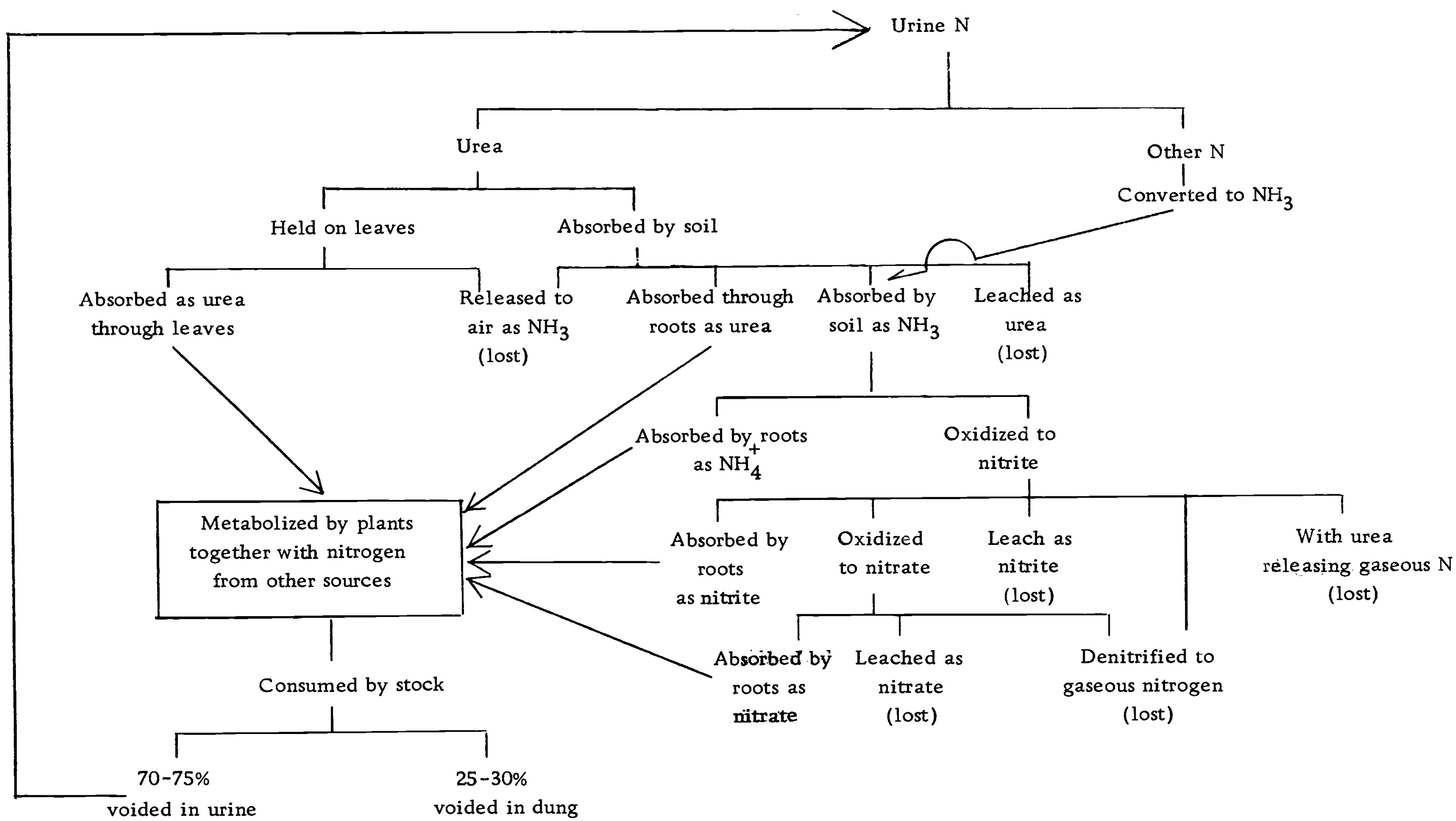


Figure 1. The urinary nitrogen cycle diagram (from Doak, 1952).

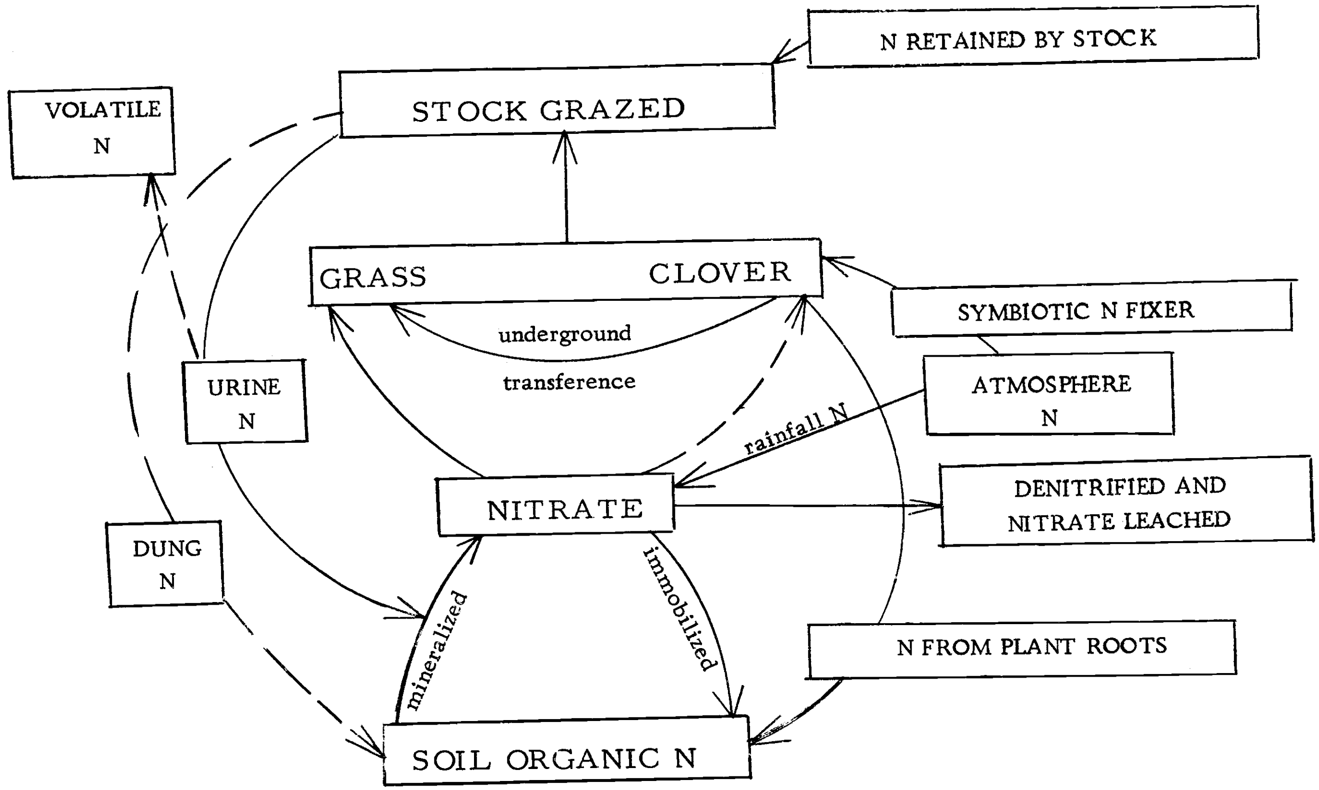


Figure 2. The N cycle on grazed grass-clover pasture.

Sulphur

Ingested sulphur, like nitrogen, tends to be largely excreted. The biggest fraction is excreted in the urine as low molecular compounds urea and sulphate, respectively. Faeces may contain small amounts of sulphate as well as organic sulphur (Walker, 1957; Doak, 1952).

Approximately 30-40 percent of the sulphur ingested by stock was shown by Walker (1957) to be voided by the animal. However, Warth and Krishnan (1935) concluded that the proportions of excreted and egested sulphur depended on the amount ingested. They found about 70 percent of the sulphur was in the urine in various forms. Some was lost by volatilization, but most of the sulphur in urine and dung was retained as a component of organic matter which is slowly mineralized and then used by the grass-legume plants. Grass growth is normally stimulated in the urine patch because of the large return of readily available nitrogen. Much of the excreted sulphate is also readily utilized (Walker, 1957).

The effect of grazing animals on sulphur status of the system appears [schematically from Walker (1957) as modified by Dawson (1971)] in Figure 3.

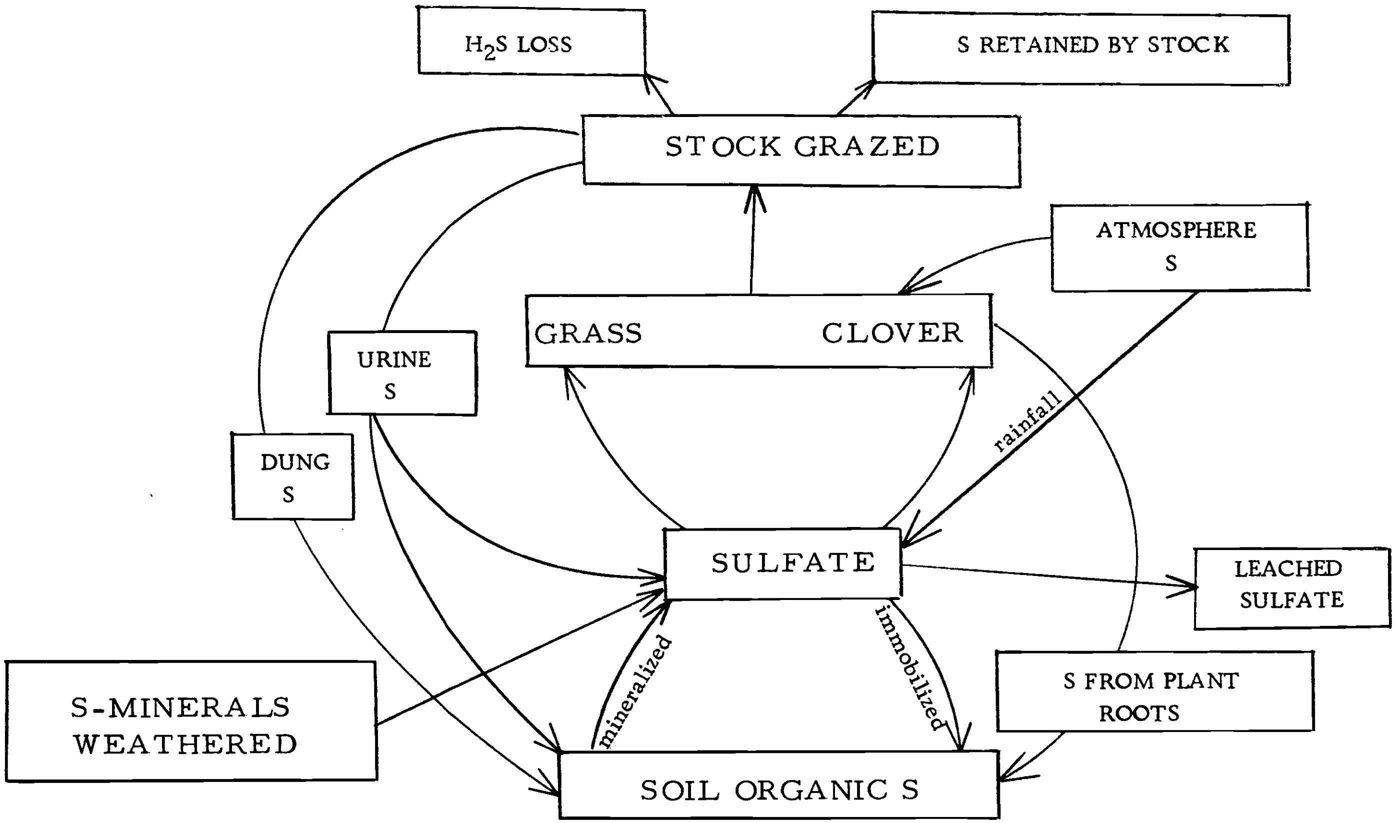


Figure 3. The S cycle on grazed grass-clover pasture.

Phosphorus

The contribution of stock faeces and urine to maintenance of soil phosphorus and high-production of pasture has been studied by Sears, Goodall and Newbold (1948), McAuliffe, Peech and Bradfield (1949), Anderson and McLachlan (1951), Watkin (1957), Bromfield (1961), Gunary (1968).

Sears, Goodall and Newbold (1948) showed that the greater part of phosphorus ingested by stock also was returned to the pasture in the form of faeces. They also indicated that the return of both dung and urine increased total dry matter production of the pasture by 33 percent. McAuliffe, Peech and Bradfield (1949) concluded that a high proportion of the organic phosphorus in faeces becomes available to plants. Gunary, however, (1968) found that although the inorganic phosphate in dung was initially highly available, its availability diminished after a period of contact with the soil.

C:N:P:S Ratio in Soil

The carbon, nitrogen, phosphorus and sulphur ratios, C:N:P:S of grassland soils have been investigated by several workers (Donald and Williams, 1954; Walker, 1955; Walker, 1956; Walker, 1957; Walker and Adams, 1958; Williams and Donald, 1957; Jackman, 1960). Apparently, the soil organic matter contains carbon, nitrogen, phosphorus and sulphur in fairly constant proportions. The average

C:N:P:S ratios approximate 100:8:1.4:1 (Walker, Adams and Orchiston, 1955; Walker, 1956; Williams and Donald, 1957; Jackman, 1960). Under New Zealand conditions, Walker (1955, 1956) found that relatively large accumulations of organic matter and organically bound nutrients are common. Furthermore, mineralization of the organically bound nitrogen, phosphorus and sulphur was necessary before these nutrients were in available forms for plant utilization. In the case of rapid organic matter accumulation a reduced nutrient supply to the pasture plants may result. Walker, Orchiston and Adams (1954) concluded that under some of the better conditions in New Zealand, the soil organic matter and hence carbon was increased more than 1 percent within a period of 30 years. They attributed this increase in carbon mainly to increased nitrogen from symbiotic nitrogen fixation and animal droppings. Proportional amounts of organic phosphorus and organic sulphur also tended to accumulate.

Normally in nature, sulphur is received in the soil from the atmosphere and from animal droppings (Walker, 1957). Phosphorus status depends mainly on the amount of phosphorus in parent material, although some addition from urine and dung is to be expected (Walker and Adams, 1958). In order for organic matter to accumulate, these authors suggested the application of superphosphate to grass-legume pastures was necessary. When sulphur and phosphorus were not added to the soil in amounts sufficient to meet demands, clover growth and symbiotic nitrogen fixation first suffered, with subsequent widening of carbon:nitrogen, carbon:sulphur, and carbon:organic phosphorus ratios. Walker (1957) observed that the average carbon:sulphur was 80-200:1 under New Zealand conditions.

Williams and Donald (1957) concluded that soil organic matter contains approximately constant proportions of carbon, nitrogen, phosphorus and sulphur in the ratio of 155:10:0.68:1.4 under both unimproved pasture and improved pasture. They suggested that the rate of soil organic matter build-up under superphosphate fertilized subterranean clover pastures may have been limited by the amounts of sulphur supplied in the superphosphate top-dressings. They also found linear relationships between total nitrogen and carbon, total nitrogen and total sulphur and total nitrogen and total phosphorus. The relatively constant C:N:P:S ratios suggest that the four nutrients are related to each other through the organic matter in the soil.

A relatively low inorganic nitrogen content of grassland soils appears typical according to Walker, Orchiston and Adams (1954). They also suggested that inorganic nitrogen is mineralized only slowly from soil organic matter to supply nitrogen need of the grass-legume association. In earlier work, Donald and Williams (1954) concluded that organic phosphorus made up a large and important portion of the total phosphorus and that soil sulphur also was probably present in an organic form under pasture conditions.

EXPERIMENTAL METHODS AND MATERIALS

Field Locations

The four locations selected for soil sampling were in Douglas (2), Coos, and Curry counties. Prerequisites were that each location include: old subterranean clover fertility field-plots; indigenous unimproved grazing land; and a fertilized intensively-stocked subterranean-clover (*Trifolium subterraneum* L.) field all adjacent to one another and on the same soil series. The past history of each field sampled, together with soil type, is given in Table 1.

