RELATIONSHIP BETWEEN SOIL FERTILITY AND THE COMPONENTS OF AND SEASONALITY OF FORAGE SUPPLY OF A HILL PASTURE

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ABSTRACT

Seven hill country sites, covering a range of soil fertility were studied with the objective of examining the relationship between soil fertility indices and the components of and seasonality of forage supply of a hill pasture under continuous grazing.

The seven sites varied from an undeveloped, unfertilized hill pasture, containing only low fertility adapted grasses and weeds to a highly productive sward dominated by high fertility responsive grasses and white clover. The differences between sites were the consequence of different fertilizer application, position on the landscape and accumulation of nutrients from dung and urine. The total C content of the soils varied from 4.7 to 7.2%, N content varied from 0.43 to 0.70% and P content from 517 to 1361 mg L^{-1}. Soils were sampled biweekly and analyzed for mineral N and Olsen and Resin P for 12 months starting in January 1993. In each season microbial C, N and P were also measured. Pasture growth and components at each site were assessed under biweekly and 4-weekly cutting regimes throughout the 12 months of the experiment. Nitrogen and P concentration of mixed pasture samples from each cut were also determined.

There was a wide range in the values of the three soil fertility indices measured (mineral N, Olsen P and Resin P). Ammonium was the dominant form of soil mineral N at all but the highest overall soil fertility site. Differences in mineral N between sites were mainly due to NO_3^- content. The seasonal pattern was similar for all sites with the lowest soil mineral N content in winter and the highest in summer. In contrast both soil P indices had smaller variation throughout the year and no clear seasonal pattern. Olsen P values at the seven sites ranged from 7.7 to 46.3 and Resin P values from 12.2 to 76.7. Microbial C and N content of soil showed little seasonal variation or differences between sites. In sharp contrast, Microbial P was higher in spring and summer than in autumn and winter and this difference decreased as the fertility of the seven sites increased. The Microbial C:P ratio decreased as fertility increased.

Annual pasture production varied more than 5-fold across the 7 sites, ranging from 3300 to 17000 kg DM/ha/year. There was little effect of cutting frequency on pasture production. Grasses adapted to low fertility environments were the dominant botanical fraction of pasture at all sites with the exception of the highest production site. High fertility responsive grass production followed the same trend as total pasture production and weeds the opposite trend. The seasonal pattern of pasture production was similar at all sites with spring and summer production accounting for more than 70% of annual production. Seasonality of pasture growth was not affected by soil fertility or cutting frequency. Nitrogen and P concentration of pasture followed the same trends of pasture production being the highest in the high production sites and extremely deficient in the low production sites. Differences in P uptake by pasture were far greater (nearly 10-fold) than differences in pasture production.

There were strong relationships between the three soil fertility indices studied and pasture growth. Monthly and seasonal mineral soil N values had a strong linear relationship with seasonal and annual pasture production indicating that N was limiting pasture growth over the range of soils studied. Spring and summer estimates of mineral N were the most reliable predictors of annual pasture production. Monthly and seasonal values of soil P fertility indices (Olsen and Resin P) were strongly related to pasture production although pasture growth appeared to be reaching a plateau at high P levels, specially in spring and summer. Due to the small variability of these indices throughout the year, relationships between Olsen P and Resin P and total pasture production were independent of sampling time, with the exception of the sampling immediately following P fertiliser application.

Estimated P levels for 95% of maximum growth were extremely high (103 and 187 µg/cc for Olsen P and Resin P, respectively). These indices are much greater than the commonly used critical level for Olsen P in these soils (20 µg/g). However, the shape of the response curve in this study may be affected by the combined effect of available P and N at the high fertility sites. Indices of P fertility were also related to pasture composition, with a strong positive linear relationship with high fertility responsive grass production, a quadratic relationship with white clover production and a negative relationship with weeds production and content.

This study suggests that in hill country pastures Olsen P and Resin P values may be satisfactory indicators of pasture productivity for animal production models. However, pasture production will continue to increase to much higher P levels than are normally associated with maximum production in conventional P fertiliser trials. This is because of the linkage of N and P in animal excreta resulting in a high nitrogen status in those areas of hill country that also have high P.

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DEDICATION

to my mother Marina

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CHAPTER 1

INTRODUCTION

New Zealand's low cost pasture industry is founded on legume based pastures topdressed with P and S containing fertilizers and relying on N inputs from biological fixation. As the amount and availability of these macronutrients increase so does the productivity of the pasture it supports. Associated with the increased productivity is a complex change in the botanical composition of the pasture and in the seasonal pattern of growth.

The term soil fertility is often used very loosely to describe the nutrient status or supply capacity of the soil and in its broader sense also to describe the productive capability of the pasture it can support. While single nutrient factor indices of soil fertility have been used extensively as tools for assessing nutrient requirements and for predicting annual pasture production, use of such indices for examining the components of and seasonality of pasture growth with changing nutrient status has received little if any attention. Establishing the relationship between soil fertility and the seasonality of forage supply is becoming increasingly important as the use of models such as Stockpol, that match pasture growth and livestock production, are used in the pastoral sector for decision making. While there is ample data to predict changes in total pasture production with changes in soil fertility measured by a single nutrient factor index, the way in which a change in soil fertility affects the seasonality of supply remains largely unresearched. While it has been established that significant temporal changes in single nutrient factor indices of soil fertility occur in grazed pastures (Saunders & Metson 1971; Robert 1987; Wheeler & Edmeades 1991) no clear seasonal trends have been found despite the marked seasonal trends found in pasture growth and nutrient uptake and in microbial biomass; all of which combine to influence the plant available nutrient pool. This would suggest that time of sampling is unimportant in determining the predictive ability of these indices (Wheeler & Edmeades 1991). Apart from their study which examined the temporal variation in soil quick tests (QT) across a range of soil types, the effect that sampling time has on single nutrient factor indices of one soil of varying fertility has not been studied. Neither has the ability of soil indices to predict the seasonal pattern of pasture growth been studied extensively.

Calibration of soil fertility indices are in general based on data from fertilizer rate trials, where nutrients in fertilizer are applied on a regular basis (Cornforth 1984). There is some evidence to suggest that when fertilizers are withheld, which was the case in large parts of North Island hill country in the mid and late 1980's (Gillingham *et al* 1990), that the ability of soil nutrient indices to accurately assess nutrient requirements decreased.

The objective of the study was to examine the relationship between soil fertility measured by commonly used single nutrient indices and the components of and the seasonality of forage supply of a hill pasture. The opportunity was also taken to examine the effect of time of sampling; fertilizer history; fertilizer cessation; slope and aspect as they affect nutrient return, on the ability of each of the commonly used single nutrient factor indices to assess nutrient status and to predict pasture growth; and to examine the relationship between pasture growth and defoliation frequency as it is influenced by soil fertility.

CHAPTER 2

2.1 INTRODUCTION

New Zealand pastures are a complex mixture of different species that share space and compete for nutrients and light. In the study of the influence of nutrient supply on the seasonality of pasture growth it is useful to have an understanding of the influence of soil mineral N and P fertility on pasture growth, the interaction between N and P and legume growth and biological N fixation, and how these interactions are influenced by defoliation. In addition to examining the close relationship between soil fertility and pasture development and the interaction between N and P in grazed pastures this review also examines very briefly the diagnostic tests used as indices of soil fertility of grazed pastures.

2.2 DEVELOPMENT SEQUENCE OF A GRAZED PASTURE

A close relationship exists between the soil fertility status of a grazed pasture and what is commonly referred to as the stage of pasture development under New Zealand conditions.

In the classical work of Sears (1953) he proposed a model for the development of New Zealand pastures following addition of fertilisers, (mainly superphosphate), inclusion of a grass-clover association and the return of nutrients in dung and urine by the grazing animal. Sears (1953) found that the pasture dominated by legumes in the first stage, slowly evolves to being grass dominated as N fixed by legumes is recycled through grazing animals and returns to the soil. The increase in soil N content causes a drop in legume growth, as a result of the increased competition from grasses. This causes the rate of N input to the system to be reduced further. An equilibrium with a balance of grasses and clover is eventually reached.

Examples of this pasture development sequence can be found in grazed systems in both New Zealand and Australia. Wolfe and Lazemby (1973) in a study of pasture development in Australia found that in the first year only clover responded to an increase in P rates, while weeds and grasses produced similar yields for all treatments. From the second year the grass component of the pasture started to produce higher yields at highest P rate, while clover yield dropped continuously compared to the first year. They reported concomitant increases in available P and total soil N following 5 years of superphosphate application. The authors speculated that the retarded effect of P on grass yield may be due to an indirect effect of legumes, or a direct response to P once N was removed as a limiting factor.

In a study in North Island hill country of New Zealand, Lambert *et al* (1986) examined the influence of grazing management and P fertiliser on pasture botanical composition over 6 years. They reviewed previous work on the subject and found that in general the process after P application involves an initial increase in legume production, and subsequently perennial ryegrass content, and a decrease in low fertility tolerant grasses and weeds. The results of their experiment did not differ greatly from this pattern. Legume growth responded to P, especially in the first two years of the experiment. By the third year, however legume percentage dropped, due to competition by ryegrass and other high fertility responsive grasses. This fact led the authors to conclude that after P fertilization, the principal factor limiting pasture growth in this soil was N.

The improvement of "soil fertility" following pasture development has been confirmed in several studies. Walker (1960) reported accumulation of soil organic matter (C, N, S and P) after 25 years of pasture development with superphosphate application, with a fall in the C:N ratio in the top 10 cm of soil from 33 to 11. He suggested that the accumulation of organic matter can not be expected to continue indefinitely, even when heavy amounts of fertiliser are applied, but at some stage the rate of decomposition of organic matter balances the rate of addition. Jackman (1964) attributed the differences in organic matter accumulation rates in a range of soils under pasture to differences in clay mineralogy of the soils. According to his calculation the time necessary to reach the steady state varied with soils and nutrient considered. Half lives (time needed to accomplish 50% of the changes) for S, that represented the extremes, ranged from 42 years in Yellow Brown Pumice Soils to 2 years in Yellow Grey Earths. While Jackman (1964) reported decrease in C:N and

C:P ratios for the 0-75 mm of soil depth with pasture development, Lewis *et al* (1987) obtained varied results in terms of C:N ratios. However C:P ratios of the three Australian soils studied decreased with pasture age. The greatest change was observed within 5 years and a relatively constant ratio thereafter.

2.3 INTERACTION BETWEEN NITROGEN AND PHOSPHORUS IN GRAZED PASTURES

2.3.1 Effect of nitrogen and phosphorus on pasture growth

Both N and P are essential nutrients for plant growth. Nitrogen is a constituent of proteins, nucleic acids and many other important substances. It forms part of most catalytic molecules. In addition to a structural role in nucleic acids, phospholipids and other substances, P plays an important role in energy metabolism due to the high energy of hydrolysis of pyrophosphate and other organic phosphate bonds. (Bidwell 1979).

2.3.2 Nitrogen deficiency and pasture growth

Plants deficient in N exhibit decreased rates of cell division and expansion, prolonged dormancy and delayed swelling of buds. In addition all morphological parts are reduced in size. In addition the major symptom of N deficiency is a paling or chlorosis of older leaves, that then spreads to younger leaves if deficiency intensifies. Chlorosis is due to a drop in chlorophyll content. (Devlin 1985).

In pasture plants, Alberda (1965) reported that as NO_3^- concentration in solution decreased the shoot:root ratio of ryegrass decreased. This was caused firstly by an absolute increase in root weight and at lower concentrations also by a decrease in leaf weight and the rate of tiller formation. Cowling (1964) also found that fertiliser N increased significantly the number of tillers per square metre.

2.3.3 Phosphorus deficiency and pasture growth

Phosphorus deficiency affects all aspects of plant metabolism and growth. Plants deficient in P develop more slowly and are often stunted. Buoma and Dowling (1962), working with subterraneun clover, found that when plants from a P deficient pasture were transferred to complete or without–P solutions, differences in leaf area were apparent two days later and the differences were statistically significant at day 5. The effect of P on plant growth was more pronounced in leaf area than in dry matter weight.

Asher and Loneragan (1967) studied the effect of different P concentrations in nutrient solution on the growth of eight pasture species. While at the lowest concentration (1.24 ug/l) all species showed symptoms of severe deficiency, increasing P concentration produced responses of varying magnitude in the different species. The P concentration necessary for maximum growth varied widely from one species to another. Loneragan and Asher (1967) observed that the shoot:root ratio for both fresh weight and P content increased markedly from plants growing at 1.24 ug/l to plants at 6.2 ug/l P. The relationship varied only slightly at higher P concentrations.They concluded that this retention of P in the roots of plants that are insufficiently supplied with P indicates that requirements of tissues nearest the source of a scarce metabolite tend to be satisfied at the expense of the supply to other organs. Hence the distribution of P between tops and roots in this case was the cause rather than the consequence of the low ratio of top:roots weights observed at 1.24 ug/l P in solution. Similar results were obtained by Atkinson (1973) with a wide range of pasture species. The leaves were the first organs to be affected, while the root growth was the least affected.

Examining the effect of constant P concentration in solution on the growth of Lolium perenne, Breeze *et al* (1984) found that growth rates were higher at higher P concentrations at early stages, however the relative growth rate (g/g DM/day) of the plants in solution of low P concentration reached similar values to the plants growing at higher P concentrations at the end of the experiment (approx 45 days). In a subsequent study examining the effect of changing the concentration of P in solution on ryegrass growth Breeze *et al* (1985) found that after 29 days of growth, ryegrass plants cut and transferred to solutions with higher or lower concentration of P were able to respond rapidly to changes in P concentration. Old leaves were capable of exporting P to tillers when growing at low P concentrations or accumulating P in order to protect tillers from P toxicity when grown at higher concentration solution.

