AN ABSTRACT OF THE THESIS OF

John Rogers for the degree of Master of Science in Crop Science presented on December, 18, 1995. Title: The Effect of Topdressed Lime Upon Pasture Production and Quality.

Abstract approved:
Redacted for privacy
Redacted for privacy

Gene Pirelli, John Hart

Soil acidity is a major factor inhibiting pasture production in western Oregon. The typical management solution to acidic soil problems is to lime. However, lime cannot be incorporated directly into the soil in established pasture. The only alternative is topdress or surface apply lime and wait for soil fauna to mix the lime through the soil profile. Unfortunately, there is little previous research to indicate if topdressed lime mixes through the soil profile, increase production, or improve quality.

A lime trial was undertaken at four sites to address these problems. The four sites were in Tillamook County, Lane County, Polk County, and on campus/Benton county. Each site consisted of three replications, except the campus site which had four replications, of 0, 1, or 2 T/A lime in a randomized block or completely randomized design. The actual liming took place in the fall of 1993. In 1994 and 1995 each site was clipped on a regular basis for total production and plant nutrient analysis. At the end of the growing season, soil was sampled to measure the degree of lime mixing and the effect of lime upon soil nutrient status.

In 1994, no significant production, plant tissue nutrient, lime mixing, or soil nutrient changes were observed. In 1995, the Tillamook and Polk County sites displayed significantly increased soil pH and soil Ca to a depth of two inches. The Lane County

and campus sites both displayed significant lime mixing to at least four inches. Also, the Tillamook and Lane County sites demonstrated significantly increased production and N uptake. Yet, the Polk County and campus sites demonstrated no significant change in production. No relevant plant tissue nutrient changes were detected. Based upon these results, lime seemed able to mix readily through the soil, pasture production could be affected by lime, plant tissue nutrient concentrations were not affected by lime, and the increased production might be due to the effects of increased soil pH upon N cycling.

THE EFFECT OF TOPDRESSED LIME UPON PASTURE PRODUCTION AND QUALITY

by

JOHN ROGERS

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

MASTER OF SCIENCE

Presented December 18, 1995
Commencement June 1996

Master of Science thesis of John Rogers presented on December, 18, 1995

APPROVED:

Redacted for privacy

Co-Major Professor, representing Crop Science

Redacted for privacy

Co-Major Professor, representing Crop Science

Redacted for privacy

Head or Chair of Department of Crop and Soil Science

Redacted for privacy

Dean of Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Redacted for privacy

John Rogers, Author

ACKNOWLEDGMENT

First, I would like to thank my advisors, Gene Pirelli and John Hart. Their guidance and patience were indispensable. I truly doubt I can pay back the time, effort, and work they put into me. Also, they are both a great deal of fun and they both fed me occasionally, which is a task in and of itself.

Special thanks should also go to David Hannaway for his advice and direction. Also, Fred Ramsey for his humor, patience, and technical advice. I think I still owe you a donut. Daniel Arp deserves credit for being understanding enough to come on board at the last second. I hope I can make the trip worthwhile.

This project would not have been possible without the assistance or cooperation of various extension agents and farmers. Particularly, I would like to thank Paul Day and Susan Aldrich-Markham of Lane and Yamhill county extension, respectively. Of course the actual cooperators, Max and Lisa Hurliman, Russ and Mary Dexter, and Kelley Gordon, who allowed to me intrude upon their land deserve great accolades.

Finally, I think this thesis would not possible without the continuous support of several people. First, my mother and brother who listened to my curmudgonly complaints. Second, the staff and congregation of Newman Center for the occasional dose of inspiration. I would like to part with a little bit of advice passed to me which seems to apply equally well to this and future circumstances "keep your mouth shut and your bowels open and you'll do just fine."

TABLE OF CONTENTS

Page

Introduction 1

Literature Review 3
- Lime Movement 3
- Production or Quality Benefits 4
- Oregon 13
- Summary 15

Materials and Methods 16
- Site Selection 16
- Site Establishment and Liming 17
- Soil Sampling and Analysis 18
- Production 19
- Nutrient Quality Analysis 19

Results 21
- Soils Data 21
- Production 39
- Plant Nutrient Data 39
- Summary 47

Discussion 65
- Lime Movement 65
- Benefits of Lime to Production or Quality 67
- Summary of Conclusions Based on the Original Objectives 72
- Afterword 73
- Summary 74

Bibliography 75

Appendices 79
- Appendix 1 Soils Data 80
- Appendix 2 Production Data 87
- Appendix 3 Plant Nutrient Data 92
- Appendix 4 Selenium 105
- Appendix 5 Growth Rates 115

LIST OF FIGURES

Page

1. The soil pH and Ca profiles for the Tillamook County site 22

2. Profile of P through the soil column for the Polk and Tillamook County sites . 23

3. The soil pH and Ca profiles for the Tillamook County site 25

4. The pH and Ca profiles for the Lane County site 28

5. The concentration of P through the soil profile for the Lane and campus site ... 29

6. The soil pH and Ca profiles for the Lane County site 30

7. The Lane County site P soil profile 31

8. The pH and Ca profiles for the campus site 33

9. The soil pH and Ca profiles for the campus site 34

10. The soil pH and Ca profiles for the Polk County site 37

11. The soil pH and Ca profiles for the Polk County site 38

12. The total production for the Tillamook and Lane County sites 41

13. The total production for the campus and Polk County sites 42

14. The total production in 1995 at the Tillammok and Lane County sites 44

15. The total production at the campus and Polk County sites 46

16. The 1994 campus plant tissue analysis results 48

LIST OF FIGURES (cont.)

Page

17. The 1994 Lane County plant tissue analysis results........ 49

18. The 1994 Tillamook County site plant tissue analysis results 50

19. The 1994 plant tissue analysis for the Polk County site 51

20. The % tissue N at the campus site........ 52

21. The % tissue N at the Lane County site 53

22. The Polk County site % plant tissue N........ 54

23. The % tissue N at the Tillamook County site........ 55

24. The 1994 plant tissue analysis for the Tillamook County site 56

25. The 1995 campus plant tissue analysis........ 57

26. The 1995 plant tissue analysis for the Polk County site 58

27. The Lane County site 1995 plant tissue analysis results........ 59

28. The 1995 tissue N for the Polk County site 60

29. The campus site % tissue N........ 61

30. The % tissue N for the Lane County site........ 62

31. The % tissue N at the Tillamook County site........ 63

LIST OF TABLES

Table | Page

1. Site characteristics 17
2. The 1994 Tillamook County soil K profile 24
3. The 1994 Lane County soil K profile 24
4. The 1994 campus soil K profile 24
5. The 1994 Polk County soil K profile 26
6. The 1995 Tillamook County K profile 26
7. The 1995 Lane County soil K profile 26
8. The 1995 campus soil K profile 35
9. The 1995 Polk County soil K profile 35
10. Tillamook County 1994 production 40
11. 1994 campus production 40
12. 1994 Lane County production 40
13. 1994 Polk County production 43
14. 1995 Tillamook County production 43
15. 1995 campus production 43
16. 1995 Lane County production 45
17. 1995 Polk County production 45
18. Total N uptake 1995 60
19. Total P uptake 1995 60
20. Total K uptake 1995 60

The Effect of Topdressed Lime Upon Pasture Production and Quality

Introduction

Oregon's livestock industry is the state's leading agricultural commodity ranked by gross sales. The combined sales of cattle, calves, dairy products, and sheep are estimated at 600 million dollars in 1989 dollars (Miles, 1995). Forage production is essential to a sustainable livestock industry. High quality, low cost forage is required for future production in a world market. Oregon livestock producers need to produce forage on approximately 2.0 million acres of pasture. At least 1.3 million of those acres in Western Oregon have moderately acidic soils (pH 5-6). Soil acidity can decrease production or quality by limiting the availability of essential nutrients and increasing the availability of toxic elements such as Al or Mn. The costs of lost pasture production or poor quality forage are difficult to assess. Yet, the frequency of acidic soils in Western Oregon suggests that the lost income and effort due to soil acidity make it a significant problem to Western Oregon dairy, beef, sheep, and hay farmers.

The most common method to ameliorate acidic soil problems is lime application. Once the soil pH is increased nutrient availability can increase and toxic element availability decreases. However, lime is not very soluble or mobile so it must be finely ground and incorporated throughout a portion of the root zone to be effective.

The limited solubility and mobility of lime pose several problems for its use on pasture. First, if the pasture is established, there are no methods to incorporate lime without destroying the pasture. The lime must be topdressed which relies mainly upon soil fauna, such as earthworms, to mix the lime through the soil. Soil fauna are affected by local circumstances which suggests that mixing of lime is variable and localized. Second, even if the lime is mixed by earthworms or other fauna, some grass species may not be able to exploit any its benefits. For example, P availability is a frequent justification for liming. However, grass seed studies in Western Oregon show that the species tested have a limited responsive to P fertilization (Horneck, 1995), since the P needs of most grass species are minimal. Finally, the increase in forage productivity or quality is uncertain in producer's minds, because no straightforward way exists to determine when and where lime is economically beneficial in moderately acidic soils. Based on these uncertainties, many producers avoid liming until the soil pH falls below 5 or they can reestablish the pasture. Unfortunately, such decisions are based on a small amount of recorded experience and driven by the relatively high cost of lime, $40 or more/ton.

These problems were rectified by a Western Oregon lime trial which met three major objectives. First, the study determined the degree to which topdressed lime was mixed through the soil profile. If topdressed lime was mixed, an increase in soil pH, Ca concentration, and possibly, P or K was measured in limed plots compared to unlimed plots. Two, a practical issue was to determine if lime could increase productivity as measured by dry matter yield or improve forage quality as measured by plant tissue N, P, or K. If the lime caused increased production or improved quality, the limed plots should have significantly higher production or beneficial changes in the concentration of plant tissue nutrients compared to the unlimed plots. Finally, the study suggested where and when lime might be most economically beneficial. If topdressed increased production or quality, the amount of time to recover its purchase price could be suggested by comparing the value of the forage in the limed plots compared to the unlimed plots. Also, the area where lime was beneficial was suggested by observing differences between sites. Thus, the study was implemented to answer these questions.

Literature Review

The three main objectives of this study are to assess lime's ability to move through the soil, lime's affect on pasture production or quality, and the likely time and place where it would be most beneficial. While the objectives have not been studied intensively in Oregon pastures, an international body of literature exists, particularly from New Zealand and Australia. These reports provide a basis to predict the likely effects of lime topdressing and a comparison for my study's results. Thus, reviewing the literature on lime movement, lime's affects on pasture production, and the available Oregon results would be beneficial.

Lime Movement

The limited literature on topdressed lime movement indicated that lime moves slowly through the soil profile, mainly by the pedoturbation of soil fauna. The rate of lime mixing was studied at two liming rates (3.55 t/ha and 4.97 t/ha) in an Australian field study (Bromfield et al., 1987). The authors' found that topdressed lime significantly increased soil pH from the surface to 16 cm in a granitic soil and to 8 cm in a basaltic soil by the study's sixth year. This result suggested that lime was mixed at the rate of 1.3 to 2 cm of soil per year. A New Zealand study (Springettt, 1983) examined the role of earthworm action on lime mixing. The study found that several species of earthworms significantly increased the pH of soil blocks after lime topdressing. The earthworm study lent credence to the idea that temperature, moisture, and soil textural classes were the main factors regulating lime movement (Bromfield et al., 1987) since those same factors regulated earthworm activity. Locally, a study of filberts observed the changes in soil pH and Ca after discing lime through the top four inches of the soil. The authors found significant increases in both soil pH and Ca through the 4-8 inches depth, four years after lime application (Baron and Gardner, 1975). This result suggested that lime was mixing through approximately an inch (2.5

cm) a year through a Western Oregon soil. Based on these studies, lime would probably mix through 1 to 3 cm per year in Western Oregon soils.

Production or Quality Benefits

Assessing lime's potential benefits on pasture production was divided into three parts. First, the ability of common pasture grasses to respond to lime under laboratory or field conditions. Second, the ability of lime to increase nutrient availability. Increased nutrient availability would imply that plant production or quality changes are possible. Third, the ability of lime to relieve mineral toxicities. Since each mechanism could improve pasture productivity or quality, the affect of lime on a few major pasture grasses, nutrient availability, and mineral toxicities was examined.

Plant Responses

A grass plant could benefit directly or indirectly from liming if it is able to exploit the soil chemical changes made by lime. Directly, a lime induced decrease in the soil $H+$ concentration could decrease the amount of energy required to move $H+$ ions across the gradient between the root and the soil solution. In theory, the energy saved could increase a plant's growth potential. However, decreased root energy demand might not translate into increased growth. Indirectly, lime may increase nutrient availability but if the nutrient is not limiting, then increased production or nutrient uptake is unlikely. For example, lime may increase P availability. Yet, if P is not limiting and the actual limiting factor is not changed, than production would not increase. Similarly, grass plants may not respond to decreased Al or Mn availability, if Al and Mn are not toxic. Thus, increased production is dependent upon the nutrient needs and sensitivities of each grass species or even cultivar. Since plant response to lime is species specific, the effects of lime upon the production or quality of ryegrasses, orchardgrass, tall fescue, and clover are examined individually.

Annual and Perennial Ryegrass

Several studies suggested that lime could increase annual or perennial ryegrass production or improve their quality. A field trial found that 2 Mg lime/ha, on a soil with a pH of 4.8, increased annual ryegrass production from 3.4 Mg/ha to 8.3 Mg/ha and significantly increased Ca and Mg concentrations in the plant tissue (Crossley and Bradshaw, 1968). Since the soil pH did not drop until the experiment's third year, while lime significantly lowered the soil Al concentration during all three years, the authors theorized that the lime relieved Al toxicity. Second, a greenhouse experiment demonstrated that increasing concentrations of Al decreased both shoot and root weight in four annual ryegrass varieties (Helyar and Anderson, 1971). Also, increasing Al concentrations in the nutrient solution significantly decreased the concentration of Ca, Mg, and K in the plant tissue of all four cultivars. These two results suggested that annual ryegrass was vulnerable to Al toxicity and lime would increase production and nutrient uptake. Third, a greenhouse study observed that if the soil pH was increased from 4.8 to 6.8, perennial rygrass dry matter yield increased by a factor of two (Guerrero et al., 1967). However, no tissue analysis was performed and only one soil type was used. These results suggested that lime increased production and nutrient uptake in annual and perennial ryegrass if the soil pH was below 5 or Al toxicity was likely. Also, the variation between varieties suggested some variety specific responses exist.

Orchardgrass

The literature concerning orchardgrass was not as conclusive as for ryegrass. A greenhouse experiment by Crossly and Bradshaw (1968) observed that lime had a variable effect upon orchardgrass dry matter yield. For example, lime caused no increased yield in one variety while doubling the yield of another variety. The results primarily depended on the soil pH the variety was grown in before the experiment (i.e. one variety was grown in an acidic soil and another was grown in a calcareous soil) and the actual variety tested. No plant tissue variables were measured nor was the soil tested periodically during the experiment so other possible sources of variation could not be identified. Another greenhouse experiment demonstrated that lime consistently doubled production when the soil pH was increased from 4.8 to 6.8 (Guerrero et al., 1967). Since this increase had a positive interaction with applied P, the authors theorized that lime caused increased P availability which was responsible for at least some of the increased production. A field study of orchardgrass seed production conducted on a Woodburn soil at the Hyslop field laboratory (pH of 5.3-5.7 and 50-59 ppm P at 0-12 inches) observed no significant increase in dry matter production or nutrient interactions due to lime applied at 3 T/A (Rampton and Jackson, 1963). The authors fertilized to alleviate any possible nutrient deficiencies and the lime was mixed thoroughly with the soil so the only possible conclusion was that acidity was not afffecting plant growth at that site. Thus, lime probably would increase orchardgrass production if Al toxicity or P deficiency was a problem in a pasture. However, these studies suggested that soil pH was not the sole limitation on orchardgrass production.

Tall Fescue

Guerrero et al. (1967) studied the effect of lime and P on tall fescue in a greenhouse experiment. They found a small increase in production when lime was applied without P but P application alone increased production by a factor of two. The production response suggested that the soil used in the experiment was P deficient and lime mildly increased its availability.

Clover

The positive growth response of clover or Rhizobia to lime has been well documented. Studies frequently report fewer or less productive nodules on clover species grown in an acidic environment which results in lower clover production and lower tissue N concentration. Some studies have even found that nodulation may completely fail below soil pH 4.8. The lower N content has frequently been attributed to lower Mo availability and sensitive nature of many Rhizobia strains to Mn. Since the soil pH related factors that typically govern clover production can vary over a small scale (0.5m to a hectare), examining the local, Oregon, experience with lime and clover production is beneficial.

In Oregon, several results pertaining to soil pH and clover or nodulation were reported. A survey of Rhizobia species throughout Oregon (Hagedorn, 1978) observed that the size of Rhizobia populations correlated only mildly with exchangeable acidity but correlated most strongly with the total percent silt and clay (correlation coefficient =0.88) and the percent organic matter (correlation coefficient= 0.74). This result suggested that when the soil pH was not limiting other factors may be more important in determining the Rhizobium population and the probability of nodulation. A greenhouse study found that adding lime, phosphate, or lime+phosphate resulted in the same yield of subterranian clover (Almendras and Bottomley, 1987). Phosphorous was required for nodulation. Thus, the authors' theorized that phosphorous could be applied directly or lime could increase its mineralization from the organic phosphorous pool. Based upon these results lime would improve clover production in P deficient soils, some high organic matter soils, or very acidic soils in Oregon.

Nutrient Availability

At a moderately acidic soil pH, the primary mechanism by which lime increases production or improves quality is to increase nutrient availability. Most essential elements' availability are affected by soil pH but N and P seem to be frequently associated with affecting pasture production. Thus, N and P are the focus of most pasture liming studies. Also, a few studies on organic matter cycling in pasture have been made since pasture is dependent on nutrient mineralization for a large portion of its nutrient requirement. Since the effect of lime upon N cycling, P availability, and organic matter cycling are considered to be the major factors governing responses to lime, they are examined in detail.

N cycling

N cycling is typically divided into three parts. First, N is fixed from the air mainly by bacteria such as *Rhizobium* or *Frankia.* Second, N that is an organic form (organic N) such as amino acids, proteins and amino sugars is converted to ammonia by a series of microbially mediated decomposition reactions. The conversion to ammonia, which becomes ammonium in solution, is termed mineralization. Third, the ammonium is converted to nitrite by bacteria (the *Nitrosamonas* genus mostly). The nitrite is converted to nitrate by other bacteria (mostly the *Nitrobacter* genus). These two steps are collectively called nitrification. The nitrate is taken up by plants. All three processes are affected by pH. These pH effects suggest that lime can influence each process, so the affect of lime upon nitrification, and N mineralization is examined.

Nitrification

Several studies suggested that pH increase, through liming, could increase nitrification rates. First, an English laboratory study (Darrah et al., 1986) used a short term nitrification assay to determine an optimum pH for nitrification. They observed that a pH between 7 and 7.5 yielded the highest relative nitrification rate. If these results were applied directly to the field, they implied that raising the soil pH from 5 or 6 to 7 would improve nitrification and plant growth (if N was limiting). Second, other culture studies observed that nitrification declined rapidly below pH 6.0 and was almost nonexistant by pH 5.5 (Tate, 1995). These results also implied that liming to raise soil pH above 6 would increase nitrification rates. Third, a laboratory study using New Zealand soils (Bramley and White, 1984) found that the optimum pH for maximum nitrification was not an absolute number but usually slightly above the originally observed soil pH. The authors theorized that the indigenous nitrifying bacterial populations were adapted to the local pH and small increases in pH would speed nitrification. Yet, large pH shifts would kill a large percentage of the nitrifying bacteria. Fourth, several New Zealand field studies suggested that increased nitrification (Edmeades et al., 1986) played a role in increasing the production of pastures after liming. This theory assumed that N was the only limiting nutrient in each case. Since this assumption was not tested, the theory was not proven. Finally, a summary of laboratory studies suggested increasing pH from even mildly acidic to neutral conditions could dramatically decrease generation times for nitrifying bacteria (Gray and Williams, 1971). For example, one study found that the generation time for *Nitrosomonas* at pH 6.2 was 100 hr while at pH 7.6 it was 38 hr. Each study reinforced the idea that nitrification was inhibited by even mildly acidic conditions so liming even mildly acidic soil would be beneficial if N was the limiting nutrient.

N mineralization

The reported research concerning the effect of lime upon N mineralization was ambiguous but two studies seemed pertinent. A laboratory study using an unidentified Minnesota soil found that lime produced a flush of N which had been mineralized during the first three or four weeks of the incubation (Clay et al., 1993). After four weeks, no difference existed between lime and unlimed incubations N mineralization rates (Clay et al., 1993). The authors theorized that at a low soil pH, accumulated ammonia killed the bacteria responsible for mineralization. Liming drove the equilibrium between ammonia and ammonium towards the non-toxic ammonium which allowed for more mineralization. However, lime could simply be solubilizing a fraction of the organic N that was unavailable at acidic soil pH. Unfortunately, the study only measured the amount of N added and the amount of N leached from the bottom of the incubating tubes so neither hypothesis was tested. Another study with perennial ryegrass on two moderately acidic soils (soil pH 5.1 and 5.3) observed that applying lime at 10 metric tons per hectare produced over two times more net N mineralization [net N min= Nuptake+ soil mineral N(final)- soil mineral N (initial)]

(Edmeades, 1981). Although bacterial populations were not affected, the authors felt that the plating methods used were insufficient to observe the actual population changes responsible for the increased net N mineralization. Although not conclusive, these two studies suggested that lime could increase mineralization.

Phosphorus (P)

Phosphorus availability is affected by soil acidity in several ways. First, Al and Fe are more soluble at an acidic soil pH than higher soil pH. Al and Fe bind to P in solution so P is no longer available. Second, P ligands to the exchange surfaces at low soil pH further decreasing the available P pool. Finally, the mineralization of organic P is decreased at low soil pH. These pH effects imply that lime increases P availability enough to affect pasture production or quality.

Several studies suggested a link between lime, P availability, and pasture production. An Australian greenhouse study (Helyar and Anderson, 1971) of perennial ryegrass observed the symptoms of Al toxicity at soil pH 4.8. The study observed that lime alone increased dry matter yield but did not affect P tissue concentration. The 2.5 Mt/ha lime application and the 600 kg/ha P application doubled the yield and increased plant tissue P by 0.3% compared to lime alone. The authors hypothesized that liming alone relieved the Al toxicity and gave the perennial ryegrass the ability to take up more P but the soil remained P deficient. The soil P deficiency was rectified by P fertilization. Similarly, another Australian field study found that lime was required to reduce P sorption particularly in soils with high concentrations of Al in the soil solution (Holford and Crocker, 1994). Unfortunately, the authors pointed out that there were very few field studies on lime-P interactions on pasture and that many laboratory studies were flawed, so generalizing their results or applying laboratory results to their field results was not possible. A New Zealand review of field studies (Mansell et al., 1984,) found that negative lime-P interactions were common in limed pastures with soil pH between 5 and 6. These results suggested that P deficiency at acidic soil pH was common in New Zealand pastures and that lime could improve P fertilizer effeciency. Finally, a laboratory greenhouse study on Andic soils showed that liming also increased P mineralization, although phosphatase activity was not affected (Trasar-Cepeda et al., 1991). Yet, the authors measured organic P (Po) as the difference between total P and inorganic P (Pi). This method was fraught with methodological difficulties since how much Pi was actually available and how much was on an exchange surface was unknown. These studies indicated lime-P interactions were a common mechanism for increased dry matter yield responses in pasture.

Organic Matter

Although the evidence was a bit tenuous, some literature proposed an important role for lime in organic matter decomposition. An Australian paper (Stockdill and Cossens, 1966) hypothesized that a soil with reduced soil fauna populations such as earthworms or an inactive microbial community, perhaps due to acid soil conditions, would allow organic matter of various sizes to accumulate on the soil surface. The organic matter would become a peat like layer that prevented soil amendment and moisture from penetrating far into the mineral soil. In such a pasture, nutrients would cycle primarily in the surface layers. Lime could help decompose the peat like layer by creating a more hospitable environment for soil fauna and microbes. The increased organic matter decomposition rates would balance or exceed organic matter input rates which would allow the peat like layer to completely decompose and improve nutrient cycling. For example, a British long term pasture study found that in acidic conditions (soil pH 4.7-5.3) macro-organic matter accumulated on the soil surface (Tyson et al, 1990). Liming reduced amount of macro-organic matter on the surface (also refered to as a layer of duff). The reductions were associated with increased dry matter production and available N in the soil. The authors suggested that these observation were due to organic matter being mineralized to N and a greater proportion of the fertilizer N (45 kg N/ha) being added to the N cycle rather than being immobilized. Although the idea was based on only one example, the theory and observations hinted that acidic conditions prevent effective nutrient cycling in pastures and lime could ameliorate the problem.

Mineral Toxicity

Al toxicity is the direct product of low soil pH. Below a soil pH of 5, the concentration of the soil Al+3 ions increases exponentially with decreasing soil pH. Since Al uptake increases with increasing Al+3 concentration, the Al+3 can quickly become toxic to the plant below soil pH 5. Also, Al seems to indirectly affect nutrient uptake (as reported in review of P). Since the direct effects of Al toxicity are common in pastures (below pH 5) and Al solubility can affect nutrient availability, the role Al toxicity in pasture production and quality is examined.

The effect of Al toxicity on nutrient uptake and yield was studied in annual ryegrass. Nutrient uptake (Rengel, 1989) was studied by growing annual ryegrass in a nutrient solution (pH 4.2) to which varying amounts of Al were added. After the typical symptoms of Al deficiency, such as stunted roots, were observed, the plant tissue was analyzed. The authors showed that Ca, Mg, and K plant tissue concentrations were lowest in the plants treated with the most Al. Unfortunately, N and P were not measured so determining if the decreased concentrations were an effect of Al toxicity or indirect effect of some other problem was not possible. Another field study (soil pH 4.72) demonstrated that liming significantly increased dry matter yield and altered P tissue concentrations but not in a consistent manner (Hillard et al., 1992). Since forage growth was responsive to lime and P, the authors thought that Al toxicity may be depressing P uptake by inhibiting root growth. Although possible, this hypothesis was not credible without direct evidence. The effects of P deficiency and Al toxicity were not separated in the study so the study could not be considered a good indicator of likely effects of Al toxicity alone on annual ryegrass. Thus, the literature indicated that liming could ameliorate the indirect and direct problems of Al toxicity.

Summary

The review of the benefits of lime on pasture production and quality yielded several important conclusions. One, annual and perennial ryegrass and orchardgrass both demonstrated increased production when limed in greenhouse studies, particularly when the original pH was below 5 and was increased beyond 6 with liming. However, field results demonstrated that lime might increase yield but not in a consistent manner. Second, lime can increase N and P availability but availability did not guarantee a pasture growth response. Also, lime decreased mineral toxicities but only when the soil pH was below 5. Finally, two studies indicated that organic matter can accumulate in low productivity pastures with acidic soils. Thus, these studies suggested that lime could increase pasture yield but that production depended on factors other than soil pH.

Oregon

The benefits of liming are dependent on local factors such as soil pH ,soil P availability, or a robust community of nitrifying bacteria. Since most published pasture research is conducted in New Zealand or Australia, their results may not apply to Oregon. Thus, my study would benefit by reviewing Oregon's typical soil problems and direct experience with liming pasture or grass.

Literature review revealed that Oregon contained many the mineral toxicities or nutritional deficiencies associated with acidic soil. Manganese toxicity was observed in Western Oregon by Jackson et al (1966). The study found 1000 ppm of Mn in the tissue of bush beans grown on a Dayton soil with a pH between 4.7-5.3. Since 700 ppm Mn was considered toxic for beans and liming lowered Mn tissue concentration to 500-700 ppm, the beans were assumed to be suffering from a toxicity due to increased Mn availability in an acidic soil. Aluminum toxicity was found in an Al sensitive variety of wheat (Nugaines) grown on a Nekia soil at pH 5.0 (Kauffman, 1976) Nugaines doubled production when 6.5 T/A of lime was added. Since Nugaines was known to be Al sensitve and the Nekia soil was known to contain a high concentration of Al, the author assumed that Al toxicity was depressing production. A lime-Phosphorus interaction was observed by Janghorbani et al. (1975) on a Dayton series soil with a soil pH 5.4. They found that alfalfa doubled production compared to a check when fertilized with 90 ppm P and 12 meq/ 100g lime compared ot either one alone. Acid soil related potassium deficiency was observed on a Deschutes sandy loam (pH 5.4) with wheat. James and Jackson (1984) demonstrated that raising the soil pH to 5.9 and adding 800 lb K/ A significantly increased Daws winter wheat production compared to adding no K or lime. Doerge et al. (1985) demonstrated Molybdenum (Mo) deficiency in a greenhouse experiment on alfalfa with a Woodburn soil (pH 5.5). Since the alfalfa yield was significantly increased due to Mo fertilization and increasing pH, they theorized that the soil was Mo deficient which was compounded by low Mo availability in acidic soils. Hemphill et al. (1982) surmised that lime increased table beet (grown on a Willamette series soil with a soil pH of 5.8) yield by increasing B uptake. However, lime decreased beet quality so it was not necessarily considered a good practice. These examples demonstrated that many of the problems associated with acid soil were present in Oregon soils and that liming may alleviate these problems pasture.

Four major studies concerning pasture liming were conducted in Oregon. The largest was conducted on an Astoria series soil (soil pH 5.1) planted with orchardgrass in Astoria, Oregon between 1957 and 1959 (Jackson and Howell, 1967). Lime was applied at 0, 3, 6, 12, and 24 T/A and mixed to a depth of 6 inches. In the first year of the study, lime caused a small but significant increase in production (2,770 lb/A increase at 24 T lime/A). The growth response declined until the end of the study (330 lb/A increase at 24 T lime/A in 1959). Two, a lime topdress study was conducted at three sites (soil pH 5-5.2) in Lincoln county in 1982 and 1983 (Bill Rogers, unpublished). No significant lime growth response was observed at any of the sites, but the results were not unexpected as bentgrass predominated. Third, an orchardgrass seed study was conducted on a Woodburn silt loam (pH 5.3-5.7) at Hyslop Farm. The site was limed at 3 T/A and disked at establishment (Rampton and Jackson, 1969).

However, no production response or nutrient interactions were observed. Fourth, Horneck (1995) studied P availability after lime or P fertilization on grass seed fields. Although the lime was incorporated at 4.5 Mg/ha, it had no significant effect on soil Pi concentration (as measured by the Bray or Olsen soil tests), soil organic P concentration, or production. Since P fertilization did not effect production or tissue P, sufficient P was available for growth and increasing P availability was unlikely to alter production or tissue P. Based upon these studies, lime seemed to not increase production or improve quality in Oregon pastures. Apparently, P deficiency was unusual too, which might be related to the infrequency of lime growth responses.

Summary

Several points are clear from a review of the literature. First, lime can increase forage grass production. Second, top dressed lime can be mixed through the soil profile. A typical mixing rate is 2 cm per year Third, the main causes of increased production in pasture at moderately acidic soil pH are increased P or N availability. Four, there are many pasture or grass seed experiments that are not affected by lime for unknown reasons. Thus, there is no completely reliable test to determine the likelihood of a positive lime growth response and its degree.

Materials and Methods

Site Selection

Sites were selected based upon three main criteria. First, the pasture should be primarily orchardgrass or perennial ryegrass. Annual ryegrass was considered acceptable but not preferred. Bentgrass was not considered acceptable. A small amount of clover was considered acceptable. But, liming clover grown on acidic soil was known to increase its production, so eliminating clover as a confounding variable was desired. Second, the soil pH was to be between 5 and 6. Preferably the soil solution pH should be between 5 and 5.5 and the site had not been limed in the previous five or more years. Finally, the site should have an interested cooperator and be logistically feasible.

Four sites were selected by Extension agents or myself. The Benton County site was on the OSU campus directly adjacent to the swine center. The vegetation consisted primarily of annual and perennial ryegrass with many small patches of orchardgrass. The soil was a Hazelair silty clay loam with a surface soil pH 5.7. The Polk County site was approximately five miles south of Monmouth Oregon. The vegetation consisted primarily of orchardgrass with a slight under canopy of bentgrass. The soil was a Bellpine silty clay loam with a soil pH of 5.3. The Tillamook site was adjacent to Highway 101 about 3 miles south of the city of Tillamook. The site was populated by orchardgrass with an understory of bentgrass. The soil was a Coquille silt loam with a surface soil pH of 5.2. The Lane County site was about 7 miles from the town of Pleasant Hill. The site was populated with orchardgrass and white clover. The soil was a Chehalis silty clay loam with a surface soil pH of 5.9 (table 1).

Table 1. Site Characteristics

Site	Series	Soil pH (0-2 inches)	%OM	Plant
Tillamook	Coquille	5.2	29.46	orchardgrass
Lane	Chehalis	5.9	11.52	orchard/clover
Polk	Bellpine	5.4	9.1	orchardgrass
Campus	Hazelair	5.6	6.60	ryegrass

Site Establishment and Liming

One hundred score calcium carbonate lime was topdressed at each site using a Gandy spreader in the fall of 1993. The lime was applied in 6 ft wide rows which were 25 ft long, except at the campus site which had 30 ft long rows. Lime was applied at 0, 1.3, or 2.6 T/A, according to a calibration at Hyslop Farm. However, the actual amount of lime spread depends upon terrain, the amount of lime in the spreader, and how the tractor is driven so the actual rate is approximately 0, 1, or 2 T/A lime. Individual sites had three replications of each treatment except at the campus site which had 4 replications of each treatment. The campus and Tillamook County sites were completely randomized designs while the Lane, Polk, and Yamhill County sites were randomized block designs. All the sites were fertilized according to the cooperators' fertilization plans which were assumed to prevent any deficiency for the 1994 spring growing season. The next year fertilization was simply 60 lbs N/A and 20 lb S/A at all sites in February based upon the previous year's soil and plant data. An additional 60 lb N/A was added to each site in May. Starting in the spring of 1994 the sites were sampled in accordance with the first two objectives.

Soil Sampling and Analysis

Soil was sampled once per year after lime application. The first year's soil samples were taken in the fall of 1994. A minimum of 21 cores per row were obtained increments of 0 to 2, 2 to 4 and 4 to 8 inches (4 to 6 inches at the Polk County site). Since the first year's results indicated that 2 inch intervals delivered insufficient resolution, the second year sampling was done in 1 inch intervals until 4 inches below the surface. At 4 inches the core was cut into a 4-7 inches segment for the >4 inches interval. This procedure was repeated for 30 cores per row because so little soil was recovered at each depth. The 1995 sample were collected during the first two weeks of June. After collection in both years, the soil was air dried and ground.

After drying and grinding, the soil pH, extractable bases, and P concentration were measured. The pH was measured by a 1:1 soil-water mixture (McLean, 1982). Extractable bases were extracted from 2g of soil with an 1N ammonium acetate solution and shaking as agitation (Knudson et al, 1982). After filtering the extract, the concentration of K, Mg, and Ca was measured by atomic absorption spectroscopy (Metcalfe, 1987). P was extracted with 0.03 N ammonium fluoride, 0.025 HCl, and shaking. After extraction, the samples were filtered and stannous chloride was added as an indicator to develop color. Phosphorus concentration was measured as absorbance at 660 nm by an ALPKEM automated analyzer.