Specifically, each location consisted of three levels of soil management, identified as follows:

1. Unimproved (M_1) sites. These supported native grasses, such as Bentgrass (*Agrostis tennuis* Sibth.), Chewings fescue (*Festuca rubra commutata* Gaud.), and Hopclover (*Trifolium agrarium* L.), but had received no fertilizer and were only seldom grazed.
2. Improved but Ungrazed (M_2) sites. These consisted of a subterranean clover experimental plot that had received annual applications of 300 pounds of single superphosphate for from 5 to 6 years and had all forage removed as hay at each cutting.
3. Improved and Grazed (M_3) sites. These consisted of fertilized and grazed subterranean clover pastures. The fertilizer and

Table 1. Soil series, location, fertilizer and grazing history for each location used in the study.

Location	Soil Series	County		Fertilizer history	Stocking rate and duration
Barker(L_1)	Dixonville	Douglas	M_1	None	Seldom grazed
			M_2	300 lbs. superphosphate for 5 years.	Not grazed
			M_3	300 lbs. superphosphate for 5 years.	1-2 ewes/ac. for 5 years.
Gross(L_2)	Demint[1]	Coos	M_1	None	Seldom grazed
			M_2	300 lbs. superphosphate for 5 years.	Not grazed
			M_3	300 lbs. superphosphate for 5 years.	3-4 ewes/ac. for 5 years.
McKenzie(L_3)	Winema	Curry	M_1	None	Seldom grazed
			M_2	300 lbs. superphosphate for 5-6 years.	Not grazed
			M_3	300 lbs. superphosphate for 8-10 years.	3-4 ewes/ac. for 8-10 years.
Rydell(L_4)	Josephine	Douglas	M_1	None	Seldom grazed
			M_2	300 lbs. superphosphate for 5-6 years.	Not grazed
			M_3	300 lbs. superphosphate for 10-12 years.	4-5 ewes/ac. for 10-12 years.

[1] Tentative Series.

stocking histories for each M_3 site are indicated in Table 1.

Soil Sampling

The soil was sampled at each location from an area equivalent in size to the previous experimental plots. Twelve soil samples were taken to a depth of 10 cm from each management level (M_1, M_2, and M_3) at the four locations. The sampled soil cores were air dried in the laboratory and ground to pass through a 14 mesh sieve and readied for chemical analysis. The soil test results obtained from the Oregon State University Soil Testing Laboratory are presented in Table 2.

Greenhouse Experiment

Concurrently with soil sampling for chemical analysis using a similar procedure, soil samples were also collected for the greenhouse experiment. Soil samples so obtained were air dried, then ground to pass through a 1 cm sieve. Rocks, gravel and plant material were removed. A blanket potassium fertilizer treatment was applied to the air dried soil after which 900 grams were carefully weighed into each plastic pot. Pots were then fertilized appropriately to provide nitrogen, phosphorus and sulphur both singly and in combinations as presented in Table 3. Analytical grade reagents supplied the nutrients which, after careful weighing, were applied to each appropriately labelled pot.

Table 2. Results of soil tests[1] from soils sampled at each location and at each level of management.

Location	Management practices	pH	K ppm	Ca meq/100g	Mg meq/100g	CEC meq/100g
Barker(L_1)	M_1	5.9	202	7.6	4.9	15.5
	M_2	5.5	150	9.6	4.4	26.3
	M_3	5.7	326	9.6	5.6	19.5
Gross(L_2)	M_1	5.5	352	6.5	4.3	21.4
	M_2	5.4	224	6.5	2.2	20.7
	M_3	5.3	224	4.8	2.2	19.9
McKenzie(L_3)	M_1	5.5	572	7.6	3.3	31.8
	M_2	5.3	178	10.3	2.8	29.8
	M_3	5.4	233	7.2	2.1	28.8
Rydell(L_4)	M_1	5.4	264	6.2	2.1	14.4
	M_2	5.1	103	2.7	1.1	20.2
	M_3	5.0	150	3.3	0.7	12.5

[1] O.S.U. Soil Testing Laboratory method (Reference).

Table 3. Amount, kind and form of nutrients applied in the greenhouse ryegrass fertilizer trials.

Treatment	Rate[1] (Kg/hec)	Per pot (mg)	Chemical	Amount of Chemical(mg)
Check	none	none	See blanket	none
N	200	80.16	NH_4NO_3	229.03
P	75	30.06	NaH_2PO_4	116.36
S	50	20.04	Na_2SO_4	88.92
NP	200+75	80.16+30.06	$NH_4NO_3+NaH_2PO_4$	229.03+116.36
NS	200+50	80.16+20.04	$NH_4NO_3+Na_2SO_4$	229.03+88.92
PS	75+50	30.06+20.04	$NaH_2PO_4+Na_2SO_4$	116.36+88.92
NPS	200+75+50	80.16+30.06+20.04	$NH_4NO_3+NaH_2PO_4+Na_2SO_4$	229.03+116.36+88.92

1 = In terms of element

Blanket = KCl equivalent to 80 Kg of K/hec

Experimental Design

A completely randomized experimental design consisting of a factorial arrangement of treatments utilizing three replications was used. Two factors were studied, namely: (1) three levels of soil management practices, and (2) eight fertilizer treatments as identified in Table 4.

Artificial lighting and controlled temperature were utilized in the greenhouse studies. The light system consisted of daylight fluorescent lamps spaced at 10 cm intervals and maintained at 30 cm above the plant tops. Aluminum foil was used on top of lamps in order to increase light efficiency. A day length of 12 hours was used. Temperature was kept at 80°F during the day time and at 65°F during the night.

Soils in the plastic pots were equilibrated with distilled water for two weeks prior to planting to achieve field capacity and to encourage volunteer grasses and clovers which were subsequently weeded out. Ryegrass (*Lolium multiflorum*) seed was then sown as the test plant at the rate of 200 seeds per pot. Soil moisture was maintained near field capacity for the duration of the experiment by the daily application of distilled water.

Table 4. Fertilizer treatments used on soils sampled at three levels of past management from each location.

Fertilizer element	Symbol	Management levels M_1	M_2	M_3
Check	C	M_1C	M_2C	M_3C
Nitrogen	N	M_1N	M_2N	M_3N
Phosphorus	P	M_1P	M_2P	M_3P
Sulphur	S	M_1S	M_2S	M_3S
Nitrogen+Phosphorus	NP	M_1NP	M_2NP	M_3NP
Nitrogen+Sulphur	NS	M_1NS	M_2NS	M_3NS
Phosphorus+Sulphur	PS	M_1PS	M_2PS	M_3PS
Nitrogen+Phosphorus+Sulphur	NPS	M_1NPS	M_2NPS	M_3NPS

[1] Refer to Table 1, p. 22.

Harvest and Analysis

Three successive harvests were made. Each time the grass was cut at prebloom stage, one inch above soil. First harvest was taken on November 25, 1970 at the age of 39 days, second harvest on January 9, 1971 some 45 days later while the third harvest was taken on February 20, 1971 at age 42 days.

At each harvest cut grass from individual plastic pots was dried in a forced air oven at 70°C for 24 hours. Dry matter weights were recorded individually from each pot and dry matter yields from first and second harvests were combined to assure sufficient plant material for subsequent chemical analysis. The dried grass samples were ground using an osterizer blender and readied for total nitrogen, total phosphorus and total sulphur determinations.

Statistical analyses on the grass yield were done through the Computer Center at Oregon State University. The data were analyzed as a completely randomized design with treatments factorially arranged. Additional calculations made on a desk calculator included: correlation, regression, coefficients of variance and L. S. D.

Laboratory Studies

In addition to the routine soil tests (Table 2) carried out at the Oregon State University Soil Testing Laboratory, soils were also analyzed by the author for oxidizable carbon, total nitrogen, total phosphorus, organic phosphorus and total sulphur using procedures indicated in Table 5. Values so obtained were reported as percentages.

Chemical analyses of ryegrass from the greenhouse experiment included: total nitrogen, total phosphorus, and total sulphur. Procedures used in plant analysis are presented in Table 6.

Table 5. Summary of the methods used for soil chemical analyses.

Test or determination	Reference	Notes on the method
pH	Jackson, 1958	1:2 soil water suspension was used to determine soil pH.
Total nitrogen	Bremner, J.M. 1965 (modified method)	Kjeldahl method
Total and organic phosphorus	Saunders, W.M.H. and Williams, E.G. 1955	2 grams of air-dry soil was ignited in a silica crucible for 1 hr. at 550 C. Ignited residue and unignited soil were extracted 16.5 hrs. with 100 ml of 1N H_2SO_4. P was determined by the vanadate-Molybdate-Yellow method using Bauch and Lomb "Spectronic 20" spectrophotometer. The difference, inorganic P from ignited soil, was organic P in soil.
Total sulphur	Tabatabai, M.A. and Bremner, J.M. 1970, Johnson, C.M. and Nishita, H. 1952	Soil sulphur was odixized to sulphate by sodium hypobromite, and then the sulphate was reduced to hydrogen sulfide and determined colorimetrically as methylene blue.
Carbon	Walkley & Black, 1934 Walkley, 1947	Organic matter was determined as easily oxidizable material using 0.1 N $KMnO_4$ to titrate the soil $K_2Cr_2O_7$ solution, and then converted from O.M. to C.
Extractable bases (Ca, Mg, K)	Schollenberger and Simon, 1945	On a single extraction (1:20 soil to extractant ratio) using 1N ammonium acetate adjusted to pH 7; K was determined by means of flame emission spectrophotometer; Ca and Mg were determined by atomic absorption.
CEC	Schollenberger and Simon, 1945	CEC was determined with 1N ammonium acetate buffered at pH 7.

Table 6. Summary of the methods used for the routine plant chemical analyses.

Test or determination	Reference	Notes on the method
Total nitrogen	Johnson and Ulrich, 1959	Micro-Kjel dahl procedure was used to determine total nitrogen in the plant tissue.
Total phosphorus	Jackson, 1958	Molybdate-Vanadate colorimetric method was used to determine phosphorus in perchloric acid digest. The color intensity was measured on a Bausch and Lomb spectronic 20 spectrophotometer.
Total sulphur	Chesnin, L. and Yien, C. H. 1950 (modified method)	A turbidimetric method; Sulphates in perchloric acid digest were precipitated with 35-60 mesh barium chloride. The precipitates were kept in suspension with a gum acacia solution, and turbidity readings were made on a Bausch and Lomb spectronic 20 spectrophotometer.

RESULTS

Greenhouse Experiments

Location One Soils

The ryegrass yields obtained in the greenhouse study from soils sampled on the Barker farm are presented in the appendix Table 1. Analysis of variance was performed on dry matter yields from the combined first and second harvest (appendix Table 6). There was a highly significant difference among mean yields obtained from plants grown in soils that had different previous management (M_1, M_2 and M_3) histories as can be seen in Table 7.

Table 7. Average dry matter yields (grams/pot) of ryegrass grown in the Barker soils as influenced by previous management.

Previous level of management	Average D. M. g/pot	Average D. M. g/pot
M_1 versus M_2	2.28	4.37**
M_1 versus M_3	2.28	4.37**
M_2 versus M_3	4.37	4.37

L. S. D. $_{.01}$ = 0.29
L. S. D. $_{.05}$ = 0.22

M_1 = Unimproved.
M_2 = Improved but not grazed
M_3 = Improved and grazed

When yields from all previous management systems were analyzed to determine the effect of applied nitrogen, phosphorus and sulphur, mean yields revealed a highly significant response from both applied nitrogen and sulphur (Table 8).

Table 8. Mean ryegrass yields (grams/pot) obtained from the application of nitrogen, phosphorus and sulphur to soils from location one.

Nutrient	Not added	Added
Nitrogen	2.88	4.47**
Phosphorus	3.62	3.73
Sulphur	3.44	3.90**

L.S.D.$_{.01}$ = 0.24

L.S.D.$_{.05}$ = 0.18

The significant differences noted in ryegrass yields grown in soils from different previous management (Table 7) suggested interesting interactions resulting from the application of nitrogen and sulphur (Table 9).

Table 9. Mean yields (grams/pot) of ryegrass grown in soils subjected to different previous managements and fertilized with nitrogen and sulphur.

	M_1		M_2		M_3	
	N_0	N_1	N_0	N_1	N_0	N_1
S_0	1.27	2.20	3.56	4.73	3.63	5.27
S_1	1.59	4.05	3.71	5.49	3.52	5.07

L.S.D.$_{.01}$ = 0.58 N_0 = No N applied S_0 = No S applied

L.S.D.$_{.05}$ = 0.44 N_1 = N applied S_1 = S applied

Added sulphur in the presence of applied nitrogen significantly increased ryegrass yields grown in the M_1 and M_2 soils, but not when added to the M_3 soil. Furthermore, ryegrass grown with applied nitrogen + sulphur in soil that had M_2 and M_3 previous management gave significantly higher yields than those grown in the unimproved soil (M_1). These results suggest real differences in the response from applied nitrogen and sulphur depending upon the previous management of the soils.

In the non-fertilized soils previous management appeared to influence the percent phosphorus in ryegrass as seen in Table 10. Unlike either nitrogen or sulphur, the percent ryegrass phosphorus tended to be higher in ryegrass grown in the unimproved soil (M_1).

The percent nitrogen increased in ryegrass when nitrogen fertilizer was applied regardless of the previous soil management. But the increase in percent nitrogen following nitrogen fertilizer was greatest in ryegrass grown in the unimproved soil (M_1). While percent phosphorus in ryegrass was affected by the application of nitrogen fertilizer, percent sulphur tended to decrease.

Interesting differences resulted from combination applications of either nitrogen + phosphorus or nitrogen + sulphur or phosphorus + sulphur to the soils. As might be expected, the application of nitrogen and sulphur produced increased percentages of these nutrients in the ryegrass. By contrast, the percent phosphorus was not appreciably

Table 10. The percent nitrogen, phosphorus and sulphur of ryegrass as influenced by applied fertilizer on soils of different previous management.

Management practice	Element analyzed	Fertilizer applied							
		C	N	P	S	NP	NS	PS	NPS
M_1	Nitrogen	1.97	3.15	1.91	1.81	3.34	2.09	1.65	2.10
	Phosphorus	0.67	0.56	-	-	0.61	0.38	0.56	0.42
	Sulphur	0.17	0.07	-	-	0.07	0.27	0.39	0.31
M_2	Nitrogen	1.96	2.42	1.88	1.89	2.28	2.40	1.75	2.22
	Phosphorus	0.42	0.32	-	-	0.42	0.31	0.47	0.30
	Sulphur	0.23	0.15	-	-	0.11	0.35	0.41	0.35
M_3	Nitrogen	1.77	2.40	1.74	1.67	2.31	2.48	1.77	2.41
	Phosphorus	0.57	0.49	-	-	0.56	0.43	0.60	0.50
	Sulphur	0.24	0.13	-	-	0.14	0.39	0.41	0.32

changed where phosphorus was added in combination with nigrogen, sulphur or nitrogen + sulphur. Regardless of previous history the application of nitrogen + phosphorus + sulphur increased the percent ryegrass nitrogen while the application of phosphorus + sulphur without nitrogen tended to result in higher percent phosphorus and sulphur.

In the unimproved soil (M_1) the percent nitrogen in ryegrass was higher where phosphorus was applied with nitrogen than where sulphur was included with nitrogen. However, the opposite was the case in the M_2 and M_3 soils.

Location Two Soils

Ryegrass yields from soil sampled on the Gross farm are presented in the appendix Table 1. The analysis of variance obtained from the combined first and second harvests is presented in the appendix Table 7. As true for location two soil, a highly significant difference among mean ryegrass yields grown on soils from this location indicated the importance of previous management history (Table 11).

Further analysis of mean ryegrass yields indicated a highly significant response to applied nitrogen, phosphorus and sulphur (Table 12).

Table 11. Average dry matter yields (grams/pot) of ryegrass grown in the Gross soils as influenced by previous management.

Previous level of management	Average D. M. g/pot	Average D. M. g/pot
M_1 versus M_2	2.37	4.49**
M_1 versus M_3	2.37	4.75**
M_2 versus M_3	4.49	4.75**

L. S. D.$_{.01}$ = 0.34

L. S. D.$_{.05}$ = 0.26

M_1 = Unimproved
M_2 = Improved but not grazed
M_3 = Improved and grazed

Table 12. Mean ryegrass yields (grams/pot) obtained from the application of nitrogen, phosphorus and sulphur to soils from location two.