2.3.4 Differences in nitrogen uptake by pasture species

Pasture species growing together have to compete for the different growth factors: light, moisture and nutrients. The ability of each species to compete for available nutrients is a key point in determining their growth and dominance in a given environment.

Mixed pastures containing legumes present a special situation when examining N uptake. There is not a strict competition for soil N between grasses and legumes, since legumes do not depend on mineral N to grow, but the presence of mineral N can influence the competition for other nutrients, moisture or light. Many authors (for example Brockman & Wolton 1963 and Wilman & Asiegbu 1982) have found that increases in N inputs or improved symbiotic N fixation enhances grass growth in a mixed pasture. This invariably results in a decline in the clover component of the pasture.

2.3.5 Differences in phosphorus uptake by pasture species

Loneragan and Asher (1967) comparing growth of eight species in solution ranging in P concentrations from 1.24 ug/l to 744 ug/l found that for each species and P treatment the amount of P absorbed was a function of both size of the root system and rate of P absorption per unit weight of root. They also observed that the ability of individual species to absorb P from high concentrations was not closely correlated to their ability to absorb P at low concentrations. This fact seems to be confirmed by Rorison (1968) who, in a comparison of four species that differ in their adaptation to their environment, found that plants adapted to low fertility environments, with low growth rate were able to absorb P and grow slowly, but in an apparently healthy state, at low P concentration (31 ug/l). In contrast, species adapted to a high fertility environment did not survive at the lowest concentration but had the highest growth rate at the highest concentration used (31000 ug/l).

In an examination of the competition between two of the most common pasture species Jackman and Mouat (1972a) found significant responses to P application in clover but not in browntop. The yield of clover in mixed plots was always lower than those of pure white clover plots even when the total dry matter yield of the mixed sward was in general higher than pure clover. The yield depression of clover in the mixed plots compared to the pure clover plots was largest at medium P rates (100-200 kg/ha superphosphate) and tended to decrease with further increases in P addition. The fact that this depression did not disappear at very high P rates led the authors to conclude that factors other than P were limiting growth of clover in the mixed pasture (probably light or soil moisture). They recognized that some effects of animal grazing can modify the conditions of competition, for example reducing competition for light through severe defoliation or modifying nutrient availability through faeces and urine cycling.

The same authors (Jackman & Mouat 1972b) in a subsequent study observed that for both white clover and browntop about 80% of the total root activity was in the top 25 mm of soil. Considering this fact and the smaller number of root tips found in white clover than in ryegrass, the authors speculate about the possible direct competition for P that may occur when the concentration gradients of two roots overlap, specially in the case of topdressed pastures, where P is located in the soil surface and in discrete granules. They concluded that the grass component of the sward is likely to decrease the P available to the plants with the consequence of depression in clover growth.

Caraduus (1980) in a pot trial comparing 10 grasses and 11 legumes observed that although the grasses explore the soil more efficiently, legumes seem to be able to absorb more P per unit length of root. On the other hand at low P levels the grasses had a higher relative yield (in respect to potential yield) than the legumes. Parfitt *et al* (1982) observed that ryegrass roots account for close to half the total dry matter yield of a ryegrass pasture while clover roots were about one quarter of the total dry matter yield. At lower P levels ryegrass absorbed more P than clover. At the higher levels the differences were smaller, as the length of root becomes less important. Similar results were obtained by Kemp and Blair (1991) comparing the uptake of P by grasses (Italian ryegrass and phalaris) and legumes (white clover and red clover). They found that the grasses showed greater efficiency (superior shoot biomass production at lower P rates) than the legumes. This was due largely to the greater root weight and P uptake per plant. From all these experiments it seems clear that low P availability is more likely to favour grass than legume growth in pastures. Similarly the species adapted to low P environments, either because of higher efficiency in uptake or lower requirements, will have a competitive advantage in low P environments.

2.3.6 Interaction between nitrogen and phosphorus uptake

Koontz and Vose (1960) in a study of the P uptake by ryegrass under two different cutting regimes (10 or 20 day intervals) and 3 N levels found that P uptake was greater in the frequently than in the infrequently defoliated treatment, except at the high N level. In all the frequently cut series P uptake increased immediately after defoliation. The same pattern was observed in the infrequently cut series but only at the high N level. They attributed the increase in P uptake after defoliation to the high P requirements of the newly differentiating and expanding tissues. Infrequently defoliated plants and those grown at low N levels probably had sufficient P reserve for new growth. Comparison of defoliation treatments showed little difference in total amount of P absorbed for low and medium N levels but at the high N level greater amounts of P were taken up by the infrequently cut ryegrass treatment.

In a comparison of the response of nodulated and unnodulated white clover and lotus plants to P, Hart *et al* (1981) found that while the growth of all plants was limited by P supply at low P levels it was limited by N at the high P rates with higher yields for unnodulated plants receiving N.

2.3.7 Phosphorus availability and nitrogen fixation by legumes

The positive effects of P fertiliser addition on legume growth in mixed pastures are well known and a number of workers (Gates & Wilson 1974; Robson *et al* 1981) have studied the reasons for these effects.

Graham and Rosas (1979) studying the P requirements for nodulation of common beans concluded that nodules were an extremely strong sink for P and N fixation activity was highly correlated with the amount of P supplied, concentration of P in nodules and with total P content of nodules. They attributed these relationships to the better carbohydrate supply to nodules at high P additions. Robson *et al* (1981) working with subterranean clover also found that P concentrations in nodules were greater than those in either roots or shoots at a given level of P supply and as the rate of P increased the concentration of N in tops of the plants also increased.

In an assessment of the differences in the distribution of P and N of nodulated and unnodulated white clover and lotus plants, Hart (1982) found a higher root:shoot ratio and a higher proportion of plant P in roots of nodulated than in unnodulated plants, specially at high P rates. He did not attribute the higher P content of the nodulated plants to the N fixing process but attributed the lower P content of the unnodulated plants to the effect of dilution in plants supplied with mineral N, as they had higher growth rates.

According to Israel (1987) who studied symbiotic N fixation in soybean, the role of P in the fixation process remains unclear. From his experiment he concluded that the increase in the ratio of nodule mass to whole plant mass indicated a greater stimulation of nodule growth by improvement in nutrition than of host plant growth. Moreover the higher response in terms of nodule number than in root mass when P rate increased suggests that P has specific role on early stages of nodule development.

2.3.8 Soil mineral nitrogen and nitrogen fixation by legumes

Lie (1974) suggested that before the symbiosis between the rhyzobium bacteria and host plant occurs "the host plant should enter a period of N hunger". Rather than mineral N *per se*, the most important factor regulating nodule formation and N fixation is the carbohydrate:N ratio of the plant. The degree of inhibition of N fixation of the nodulated plant by mineral N depends on a number of factors such as the concentration and form of the N compound, time of application of N, growing conditions of the plant and type of host plant and bacterial strain.

It has been suggested that a small amount of mineral N is beneficial for plant development and N fixation. In a study examining root weight and total nodule numbers of white clover in a mixed ryegrass and timothy pasture receiving four successive monthly N applications Young (1958) found that after the first N application, white clover root weight and nodule number was larger than that of the treatment not receiving N. Both treatments had similar results for the second application while control was superior to the N treatment thereafter. Davidson and Robson (1986) working with white clover receiving the same total N input as nitrate but in different combinations of rates and timing, found that some N fixation occurred at all nitrate concentrations. High nitrate concentrations (98 mg/l N or more) caused a rapid decrease in N fixation, partly due to a decrease in nodule dry weight and partly due to a decrease in rate of N fixation per unit of dry weight of nodules. The increase in N fixing capacity of plants that were transferred from high to low nitrate concentration was similarly rapid and was accompanied by increases in nodule dry weight and number.

2.3.9 Effect of nutrient return in dung and urine on nitrogen fixation

In a grazed pasture large amounts of N in faeces and urine are returned to a small percentage of the grazed pasture. Young (1958) in a grazing study examined the effect of different N fertiliser rates with or without excreta returns on the growth of a white clover in a ryegrass based pasture. She found that both excreta and/or mineral N negatively affected white clover production and N fixing capacity. Interestingly she failed to find any differences between treatments in the number of nodules per unit weight of roots. Therefore the lower N fixation of the plants that received N was attributed to depressed root growth as well as nodule decay, since the numbers of green and brown nodules were higher in the N treatments.

Ledgard *et al* (1982) compared N and K fertiliser application with cow urine application in ryegrass-white clover pastures. They found that urine had a negative effect on N fixation and this effect was more dramatic in winter (N fixation almost stopped) than in spring (40-60% decline compared to control) This negative effect was evident two weeks after application and lasted until the end of the experiment (13 weeks). They attributed the initial drop in N fixation to absorption of mineral N by the legumes as plants had lower N fixation per unit of clover weight. After the second harvest (56 days) it was probably due to a decrease in clover growth since the N fixing capacity per unit weight of white clover returned to the same level as the control. Similar results were obtained by Marriot *et al* (1987) who applied sheep urine to ryegrass-white clover pasture at a rate equivalent to that of a single urination (556 kg N/ha). Nitrogen fixing activity was reduced immediately following urine application. After 18 days activity increased, but still remained less than 50 % of control for 57 days after urine application.

In mixed pastures it is very difficult to dissociate the negative effect of mineral N on N fixation from the indirect effect of increased grass growth. Marriot *et al* (1987) explained the decrease in legume growth under urine application as a function primarily of greater grass growth and thus lower levels of light penetration into the sward. The depression in N fixing activity as a consequence of urine and dung deposition can partially explain the fluctuations in botanical composition that are common in grazed pastures. However the recuperation of N fixing capacity by legumes after the mineral N concentration drops indicates that permanent damage of the grass-legume balance is unlikely to occur.

2.4 INTERACTION BETWEEN DEFOLIATION AND PASTURE GROWTH

2.4.1 Pasture growth after defoliation

Brougham (1955) found that pasture growth after defoliation could be described by a sigmoid growth curve. The curves had three distinct phases 1) In the first 3-4 weeks the daily accumulation rate of dry matter increased until all light was intercepted. 2) After this initial increase in leaf area index there was a 4-5 weeks period of constant growth. 3) In the last growth phase the rate of accumulation of dry matter declined. He also found differences between species in the slope of the sigmoid growth curve. While ryegrass growth had a similar pattern to mixed pasture growth, reflecting the dominance of the grass component of the sward, clover growth rate did not decline during the 9 week period of the study. The author explained that factors other than seasonal and climatic variations such as physiological stage, nutrients and water availability also affect the slope of the growth curve.

In a subsequent study, Brougham (1956) measuring regrowth of pastures defoliated to 2.5, 7.5 and 12 cm height found that maximum growth rate was approximately the same for all treatments. However the dry matter produced was greatest for the highest cutting height because it took more time to reach the full light intersection for herbage cut at 2.5 and 7.5 cm than for 12 cm . Leaf efficiency, measured in terms of dry matter accumulation per area of leaf during the initial regrowth period however was greater for the 2.5 and 7.5 cm than for the 12 cm treatment. This experiment showed that the more intense the defoliation, the lower was the initial rate of regrowth and the longer the time taken to attain maximum growth rate.

Considering the shape of the growth curve it would be expected that increasing the period between defoliations would increase pasture production, however the literature does not always support this assumption. While Bland (1967), and Frame (1973) reported greater dry matter yields for longer spells, Betts *et al* (1978) obtained similar production from ryegrass-white clover pastures grazed every 3, 4 and 5 weeks.

In a comparison of two defoliation frequencies of a white clover-ryegrass pasture (cutting or grazing) Frame (1966) obtained higher yields under grazing. He attributed this to the recirculated N by the grazing animals. Curll and Wilkins (1985) obtained similar results with ryegrass- white clover pastures. They found that in the first three weeks after defoliation growth rates of cutting treatments were lower than that of grazed treatments. In the following three-week period the growth rate of the laxly-grazed pasture continued to be higher than the corresponding cut pasture, but the reverse was true for the intensively grazed pasture, with the cut treatment having the higher growth rate. Similar results were obtained by Scott (1973) who found an interaction between defoliation frequency and seasonal growth. Treatments defoliated most frequently in winter provided higher yields in early spring. This was attributed to the fact that herbage was maintained at a short and leafy stage of growth as well as the higher availability of N recycled by the grazing animals.

The effect of defoliation frequency on pasture production not only depends on the phase of the growth curve at the defoliation date but also on other factors that influence plant recovery after defoliation. In an attempt to evaluate the effect of defoliation frequency on pasture growth of a perennial ryegrass pasture under cutting or rotational grazing, Binnie and Chesnut (1991) found an interaction between defoliation frequency and harvest method. Even when in both cases the less frequent harvested pastures produced more, the superiority of the longer spell (4 weeks) over the shorter spell (3 weeks) under cutting was more marked than the superiority of the longer spell over the shorter spell under grazing.

2.4.2 Interaction between defoliation and nutrient status

Troughton (cited by MacLachlan 1968) pointed out that defoliation of pasture reduced plant growth, and that fertiliser additions may lessen this effect but not completely counteract it. According to this author dry matter production falls as pastures are more intensively grazed and, associated with this, there is an increase in the length of time before regrowth starts. When pastures are grazed there is a combined effect of defoliation and nutrient cycling through the animals.

MacLachlan (1968) in Australia concluded that the pasture response to added P, N and S was lower at the higher stocking rate treatment due to a more frequent turnover of nutrients at the higher grazing intensity. However higher responses to added nutrients when pastures are infrequently defoliated, as reported by MacLachlan (1968) and Caraduus and Snaydon (1988), can be a consequence of the increase in pasture growth rate concomitant with a larger photosynthetic capacity.