Organic matter was measured at each site to estimate the sites nutrient cycling potential. Organic matter was measured by drying the samples, weighing them, and igniting the sample in a muffle surface. The difference between the weight of the dry and ignited sample is the percent organic matter (OM) (Nelson and Sommers, 1982). Organic matter for the Polk county samples were also determined by the Walkly-Black method which digested the soil in 10 ml of 1N potassium chromate and 20 ml concentrated sulfuric acid. Percent OM was determined after titrating the unreacted potassium chloride with ferrous ammonium sulfate using O-phenanthroline as an indicator.

Production

Production was measured by clipping the grass in each row. The grass was clipped in a 3 ft wide swath after it grew to approximately 8-10 inches in height. Approximately, 1 to 2 inches of grass was left behind after clipping. This procedure was supposed to simulate grazing. At the Tillamook County and Campus sites, each row was clipped with a sickle mower. Clippings from each row were weighed and a subsample was taken for later analysis and moisture determination. After clipping the 3 ft wide sampling swath, the entire plot was mowed to a uniform height. At Polk, Yamhill, and Lane Counties a 1 ft^2 sample was cut from inside a wire cage in each row. After 1 year these sites were harvested by the same methods used in Tillamook and Benton Counties.

The subsamples were dried in the gas dryers at Hyslop Farm. Once dry, the ratio of dry weight to wet weight was calculated. The ratio was used to convert each plots weight to dry weight. Finally, the weight of dry matter (DM) of each plot was converted to weight of dry matter per acre.

Nutrient Quality Analysis

Dried and ground plant tissue was analyzed for protein and various mineral nutrients. NIRS (Near Infrared Reflectance Spectrometer) quantified percent protein by measuring the amount infrared light between 1100 and 2500 nm reflected to a photoelectric diode (Meloan, 1963). Percent N was calculated by dividing percent protein by 6.25 (Watson and Isaac, 1990). The mineral nutrient's, P, Mg, Mn, K, Ca, Fe, and Zn, were measured by ICP (Inductively Coupled Plasma Spectrophotometer). ICP vaporizes samples with a plasma flame and measures emitted spectrum of light (Metcalf, 1987).

After chemical and tissue analysis all soil and plant sample results were subjected to statistical analysis. Since the study was observational, each site, clipping, and year of each parameter was analyzed individually and no attempt was made to pool data between sites, clippings or years without a prior justification. The Tillamook County (8 degrees of freedom) and campus (11 degrees of freedom) results were both analyzed with one way ANOVAs since they were both completely randomized designs. The Lane County (8 degrees of freedom) and Polk County (8 degrees of freedom) sites were analyzed with a multivariate ANOVA since both sites contained three blocks. Significance was tested on the 95% confidence interval for all measurements. All statistical analyses were conducted on the STATGRAPHICs computer program except the standard deviations which were calculated in the EXCEL spreadsheet software package.

Results

This project was designed as an observational study. No attempt was made to randomize site selection nor were sites chosen to test a characteristic at a variety of different levels, therefore each site's parameters were analyzed separately and data could not be pooled across sites. Based upon these constraints and the first two objectives the data was divided into three broad categories. The categories were soils data (lime mixing), production, and plant tissue nutrient data.

Soils Data

Tillamook

In 1994, the lime had little effect on soil pH, Ca, K or P at the Tillamook County site. Soil pH and Ca were only increased in the limed plots at the 0-2 inch layer. For example, at the 0-2 inch depth, soil Ca increased by 8-10 meq Ca/ (100g soil) per ton of lime added (Fig 1). Lime was visible at the surface which indicated a large concentration of lime at the surface. No significant changes in soil P or K (Fig. 2,Table 2) were observed . For example, all measured soil P values were within the 95% confidence interval (11-16 ppm soil P) which implied that there were no significant treatment differences. The 1994 data demonstrated that lime did not cause significant change in any parameter below the 0-2 inch depth.

In 1995 at the Tillamook County site, lime significantly increased soil pH, Ca and K, while P was not measured. The soil pH in the limed plots was significantly increased through the second inch. For example, at the 1-2 inch layer, the check's average soil pH was 4.98 while the average soil pH of the 2 T/A limed plots was 5.60. The soil Ca was significantly increased by at least 2 meq Ca/ 100g soil in the limed plots to the 2-3 inch layer of the soil (Fig. 3). A significant decrease of 104 ppm soil K occured between the check and the 2 T/A lime treatment at the 0-1 inch layer (Table 6). No other significant effects on K were seen. Since a previous study (Horneck, 1995)

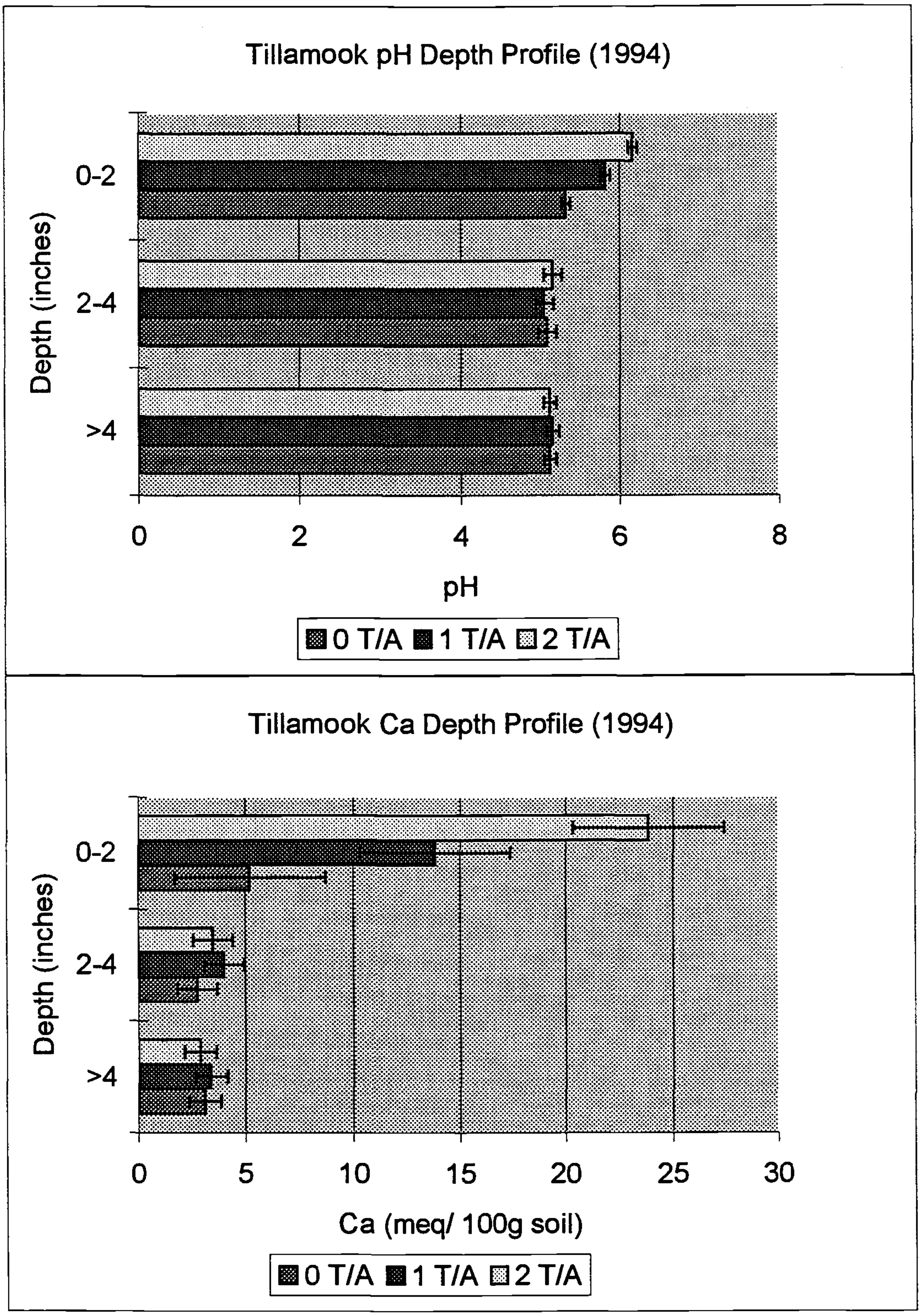
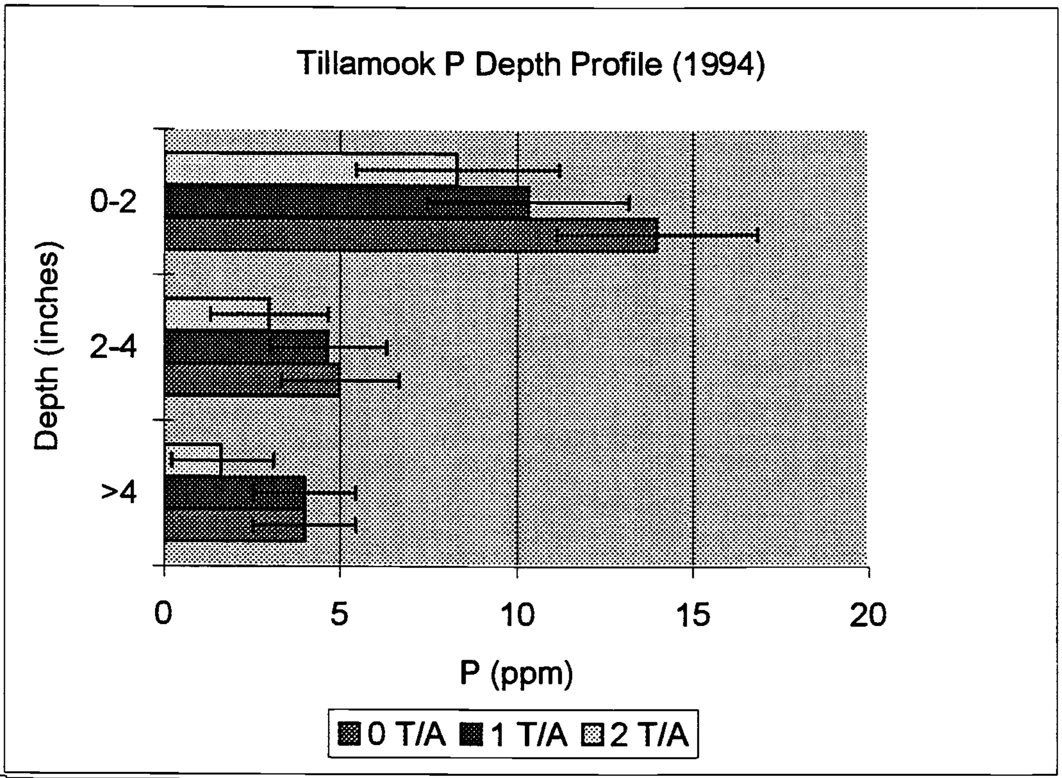


Fig. 1 The soil pH and Ca profiles for the Tillamook county site. The error bars represent the 95% confidence interval and the legend represents the lime application rate.



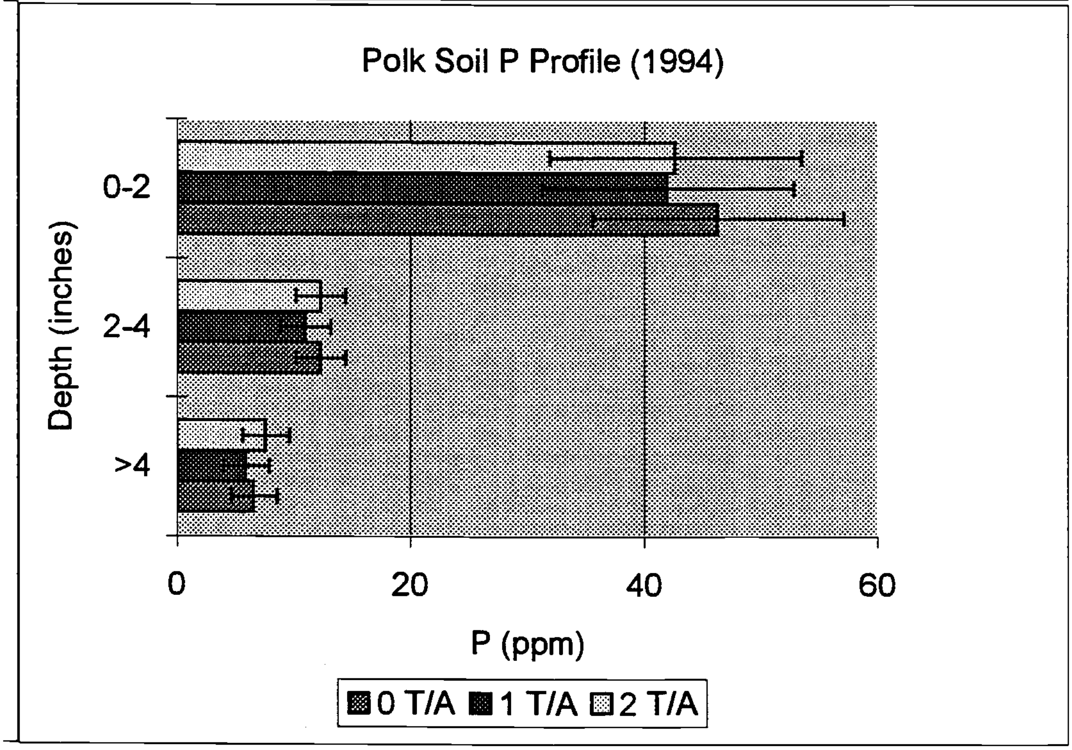


Fig. 2 The profile of P through the soil column for the Polk and Tillamook county sites. The error bars denote the 95% confidence interval and the legend represents the lime application rate.

Table 2 The 1994 Tillamook soil K profile

Trt	0-2 (inches)		2-4 (inches)		>4 (inches)	
Lime (T/A)	K (ppm)	SD	K (ppm)	SD	K (ppm)	SD
0	781	70.3	317	59.5	237	55.6
1	797	390	297	84.5	218	85.1
2	659	47.5	268	31.2	659	46.2

LSD=461 LSD=124 LSD=129

SE=133 SE=36.0 SE=37.2

Table 3 The 1994 Lane soil K profile

Trt	0-2 (inches)		2-4 (inches)		>4 (inches)	
Lime (T/A)	K (ppm)	SD	K (ppm)	SD	K (ppm)	SD
0	333	47.2	198	21.0	216	1.7
1	318	28.9	209	60.6	239	66.2
2	316	51.0	196	18.0	225	35.2

LSD=115 LSD=80.5 LSD=76.7

SE=29.3 SE=20.5 SE=19.5

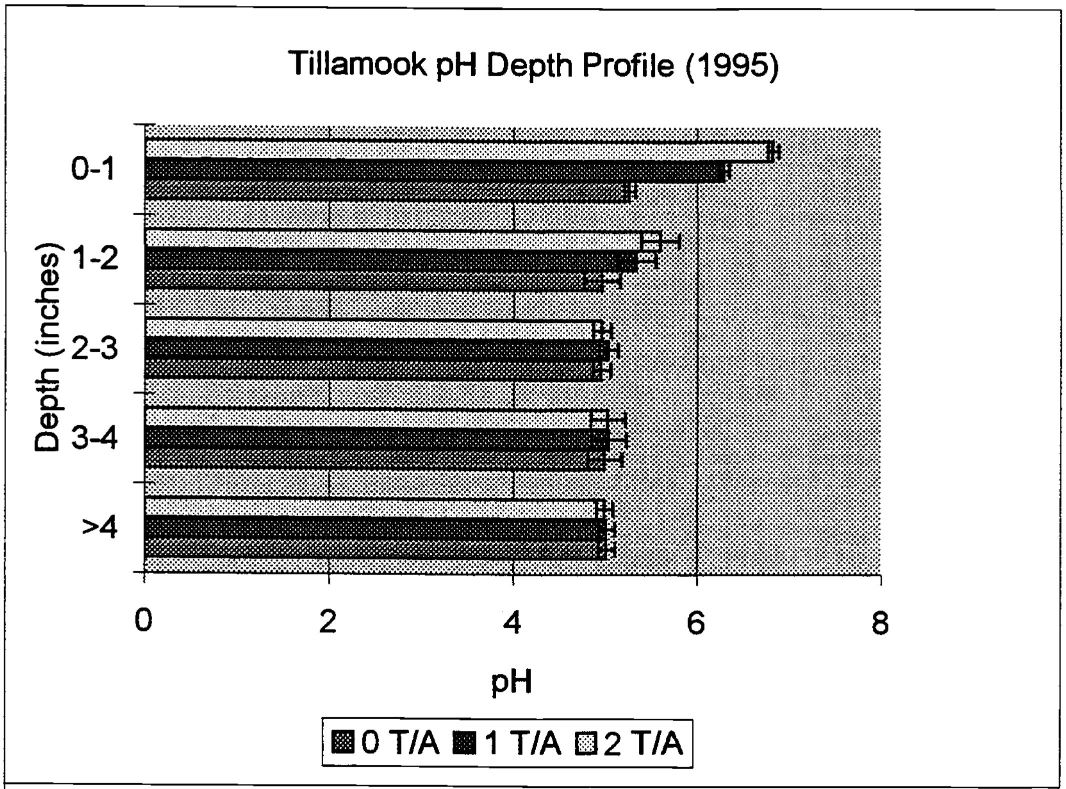
Table 4 The 1994 campus soil K profile

Trt	0-2 (inches)		2-4 (inches)		>4 (inches)	
Lime (T/A)	K (ppm)	SD	K (ppm)	SD	K (ppm)	SD
0	445	32.4	416	44.5	437	56.2
1	*397	13.9	416	23.6	458	43.0
2	*392	10.6	387	23.8	422	48.2

LSD=33.9 LSD=51.4 LSD=79.1

SE=10.6 SE=16.1 SE=24.7

* Significant at the 95% confidence level0



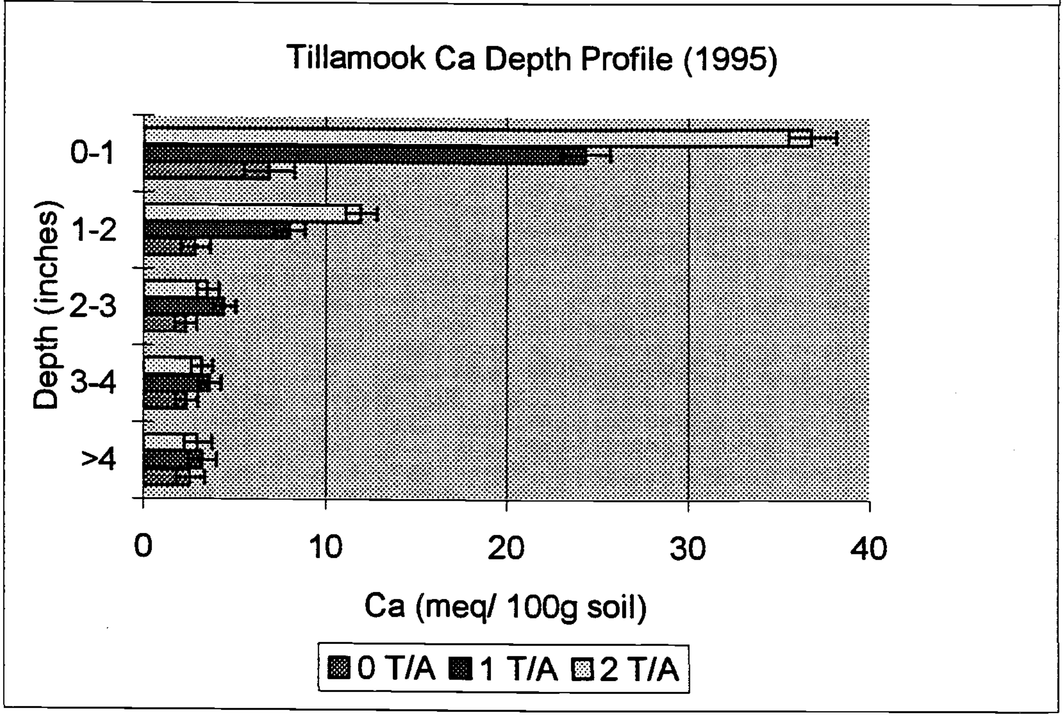


Fig. 3 The soil pH and Ca profiles for the Till. county site. The error bars represent the 95% confidence interval and the legend represents the lime application rate.

Table 5 The 1994 Polk soil K profile

Trt	0-2 (inches)		2-4 (inches)		>4 (inches)	
Lime (T/A)	K (ppm)	SD	K (ppm)	SD	K (ppm)	SD
0	415	76.5	140	4.0	159	8.30
1	346	21.5	185	28.9	165	25.5
2	355	52.3	355	42.9	193	20.0
	LSD=135		LSD=62.6		LSD=11.9	
	SE=34.3		SE=15.9		SE=11.9	

Table 6 The 1995 Tillamook soil K profile

Trt	0-1 (inches)		1-2 (inches)		2-3 (inches)		3-4 (inches)		>4 (inches)	
Lime (T/A)	K (ppm)	SD	K (ppm)	SD	K (ppm)	SD	K (ppm)	SD	K (ppm)	SD
0	564	40.6	389	41.7	334	54.6	257	37.6	220	59.6
1	*577	67.7	*308	48.7	316	47.9	308	36.9	229	33.6
2	*460	24.4	*238	17.0	242	31.9	212	19.2	187	40.5
	LSD=95.3		LSD=76.5		LSD=91.6		LSD=64.7		LSD=91.8	
	SE=27.5		SE=22.1		SE=26.5		SE=18.7		SE=26.5	

* Statistically significant at the 95% confidence level

Table 7 The 1995 Lane soil K profile

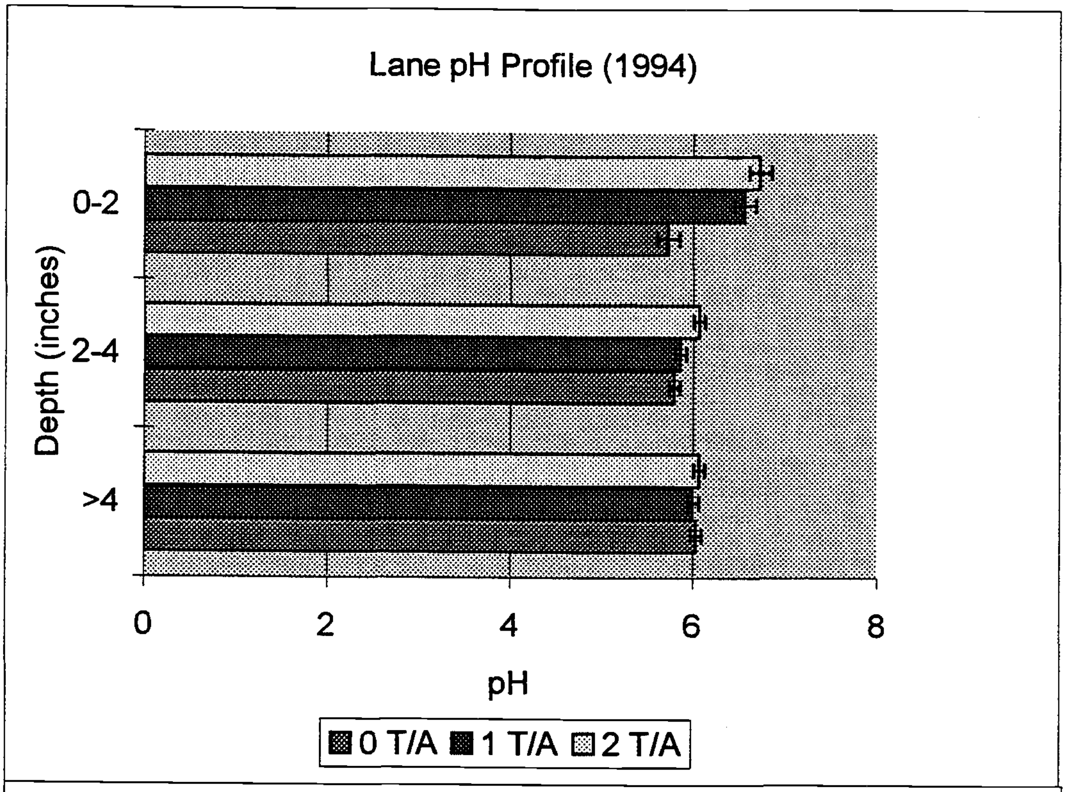
Trt	0-1 (inches)		1-2 (inches)		2-3 (inches)		3-4 (inches)		>4 (inches)	
Lime (T/A)	K (ppm)	SD	K (ppm)	SD	K (ppm)	SD	K (ppm)	SD	K (ppm)	SD
0	162	23.8	265	17.9	164	10.3	153	15.8	158	15.2
1	178	25.1	268	8.10	143	4.50	135	13.7	144	17.9
2	142	18.0	274	47.2	166	28.2	151	2.20	169	13.7
	LSD=56.2		LSD=71.1		LSD=45.0		LSD=19.3		LSD=36.3	
	SE=14.3		SE=18.1		SE=11.5		SE=4.9		SE=9.2	

concluded that the P soil test was not accurate enough to distinguish between treatments and the concentration of plant tissue P was at the sufficiency level in all clippings, the P soil test was considered an unneccessary expense for this study at every site except Lane. Thus, the 1995 Tillamook site results demonstrate lime movement through at least the second inch by 1995.

Lane

The 1994 soil results for the Lane County site were similar to the Tillamook County results. The only statistically significant differences between treatment and check were at the surface to 2 inch layer of the soil profile for soil pH and Ca (Fig, 4). For instance, the average soil pH of the check plots at the 0-2 inch layer was 5.73 while the average of the 2 T/A limed plots was 6.73. P and K were unaffected (Fig 5, Table 3). Thus, the 1994 results demonstrated little to no detectable lime movement below the surface.

In 1995, soil pH and Ca were affected by liming while soil K and P were not. The soil pH was significantly increased in the limed plots through the >4 inch sampling layer (Fig 6). For example, at the >4 inch layer, the average soil pH of the check plots was 5.58 while the average soil pH of the 2 T/A limed plots was 5.90. The soil Ca profile demonstrated a significant increase between the treatments and the check to the 3-4 inch segment of the profile (Fig. 6). For instance, at the 3-4 inch layer the soil Ca of the check plots varied between 11 and 11.8 meq Ca/ 100g soil while the 2 T/A lime plots' soil Ca varied between 12 and 12.5 meq Ca/ 100g soil. As a monitoring tool, soil P was measured in 1995 and no significant differences were observed (Fig 7) at the 95% confidence interval. K also demonstrated no significant differences (Table 7). For example, the soil K of all the treatments in the 0-1 inch layer was between 142 and 162 ppm which was within the limits of experimental error. Based upon these results, the Lane county site displayed practically significant lime movement in the second year.



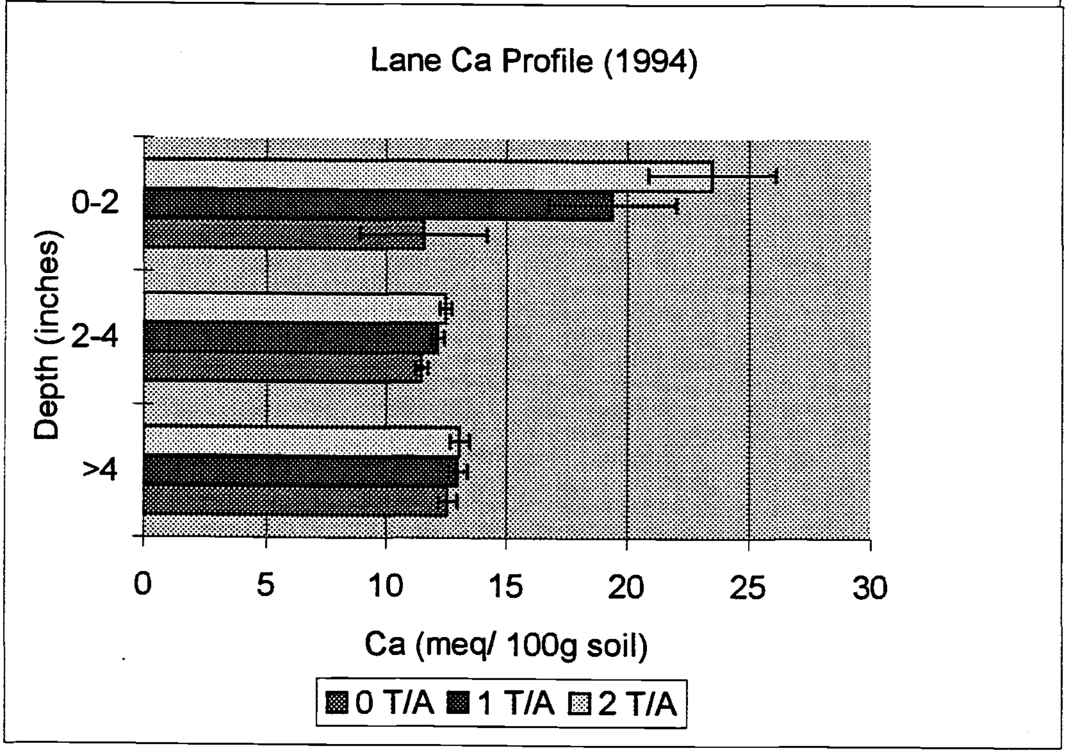
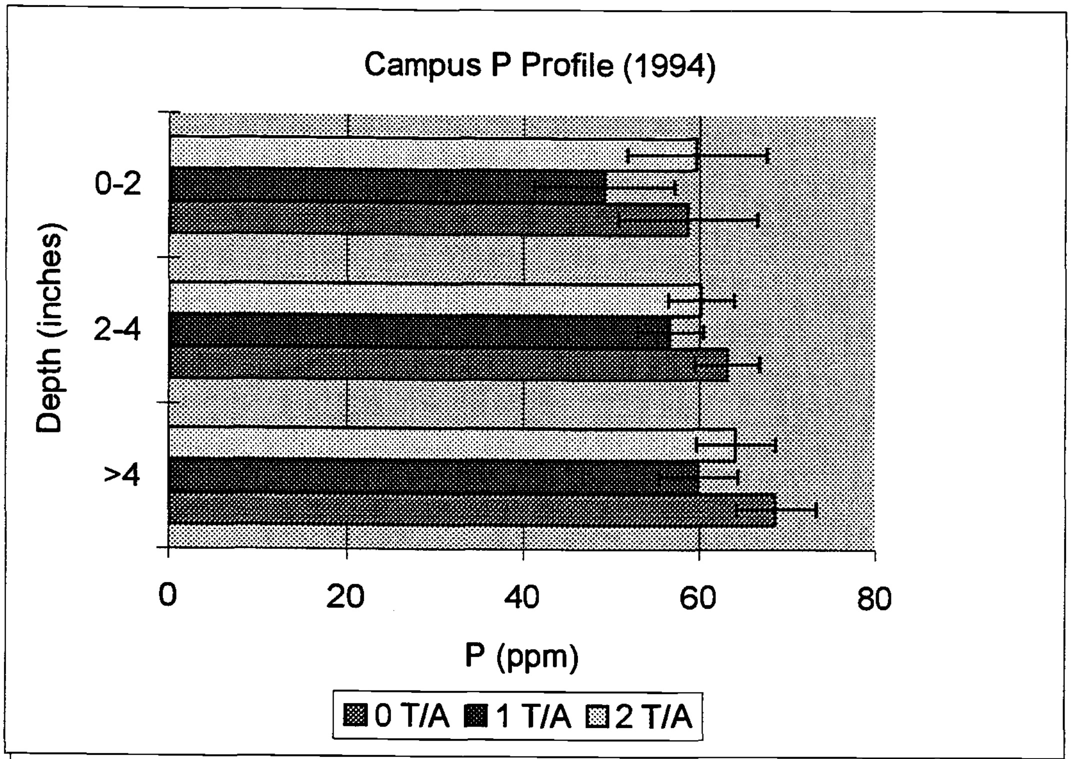


Fig. 4 The pH and Ca profiles for the Lane county site. The error bars represent the 95% confidence interval and the legend represents lime application rate.



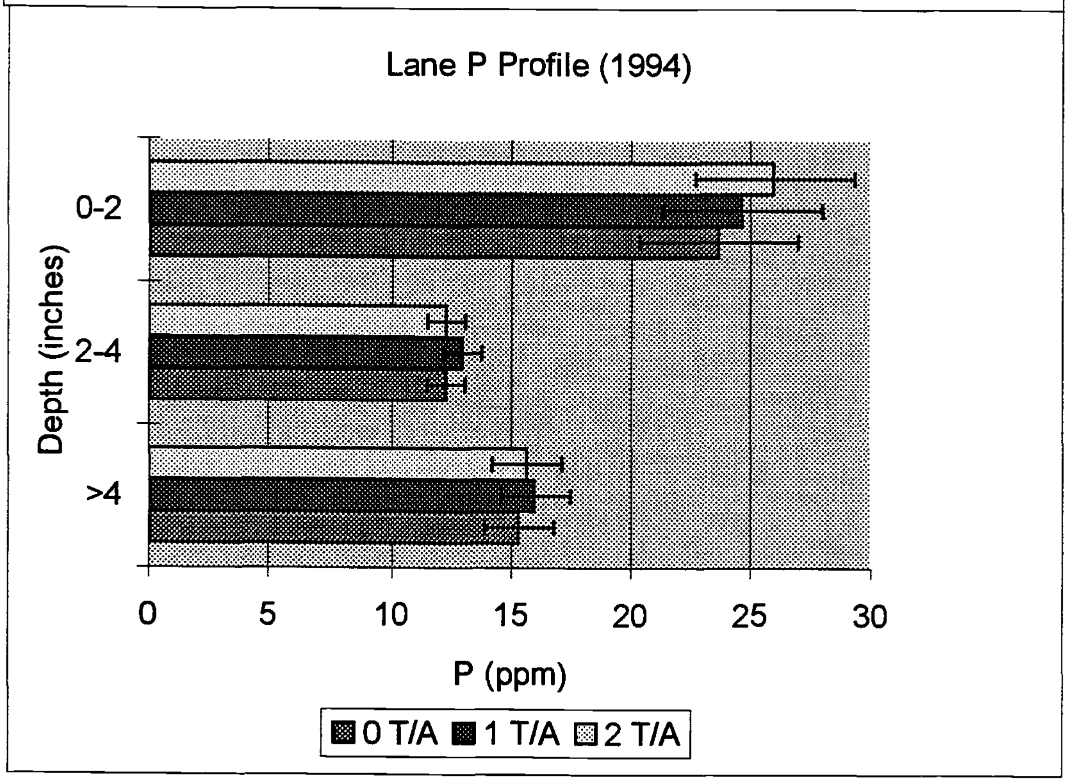
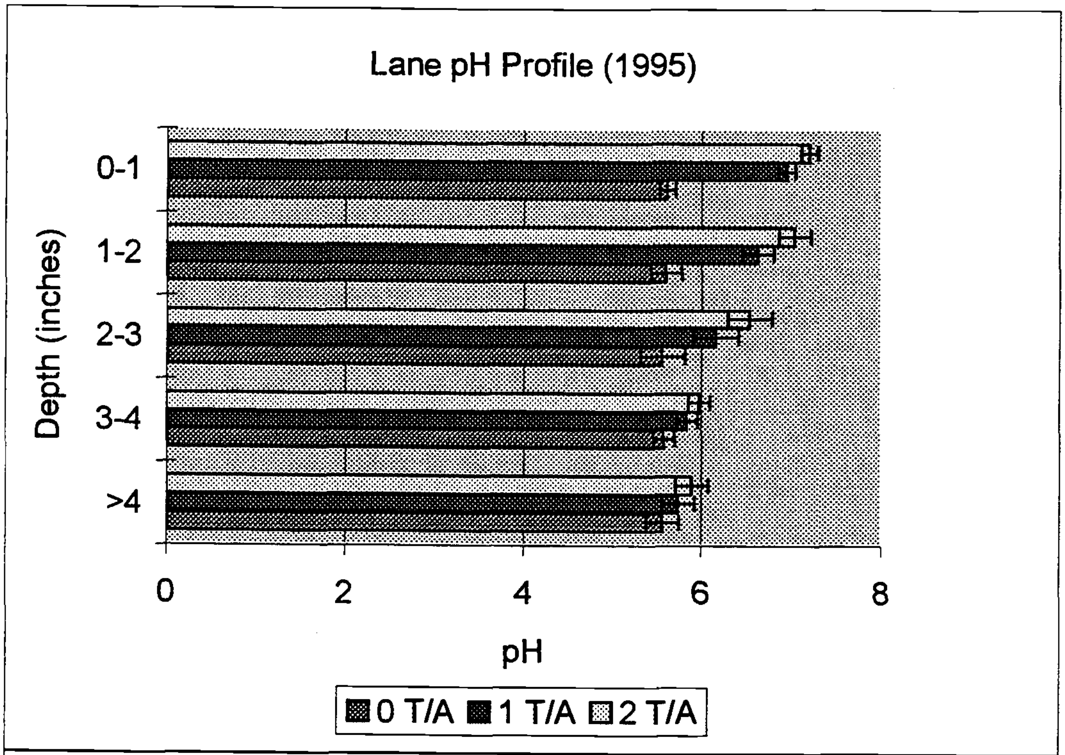


Fig. 5 The concentration of P through the soil profile for the Lane and campus sites. The error bars denote the 95% confidence interval and the legend represents the lime application rate.