Nutrient	Not added	Added
Nitrogen	3.09	4.65**
Phosphorus	3.69	4.05**
Sulphur	3.70	4.04**

L. S. D.$_{.01}$ = 0.28

L. S. D.$_{.05}$ = 0.21

Possible effects of different previous soil managements together with combination of added nutrients revealed only one high significant interaction, namely that of nitrogen x management as shown in Table 13. Soils from each previous management showed response to applied nitrogen, the unimproved soil M_1 being most deficient in this nutrient. Regardless of whether or not nitrogen was applied, the average ryegrass yield from the M_2 and M_3 soils was significantly greater than yields obtained from the unimproved soil (M_1). No difference was observed between ryegrass yields obtained from the M_2 and M_3 soils in the presence of applied nitrogen.

Table 13. Mean yields (grams/pot) of ryegrass grown in soils of different previous management and fertilized with nitrogen.

	M_1	M_2	M_3
N_0	1.33	3.78	4.17
N_1	3.40	5.20	5.33

$L.S.D._{.01} = 0.48$ M_1 = Unimproved N_0 = No N applied
M_2 = Improved, not grazed
$L.S.D._{.05} = 0.36$ M_3 = Improved and grazed N_1 = N applied

In the absence of applied nutrients, M_3 management appeared to influence the percent ryegrass nitrogen (Table 14). Ryegrass grown in the M_3 soil contained the highest percent nitrogen (Table 14). When nitrogen fertilizer was applied, nitrogen increased in ryegrass regardless of the soil's previous management. But the rate of nitrogen increase was smallest in ryegrass grown in the M_3 soil consistent with the observed yield response noted in Table 13. The percent phosphorus and sulphur in ryegrass was not affected by the application of nitrogen fertilizer.

Following the combination applications of either nitrogen + phosphorus or nitrogen + sulphur an increase in the percent ryegrass nitrogen and sulphur was noted (Table 14) over check treatment while the percent of phosphorus only changed slightly. The percent ryegrass nitrogen was not changed where nitrogen was applied with phosphorus or with sulphur.

When the percent ryegrass nutrient status was compared following the application of either phosphorus + sulphur or nitrogen + phosphorus + sulphur the percent nitrogen and sulphur in ryegrass increased, especially in ryegrass grown in the M_1 and M_2 soils. Ryegrass percent phosphorus and sulphur tended to be higher when these nutrients were applied to the soil in the absence of added nitrogen fertilizer.

Location Three Soils

Yields of ryegrass obtained from soils sampled at the McKenzie farm are presented in the appendix Table 1. The analysis of variance on dry matter yields for combined first and second harvests is presented in the appendix Table 8. The mean ryegrass yield again was significantly influenced by the previous management (Table 15). It is apparent that yields from ryegrass grown on the M_2 and M_3 soils were significantly greater than ryegrass yields obtained in the M_1 soil. Moreover, average yield from M_3 soil was significantly higher than yields obtained from M_2 soil.

Table 14. The percent nitrogen, phosphorus and sulphur of Ryegrass as influenced by applied fertilizer on soils of different previous management.

Management practice	Element analyzed	Fertilizer applied							
		C	N	P	S	NP	NS	PS	NPS
M_1	Nitrogen	1.98	2.67	2.03	1.96	2.00	2.27	1.99	2.23
	Phosphorus	0.48	0.32	-	-	0.31	0.30	0.55	0.35
	Sulphur	0.37	0.29	-	-	0.18	0.48	0.56	0.39
M_2	Nitrogen	1.92	2.65	2.00	2.17	2.56	2.30	1.93	2.65
	Phosphorus	0.41	0.42	-	-	0.43	0.39	0.45	0.43
	Sulphur	0.17	0.15	-	-	0.13	0.32	0.40	0.41
M_3	Nitrogen	2.45	2.94	1.98	2.24	2.80	2.72	2.01	2.59
	Phosphorus	0.35	0.34	-	-	0.34	0.35	0.37	0.30
	Sulphur	0.44	0.46	-	-	0.41	0.51	0.51	0.43

Table 15. Average dry matter yields (grams/pot) of ryegrass grown in the McKenzie soils as influenced by previous management.

Previous level of management	Average D.M. g/pot	Average D.M. g/pot
M_1 versus M_2	2.05	2.90**
M_2 versus M_3	2.90	5.01**

$L.S.D._{.01} = 0.29$

$L.S.D._{.05} = 0.22$

Nitrogen, phosphorus and sulphur applied to the soils resulted in highly significant differences in mean yields over check treatments (Table 16).

Table 16. Mean ryegrass yields (grams/pot) obtained from the application of nitrogen, phosphorus and sulphur to the soils from location three.

Nutrient	Not added	Added
Nitrogen	2.80	3.84**
Phosphorus	3.05	3.59**
Sulphur	3.19	3.45**

$L.S.D._{.01} = 0.24$

$L.S.D._{.05} = 0.18$

Further examination of the yield data indicated previous soil management affected the ryegrass response pattern (Table 17). On the M_1 soil the only significant interaction resulted from the application of nitrogen + phosphorus or nitrogen + phosphorus + sulphur. In both instances highly significant increased ryegrass yields over the check were recorded.

Table 17. Mean yields (grams/pot) of ryegrass in soils subjected to different previous management and subsequently fertilized with nitrogen, phosphorus and sulphur in greenhouse trials.

Treatment	M_1	M_2	M_3
C	1.52	1.78	4.83
N	1.96	2.61	5.80
P	1.45	1.75	4.74
S	1.31	1.72	4.34
NP	3.09	3.65	5.11
NS	1.98	3.72	5.03
PS	1.60	3.85	4.74
NPS	3.50	4.10	5.53

$L.S.D._{.01} = 0.82$

$L.S.D._{.05} = 0.62$

On the M_2 soil, applied nitrogen was the only nutrient which, when applied singly, resulted in a significant yield increase over the check. However, all combinations of any two or more nutrients when added to the M_2 soil also resulted in highly significant ryegrass yield response.

Interestingly, the only nutrient required for highest yield of ryegrass grown in the M_3 soil was nitrogen which, when added, resulted in a highly significant yield response over the check treatment.

In the absence of applied nutrients the percent ryegrass phosphorus and sulphur tended to be higher in ryegrass grown in the M_2 and M_3 soils than in the unimproved soil (M_1) while the percent nitrogen was higher in ryegrass grown in the M_3 soil (Table 18). When nitrogen fertilizer was applied to the M_1 or M_3 soils, percent ryegrass nitrogen was increased. The application of nitrogen decreased ryegrass sulphur on the M_2 soil; it slightly reduced the percent of phosphorus on all three soils, M_1, M_2 and M_3.

With one exception, the application of nitrogen + sulphur to the soils resulted in an increase in the percentage of these nutrients in the ryegrass. The percent ryegrass sulphur grown in the M_3 soil was not increased following the application of combination fertilizer containing sulphur. When phosphorus + sulphur were added to the soils with or without nitrogen neither ryegrass percent nitrogen nor percent sulphur were markedly different from values of the check.

Location Four Soils

Ryegrass yields from soils obtained from the Rydell farm are presented in the appendix Table 1. Combined first and second harvests were statistically analyzed (Appendix Table 9). The mean yields of ryegrass grown in soils representing three different previous management practices are presented in Table 19. As with the other

Table 18. The percent nitrogen, phosphorus and sulphur of Ryegrass as influenced by applied fertilizer on soils of different previous management.

Management practice	Element analyzed	C	N	P	S	NP	NS	PS	NPS
M_1	Nitrogen	2.04	3.43	2.01	2.31	2.72	3.41	2.00	2.30
	Phosphorus	0.22	0.15	-	-	0.23	0.19	0.37	0.23
	Sulphur	0.17	0.21	-	-	0.18	0.31	0.29	0.27
M_2	Nitrogen	2.12	2.27	1.97	1.97	2.36	2.42	2.27	2.31
	Phosphorus	0.42	0.35	-	-	0.33	0.27	0.29	0.27
	Sulphur	0.27	0.09	-	-	0.09	0.41	0.32	0.35
M_3	Nitrogen	2.76	3.30	2.93	3.14	3.34	3.26	2.80	2.86
	Phosphorus	0.30	0.25	-	-	0.27	0.27	0.32	0.23
	Sulphur	0.27	0.27	-	-	0.24	0.29	0.29	0.27

three soils, ryegrass yields obtained from soils of different previous management were significantly different at the 1 percent level (Table 19).

Table 19. Average dry matter yields (grams/pot) of ryegrass grown in the Rydell soils as influenced by previous management.

Previous level of management	Average D.M. g/pot	Average D.M. g/pot
M_1 versus M_2	2.96	3.80**
M_2 versus M_3	3.80	7.44**

L.S.D.$_{.01}$ = 0.39

L.S.D.$_{.05}$ = 0.29

Analyses of the effect of applied nitrogen, phosphorus and sulphur revealed highly significant responses to applied nitrogen and phosphorus but not sulphur (Table 20).

Table 20. Mean ryegrass yields (grams/pot) obtained from the application of nitrogen, phosphorus and sulphur to the soils from location four.

Nutrient	Not added	Added
Nitrogen	4.34	5.13**
Phosphorus	4.50	4.96**
Sulphur	4.72	4.75

L.S.D.$_{.01}$ = 0.32

L.S.D.$_{.05}$ = 0.24

Differences in yields due to previous management (M_1, M_2 and M_3) and response following fertilizer applications (Tables 19 and 20) suggested the possibility of a fertility x previous management interaction. This showed ryegrass yield in subsequent analyses as a highly significant interaction resulting from applied nitrogen and sulphur in combination (Table 21).

Table 21. Mean yields (grams/pot) of ryegrass grown in soils subjected to different previous management and fertilized with nitrogen and sulphur.

	N_0	N_1
S_0	4.44	4.99
S_1	4.23	5.27

L.S.D. $_{.01}$=0.45 N_0 = No N applied S_0 = No S applied

L.S.D. $_{.05}$=0.33 N_1 = N applied S_1 = S applied

There was also a highly significant interaction from the application of nitrogen + phosphorus to the M_1 and M_2 soil but not in the M_3 soil, as seen in Table 22.

Table 22. Mean yields (grams/pot) of ryegrass grown in soils subjected to different previous management and fertilized with nitrogen and phosphorus.

	M_1		M_2		M_3	
	N_0	N_1	N_0	N_1	N_0	N_1
P_0	1.92	2.55	3.33	3.94	7.09	7.99
P_1	2.80	4.58	3.36	4.56	7.32	7.36

L.S.D. $_{.01}$ = 0.77 N_0 = No N applied P_0 = No P applied

L.S.D. $_{.05}$ = 0.58 N_1 = N applied P_1 = P applied

Furthermore, the mean yield of ryegrass grown in the M_3 soil was significantly higher than yields produced in the M_1 or M_2 soils. The evidence suggests that the different response obtained from applied nitrogen and phosphorus depends upon any previous soil management.

In the absence of applied fertilizer, previous management influenced the percent ryegrass phosphorus and sulphur (Table 23). The percent phosphorus tended to be higher in ryegrass grown in the M_2 soil while percent ryegrass sulphur was higher in both the M_2 and M_3 soils.

The percent nitrogen in ryegrass grown in M_3 soil was not increased when nitrogen fertilizer was applied; neither were percent phosphorus or sulphur.

Percent nitrogen tended to increase in ryegrass over non-fertilized soil when nitrogen and sulphur were applied together. The application of sulphur to the soils resulted in an increase in percent sulphur. However, the percent ryegrass phosphorus did not appear to change following the addition of this nutrient to the soils. Percent phosphorus and sulphur in ryegrass grown in the M_1 and M_2 soils tended to be higher when phosphorus + sulphur were applied without nitrogen.

Table 23. The percent nitrogen, phosphorus and sulphur of Ryegrass as influenced by applied fertilizer on soils of different previous management.

Management practice	Element analyzed	C	N	P	S	NP	NS	PS	NPS
M_1	Nitrogen	2.67	3.36	1.64	2.49	2.24	3.19	1.85	1.94
	Phosphorus	0.20	0.19	-	-	0.23	0.18	0.32	0.21
	Sulphur	0.13	0.24	-	-	0.21	0.27	0.29	0.25
M_2	Nitrogen	2.15	3.20	2.24	2.18	2.72	3.29	2.15	2.69
	Phosphorus	0.33	0.30	-	-	0.35	0.30	0.40	0.28
	Sulphur	0.23	0.21	-	-	0.17	0.32	0.35	0.29
M_3	Nitrogen	2.44	2.64	2.02	2.49	3.72	3.23	3.04	3.07
	Phosphorus	0.26	0.23	-	-	0.27	0.23	0.30	0.29
	Sulphur	0.24	0.23	-	-	0.24	0.31	0.29	0.32

Soil C:N:P:S Status

The percent dichromate oxidizable carbon, total nitrogen, total phosphorus, organic phosphorus and total sulphur from the surface 10 cm of soils subjected to different previous management are presented in Table 24 for the four locations. Soils from location three had greatest quantities of oxidizable carbon due to high organic matter. This field was located just one mile from the Pacific Ocean. Only at location four was the percent oxidizable carbon in the fertilized but not grazed soil (M_2) higher than in unimproved soil (M_1) or improved and grazed soil (M_3). A plausible explanation was that this M_2 soil sample was collected from the south slope on the same valley where the M_3 sample was taken. CEC and other nutrients were also different (Table 24) from M_1 and M_3 soils.

There were some differences in percent nitrogen within locations but with no clear trend which could be attributed to previous management (Table 24).

When rounded to the nearest hundredth, the percent of total phosphorus and total sulphur appeared rather constant within locations. Note that soils from location three (near the ocean) contained almost double the total sulphur content of other locations. No distinct trend in percent soil organic phosphorus was evident within or between locations.

Table 24. Soil test results from each location and for different previous management.

Location	Management practices	Percent				
		Oxidizable carbon	TN	TP	OrP	TS
Barker (L_1)	M_1	5.05	0.23	0.07	0.03	0.01
	M_2	4.30	0.26	0.06	0.03	0.02
	M_3	3.84	0.21	0.06	0.03	0.03
Gross (L_2)	M_1	4.02	0.27	0.08	0.01	0.02
	M_2	3.81	0.25	0.08	0.04	0.02
	M_3	2.99	0.22	0.09	0.04	0.02
McKenzie (L_3)	M_1	6.64	0.53	0.08	0.05	0.04
	M_2	6.11	0.46	0.10	0.02	0.04
	M_3	6.31	0.51	0.12	0.08	0.04
Rydell (L_4)	M_1	3.22	0.25	0.04	0.03	0.01
	M_2	4.31	0.33	0.07	0.04	0.01
	M_3	2.90	0.23	0.04	0.02	0.01

The high correlation (r = 0.89) obtained when the oxidizable carbon and total nitrogen values from all soils studied were related (Figure 4) merely confirmed the constancy of soil C:N ratios in soils under contrasting environmental conditions.

A similar though not as good relationship existed between soil total nitrogen and total phosphorus (Figure 5). The value r = 0.66 from such a correlation affirms that soil nitrogen status was related to soil phosphorus status. A higher correlation existed between soil total nitrogen and total sulphur (r = 0.79), Figure 6.

The C:N, C:S, C:P, N:S ratios obtained from all soils studied appear in Table 25.

The C:N ratio appeared rather constant. Apart from the results for location one soil, the C:N ratio appeared little influenced by previous management.

At each location the C:S ratio and C:P ratio were lower in the improved (M_3) soils than in the unimproved (M_1) soils. The C:S ratio ranged from 361:1 to 122:1 and the C:P ratio ranged from 80:1 to 34:1. The N:S ratio ranged from 17:1 to 7:1.

A mean C:N:P:S ratio for unimproved (M_1) soils was 156:10:2.5:.7 while the mean ratio of improved (M_3) soils was 142:10:2.8:1. Apart from the slightly lower C:N ratio associated with soils from improved pastures few differences were evident in the C:N:P:S ratios as a result of previous management.