Surprisingly little work has studied the interaction between defoliation frequency and pasture growth as it is influenced by soil fertility under New Zealand conditions. Based on the available literature the rate of recovery of pastures after defoliation should increase as the nutrient supply is increased given other factors are not limiting growth.

2.4.3 Effect of defoliation frequency and intensity on nitrogen fixation by legumes

Numerous studies have investigated the effect of defoliation on the biological N fixation process. Buttler *et al* (1958) studying the effect of periodical (from 12 to 14 days) defoliations of white clover, red clover and lotus concluded that under successive defoliations the root systems of the three species suffer cyclic decay and renewal. White clover showed a more extensive turnover of root and nodule tissue than red clover and lotus, resulting from the progressive death of older roots and nodules that were rapidly replaced by new stolon roots heavily nodulated.

Also working with white clover, Chu (1971) observed a 30% decrease in total nodule numbers 3 days after severe defoliation. The difference in nodule numbers relative to control was 47% at the end of the experiment (29 days). The rate of appearance and the size of nodules were also lower in defoliated than in undefoliated plants. Since nodule numbers per dry weight of roots were similar in both treatments the author attributed the effect of defoliation on nodule number mainly to root losses. Fixation capacity, measured by acetylene reduction per mg nodule, recovered more rapidly than nodule number.

Ryle *et al* (1985) observed that nodules of white clover were not shed from plants immediately after defoliation, but senescenced more rapidly than those from undefoliated plants, especially the older larger nodules. At the same time carbohydrate content dropped markedly. Photosynthetic rates attained previous levels in 9 and 5 days in two experiments that simulated defoliation (cutting petioles and stolons longer than 6 cm in experiment 1 and removing tissue longer than 5 cm in experiment 2) while N fixation rates took the same time to recover, emphasising the link between photosynthesis (carbohydrate supply) and N fixation. The authors explain the reason for this behaviour as being a strategy of the plant for survival which consists of directing most assimilates to shoot growth at the expense of root and nodule growth until photosynthetic function is restored.

In a comparison of single and continuous (dairy) defoliation in white clover, in order to study the effect of these treatments on N fixation, Gordon *et al* (1990) found in both cases that defoliation reduced acetylene reduction activity by more than 80% within 3 hours and by almost 100% within 24 hours. Continuously defoliated plants did not recover N fixation capacity, while defoliated plants that were allowed to recuperate began to fix N again within 3 days and reattained their original fixation capacity in approximately 14 days.

In a study of the effect of defoliation on pasture regrowth and N fixation in a grazed ryegrass-white clover pasture Hoglund and Brock (1978) observed that the uptake of N by ryegrass increased at the beginning of the regrowth period but tended to drop at the end (28 days). White clover, in contrast, accumulated N during the whole period. Measurements of soil mineral N during the same period showed a continuous drop in levels of NH_4^+ and NO_3^- after grazing. The small amount of mineral N in soil at the end of the regrowth period was identified by the authors as the cause of the low uptake of N by grasses at the end of the study period. The N fixation rate was initially very low and then increased before tending to plateau. The authors explain that defoliation effects on N fixation are commonly interpreted in terms of reduced carbohydrate supply to nodules. From this work they concluded that increased soil mineral N, which leads to increase of mineral N uptake by legumes and/or reduced demand for N after defoliation may be the limiting factors; the drop in demand for N being due to the removal of most of the active meristem rather than simply a matter of carbohydrate supply.

2.4.4 Effect of defoliation frequency and intensity on pasture botanical composition

According to Lynch (1947) in pasture measurements: "The intimate relationship between the sward and the grazing animal cannot be overlooked, for the grazing animal is a major factor in determining the production from pastures. More particularly, however, the kind of stock used and the severity of grazing profoundly influence the pasture species that make up the sward. Each pasture element reacts differently to grazing and management and on an experimental scale at least, it is possible to vary the sward composition at will by adjusting the management to which the pasture is subjected". He also explained that in grazing trials it is in general difficult to eliminate an appreciable part of the error, such as the relative efficiency of utilization of the herbage.

The different morphological characteristics of the species induce different reactions, in terms of growth, to different defoliation regimes. Ennik (1965) comparing the effect of rotational and continuous grazing on the botanical composition of a permanent pasture over 7 years in the Netherlands found that some species like *Holcus lanatus, Ranunculus repens, Agrostis stolonifera, Poa trivialis* and *Agrostis tenuis* were favoured by continuous grazing while *Lolium perenne* and *Trifolium repens* were favoured by rotational grazing.

The adaptive ability of species to grow under a given defoliation regime will improve their competitive advantage under such conditions. According to Haynes (1980) grasses are extremely well adapted to grazing since their meristems are close to the soil surface and are thus not likely to be reached by the animals, while tillers and leaves are able to regrow after defoliation. Stoloniferous legumes like white clover are also well adapted to grazing since they are rooted at frequent intervals.

The foliage architecture of white clover (horizontal leaves that intercept light very efficiently) suggests that this species, in a mixed sward, will be favoured by frequent defoliation that prevents grass shadowing. Coincident with this hypothesis are the results obtained by Bland (1967) who found that increasing cutting frequency from 2 to 6 cuts per year in a ryegrass-white clover pasture increased the white clover proportion of total yield dramatically. However, Wolton *et al* (1970) comparing different defoliation heights in a ryegrass white clover sward found that defoliation at a late stage of growth, corresponding to a high defoliation height (30.5–38 cm) did not seem to affect negatively white clover production as might be expected considering the growth habit of white clover. In order to explain this result the authors speculate about the effect of moderate shadow in increasing the size of the plant components and the number of stolons that develop.

Other workers (Frame 1973; Betts *et al* 1978; Wilman & Asiegbu 1982) also found little or no difference in the white clover proportion of total herbage when pastures were defoliated at different frequencies. A possible explanation for these results is found in the work of Curll and Wilkins (1985) who studied the effect of defoliation period and the competition of a mixed sward under a grazing or cutting regime. They concluded that "The clover cultivar used in this study was able to adapt its growth habit to suit both infrequent cutting and grazing by set stocked sheep." In Curll and Wilkins' (1985) field experiment plants infrequently cut had longer leaves and petioles, but under grazing they reverted to small leaves with short petioles.

In a study of the effect of intensity of grazing on botanical composition, Simpson *et al* (1973), comparing two continuous stocking rates at different P levels in pastures containing phalaris and subterranean clover, observed positive responses in dry matter production to P application in both grazing treatments and higher total yield for the high grazing pressure. They found a significant interaction between fertiliser use and grazing. High grazing pressure increased the invasion by annual grasses and weakened the production of phalaris especially at low P. But phalaris yields were similar at both grazing pressures when high P rates were used. White clover yields were higher at high stocking rates than at low stocking rates in low P treatments but similar for both grazing pressures at the highest P rate. At high P rates and high grazing pressures the annual grasses, phalaris and white clover had similar yields but the addition of N, or temporary withholding of P fertiliser caused a rapid change to grass dominance, especially in the plots that had received high P rates in the past.

Robinson and Lazenby (1974), found a negative response in the proportion of white clover in the pasture at high stocking rates. Similar results were obtained by Curll and Wilkins (1983) but in this experiment it is not possible to dissociate the effect of intensity of defoliation from the effect of treading and excreta return. According to these authors white clover is more sensitive to treading than ryegrass and the larger N returns of the high stocked paddocks might have suppressed clover and benefitted ryegrass. When interpreting the literature it is also important to consider the intensity of defoliation from study to study. For example the high stocking rate in Robinson and Lazemby (1974) was higher than that of Simpson *et al* (1973).

2.5 DIAGNOSTIC TESTS FOR ASSESSMENT OF SOIL FERTILITY AND PASTURE GROWTH

Even though a large number of plant and soil diagnostic tests have been developed for assessing nutritional requirements and predicting pasture growth responses to applied nutrients, each test or indicator has limitations. A combination of diagnostic tools, as was suggested by Asher (1991), are required in order to permit a comprehensive evaluation of the nutritional status of legume-based grazed systems particularly when inputs are not only fertilisers but also nutrients contained in organic matter and dung and urine.

It is not the intention of this section of the review to exhaustively review the literature on the subject of soil testing and plant analysis but simply to examine the state of knowledge on the commonly used indices of soil fertility.

2.5.1 Single nutrient indicators (soil tests)

Most soil tests involve the extraction of a nutrient from a soil sample. According to Cope and Evans (1985) the earliest attempts at soil testing tried to relate the total amount of nutrients in soils, or extraction of nutrients by strong acids, to soil fertility levels and yields. These attempts failed and researchers focused on extractants that attempted to quantify the available nutrient pool – the concept of availability being defined as the portion of nutrient that is likely to be absorbed by the plants in a given time. The extractant must remove from the soil in a short period an amount of nutrient that is directly proportional to what is removed by the plants in a growing season. Once an adequate extractant is found it is necessary to calibrate the soil analysis values with field experiments in order to find the relationship between soil test levels and plant growth. Danhke and Olson (1990) explain that in addition to the extractant other factors such as soil:solution ratio, extraction time and shaking speed are important aspects that need to be considered when evaluating the suitability of soil tests.

2.5.1.1 Soil tests for Nitrogen

Of the macronutrients, N most limits pasture production in New Zealand (Ball 1975; Smith & Cornforth 1982). Soil tests for N, however, are not usually included in most soil test services because the characteristics of this nutrient make it extremely difficult to quantify the available N pool.

Most of the N in soil is in complex organic compounds and slowly becomes available to plants through microbial decomposition. Dahnke and Johnson (1990) identified the variable influence of environmental and soil factors on the organic matter decomposition and the susceptibility of the mineral forms of N to losses, as problems that need to be considered in developing tests for available N.

According to Keeney (1982) available N is derived from many sources, including fertiliser, biological N fixation and the mineralization of organic N from plant litter and soil organic matter. In the case of New Zealand pastures important amounts of available N are added in the form of dung and urine.

There are two sources of available N: mineral (NO_3^- and NH_4^+) and the potentially mineralizable organic N. According to Whitehead (1966) any attempt to assess soil N availability must take into account both N sources. Simple methods for extraction and determination of NO_3^- and NH_4^+ have proved to be adequate. In contrast a wide range of biological and chemical tests are available for assessment of mineralizable organic N. Incubation of samples under controlled conditions for a given time followed by measurement of N mineralized in the period has been widely used for assessing the potentially mineralizable N pool (Keeney 1982).

Standford (1982) reported a number of experiments that used aerobic or anaerobic incubations and found good relationships between N released during the incubation period and that absorbed by plants in parallel experiments. Nevertheless this author emphasized the need for finding more reliable and rapid methods. Amongst others he cited the use of mild extractants like boiling water or boiling $CaCl_2$, or the use of stronger mineral acids, bases and chelating agents. From his review it can be concluded that the extraction methods of intermediate or low intensity are more likely to be related to the actual N released by the soil than intensive extraction procedures with alkalis, acids or strong oxidants.

Comparing several chemical extractants to predict the supply of grass growing at 18 different sites through the UK Whitehead (1966) found that only a few methods behaved appreciably better than total soil N. Knowing the effect of temperature and water status on the rate of mineralization, the author calculated an adjusting factor that considers these factors. After adjusting with this factor all methods improved, especially autoclaving with 0.01M $CaCl_2$. This method explained 65 % of the variation in pasture growth compared to 34 % for total soil N. In a second study testing some of these methods with the same soils but calibrated against a pot experiment he obtained better relationships between estimated N availability and pasture growth for all methods. Comparing the results from both experiments the author emphasized the difficulties of assessment of mineralizable N under field conditions.

From the literature reviewed it is clear that there is not a simple and effective method for assessing available soil N despite its importance in grazed pastures. The principal cause for the lack of agreement between studies is probably the result of the fact that no method is sufficiently robust for assessing soil N availability under a wide range of situations. Under field conditions the success of N availability prediction will depend on environmental conditions and other factors rather than the method itself, because the actual amount of mineralized N depends on such conditions and no method is able to forecast these factors for the upcoming season.

2.5.1.2 Soil tests for phosphorus

There have been a number of attempts to find extractants that give an adequate assessment of available P in soil. Cope and Evans (1985) mention three extracting solutions Mehlich I (0.05N HCl + 0.025N H_2SO_4), Bray P1 (0.03N NH_4F + 0.025N HCl) and Olsen (0.5M $NaHCO_3$) as the most commonly used extractants in the United States of America. The use of the different extractants in this case is a response mainly to soil characteristics as well as source of P fertiliser used. Nevertheless Fixen and Grove (1990) recognize that much of the work in selection of extractants is empirical rather than the product of a study of how the extractant acts.

Saunders (1987) mentions the early use of the Truog extractant (0.02N H_2SO_4) in New Zealand, and comments that from his experience the Olsen method (adopted later) is more reliable for a wide range of soils under pasture. However, as Cornforth *et al* (1983) and Mackay *et al* (1984) have pointed out, the Olsen test does not seem to be successful in the assessment of available P when insoluble or partially soluble sources are applied. This fact has led to research into other extractants that are more effective in assessing the contribution of partially soluble fertiliser products to the plant available pool.

The extractants mentioned above are based on the attack of soil compounds by the extractant solution, releasing P. A different approach involves the use of resins that exchange anions for soil P. This is an attempt to mimic the action of plant roots. The combined use of cation and anion resins was first proposed by Vaidyanathan and Talibudeen (1970).