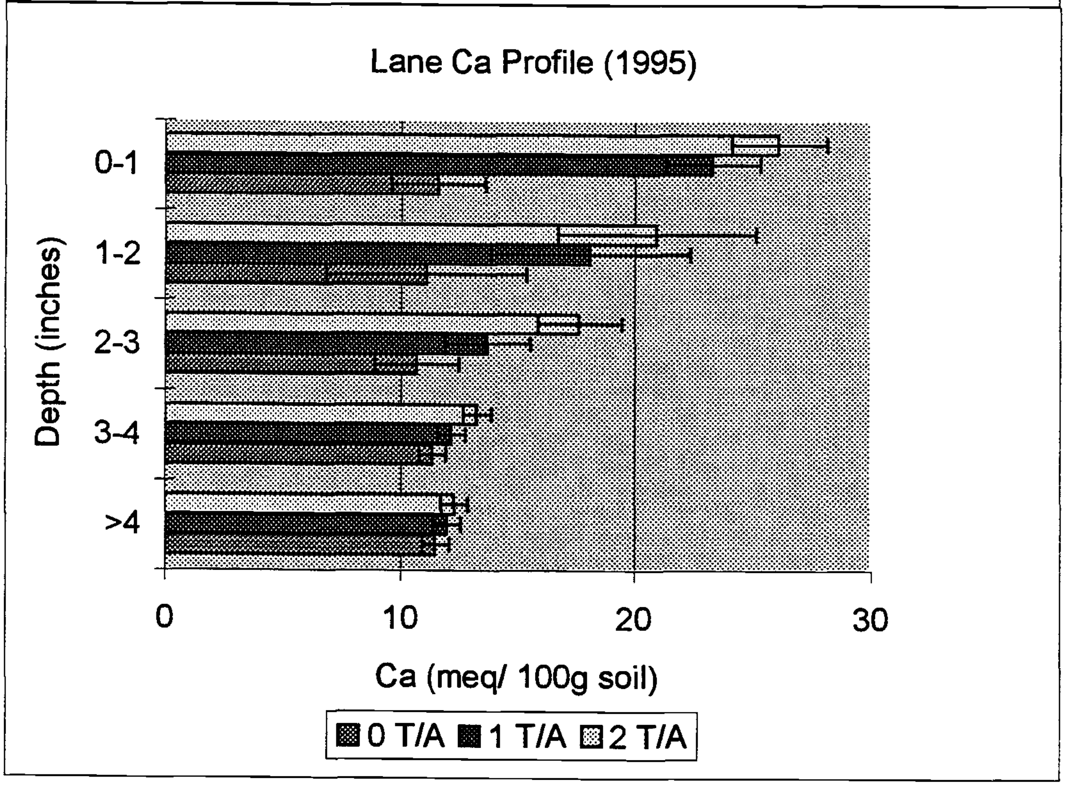


Fig. 6 The soil pH and Ca profiles for the Lane county site. The error bar represent the 95% confidence interval and the legend describes the lime application rate

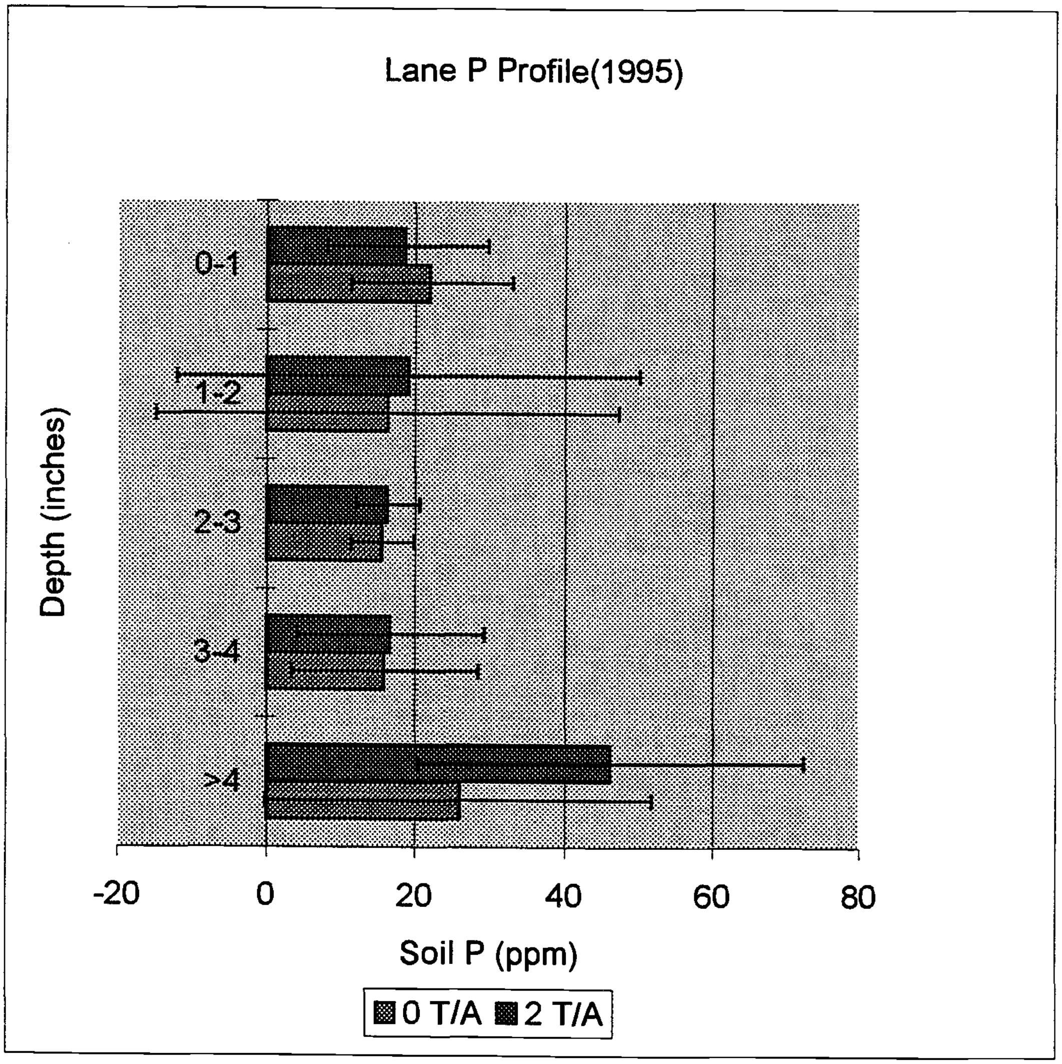
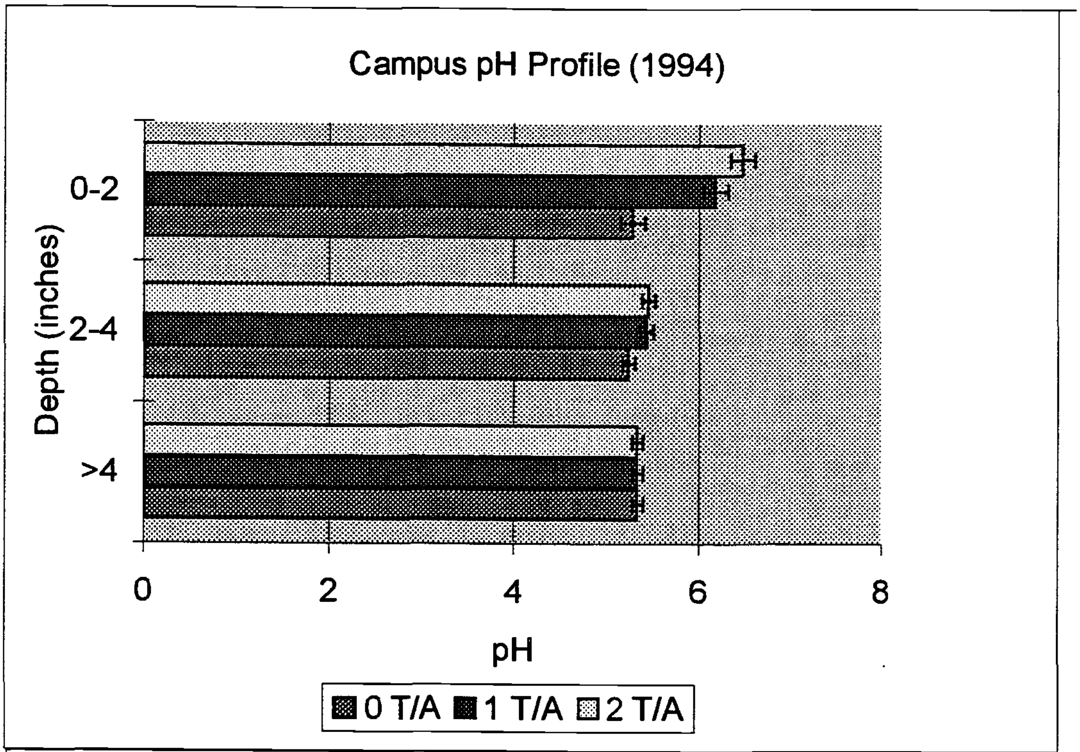


Fig. 7 The Lane county site P soil profile. The error bars represent the 95% confidence interval and the legend represents the lime application rate.

Campus

The 1994 Campus soil test results showed significant differences for soil pH, Ca, and K but not for P. The soil pH displayed a significant increase of at least 0.2 pH units above the check (soil pH 5.25) from the surface to the 2-4 inch segment of the profile (Fig 8). The soil Ca profile demonstrated significant increases of at least 5 meq Ca/ 100g soil above the check at the 0-2 inch segment of the profile (Fig 8). At the 2-4 inch depth, the 2 T/A limed plots had an average of 0.88 more meq Ca/ 100g soil than the unlimed plots. This difference yielded a p value of 0.07 (F=3.610) which was marginally significant on a 95% confidence interval (i.e. the p value is close enough to the 95% confidence interval to be considered significant if there is additional evidence or reasoning that the result should be significant). Soil P was similar through the soil profile (Fig 5). Soil K displayed a significant 48 ppm decrease (Table 4) with increasing lime application only at the surface to 2 inch segment of the soil profile. In 1994, minimal changes were observed in the measured soil parameters

In 1995, the Campus soil tests displayed significant treatment differences for soil pH, Ca, and K while P was not measured. The lime application created a significant increase in pH from the surface to the >4 inch segment of the profile (Fig. 9). For example, at the >4 inch segment, the average soil pH of the 1 T/A lime application was 5.72 and the soil pH of the 2 T/A lime application was 5.70 while the average check soil pH was 5.35. The soil Ca profile (Fig. 9) displayed a significant increase of 0.2 meq Ca/ 100g soil or more above the check through the +4 inch segment of the profile. Liming did not significantly affect soil K at any depth except the 1-2 inch layer (Table 8). At the 1-2 inch layer, the 2 T/A lime application created a 48 ppm decrease in soil K compared to the check. Thus, in 1995 the liming increased the soil pH and Ca profile to the greatest depth measured.



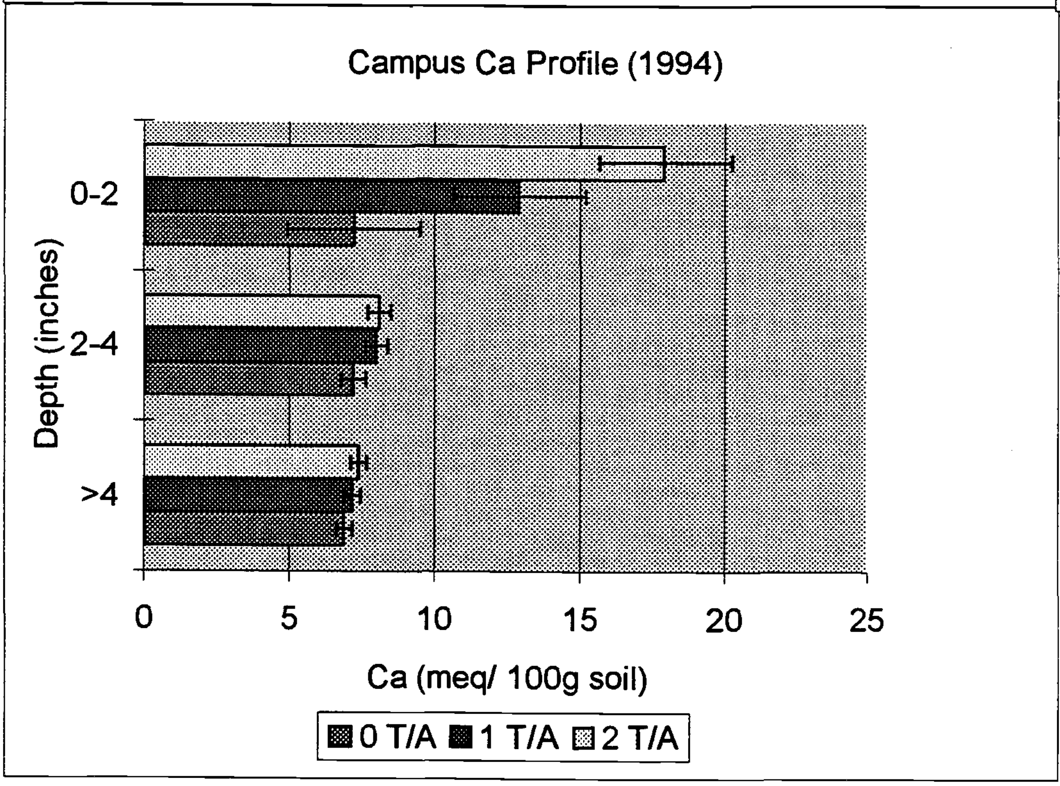


Fig. 8 The pH and Ca soil profiles for the campus site. The error bars represent the 95% confidence interval and the legend represents the lime application rate

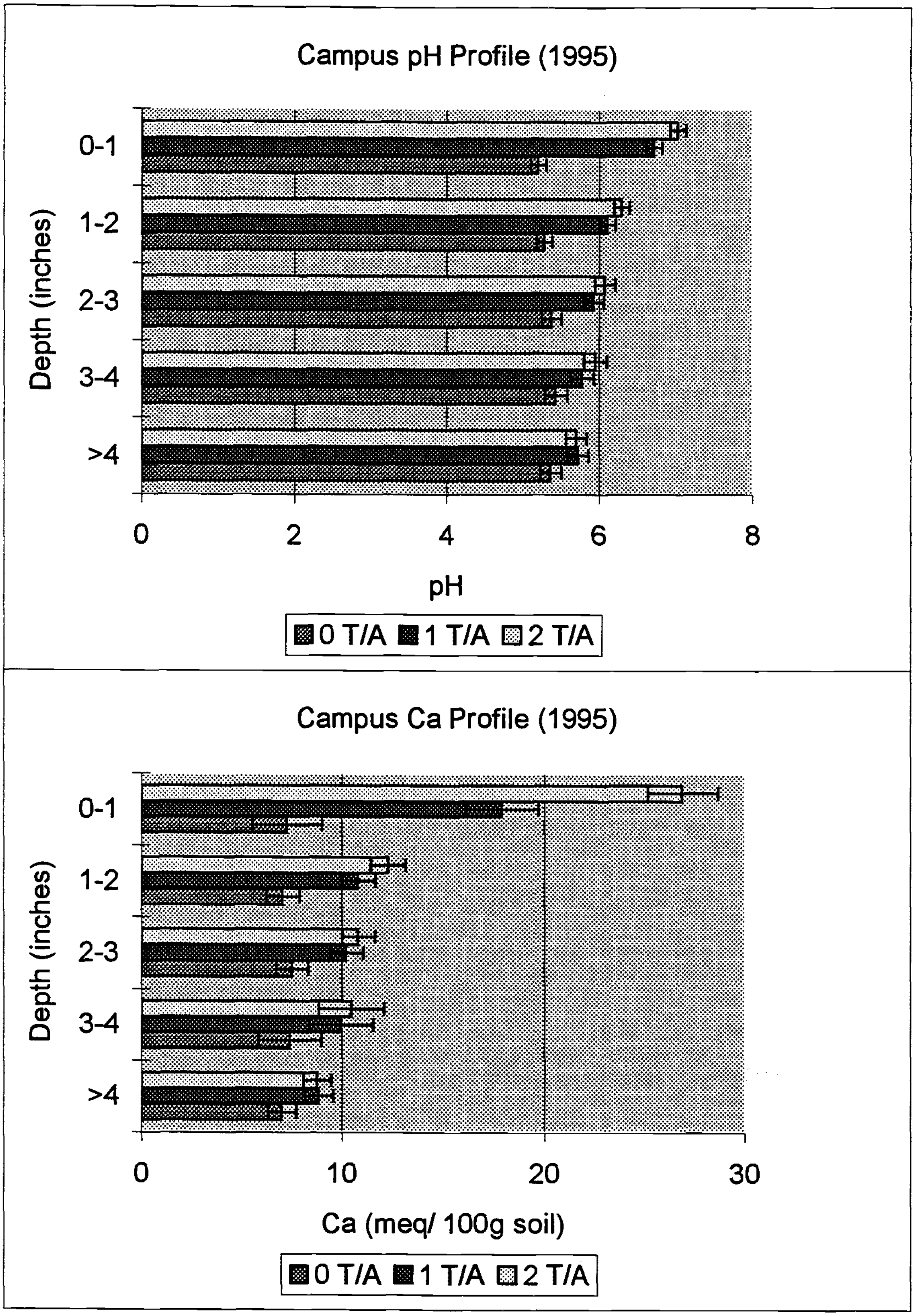


Fig. 9 The soil pH and Ca profiles for the campus site. The error bars represent the 95% confidence interval and the legend represents the lime application rate

Table 8 The 1995 campus soil K profile

Trt	0-1 (inches)		1-2 (inches)		2-3 (inches)		3-4 (inches)		>4 (inches)	
Lime (T/A)	K (ppm)	SD	K (ppm)	SD	K (ppm)	SD	K (ppm)	SD	K (ppm)	SD
0	332	47.0	309	23.9	342	25.7	370	27.0	400	47.7
1	278	22.2	295	21.7	344	28.9	360	63.1	416	48.8
2	281	28.2	*261	12.4	306	25.6	354	40.7	382	42.1
	LSD=54.7		LSD=32.0		LSD=42.8		LSD=73.4		LSD=74.1	
	SE=17.1		SE=10.0		SE=13.4		SE=22.9		SE=23.2	

* Statistically significant at the 95% confidence level

Table 9 The 1995 Polk soil K profile

Trt	0-1 (inches)		1-2 (inches)		2-3 (inches)		3-4 (inches)		>4 (inches)	
Lime (T/A)	K (ppm)	SD	K (ppm)	SD	K (ppm)	SD	K (ppm)	SD	K (ppm)	SD
0	274	29.6	191	37.4	161	36.6	139	32.0	134	21.5
1	*228	17.6	160	6.92	152	13.8	155	9.20	139	17.9
2	*238	35.0	190	29.0	187	37.4	177	53.4	169	33.5
	LSD=22.0		LSD=48.6		LSD=57.9		LSD=72.2		LSD=45.7	
	SE=5.59		SE=12.4		SE=14.7		SE=18.4		SE=11.6	

* Statistically significant at the 95% confidence level

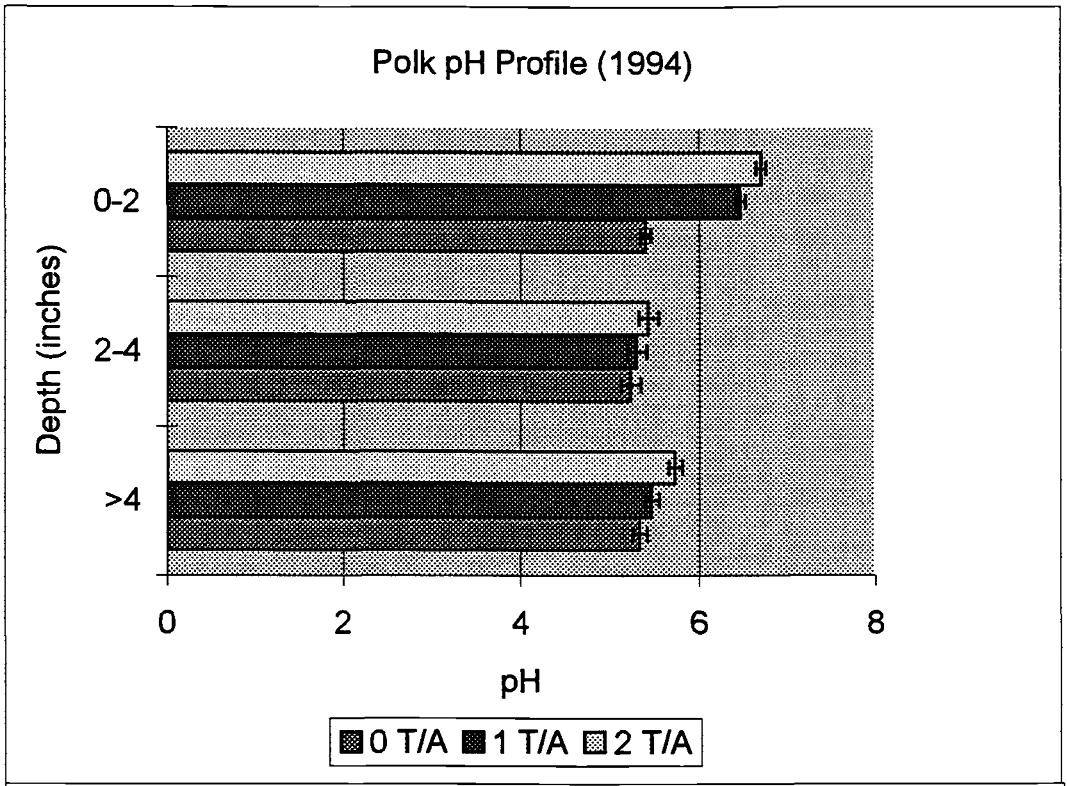
Polk

The 1994 Polk soil test results demonstrated significant treatment differences for soil pH and Ca, while soil K and P were unaffected. The limed plots had a significantly increased soil pH only at the 0-2 inch layer of the profile (Fig 10). The soil Ca also displayed significant increases only at the 0-2 inch samples (Fig 10). Both K and P (Table 5 and Fig. 2, respectively) demonstrated no significant treatment differences. Thus, in 1994 lime only affected the top two inches of soil.

In 1995, soil pH, Ca, and K demonstrated significant treatment differences while soil P was not tested. Soil pH was increased in the limed plot by at least 0.3 of a pH unit through the 1-2 inch layer (Fig. 11). At the 2-3 inch layer $p=0.07$ ($F=5.68$) which was marginally significant at the 95% confidence interval. The soil Ca showed (Fig 11) a similar pattern to soil pH since liming caused a significant increase in soil Ca through the 2-3 inch layer. For example, at the 2-3 inch layer, the 2 T/A limed plots had an average soil Ca of 7.1 meq Ca/ 100g soil while the check was 5.5 meq Ca/ 100g soil. The +4 inch layer demonstrated a treatment difference but it was based on one sample (8.1 meq/ 100g soil) which suggested either experimental error or simply an outlier. The 0-1 inch layer demonstrated a significant treatment decrease in soil K (Table 9). At the 0-1 inch layer, the limed plots were an average of 36 ppm soil K lower than the unlimed check plots. In 1995 lime caused significant soil pH and Ca increases through the 2 inch level and may have increased soil pH and Ca at the 2-3 inch depth.

Soil Summary

Lime did not cause significant soil pH or Ca increases below 2 inch at any site one year after lime was applied. In 1995, the lime caused significant increases in soil pH and Ca through the 1-2 inch layer, at least, and usually further. Second, the P soil test did not detect treatment differences. Third, a significant treatment difference in the K soil test for the 0-1 inch or 1-2 inch samples was occassionally found. These results



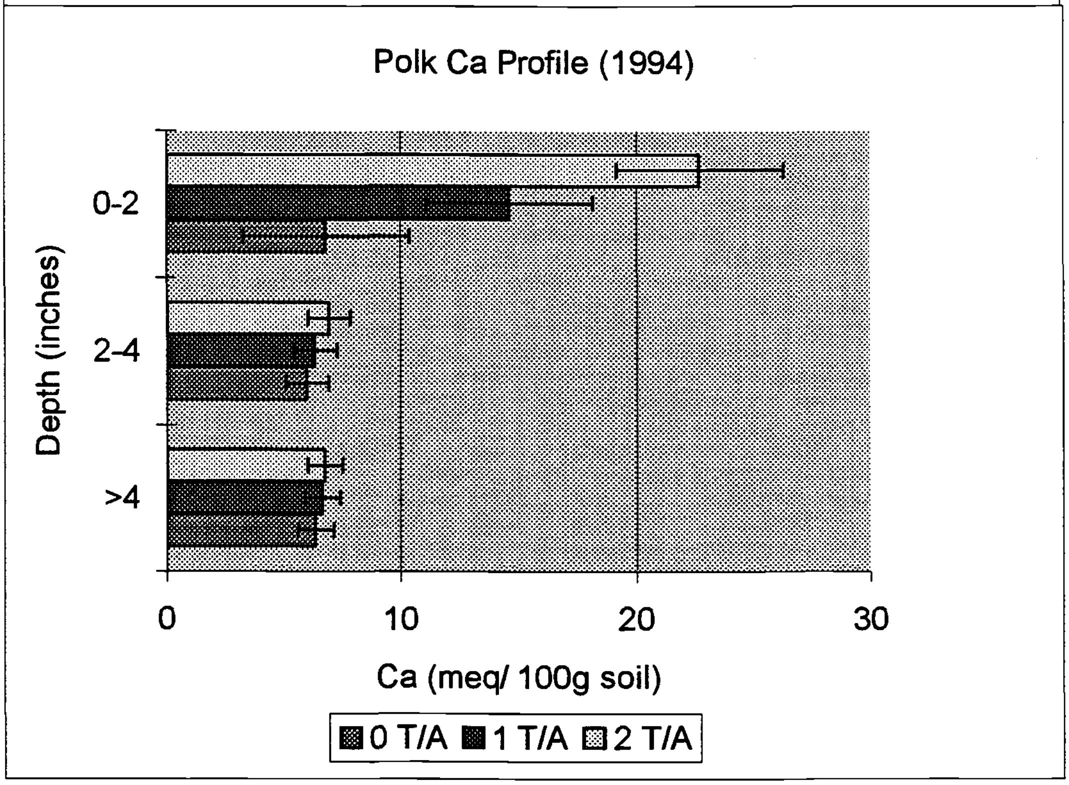
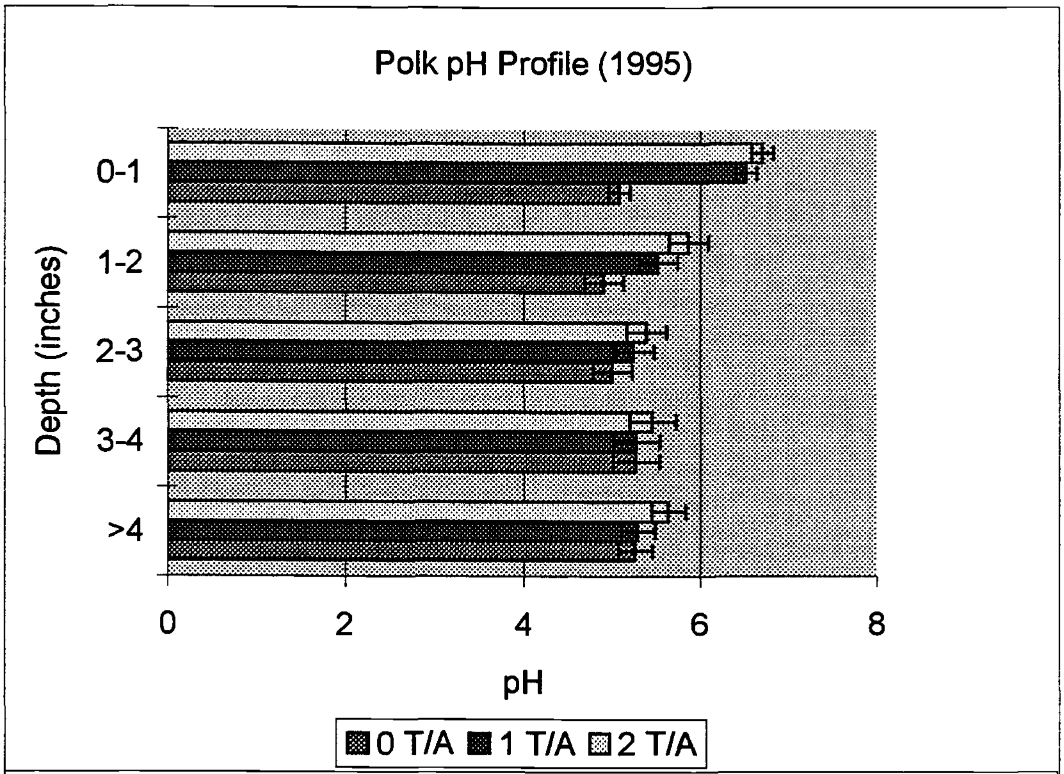


Fig. 10 The soil pH and Ca profiles for the Polk county site. The error bars represent the 95% confidence interval and the legend represents the lime application rate.



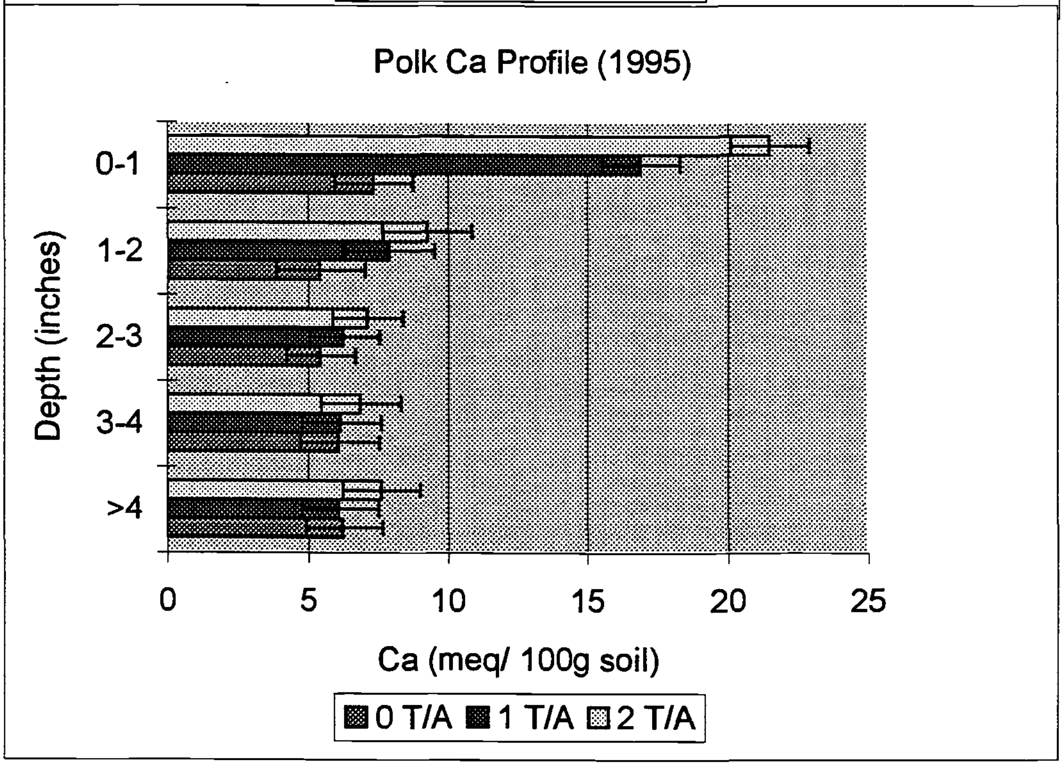


Fig.11 The soil pH and Ca profiles for the Polk county site. The error bars rperesent the 95% confidence interval and the legend represents the lime application rate.

demonstrated that lime was mixed through the soil profile after two years but that consistent soil nutrient differences were difficult to detect and interpret.

Production

No significant differences in production from the lime treatments were found at any site in 1994. This analysis included both individual clippings (Tables 10-13) and total production (Fig 12- 13). For example, the Tillamook County site's production varied between 5619 lb DM/A and 5447 lb DM/A which was too small to be considered significant.

However, in 1995 at two sites liming increased dry matter production. The limed plots at the Tillamook County site had a 945 lb DM/A increase in total production for the entire growing season (Table 14 and Fig 14) at 2 T lime /A compared to the check plots. The limed plots at the Lane County site did not have a statistically significant increase in production, since p=0.09. But lime practically increased total production by 2794 lb DM/A at 2 T of lime/A (Table 16, Fig 14). Also, the production declined by approximately half for the second clipping compared to the first and third clippings (Table 16). Both the Campus and Polk County sites had treatment differences of 100-300 lb DM/A which was not significant and did not necessarily follow the pattern of lime application (Tables 15, 17 and Fig. 15). Also, they both continuously increased their production over the clipping season (Tables 15, 17). Thus, two sites demonstrated significant, whether practical or statisitical, increases in dry matter production and two sites demonstrated no significant changes in production.