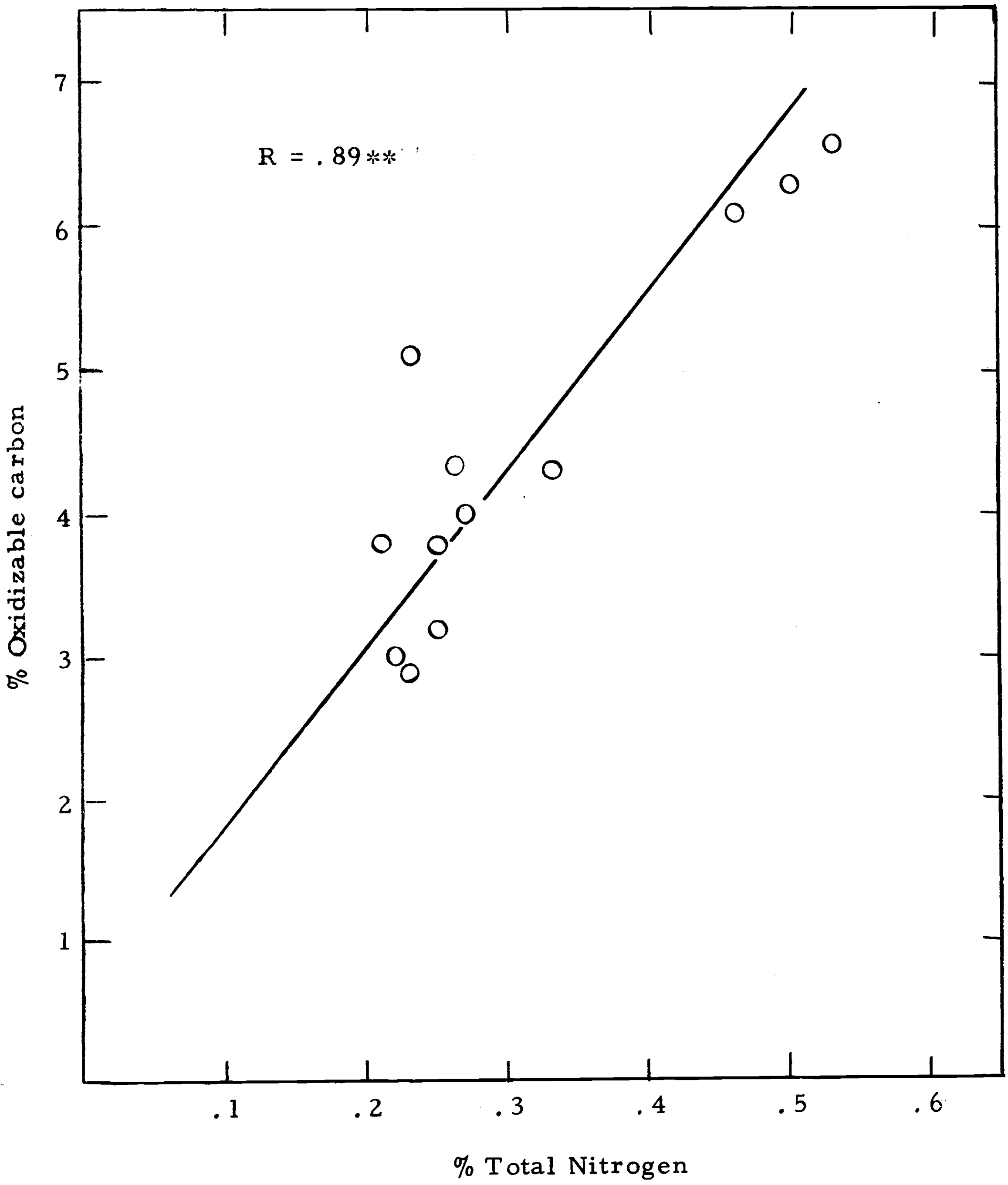


Figure 4. The relationship between oxidizable carbon and total soil nitrogen.

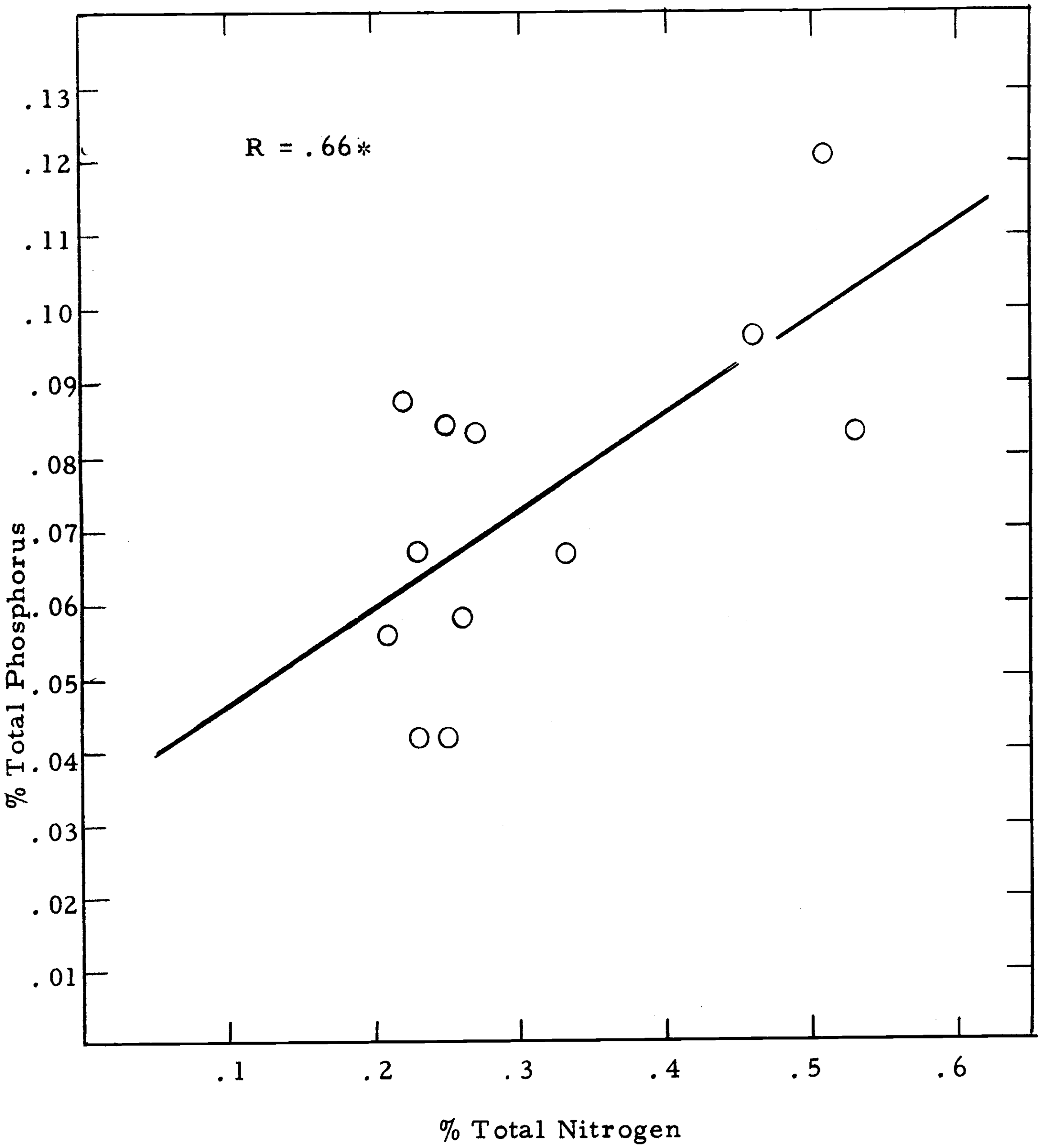


Figure 5. The relationship between soil total nitrogen and soil total phosphorus.

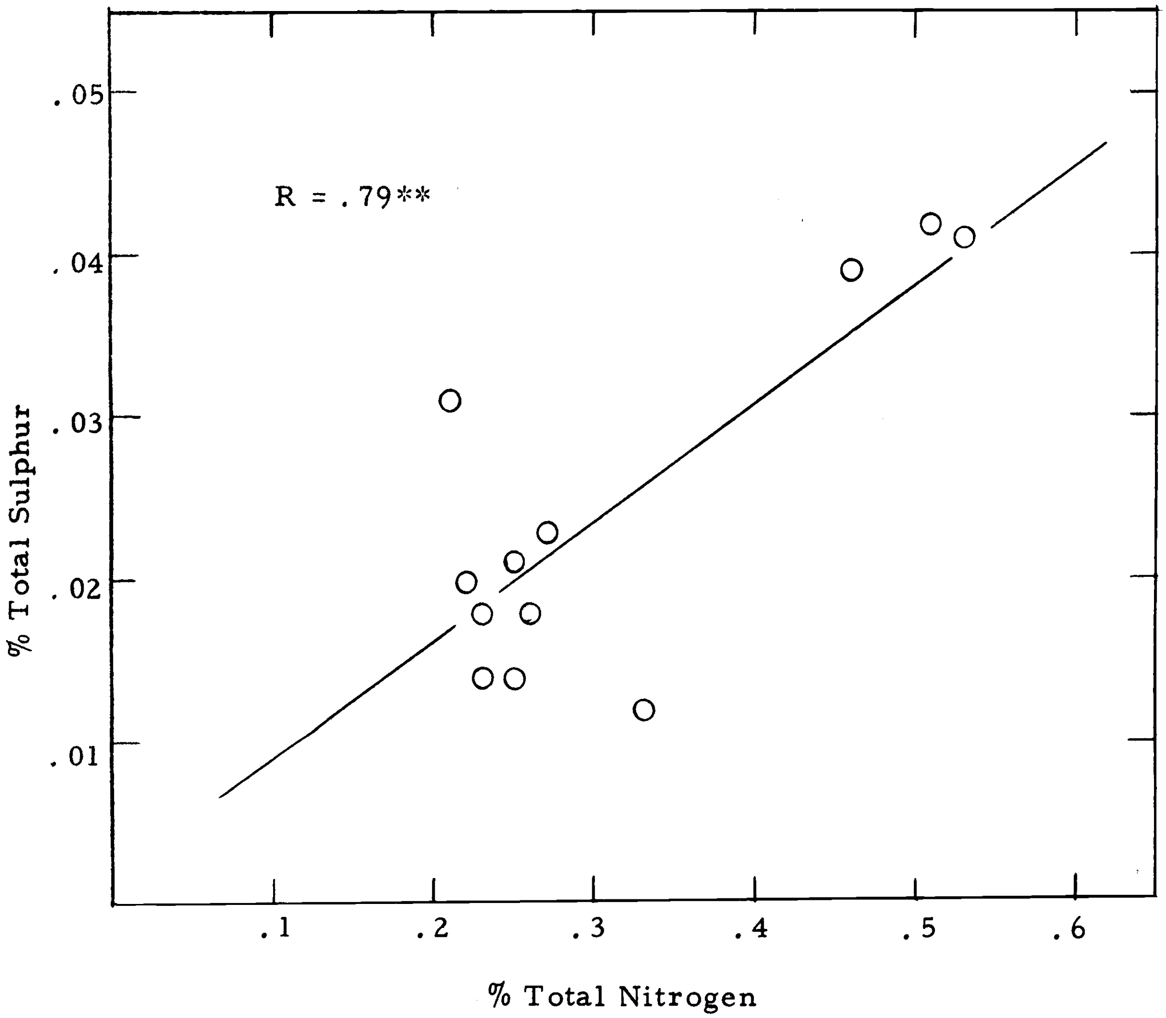


Figure 6. The relationship between soil total nitrogen and soil total sulphur.

Table 25. Carbon:nitrogen, Carbon:sulphur, Carbon:phosphorus and Nitrogen:sulphur ratios from soils sampled from each location.

Location	Management practice	C:N	C:S	C:P	N:S
Barker(L_1)	M_1	22:1	361:1	76:1	17:1
	M_2	16:1	245:1	74:1	15:1
	M_3	18:1	122:1	68:1	7:1
Gross(L_2)	M_1	15:1	179:1	48:1	12:1
	M_2	15:1	182:1	46:1	12:1
	M_3	14:1	154:1	34:1	11:1
McKenzie(L_3)	M_1	13:1	162:1	80:1	13:1
	M_2	13:1	157:1	64:1	12:1
	M_3	13:1	152:1	52:1	13:1
Rydell(L_4)	M_1	13:1	230:1	77:1	18:1
	M_2	13:1	360:1	64:1	27:1
	M_3	13:1	165:1	68:1	13:1

DISCUSSION

Conservation of the soil resource has much to do with alternatively restoring, maintaining or improving the soil fertility status. The dung and urine return on fertilized grass-legume pasture has been demonstrated as a proven means of improving soil fertility and productivity (Melville and Sears, 1953; Sears and Thurston, 1953). The present investigation involved four factors in previous management: (1) application of superphosphate fertilizer, (2) symbiotic nitrogen fixation by subterranean clover, (3) dung and urine returns by animals, and (4) time or period the field was subjected to one or a combination of these management practices. Thus this study was initiated to test the hypothesis that intensively grazed grass-legume pastures which have received annual superphosphate topdressing accumulated a reserve of nitrogen, phosphorus and sulphur which could be determined directly by soil chemical analysis and indirectly by biological assay.

Greenhouse Study

One of the simplest techniques designed to measure the influence of previous management on the soil fertility status of soils is that of a biological assay where a grass crop is grown in soil sampled from areas which had been subjected to contrasting histories. Soils from four locations in Western Oregon were sampled in such a way as to include 10 cm of topsoil from nearly adjacent fields where each had been subjected to three different management practices namely, unimproved soil (M_1), improved but not grazed soil (M_2) and an improved grazed soil (M_3). The period in which soils M_2 and M_3 had been improved and/or grazed increased from location one to location four (Table 1). The unimproved M_1 soil in a sense was a reference for each location since it was neither fertilized nor grazed.

While the present investigation was conducted in the greenhouse on soils taken from fields, considerable experimentation on improved grass-legume pastures in situ has pointed out management practices which enhance soil fertility. Thus superphosphate applied to clover dominant pastures usually resulted in increasing the rate of symbiotic nitrogen fixation and enhanced soil nitrogen status (Truble and Donald, 1938; Anderson and McLachlan, 1951; Greenland, 1971). Improved (M_2) and grazed soil (M_3) received both phosphorus and sulphur from superphosphate followed by nitrogen from symbiotic nitrogen fixation while M_3 soils in addition undoubtedly benefited differentially from nutrients recycling due to animal excreta (Sears and Newbold, 1942; Sears, 1953; Jones, Lawler and Ruckman, 1970).

For soils from location one, average ryegrass yields grown in the unimproved soils (M_1) suggested that both nitrogen and sulphur but not phosphorus limited ryegrass growth (Figure 7). On the improved (superphosphate fertilized soils, M_2), the ryegrass yield indicated a similar response to nitrogen as in the M_1 soils, but in this case nitrogen + phosphorus treatment showed marked response. On the average, however, yields from M_2 soils were greater than those from M_1 soils indicating that in five years of superphosphate application, the clover already had improved nitrogen status of the soil. Ryegrass yields on soils from the fertilized and grazed fields (M_3) showed that only nitrogen limited ryegrass yields; average yields were higher than those obtained from either the M_1 or M_2 soils (Figure 7).

For location two, ryegrass yields on soils from M_1, M_2 and M_3 areas closely paralleled those obtained for location one soil from similar treatments. One exception involved nitrogen + phosphorus where on the M_1 soil phosphorus was apparently the second limiting element after nitrogen (Figure 8). That the application of all three nutrients, nitrogen, phosphorus and sulphur, to ryegrass grown in M_1 soil did not result in as high yields as obtained on either M_2 or M_3 soils similarly treated, suggested some other factors were limiting plant growth. Nitrogen, phosphorus and sulphur appeared as limiting nutrients on the improved soils M_2 and M_3 at location two.

For soils from location three, ryegrass yields obtained on the M_2 soil did not attain those obtained from the M_3 soil. These soils were noted for their high organic matter status which possibly reduced availability of added phosphorus and sulphur. Perhaps the most important difference in ryegrass yields obtained from soils at this

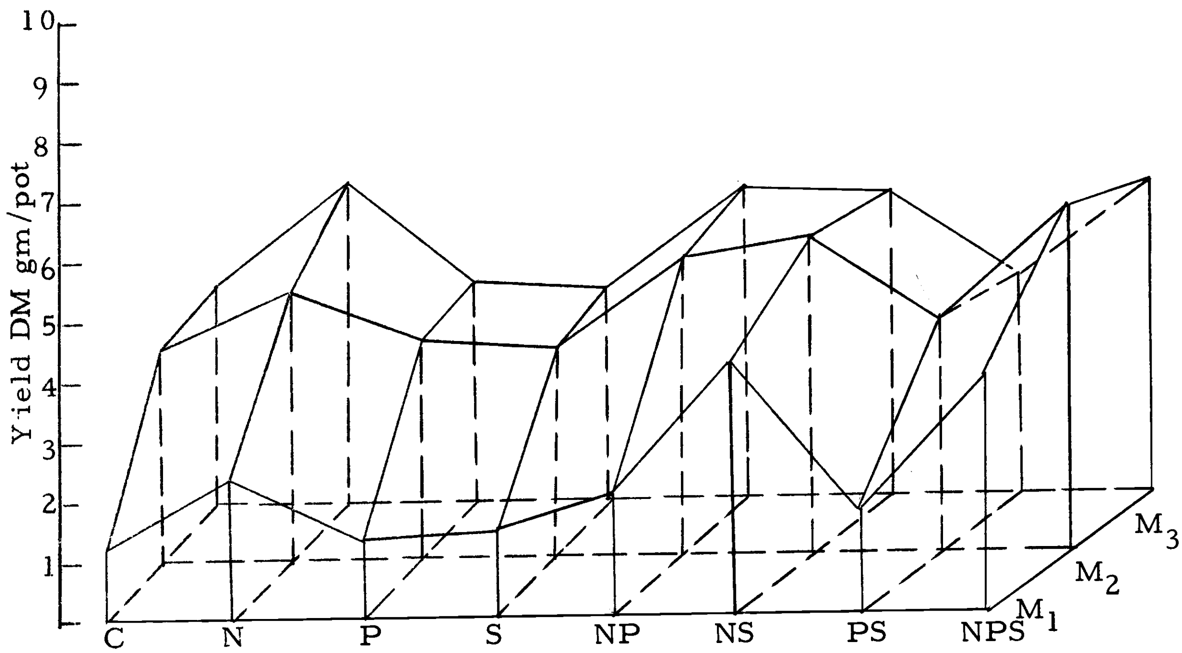


Figure 7. Average ryegrass yields (gm/pot) grown in variously fertilized soil from the Barker location as influenced by previous management.