Saggar *et al* (1991) found that combined cation and anion exchange resins could more accurately assess available P than the Olsen test when both soluble and insoluble P sources were used. When fertiliser history is unknown this approach offers an advantage over the existing tests. However Resin P as an indicator of available soil P and as a tool for predicting pasture growth has not been evaluated widely under New Zealand conditions.

From the literature reviewed it is clear that this area of research is very dynamic. Even though some of the methods in use were proposed many years ago, new methods are continuously being tested. However it is unlikely that a uniform extractant for all soils and conditions will be found.

2.5.2 Plant analysis

Plant analysis is sometimes seen as more reliable than soil testing since it checks the actual nutritional status of plants. According to Asher (1991) one of the advantages of plant analysis is that it makes it possible to detect deficiencies before they are detrimental to plant growth.

However, interpretation of plant analysis is sometimes difficult. In general, critical concentrations are calculated from experiments that relate growth to increasing rates of the nutrient under study when all the other nutrients are in adequate supply. It is possible then to relate nutrient concentrations to plant yield. Some authors prefer to use a range of sufficiency rather than an optimum concentration (Cornforth 1984). On the other hand, tissue concentration will depend on the plant part sampled and the on the stage of crop growth. These must be known in order to interpret correctly the results of plant analysis (Asher 1991).

In a grazed pasture the variable botanical composition adds to the difficulty of interpretation. McNaught (1970) advised analysing the components separately, with the clover being the most sensitive indicator of the nutritional status of the pasture as a whole. While healthy ryegrass usually shows higher P, S, K, Mn and Na, associated clover has much higher Ca and B and higher N, Mg, Zn, Cu and Fe. He also warns about seasonal and year to year variation in tissue content due more to environmental factors rather than nutrient availability.

Joblin and Keogh (1979) emphasized the variation of nutrient composition in grazed ryegrass pastures. They studied the effect of urine on nutrient concentration. While N and K concentration were higher in plants from urine patches, concentrations of P, Ca, Mg and Mn were lower than the rest of the pasture. The authors speculate that N concentrations would be more even if legumes were present in the pasture. Saunders (1984) on the other hand compared patches affected by either dung or urine with the remainder of a mixed pasture. He found higher P and K concentrations in the patches while the reverse occurred for Ca. There was not a consistent difference for N probably due to the lower clover proportion of the patches.

According to Craighead (1991) the fact that the species composition of a pasture is variable, makes it difficult to know the best procedure for sampling. According to this author not only critical values for each nutrient but nutrient balance in the plant must also be monitored.

It can be concluded that plant analysis is a more reliable measurement than soil analysis, especially when total nutrient content is measured. However the variation in nutrient content in New Zealand pastures due to variation in species composition and growth stage of the plants seems to make tissue measurements of N and P only useful as a complement to other analyses.

2.5.2.1 Critical nitrogen concentrations for pasture plants

In this section only total N measurements are considered although measurements of other forms of N (especially NO_3^-) have been used successfully for assessing the N status of the whole plant.

Melville and Sears (1953) found very important differences in the N content of pastures associated with clover presence. While in the clover-less treatment the average N content of grasses was 2.31% and 2.36% for no return and return of dung and urine respectively, it was 4.81% and 4.95% for clovers and 3.49% and 3.86% for grasses in the mixed pasture.

McNaught (1970) established critical levels for clovers of between 4.5 and 5.5 % N while for ryegrass the levels were 4.0 and 4.5%. He associated low N levels in clovers with other nutrient deficiencies, mainly sulphur. Cornforth (1984) suggested optimum N concentrations from 4.5 to 5.0% for ryegrass and from 4.8 to 5.5% for white clover.

2.5.2.2 Critical phosphorus concentrations for pasture plants

Ozanne (1980) advises analysis of the pasture legume component and not the mixed pasture in order to detect P deficiencies that can be masked in grasses due to the dependence on soil mineral N that is likely to be limiting growth, as well as the competitive advantage of grasses in terms of P absorption. According to McNaught (1970) critical P levels for clovers are from 0.3 to 0.4% and for ryegrass 0.28 to 0.36%. Cornforth (1984) suggested slightly higher levels (optimum between 0.35 and 0.40% for white clover and ryegrass).

2.5.3 Symbiotic N fixation

In their review of the methodologies used for measurements of N fixation Hardy *et al* (1968) concluded that while many methods are suitable for laboratory conditions only a few can be used in field experiments. They cited as the most widely used, Kjeldahl and isotopic analysis of plants supplied with ^{15}N. They proposed the use of acetylene reduction for assessing of N fixation in field experiments.

Bremmer and Hauck (1980) described three methods that use ^{15}N for assessment of N fixation. One uses enrichment of soil organic matter with ^{15}N. It is possible to calculate then the proportion of soil and fixed N in legumes growing in this enriched medium. The second isotopic procedure compares the dilution of supplied ^{15}N in the legume and associated grass, thus calculating the surplus of N in legume represented by fixation. The third method is based on natural variations in ^{15}N:^{14}N ratios in legumes and non-legumes.

Acetylene reduction is based on the versatile nature of nitrogenase as a reducing catalyst. This enzyme is able to reduce other substances than N. It is possible to quantify the reduction of a known amount of acetylene supplied, and using a simple equation calculate the corresponding N fixation rate. One of the problems arising from the use of this test is the calculation of the equivalence between ethylene produced and fixed N. Even though the theoretical rate is 3 moles of ethylene per mole of N, empirical rates are usually higher: 3.7 (Sinclair 1972), 3.38 (Halliday & Pate 1976).

Comparing ^{15}N dilution and acetylene reduction for assessment of N fixation by white clover in hill pasture in UK, Haystead and Lowe (1977) concluded that ^{15}N dilution is a more accurate technique for assessing N fixation while the advantage of acetylene reduction is its simplicity.

Unfortunately in this study it is not possible to compare values of fixed N because the total N fixed measured by the acetylene reduction method were not reported.

In a series of experiments throughout New Zealand, N fixation in pastures was calculated using the acetylene reduction method (Ball *et al* 1979). From these experiments it is difficult to reach general conclusions about N fixation efficiencies since amounts of fixed N, seasonal distribution, and amounts of N fixed per ton of white clover produced varied widely from one site to another and from year to year within each site. Nevertheless the calculated amounts of N fixed annually were lower than 250 kg N/ha, except for one site. These results are in disagreement with previous measurements (Sears 1965; Brock 1973) that were in general much higher.

2.5.4 Measurements of microbial biomass

Microbial biomass is the most active constituent of soil organic matter, even when it represents only a small proportion of total soil carbon (Jenkinson 1988). Hence measurements of its nutrient content enables the estimation of the portion of organic nutrients that is likely to become available in a short time.

Most microbial biomass measurements are based on fumigation of soil samples and determining the amounts of the nutrient under study in the fumigated and unfumigated sample. Many substances have been proposed as biocides. Hedley and Stewart (1982) tested three substances: chloroform, ethanol and isopropanol. They found that the recovery of fungal P added to the soil was considerably higher with chloroform than with the others. McLaughlin *et al* (1986) compared chloroform, commonly used with B-Priopiolactone, hexanol, ethanol, ethylene oxide and methyl bromide. They concluded that chloroform and hexanol consistently pull out more nutrient then the other biocides. Considering this result they recommend the use of hexanol as it is less hazardous for human health than chloroform and as efficient.

In the preparation of samples it has been found that drying affects microbial population, so most workers (Powlson & Jenkinson 1976; Brooks *et al* 1982) recommend the use of fresh samples. On the other hand McLaughlin and Alston (1984) found that contamination of the soil sample with plant material can led to overestimation of microbial biomass nutrients. It is assumed that the pre-incubation of the soils recommended for overcoming the effects of sampling does not affect the microbial biomass compared to the fresh soil. According to Tate *et al* (1991) this assumption seems to be erroneous in some cases.

It is very difficult to reach a conclusion about the suitability of microbial biomass measurements for assessment of potential availability of nutrients. More research is needed in order to understand microbial turnover in soils and its relationship with nutrients availability.

CHAPTER 3

3.1 INTRODUCTION

Seven sites covering a range in soil fertility were chosen at AgResearch Ballantrae Hill Country Research Station, 20 km NE of Palmerston North to examine the relationship between indicators of soil fertility and the seasonality and components of forage supply. The range in fertility was obtained by selecting sites which differed fertiliser history, land slope, and aspect. Fertiliser history of the sites ranged from no fertiliser over the last 13 years to high inputs for the last 20 years.

3.2 SITE CHARACTERISTICS

3.2.1 Soil characteristics

Soils in the experimental area are hill and related steepland yellow-brown earths or steepland intergrades to yellow grey earths formed from a mixture of parent materials, including sandy siltstones, silty sandstones and silty mudstones. These soils are classified as Fine loamy mix masic Typic Distrochepts (USDA). The hill soils which includes the Ngamoka series are found at sites 3, 4, 5, 6 and 7 and are classed as central yellow-brown earths. These are characterized by deep well structured silt loam topsoils overlying yellowish brown friable to slightly firm subsoils. The soils on moderate and steep slopes which includes the Mangamahu series and covers sites 1 and 2 are classed as steepland soils associated with central yellow-brown earths and intergrades to yellow grey earths. These have similar profiles to the associated hill soils except that they are generally shallower over the parent rock and are more variable in the thickness and development of the soil. Mangamahu steepland soils (MmSS) (sites 1 and 2) occur on the steep faces. Profiles are in general shallow with a fine sandy loam A horizon from 5 to 23 cm. In contrast the Ngamoka soils are formed from silty drift material overlying a silty sandstone. Ngamoka Silt Loam (Ng) (sites 3, 4, 5 and 6) is a deep soil occurring on undulating to easy rolling slopes. Slopes on Ngamoka Hill Soils (NgH) (site 7) are very stable and no signs of slipping are observed. Ngamoka soils are strongly leached and topsoils are strongly to moderately acid, very low to low in P, low in exchangeable Ca, medium in exchangeable Mg. Exchangeable K ranges from low to high.

3.2.2 Pasture composition

The pasture at all 7 sites was oversown in 1974 with white clover, *lotus pedunculatus*, red clover and subterranean clover. This exercise was repeated, except for subterranean clover, in 1977.

From 1975 the area was divided into 4, 10 ha farmlets and different fertiliser rates were added annually creating a range of fertility. As a consequence of the different nutrient availability there are marked differences in pasture composition.

Table 3.1 Pasture composition at the beginning of the experiment.

Field site	Percentage species[1]				
	HFG	LFG	WCL	OLEG	OSPS
1	1.7	68.7	20.9	1.6	7.1
2	1.8	63.5	0.1	0.1	34.5
3	6.4	69.1	5.9	1.2	17.4
4	3	71.5	2.0	0.6	22.9
5	21.6	65.0	8.3	1.0	4.1
6	25.2	41.0	29.1	0	4.7
7	59.1	20.2	18.7	0	2.0

[1] HFG: high fertility responsive grasses; LFG: low fertility adapted grasses; WCL: white clover; OLEG: other legumes and OSPS: other species.

3.2.3 Fertiliser history

The amounts of P added to the different sites since 1975 are presented in Table 3.2. Phosphorus was applied in the form of single superphosphate except for the basal application (1975) when part of the fertiliser applied was diammonium phosphate. Sites 1 to 4 received 125 kg/ha single superphosphate from 1977, while for sites 2 and 4 fertiliser application was discontinued from 1980. This rate continued to be applied to sites 1 and 3 until 1993. Sites 6 and 7 receive single superphosphate at 375 kg/ha.

Table 3.2 Phosphorus inputs (kg/ha) to the 7 sites.

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
1975	19	19	19	19	72	72	72
1976	0	0	0	0	49	49	49
1977	12	12	12	12	86	86	86
1978	12	12	12	12	48	48	48
1979	12	12	12	12	36	36	36
1980	12	12	12	12	36	36	36
1981	12	0	12	0	0	36	36
1982	12	0	12	0	0	36	36
1983	12	0	12	0	0	36	36
1984	12	0	12	0	0	36	36
1985	12	0	12	0	0	36	36
1986	12	0	12	0	0	36	36
1987	12	0	12	0	0	36	36
1988	12	0	12	0	0	36	36
1989	12	0	12	0	0	36	36
1990	12	0	12	0	0	36	36
1991	12	0	12	0	0	36	36
1992	12	0	12	0	0	36	36
1993	12	0	12	0	0	36	36
Total	216	43	216	43	327	783	783

Fertilisation of sites 1, 3, 6 and 7 took place on the 20 October 1992 and 19 October 1993 at the rates shown above.

Lime was applied to sites 5, 6 and 7 at a rate of 1250 kg/ha in 1975 and 2500 kg/ha in 1979.

3.2.4 Grazing regime

As a consequence of the differential pasture production at each site the stocking rates have varied from the initial 6 stocking units (SU) per hectare in 1975 to 16 SU/ha on the paddocks receiving 36 kg P/ha/year (sites 6 and 7) to 10.6 SU/ha at the paddocks receiving 12 kg P/ha/year (sites 1 and 3). For the treatments where fertiliser application was discontinued stocking rates were reduced to 11.0 SU/ha on the paddocks that used to receive 36 kg P/ha/year (site 5) and 8.6 SU/ha at the paddocks where 12 kg P/ha/year used to be applied (sites 2 and 4).

3.2.5 Slope and aspect characteristics

Slope and aspect characteristics of the seven sites used in the study are presented in Table 3.3. The last column shows an estimation of the net change in nutrient transfer at each site, based on position of each site on the landscape.

Table 3.3 Topographic characteristics of the sites.

Field site	Aspect	Slope	Nutrient balance
1	NW	moderate	–
2	N	low to moderate	+
3		low	0
4	E	low	0
5	W	low	+
6	NW	moderate	–
7	E	low	+

3.3 CLIMATE

Climatic information from the meteorological station located at the Research Station for the 12 months of the experiment and the long term averages (1970 to 1993) average are presented in Table 3.4.