Plant Nutrient Data

In 1994, lime caused no significant differences in the concentration of any nutrient in tissue except for Mn (Fig. 16-23). Lime caused the concentration of Mn in plant tissue to decrease by at least 34 ppm in the first and third clippings at the Lane County site (Fig. 17).

Table 10 Tillamook 1994 production

Trt	Clipping (3/28/94)		Clipping (5/13/94)		Clipping(6/7/94)		Total	
Lime (T/A)	Prod. (lb DM/A)	SD	Prod. (lb DM/A)	SD	Prod. (lb DM/A)	SD	Prod (lb DM/A)	SD
0	342.1	4.88	2443.3	232.94	2270.6	1017.60	5056.0	925.23
1	480.7	34.96	2665.8	373.82	2300.8	634.49	5447.3	572.14
2	413.9	87.6	2524.3	116.21	2266.4	295.81	5204.6	225.32
	LSD=217.1		LSD=743.2		LSD=2015		LSD=2065	
	SE=42.21		SE=151.8		SE=411.7		SE=401.7	

Table 11 1994 campus production

Trt	Clipping (4/4/94)		Clipping (5/30/94)		Total	
Lime (T/A)	Prod (lb DM/A)	SD	Prod (lb DM/A)	SD	Prod (lb DM/A)	SD
0	638.00	271.93	2043.4	114.09	2681.3	311.06
1	817.70	355.59	2117.3	93.29	2935.0	445.41
2	586.01	68.65	2066.3	49.47	2660.6	310.31
	LSD=637.3		LSD=203.1		LSD=768.0	
	SE=138.1		SE=44.88		SE=166.5	

Table 12 1994 Lane production

Trt	Clipping (4/20/94)		Clipping (5/23/94)		Clipping (6/21/94)		Total	
Lime (T/A)	Prod (lb DM/A)	SD	Prod. (lb DM/A)	SD	Prod (lb DM/A)	SD	Prod (lb DM/A)	SD
0	2962.1	244.13	4688.2	402.21	3228.44	979.50	10878.7	1166.7
1	2514.6	195.31	3921.0	551.18	2365.39	209.61	8800.96	370.4
2	2514.6	399.67	2767.3	2335.2	2099.02	1655.5	7380.85	2564.3
	LSD=924.5		LSD=4155		LSD=2561		LSD=6941	
	SE=166.4		SE=748.0		SE=461.2		SE=1249	

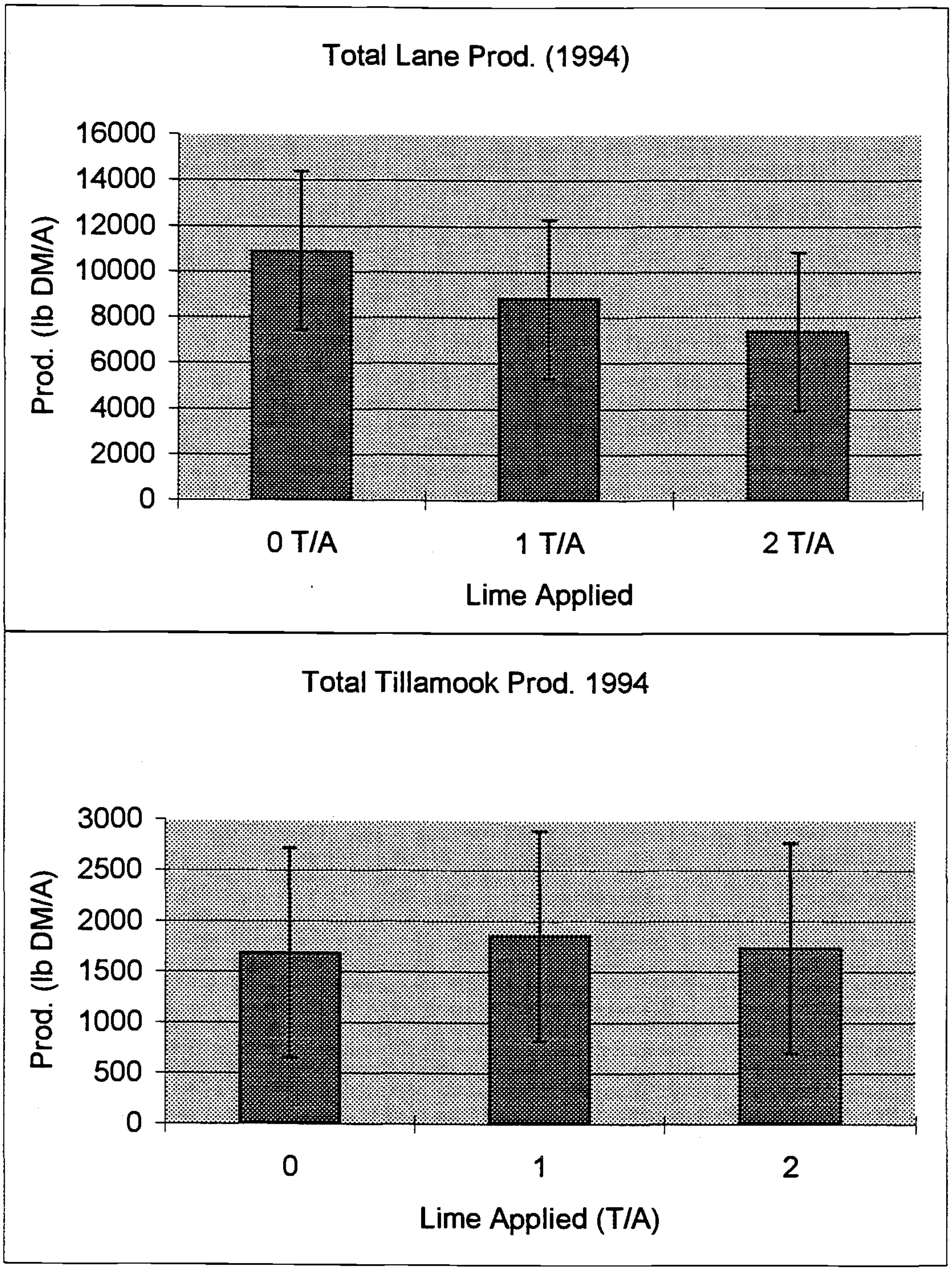


Fig. 12 The total production for the Tillamook and Lane county sites. The error bars denote the 95% confidence interval.

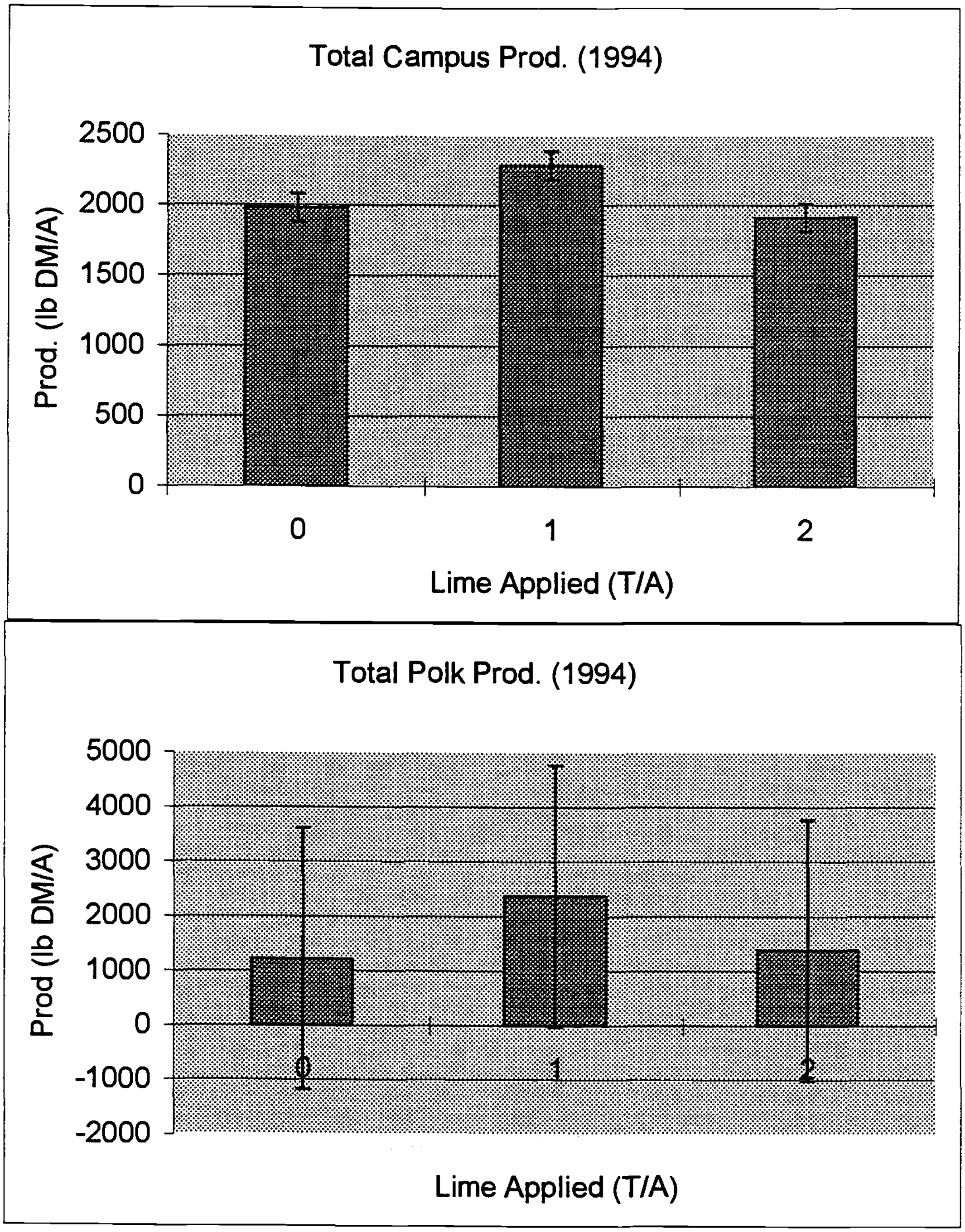


Fig. 13 The total production for the campus and Polk county sites. The error bars denote the 95% confidence interval.

Table 13 1994 Polk production

Trt	Clipping (4/5/94)		Clipping (5/18/94)		Total	
Lime (T/A)	Prod. (lb DM/A)	SD	Prod. (lb DM/A)	SD	Prod. (lb DM/A)	SD
0	671.26	287.68	543.40	693.72	1241.7	732.40
1	1246.6	417.99	1118.8	870.12	2365.4	453.18
2	735.18	308.26	1374.5	276.82	2109.7	332.19
	LSD=1272 SE=229.0		LSD=2394 SE=431.0		LSD=1129 SE=287.4	

Table 14 1995 Tillamook production

Trt	Clipping (4/10/95)		Clipping (5/15/95)		Clipping (6/15/95)		Total	
Lime (T/A)	Prod. (lb DM/A)	SD	Prod. (lb DM/A)	SD	Prod. (lb DM/A)	SD	Prod. (lb DM/A)	SD
0	1363.7	117.57	1645.7	196.16	1193.3	47.16	4202.6	163.35
1	1490.0	249.68	2061.3	149.32	1170.6	58.16	*4722.0	70.53
2	1770.7	64.51	2017.7	229.50	1359.3	255.41	*5147.7	216.94
	LSD=327.0 SE=94.47		LSD=549.6 SE=112.3		LSD=307.1 SE=87.72		LSD=323.5 SE=93.52	

* Statistically significant at the 95% confidence level

Table 15 1995 campus production

Trt	Clipping (4/6/95)		Clipping (5/11/95)		Clipping (6/22/95)		Total	
Lime (T/A)	Prod. (lb DM/A)	SD	Prod. (lb DM/A)	SD	Prod. (lb DM/A)	SD	Prod. (lb. DM/A)	SD
0	1844.5	215.57	2699.2	437.96	4315.8	584.76	8859.5	966.23
1	1796.2	138.28	2539.0	481.51	4681.0	879.35	9016.2	1244.9
2	1689.0	203.90	3125.5	161.96	4346.8	292.62	9161.2	282.25
	LSD=427.7 SE=94.50		LSD=875.9 SE=193.5		LSD=3098 SE=316.3		LSD=2148 SE=474.6	

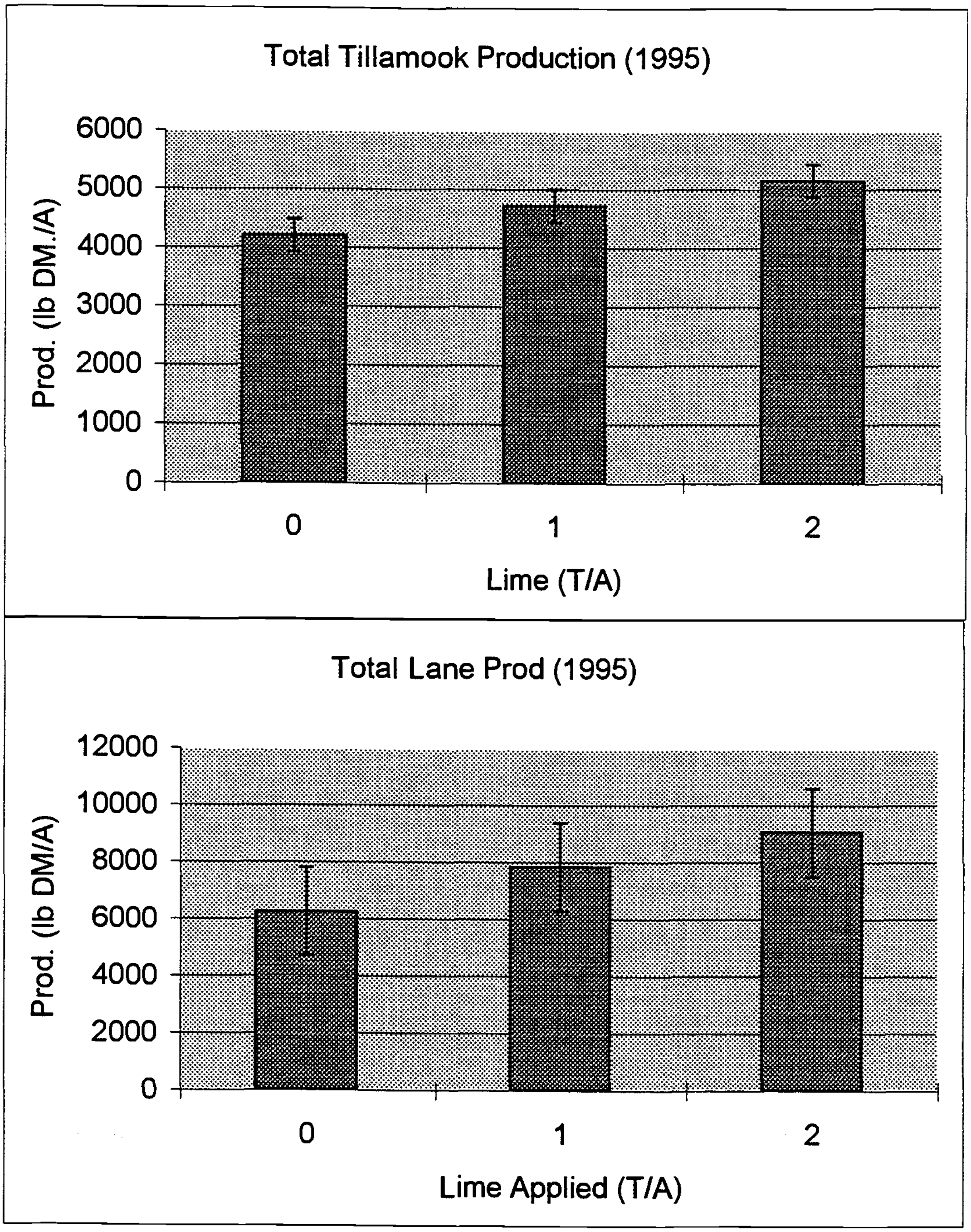


Fig. 14 The total production in 1995 at the Tillamook and Lane county sites. The error bars represent the 95% confidence interval.

Table 16 1995 Lane production

Trt	Clipping (3/29/95)		Clipping (4/26/95)		Clipping (6/1/95)		Total	
Lime (T/A)	Prod. (lb DM/A)	SD	Prod. (lb DM/A)	SD	Prod. (lb DM/A)	SD	Prod. (lb DM/A)	SD
0	1989.7	210.60	1123.1	47.52	2819.0	806.36	6251.6	671.96
1	2447.6	305.92	1566.3	178.87	3819.0	836.49	7832.9	1279.2
2	3181.0	824.24	1625.3	256.13	4239.0	1016.5	9045.4	1236.0
	LSD=1894 SE=341.0		LSD=639.2 SE=115.1		LSD=2204 SE=396.8		LSD=3644 SE=656.1	

Table 17 1995 Polk production

Trt.	Clipping (3/28/95)		Clipping (5/4/95)		Clipping (6/9/95)		Total	
Lime (T/A)	Prod. (lb DM/A)	SD	Prod (lb DM/A)	SD	Prod. (lb DM/A)	SD	Prod. (lb DM/A)	SD
0	349.33	117.17	1109.7	100.31	2313.0	86.79	3772.0	142.50
1	424.33	64.73	1113.0	169.34	2266.3	177.37	3803.7	373.71
2	384.67	25.42	1072.3	58.6	2252.3	184.69	3709.3	243.64
	LSD=270.1 SE=48.62		LSD=394.2 SE=70.96		LSD=692.3 SE=124.6		LSD=752.6 SE=135.5	

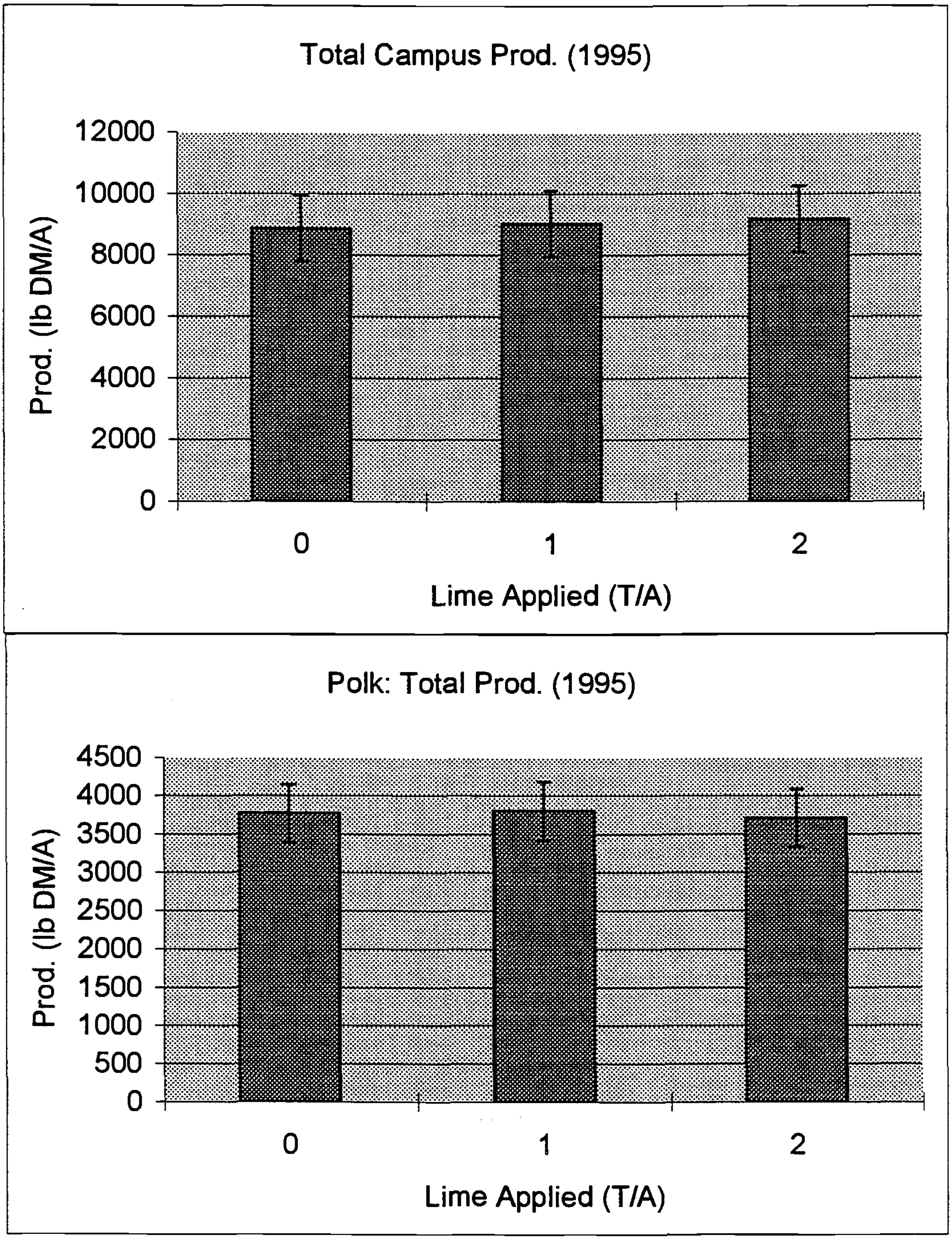


Fig. 15 The total production at the campus and Polk county sites. The error bars denote the 95% confidence interval.

In 1995 lime caused significant differences only in Mn plant tissue nutrient concentration (Fig. 24- 31). Lime caused the Mn concetration to significantly decrease by at least 51 ppm in the second and third clippings at the Tillamook site(Fig. 24). All clippings of the limed plots at the Lane site demonstrated at least a 90 ppm decrease in plant tissue Mn (Fig. 27). Lime decreased the Mn tissue concentration at all the other sites but the decreases were not significant (Fig, 25 and 26).

Also in 1995, lime caused increased N uptake at the Tillamook and Lane County sites. At the Tillamook County site 2 T/A of lime caused a significant increase in total N uptake of 30 lb N/A. At the Lane County site 2 T/A of lime caused a 120 lb N/A increase in total N uptake at which was a practically significant increase ($p=0.08$ so the difference was not statistically significant at the 95% confidence interval) (Table 18). Also, at the Lane, Campus, and Tillamook sites, N uptake exceeded the amount of N applied (120 lb N/A). Thus, lime caused additional N uptake at the Lane and Tillamook County sites.

Summary

Three major results were derived from this study. One, topdressed lime mixed at least 2 inch in 2 years but it had no measurable effect on nutrients in the soil. Two, topdressed lime significantly increased production at two pastures but it did not effect the production at another two pastures. Three, topdressed lime had no effect on the tissue concentration of a plant nutrient, except Mn. Yet, Mn was below toxic levels. The only significant uptake effects were with N at the two growth responsive sites.

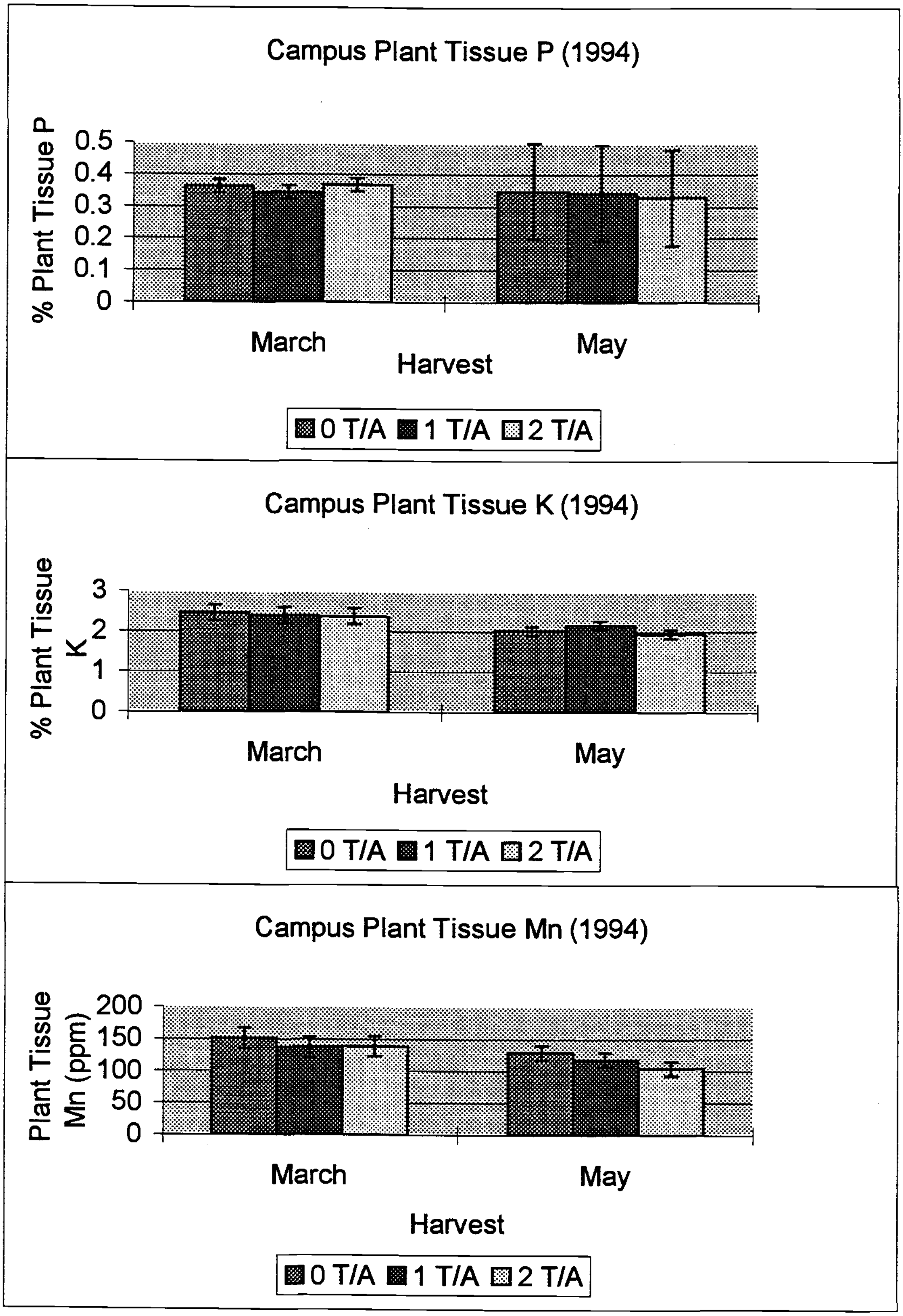


Fig. 16 The 1994 campus plant tissue analysis results. The error bars represent the 95% confidence interval and the legend represents the lime application rate.

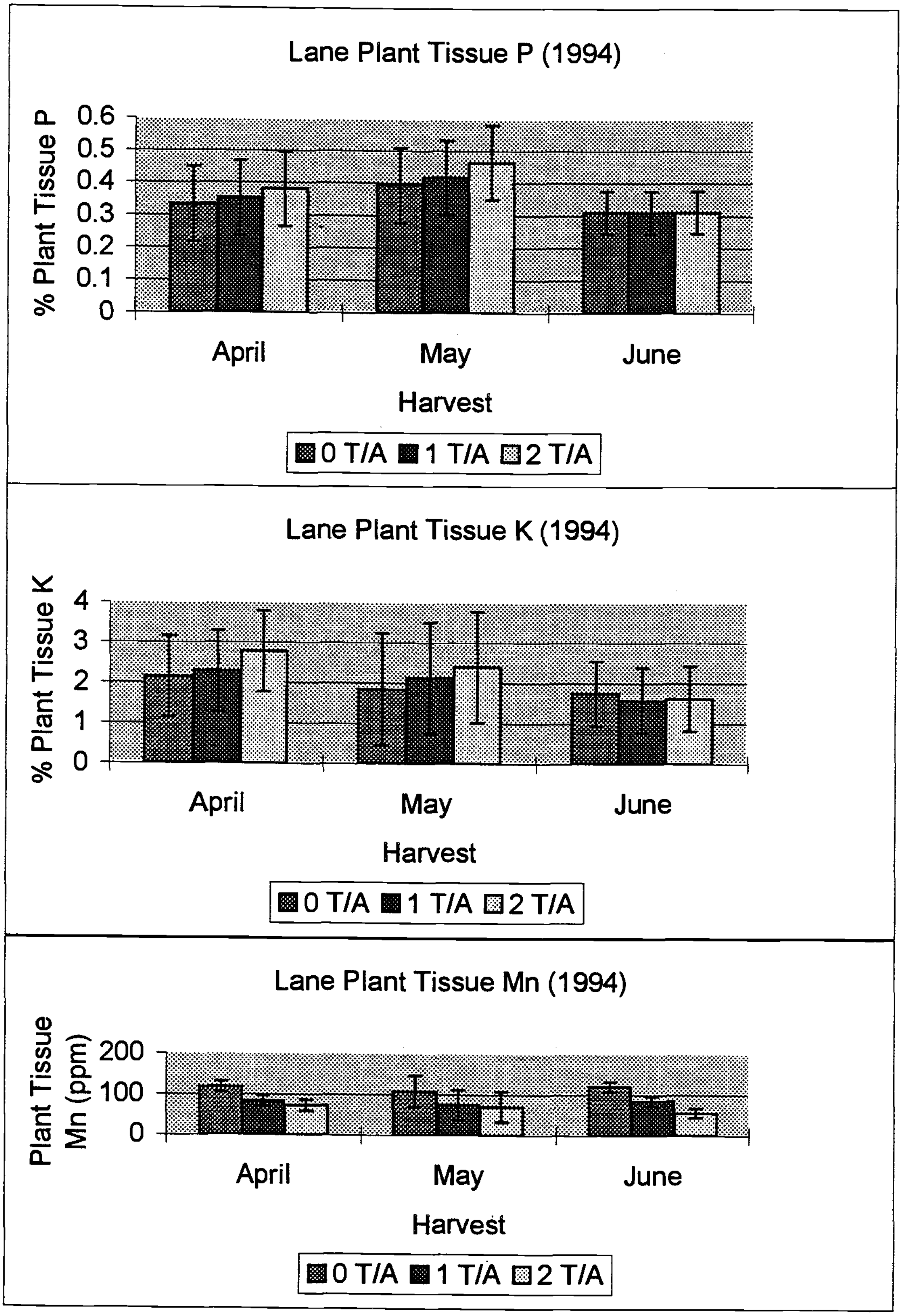
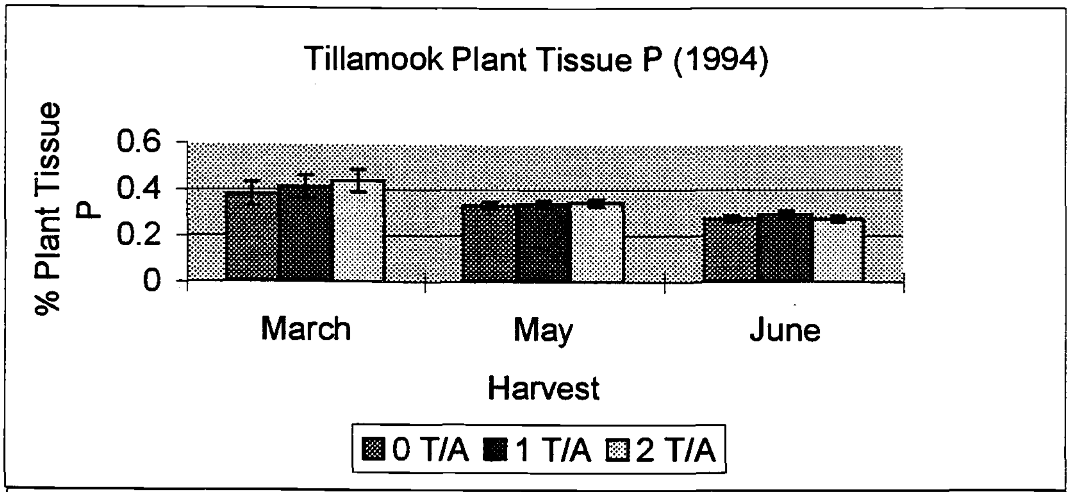
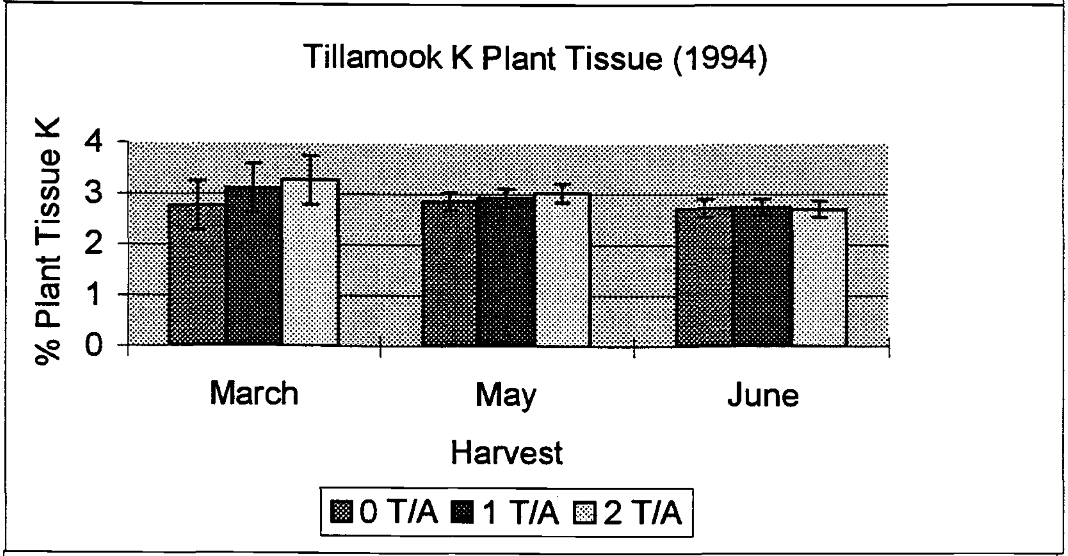


Fig. 17 The 1994 plant tissue results for the Lane site. The error bars represent the 95% confidence interval and the legend represents the lime application rate.





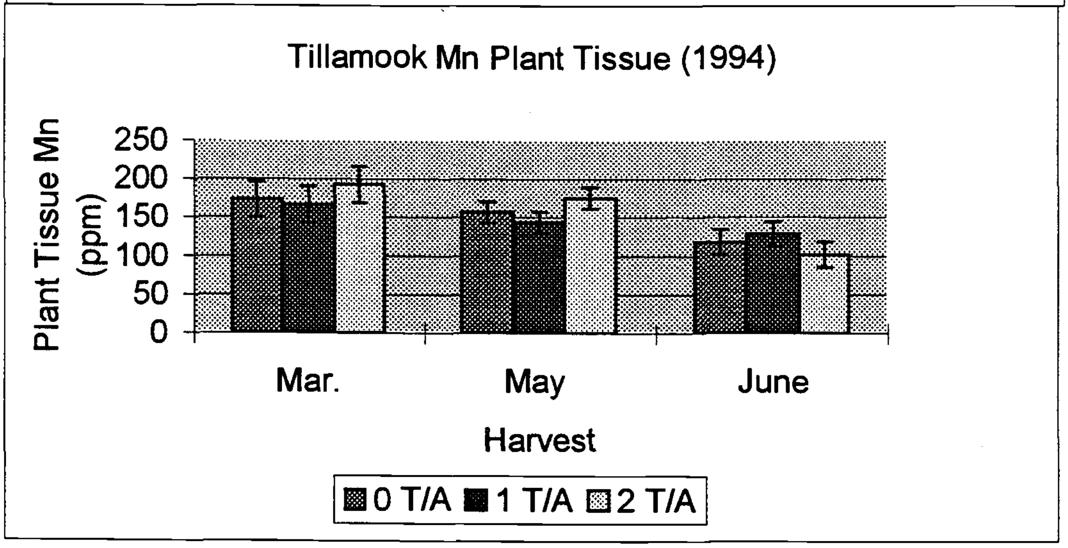


Fig. 18 The 1994 Tillamook site plant tissue analysis results. The error bars denote the 95% confidence interval and the legend represents the lime application rate.