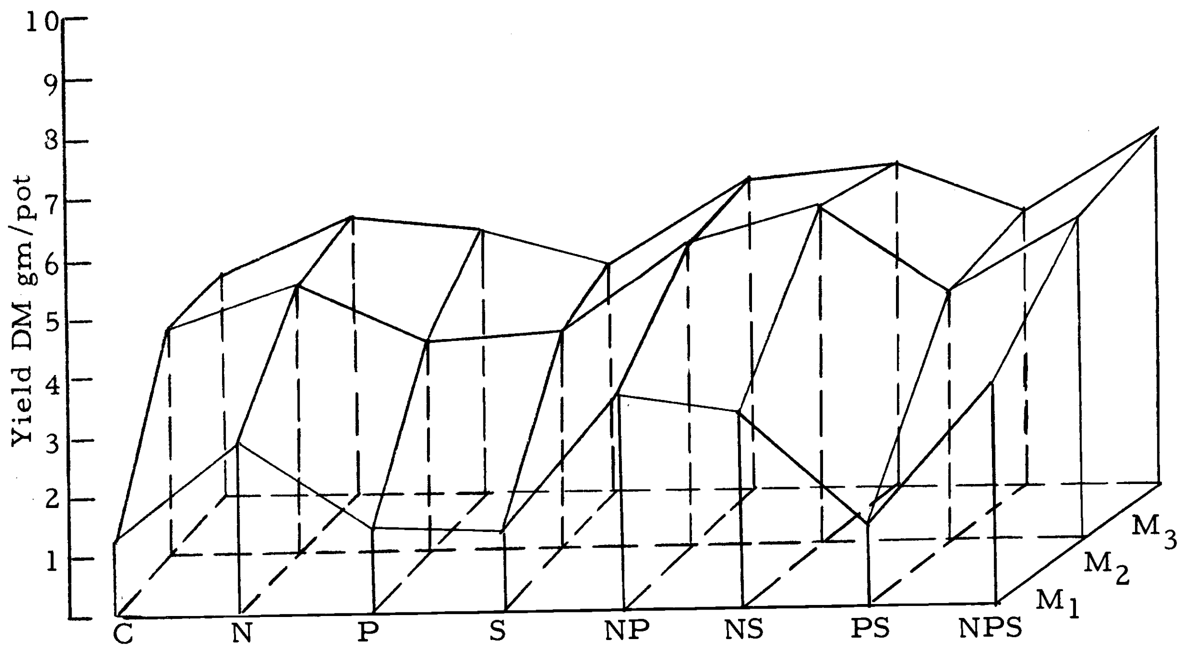


Figure 8. Average ryegrass yields (gm/pot) grown in variously fertilized soil from the Gross location as influenced by previous management.

location (McKenzie) was the differences due to previous management. The influence of dung and urine return, recycling of nitrogen, phosphorus and sulphur was apparent. Soils which had been subjected to ten years of annual applications of superphosphate and that were heavily grazed M_3 apparently had accumulated a high reserve fertility (Figure 9). In fact, nitrogen proved to be the only limiting nutrient as reflected by ryegrass yield when grown in the M_3 soil at location three. Even in the absence of any applied nutrient, plant yields on this soil more than doubled over those obtained on the fertilized but not grazed M_2 soil.

McLachlan and Norman (1962) indicated that the maximum fertilizer requirement for optimum production on unimproved pasture was greater than for improved pasture due to the residual effect and soil organic matter accumulation. When the stocking rates were increased the recycling of nitrogen, sulphur and phosphorus in the intra-system was also increased; however, some parts were readied for uptake by the plant and some were accumulated in soil organic matter which slowly mineralized (Walker, 1956, 1957; Gunary, 1968).

For soils from location four (Figure 10), further confirmation of the role of the heavy stocking on well fertilized grass-legume pastures over a period of about 12 years was obtained from ryegrass grown in M_3 soils. Indeed, no ryegrass response to applied nutrients (singly or combination) on this M_3 soil was observed. Moreover, not

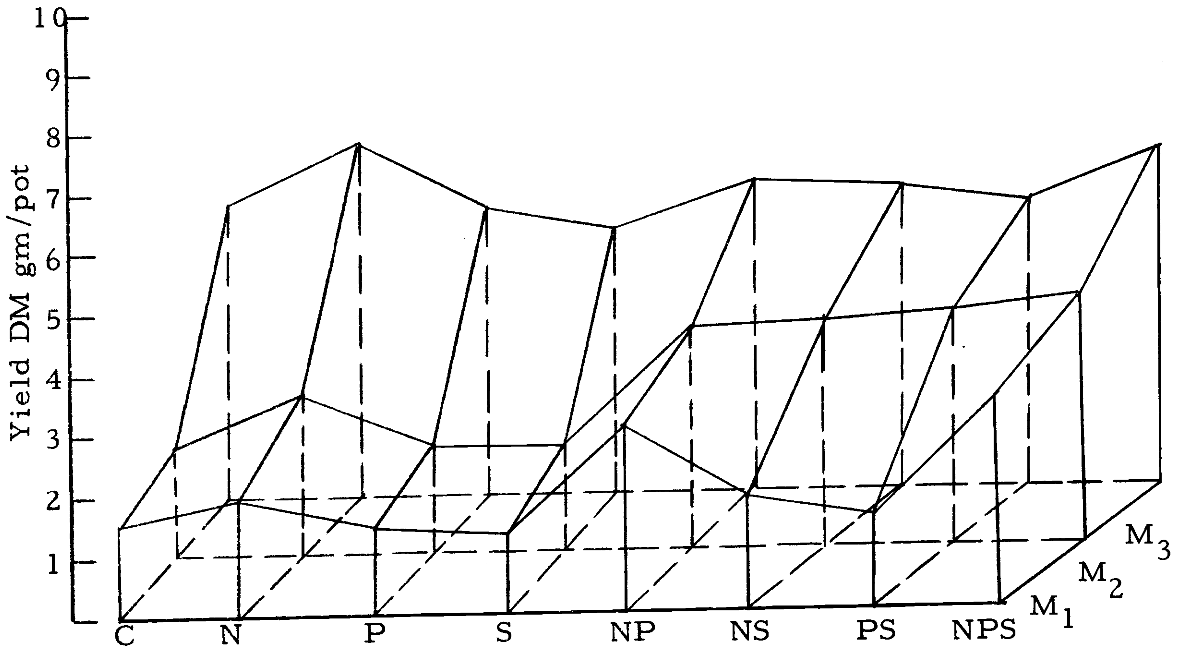


Figure 9. Average ryegrass yields (gm/pot) grown in variously fertilized soil from the McKenzie location as influenced by previous management.

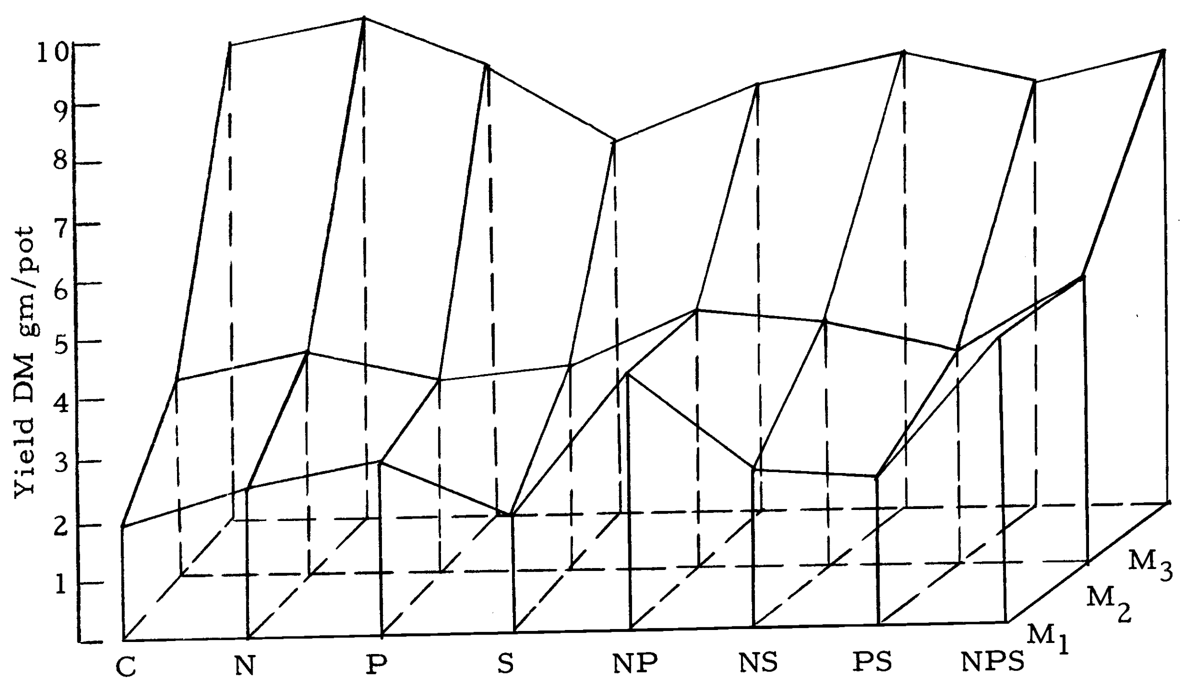


Figure 10. Average ryegrass yields (gm/pot) grown in variously fertilized soil from the Rydell location as influenced by previous management.

only were the highest ryegrass yields obtained from M_3 soil at this location (Rydell), but there were marked differences in yields between soils depending on previous management histories.

It is apparent from the ryegrass yields obtained from the variously fertilized soils from the three different previous management systems that location one and two could be placed in one group and location three and four in another (Figure 15). A suggested grouping of this kind based on pattern of ryegrass yield obtained according to treatment emphasized the role of nutrient recycling following a decade or more of improved superphosphate grass-legume pastures heavily stocked. Similar results have been reported by Sears and Thurston (1953) and Jones, Lawler and Ruckman (1970). When one reflects upon the current pollution problems associated with heavy commercial nitrogen fertilizer application to fields or alternatively nitrate losses from feed lot operations one can view in perspective that intensively grazed grass-legume pasture is based on a sound ecological principle of nitrogen recycling.

The previous fertilization and grazing influence on soil fertility status of grass-legume pastures can be further examined on the basis of both yield and nutrient content of the ryegrass. In Figure 11 and Appendix Table 5 are presented the average ryegrass yields from each location for soils subjected to the three different previous managements. Ryegrass yields on all M_1 soils tended to be similar. No

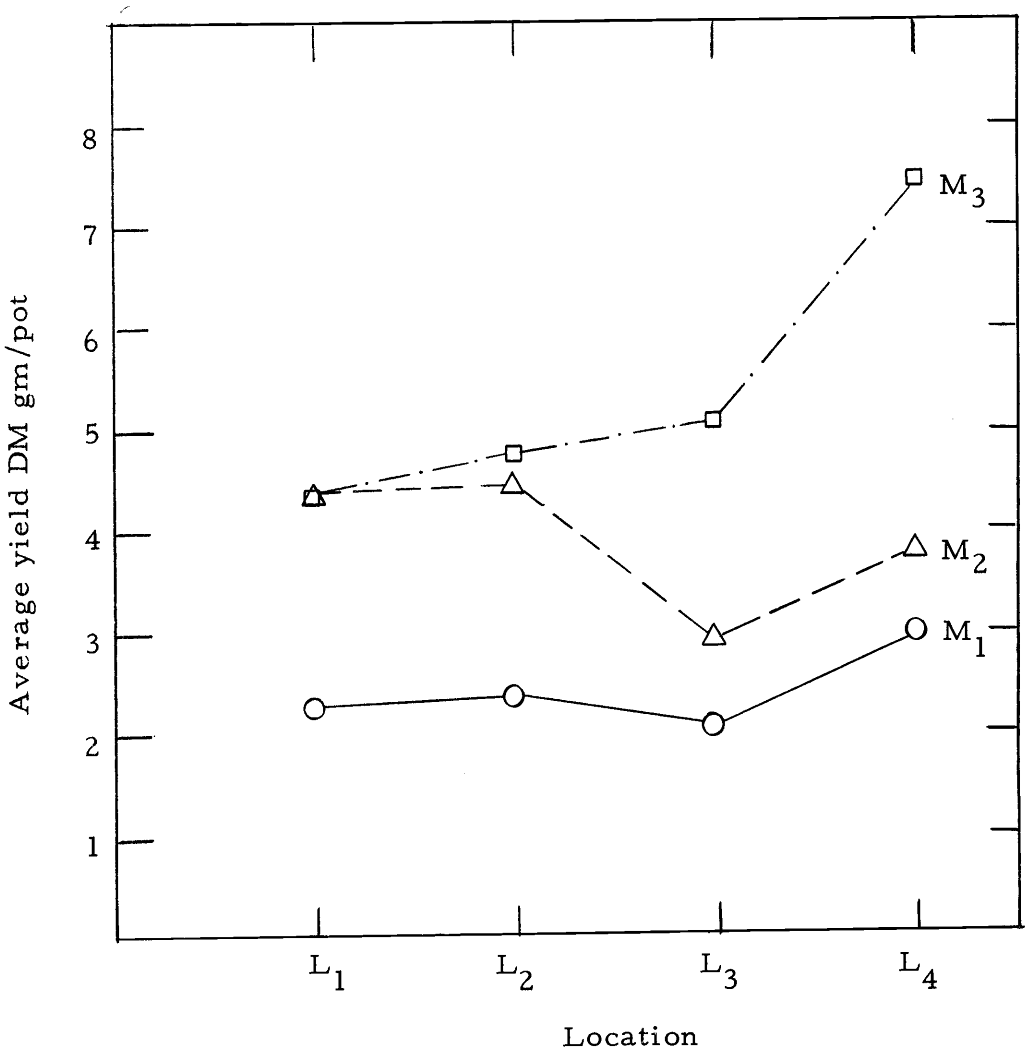


Figure 11. Average ryegrass yields (gm/pot) as influenced by previous soil management at each location.

ready explanation can be given why average ryegrass yields from M_2 soils at location three were lower than the other locations. Possibly the low soil temperature from this coastal soil and associated high soil organic matter status (Table 24), partially immobilized the nitrogen, phosphorus and sulphur. Nevertheless, average ryegrass yields from M_2 soil were higher than those obtained from the M_1 soils.

Average yield of ryegrass grown in the M_3 soils showed a marked increase from location one to location four reflecting the build-up in nitrogen, phosphorus and sulphur resulting from a varying period of fertilization and grazing. The residual effect of superphosphate (McLachlan and Norman, 1962) and the return of dung and urine on the pasture was a significant factor in the recycling of nutrients (Melville and Sears, 1953; Walker, 1956, 1957; Watkin, 1957 and Wolton, 1963).

The degree of difference between mean yield of ryegrass grown in the soils which had no annual excreta returned (M_2) compared with those grazed (M_3) widened from location one to location four due to increasing effects from stocking. Jones, Lawler and Ruckman (1970) have reported similar observations. The higher yields obtained from ryegrass on the M_3 soils could also be due to effects other than residual nutrient accumulation. Greenland (1971), for instance, has shown that improved pastures, by stabilizing the soil in a condition less likely to develop a crust, will have an effect on yield independent of their effects on the nitrogen status of the soil.