Table 3.4 Monthly mean air temperature (°C) and monthly accumulated rainfall (mm) from January 1993 to January 1994 and long term averages (1970–93).

	Air temp (°C) 1993	Air temp (°C) 1994	Air temp (°C) long term	Rainfall (mm) 1993	Rainfall (mm) 1994	Rainfall (mm) long term
Jan	14.7	16.9	16.5	57	46	82.4
Feb	14.5		16.6	43		80.0
Mar	13.5		15.6	126		100.2
Apr	11.4		12.8	94		90.1
May	11.2		10.3	68		107.9
Jun	9.9		8.7	102		107.9
Jul	8.1		7.9	11		113.5
Aug	7.5		8.5	49		99.9
Sep	8.3		10.0	71		107.5
Oct	12.1		11.6	56		109.1
Nov	11.1		13.3	171		95.0
Dec	13.9		15.1	102		108
Accumulated rainfall (mm)				950		1202

Mean monthly air temperatures for 1993 were nearly 2 degrees below the long-term average in the first four months of 1993. Mean temperatures for May, June and July were slightly above the long term average, but from late winter (August) until the end of the year, except for October, temperatures were lower than the long-term mean for those months. Temperatures for January 1994 were slightly higher than the long term average.

Rainfall in all months in 1993, except March, April and November was less than the long-term average. This tendency was reflected in the accumulated rainfall that was more than 200 mm below the long term annual average. January 1994 was also below the long term average for this month.

In general the climate in 1993–94 when the study was conducted was colder and drier than the long-term average for this Research Station.

3.4 EXPERIMENT MANAGEMENT

3.4.1 General management

The field experiment started on 22 January 1993.

The paddocks where the seven sites were chosen were continuously grazed by sheep. The stocking rate in each of the farmlets was calculated from the pasture production with the primary objective of maintaining the same grazing pressure at all sites. Hence the pasture height and availability was similar at all sites throughout the study.

Each site covered approximately 100 m^2 and was divided into 3 replicate areas across the slope, except at site 2, where two of the replicate areas were side by side in the same part of the slope. Pasture production was assessed by the exclusion cage pretrimming technique. Each cage had an area of 0.5 m^2. In each of the 3 replicate areas at each site there were 2 cages. Cages were divided in two parts and each half cage was treated as a unit. Pasture production was measured with either biweekly or 4 weekly harvests. After the 4-weekly cut the cages were moved along the block, avoiding the same site for at least 4 months.

3.4.2 Harvesting procedures

For the biweekly cut, 14 days after the placement of the cage, the pasture of one half of the cage (0.25 m^2) was harvested and the cage returned to the same place. After a further 2 weeks the other half of the cage was harvested and the cage moved to a new place. Pastures were cut to a height of 0.5 cm approximately. The two cages on each replicate area were positioned two weeks apart. Thus at each site at each harvest each replicate had one cage with two weeks growth over the whole area and one cage with half area having 4 weeks growth The comparison of 2 and 4 weekly cutting was therefore overlapped. As a consequence of this system in the first cut (5 February 1993) only biweekly growth was harvested and in the last cut (7 February 1994) only 4 weekly growth was harvested.

The calendar of harvest dates for each of the seven sites is presented in Table 3.5. There were in general 14 and 28 days between biweekly and 4 weekly cuts respectively, except for the cuts of the 18 October 1993, 23 December 1993, 10 January 1994 and 25 January 1994. Those harvests were made after slightly longer or shorter periods.

Pasture was cut with electric shears and all herbage was placed in a plastic bag. During autumn, winter and spring it was necessary to wash all samples because of earthworm cast contamination. After washing, the samples were weighed and split into two portions of approximately the same weight. Half was weighed and dried at 70°C for 24 hours. This sample was then weighed and ground. The other half of the sample was used to assess botanical composition.

3.4.3 Botanical composition

Pasture samples from biweekly harvests were dissected into the following groups of species:

GRASS – All Grasses.
LEG – All Legumes.
OSPS – Other species.
DEAD MATTER – Dead plant material and pieces of dung.

Table 3.5 Harvest calendar for each site.

Date	Harvest no.	No. of cages 2 weekly harvested	No. of cages 4 weekly harvested
5 Feb 1993	1	3	
19 Feb 1993	2	3	3
5 Mar 1993	3	3	3
19 Mar 1993	4	3*	3*
2 Apr 1993	5	3	3
16 Apr 1993	6	3	3
30 Apr 1993	7	3	3
14 May 1993	8	3	3
28 May 1993	9	3	3
11 Jun 1993	10	3	3
25 Jun 1993	11	3	3
9 Jul 1993	12	3	3
23 Jul 1993	13	3	3
6 Aug 1993	14	3	3
20 Aug 1993	15	3	3
3 Sep 1993	16	3*	3*
17 Sep 1993	17	3	3
1 Oct 1993	18	3	3
18 Oct 1993	19	3	3
1 Nov 1993	20	3	3
15 Nov 1993	21	3	3
30 Nov 1993	22	3	3
13 Dec 1993	23	3	3
23 Dec 1993	24	3	3
10 Jan 1994	25	3	3
25 Jan 1994	26	3	3
7 Feb 1994	27		3

* On 19 March 1993 one cage from site 1 and one from site 2 were out of place and hence they could not be harvested. On 3 September 1993 one cage from site 2 and one from site 3 could not be harvested because the growth was negligible.

Pasture samples from 4-weekly harvests were dissected into the following species or groups of species:

HFG – High fertility responsive grasses: ryegrass *(Lolium perenne)*, Yorkshire fog (*Holcus lanatus*), poa (*Poa* sp), cocksfoot (*Dactylis glomerata*).

LFG – Low fertility tolerant grasses: Any other grasses present in the sample. The most common were: browntop (*Agrostis capillaris*), sweet vernal (*Anthoxantium odoratum*), crested dogstail (*Cynosarus cristatus*), danthonia (*Rytidosperma* spp) and chewing fescue (*Festuca rubra*) .

WCL – White clover (*Trifolium repens*).

OLEG – Other legumes : any other legume present in the sample. The most common were: suckling clover (*Trifolium dubium*), subterranean clover (*Trifolium subterraneum*) and lotus (*Lotus* spp).

OSPS – Other species : The most common were: catsear (*Hypochoeris radicata*), hawkbit (*Leontodon taraxacoides*), ribgrass (*Plantago lanceolata*), chickweed (*Cerastium glomeratum*), *Nertera setulosa* and moss.

DEAD MATTER – dead plant material and pieces of dung.

Botanical composition was expressed as the percentage of the dry weight of each species of the total dry weight. Results of botanical composition reported in the thesis correspond to the proportion of species after dead matter content was subtracted.

3.4.4 Estimation of pasture yield through measurement of pasture height

In order to relate measured pasture heights to pasture production linear regressions for all measurements and for each site were calculated. The equation proposed in this case is:

DM = intercept + (coef * height)

The following table shows the parameters for the linear regressions of DM produced (kg/ha) against pasture height (cm).

Table 3.6 Parameters for the linear regression of DM produced (kg/ha) against pasture height (cm).

Field site	Intercept	Coef height	r^2	No. of pairs
All	-96 **	392 **	0.82	1086
1	-220 **	513 **	0.75	153
2	-151 **	419 **	0.46	154
3	-206 **	466 **	0.55	155
4	-130 **	388 **	0.45	156
5	-127 **	437 **	0.79	156
6	-30 NS	397 **	0.82	156
7	-24 NS	356 **	0.85	156

The negative intercept for all equations indicates the height of the cut pasture. If pasture was cut at 0 cm, the intercept would be 0.

The coefficient corresponds to the increase in yield for 1 cm increase in pasture height. Coefficients ranged from 356 kg in site 7 to 513 kg in site 1. Site 7 had the highest pasture, but it is likely that the density was lower. Webby and Pengelly (1986) in hill country found the same pattern of lower dry matter per cm height when the pasture was higher in spring and summer.

The (r^2) of the regression lines followed the same order as pasture yields, being the highest for site 7 (0.85) and the lowest for site 4 (0.45). Probably the poorer fit observed in the low yield sites was a consequence of the limited variation in heights in these sites throughout the year. Nevertheless the r^2 of all measurements is rather high (0.82).

The tendency for lower densities as the pasture height increased led Webby and Pengelly (1986) to fit quadratic equations rather than linear regression lines. When quadratic equations fitted to data from this experiment no major improvement was found in r^2, while the significance of the parameters dropped for all sites except 6 and 7. The following table shows the parameters obtained for these two sites.

Table 3.7 Parameters for the quadratic regression of DM produced (kg/ha) on pasture height (cm).

Field site	Intercept	Coef height	Coef height^2	r^2
6	-269 **	642 **	-41 **	0.85
7	-272 **	529 **	-20 **	0.86

For these two sites the quadratic model gives a better explanation of the relationship between pasture production and height than the linear model.

3.4.5 Soil sampling

At the beginning of the experiment and at each harvest date except for the last two harvests one soil sample composed of 20 cores (2.5 cm diameter * 7.5 cm depth) was taken from each site. Samples were immediately ground to pass a 2 mm sieve. Approximately half of the sample was then dried at room temperature. Between 50 and 60 g of fresh sample was weighed, oven dried and reweighed. The volumetric water contents of soils were then calculated.

Two samples, each composed of 7 cores (2.5 cm diameter * 7.5 cm depth) were taken from each site at each harvest date from the 19 March 1993 to 10 January 1994 to determine N_2 fixation by an acetylene reduction procedure.

Three cores (7 cm diameter * 7.5 cm depth) were taken from each site on the 29 January 1993 for bulk density calculation (oven dry weight of each core divided by volume of the core)

Two cores (10 cm diameter * 7.7 cm depth) were taken from each site on February 1994 for measurement of water holding capacity.

3.5 CHEMICAL ANALYSIS

3.5.1 Soil samples

All soil samples were analyzed for mineral N, Olsen P and Resin P as described below.

Soils from the 22 January 1993 sampling were analyzed for total nutrient content and soil pH as follows.

– pH in water. pH was determined at a 1:2.5 soil:solution ratio after a 16 hour equilibration period.

– Total N. The method used was a modified semi-micro Kjeldahl method in which the sample is digested in 50 ml test tubes in a drilled aluminium block (350°C). For subsequent NH_4^+ determination a colorimetric AutoAnalyzer method was used (Searle 1975).

– Total P. From the same digestion mentioned above, P was determined colorimetrically by ascorbic acid reduction of the phosphomolybdate complex (Colwell 1965).

– Total C (Leco). The method used involves the purification and measurement of CO_2 evolved when a sample is heated in a stream of O_2 (Searle 1967).

– Mineral N. Duplicate fresh soil samples were extracted with 2M KCl (1:10 soil: solution ratio). After 1 hour shaking the solutions were filtered. Extracts were kept in a cold room and NO_3^- and NH_4^+ concentrations measured by an autoanalyzer (adapted from Kamphake *et al* 1967). Gravimetric water content was used for correcting the results to a dry basis. Results were expressed as kg N/ha using bulk density and gravimetric water content.

– Olsen P. Dry soil samples were extracted with $NaHCO_3$ (pH 8.5) at a 1:20 soil:solution ratio (Olsen *et al* 1954). After shaking for 30 minutes, extracts were centrifuged and filtered. Colorimetric P determination was made using the method of Murphy and Riley (1962).

– Resin P (Anion exchange resin (AER) plus cation exchange resin (CER)). Dry soil samples were shaken with water at a 1:30 soil:solution ratio in the presence of one strip an anion exchange resin and one strip of a cation exchange resin for 16 hours (Saggar *et al* 1990). The anion strip was rinsed and eluted with 20 ml of 5% NaCl. Colorimetric determination of the P released from the anion strip was made using the procedure of Murphy and Riley (1962). For both soil P measurements results were expressed as ugP/cc using bulk density data for the calculation.

3.5.2 Water holding capacity

To determine water holding capacity at low suctions (1 to 10 kPa) intact soil cores to a depth of 75 mm were collected, using 100 mm diameter steel tube, from each site. The intact core was first placed in a water bath until completely saturated and then put on a series of sand beds, starting with 1, then 5 and 10 kPa of suction. Cores were weighed as they came off each sand beds and then oven dried at 105 °C for 48 hours. For determining water holding capacity at the higher tensions (50 and 100 kPa) sieved soil from each site was placed into 50 mm diameter* 10 mm high aluminium rings and put on pressure plates evacuated to 50 and 100 kPa for 7 days. Soils were again weighed before drying at 105°C for 24 hours.

3.5.3 Nitrogen fixation

Estimations of N fixation were made at each site on the cutting dates from 19 March 1993 to 10 January 1994 and an additional sampling on the 3 March 1994. The method is a modification of the acetylene reduction assay used by Hardy *et al* (1968). Details of the modifications are described by Hoglund and Brock (1978).

Seven soil cores were placed in a 580 ml jar. After sealing, 30 ml of the air head space was replaced by acetylene and the jars incubated for 60 minutes in a shaded area. A gas blank containing no soil cores was also incubated at each sampling. At the end of the incubation, gas samples were transferred to evacuated vials using double-ended needles. Gas samples were analyzed for ethylene in a gas chromatograph. A ratio of 3:1 ethylene produced: N fixed was assumed. Time and area factors were used for calculation of N fixation in terms of kg/ha/day.

3.5.4 Microbial biomass measurements

Biomass measurements include microbial C, N and P and metabolic quotient. Inorganic P (extracted with $NaHCO_3$) was measured in the same moist samples. The procedure for estimating microbial C, N and P was based on chloroform fumigation (Jenkinson and Powlson 1976; Brookes *et al* 1981).