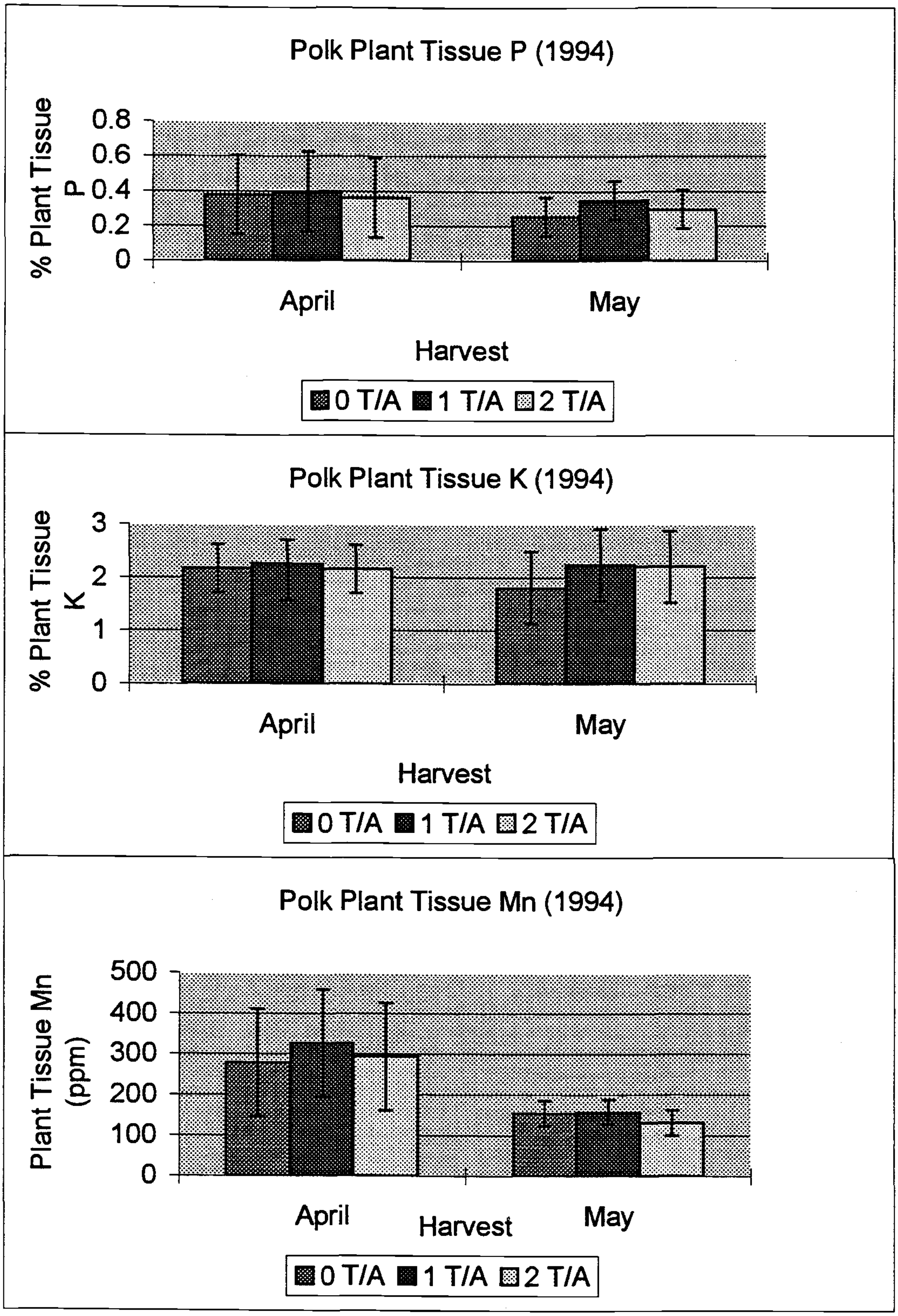


Fig. 19 The 1994 plant tissue analysis for the Polk site. The error bars represent the 95% confidence interval and legend denotes the lime applicatin rate

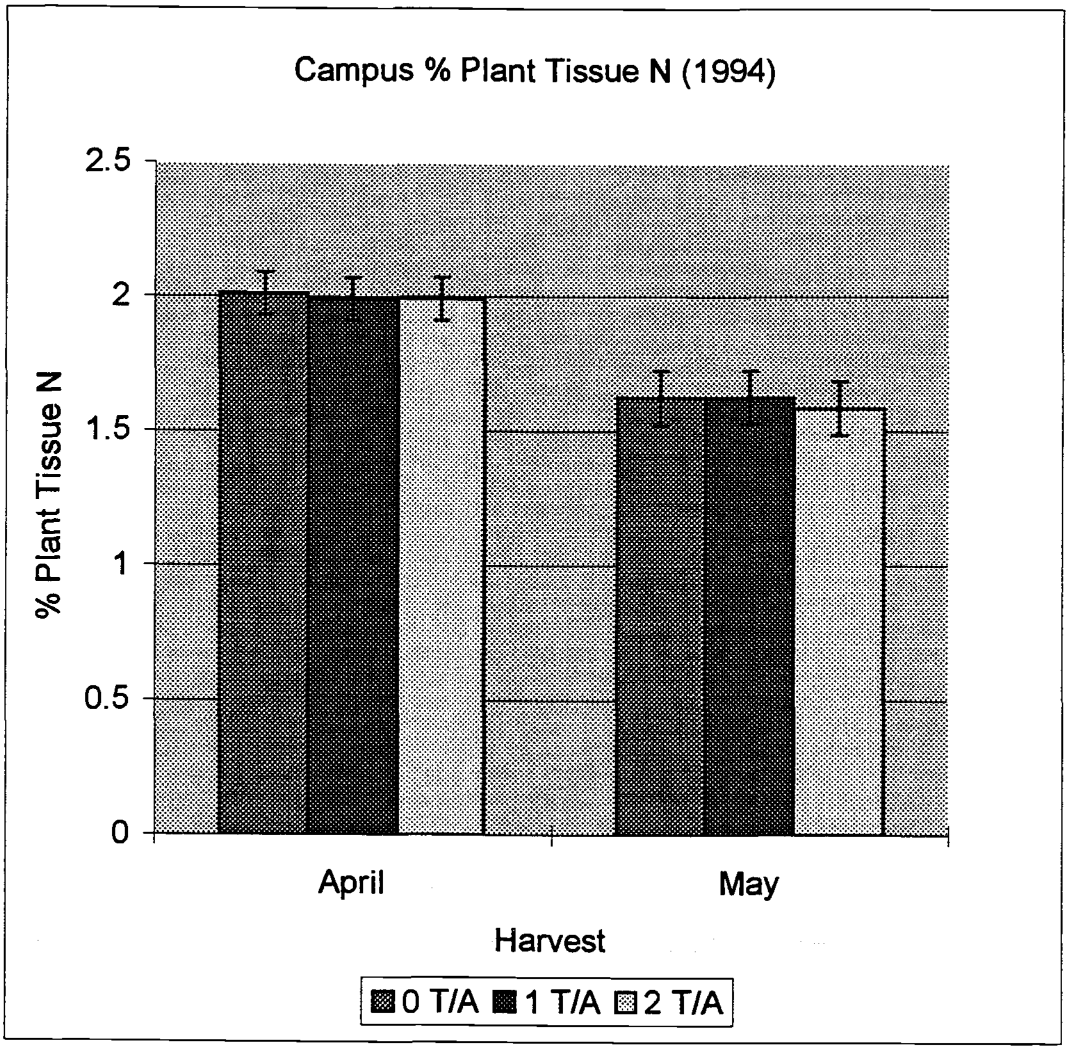


Fig. 20 The % tissue N at the campus site. The error bars represent the 95% confidence interval and the legend represents the lime application rate.

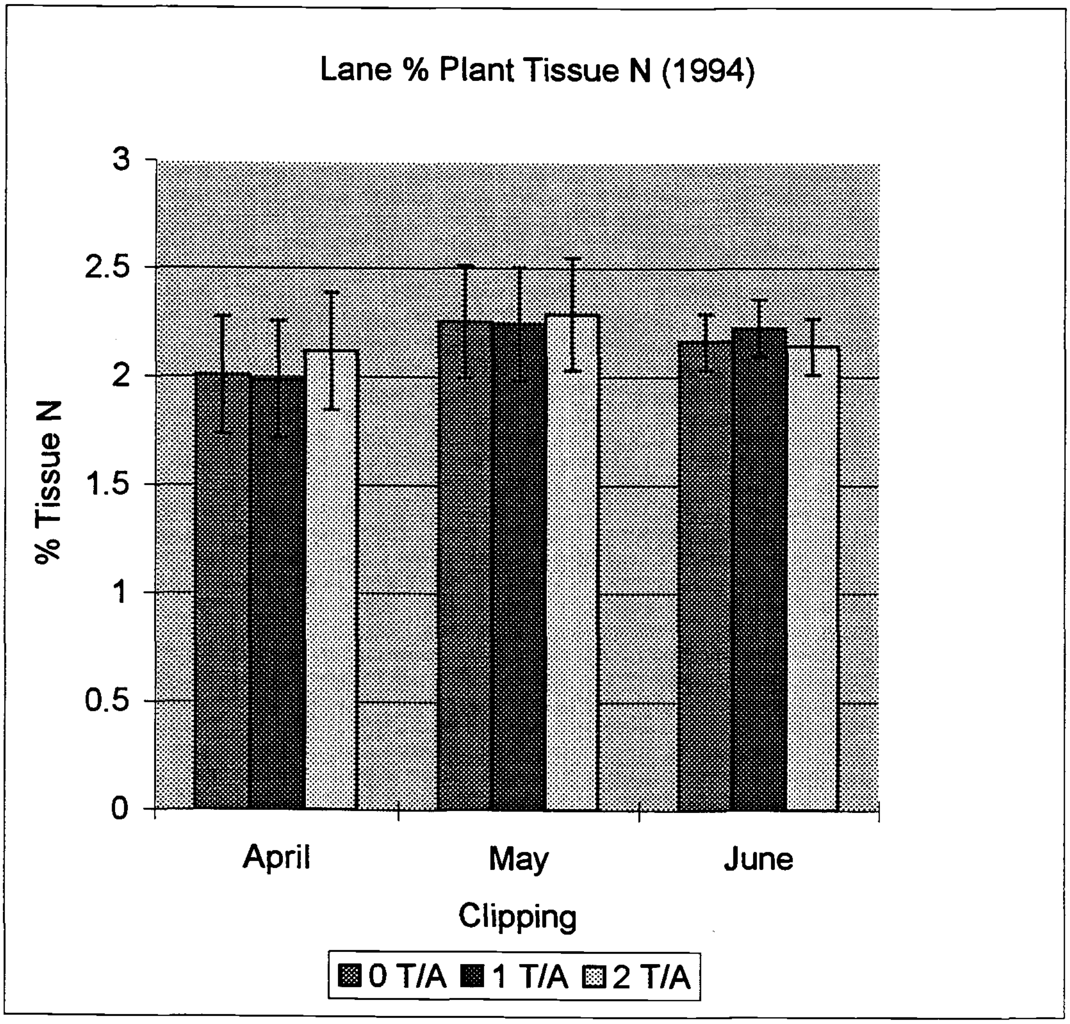


Fig. 21 The % tissue N at the Lane county site. The error bars represent the 95% confidence interval and the legend represessents the lime application rate.

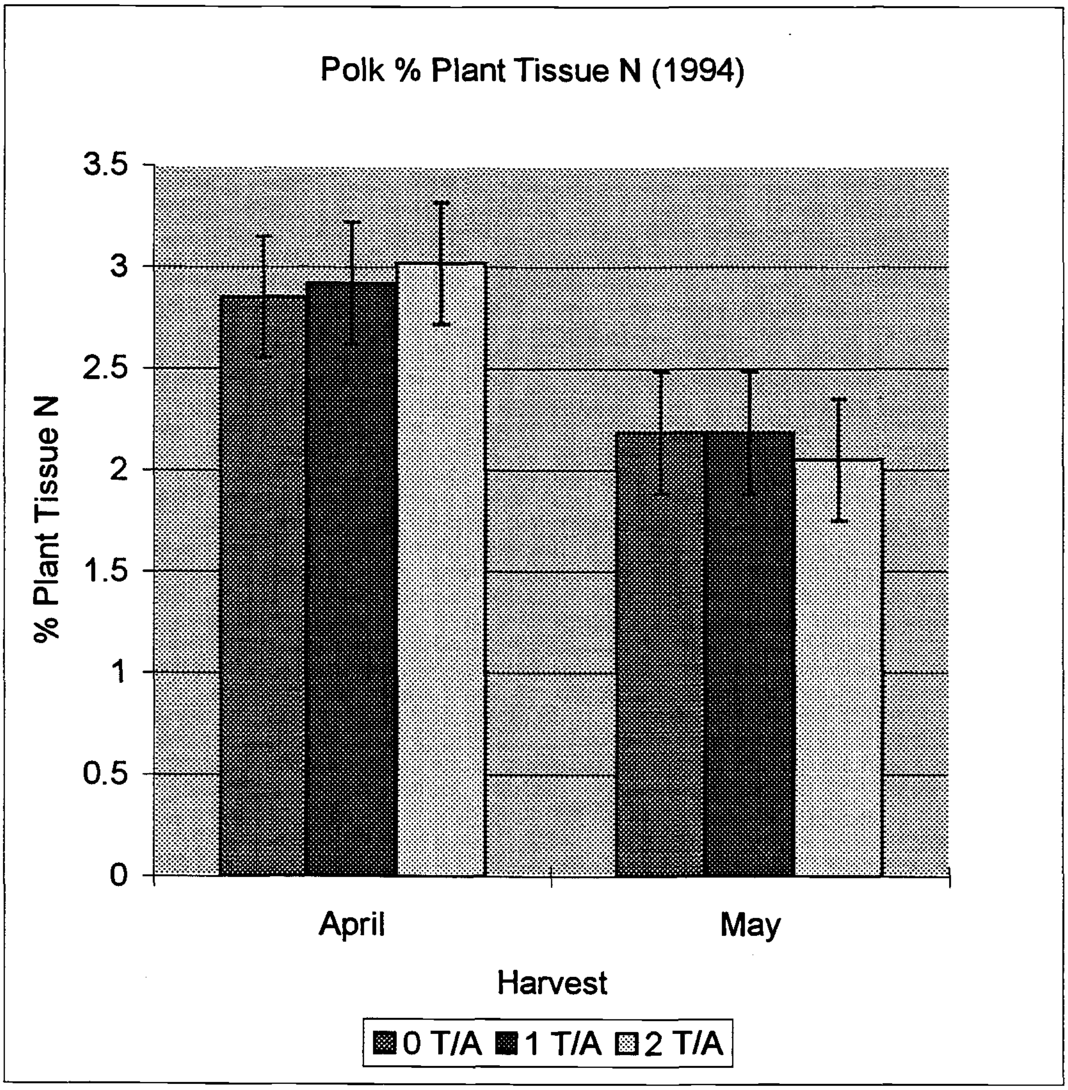


Fig. 22 The Polk county site % plant tissue N. The error bars represent the 95% confidence interval and the legend represents the lime application rate

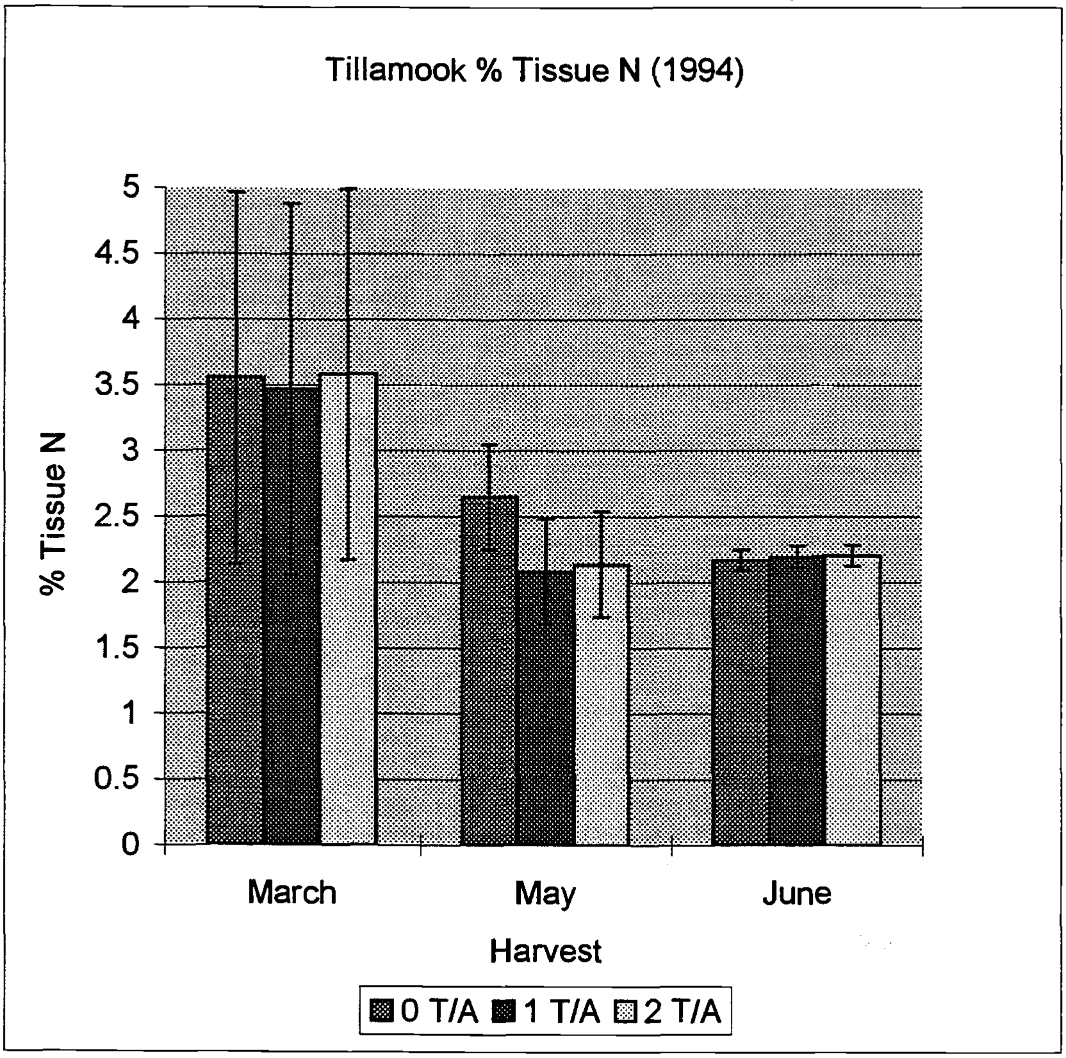


Fig. 23 The % tissue N at the Tillamook county site. The error bars represent the 95% confidence interval and the legend represents the lime application rate

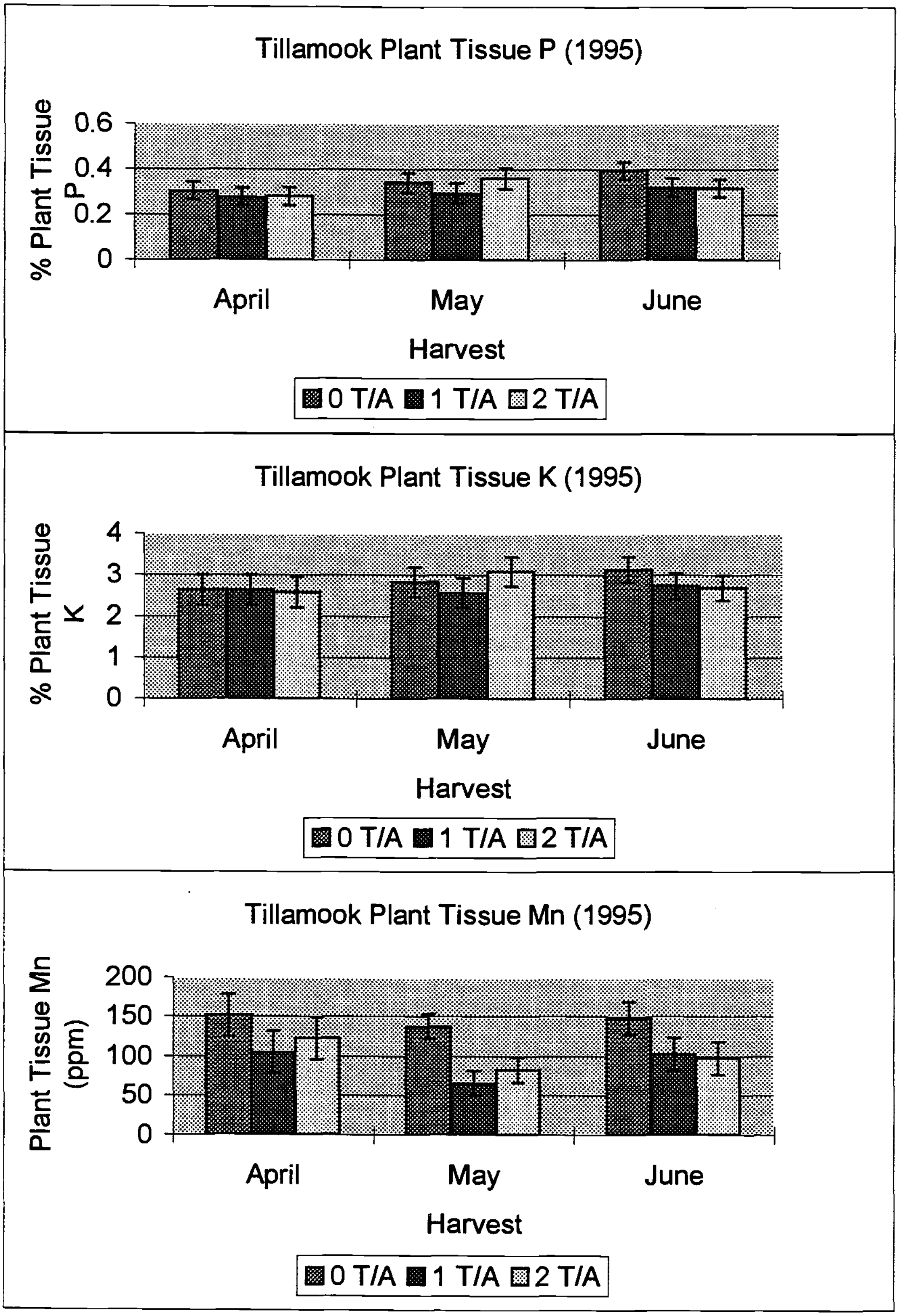
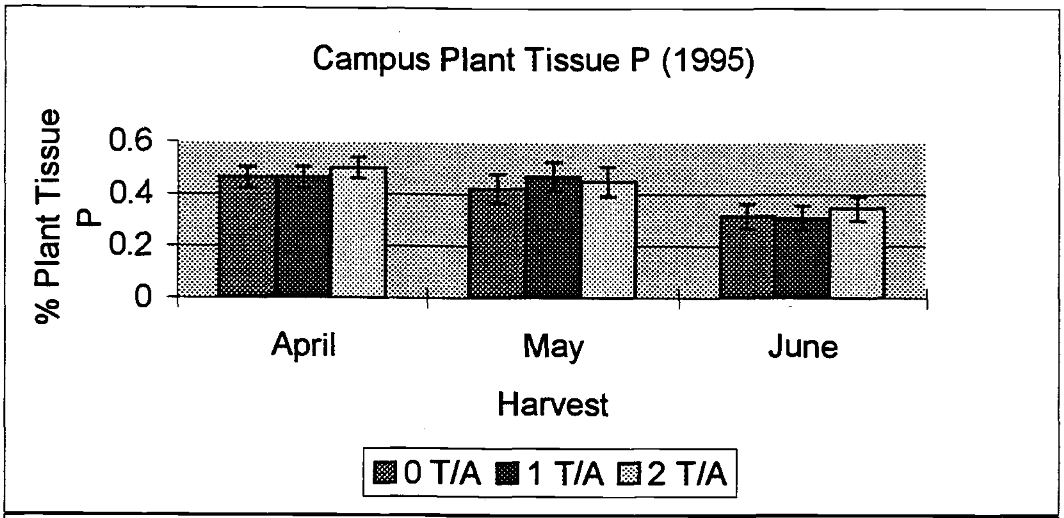
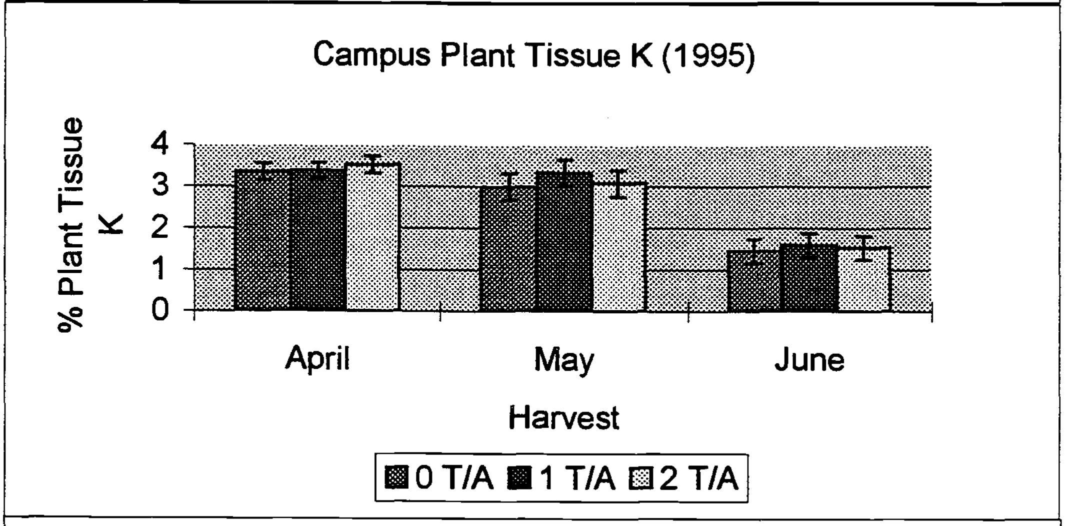


Fig. 24 The 1994 plant tissue analysis for the Tillamook county site. The error bars represent the 95% confidence interval and the legend represents the lime application rate.





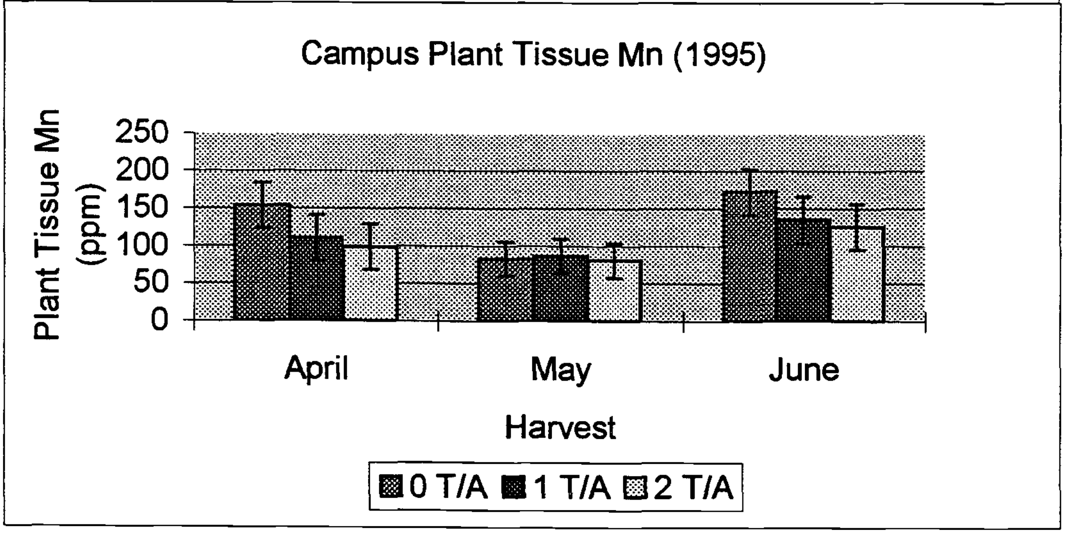
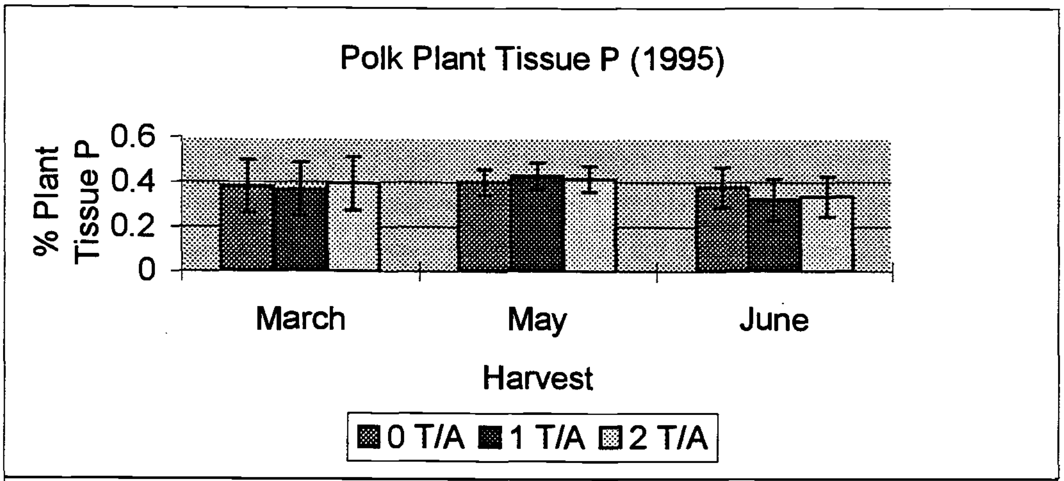
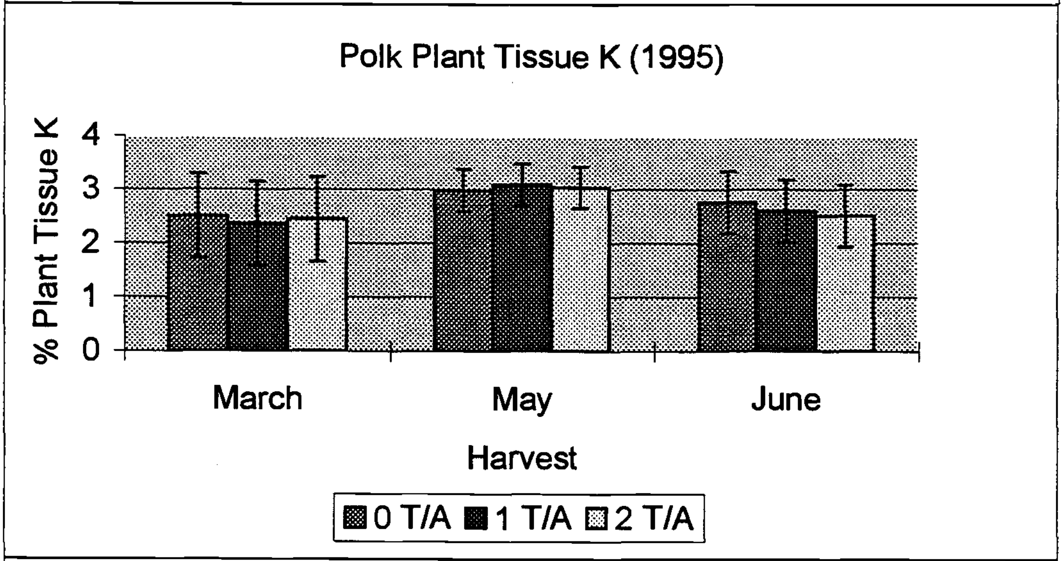


Fig. 25 The 1995 campus site plant tissue analysis. The error bars represent the 95% confidence interval and the legend represents the lime application rate.





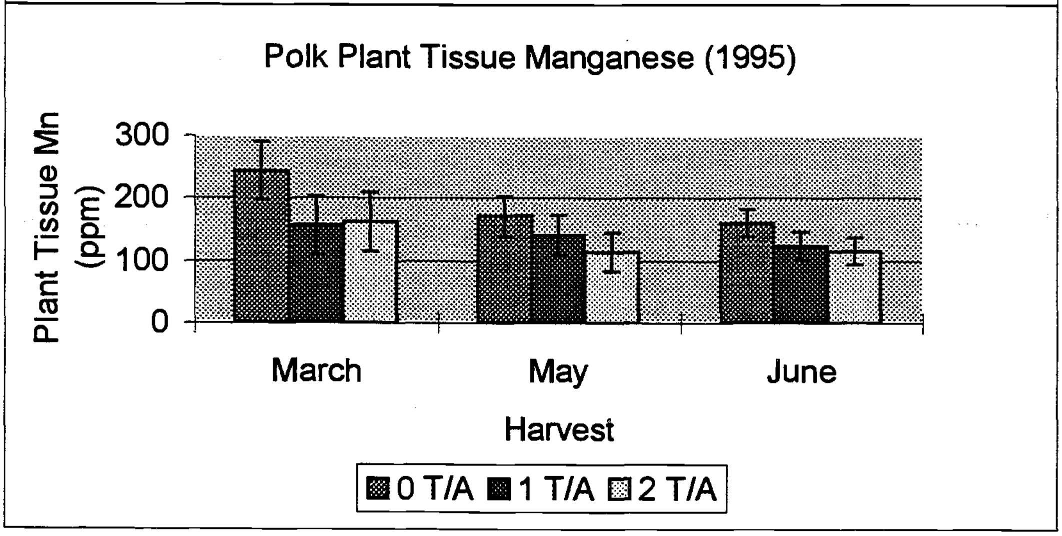


Fig.26 The 1995 plant tissue analysis for the Polk county site. The error bars represent the 95% confidence interval and the legend represents the lime application rate.