Average content of nitrogen in ryegrass (mg N/pot) grown in the differently managed soils from each location (Figure 12, Appendix Table 5) showed that the application of superphosphate and stocking history markedly affected the nitrogen content of the assay crop. Moreover, this influence paralleled the results for mean ryegrass yields. Ryegrass nitrogen was not different among the M_1 soils. Superphosphate applied annually to the soils (M_2) had the effect of increasing ryegrass nitrogen. Ryegrass nitrogen content increased markedly from location one to location four (M_3 soils) dramatically indicating the influence that superphosphate and stocking history had imposed on the soil nitrogen supplying capability. Those results are consistent with the work of Jones, 1964; McNaught and Chrisstoffels, 1961; Bouma, Spencer and Dowling, 1969.

The influence of dung and urine returns on grazed-legume pastures has been eloquently illustrated by Melville and Sears (1953). These workers showed yields of nitrogen from grazed grass-legume pasture to be about 25 percent higher than from comparable ungrazed pastures.

It is likely that the phosphorus content of ryegrass grown in the M_1 soils more reflects the amount of phosphorus in the soil parent material than any other factor as Walker and Adams (1958) showed. The phosphorus content of ryegrass (Figure 13, Appendix Table 5) was

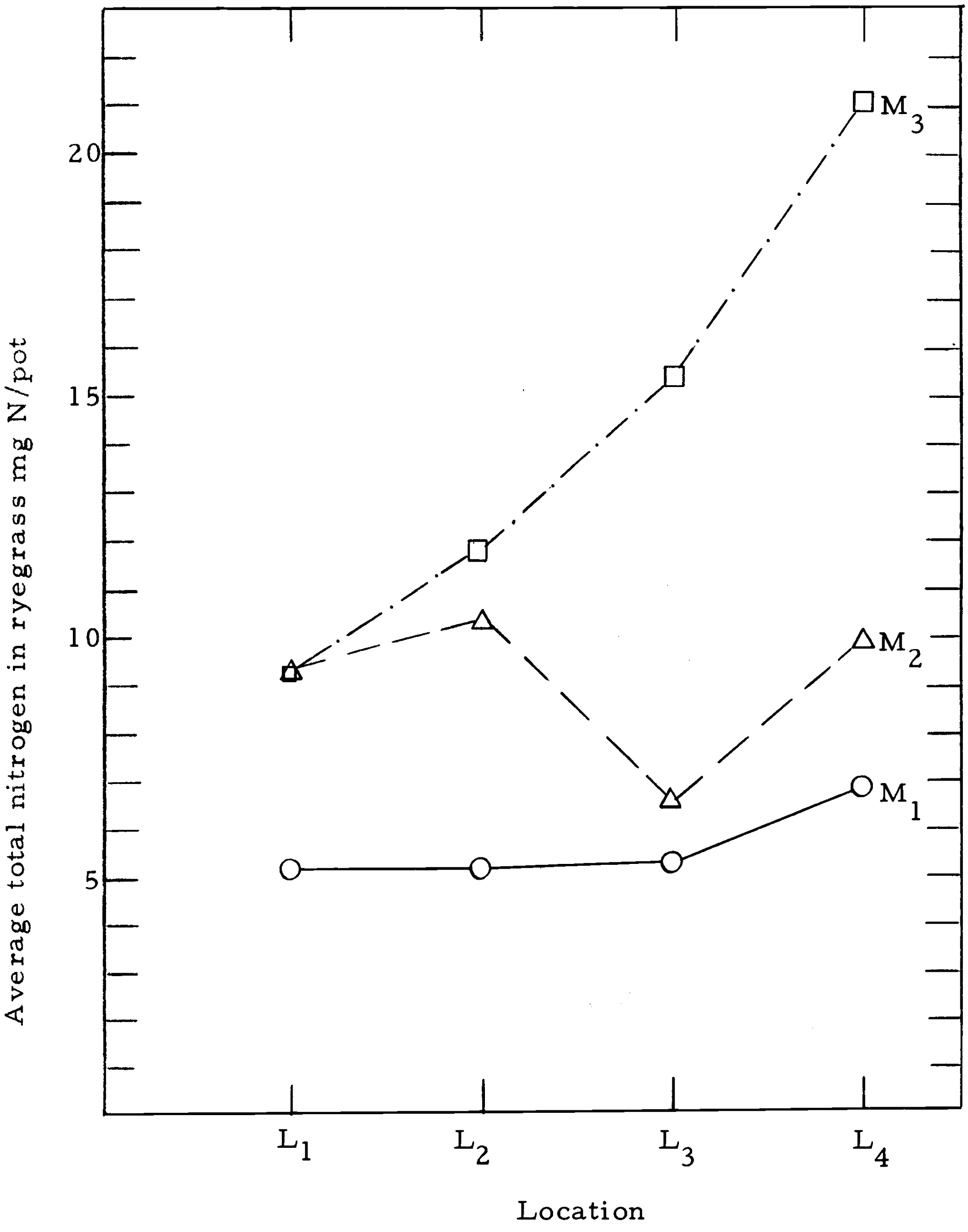


Figure 12. Average nitrogen content (mg N/pot) of ryegrass as influenced by previous soil management at each location.

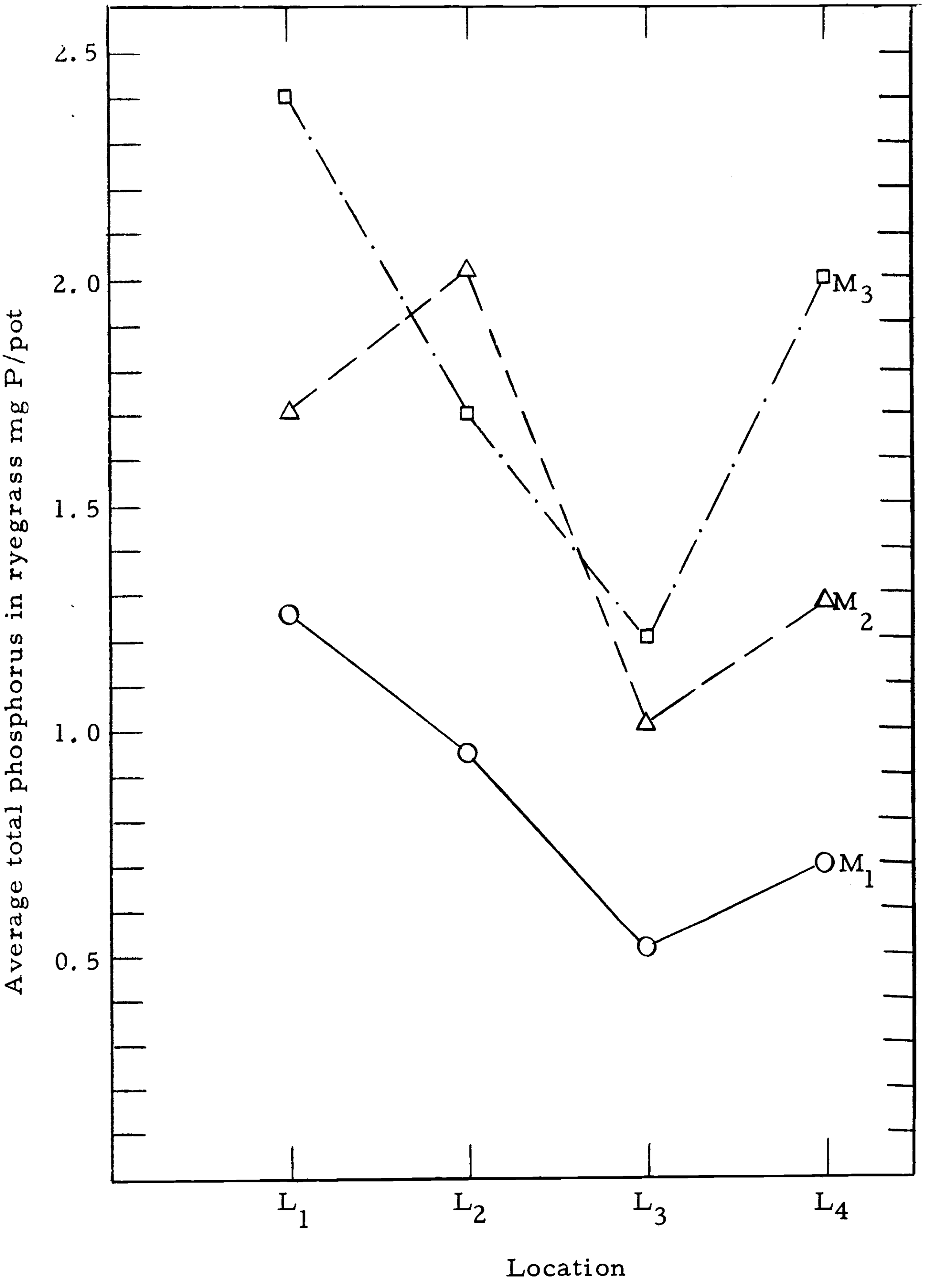


Figure 13. Average phosphorus content (mg P/pot) of ryegrass as influenced by previous soil management at each location.

increased in the improved soils (M_2 and M_3) undoubtedly due partially to previous superphosphate applications. However, at location four the much higher ryegrass phosphorus content might also reflect the return by dung and urine. That ryegrass phosphorus content was uniformly low at location three again might be associated with the high soil organic matter status of this cool coastal soil. Gunary (1968) has shown that the organic phosphate in dung was initially highly available, but its availability diminished after a period of contact with the soil.

As might be expected the ryegrass sulphur content varied least among locations when grown in the M_1 soils. The ryegrass sulphur content was higher on the improved soils M_2 than the unimproved soils even in the absence of returns from dung and urine. Jones (1964) pointed out that total sulphur uptake increased with increasing application of superphosphate. However, there was a considerable increase in ryegrass sulphur content in plants grown in soils (M_3) from pasture that had not only been fertilized but also subjected to heavy stocking (Figure 14, Appendix Table 5). Warth and Krishnan (1935) reported that the proportions of excreted and egested sulphur depend on the amount ingested but about 70 percent is found in the urine in various forms. As much as 84 percent of the sulphur was excreted in the urine when sulphate was added to the diet (Doak, 1952).

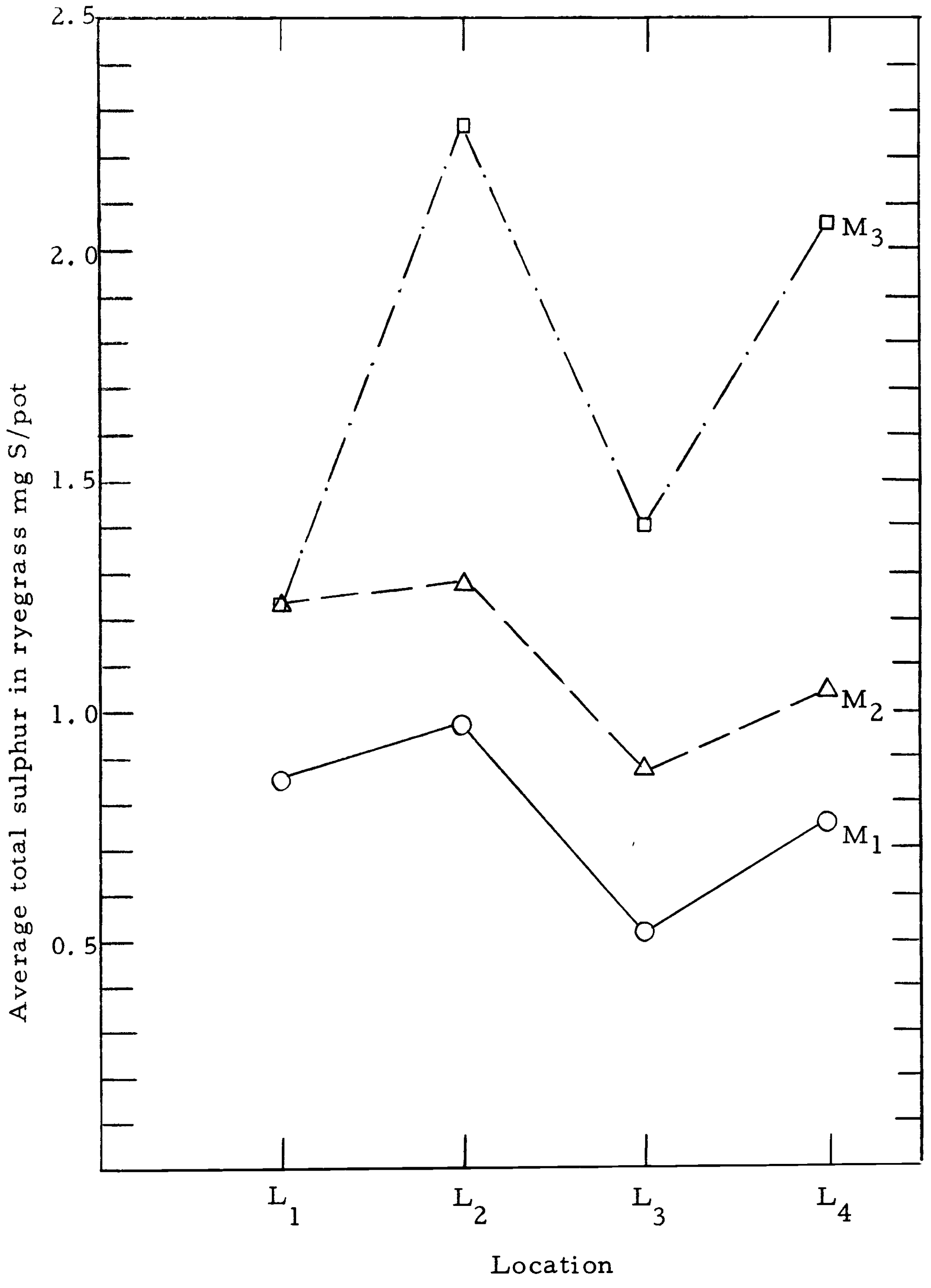


Figure 14. Average sulphur content (mg S/pot) of ryegrass as influenced by previous soil management at each location.

It is of interest to note that due to the relatively low plant sulphur content in ryegrass grown in the M_3 soil from location three, there is not a steady increase in ryegrass sulphur content associated with the anticipated greater dung and urine return as was the case with nitrogen. The total sulphur content of this M_3 soil at location three was quite high which again suggests a limitation this soil might have to readily mineralize and recycle available sulphur (Table 24).

Soil Chemical Analysis

The carbon, nitrogen, phosphorus and sulphur status were determined for the top 10 cm of soils to see whether simple soil chemical analyses would reflect changes in soil fertility status resulting from previous management.

Various researchers have attempted to analyze surface soil properties utilizing C:N:P:S ratios (Donald and Williams, 1954; Walker, 1956, 1957; Williams and Donald, 1957; Walker and Adams, 1958; and Williams, Williams and Scott, 1960), and several investigations (Donald and Williams, 1954; Walker, 1956, 1957) have reported changes in soil organic matter following years of applied superphosphate to grass-legume pastures. It was hoped that such changes in organic matter of M_1, M_2 and M_3 soils would not merely be limited to qualitative ones but would also appear as quantitative changes detectable by chemical analyses. Ratios of the major element constituents of organic matter C, N, P and S do provide some indication of qualitative changes in the soil organic fraction. Narrow ratios suggest more microbial activity and hence increased evidence for recycling of elements from complex organic molecules to simple ionic forms available to plants. It is likely that the C:N:P:S ratios in themselves provide too gross values for critical analytical analysis and hence pose problems in interpretation. It is interesting, however, that the trend in changes of the C:N:P:S ratios from unimproved to improved soil observed in this study were consistent with the bioassay results obtained in the greenhouse ryegrass experiment.

The tendency for oxidizable carbon to be higher in the unimproved soils and lowest in the improved grazed M_3 soils (Table 24) could be explained on the basis of increased biological activity in the improved grazed soils. On the other hand little change in percent nitrogen or organic phosphorus within locations could be attributed to previous management. As has been noted by other workers (Williams and Donald, 1957; Williams, Williams and Scott, 1960) there was a high correlation between oxidizable carbon and total nitrogen values obtained. In three of the four locations, the C:N ratios remained constant regardless of previous management. This would suggest a similar gain and loss budget for carbon and nitrogen balance in the improved as well as the unimproved soils.