3.5.5 Analysis of pasture samples

All composite pasture samples were analyzed for total N and P content. After acid digestion and dilution with distilled water, N and P contents were measured in an autoanalyzer using the same method described above for soil total N and P.

3.6 STATISTICAL ANALYSIS

Growth rates, and N and P pasture content were subjected to analysis of variance to determine the statistical significance of the effect of cutting frequency. In the discussion significantly different means (1%) are denoted by (a) and (b).

Linear and quadratic regressions were used to examine the relationship between variables which included: soil fertility indices (mineral N, Olsen P and Resin P), pasture production and components and pasture N and P content and accumulation. For Olsen and Resin P and pasture yield data an exponential model (y=A*(1-e-cx) was also used. The parameters in the models were estimated by least squares. In the discussion 5% significance level is denoted by * and 1% significance level is denoted by **.

CHAPTER 4

4.1 INTRODUCTION

The relationship between soil fertility, measured by three single nutrient indicators and the seasonality of forage supply of a grazed pasture was examined by selecting seven field sites that ranged in soil fertility from an undeveloped, untopdressed hill pasture containing only low fertility tolerant species to a highly developed, regularly fertilised pasture containing ryegrass and white clover. To test the robustness of these 3 indices of soil fertility the differences in the fertility of the seven sites was not obtained by applying differential rates of fertiliser as is the general case in the evaluation of soil fertility indices, but by identifying sites in the field that varied in fertility as a result of not only different fertiliser inputs but also as a result of fertiliser cessation, slope position on a hill landscape as its affects nutrient return in dung and urine, and aspect as it impacts on nutrient supply through its influences soil-water relationships.

The 7 sites had either (1) received low (125 kg superphosphate/ha/year) or high (375 kg superphosphate/ha/year) annual fertiliser inputs for the last 18 years, (2) low or high fertiliser history in the 1970s but had received no fertiliser in the last 13 years, (3) or were located on low or medium slope positions on a hill landscape, where the low slopes received a net gain of nutrients in dung and urine, and medium slopes a net loss of nutrient and (4) were located on different aspects, which impacts on nutrient supply and pasture growth through its influence on soil water characteristics.

Of the three single nutrient indices of soil fertility, two measured P (Olsen P and Resin P) and one measured mineral N status. The bicarbonate extractant developed by Olsen *et al* (1954) has been used in New Zealand for nearly 20 years and is used for assessing the P status of pasture soils and as the basis for calculation of P fertiliser requirements. In a study in New Zealand with the Resin P test, which uses a combined anion and cation exchange resin, Saggar *et al* (1992) found that the Resin technique accounted for a greater amount of variation in plant growth than the

Olsen P test. The Resin P test had the added ability of assessing the nutrient status and predicting plant responses in soils to which P fertiliser containing both soluble and insoluble P sources had been added.

Significant temporal variation has been found in the commonly used indices of soil fertility in grazed pasture (Roberts 1987; Wheeler & Edmeades 1991). However, apart from the study of Wheeler and Edmeades (1991) the temporal changes in P (Olsen or Resin) and mineral N at different levels of fertility on the same soil type have not been studied. With the continuous need to upgrade the ability of soil fertility indices to assess more accurately nutrient requirements, there is an increasing need to understand more about the behaviour of these indices under a range of temporal and spatial conditions.

The lack of any definitive seasonal pattern in the temporal differences in commonly used indices (Saunders & Metson 1971; Roberts 1987) is difficult to understand given the large seasonal variation in plant growth (Baars *et al* 1975; Radcliffe 1975), nutrient uptake (Metson & Saunders 1978; Hay *et al* 1985; Crush *et al* 1989) and microbial biomass (Perrot *et al,* 1990; Tate *et al* 1991). Fluxes of nutrients through the microbial biomass can be substantial and relevant for nutrient cycling (Tate *et al* 1991; Sparling *et al* 1994). In an attempt to better understand the temporal differences of the two P indices (Olsen and Resin P) and mineral N pool, changes in the microbial P, N, and C pools were also examined.

The objectives of this section of the study were to :

1) describe the physical and chemical characteristics of the 7 sites used;
2) evaluate the temporal changes in the one N (mineral N) and two P (Olsen P and Resin P) indices over 12 months at each of the 7 sites;
3) examine the temporal differences in the microbial biomass C, N, and P pools at each of the 7 sites in relation to their influence on nutrient supply.

4.2 CHARACTERISTICS OF SOIL AT EACH FIELD SITE

Site 1 was located on the NW aspect of a moderate slope. The prevailing wind was NW. Both the topographic characteristics of the site and the prevailing wind result in a net loss of nutrients in dung and urine by the grazing animals away from this site.

Site 2 was located on a N aspect of low to medium slope. The site is exposed to the prevailing winds and there is a net loss of nutrients from the site in dung and urine.

Site 3 was located in the saddle of a hill, with a low slope, but exposed to the prevailing NW winds. While the topographic characteristics of the sites would encourage the camping of grazing animals, exposure to the wind probably explains why there is no apparent accumulation of dung.

Site 4 was located on an E aspect of low slope and protected from the NW winds. Site 4 was potentially a stock camping area. However dung was not observed to accumulate at this site at greater rate than in the neighbouring area during the course of the study.

Site 5 was located on a W aspect of low slope and protected from the prevailing NW wind. This site was an active camping area for sheep. Dung was observed at this site throughout the 12 months of measurement.

Site 6 was located on a NW aspect of moderate slope and exposed to prevailing winds. Like site 1 site 6 would lose nutrient via animal transfer.

Site 7 was located on an E aspect of low slope and protected from prevailing NW winds. Like site 5 this site was an active camping area for sheep. Fresh dung was found at the site throughout the study.

4.2.1 Physical and chemical characteristics of soils

Several of the basic characteristics of the soil at each site at the start of the study are summarized in Table 4.1.

Table 4.1 Soil physical and chemical characteristics at each site.

Field site	Bulk density Mg/m^3	pH_w	C (%)	N (%)	P (mg/kg)	C:N ratio	C:P ratio	N:P ratio
1	0.89	5.3	5.3	0.43	565	12.3	94	7.6
2	0.85	5.6	4.7	0.44	517	10.7	91	8.5
3	0.79	5.4	5.7	0.53	744	10.7	77	7.1
4	0.74	5.3	6.1	0.58	994	10.5	61	5.8
5	0.85	5.6	6.2	0.61	940	10.2	66	6.5
6	0.86	5.5	5.6	0.56	952	10.0	59	5.9
7	0.78	5.5	7.2	0.70	1361	10.3	53	5.1

Bulk density ranged from a low of 0.74 Mg/m^3 at site 4 to 0.89 Mg/m^3 at site 1. There was no apparent relationship between bulk density and slope position, aspect or fertiliser history of the 7 soils.

Soil pH values ranged from 5.3 to 5.6. Sites 5,6 and 7 had received lime in 1975 and 1978. These showed a slightly higher pH than the other sites with the exception of site 2.

Site 2 had the lowest C content of all sites followed by sites 1, 3 and 6. Sites 4, 5 and 7 contained the highest C contents. Sites 1 and 2 also contained the lowest percentages of N. Sites 3 and 6 again represented the medium range and sites 4, 5 and 7, all located on low slope areas and representing sites which could potentially accumulate nutrient deposited in dung and urine, contained the highest C content and had the highest N contents. Sakadevan (1991) also found higher C and N contents in soils from low slope compared to soils from medium slope positions.

As with C and N, site 2 had the lowest P content, followed by sites 1 and 3. Sites 4, 5 and 6 had similarly higher contents, while site 7 was the highest. The range in total P values was much greater than the range in total C or N .

The P content of the sites reflects not only the effect of different fertiliser inputs over the past 18 years but also the effect that the slope and aspect has on the grazing and camping behaviour of the grazing animal. While sites 2 and 4 represent sites with low P fertiliser inputs over the past 18 years the total P content of site 4 was greater than sites 1 and 3 which had both received 50% more fertiliser than site 4. The P content of soil 4 was similar to sites 5 and 6, which had received 100 and 200% more fertiliser respectively. Site 6 had received 50% more fertiliser than site 5 but contained only slightly more P, again demonstrating the differences in the nutrient content of the sites due to factors other than fertiliser inputs.

Most sites had C:N ratios between 10 and 11, except for site 1 where the ratio was higher (12.5). Since the C content of site 1 was not high, the high ratio can be attributed to the poor N content. Ratios that relate P content with either C or N were generally driven by the variations in P, being highest for sites 1, 2 and 3, and the lowest for site 7.

4.2.2 Soil water holding capacity

Measurements of water holding capacity at suctions from 1 to 100 kPa are presented in Fig. 4.1.

Large differences were found in the water holding capacities of the soils at the 7 sites. Volumetric moisture contents varied from 38% in site 1 to 50% in site 2 at 10 kPa of suction. There were no apparent relationships between water holding capacity and site history. At low suction (between 1 and 10 kPa) sites on low slopes (2, 4, 5 and 7), retained the most water followed by sites 3 and 6, while site 1 on a moderate slope had a much lower capacity for water retention (Fig. 4.2). At higher pressures (50 and 100 kPa) differences between soils were less apparent. Sites 1 and 2 however were lower than the other sites. The low organic matter contents of the soils at these two sites (Table 4.1) might partially explain their lower water holding capacity. From the water holding capacity data it is apparent that site 1 behaved in a different way from the other six sites.

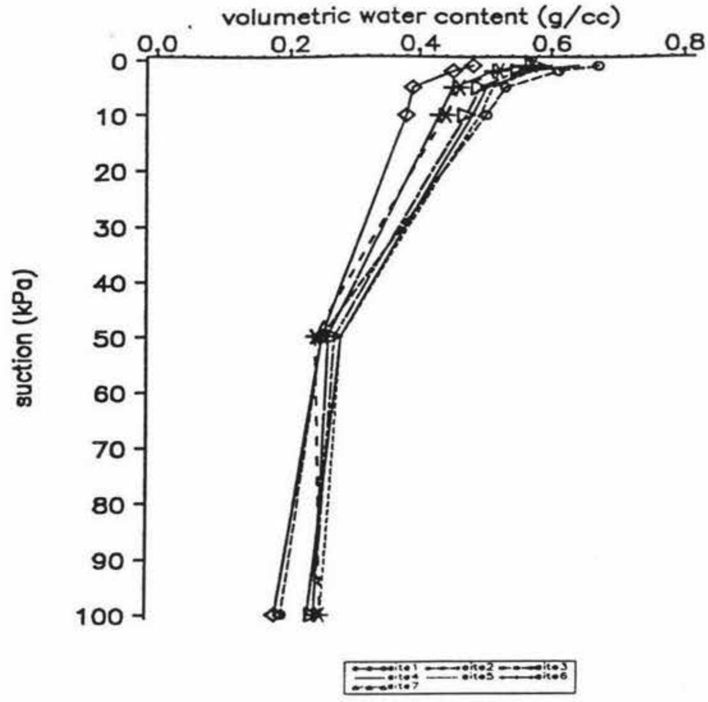


Figure 4.1 Volumetric water holding capacity at seven sites.

4.2.3 Changes in soil water content

The mean volumetric water content of the soil (g/cc) at each site over the 12 months of study as well as the coefficients of variation, as a measure of temporal variation in water content, are presented in Table 4.2. The complete data are presented in Appendix 4.2.

Since the soil water content was measured on sieved soil, some water would have been lost by evaporation from the time the soils were collected to the time they were ovendried. This loss would however have been small as soils were stored in plastic bags and generally processed within two days of collection.

Table 4.2 Mean volumetric water content of soil (g water/cc of soil) and coefficient of variation for the seven sites over the 12 months of the study.

Field site	Volumetric water content	Coefficient of variation (%)
1	0.28	22.0
2	0.49	17.6
3	0.45	19.0
4	0.61	18.3
5	0.50	21.4
6	0.42	21.5
7	0.56	21.9

The volumetric soil water content varied from an average of only 28% at site 1 to an average of 61% at site 4. The water content of the soil at site 1 never approached the water content of the other 6 sites, despite adequate rainfall in February, March and again in November. The wettest sites, all represent low slope areas (sites 4, 5 and 7) while the driest sites (6 and 1) were both located on medium slopes, facing the prevailing North West winds.

There was a trend of increasing water content from the beginning of the experiment until the end of the winter. From early spring onwards a decreasing trend is apparent. Despite these seasonal tendencies, that were probably related to evapotranspiration of the pasture, the small variations in water content can be related to precipitation in the period before sampling. This relationship is particularly apparent for the low levels of soil moisture in May and November corresponding to low rain periods and the high water content of all soils after the peak of rain at the end of November.