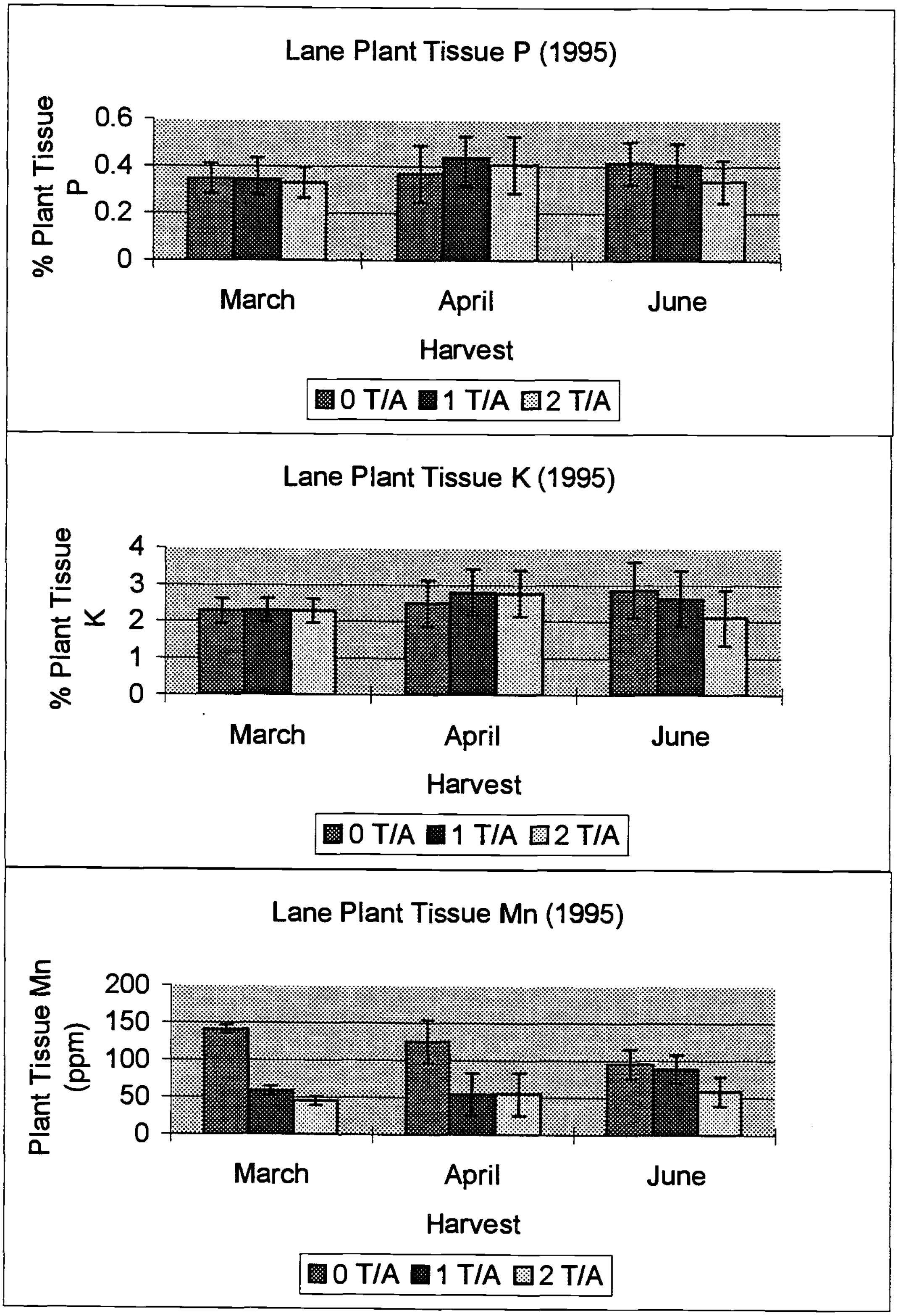


Fig. 27 The Lane county site 1995 plant tisse analysis results. The erro bars represent the 95% interval and the legend represents the lime application rate.

Table 18 Total N Uptake 1995

Trt	Tillamook		Lane		Polk		Campus	
Lime (T/A)	N Uptake (lb N/A)	SD	N Uptake (lb N/A)	SD	N Uptake (lb N/A)	SD	N Uptake (lb N/A)	SD
0	112.87	21.71	163.67	6.70	96.09	8.78	188.63	20.81
1	142.23	4.03	204.08	22.65	97.76	11.30	200.27	25.62
2	*160.9	9.88	239.98	36.49	97.82	1.20	195.67	15.83
	LSD=27.91		LSD=96		LSD=24.84		LSD=33.83	

*Significant at the 95% confidence level

Table 19 Total P Uptake 1995

Trt	Tillamook		Lane		Polk		Campus	
Lime (T/A)	P Uptake (lb P/A)	SD	P Uptake (lb P/A)	SD	P Uptake (lb P/A)	SD	P Uptake (lb P/A)	SD
0	13.26	3.75	23.23	2.55	14.83	1.80	33.11	0.79
1	14.94	1.33	27.68	5.50	14.27	1.72	34.00	4.67
2	16.76	0.67	30.55	5.93	14.58	1.14	37.31	3.82
	LSD=4.64		LSD=18.96		LSD=3.87		LSD=5.61	

Table 20 Total K Uptake 1995

Trt	Tillamook		Lane		Polk		Campus	
Lime (T/A)	K Uptake (lb K/A)	SD	K Uptake (lb K/A)	SD	K Uptake (lb K/A)	SD	K Uptake (lb K/A)	SD
0	106.46	30.26	170.23	25.03	108.16	6.29	205.77	10.36
1	122.33	12.25	205.42	43.59	103.32	7.36	217.38	18.94
2	135.98	6.02	231.64	44.10	98.4	7.34	221.73	27.72
	LSD=38.28		LSD=145.16		LSD=17.9		LSD=32.44	

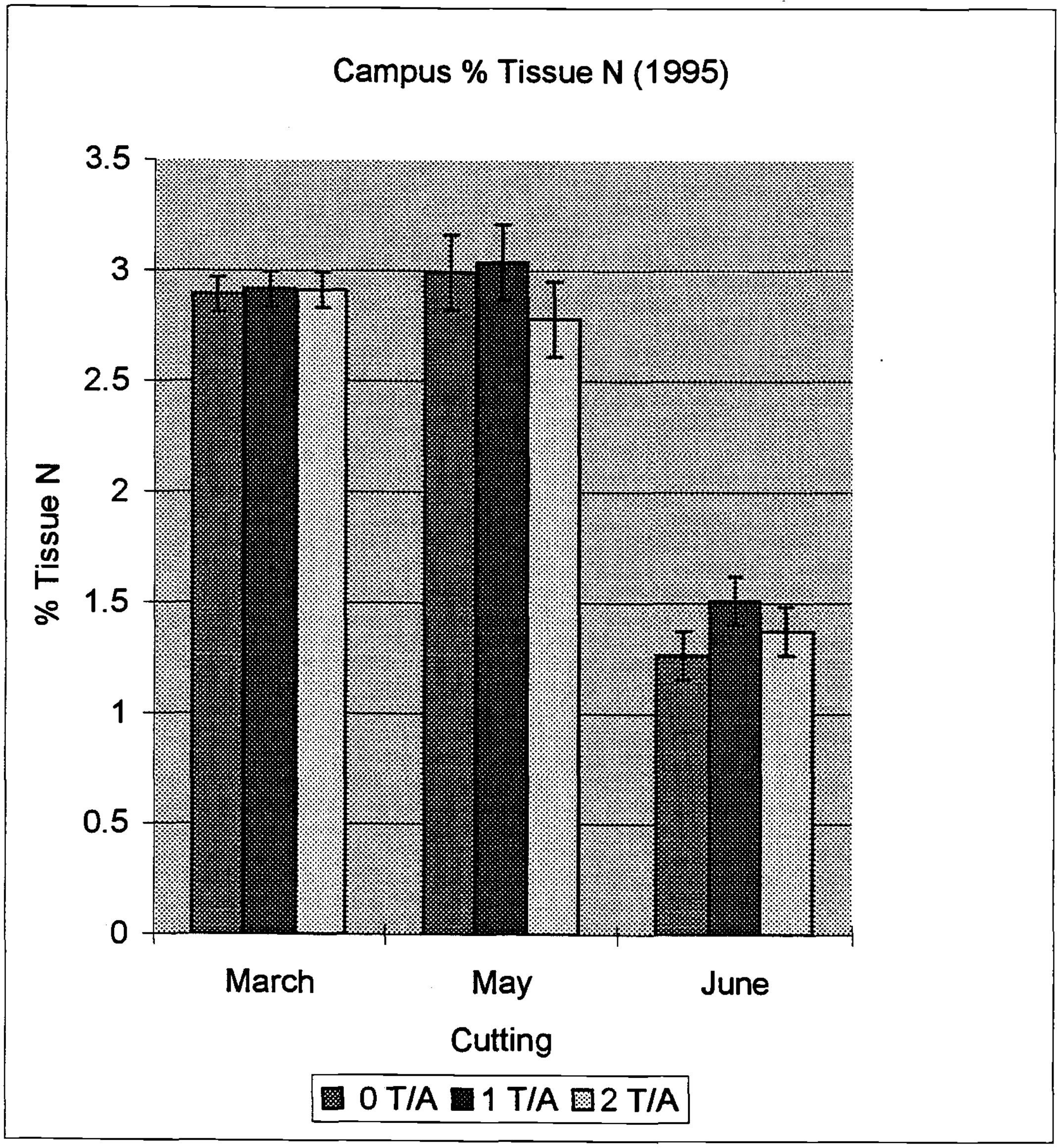


Fig. 29 The campus site % tissue N. The error bars repressent the 95% confidence interval and the legend represents the lime application rate.

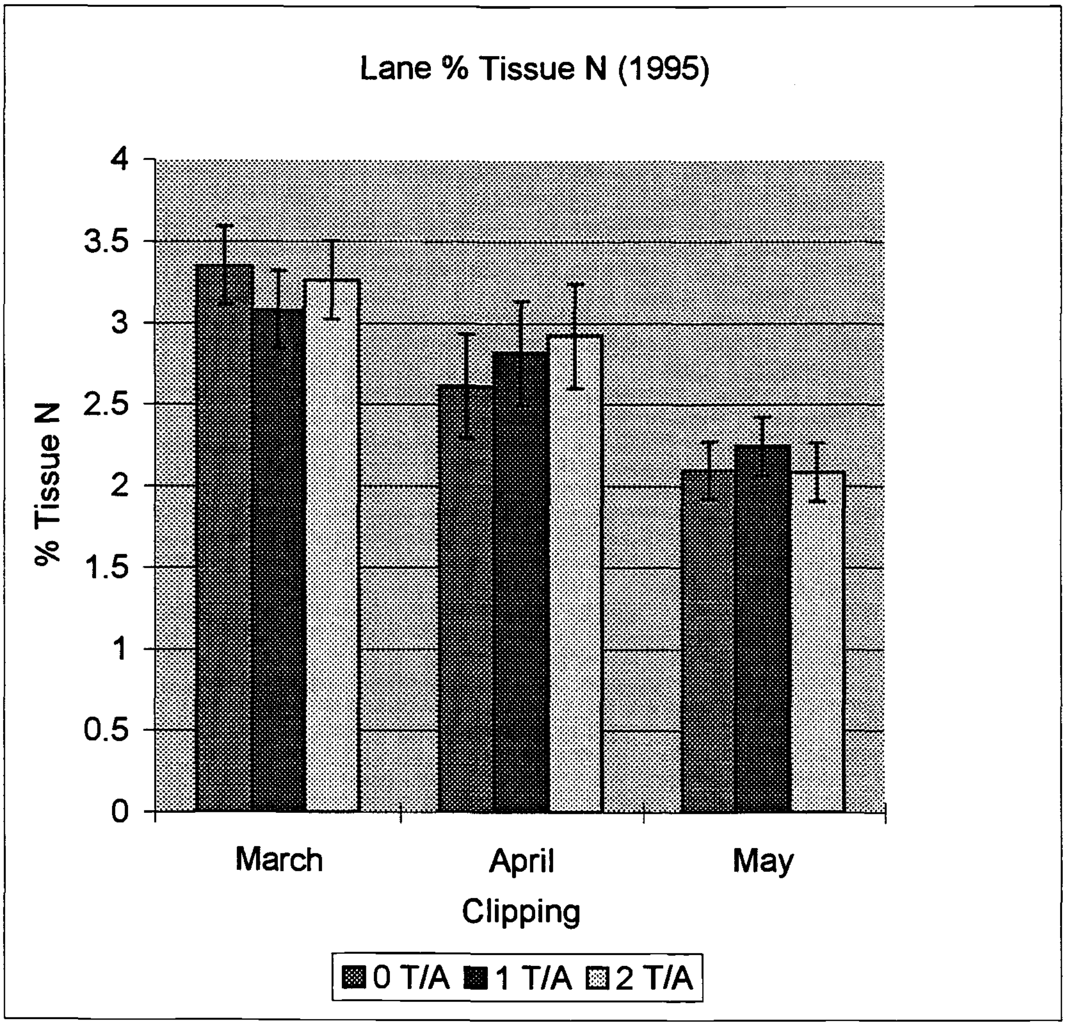


Fig. 30 The % tissue N for the Lane county site. The error bars represent the 95% confidence interval and the legend denotes the lime application rate.

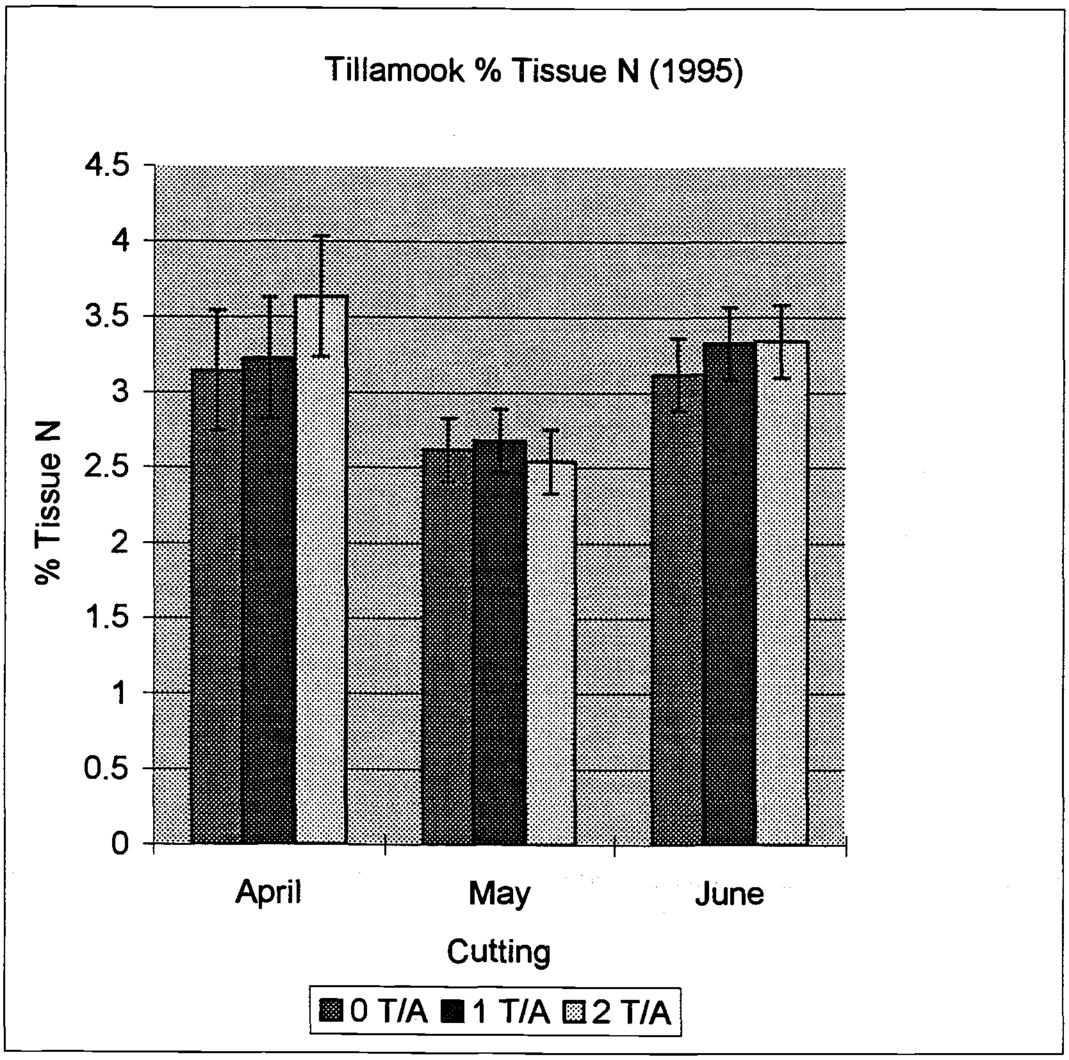


Fig. 31 The % tissue N at the Tillamook county site. The error bars represent the 95% confidence interval and the legend represents the lime application rate.

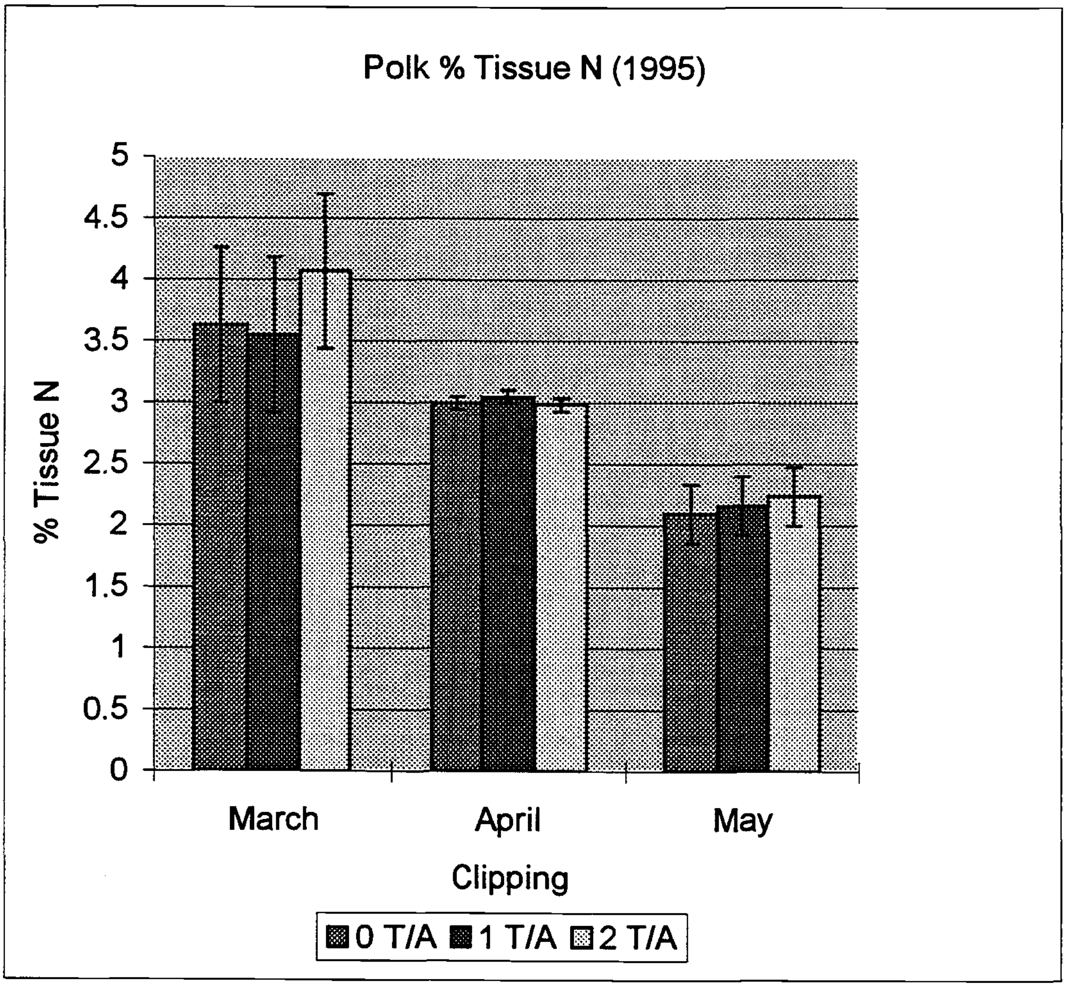


Fig. 28 The 1995 tissue N for the Polk county site. The error bars represent the 95 % conifdence interval and the legend represents the lime application rate

Discussion

This study is observational so the conclusions can only apply to the sites themselves and cannot be extended to other circumstances without prior knowledge or justification. Also, the data between sites cannot be pooled since the sites are not designed the same, randomly selected from a population of soils or pastures, and do not have the same sampling dates. Thus, each variable at each site is a unique observation and the conclusions only apply to a certain variable at a specific site. Fortunately, a great deal is known about lime and the sites are typical Western Oregon pastures, so some generalization of the conclusions is allowed if the above caveats are borne in mind. Since the data is observational each of the three objectives, the ability of lime to be mixed through the soil profile, to increase pasture production of quality, and to suggest (but not demonstrate) when and where lime is economically beneficially is examined individually.

Lime Movement

Lime, as measured by soil pH and Ca, was mixed at each site. At the Tillamook site lime moved little in the first year. Yet, by the second year lime caused a significant soil pH and Ca increase to a depth of two inches. Applying New Zealand and Australian literature to this study, soil fauna, primarily earthworms, mixed the lime. The three factors that affect soil fauna were temperature, soil textural class, and moisture. Since the coastal temperature regime was cooler than any other site and the site dried out quickly, the Tillamook site had the least amount of time when conditions were conducive to soil fauna and the mixing of lime. The Tillamook site ,in fact, demonstrated the smallest amount of lime movement measured but still had increased production (table 16). This observation implied that lime movement to only 2 inches was required by the mechanism that increased production. A similar amount of movement was observed at Polk County where soil pH and Ca concentrations in the limed plots were significantly increased to a depth of 3 inches in 1995. The Polk County site dries relatively quickly, approximately two weeks after the end of the spring rains, which could limit biological activity and mixing. However, the observed soil pH change with depth was similar to the amount of change observed by an Australian group (Bromfield et al., 1987) which suggested that the Polk site's soil results were "typical" or at least within expectations. At the Lane County site the soil pH and Ca increased only in the surface to two inch samples in 1994. Yet, by 1995 soil pH and the concentration of soil Ca were significantly higher in the limed plots from the surface to the 3-4 inch layer. The site's high water holding capacity, irrigation, and high organic matter content probably contributed to a large amount of soil fauna activity during the warm summer months. The additional activity probably lead to the incorporation of lime to 3-4 inches. The relatively large amount of lime movement (significant differences at >4 inches for both soil pH and Ca) observed on the campus site by 1995 was probably due to both small soil fauna and the endemic population of gophers. While gophers' mixing was destructive to the pasture, the gopher's activity mixed the lime quickly. These observations suggested that topdressing was an effective method for applying lime to pastures since most climatic and soil conditions were conducive to soil fauna mixing it.

Another aspect of lime mixing was its affect on the nutrient availability of P and K. While the lime probably increased P availability, no significant changes in soil P were ever detected even in surface samples. This contradiction was probably due to insensitivity of the soil P test because it measures the large "plant available" P pool which may or may not be actually plant available and it did not measure the organic P pool. For example, the soil test values for Tillamook were between 5 and 12 ppm P which was considered a deficient soil test level. However, the plant tissue concentrations were always at least sufficient probably because the soil test did not measure the organic P pool or grass plants were able to take up more P than the fertilizer recommendation assume. K demonstrated significant decreases in soil concentration at Tillamook and campus sites with increased lime. The decrease might be due to increased total uptake at those sites or decreased K availability. Potassium ions could be trapped by collapsing silicate layers in clays which could reduce availability and yield the observed results. Also, Ca competes with K for exchange sites so a high concentration of Ca could remove K from exchange sites. Thus, soil tests would measure decreased soil K. However, the amount of K uptake seemed comparable to the amount of decreased soil K which suggested that uptake was the primary fate for K. The soil tests for P and K did not detect the movement of lime probably because the soil tests were insensitive to the soil chemical changes taking place and sufficient amounts of each nutrient were available for plant growth.

Benefits of Lime to Production or Quality

Production

Although no treatment differences were measured for dry matter yield in 1994, treatment differences in dry matter production were observed at the Tillamook and Lane County sites in 1995. At the Tillamook County site, lime application caused a 450 lb DM/A increase in production per ton of lime applied or approximately an 11% increase in production per ton of lime. This increase was similar to responses observed for sedimentary soils in New Zealand (Edmeades et al., 1984). The Lane County site increased produced by approximately 1500 lb DM/A for each ton of lime applied. However, the increase was not significant at the 95% confidence interval. The high yield from the Campus site seemed to indicate that it was at maximum yield and little could be done to improve the production. The low yield at the Polk County site in 1995 suggested that some unidentified factor was inhibiting production. However, there were some ambiguities which challenge the credibility of these conclusions.

One ambiguity was the Lane County site had the largest treatment difference but the difference was not statistically significant based upon a 95% confidence interval ($p=0.09$). This ambiguity was probably due to the blocking used at the Lane County site which decreased the accuracy of the analysis (i.e. the confidence interval was larger because some of the variation was attributed to blocking should be given to the treatment effects). Since the Lane County site demonstrated a practically significant increase in dry matter production and the treatment difference was visible to the naked eye, the site should be considered to have demonstrated a significant increase in dry matter production. The other ambiguity was the species composition of the Campus site was different from the other sites. Perennial ryegrass was more tolerant to low soil pH and required greater N and P uptake than orchardgrass. However, the physiological differences between the two grass species were small enough that I could safely assume that both would increase production or improve quality if grass could benefit from liming. Although, I would expect the two species to have different degrees of growth or quality response Since most of the ambiguities have been resolved, the production data demands an explanation of the mechanism behind the positive growth response.

Although the mechanism for increased yield is not an objective, understanding it can point out future research directions, indicate where a response was likely ,and how long it could persist. Therefore, hypothesizing a mechanism for the lime response is likely to be a profitable venture.

By process of elimination the most likely reason for a positive growth response was increased N availability. Al toxicity was an unlikely mechanism since the soil pH of the Lane County site was never below 5.45 in any measurement and was usually between 5.6 and 5.9 in the check plots. At these soil pH values, Al toxicity was considered a remote possibility since Al^{+3} frequently did not appear in measurable quantities until below soil pH 5 (Kauffman, 1976). Mn toxicity was also considered unlikely since plant tissue concentrations in the second year never rose above 243 ppm. Since the toxic range for most vegetables was 700 ppm Mn in plant tissue, 243 ppm plant tissue Mn was not close to toxic levels (Jackson et al., 1966). Although Mn did change significantly with treatment, the change was probably due to decreased availability. Phosphorus deficiency was considered improbable since P tissue concentrations did not vary significantly with treatment and were all well above the levels considered deficient. For example, P plant tissue concentration at the Tillamook County site varied between 0.28 and 0.39 % tissue P. Since percent tissue P near 0.3% was considered adequate (Kelling and Matocha, 1990) and there were no obvious deficiency symptoms, P was probably not deficient at the Tillamook County site. Although soil tests for P were available, they were not useful for delineating deficient soils during this study. Fourth, K was not considered to be deficient since soil test values were well above recommendation (200 ppm) and the plant tissue concentrations did not follow the treatment levels. Fifth, both micronutrient deficiency and disease/ pests were considered unlikely due to a lack of observable symptomology consistent with either problem. Also, plant tissue analysis did not demonstrate any deficiencies or treatment effects. N was the only major nutrient that could not be disregarded.

Circumstantial evidence promoted the idea that N was the limiting nutrient and responding to treatment. Some symptomology consistent with N deficiency such as a lighter green color and yellowing at the tips was observed during the second cutting at the Lane site. Also, the total N uptake by the check plots of the growth responsive sites was close to the to the 120 lb N/A applied to each plot. Since most of N was provided from applied urea or ammonium sulfate and nitrate is a preferred nutrient, nitrification was probably involved in the growth response. Previous studies have demonstrated that the optimum pH for nitrification was between pH 7 and pH 7.5 (Darrach et al., 1987). Since liming increased the Tillamook and Lane sites' soil pH from less than 6 to at least 6.8, the soil pH was closer to the optimum soil pH for nitrification after liming. Thus, liming probably increased the nitrification rate. An additional role for N mineralization seemed possible because the Lane and Tillamook sites had significantly increased N uptake above the amount of N applied. Similarly, a series of New Zealand pasture liming studies found that N mineralization probably played a major role in pasture lime response (Edmeades, 1981, 1984). Based upon process of elimination and some circumstantial evidence, N seemed to be the limiting nutrient and that nitrification or N mineralization was involved in creating the positive growth response observed.

Quality

The only significant treatment differences were observed in the tissue Mn concentration and total N uptake. In 1994 the Lane county site had a significant decrease in tissue Mn concentration with increased lime application rate in the first and third clippings. In 1995, Lane and Tillamook demonstrated significant decreases in tissue Mn concentration and the other sites demonstrated decreased tissue Mn concentrations with increased lime application which were not statistically significant. Since the Mn concentrations were well below the minimum level considered to be toxic (toxicity may start around 700 ppm while all measured Mn values were below 243 ppm), Mn probably did not play a direct role in the positive growth responses. An indirect mechanism by which decreased Mn availability could increase production was possible but unlikely. The observed differences were probably due to decreased Mn availability after liming. A significant increase in total N uptake with increased lime application was measured at the Tillamook site and at the Lane site. This study was not designed to define the role of N uptake or availability in pasture production so there was no way to distinguish if N was the cause or the effect of increased production. However, the total uptake for Lane and Tillamook check plots was approximately the applied level of N (120 lb N/A) while total uptake in the limed plots was greater than applied N. For example, the total N uptake for the check plots at the Tillamook site was 113 lb N/A while the forage in the 2 T/A lime application took up 156 lb N/A. Thus, the increased production used only N that was mineralized. Since total N uptake at the Polk site was less than the amount applied, nitrification, ammonification, or some other factor might had been inhibited. The campus site had N uptake beyond the amount applied (at least 68 lb N/A). The additional N was probably mineralized N or imported by gophers. However, the exact proportion provided by mineralization or the gophers could not be determined. Since most essential nutrients were available at least sufficient levels in the soil except for N and S (which were applied), liming was unlikely to alter any tissue nutrient concentration even if nutrient availability was increased. Thus, the fact that any tissue nutrient concentration (except Mn) was not affected by liming was not surprising. Particularly when a similar result was observed by Edmeades (1981).

Where and When Lime is Useful

This study is not specifically designed to assess where and when liming is likely to be most economically beneficial. It includes only four small plots that are not chosen to be a level of a certain parameter or random members of a certain population of soils. However, this study can possibly provide useful observations to suggest future research. Based on the third objective (where and when lime would be most economically beneficial) the two issues to examine are the contrasts between responsive and nonresponsive sites (where) and the cost accounting of the productivity increase (when liming becomes profitable).

The most striking contrasts between the growth responsive and unresponsive sites were soil type and organic matter content. The two responsive sites were recent alluvial soils that were either mollisols or inceptisols with loamy textures while the unresponsive sites were ultisols or mollisols which intergraded to an ultisol. This observation was similar to the results discussed in the literature review. For example, Jackson and Rampton's (1963) research did not observe increased production with lime on a Woodburn series soil which intergrades to an Ultisol . Yet, Jackson and Howell's (1969) orchardgrass production studies on an Astoria series soil, which was a recent alluvial soil, demonstrated a 500 to 1200 lb/A increase in production due to liming. The difference in soils suggested the possibility that clay content, base saturation or a related factor controlled the mechanism that inhibited or stimulated certain sites. Another contrast was the amount of organic matter in the soil. The responsive sites contained between 13-25% OM in their surface inch while the unresponsive sites contained between 3-8% OM in their surface inch. High organic matter content might have been the source of N for mineralization or contributed to increased nitrification which could lead to increased production. This hypothesis assumed that N was the nutrient which limited production. More likely the recent alluvial soils contained more OM than older weathered soils which was a cofactor to the actual variables governing production. Since lime response was considered to be site specific, finding a consistent pattern in the heterogeneous conditions of Western Oregon could be very difficult.

The two main economic scenarios are no response and the maximum response observed. The no response scenario is simple since there is no direct return on lime's investment. Assuming the yield increase observed at the Lane county site, lime costs $40.00/Ton ,and the standing forage is worth $ 20/ Ton, lime returned approximately 40% (at 1 T/A lime) of its costs per year. If productivity is maintained at the 1995 Lane county level, approximately 2.5 to 3 growth responsive years are required for lime to pay back the original cost. Obviously, if the forage is managed to be of higher quality, it is worth more and lime's costs are returned faster. For example, if the forage is assumed to be of moderate quality and worth $40/ T, then the amount of time required to return lime's cost is halved. Also, there are additional advantages to liming. For example, a more vigorous pasture is more resistant to competition from weeds, particularly bentgrass. Also, if the grass N uptake after liming, the pasture can be used to alleviate some manure management problems. This analysis indicates that lime can pay for itself in a reasonable time frame.

Summary of Conclusions Based on the Original Objectives

Several conclusions were reached from this study. First, topdressed lime was mixed through the soil to a depth of at least two inches. Two inches was enough to prompt a positive response in pasture dry matter production. Second, production was increased at two of the four sites for unknown reasons. Third, although no significant differences in the nutrient concentrations were measured, the total uptake of N suggested that some of the increased dry matter production was due N mineralization and N was limiting production. Finally, recent alluvial soils were growth responsive while the ultic soils were not growth responsive. Also, lime seemed to be a beneficial investment even at a moderate (pH 5-6) soil pH. Based on these conclusions, liming seems a wise investment since it increased production, prevented mineral toxicities, and increased N uptake.

Afterword

During this study a variety conclusions not directly related to the project's objectives were made. These conclusions mainly focused on possible reasons for the results at certain sites and the prospects for elucidating the mechanism behind increased production after liming. Since these conclusions could be useful to future research, they were examined in detail.

Three major conclusions were worth noting but not directly related to the projects objectives. First, the Polk site's production was half the Lane's and Campus' pasture production even though it experiences the same climate and received the same fertilization regime. Examining the growth rates at this site (appendix 5) indicated that the pasture's growth rate by the end of spring was on par with the other sites but the early spring growth rates were 4 to 5 times less than the other sites. This observation suggested that either a disease or poor nutrient cycling was preventing early spring growth. Since damping off was not observed at the site, poor nutrient cycling seemed to be the likely cause. Second, the Lane County site demonstrated a certain degree of patchy growth and increased production near the western edge of the site (however, this spatial variation was not enough to warrant blocking). The western edge of the site was near tree frequently used by resting animals. Thus, the increased production and variation could be the result of more manure and urine spots at that end of the site. Finally, the large amount of error in the 1994 results from the Polk and Lane County sites demonstrated that hand clipping was an ineffective means of measuring pasture production and freezing samples might affect the concentration of P or K in tissue. These conclusions demonstrated that pasture studies must cover enough area to prevent sampling error from overwhelming the results.

Resolving the issues concerning the identification of responsive sites and the mechanism for the response (the questions are related in that answering one may answer the other) requires a two pronged approach. One part is simply the expansion of the current study to include many more sites. These sites should contain only the 0 and 2 T/A lime application with three replications of each. Preferably the sites could be chosen to include a variety of levels of a factor observed to contrast between growth responsive and unresponsive sites observed in this study. For example, sites could be chosen with a variety of OM concentrations or levels of base saturation which could be regressed against increased dry matter yield to test their significance. The second prong would be to test the role of nitrogen. A lime-N study could be designed to guarantee that N is the only limiting nutrient. N would be applied as labeled organic N or a known quantity of organic N in a factorial arrangement with lime. Although the experiment would not clarify whether mineralization or nitrification is stimulated by liming, the experiment would demonstrate that some aspect of N cycling is or is not part of the lime growth response. For example, one experiment would be to apply manure containing a known amount of N with 2 T/A topdressed lime in a factorial arrangement on a pasture. This experiment would determine if topdressed lime stimulated N mineralization and dry matter production. Also, incubation studies of the nitrification and N mineralizing potential of limed and unlimed pastures could be beneficial These two approaches go elucidate a great deal concerning the likely benefit of lime upon pasture.