Perhaps the most interesting relationship revealed was that for soil total nitrogen and total sulphur. These elements were highly correlated and furthermore a good correlation was also noted between total nitrogen and total phosphorus. One might infer that most of the soil phosphorus and sulphur are held in an organic form and changes in soil nitrogen are directly associated with changes in soil phosphorus and soil sulphur status. Soil organic matter accumulation and the subsequent decay necessary for recycling of nitrogen, phosphorus, and sulphur indicate an interdependence of these elements. That the improved grazed grass-legume M_3 soils generally had lower C:S, C:P and N:S ratios than unimproved soils support the hypothesis that recycling of these nutrients more likely occurs in the former situation.

The mean C:N:P:S ratio for unimproved (M_1) soils was 156:10:2.5:.7 while the mean ratio of improved (M_3) soils was 142:10:2.8:1. While these ratios did not markedly differ from one to another, they do suggest that previous fertilizer and stocking history could be initiating a change qualitatively in the soil organic matter that favors more efficient recycling of nutrients. That organic material added to a soil with narrower C:N ratios tendsto release available nitrogen more readily is well recognized. It might well be that the somewhat narrower C:N:P:S ratio found in improved soils results in a more rapid recycling of all three nutrients.

SUMMARY AND CONCLUSIONS

The study was initiated to investigate the influence of previous fertilizer and stocking history on surface soil fertility. More particularly, it involved both laboratory and greenhouse trials designed to determine the carbon, nitrogen, phosphorus and sulphur status of these soils. Four pasture locations in Western Oregon were selected for study. At each location three adjacent fields were sampled representing different management practices ranging from unimproved, improved fertilized, to improved fertilized and variously stocked. Soils sampled to a depth of 10 cm were subsequently used for bioassay in greenhouse studies and for chemical analysis. Percentages of oxidizable carbon, total nitrogen, total phosphorus, organic phosphorus and total sulphur were determined in the laboratory.

The greenhouse study involved growing ryegrass in sieved soil taken from all 12 fields (four locations). Nitrogen, phosphorus and sulphur were applied both singly and in combination to all soils planted to ryegrass (Lolium multiflorum). Two harvests at prebloom stage were considered. Dry matter yields as well as total plant nitrogen, phosphorus and sulphur were determined.

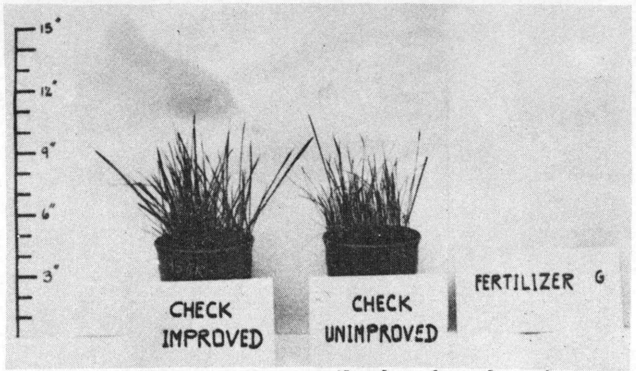
Analyses of results showed that both dry matter yields and nutrient status of ryegrass were significantly influenced by previous fertilizer history and stocking practices. Ryegrass yields on soils from subterranean clover fields which had received annual topdressing of superphosphate and had been grazed were markedly higher than yields obtained from unimproved soils. Moreover, ryegrass yields were directly proportional to the years of fertilizer history and duration of stocking.

Where previous stocking had been the heaviest, no response to applied nutrients was noted in ryegrass yields. Furthermore, the sulphur and particularly nitrogen contents of ryegrass increased, as did yield, in accordance with the previous superphosphate and stocking intensity practices.

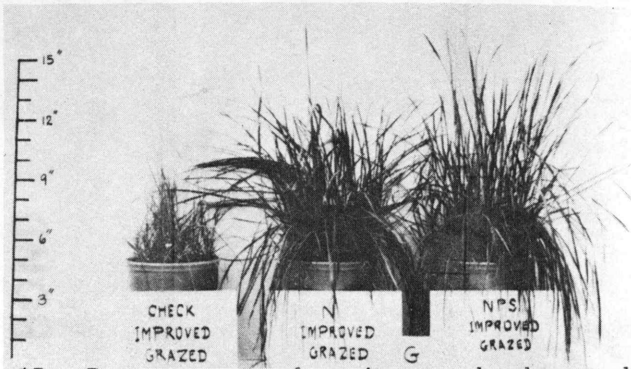
Generally, soil from fertilized but not grazed subterranean clover fields were intermediate in ryegrass yields and nutrient composition. Although not as productive as their fertilized and stocked counterparts, improved but not grazed soils gave better ryegrass yields than the unimproved soils.

There was considerable evidence from the ryegrass greenhouse experiments on soils of contrasting histories that the application of superphosphate increased soil phosphorus and sulphate reserves. Moreover, that these nutrients stimulated, through symbiotic nitrogen fixation of the clover, a build-up in reserve soil nitrogen appeared evident. However, each one of these nutrients remained deficient in any of the soils studied so long as the fields had not been stocked. Only in situations where considerable stocking of pastures had occurred was there sufficient reserve accumulation of nitrogen, phosphorus and sulphur to supply ryegrass. These results confirm the importance of dung and urine in recycling of nitrogen, sulphur and possibly phosphorus. We suggest that sulphur rather than phosphorus is the first limiting nutrient after nitrogen in improved intensively grazed grass-legume pasture in Western Oregon.

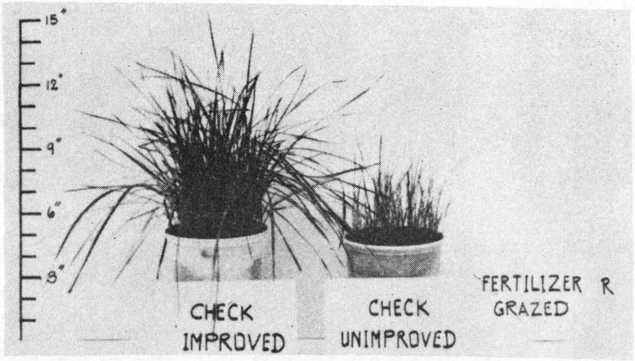
From the soil chemical analysis it was concluded that the average C:N:P:S ratios (156:10:2.5:.7) for unimproved M_1 soils and average C:N:P:S ratios (142:10:2.8:1) for fertilized stocked soils were not markedly different. However, there was a suggestion that previous superphosphate fertilizer and stocking history could be effecting a qualitative change in soil organic matter. Furthermore, the tendency of a narrow C:N:P:S ratio in the improved soils might suggest hastened cycling of these nutrients from soil to plant. The narrower C:S, C:P and N:S ratios of improved fertilized grazed soils further supports the hypothesis that recycling of these nutrients into available forms is favored in these soils.



15a. Ryegrass grown on soil taken from location one where differences in check treatments due to past management are minimal.



15c. Ryegrass response from nitrogen, phosphorus and sulphur applied to soil taken from a lightly stocked field.



15b. Ryegrass grown on soil taken from location four where marked differences in check treatments indicate effect of past management on subsequent plant growth.

15d. Ryegrass response from nitrogen applied to soil taken from a heavily stocked field.

Figure 15. Ryegrass response to past management practices or to apply nutrients.

BIBLIOGRAPHY

Anderson, A. J. 1942. Molybdenum deficiency on a South Australian ironstone soil. The Journal of Australian Institute of Agricultural Science 8:73-75.

____________ 1946. Molybdenum in relation to pasture improvement in South Australia. Journal of the Council Science and Industrial Research 19:1-15.

Anderson, A. J. and D. Spencer. 1950a. Molybdenum in nitrogen metabolism of legumes and non-legumes. Australian Journal of Scientific Research 3B-431-449.

Anderson, A. J. and K. D. McLachlan. 1951. The residual effect of phosphorus on soil fertility and pasture development on acid soils. Australian Journal of Agricultural Research 2:377-400.

Anderson, A. J. and D. V. Moye. 1952. Lime and molybdenum in clover development on acid soils. Australian Journal of Agricultural Research 3:95-110.

Anderson, A. J. 1956. Molybdenum deficiencies in legumes in Australia. Soil Science 81:173-182.

Andrew, C. S. 1962. Influence of nutrition on nitrogen fixation and growth of legumes. In: A review of nitrogen in the tropics with particular reference to pastures; a symposium, ed. by a committee of the Division of Tropical Pastures, Commonwealth Scientific and Industrial Research Organization, Australia. Farnham Royal, Bucks, England. (Commonwealth Agricultural Bureaux. Commonwealth Bureau of Pastures and Field Crops. Bulletin 46).

Bouma, D., K. Spencer and E. J. Dowling. 1969. Assessment of the phosphorus and sulphur status of subterranean clover pastures. 3. Plant tests. Australian Journal of Experimental Agriculture and Animal Husbandry 9:329-340.

Bremner, J. M. 1965. Total nitrogen. In: Methods of soil analysis. Part 2. Chemical and microbiological properties, ed. by C. A. Black et al. Madison, Wisconsin. p. 1149-1178. (American Society of Agronomy. Agronomy: a series of Monographs. No. 9).

Brockman, J. S., P. G. Shaw and K. M. Wolton. 1970. The effect of phosphate and potash fertilizers on cut and grazed grassland. The Journal of Agricultural Science 74:397-407.

Bromfield, S. M. 1961. Sheep faeces in relation to the phosphorus cycle under Pastures. Australian Journal of Agricultural Research 12:111-123.

Bromfield, S. M. and O. L. Jones. 1970. The effect of sheep on the recycling of phosphorus in hayed-off pastures. Australian Journal of Agricultural Research 21:699-711.

Carter, E. D. and H. R. Day. 1970. Interrelationships of stocking rate and superphosphate rate on pasture as determinants of animal production. I. Continuously grazed old pasture land. Australian Journal of Agricultural Research 21:473-491.

Chesnin, L. and C. H. Yien. 1950. Turbidimetric determination of available sulphates. Soil Science Society of America, Proceedings 15:149-151.

Dawson, M. D. and H. S. Bhella. 1971. Subterranean clover (Trifolium subterraneum L.) yield and nutrient content as influenced by soil molybdenum status. Agronomy Journal (In Press).

Dawson, M. D. and W. S. McGuire. 1971. Professor of Soils and Farm Crops. Oregon State University, Department of Soils and Farm Crops. Personal communication. Corvallis, Oregon.

Doak, B. W. 1929. The value of sulphur for fertilization of lucerne. New Zealand Journal of Science and Technology 11:25-29.

__________ 1952. Some chemical changes in the nitrogenous constituents of urine when voided on pasture. The Journal of Agricultural Science 42:162-171.

Donald, C. M. and C. H. Williams. 1954. Fertility and productivity of a podzolic soil as influenced by subterranean clover (Trifolium subterraneum L.) superphosphate. Australian Journal of Agricultural Research 5:664-687.

During, C. 1967. Fertilizers, and soils in New Zealand farming. Wellington, New Zealand, R. E. Owen. 322 p.

Eliss, J. E. 1967. Phosphorus, molybdenum and some of sulphur trials on subterranean clover and residual soil sulphate studies. A term paper submitted for the degree of Master of Agriculture. Corvallis, Oregon State University, 1967. 48 numb. leaves.

Evans, H. J., E. R. Purvis and F. E. Bear. 1951. Effect of soil reaction on availability of molybdenum. Soil Science 71:117-124.

Greenland, D. J. 1971. Changes in the nitrogen status and physical condition of soils under pastures, with special reference to the maintenance of the fertility of Australian soils used for growing wheat. Soils and Fertilizers 34:237-251.

Greenwood, R. M. 1961. Pasture establishment on a podzolised soil in Northland. III. Studies on rhizobial populations and the effects of inoculation. New Zealand Journal of Agricultural Research 4:375-389.

Gunary, D. 1968. The availability of phosphate in sheep dung. The Journal of Agricultural Science 70:33-38.

Hilder, E. J. 1954. Some aspects of sulphur as a nutrient for pastures in New England soils. Australian Journal of Agricultural Research 5:39-54.

Jackman, R. H. 1960. Organic matter stability and nutrient availability in Taupo Pumice. New Zealand Journal of Agricultural Research 3:6-23.

Jackson, M. L. 1958. Soil chemical analysis. Englewood Cliffs, New Jersey, Prentice-Hall. 498 p.

Jenkins, H. V., J. M. Vincent and L. M. Waters. 1954. The root-nodule bacteria as a factor in clover establishment in the red Basaltic soils of the Lismore District, New South Wales. III. Field inoculation trials. Australian Journal of Agricultural Research 5:78-89.

Jensen, H. L. 1942. Nitrogen fixation in leguminous plants. I. General characters of root-nodule bacteria isolated from species of Medicago and Trifolium in Australia. The proceedings of the Linnean Society of New South Wales 69:98-108.

__________ 1944. Nitrogen fixation in leguminous plants. V. Gains of nitrogen by Medicago and Trifolium in acid and alkaline soil. The Proceedings of the Linnean Society of New South Wales 59:229-237.

Johnson, C. M. and H. Nishita. 1952. Microestimation of sulphur in plant materials, soils, and irrigation waters. Analytical Chemistry 24:736-742.

Johnson, C. M. and A. Ulrich. 1959. Analytical methods for use in plant analysis. Part II. Davis. p. 25-78. (California Agricultural Experiment Station. Bulletin 766).

Jones, M. B. 1964. Effect of applied sulphur on yield and sulphur uptake of various California dryland pasture species. Agronomy Journal 56:235-237.

Jones, M. B. and J. E. Ruckman. 1969. Effect of particle size on long-term availability of sulphur on annual-type grasslands. Agronomy Journal 61:936-939.

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

Kliewer, W. M. and W. K. Kennedy. 1960. Studies on response of legumes to molybdenum and lime fertilization on Mardin Silt Loam soil. Soil Science Society of America, Proceedings 24:377-380.

Lavy, T. L. and S. A. Barber. 1963. A relationship between the yield response of soybeans to molybdenum application and the molybdenum content of the seed produced. Agronomy Journal 55:154-155.

Lodge, R. W. 1954. Effects of grazing on the soils and forage of mixed prairie in South Western Saskatchewan. Journal of Range Management 7:166-170.

McAuliffe, C., M. Peech and R. Bradfield. 1949. Utilization by plants of phosphorus in farm manure. II. Availability to plants of organic and inorganic forms of phosphorus in sheep manure. Soil Science 68:185-195.

McLachlan, K. D. 1955. Phosphorus, sulphur and molybdenum deficiencies to soil from Eastern Australia in relation to nutrient supply and some characteristics of soil and climate. Australian Journal of Agricultural Research 6:673-684.

McLachlan, K. D. and B. W. Norman. 1962. Effects of previous superphosphate applications on the pasture environment and the response by pasture to a current dressing. Australian Journal of Agricultural Research 13:836-852.

McLachlan, K. D. and B. W. Norman. 1966. Observation on the superphosphate requirements of two grazing experiments. Australian Journal of Experimental Agriculture and Animal Husbandry 6:22-24.

McLachlan, K. D. 1968. Stocking rate and the superphosphate requirements of sown pasture on acid soil. Australian Journal of Experimental Agriculture and Animal Husbandry 8:33-39.

McNaught, K. J. 1957. Potassium deficiency in pastures. I. Potassium content of legumes and grasses. New Zealand Journal of Agricultural Research 1:148-181.

McNaught, K. J. and P. J. E. Chrisstoffels. 1961. Effect of sulphur deficiency on sulphur and nitrogen levels in pastures and lucerene. New Zealand Journal of Agricultural Research 4:177-196.

Melville, J. and P. D. Sears. 1953. Pasture growth and soil fertility. II. The influence of red and white clovers, superphosphate, lime and dung and urine on the chemical composition of pasture. New Zealand Journal of Science and Technology A. 35(sup):40-41.

Newman, R. J. 1948. Pasture investigations in the Western District. Journal of Agricultural Victoria 46:49-57.

Parker, M. B. and H. B. Harris. 1962. Soybean response to molybdenum and lime and the relationship between yield and chemical composition. Agronomy Journal 54:480-483.

Petersen, R. G., H. L. Lucas and G. O. Mott. 1965. Relationship between rate of stocking and per animal and per acre performance on pasture. Agronomy Journal 57:27-30.

Peterson, H. B. and T. H. Gooding. 1941. The geographic distribution of Azotobacter and Rhizobium meliloti in Nebraska soils in relation to certain environmental factors. University of Nebraska Agricultural Experimentation Research Bulletin. 121. 24 p.

Powers, W. L. 1940. The use of sulphur in soils. Texas Gulf, sulphur company.