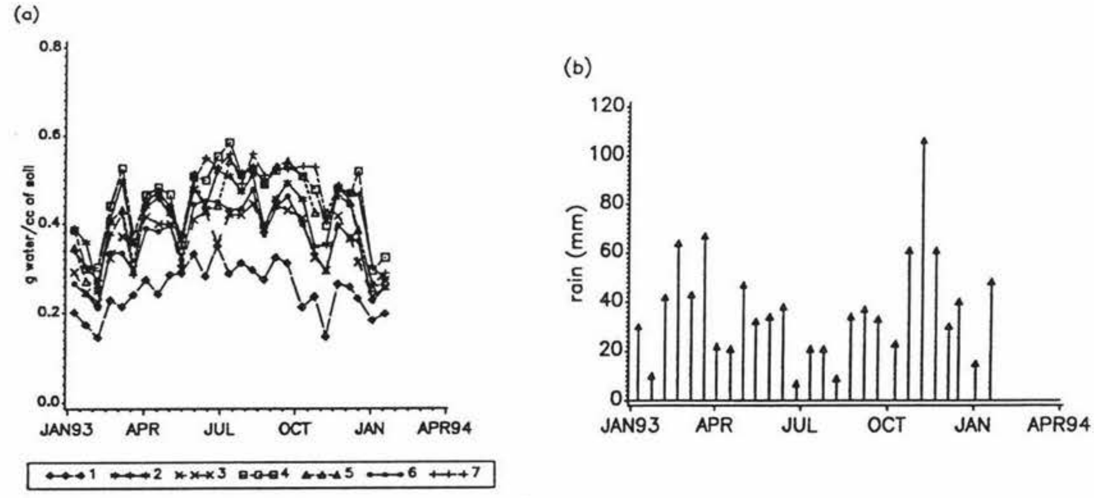


Figure 4.2 (a) Changes in volumetric water content of soil (g/cc) at each of the seven sites and (b) rainfall (mm) accumulated in the fortnight preceding sampling.

The very low water holding capacity of soil at site 1 only partially explains the lower soil water contents at this site throughout the study. While for nearly all the other sites, the mean water content was near or above water holding capacity at 10 kPa suction, the mean water content of soil at site 1 (0.28 g water/cc) was nearer the moisture content obtained at 50 kPa (0.25 g/cc) than 10 kPa (0.38). If water retained at 33 kPa (1/3 bar) is used as an estimation of field capacity then for most of the studied period pasture at site 1 was under water stress. If the limited water holding capacity of the soil at this site is combined with the slope and aspect of the site then moisture would limit pasture growth at this site throughout the year. The variation in water holding capacity and water content between sites is an additional factor that must be considered when examining the effectiveness of soil fertility indices.

4.3 ASSESSMENT OF NUTRIENT SUPPLY

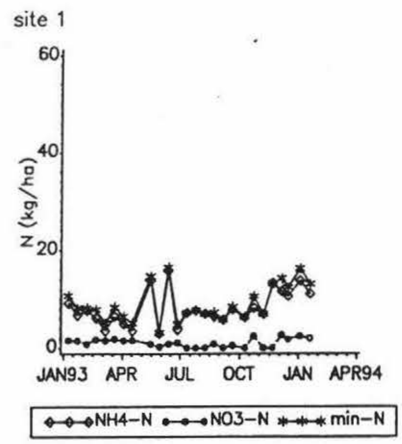
4.3.1 Mineral Nitrogen

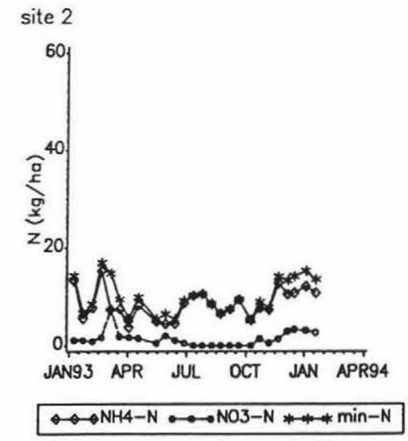
The mean content of the different forms of mineral N of the soil at each site over the 12 months of measurement and an estimation of the temporal variation (coefficient of variation) are presented in Table 4.3 and Figure 4.3. Complete data are presented in Appendix 4.3.

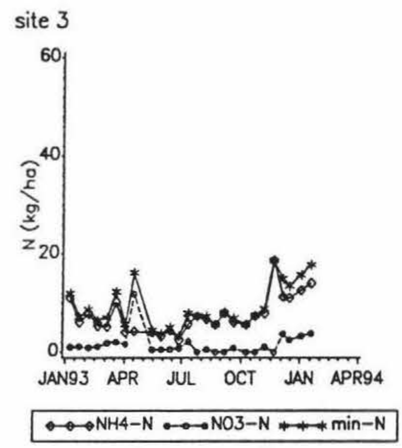
Table 4.3 Mean ammonium-nitrogen, nitrate-nitrogen and total mineral nitrogen contents of soils (kg/ha) and coefficient of variation (%) at each of the seven sites.

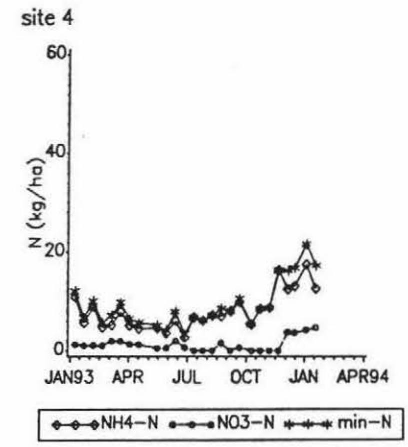
Field site	NH_4-N		NO_3-N		Mineral N	
	Mean (kg/ha)	CV (%)	Mean (kg/ha)	CV (%)	Mean (kg/ha)	CV (%)
1	8.4	43.2	1.1	81.4	9.5	41.1
2	8.1	35.0	1.3	115.0	9.4	35.9
3	6.2	49.9	1.3	147.3	7.5	49.1
4	5.8	47.4	0.9	107.8	6.7	50.0
5	7.8	56.0	4.8	60.3	12.6	42.4
6	9.8	49.0	4.9	85.5	14.7	45.0
7	8.1	57.8	14.9	53.4	23.0	39.2

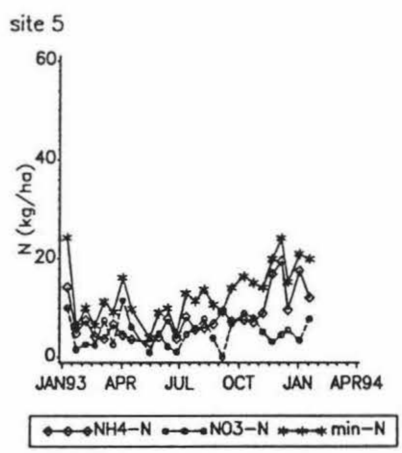
Except for site 7, NH_4^+ was the dominant mineral N form in soils at all sites, constituting about 80% of total mineral N in soils at sites 1 to 4. In soils at sites 5 and 6 NH_4^+ was still the predominant form (>60%) but at these sites NO_3^- was also found in significant amounts. At site 7 NO_3-N was the dominant (>60%) form of N in the mineral N pool. The mean amount of NH_4^+-N did not differ greatly from site to site, varying from 6.2 kg N/ha in site 4 to 9.8 kg N/ha in site 6. In contrast NO_3-N varied from very low concentrations in sites 1 to 4, to medium levels (4.8 and 4.9 kg N/ha) in sites 5 and 6, and to a high level of 14.9 kg N/ha at site 7.

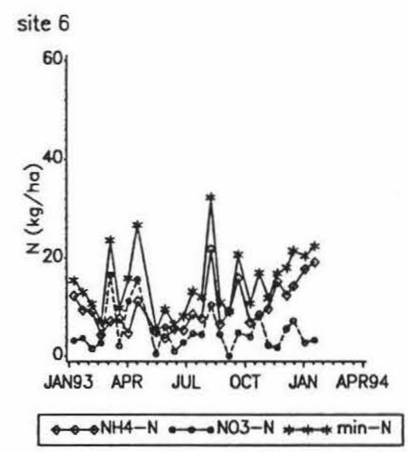












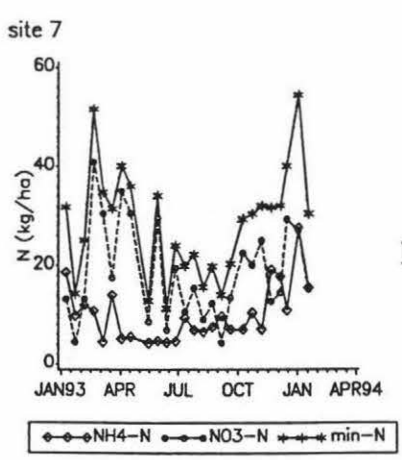


Figure 4.3 Temporal changes in ammonium N (kg/ha), nitrate N (kg/ha) and total mineral N (kg/ha) in soil at each site.

When temporal changes in mineral N fractions are examined (Fig. 4.3) there are some general trends. There was a period of high variability at the beginning of the study, with a tendency for decreasing amounts in winter. From early spring until the end of January there was an increase in the amounts of mineral N. The proportion of NO_3-N increased during this period. The trend for decreasing amounts of mineral N in winter is the opposite to that found by Sakadevan (1991) in a study at four sites of varying fertility in hill country. This author found lower mineral N contents in spring and summer and attributed this to the increased N absorption by pasture plants at that time of the year. Weather conditions in autumn 1993 were cool and dry, resulting in below average pasture growth. Similarly spring 1993 and summer 1994 were unusually dry. This must have been sufficient to limit plant uptake of N but still sufficient to enable mineralization. This would explain the higher amount of soil mineral N found in autumn and late spring-early summer compared to winter, when the mineralization process is depressed by low temperatures.

Based on mineral N levels, the soil fertility status of the sites can be ranked from the least to the most fertile in the following order : 4, 3, 2, 1, 5, 6, 7.

4.3.2 Indices of available Phosphorus

4.3.2.1 Olsen P status of soils

Mean Olsen P values, expressed on both a weight and a volume basis, measured over 12 months, standard deviation and coefficient of variation are presented in Table 4.4 and Fig. 4.4, with an expanded scale in Fig. 4.4 b to illustrate the differences in Olsen P in the medium and low P sites. Complete data are presented in Appendix 4.4.

The following discussion of Olsen P values only considers the volume based measurements (μg/cc).

Table 4.4 Mean Olsen P values, standard deviation (STD) and coefficient of variation (CV %) for each soil.

Field site	Olsen P (μg/g)	STD	CV %[1]	Olsen P (μg/cc)	STD
1	17.0	1.2	7.4	15.1	1.1
2	9.0	1.3	14.8	7.7	1.1
3	11.9	1.8	15.4	9.4	1.4
4	9.2	1.3	13.7	6.8	0.9
5	14.2	1.9	13.3	12.0	1.6
6	32.4	4.0	12.3	27.9	3.4
7	59.3	15.3	25.4	46.3	12.0

[1] Coefficients of variation are common for both weight and volume basis

Sites 2 and 4, which had not been topdressed with a phosphatic fertiliser for the last 13 years and had received low inputs previously, had the lowest Olsen P values. Sites 3 and 1 have received 12 kg P/ha each year since 1975. Site 5 like site 2 and 4 has not been topdressed for the past 13 years but previous to 1980 received high P rates (327 kgP/ha accumulated). Sites 6 and 7 have received high P fertiliser inputs (36 kgP/ha/year) for the past 17 years. The seven sites showed a wide range of P availability with two sites that can be considered low P (sites 2 and 4), three sites medium P (sites 1,3 and 5), one site high (site 6) and one site with a very high Olsen P status (site 7). Although site 5 has not received recent fertiliser inputs, the site receives regular inputs of P in dung. This helps explain why the Olsen P value has remained high. While total C, N and P data suggested that site 4 like sites 5 and 7 was a campsite, the Olsen P data do not support that contention.

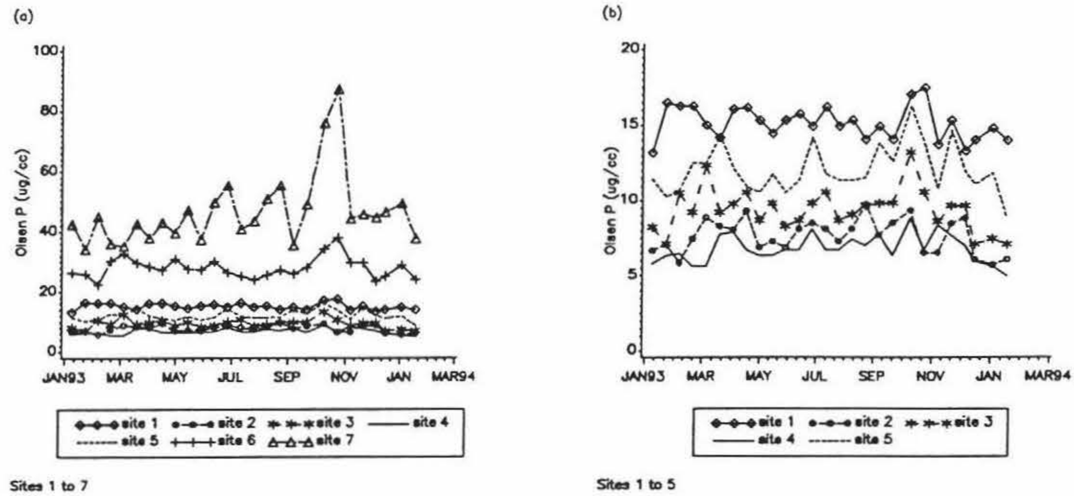


Figure 4.4 Changes in Olsen P (μg/cc) values in soils at (a) each of the seven sites and (b) sites 1 to 5.

There were no apparent seasonal patterns in Olsen P values across the 7 sites (Fig. 4.5), despite the large variation in initial Olsen P values, fertiliser and dung inputs between sites and, as will be shown in the next chapter, large seasonal differences in P uptake by the pastures. Previous workers (Saunders & Metson 1971; Roberts 1987; Wheeler & Edmeades 1991) also failed to find any definitive seasonal pattern in Olsen P. Despite the narrow range in Olsen P values at sites 1 to 5 the sites could be ranked, because of the small amount of variation, in the same order at nearly every biweekly sampling. The impact of fertiliser inputs at sites 1, 3, 6 and 7 on Olsen P values was only apparent on the two sampling dates immediately following fertiliser application.