Summary

Top dressed lime can be mixed enough to create an increase in dry matter production. Second, circumstantial evidence suggested that N was limiting and that N cycling was likely involved with the growth response. Third, the growth response was only found at sites composed young, alluvial soils with high OM while the unresponsive sites were weathered soils with lower OM. However, the study's observational design and limited scope constrained the credibility and significance of these observations. Based upon these conclusions the current scope of the study should be increased to more sites with a variety of different taxonomic classes and a short term nitrification assay added to the standard measurement protocol.

Bibliography

Alemendras, A. and P. Bottomley. 1987. Influence of lime and phosphate on a soil grown *Trifolium Subterraneum* L. by indigenous *Rhizobium trifolii. Applied and Environmental Microbiology*. 53 (9): 2090-2097.

Baron, L.C. and E. H. Gardner. 1975. Liming for filbert production in Western Oregon. *Oregon Agriculture Experiment Station Circular.* 650: 1-18.

Bramley, R., and R. White. 1989. The effect of pH, liming, moisture, and temperature on the activity of nitrifiers in a soil under pasture. *Australian Journal of Soil Research.* 27: 711- 724.

Bromfield, S., R. Cummings, D. David, and C. Williams. 1987. Long-term effects of incorporated lime and topdressed lime on the pH in the surface and subsurface of pasture soils. *Australian Journal of Experimental Agriculture*. 27: 533-538.

Clay, D., C. Clapp, R. Dowdy, and J. Molina. 1993. Mineralization of nitrogen in fertilizer-acidified lime-amended soils. *Biology and Fertility of Soils.* 15: 249-252.

Crossley, G. and A. Bradshaw. 1968. Differences in the response to mineral nutrients of populations of ryegrass, *Lolium perenne* L., and orchardgrass, *Dactylis glomerta* L. *Crop Science*. 8: 383-387.

Darrah, P.R., P.H. Nye, and R.E. White. 1986. Simultaneous nitrification and diffusion in soil. V. The effects of pH change, following the addition of ammonium sulphate, on the activity of nitrifiers. *J. Soil Sci.* 37:479-484.

Doerge, T., P. Bottomley, and E. Gardner. 1985. Molybdenum limitations to alfalfa growth and nitrogen content on a moderately acid, high-phosphorus soil. *Agronomy Journal.* 77: 895-901.

Edmeades, D., G. Rhys, C. Smart, and D. Wheeler. 1986. Effect of lime on soil nitrogen uptake by a ryegras-white clover pasture. *New Zealand Journal of Agricultural Research.* 29: 49-53.

Edmeades, D.M., M. Judd, and S. Sarathehandra. 1981. The effect of lime on nitrogen mineralization as measured by grass growth. *Plant and Soil.* 60: 177-186.

Edmeades, D., R. Pringle, P. Shannon, and G. Mansell. 1984. Effects of lime on pasture production on soils in the North Isalnd of New Zealand: 4. predicting lime response. *New Zealand Journal of Agricultural Research.* 27: 371-382.

Edmeades, D., R. Pringle, P. Shannon, and G. Mansell. 1984. Effects of lime on pasture production on soils in the North Isalnd of New Zealand: 1. introduction and description of the database. *New Zealand Journal of Agricultural Research.* 27: 349-356.

Gray, T. and S. Williams. 1971. *Soil- Microorganisms.* Great Britian. Oliver and Boyed. pp 156-168.

Guerrero, F., W. Williams, and W. Martin. 1967. Yield and mineral composition of grass species grown on acid grassland soils. *The Journal of Range Management.* 20(2): 107-108.

Hagedorn, C. 1978. Effectiveness of *Rhizobium trifolii* populations associated with *Trifolium subterraneum* L. in Southwest Oregon soils. *Soil Science Society of America Journal.* 42: 447-451.

Helyar, K., and A. Anderson. 1971. Effects of lime on five species on aluminum toxicity and on phosphorus availability. *Australian Journal of Agricultural Research.* 22: 707-721.

Hemphill, D., M. Weber, and T. Jackson. 1982. Table beet yield and boron deficiency as influenced by lime, nitrogen, and boron. *Soil Science Society of America Journal.* 46: 1190-1192.

Hillard, J., V. Hay, and F. Hons. 1992. Annual ryegrass response to limestone and phosphorus on an Ultisol. *Journal of Plant Nutrition.* 15 (8): 1253-1268.

Holford, I., and G. Crocker. 1994. Long term effects on pasture yields to phosphate fertilizers on eight acidic soils. *Australian Journal of Agriculture.* 45: 1051-1062.

Horneck, D. 1995. Nutrient management and cycling in grass seed crops. *Oregon State Univ. Ph.D. Thesis.*

Jackson, T., P. Westermann, and D. Moore. 1966. The effect of chloride and lime on manganese uptake by bush beans and sweet corn. *Soil Science Society of America Journal.* 30: 70-73.

Jackson, T. and H. Howell. 1967. Effect of fertilizers on irrigated grass-legume pasture on an Astoria soil series. *Oregon Agriculture Experiment Station Technical Bulletin.* 108: 1-43.

James, S. and T. Jackson. 1984. The effect of pH and potassium chloride on the yield and test weight of daws winter wheat. *Special report of the Oregon State University Agricultural Experiment Station. Corvallis: The Station.* 717: 11-13.

Janghorbani, M., S. Roberts, and T. Jackson. 1975. Relationship of exchangeable acidity to yield and chemical composition of alfalfa. *Agronomy Journal.* 67: 350-354.

Kauffman, M., 1976. The effect of soil acidity and lime placement on root growth and yield of winter wheat and alfalfa. *Oregon State Univ. M.S. Thesis.*

Kelling, K.A. and J.E. Matocha. 1990. Plant Analysis as an Aid in Fertilizing Forage Crops. In *Soil Testing and Plant Analysis*, 3rd Edition, R.L. Westerman (ed.), Soil Science Society of America, Madison, WI.

Mansell, G., R. Pringle, D. Edmeades, and P. Shannon. 1984. Effects of lime on pasture production on soils in the North Island of New Zealand: 3. interaction of lime with phosphorus. *New Zealand Journal of Agricultural Research.* 27: 363-369.

McLean, E. 1982. Soil pH and lime requirement. In *Methods of Soil Analysis,* p. 199-223. A. Page, R. Miller, and D. Keeney (eds.), American Society of Agronomy, Madison, WI.

Meloan, C.E. 1968. *Instrumental Analysis Using Spectroscopy.* Lea and Febiger, Philadelphia, PA.

Metcalfe, E. 1987. *Atomic absorption and emission spectroscopy.* New York: John Wiley and Sons.

Miles, S.D. 1995. *Oregon County and State Agricultural Estimates.* OSU Extension Service, Special Report 790, Corvallis, OR.

Nelson, D. and L. Sommers. 1982. Total carbon, organic carbon, and organic matter, p. 539-594. In *Methods of Soil Analysis,* Part 2. A. Page, R. Miller, and D. Keeney (eds.), American Society of Agronomy, Madison, WI.

Rampton, H. and T. Jackson. 1969. Orchardgrass seed production in Western Oregon: Influence of fertilizers, lime, and cultural practices on the yield and quality of orchardgrass seed. *Oregon Agricultural Experiment Station Technical Bulletin.* 108: 1-43.

Rengel, Z. and D. Robinson. 1989. Aluminum effects on growth and macronutrient uptake by annual ryegrass. *Agronomy Journal.* 81: 208-215.

Rogers, B. 1984. Paper mill waste lime as a pasture topdress. *unpublished.*

Springett, J. 1983. The effect of five species of earthworms on some soil properties. *Journal of Applied Ecology.* 20: 865-872.

Stockdill, S.M.J. and G.G. Cossens. 1969. Earthworms a must for maximum production. *New Zealand Journal of Agriculture*. 119 (1): 61, 63, 65, 67.

Tate, R. 1995. *Soil Microbiology*. New York. John Wiley and Sons. pp. 254-278.

Trasar-Cepada, T., T. Carballas, F. Gil-Sortes, and E. De Blas. 1991. Liming and the phosphatase activity and mineralization of phosphorus in an Andic soil. *Soil Biology and Biochemistry*. 23 (3): 209-13.

Tyson, K., D. Roberts, C. Clement, and E. Grawood. 1990. Comparison of crop yields and soil conditions during 30 years under annual tillage or grazed pasture. *Journal of Agricultural Science*. 115: 29-40.

Watson, M. E. and R. A. Isaac. 1990. Analytical instruments for soil and plant analysis. in *Soil testing and plant analysis*. ed. R.L. Westerman, 691-740. Madison, Wisconsin : Soil Science Society of America.

Appendices

Appendix 1
Soils Data

Appendix 1 Soils data

1994 Soils Data
All depth profiles in inches

Campus trt	pH 0-2"	pH 2-4"	pH +4"	trt	P (ppm) 0-2"	P (ppm) 2-4"	P (ppm) +4"	trt	K (ppm) 0-2"	K (ppm) 2-4"	K (ppm) +4"
0	5.3	5.3	5.4	0	57	66	66	0	429	449	499
0	5.3	5.3	5.4	0	64	68	71	0	488	449	437
0	5.4	5.2	5.3	0	54	59	75	0	449	410	449
0	5.2	5.2	5.3	0	60	60	63	0	413	355	363
1	6.1	5.5	5.3	1	38	52	61	1	390	441	515
1	5.9	5.3	5.5	1	46	56	53	1	386	429	468
1	6.4	5.4	5.3	1	60	64	65	1	417	402	429
1	6.3	5.6	5.3	1	53	55	61	1	394	390	421
2	6.4	5.5	5.4	2	57	62	69	2	398	413	464
2	6.3	5.5	5.4	2	50	64	68	2	402	402	421
2	6.7	5.5	5.3	2	52	54	65	2	390	367	449
2	6.5	5.4	5.3	2	80	61	55	2	378	367	355

Lane trt	pH 0-2"	pH 2-4"	pH +4"	trt	P (ppm) 0-2"	P (ppm) 2-4"	P (ppm) +4"	trt	K (ppm) 0-2"	K (ppm) 2-4"	K (ppm) +4"
0	5.7	5.9	6.1	0	23	12	14	0	386	218	218
0	5.6	5.7	5.9	0	24	12	15	0	296	176	215
0	5.9	5.8	6.1	0	24	13	17	0	316	199	215
1	6.6	5.9	6.0	1	21	12	14	1	308	160	183
1	6.6	5.8	5.9	1	27	14	18	1	296	191	222
1	6.5	5.9	6.1	1	26	13	16	1	351	277	312
2	6.6	6.1	6.1	2	21	11	15	2	316	179	199
2	6.8	6.1	6.0	2	25	13	17	2	367	195	211
2	6.8	6.0	6.1	2	32	13	15	2	265	215	265

Tillamook trt	pH 0-2"	pH 2-4"	pH +4"	trt	P (ppm) 0-2"	P (ppm) 2-4"	P (ppm) +4"	trt	K (ppm) 0-2"	K (ppm) 2-4"	K (ppm) +4"
0	5.4	5.2	5.2	0	14	5	3	0	862	386	285
0	5.3	5.1	5.2	0	10	3	4	0	749	285	250
0	5.3	5.0	5.0	0	18	7	5	0	733	281	176
1	5.9	5.2	5.1	1	13	7	6	1	1248	394	316
1	5.8	5.1	5.2	1	10	3	4	1	562	242	179
1	5.8	4.9	5.2	1	8	4	2	1	581	254	160
2	6.1	5.1	5.2	2	8	3	3	2	651	304	226
2	6.2	5.2	5.1	2	10	3	1	2	710	250	144
2	6.2	5.2	5.1	2	7	3	1	2	616	250	148

Polk	pH			P (ppm)				K (ppm)			
trt	0-2"	2-4"	+4"	trt	0-2"	2-4"	+4"	trt	0-2"	2-4"	+4"
0	5.5	5.2	5.4	0	58	13	5	0	503	187	168
0	5.3	5.2	5.4	0	41	13	9	0	367	191	156
0	5.4	5.3	5.2	0	40	11	6	0	374	195	152
1	6.5	5.3	5.5	1	49	11	6	1	367	207	191
1	6.4	5.3	5.4	1	38	11	6	1	324	152	140
1	6.5	5.3	5.5	1	39	11	6	1	347	195	164
2	6.6	5.6	5.8	2	34	10	6	2	312	164	164
2	6.7	5.4	5.6	2	43	12	7	2	339	172	176
2	6.8	5.3	5.8	2	51	15	6	2	413	242	203

Campus	Ca (meq/100g)				Mg(meq/100g)		
trt	0-2"	2-4"	+4"	trt	0-2"	2-4"	+4"
0	7.1	6.8	6.5	0	2.7	2.4	2.2
0	6.8	7.3	6.8	0	2.4	2.4	2.3
0	8.2	7.3	7.2	0	2.5	2.4	2.3
0	6.8	7.3	7.0	0	2.5	2.5	2.3
1	12.0	7.9	6.7	1	2.7	2.7	2.3
1	9.6	7.1	7.0	1	2.6	2.4	2.5
1	16.8	8.0	7.5	1	2.4	2.4	2.3
1	13.4	8.8	7.4	1	2.7	2.6	2.4
2	15.5	7.6	7.0	2	2.4	2.4	2.3
2	13.9	7.9	7.2	2	2.5	2.3	2.2
2	21.5	8.0	7.6	2	2.6	2.5	2.4
2	21.0	8.7	7.6	2	2.4	2.5	2.5

Lane	Ca (meq/100g)				Mg(meq/100g)		
trt	0-2"	2-4"	+4"	trt	0-2"	2-4"	+4"
0	11.5	11.3	12.7	0	5.6	4.9	4.4
0	11.5	11.6	12.6	0	5.3	4.9	4.5
0	11.8	11.5	12.5	0	5.2	4.7	4.5
1	20.7	12.1	12.9	1	5.1	4.6	4.3
1	19.0	12.3	13.1	1	4.8	4.9	4.6
1	18.5	12.1	13.1	1	5.0	4.7	4.6
2	21.4	12.1	12.7	2	5.1	4.8	4.3
2	23.4	12.9	13.1	2	5.2	4.6	4.5
2	25.7	12.5	13.5	2	4.8	4.7	4.4

Tillamook	Ca (meq/100g)				Mg(meq/100g)		
trt	0-2"	2-4"	+4"	trt	0-2"	2-4"	+4"
0	5.7	3.6	4.0	0	2.9	1.3	1.4
0	4.9	3.0	3.5	0	2.5	1.0	1.1
0	5.1	1.7	1.9	0	2.8	0.69	0.67
1	16.1	5.2	4.0	1	2.8	1.4	1.4
1	12.5	3.0	3.2	1	2.1	0.92	0.94
1	13.0	3.9	3.0	1	2.4	1.0	0.92
2	18.5	3.4	3.4	2	2.3	1.0	1.1
2	23.1	2.9	2.8	2	2.8	0.85	0.82
2	30.0	4.2	2.5	2	2.3	0.96	0.77

Polk	Ca (meq/100g)				Mg(meq/100g)		
trt	0-2"	2-4"	+4"	trt	0-2"	2-4"	+4"
0	7.7	6.7	7.1	0	2.2	1.6	1.6
0	6.5	6.2	6.4	0	2.1	1.8	1.7
0	6.4	5.2	5.7	0	2.3	1.8	1.9
1	15.2	6.9	7.3	1	2.1	1.6	1.6
1	12.8	5.9	6.5	1	2.1	1.7	1.8
1	16.0	6.3	6.3	1	2.3	1.7	1.9
2	19.2	7.9	7.8	2	2.0	1.6	1.6
2	22.3	7.1	7.6	2	2.1	1.7	1.7
2	26.6	5.4	8.3	2	2.4	1.8	2.0

Appendix 1 Soils data

The 1995 Soils Results
All depth profiles in inches

Lane	pH						K (ppm)				
trt	0-1"	1-2"	2-3"	3-4"	+4"	trt	0-1"	1-2"	2-3"	3-4"	+4"
0	5.65	5.65	5.75	5.63	5.59	0	167.7	269.1	159.9	171.6	168.8
0	5.61	5.64	5.45	5.51	5.56	0	183.3	245.7	156.0	144.3	140.4
0	5.62	5.54	5.51	5.62	5.58	0	136.5	280.8	175.5	144.3	163.8
1	6.88	6.53	6.10	5.87	5.76	1	206.7	261.3	148.2	148.2	159.9
1	7.04	6.67	6.36	5.87	5.80	1	167.7	276.9	140.4	136.5	148.2
1	6.98	6.75	6.06	5.81	5.69	1	159.9	265.2	140.4	120.9	124.8
2	7.17	7.07	6.73	5.92	6.11	2	120.9	327.6	148.2	152.1	167.7
2	7.21	6.94	6.54	5.95	5.78	2	152.1	257.4	198.9	152.1	183.3
2	7.26	7.16	6.38	6.09	5.81	2	152.1	237.9	152.1	148.2	156.0

Polk	pH						K (ppm)				
trt	0-1"	1-2"	2-3"	3-4"	+4"	trt	0-1"	1-2"	2-3"	3-4"	+4"
0 T/A	5.03	4.96	5.04	5.19	5.35	0	281	176	144	125	133
0 T/A	5.02	4.86	4.98	5.17	5.19	0	242	164	136	117	113
0 T/A	5.27	4.97	5.06	5.51	5.31	0	300	234	203	176	156
1 T/A	6.39	5.85	5.50	5.43	5.36	1	226	168	168	160	160
1 T/A	6.44	5.33	5.20	5.26	5.32	1	211	156	144	160	129
1 T/A	6.73	5.43	5.11	5.19	5.25	1	246	156	144	144	129
2 T/A	6.55	5.73	5.38	5.40	5.50	2	238	191	172	152	168
2 T/A	6.75	5.93	5.53	5.54	5.68	2	203	160	160	140	136
2 T/A	6.80	5.98	5.32	5.48	5.78	2	273	218	230	238	203

Tillamook	pH						K (ppm)				
trt	0-1"	1-2"	2-3"	3-4"	+4"	trt	0-1"	1-2"	2-3"	3-4"	+4"
0	5.29	5.03	5.04	5.09	5.11	0	577.2	425.1	378.3	300.3	284.7
0	5.31	4.96	5.00	5.07	5.03	0	596.7	397.8	351.0	241.8	206.7
0	5.25	4.94	4.88	4.86	4.95	0	518.7	343.2	273.0	230.1	167.7
1	6.30	5.34	5.01	5.02	5.03	1	612.3	362.7	370.5	304.2	265.2
1	6.31	5.26	5.05	5.01	5.05	1	620.1	292.5	296.4	249.6	222.3
1	6.26	5.46	5.10	5.15	5.01	1	499.2	269.1	280.8	234.0	198.9
2	6.85	5.46	4.97	4.99	5.02	2	487.5	249.6	276.9	234.0	234.0
2	6.82	5.64	4.98	5.01	5.00	2	452.4	245.7	234.0	202.8	163.8
2	6.80	5.71	4.99	5.12	5.00	2	440.7	218.4	214.5	198.9	163.8

Campus	pH						K (ppm)				
trt	0-1"	1-2"	2-3"	3-4"	+4"	trt	0-1"	1-2"	2-3"	3-4"	+4"
0	5.22	5.37	5.30	5.33	5.37	0	315.9	308.1	339.3	393.9	440.7
0	5.40	5.24	5.47	5.58	5.34	0	315.9	308.1	367.7	378.3	421.2
0	5.08	5.29	5.37	5.36	5.34	0	296.4	339.3	354.9	378.3	405.6
0	5.05	5.17	5.31	5.41	5.35	0	401.7	280.8	308.1	331.5	331.5
1	6.62	6.23	6.17	5.75	5.65	1	276.9	315.9	358.8	425.1	475.8
1	6.51	6.05	5.86	6.03	5.73	1	309.2	296.4	335.4	286.1	436.8
1	6.62	5.94	5.81	5.69	5.69	1	269.1	304.2	374.4	397.8	374.4
1	6.79	6.09	5.89	5.66	5.82	1	257.4	265.2	308.1	331.5	378.3
2	7.08	6.28	5.96	5.80	5.49	2	257.4	276.4	339.3	401.7	436.8
2	7.02	6.29	6.09	6.00	5.66	2	263.5	253.5	312	370.5	393.3
2	7.12	6.50	6.37	6.29	6.14	2	284.7	265.2	292.5	331.5	351.0
2	6.92	6.12	5.89	5.73	5.51	2	319.8	248.7	280.8	312.0	347.1

Lane	Ca (meq/100g)						Mg (meq/100g)				
trt	0-1"	1-2"	2-3"	3-4"	+4"	trt	0-1"	1-2"	2-3"	3-4"	+4"
0	10.9	11.2	11.1	11.0	11.2	0	0.41	0.52	0.48	0.45	0.13
0	12.0	11.1	10.6	11.3	11.6	0	0.46	0.45	0.45	0.41	0.40
0	12.0	11.1	10.4	11.8	11.7	0	0.41	1.87	1.71	1.73	1.86
1	22.3	17.0	13.2	12.2	12.3	1	0.42	0.49	0.79	0.55	0.54
1	22.8	17.9	14.9	12.4	12.1	1	0.49	0.42	0.46	0.48	0.44
1	25.0	19.5	13.1	12.0	11.6	1	0.43	0.43	0.44	0.46	0.45
2	27.2	22.8	16.6	13.0	12.5	2	0.78	0.40	0.53	0.49	0.53
2	26.1	15.7	20.3	13.0	12.0	2	0.39	0.46	0.43	0.46	0.41
2	25.2	24.4	16.1	13.9	12.5	2	0.40	0.35	0.45	0.49	0.47

Polk	Ca (meq/100g)						Mg (meq/100g)				
trt	0-1"	1-2"	2-3"	3-4"	+4"	trt	0-1"	1-2"	2-3"	3-4"	+4"
0	7.3	5.6	5.8	6.3	6.7	0	2.28	1.71	1.56	1.64	1.60
0	6.9	5.5	5.4	6.2	6.6	0	2.16	1.74	1.59	1.64	1.75
0	7.9	5.2	5.2	5.9	5.6	0	2.50	1.87	1.71	1.73	1.86
1	17.1	10.0	7.5	6.9	6.9	1	1.76	1.68	1.57	1.56	1.78
1	15.5	6.6	6.1	5.9	6.2	1	1.80	1.83	1.75	1.78	1.88
1	18.2	7.1	5.3	5.8	5.4	1	1.97	1.87	1.64	1.71	1.71
2	20.3	9.5	7.5	6.5	7.2	2	1.89	1.66	1.47	1.64	1.67
2	20.4	9.5	7.4	7.7	8.1	2	1.57	1.81	1.69	1.68	1.63
2	23.7	8.8	6.5	6.5	7.6	2	1.94	2.06	1.96	1.97	2.04

Tillamook

	Ca (meq/100g)				
trt	0-1"	1-2"	2-3"	3-4"	+4"
0	7.0	3.5	2.7	2.8	3.1
0	7.4	2.8	2.8	2.8	2.9
0	6.3	2.3	1.4	1.5	1.7
1	23.9	7.6	4.8	3.6	3.6
1	25.3	7.5	4.0	3.2	3.2
1	24.0	8.9	4.7	4.3	3.0
2	36.4	11.0	4.2	3.2	4.3
2	39.2	11.8	3.5	2.7	2.4
2	35.0	13.2	3.0	3.8	2.3

	Mg (meq/100g)				
trt	0-1"	1-2"	2-3"	3-4"	+4"
0	3.46	1.94	1.19	1.09	1.20
0	3.01	1.44	1.01	0.93	0.97
0	2.92	1.40	0.72	0.65	0.62
1	2.59	1.76	1.34	1.01	1.16
1	2.57	1.67	1.23	1.00	1.01
1	2.51	1.70	1.18	1.05	0.91
2	1.76	1.31	1.05	0.95	1.15
2	2.15	1.54	1.00	0.83	0.78
2	1.67	1.28	0.78	0.79	0.78

Campus

	Ca (meq/100g)				
trt	0-1"	1-2"	2-3"	3-4"	+4"
0	6.8	6.9	7.8	7.1	6.6
0	9.3	7.0	7.8	8.4	7.2
0	6.4	7.5	7.5	7.0	7.3
0	6.6	6.8	7.0	7.1	6.9
1	19.8	11.9	10.8	8.6	8.1
1	16.1	10.7	10.0	14.1	8.5
1	17.4	10.1	9.4	8.7	9.6
1	18.6	10.6	10.8	8.4	9.3
2	26.0	11.4	9.7	9.4	7.8
2	29.0	14.0	11.2	10.8	8.3
2	29.9	13.3	12.9	13.3	10.7
2	22.9	10.5	9.5	8.4	8.3

	Mg (meq/100g)				
trt	0-1"	1-2"	2-3"	3-4"	+4"
0	2.35	2.42	2.47	2.51	2.29
0	2.25	2.28	2.24	2.30	2.26
0	2.19	2.55	2.41	2.22	2.25
0	2.30	2.34	2.38	2.37	2.33
1	2.23	2.53	2.61	2.49	2.46
1	2.21	2.48	2.54	2.40	2.38
1	1.91	2.31	2.48	2.65	2.49
1	2.21	2.39	2.71	2.55	2.60
2	1.78	2.24	2.65	2.60	2.23
2	1.76	2.00	2.17	2.35	2.32
2	1.90	2.30	2.44	2.33	2.50
2	1.88	2.14	2.35	2.30	2.47

Appendix 2
Production Data

Appendix 2

1994 Production Results

Trt Lime (T/A)	Tillamook clip 1 (lb DM/A)	clip 2 (lb DM/A)	clip 3 (lb DM/A)
0	345	2609	2010
0		2178	1408
0	339	2542	3393
1	516	3097	1956
1	446	2464	1913
1	480	2435	3033
2	315	2646	2203
2	443	2414	2589
2	482	2511	2007

Trt Lime (T/A)	Polk clip 1 (lb DM/A)	clip 2 (lb DM/A)
0	671	1342
0	958	96
0	385	192
1	1438	767
1	767	2109
1	1534	479
2	863	1055
2	958	1534
2	384	1534

Trt Lime (T/A)	Campus clip 1 (lb DM/A)	clip 2 (lb DM/A)
0	563	2204
0	402	1958
0	1030	2044
0	555	1966
1	1341	2241
1	725	2133
1	637	2069
1	565	2026
2	507	2139
2	636	2055
2	614	2029
2		2041

Trt Lime (T/A)	clip 1 (lb DM/A)	Lane clip 2 (lb DM/A)	clip 3 (lb DM/A)
0	2749	5114	2525
0	2909	4315	2813
0	3228	4634	4347
1	2557	4027	2557
1	2301	4411	2142
1	2685	383	2397
2	2110	4027	1055
2	2909	4411	3004
2	2525	3324	2238

Trt Lime (T/A)	Tillamook clip 1 (lb DM/A)	clip 2 (lb DM/A)	clip 3 (lb DM/A)
0	1238	1866	1246
0	1382	1490	1155
0	1471	1581	1179
1	1206	2230	1211
1	1589	1946	1197
1	1675	2008	1104
2	1780	1919	1653
2	1702	2280	1189
2	1830	1854	1236

Trt Lime (T/A)	Lane clip 1 (lb DM/A)	clip 2 (lb DM/A)	clip 3 (lb DM/A)
0	1746.6	1492	3639
0	2104.8	1440	2791
0	2117.6	1397	2027
1	2558.3	1480	3604
1	2682.7	1772	4742
1	2101.7	1447	3111
2	2968.4	1912	5384
2	2484	1419	3890
2	4090.8	1545	3443

Trt Lime (T/A)	Campus clip 1 (lb DM/A)	clip 2 (lb DM/A)	clip 3 (lb DM/A)
0	1851	2640	4884
0	2076	2814	4755
0	1895	3199.7	3847
0	1556	2144	3777
1	1764	2254	4764
1	1831	2582	5661
1	1961	3200	4777
1	1629	2120	3522
2	1543	3248	4757
2	1838	3091	4222
2	1889	2911	4077
2	1486	3252	4331

Trt Lime (T/A)	Polk clip 1 (lb DM/A)	clip 2 (lb DM/A)	clip 3 (lb DM/A)
0	482	1218	2304
0	260	1020	2439
0	306	1091	2466
1	418	1069	2395
1	492	1300	2340
1	363	970	2064
2	369	1133	2327
2	414	1068	2388
2	371	1016	2042

Appendix 3
Plant Nutrient Data

Appendix 3 Plant nutrient data

The 1994 Plant Tissue Results (excluding N)

Campus — Cut 1

trt	%P	%K	%S	%Ca	%Mg	Mn (ppm)	Fe (ppm)	Cu (ppm)	B (ppm)	Zn (ppm)
0	0.34	2.51	0.44	0.41	0.16	141	168	6	8	20
0	0.35	2.19	0.44	0.48	0.14	132	508	7	8	23
0	0.39	2.67	0.39	0.94	0.18	177	335	14	8	42
0	0.37	2.45	0.49	0.45	0.15	154	283	8	8	21
1	0.35	2.59	0.44	0.48	0.15	130	181	7	7	19
1	0.34	2.37	0.41	0.46	0.15	149	231	7	7	19
1	0.34	2.22	0.44	0.45	0.14	133	204	6	8	20
1										
2	0.38	2.52	0.49	0.48	0.16	165	254	7	8	25
2	0.39	2.49	0.47	0.5	0.15	122	185	7	9	28
2	0.38	2.43	0.48	0.48	0.14	121	254	7	8	24
2	0.32	2.04	0.42	0.33	0.13	145	247	6	7	20

Campus — Cut 2

trt	%P	%K	%S	%Ca	%Mg	Mn (ppm)	Fe (ppm)	Cu (ppm)	B (ppm)	Zn (ppm)
0	0.38	2.04	0.42	0.38	0.16	147	132	4	7.5	19
0	0.33	1.82	0.35	0.34	0.14	123	111	4	7.3	16
0	0.34	2.11	0.37	0.4	0.16	122	129	4	7.3	20
0	0.34	2.12	0.37	0.43	0.17	123	140	5	7.3	20
1	0.35	2.08	0.41	0.41	0.17	107	139	4	10.5	18
1	0.36	2.22	0.39	0.42	0.17	140	148	6	7.5	22
1	0.32	2.3	0.27	0.42	0.17	107	141	5	6.5	20
1	0.34	2.05	0.35	0.45	0.17	115	155	4	7.3	17
2	0.32	1.86	0.32	0.4	0.15	98	101	4	7.3	18
2	0.32	1.95	0.31	0.41	0.15	88	106	4	7.3	19
2	0.34	1.84	0.38	0.37	0.15	114	126	3	7.3	15
2	0.33	2.12	0.33	0.46	0.18	116	133	6	7.1	22

Lane trt	Cut 1 %P	%K	%S	%Ca	%Mg	Mn (ppm)	Fe (ppm)	Cu (ppm)	B (ppm)	Zn (ppm)
0	0.29	1.82	0.18	0.48	0.2	124	294	6	8	20
0	0.42	2.71	0.2	0.6	0.27	110	328	9	9	23
0	0.29	1.89	0.17	0.39	0.19	117	750	7	6	18
1	0.42	2.97	0.26	0.6	0.25	90	197	8	9	26
1	0.28	1.48	0.17	0.59	0.18	81	1849	4	6	15
1	0.36	2.39	0.17	0.41	0.18	79	111	7	5	22
2	0.4	3.14	0.25	0.54	0.23	56	123	8	6	22
2	0.38	2.76	0.2	0.63	0.24	77	498	8	8	23
2	0.36	2.43	0.19	0.65	0.23	82	706	8	6	24

Lane trt	Cut 2 %P	%K	%S	%Ca	%Mg	Mn (ppm)	Fe (ppm)	Cu (ppm)	B (ppm)	Zn (ppm)
0	0.49	2.54	0.23	1.05	0.46	176	159	13	31	40
0	0.38	1.51	0.21	0.56	0.26	77	128	4	11	15
0	0.31	1.48	0.18	0.47	0.23	73	88	3	8	12
1	0.45	2.61	0.24	0.75	0.33	77	241	9	12	27
1	0.39	1.73	0.22	0.6	0.25	74	165	6	11	23
1	0.41	2.03	0.2	0.66	0.3	74	131	7	9	24
2	0.5	2.54	0.24	0.97	0.38	72	250	9	15	29
2	0.35	1.66	0.2	0.51	0.22	63	136	6	9	21
2	0.54	2.99	0.37	0.87	0.38	75	171	9	14	27

Lane trt	Cut 3 %P	%K	%S	%Ca	%Mg	Mn (ppm)	Fe (ppm)	Cu (ppm)	B (ppm)	Zn (ppm)
0	0.31	1.95	0.14	0.41	0.2	128	176	5	9	21
0	0.25	1.25	0.09	0.3	0.15	113	108	3	7	17
0	0.37	2.02	0.11	0.55	0.26	119	245	5	11	19
1	0.36	2.07	0.13	0.73	0.28	88	761	8	11	22
1	0.27	1.16	0.1	0.47	0.19	82	364	2	10	13
1	0.34	1.49	0.12	0.41	0.18	82	191	3	7	15
2	0.29	1.82	0.14	0.55	0.2	71	415	5	10	19
2	0.3	1.53	0.17	0.68	0.22	61	1026	5	13	15
2	0.28	1.49	0.16	0.28	0.14	34	56	2	5	11

Tillamook trt	%P	%K	%S	%Ca	%Mg	Cut 1 Mn (ppm)	Fe (ppm)	Cu (ppm)	B (ppm)	Zn (ppm)
0	0.44	3.36	0.41	0.38	0.24	172	486	18	6	52
0										
0	0.32	2.15	0.24	0.34	0.16	174	345	12	4	47
1	0.43	3.05	0.41	1.42	0.21	173	651	19	5	53
1	0.39	2.88	0.38	1.28	0.20	182	422	20	5	55
1	0.41	3.35	0.35	0.76	0.20	144	366	13	4	45
2	0.41	3.33	0.37	0.96	0.20	166	456	18	4	47
2	0.46	3.29	0.36	1.16	0.22	214	469	18	5	59
2	0.44	3.15	0.36	1.02	0.21	197	500	17	5	54

Tillamook trt	%P	%K	%S	%Ca	%Mg	Cut 2 Mn (ppm)	Fe (ppm)	Cu (ppm)	B (ppm)	Zn (ppm)
0	0.34	3.08	0.29	0.25	0.18	149	237	7	4	26
0	0.35	2.91	0.29	0.27	0.17	162	235	6	4	23
0	0.30	2.53	0.22	0.22	0.15	160	207	5	3.9	22
1	0.34	3.01	0.28	0.33	0.16	117	177	6	4	22
1	0.34	2.90	0.28	0.33	0.16	155	272	7	4	23
1	0.33	2.85	0.28	0.36	0.17	158	264	7	4	22
2	0.34	3.10	0.29	0.37	0.17	171	328	7	4	24
2	0.35	3.04	0.27	0.40	0.18	176	328	7	4	23
2	0.34	2.90	0.28	0.35	0.16	178	216	6	4	23