Rossiter, R. C. and E. H. Kipps. 1947. The effect of potassium on the growth of subterranean clover and other pasture plants on Crawley Sand. I. Pot-culture experiments. Journal of the Council for Scientific and Industrial Research 20:379-388.

Rossiter, R. C. 1947. The effect of potassium on the growth of subterranean clover and other pasture plants on Crawley Sand. II. Field-plot experiments. Journal of the Council for Scientific and Industrial Research 20:389-401.

______________. 1952. Studies on the nutrition of pasture plants in the South-West of Western Australia. IV. The growth of subterranean clover (Trifolium subterraneum L.) as effected by lime, molybdenum and potassium. Australian Journal of Agricultural Research 3:244-258.

Rubins, E. J. 1956. Molybdenum deficiencies in the United States. Soil Science 81:191-197.

Saunders, W. M. H. and E. G. Williams. 1955. Observations on the determination of total organic phosphorus in soils. The Journal of Soil Science 6:254-267.

Schollengberger, C. J. and R. H. Simon. 1945. Determination of exchange capacity and exchangeable bases in soil-ammonium acetate method. Soil Science 59:13-24.

Sears, P. D. and R. P. Newbold. 1942. The effect of sheep dropping on yield, botanical composition of pasture. New Zealand Journal of Science and Technology 24:36A.

Sears, P. D., V. C. Goodall and R. P. Newbold. 1948. The effect of sheep droppings on yield, botanical composition, and chemical composition of pasture. New Zealand Journal of Science and Technology 30:231-250.

Sears, P. D. 1953a. Pasture growth and soil fertility. I. The influence of red and white clovers, superphosphate, lime and sheep grazing, on pasture yields and botanical composition. New Zealand Journal of Science and Technology A. 35(Sup):1-29.

Sears, P. D. and W. G. Thurston. 1953. Effect of sheep droppings on yield, botanical composition and chemical composition of pasture. II. Results of field-trial at Lincoln, Canterbury, for the year 1944-1947. New Zealand Journal of Science and Technology 34:445-459.

Sears, P. D. and L. T. Evans. 1953. Pasture growth and soil fertility. III. The influence of red and white clover, superphosphate, lime, and dung and urine on soil composition, and on earthworm and grass-grub populations. New Zealand Journal of Science and Technology A. 35(Sup):42-52.

Sears, P. D. 1953b. Pasture growth and soil fertility. IV. Influence on soil fertility of clovers, superphosphate, lime and dung and urine applied to the pastures, as measured by the growth of subsequent forage crops. New Zealand Journal of Science and Technology A. 35(Sup):53-67.

__________ 1953c. Pasture growth and soil fertility. VII. General discussion of the experimental results, and of their application to farming practice in New Zealand. New Zealand Journal of Science and Technology A. 35:221-236.

Stout, P. R. et al. 1951. Molybdenum nutrition of crop plants. Plant and Soil 3:51-87.

Tabatabai, M. A. and J. M. Bremner. 1970. An alkaline oxidation method for determination of total sulphur in soils. Soil Science Society of America, Proceedings 34:62-65.

Vincent, J. M. 1954a. The root-nodule bacteria of pasture legumes. The Proceedings of the Linnean Society of New South Wales 79:4-32.

Vincent, J. M. and L. M. Waters. 1954. The root-nodule bacteria as factors in clover establishment in the red Basaltic soils of the Lismore District, New South Wales. 2. Survival and success of inocula in laboratory trials. Australian Journal of Agricultural Research 5:61-76.

Virtanen Arttui Ilmari, Synnove von Hausen and Tauno Laine. 1937. Investigations on the root nodule bacteria of leguminous plants. XIX. Influence of various factors on the excretion of nitrogenous compounds from the nodules. The Journal of Agricultural Science 27:332-348.

Walker, T. W., H. D. Orchiston and A. F. R. Adams. 1954. The nitrogen economy of grass-legume associations. Journal of the British Grassland Society 9:249-274.

Walker, T. W., A. F. R. Adams and H. D. Orchiston. 1955a. The effects and interaction of sulphur, phosphorus and molybdenum on the growth and composition of clover. New Zealand Journal of Science and Technology A. 36:470-482.

Walker, T. W. 1955. Sulphur responses on pastures in Australian and New Zealand. Soils and Fertilizers 18:185-187.

_______________ 1956. The nitrogen cycle in grassland soils. Journal of the Science of Food and Agriculture 7:66-72.

_______________ 1957. The sulphur cycle in grassland soils. Journal of the British Grassland Society 12:10-18.

Walker, T. W. and A. F. R. Adams. 1958. Study on soil organic matter: I. Influence of phosphorus content of parent materials on accumulations of carbon, nitrogen, sulphur and organic phosphorus in grassland soils. Soil Science 85:307-318.

Walkley, A. and I. A. Black. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Science 37:29-38.

Warth, F. J. and T. S. Krishnan. 1935. Sulphur and sulphate balance experiments with sheep. The Indian Journal of Veterinary Science and Animal Husbandry 5:319-331.

Watkin, B. R. 1954. The animal factor and levels of nitrogen. Journal of the British Grassland Society 9:35-46.

_______________ 1957. The effect of dung and urine and its interactions with applied nitrogen, phosphorus and potassium on the chemical composition of pasture. Journal of the British Grassland Society 12:264-277.

Williams, C. H. and C. M. Donald. 1957. Changes in organic matter and pH in a podzolic soil as influenced by subterranean clover and superphosphate. Australian Journal of Agricultural Research 8:179-189.

Williams, C. H. and A. Steinbergs. 1958. Sulphur and phosphorus in some Eastern Australian soils. Australian Journal of Agricultural Research 9:483-491.

Williams, C. H., E. G. Williams and N. M. Scott. 1960. Carbon, nitrogen, sulphur and phosphorus in some Scottish soils. The Journal of Soil Science 2:334-346.

Willoughby, W. M. 1953. Some factors affecting grass-clover relationships. Australian Journal of Agricultural Research 5:157-180.

Wilson, J. K. 1939. Leguminous plants and their associated organisms (Cornell University. Agricultural Experiment Station. Memoir 22).

Wilson, P. W. 1940. The biochemistry of symbiotic nitrogen fixation. The University of Wisconsin Press. Donnelley & Sons, Chicago. 302 p.

Wolton, K. M. 1963. An investigation into the simulation of nutrient returns by the grazing animal in grassland experimentation. Journal of the British Grassland Society 18:213-219.

APPENDIX

Appendix Table 1. Average yield (grams dry matter/pot) for combined first and second harvest of ryegrass from greenhouse trials.

Location	Management practice	Treatment							
		C	N	P	S	NP	NS	PS	NPS
Barker (L_1)	M_1	1.23	2.36	1.31	1.48	2.05	4.20	1.70	3.90
	M_2	3.49	4.51	3.63	3.52	4.96	5.25	3.90	5.73
	M_3	3.58	5.34	3.68	3.49	5.20	5.03	3.55	5.12
Gross (L_2)	M_1	1.26	2.96	1.42	1.31	3.65	3.29	1.31	3.74
	M_2	3.75	4.57	3.51	3.66	5.13	5.69	4.21	5.41
	M_3	3.77	4.72	4.41	3.87	5.24	5.45	4.62	5.92
McKenzie (L_3)	M_1	1.52	1.96	1.45	1.31	3.09	1.98	1.60	3.50
	M_2	1.78	2.61	1.75	1.72	3.65	3.72	3.85	4.10
	M_3	4.83	5.80	4.74	4.34	5.11	5.03	4.74	5.53
Rydell (L_4)	M_1	1.86	2.43	2.86	1.99	4.31	2.67	2.47	4.85
	M_2	3.25	3.76	3.19	3.42	4.33	4.11	3.52	4.79
	M_3	7.49	8.38	7.57	6.25	7.11	7.59	7.07	7.60

Appendix Table 2. Total nitrogen content (milligrams N/pot) in ryegrass from greenhouse experiment.

Location	Management practice	Treatment							
		C	N	P	S	NP	NS	PS	NPS
Barker (L_1)	M_1	2.42	7.43	2.50	2.68	6.85	8.77	2.80	8.19
	M_2	6.84	10.90	6.81	6.65	11.33	12.57	6.82	12.73
	M_3	6.32	12.79	6.42	5.81	12.01	12.48	6.27	12.32
Gross (L_2)	M_1	2.49	7.90	2.88	2.57	7.30	7.48	2.61	8.35
	M_2	7.21	12.13	7.01	7.95	13.12	13.09	8.14	14.33
	M_3	9.24	13.86	8.74	8.69	14.65	14.84	9.26	15.33
McKenzie (L_3)	M_1	3.11	6.73	2.92	3.03	8.39	6.76	3.20	8.04
	M_2	3.77	5.93	3.44	3.39	8.60	9.01	8.74	9.47
	M_3	13.32	19.16	13.89	13.61	17.08	16.39	13.25	15.80
Rydell (L_4)	M_1	4.96	8.16	4.70	4.97	9.64	8.52	5.07	9.75
	M_2	6.99	12.04	7.15	7.45	11.79	13.51	7.57	12.89
	M_3	19.37	22.12	15.26	15.56	26.45	24.52	21.46	23.32

Appendix Table 3. Total phosphorus content (milligrams P/pot) in ryegrass from greenhouse experiment.

Location	Management practice	Treatment					
		C	N	NP	NS	PS	NPS
Barker (L_1)	M_1	0.82	1.31	1.24	1.60	0.94	1.64
	M_2	1.47	1.44	2.09	1.63	1.83	1.72
	M_3	2.04	2.60	2.89	2.16	2.12	2.56
Gross (L_2)	M_1	0.61	0.94	1.13	0.99	0.72	1.29
	M_2	1.54	1.92	2.22	2.22	1.88	2.33
	M_3	1.32	1.61	1.78	1.91	1.71	1.78
McKenzie (L_3)	M_1	0.33	0.28	0.70	0.38	0.58	0.81
	M_2	0.74	0.91	1.19	1.00	1.12	1.11
	M_3	0.35	1.45	1.38	1.33	1.49	1.24
Rydell (L_4)	M_1	0.37	0.46	0.99	0.48	0.88	1.02
	M_2	1.06	1.13	1.52	1.23	1.41	1.34
	M_3	2.06	1.93	1.88	1.75	2.12	2.20

Appendix Table 4. Total sulphur content (milligrams S/pot) in ryegrass from greenhouse experiment.

Location	Management practice	Treatment					
		C	N	NP	NS	PS	NPS
Barker (L_1)	M_1	0.21	0.16	0.15	1.12	0.66	1.20
	M_2	0.79	0.66	0.53	1.82	1.61	1.98
	M_3	0.86	0.71	0.73	1.94	1.47	1.64
Gross (L_2)	M_1	0.46	0.87	0.67	1.57	0.73	1.50
	M_2	0.62	0.67	0.65	1.82	1.68	2.23
	M_3	1.66	2.17	2.16	2.76	2.34	2.53
McKenzie (L_3)	M_1	0.26	0.41	0.56	0.61	0.47	0.93
	M_2	0.47	0.24	0.34	1.54	1.23	1.42
	M_3	1.29	1.55	1.23	1.47	1.39	1.48
Rydell (L_4)	M_1	0.24	0.68	0.89	0.71	0.80	1.23
	M_2	0.74	0.80	0.75	1.31	1.22	1.41
	M_3	1.91	1.90	1.71	2.33	2.07	2.43

Appendix Table 5. Average yield, nitrogen, phosphorus and sulphur content in ryegrass from combined first and second harvest.

Location	Management practice	Average yield D.M./pot	Average nitrogen milligrams N/pot	Average phosphorus milligrams P/pot	Average sulphur milligrams S/pot
Barker (L_1)	M_1	2.28	5.21	1.26	0.85
	M_2	4.37	9.33	1.70	1.23
	M_3	4.37	9.30	2.40	1.23
Gross (L_2)	M_1	2.37	5.23	0.95	0.97
	M_2	4.49	10.37	2.02	1.28
	M_3	4.75	11.83	1.69	2.27
McKenzie (L_3)	M_1	2.05	5.27	0.51	0.51
	M_2	2.90	6.54	1.01	0.87
	M_3	5.02	15.31	1.21	1.40
Rydell (L_4)	M_1	2.96	6.97	0.70	0.76
	M_2	3.80	9.92	1.28	1.04
	M_3	7.44	21.01	1.99	2.06

Appendix Table 6. ANOV for Barker location.

Source of Variation	SS	df	MS	F
N	45.4899	1	45.4899	322.4279**
P	0.1974	1	0.1974	1.3992
NP	0.0654	1	0.0654	0.4636
S	3.8134	1	3.8134	27.0290**
NS	2.1184	1	2.1184	15.0148**
PS	0.0455	1	0.0455	0.3225
NPS	0.0012	1	0.0012	0.0083
M	70.1406	2	35.0703	248.5749**
NM	0.1490	2	0.0745	0.5279
PM	0.6355	2	0.3178	2.2522
NPM	0.3222	2	0.1611	1.1419
SM	4.4947	2	2.2973	16.2832**
NSM	1.9623	2	0.9812	6.9543**
PSM	0.0031	2	0.0016	0.0110
NPSM	0.0514	2	0.0257	0.1820
R	1.1676	2	0.0584	---
Error	6.4900	46	0.1411	---
Total	137.2474	71	---	---

** F value significant at 1% level.
* F value significant at 5% level.
C.V. = 10.22%

Appendix Table 7. ANOV for Gross location.

Source of Variation	SS	df	MS	F
N	43.5555	1	43.5555	223.9532**
P	2.2614	1	2.2614	11.6274**
NP	0.0365	1	0.0365	0.1874
S	2.0876	1	2.0876	10.7340**
NS	0.6884	1	0.6884	3.5394
PS	0.0200	1	0.0200	0.1028
NPS	0.4325	1	0.4325	2.2236
M	82.0690	2	41.0345	210.9905**
NM	2.6878	2	1.3439	6.9100**
PM	0.6001	2	0.3001	1.5428
NPM	0.3836	2	0.1918	0.4720
SM	0.5845	2	0.2923	1.5028
NSM	0.0713	2	0.0357	0.1834
PSM	0.0453	2	0.0227	0.1165
NPSM	0.5758	2	0.2879	1.4803
R	0.1573	2	0.0786	---
Error	8.9463	46	0.1945	---
Total	145.2029	71	---	---

** F value significant at 1% level.
* F value significant at 5% level.
C.V. = 11.40%

Appendix Table 8. ANOV for McKenzie location.

Source of Variation	SS	df	MS	F
N	19.3961	1	19.3961	137.8344**
P	5.2434	1	5.2434	37.2612**
NP	0.1953	1	0.1953	1.3880
S	1.2246	1	1.2246	8.7025**
NS	0.0036	1	0.0036	0.0257
PS	1.9241	1	1.9241	13.6730**
NPS	0.5530	1	0.5530	3.9298
M	111.8278	2	55.9139	397.3413**
NM	1.0242	2	0.5121	3.6390*
PM	2.4260	2	1.2130	8.6201**
NPM	2.2944	2	1.1472	8.1524**
SM	3.9483	2	1.9742	14.0289**
NSM	0.1801	2	0.0901	0.6400
PSM	0.1830	2	0.0915	0.6501
NPSM	2.6289	2	1.3145	9.3410**
R	0.0568	2	0.0284	---
Error	6.4731	46	0.1407	---
Total	159.5827	71	---	---

** F value significant at 1% level.
* F value significant at 5% level.
C.V. = 11.30%

Appendix Table 9. ANOV for Rydell location.

Source of Variation	SS	df	MS	F
N	11.3209	1	11.3209	45.5699**
P	3.8134	1	3.8134	15.3501**
NP	0.4095	1	0.4095	1.6484
S	0.0177	1	0.0177	0.0714
NS	1.0927	1	1.0927	4.3986*
PS	0.9823	1	0.9823	3.9542
NPS	0.2346	1	0.2346	0.9444
M	271.8919	2	135.9460	547.2230**
NM	2.7118	2	1.3559	5.4579**
PM	10.4527	2	5.2264	21.0377**
NPM	3.2225	2	1.6113	6.4858**
SM	1.9584	2	0.9792	3.9416
NSM	0.4953	2	0.2477	0.9970
PSM	1.3464	2	0.6732	2.7099
NPSM	0.1636	2	0.0818	0.3293
R	1.5580	2	0.7790	---
Error	11.4277	46	0.2484	---
Total	323.0997	71	---	---

** F value significant at 1% level.
* F value significant at 5% level.
C.V. = 10.53%