Tillamook trt	%P	%K	%S	%Ca	%Mg	Cut 3 Mn (ppm)	Fe (ppm)	Cu (ppm)	B (ppm)	Zn (ppm)
0	0.27	2.86	0.29	0.22	0.16	106	110	10	5	22
0	0.29	2.82	0.34	0.23	0.17	147	121	10	6	26
0	0.26	2.46	0.22	0.16	0.14	100	99	8	0	20
1	0.28	2.68	0.28	0.24	0.14	127	212	14	5	25
1	0.30	2.74	0.29	0.24	0.16	136	111	10	5	27
1	0.30	2.77	0.32	0.29	0.18	122	227	21	6	30
2	0.29	2.83	0.32	0.25	0.15	100	101	11	4	26
2	0.26	2.51	0.25	0.22	0.14	93	147	12	4	23
2	0.27	2.73	0.26	0.23	0.14	112	161	13	4	25

Polk trt	%P	%K	%S	%Ca	%Mg	Cut 1 Mn (ppm)	Fe (ppm)	Cu (ppm)	B (ppm)	Zn (ppm)
0	0.40	2.55	0.71	0.59	0.13	283	135	6	4	34
0	0.38	1.91	0.43	0.45	0.15	345	190	4	4	27
0	0.35	2.02	0.42	0.46	0.12	206	121	4	4	21
1	0.47	2.58	0.76	0.81	0.15	348	242	5	5	26
1	0.29	1.62	0.38	0.45	0.09	209	96	4	3	16
1	0.43	2.55	0.58	0.51	0.16	421	305	7	5	33
2	0.38	2.46	0.70	0.41	0.13	317	135	7	4	27
2	0.34	1.84	0.38	0.51	0.12	269	145	4	4	17

2

Polk trt	%P	%K	%S	%Ca	%Mg	Cut 2 Mn (ppm)	Fe (ppm)	Cu (ppm)	B (ppm)	Zn (ppm)
0	0.28	2.24	0.31	0.31	0.12	153	204	5	4	22
0	0.27	1.63	0.22	0.27	0.11	162	441	2	3	15
0	0.21	1.54	0.30	0.24	0.08	149	148	2	1	15
1	0.35	2.28	0.33	0.36	0.13	155	284	4	4	22
1	0.38	2.48	0.34	0.50	0.17	161	142	6	5	25
1	0.31	1.95	0.40	0.35	0.10	156	105	3	1	18
2	0.41	3.03	0.43	0.46	0.16	182	204	7	5	27
2	0.19	1.57	0.25	0.23	0.07	101	58	3	1	13
2	0.28	1.99	0.28	0.25	0.09	111	53	4	1	18

Appendix 3 Plant nutrient data

1995 Plant Tissue Results (excluding N)

Tillamook trt (T/A)	%P	%K	%S	%Ca	%Mg	Cut 1 Mn (ppm)	Fe (ppm)	Cu (ppm)	B (ppm)	Zn (ppm)
0	0.35	3.02	0.28	0.30	0.19	177	539	8	3	28
0	0.32	2.71	0.25	0.28	0.18	138	473	8	3	26
0	0.24	2.14	0.17	0.22	0.14	139	240	6	2	23
1	0.29	2.91	0.26	0.33	0.14	112	564	8	3	21
1	0.28	2.60	0.24	0.33	0.14	111	313	7	3	20
1	0.26	2.37	0.21	0.29	0.13	91	338	6	3	18
2	0.24	2.15	0.24	0.31	0.12	89	279	5	2	16
2	0.30	2.86	0.24	0.39	0.15	113	351	8	3	20
2	0.30	2.70	0.27	0.41	0.16	165	400	9	3	27

Tillamook trt (T/A)	%P	%K	%S	%Ca	%Mg	Cut 2 Mn (ppm)	Fe (ppm)	Cu (ppm)	B (ppm)	Zn (ppm)
0	0.40	3.38	0.14	0.31	0.19	160	442	10	8	35
0	0.35	2.77	0.11	0.29	0.17	130	129	8	8	27
0	0.27	2.33	0.09	0.23	0.11	122	72	7	7	22
1	0.31	2.64	0.12	0.37	0.15	62	136	8	8	23
1	0.30	2.66	0.10	0.28	0.12	61	94	7	7	20
1	0.27	2.37	0.10	0.30	0.12	73	145	8	7	19
2	0.36	3.35	0.13	0.36	0.16	93	274	10	8	25
2	0.37	3.10	0.12	0.30	0.33	92	97	9	7	20
2	0.35	2.78	0.12	0.33	0.32	62	86	8	7	19

Tillamook trt (T/A)	%P	%K	%S	%Ca	%Mg	Cut 3 Mn (ppm)	Fe (ppm)	Cu (ppm)	B (ppm)	Zn (ppm)
0	0.38	3.17	0.36	0.28	0.24	144	363	10	4	37
0	0.40	3.39	0.44	0.45	0.28	118	573	13	4	33
0	0.40	2.79	0.32	0.29	0.24	181	315	7	4	35
1	0.28	2.52	0.29	0.21	0.17	110	367	7	3	24
1	0.38	3.13	0.40	0.40	0.23	107	512	10	4	26
1	0.30	2.53	0.33	0.36	0.21	90	396	9	3	20
2	0.31	2.67	0.34	0.37	0.19	113	693	8	4	25
2	0.28	2.41	0.32	0.34	0.21	85	488	9	3	22
2	0.36	2.96	0.41	0.43	0.24	94	406	11	4	26

Cut 1

Campus trt (T/A)	%P	%K	%S	%Ca	%Mg	Mn (ppm)	Fe (ppm)	Cu (ppm)	B (ppm)	Zn (ppm)
0	0.38	2.89	0.18	0.41	0.15	103	971	10	9	24
0	0.45	3.45	0.49	0.37	0.18	146	380	9	5	26
0	0.47	3.70	0.55	0.42	0.18	132	342	8	5	26
0	0.54	3.66	0.56	0.60	0.22	234	593	10	9	30
1	0.49	3.57	0.46	0.53	0.18	99	475	9	5	25
1	0.41	3.07	0.18	0.49	0.15	88	531	9	9	22
1	0.45	3.28	0.41	0.45	0.15	100	204	8	5	22
1	0.49	3.56	0.48	0.38	0.17	155	353	10	4	25
2	0.46	3.47	0.48	0.51	0.18	116	1202	10	5	23
2	0.49	3.55	0.43	0.56	0.17	88	371	8	5	24
2	0.51	3.63	0.45	0.49	0.17	101	298	10	5	25
2	0.53	3.40	0.47	0.60	0.17	87	276	8	5	25

Cut 2

Campus trt (T/A)	%P	%K	%S	%Ca	%Mg	Mn (ppm)	Fe (ppm)	Cu (ppm)	B (ppm)	Zn (ppm)
0	0.41	2.99	0.19	0.40	0.15	72	189	8	9	25
0	0.41	2.91	0.17	0.33	0.15	77	119	8	8	25
0	0.38	2.90	0.16	0.29	0.14	75	94	7	8	24
0	0.48	3.17	0.20	0.20	0.16	107	183	9	9	29
1	0.51	3.69	0.20	0.50	0.18	100	172	10	10	32
1	0.35	2.69	0.13	0.32	0.12	55	103	7	6	21
1	0.45	3.26	0.19	0.46	0.46	73	123	8	8	25
1	0.55	3.67	0.20	0.49	0.49	119	126	10	9	29
2	0.52	3.58	0.20	0.55	0.55	82	192	10	9	28
2	0.36	2.61	0.14	0.33	0.33	53	182	8	8	20
2	0.50	3.41	0.18	0.38	0.38	133	148	11	9	29
2	0.41	2.72	0.14	0.58	0.58	56	109	7	10	23

Cut 3

Campus trt (T/A)	%P	%K	%S	%Ca	%Mg	Mn (ppm)	Fe (ppm)	Cu (ppm)	B (ppm)	Zn (ppm)
0	0.31	1.62	0.35	0.34	0.17	164	63	3	5	25
0	0.28	1.21	0.31	0.28	0.14	152	47	2	5	18
0	0.31	1.23	0.34	0.29	0.15	150	87	2	4	19
0	0.36	1.73	0.39	0.33	0.20	222	97	4	5	29
1	0.22	1.34	0.28	0.28	0.12	85	52	3	5	19
1	0.27	1.56	0.34	0.36	0.15	102	72	4	5	22
1	0.37	1.59	0.39	0.36	0.19	164	64	3	5	23
1	0.37	1.85	0.36	0.33	0.19	189	86	4	5	25
2	0.31	1.27	0.27	0.28	0.14	117	64	2	5	21
2	0.28	1.02	0.24	0.28	0.13	101	44	2	4	15
2	0.41	2.13	0.46	0.43	0.22	164	271	5	5	27
2	0.38	1.71	0.35	0.39	0.20	121	108	4	6	29

Polk trt (T/A)	%P	%K	%S	%Ca	%Mg	Cut 1 Mn (ppm)	Fe (ppm)	Cu (ppm)	B (ppm)	Zn (ppm)
0	0.48	2.87	0.55	0.47	0.20	277	288	11	5	61
0	0.30	2.10	0.41	0.31	0.14	166	222	7	4	30
0	0.36	2.52	0.53	0.39	0.17	287	278	9	4	36
1	0.36	2.07	0.43	0.46	0.13	144	461	6	4	36
1	0.42	2.88	0.56	0.53	0.17	169	307	10	4	43
1	0.32	2.12	0.43	0.46	0.13	156	425	8	3	32
2	0.45	2.61	0.54	0.57	0.16	170	327	10	4	43
2	0.31	1.98	0.37	0.44	0.12	108	300	6	3	26
2	0.42	2.74	0.52	0.63	0.17	207	658	10	5	41

Polk trt (T/A)	%P	%K	%S	%Ca	%Mg	Cut 2 Mn (ppm)	Fe (ppm)	Cu (ppm)	B (ppm)	Zn (ppm)
0	0.36	2.66	0.15	0.32	0.11	118	94	7	7	23
0	0.42	3.20	0.18	0.37	0.15	143	112	9	8	31
0	0.42	3.08	0.20	0.37	0.14	252	80	9	7	39
1	0.38	2.78	0.17	0.41	0.11	109	93	8	6	27
1	0.49	2.87	0.16	0.45	0.13	126	154	9	8	27
1	0.42	3.64	0.21	0.52	0.16	188	144	11	7	34
2	0.38	2.92	0.17	0.45	0.11	102	133	9	7	26
2	0.40	2.95	0.17	0.46	0.12	108	103	8	7	27
2	0.46	3.24	0.20	0.49	0.14	132	122	10	8	34

Polk trt (T/A)	%P	%K	%S	%Ca	%Mg	Cut 3 Mn (ppm)	Fe (ppm)	Cu (ppm)	B (ppm)	Zn (ppm)
0	0.44	3.00	0.38	0.41	0.23	182	119	8	6	37
0	0.34	2.76	0.38	0.36	0.17	166	111	7	4	31
0	0.35	2.53	0.33	0.32	0.16	131	134	6	4	29
1	0.40	3.06	0.44	0.45	0.19	151	126	8	5	31
1	0.25	2.10	0.28	0.34	0.14	102	98	5	4	24
1	0.32	2.65	0.36	0.40	0.17	119	123	7	4	31
2	0.33	2.36	0.33	0.40	0.17	115	120	7	4	25
2	0.38	2.78	0.40	0.45	0.19	132	115	8	5	32
2	0.30	2.37	0.30	0.37	0.15	98	290	6	4	25

Lane trt (T/A)	%P	%K	%S	%Ca	%Mg	Cut 1 Mn (ppm)	Fe (ppm)	Cu (ppm)	B (ppm)	Zn (ppm)
0	0.33	2.07	0.52	0.35	0.18	143	182	5	5	20
0	0.35	2.31	0.60	0.35	0.19	136	109	6	5	24
0	0.36	2.45	0.64	0.38	0.19	144	111	7	6	26
1	0.38	2.31	0.69	0.52	0.20	66	166	6	5	22
1	0.26	1.88	0.48	0.33	0.14	49	167	5	3	16
1	0.39	2.69	0.84	0.51	0.21	61	129	8	6	24
2	0.33	2.31	0.54	0.42	0.17	45	214	6	5	19
2	0.31	2.09	0.52	0.46	0.17	46	145	6	5	19
2	0.35	2.45	0.69	0.48	0.19	43	103	7	5	20

Lane trt (T/A)	%P	%K	%S	%Ca	%Mg	Cut 2 Mn (ppm)	Fe (ppm)	Cu (ppm)	B (ppm)	Zn (ppm)
0	0.31	2.10	0.12	0.34	0.15	97	57	7	10	22
0	0.46	3.00	0.17	0.43	0.21	171	97	10	11	35
0	0.33	2.36	0.12	0.37	0.16	106	81	8	12	25
1	0.32	2.14	0.13	0.34	0.14	40	45	6	8	20
1	0.51	3.21	0.17	0.57	0.24	57	99	10	12	30
1	0.48	3.02	0.17	0.61	0.23	65	131	10	13	32
2	0.40	2.74	0.12	0.40	0.19	39	58	7	9	23
2	0.36	2.53	0.12	0.41	0.16	48	58	8	9	21
2	0.46	3.01	0.17	0.59	0.23	77	103	10	12	29

Lane trt (T/A)	%P	%K	%S	%Ca	%Mg	Cut 3 Mn (ppm)	Fe (ppm)	Cu (ppm)	B (ppm)	Zn (ppm)
0	0.45	3.20	0.33	0.54	0.28	92	146	8	7	29
0	0.41	2.92	0.28	0.40	0.26	132	137	6	7	28
0	0.38	2.43	0.21	0.45	0.25	62	168	5	7	20
1	0.45	3.32	0.24	0.58	0.28	108	164	8	7	28
1	0.44	2.51	0.21	0.46	0.25	64	137	6	7	21
1	0.33	2.03	0.21	0.32	0.21	93	114	4	7	19
2	0.30	1.92	0.17	0.36	0.19	54	101	5	7	16
2	0.33	1.96	0.21	0.41	0.21	60	302	5	6	18
2	0.38	2.43	0.21	0.45	0.25	62	168	5	7	20

Appendix 3 Plant Nutrient Data

The 1994 Plant Tissue Quality Results

Tillamook trt	Cut 1 % Prot	Cut 2 % Prot	Cut 3 % Prot	trt	Cut 1 %N	Cut 2 %N	Cut 3 %N
0	22.85	14.06	12.93	0	3.656	2.2496	2.0688
0		14.04	14.07	0	0	2.2464	2.2512
0	21.52	21.52	13.62	0	3.4432	3.4432	2.1792
1	22.87	13.19	13.22	1	3.6592	2.1104	2.1152
1	20.36	12.49	14.02	1	3.2576	1.9984	2.2432
1	21.79	13.31	13.9	1	3.4864	2.1296	2.224
2	22.71	12.89	13.34	2	3.6336	2.0624	2.1344
2	22.31	13.15	14.34	2	3.5696	2.104	2.2944
2	22.15	13.99	13.61	2	3.544	2.2384	2.1776

Lane trt	Cut 1 % Prot	Cut 2 % Prot	Cut 3 % Prot	trt	Cut 1 %N	Cut 2 %N	Cut 3 %N
0	10.77	14.02	13.95	0	1.7232	2.2432	2.232
0	13.98	13.73	12.61	0	2.2368	2.1968	2.0176
0	12.87	14.5	14	0	2.0592	2.32	2.24
1	11.69	14.44	13.82	1	1.8704	2.3104	2.2112
1	14.17	13.34	13.24	1	2.2672	2.1344	2.1184
1	11.35	14.3	14.65	1	1.816	2.288	2.344
2	14.18	14.48	13.43	2	2.2688	2.3168	2.1488
2	15.08	14.42	13.79	2	2.4128	2.3072	2.2064
2	10.42	14.01	12.87	2	1.6672	2.2416	2.0592

Polk trt	Cut 1 % Prot	Cut 2 % Prot	trt	Cut 1 %N	Cut 2 %N
0	19.47	12.28	0	3.1152	1.9648
0	15.01	14.57	0	2.4016	2.3312
0	18.97	14.1	0	3.0352	2.256
1	17.54	12.71	1	2.8064	2.0336
1		14.13	1	0	2.2608
1	15.11	13.58	1	2.4176	2.1728
2	19.25	13.87	2	3.08	2.2192
2	16.18	10.42	2	2.5888	1.6672
2	21.16	14.15	2	3.3856	2.264

Campus trt	Cut 1 % Prot	Cut 2 % Prot
0	12.36	9.77
0	12.11	8.8
0	13.29	11.28
0	12.55	10.71
1	12.92	10.61
1	11.57	10.4
1	12.64	9.67
1	13.19	10.79
2	11.86	9.27
2	12.28	9.94
2	13.2	10.38
2		10.04

trt	Cut 1 %N	Cut 2 %N
0	1.9776	1.5632
0	1.9376	1.408
0	2.1264	1.8048
0	2.008	1.7136
1	2.0672	1.6976
1	1.8512	1.664
1	2.0224	1.5472
1	2.1104	1.7264
2	1.8976	1.4832
2	1.9648	1.5904
2	2.112	1.6608
2	0	1.6064

Appendix 3 Plant nutrient data

The 1995 Plant Tissue Quality Results

Polk trt	Cut 1 % protein	Cut 2 % protein	Cut 3 % protein	Polk trt	Cut 1 %N	Cut 2 %N	Cut 3 %N
0	23.04	18.74	13.75	0	3.6864	2.9984	2.2
0	24.22	19.13	13.99	0	3.8752	3.0608	2.2384
0	20.76	18.28	11.49	0	3.3216	2.9248	1.8384
1	20.98	18.97	12.1	1	3.3568	3.0352	1.936
1	23.48	18.95	14.1	1	3.7568	3.032	2.256
1	22.08	19.23	14.26	1	3.5328	3.0768	2.2816
2	21.57	18.58	14.08	2	3.4512	2.9728	2.2528
2	23.47	18.67	13.27	2	3.7552	2.9872	2.1232
2	31.21	18.66	14.58	2	4.9936	2.9856	2.3328

Lane trt	Cut 1 % protein	Cut 2 % protein	Cut 3 % protein	Lane trt	Cut 1 %N	Cut 2 %N	cut 3 %N
0	19.15	12.85	12.79	0	3.064	2.056	2.0464
0	20.41	17.72	13.82	0	3.2656	2.8352	2.2112
0	23.25	18.41	12.69	0	3.72	2.9456	2.0304
1	19.2	16.66	13.49	1	3.072	2.6656	2.1584
1	18.3	18.1	13.16	1	2.928	2.896	2.1056
1	20.23	18	15.47	1	3.2368	2.88	2.4752
2	20.96	18.6	13.45	2	3.3536	2.976	2.152
2	20.24	17.15	13.02	2	3.2384	2.744	2.0832
2	19.95	19.04	12.63	2	3.192	3.0464	2.0208

Tillamook trt	Cut 1 % protein	Cut 2 % protein	Cut 3 % protein	Tillamook trt	Cut 1 %N	Cut 2 %N	Cut 3 %N
0	20.25	16.67	20.93	0	3.24	2.6672	3.3488
0	20.31	17.1	18.46	0	3.2496	2.736	2.9536
0	18.33	15.32	19.1	0	2.9328	2.4512	3.056
1	20.72	18.24	18.44	1	3.3152	2.9184	2.9504
1	20.19	14.81	21.76	1	3.2304	2.3696	3.4816
1	19.57	17.19	22.14	1	3.1312	2.7504	3.5424
2	21.15	17.05	19.66	2	3.384	2.728	3.1456
2	19.57	15.34	21.24	2	3.1312	2.4544	3.3984
2	27.4	15.22	21.72	2	4.384	2.4352	3.4752

Campus trt	Cut 1 % protein	Cut 2 % protein	Cut 3 % protein	Campus trt	Cut 1 %N	Cut 2 %N	Cut 3 %N
0	19.16	19.6	8.45	0	3.0656	3.136	1.352
0	17.39	17.94	7.64	0	2.7824	2.8704	1.2224
0	17.82	18.68	7.2	0	2.8512	2.9888	1.152
0	17.91	18.53	8.3	0	2.8656	2.9648	1.328
1	18.54	18.81	10.37	1	2.9664	3.0096	1.6592
1	18.15	19.22	9.99	1	2.904	3.0752	1.5984
1	17.28	18.51	8.51	1	2.7648	2.9616	1.3616
1	18.9	19.37	8.84	1	3.024	3.0992	1.4144
2	18.1	19.14	8.4	2	2.896	3.0624	1.344
2	17.99	19.03	7.92	2	2.8784	3.0448	1.2672
2	18.97	16.71	10.19	2	3.0352	2.6736	1.6304
2	17.71	14.65	7.81	2	2.8336	2.344	1.2496

Appendix 4
Selenium

Appendix 4 Selenium

Introduction

Selenium (Se) is not an essential plant nutrient but it is an necessary nutrient for livestock. In Oregon, the soil typically contains too little Se for forage alone to meet the nutritional requirements of livestock. If pastures could be fertilized with Se, the problem could be remedied. However, Se fertilization is currently illegal because Se fertilization may contaminate water supplies with toxic levels of Se. Therefore, livestock producers must directly inject Se into their animals or place a bolus of Se in the foregut. Both procedures are time consuming and expensive, particularly when the necessary blood tests are included in the costs. Since one of the keys to profitable pasture use is to lower its costs, an inexpensive alternative method providing Se to livestock could increase the competitiveness of western Oregon livestock producers.

One possible method to increase Se in forage is pasture liming. Liming could possibly increase the plant available pool of Se. Increased availability is associated with increased uptake by forages. Thus, an important objective of this pasture liming project is to determine if lime can increase Se uptake in forage. If lime increases uptake, the limed plots should have grass forage with higher tissue concentrations of Se than unlimed plots.

Literature Review

The objective of this study is to determine if lime can increase the uptake of Se in forage. This objective is based on the hypothesizes that lime can increase Se's availability and forage can uptake the available Se. However, relatively little is known concerning the behavior of Se in the soil and its uptake. Therefore, examining the available literature about the forms of Se in the soil, the factors affecting its availability (including pH), the ability of forages to uptake Se, and the amount of Se available in Oregon soils would be beneficial in predicting or evaluating the effect of pasture liming upon Se.

Se in the Soil

Se is found in several forms in the soil. Elemental Se is found rarely observed in nature and only near Se sources. It is probably rapidly oxidized into other forms. However, some reductive processes may be important in producing elemental Se. Se^{-2} is not soluble and plants do not absorb it (National Research Committee, 1983). Selenite is seen in acidic soils where it is frequently bound to sesquioxides (National Research Committee, 1983). Plants do not uptake much selenite in the field which suggests that plants cannot uptake much selenite or it is not very mobile. Selenate is found at neutral or alkaline soil pH. It is the primary form of selenium that plants take up. Organic forms of Se exist but the soluble portion of the pool is unknown (Shamberger, 1983). Approximately 10-40% of Se is exchangeable. Although the exact percentage of each Se form in the Se soil pool is unknown, every form except selenate is at best slightly plant available. Since selenate is most plant available form of Se and it is found at neutral or basic soil pH, liming may increase its availability.

Se Availability

The two major factors that govern Se availability were pH and sulphate concentration. Se , in the selenate form, becomes more available at neutral or alkaline pH but a South African study found that adding lime to selenate fertilized pots containing ryegrass decreased or did not affect the Se plant tissue concentration (Higgins and Fey, 1993). Also, lime decreased Se fertilizer efficiency in the same study (Higgins and Fey, 1993). Yet, a greenhouse study on alfalfa in eight different soil series (including Woodburn silt loam from Corvallis) concluded that the soluble selenites (a selenized phosphate in this case) were immobilized at acidic soil pH by sorbing to hydrous sesquioxides (Cary et al, 1967). This study suggested that raising soil pH could increase Se availability. Sulfate apparently increased the solubility of selenate in an Idaho study which observed that sulfate increased the amount of Se leaching from soil in the pot while concurrently increasing Se uptake (Carter et al, 1969). These studies indicated that lime's affect upon Se availability was uncertain. Yet, sulfate significantly increased Se availability.

Se Uptake by Forages

The uptake of Se is a complex phenomenon which can be affected by many environment and physiological factors. However, the hypothesis being tested only requires that forages are able to uptake available Se. Therefore, forages' ability to uptake increases in available Se and variations in plants ability to uptake Se are examined.

Se uptake has been examined in series of Se fertilization studies and comparison of tissue Se in various forages. A recent Canadian greenhouse study on Alfalfa, Timothy, and Barley found that only selenate achieved desired plant Se concentrations of about 1 ppm at 40 g/ha while all forms of selenites had no effect at the same rates (Gupta and Winter, 1989). The authors suggested that the greater availability of selenate compared to selenite was the cause for the different results. Similarly, several studies have observed that selenite was less likely to be taken up than selenate. For example, a field study in Idaho was fertilized with 1.2 to 1.62 Kg/ha of Se reported that copper selenates yielded alfalfa with up to 25 ppm (over 5 ppm is considered toxic) while copper or iron selenite preparations maintained plant tissue concentrations between 0.5 and 2 ppm (Carter et al, 1969). These studies demonstrated that increased Se availability from fertilization resulted in increased Se uptake. Additionally, selenate was more likely to be taken up than selenite. Since selenate was more available at alkaline or neutral pH, these results suggested increasing pH would increase plant available Se and Se uptake.

The two main source of variation concerning forage uptake of Se were plant growth and species. Two studies with alfalfa observed that the concentration of Se in tissue decreases or maintains a constant level with multiple cuttings (Cary et al, 1969 and Carter et al ,1969). There was no hypothesis proffered for the observed effect. The information concerning the effect of plant species was contradictory. One study found that there was little difference between alfalfa, alsike clover, red clover, timothy and fescue (0.19ppm, 0.19ppm, 0.13ppm, 0.20 ppm, and 0.17ppm Se, respectively) (Ehlig et al, 1968). However, the authors did note that Se uptake increased with increasing dry matter production. However, a New Zealand study suggested that the differences between grasses and clovers were large enough to be important. For example, in unfertilized pots brown top or bentgrass, ryegrass, orchardgrass contained 0.035, 0.030, 0.020 ppm Se , respectively, while white clover contained only .017 ppm Se (Davies and Watkinson, 1966). These studies suggested that plant physiology played an important but inconsistent role in Se uptake.

The Geographic Distribution of Se

Because parent material in Western Oregon, Western Washington, and California are low in Se, soils in each state were all low in Se. Field testing found that 81% of soil tests had Se levels between 0.0 and 0.5 ppm Se (Carter et al, 1968). These soil test levels were considered too low to support adequate Se in plant tissue to prevent white muscle disease (WMD) in cattle and sheep. Although the soil test did reflect the increased probability of WMD in Oregon, it was not accurate enough to determine the likelihood that any individual location would contain Se deficient forage. For example, a greenhouse experiment demonstrated that the soil test value for a Benton County Woodburn silt loam was 0 ppm while alfalfa on the same soil had 2 ppm Se in plant tissue (Carter et al, 1968). The result was supposedly due to alfalfa's ability to concentrate Se even when it was at very low concentrations in the soil. Additionally, Se can vary widely over a small area (usually between .05-.5 ppm) because of external sources of Se. For instance, Se can be taken up from irrigation water or as a constituent in a common P fertilizer sold in Oregon during the 1960's naturally contained small amount of Se Carter et al, 1968). Based upon these considerations, the literature indicated that Western Oregon soils contained insufficient Se to meet the needs of most grazing animals which can further be depleted by continued cropping and removal of forage plants.

Summary

Several conclusions were drawn from these previous studies. First, selenate was the most mobile and plant available form of Se. Second, limes affect upon Se availability was uncertain while sulfate seemed to increase Se availability. Third, many forages could uptake increased amounts of Se. Finally, Se was very low in the Pacific Northwest but there was no accurate Se soil test. The literature review indicated that lime might increase Se availability.

Materials and Methods

The Se forage concentration study followed the procedures previously mentioned for harvesting and sampling at the four sites. Since Se testing was expensive it was only conducted at a responsive site (Tillamook) and an unresponsive site (Polk), on the 0 and 2 T/A treatments, for the first and last clippings (with only 2 replications), and only during the second year. Once samples were prepared they were sent to the Forage Analysis Lab at Oregon State University.

At the Forage Analysis Lab, the samples underwent digestion, titration, and colormetric measurement based on Brown and Watkins (1977). The samples were digested by dissolving them in 10 ml concentrated HNO_3 and $HClO_4$ overnight in acid washed flasks with a known weight. Next the samples were heated until completely digested or fuming. After digestion, the samples were titrated to pH 2-3 with 15 ml 0.009 M EDTA and 2 drops bromecresol green as indicators of the desired "yellow" color. The final weight of the titrated sample flask was recorded. The actual colormetric measurement was done by an automated analyzer and compared with known standards that were analyzed simultaneously with the unknown samples. The final concentration of Se in tissue was determined by the equation

$([sample\_solution]*Final\_Sample\_weight) / (weight\_of\_tissue) = ngSe / g\_Tissue$

After chemical analysis the results were subjected to statistical analysis. Each individual clipping at each site was tested with an ANOVA in the STATGRAPHICS statistical computer program. Since this study was observational, no attempt was made to pool data or directly compare results between sites or clippings. The results were recorded.

Results

Two major results were derived from studying Se in forage. First, no significant treatment differences were observed which implied that lime had no effect on Se availability or uptake at any site or clipping (Table 1). Two, all the recorded tissue concentrations were below 0.06 ppm which was considered the minimal acceptable Se forage concentration to prevent Se deficiency in animals (Table 1). The results suggested that there was very little Se available and lime did not increase its availability to any measurable degree.

Table 1 1995 Se Plant Tissue Concentration

Trt	Polk Clipping (3/28/95)		Polk Clipping (6/9/95)		Tillamook Clipping (4/10/95)		Tillamook Clipping (6/15/95)	
Lime (T/A)	Tissue Se (ppm)	SD	Tissue Se (ppm)	SD	Tissue Se (ppm)	SD	Tissue Se (ppm)`	SD
0	0.008	0.0007	0.022	0.011	0.048	0.005	0.028	0.0028
2	0.008	0.0014	0.013	0.0014	0.035	0.023	0.017	0.0042
	LSD=0.0048		LSD=0.032		LSD=0.070		LSD=0.016	
	SE=.0008		SE=0.0054		SE=0.012		SE=0.025	

Discussion

Like other aspects of the pasture liming study, the Se uptake data is observational. Thus, the conclusions apply only to the sites sampled on the dates sampled. Any conclusion that extended beyond the two sites is supposition and is only meant to suggest future research. Bearing in mind these limitations, the affect of lime upon Se uptake is examined.

Lime created no significant increase in Se uptake at the two sites examined. The data did suggest that there might be a slight decrease in uptake with increasing pH but it was definitive nor would such an effect coincide with any theory of Se's behavior in the soil. Also, the highest level observed was .052 ppm which implied that the so little Se in the soil that even if lime could increase Se availability it still might not be enough to go beyond the .06 ppm level. If these results were indicative of Western Oregon pastures, than topdressed lime would not directly increase Se uptake by forages.

The only problem with this conclusion was the variability of the results between clippings and sites. However, the literature review indicated that Se uptake was commonly variable and that the observed differences were due to unmeasured changes in physiological state or soil chemistry. Therefore, assuming that the distribution of Se in the soil stated in the literature was accurate and my results were typical, livestock's Se requirement should be met by injection or a bolus in the foregut.

Bibliography

Brown, M.W. and J. Watkinson. 1977. An automated fluorametric method for the determination of nanogram quantities of selenium. *Analytica Chimica Acta*. 89: 29- 35.

Brown, M.W. and D.L. Carter. 1969. Leaching of added selenium from alkaline soil as influenced by sulfate. *Soil Science Society of America Proceedings*. 33(4): 563-565.

Carter, D.L., M. J. Brown, W. Allaway, and E. Cary. 1968. Selenium content of forage and hay crops in the Pacific Northwest. *Agronomy Journal*. 60: 532- 534.

Cary, E. E., G. Weizorek, and W. H. Allaway. 1967. Reactions of selenite- selenium added to soils that produce low selenium forages. *Soil Science of America Proceedings*. 31: 21- 26.

Cary, E. E., and W. H. Allaway. 1973. Selenium content of field crops grown on selenite- treated soils. *Agronomy Journal*. 65: 922- 925.

Davies, E. B. and J. H. Watkinson. 1966. Uptake of native and applied selenium by pasture species. *New Zealand Journal of Agricultural Research*. 9: 317- 327.

Ehlig, C. F., W. H. Allaway, E. E. Cary, and J. Kubota. 1968. Differences among plant species in selenium accumulation low in available selenium. *Agronomy Journal*. 60: 43- 47.

Gupta, U. and S. A. Winter. 1989. Effects of selenate vs. selenite forms of selenium in increasing the selenium concentration in forage and cereals. *Canadian Journal of Soil Science*. 69: 532- 534.

Higgins, S. P. and M. V. Fey. 1993. Selenium in some grass pastures of Natal and fertilizer- induced Se uptake by ryegrass (*Lolium multiflorum*). *South African Journal of Plant and Soil*. 10: 188- 192.

National Research Committee: Subcommittee on selenium. 1983. in *Selenium in nutrition*. Washington D.C.: National Academy Press.

Shamberger, R. 1983. in *Biochemistry of selenium*. New York: Plenum Press.

Appendix 5
Growth Rates

Appendix 5 Growth Rates

Forage growth rates are useful numbers if they are accurate. They provide a means to calculate stocking rates or to estimate nutrient uptake by forage which is used to assist fertilization. Since growth rates are so useful, they are reviewed for this and previous Oregon pasture studies.

The growth rates were calculated on the basis of pounds of dry matter per acre per heat unit. Pounds dry matter per acre were used because many studies were done before the adoption of the metric system and many potential users of the results were not as familiar with the metric system as the English system of units. Heat units provided a means to compare studies done at different times and places by removing some of the climatic differences between sites. Heat units were calculated as a Tsum $(\frac{Max\ .Temp\ + Min\ .Temp}{2})$ with 0 C as the base temperature and January first as the starting date to accumulate heat units in every case. Although this method of calculating heat units possessed a few problems, the methods simplicity outweighed the potential difficulties.

The growth rates were presented in three different ways. First, the total accumulated production at any point (i.e. how much forage had been harvest since Jan.1) was graphed against total accumulated heat units. The growth rates were the slope of the line. Second, the accumulated growth rate was a measure of how much forage had accumulated per accumulated heat units. For example, if 1000 lb DM/A had accumulated in 500 total heat units from Jan. 1 than the growth rate was 2 lb DM/A/hu. Although this method of calculation subdued many trends, it was the most honest way to calculate growth rates based on pasture clippings that may have occurred long after growth stopped. Finally, the growth rate based on the amount of dry matter and heat units accumulated between clippings was calculated. Since this method was closer to the actual growth patterns of forage, this method was referred to as the instantaneous growth rate.

The data for these growth was of variable quality. In a few cases I had to make guesses based on decades old field notes. For example, I had to back calculate plot size from field notes for much of the Astoria data. There was no good method to assess the quality of the data so no assessment was made. However, these growth rates were the only concise review of pasture production in Western Oregon. The graphs were stored as an EXCEL file on the disk under the name OSTRICH.XLS.