Standard deviations as well as coefficients of variation were generally low, with the highest values for site 7. This result coincides with data from Rowarth *et al* (1991) who found a much higher variability (coefficient of variation) in Olsen P values in samples taken from campsites than samples taken from easy or steep slopes. If the variation (coefficient of variation) in Olsen P values is more closely examined the highest variation occurs at both extremes of Olsen P values (Fig. 4.4). At sites 2 and 3 high variability in soil Olsen P values can be attributed to the influence of even small changes given the low mean values while at the opposite extreme, high variability is probably related to the spatial variability as a consequence of uneven dung deposition (Haynes & Williams 1991). These data conflict with those reported by Wheeler and Edmeades (1991) who found that the variation of MAF P quick tests for samples taken at different times increased linearly with the overall site mean. The fact that some of the sites (1, 3, 6 and 7) were fertilised during the study (October) does not seem to have contributed to the variability in Olsen P values at sites 1 and 6.

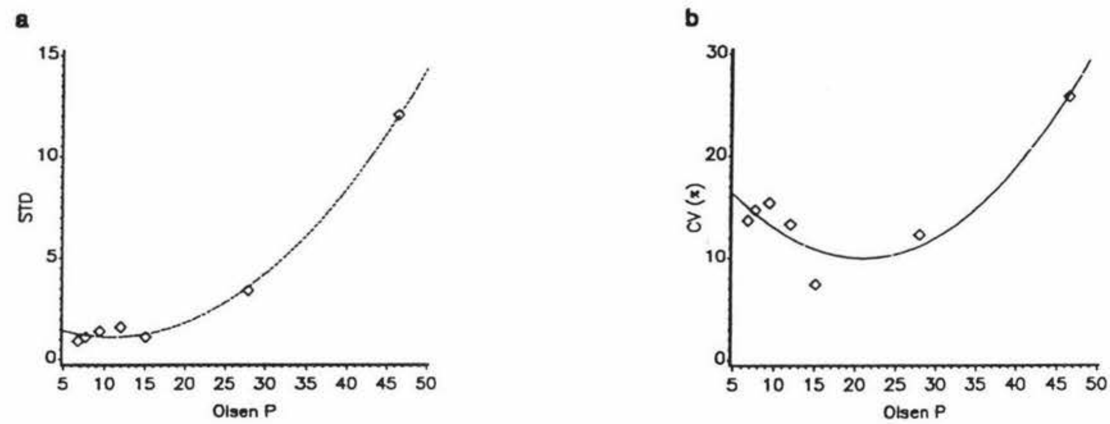


Figure 4.5 Relationship between coefficient of variation (%) and mean Olsen P (µg/cc).

4.3.2.2 Resin P status of soils

Mean Resin P values expressed on both a weight and volume basis measured over 12 months, standard deviations and coefficients of variation are presented in Table 4.5 and Fig. 4.5 with an expanded scale in Fig. 4.5b to illustrate the differences in Resin P in the medium and low P sites. Complete data are presented in Appendix 4.5.

The following analysis of Resin P values only considers volume based measurements (µg/cc).

Table 4.5 Meán Resin P values, standard deviation (STD) and coefficient of variation for each soil.

Field site	Resin P µg/g	STD	CV %[1]	Resin P µg/cc	STD
1	26.5	3.4	12.9	23.6	3.0
2	15.3	2.5	16.7	13.0	2.2
3	19.2	3.1	16.2	15.1	2.4
4	16.4	·2.5	15.4	12.2	1.9
5	28.2	3.3	11.6	24.0	2.8
6	61.5	6.8	11.1	52.9	5.9
7	98.3	18.0	18.3	76.7	14.0

[1] Coefficient of variation is common for both weight and volume basis

The lowest values for Resin P were found at sites 2, 3 and 4, medium values for sites 1 and 5a, high value for site 6 and a very high value for site 7.

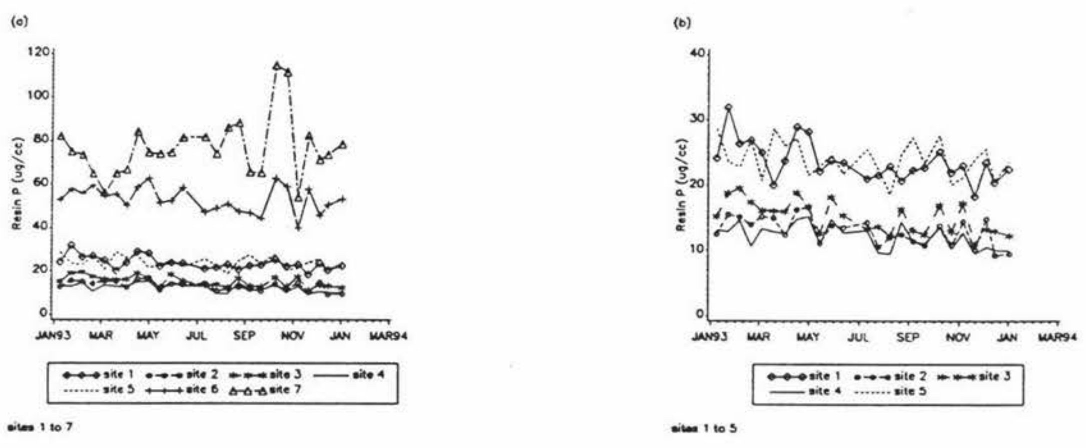


Figure 4.6 Changes in Resin P (µgP/cc) values in soils (a) at seven sites and (b) for sites 1 to 5.

In contrast to the results for Olsen P, the rankings of sites 2, 3 and 4 in one group and 1 and 5 in another group changed frequently during the year. As for Olsen P values, the effect of fertiliser application during the study was short lived. At the medium and low P sites Resin P values appeared to decrease during the 12 months of measurement. No explanation was found for this tendency. Moreover the decline was independent of fertiliser application indicating that P depletion was an unlikely explanation. There were no apparent seasonal trends in Resin P values for any of the sites studied.

Coefficients of variation (Table 4.6) indicate the small variability in Resin P values during the year. The CV ranged from 11.1% at site 6 to 18.3% at site 7. As for Olsen P the highest coefficient of variation corresponded to site 7 and the same pattern of higher variation at both extremes of the Resin P range was found (Fig. 4.7).

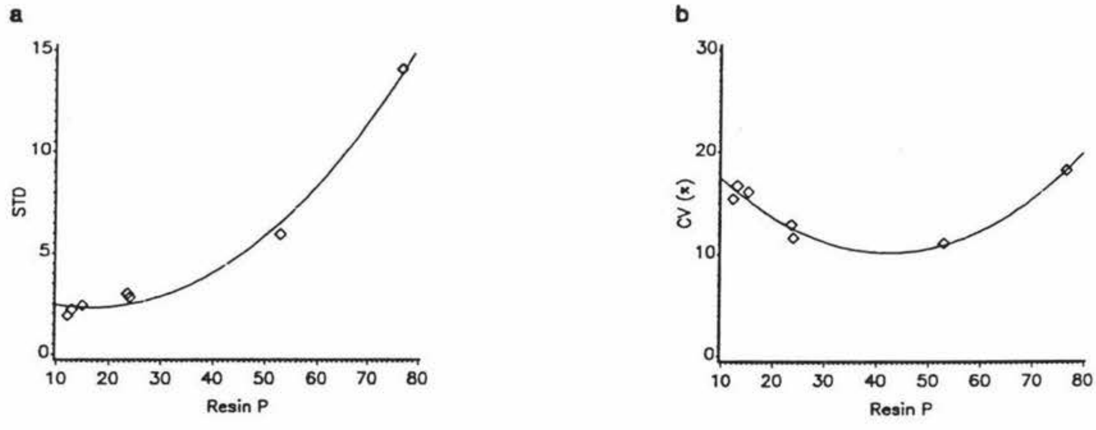


Figure 4.7 Relationship between (a) Standard deviation and (b) coefficient of variation (%) and mean Resin P (μg/cc).

4.3.3 Comparison of Olsen P and Resin P measurements

Except for sites 1 and 5 the two fertility indices ranked the P status of the 7 sites in the same order. While Olsen P values for site 1 were higher than for site 5, the reverse was true for Resin P values. Resin P is known to be more effective in detecting available P where P is associated with Ca compounds, such as rock phosphate fertilisers (Saggar *et al* 1992). Site 5 has received large lime inputs in the past, resulting in a higher pH (5.6 at site 5 compared to 5.3 at site 1). This could explain, in part, the higher available P measured by the Resin P method at site 5. Another possible explanation is that the superphosphate applied to site 5 in the 1970's contained a significant amount of unreactive phosphate rock because of the extensive use of Christmas Island phosphate rock at that time, which is detectable by the Resin P but not by the Olsen P procedure. The amount of superphosphate applied in the 1970s to site 5 was greater than the amount applied to site 1.

There were small differences in variability (CV%) between Olsen P and Resin P (Tables 4.4 and 4.5, respectively). Olsen P had a lower CV than Resin P for sites 1 to 4 while the reverse was true for sites 5 to 7.

A good linear relationship (r^2=0.94) was found between Olsen and Resin P values when data from each of the biweekly samplings was compared (Fig. 4.6). The intercept was close to 0, and the slope of the regression line indicates that for every incremental increase in Olsen P values, Resin P values increased 1.59 times. Saggar *et al* (1992) found that the Resin P technique extracted nearly twice the amount of P extracted by the Olsen method. They also found a marked influence of both soil type (mainly due to P sorption capacity) and P source on the amounts of P extracted by the two extractants. Although not reported in the study by Saggar *et al* (1992), the relationship between methods was very poor. In the present study the two soil types used were very similar and all P fertiliser applied at the two sites was single superphosphate. The strong linear nature of the relationship between Resin and Olsen P also suggests that both these extractants remove P proportionally from the same pools even when the P source is not only fertiliser but also dung and organic matter.

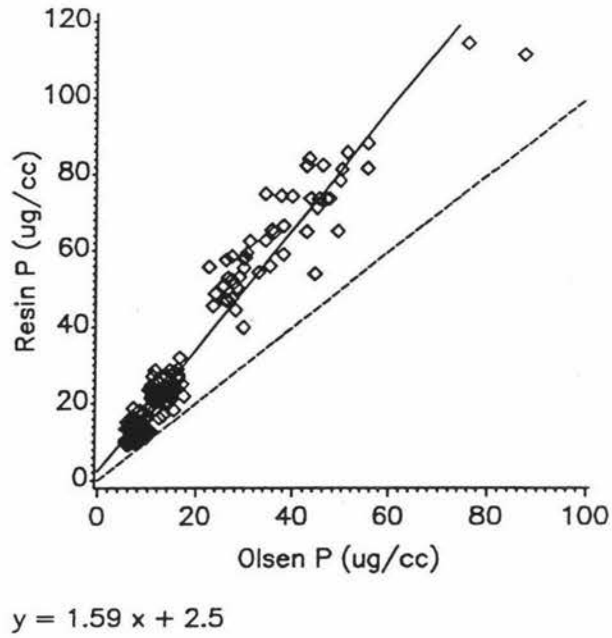


Figure 4.8 Relationship between Resin P and Olsen P (µg/cc).

4.4 SOIL MICROBIAL BIOMASS MEASUREMENTS

In an attempt to better understanding the temporal differences in the N (Mineral N) and P indices (Olsen P and Resin P) used in this study the temporal changes in the soil microbial biomass N, P and C pools were examined.

4.4.1 Microbial Carbon

Microbial C varied from 871 to 1471 ug C/g soil (Fig. 4.9). The variation across sites was much higher than the variation between seasons within each site. Sites 4 and 3 had the highes microbial C contents while sites 1, 2 and 6 the lowest. Microbial C measurements were not well related to total C content of the soils (r^2 for linear regression = 0.29, 0.21, 0.01 and 0.03 for summer, autumn, winter and spring measurements, respectively). The microbial pool represented less than 3% of the total C of the soil to a depth of 7.5 cm at these field sites. There was no apparent relationship between microbial C and the three soil indices of fertility (mineral N, Olsen P and Resin P), despite the extremes in fertility encompassed in the seven sites and the diversity in the sources of P inputs. These results agree with those of Tate *et al* (1991) who found little differences in microbial C at two sites contrasting in P fertility.

The seasonal variation within sites indicates that for most sites the highest microbial C contents occurred in summer (Fig. 4.9). Sites 1 and 3 have the opposite pattern with the highest content in winter and the lowest in summer. The low water content of sites 1 and 3 in summer (Fig. 4.2) could have affected microbial activity at that time.

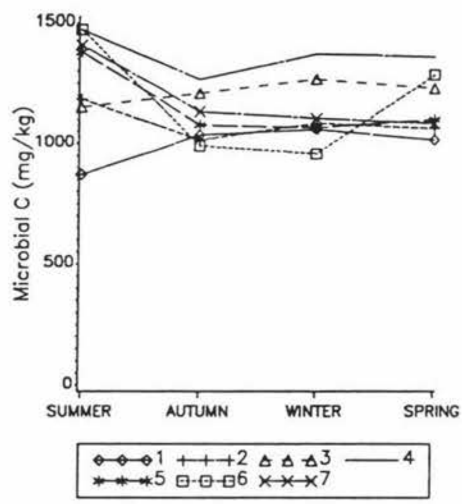


Figure 4.9 Seasonal changes in microbial C (mg C/kg soil).

4.4.2 Microbial Nitrogen

Microbial N to a depth of 7.5 cm ranged from 66 kg N/ha at site 1 to 210 kg N/ha at site 6 and represented from 3 to 6.5% of total soil N. Site 6 had consistently higher levels than the other sites while site 1 showed the lowest levels. Mineral soil N levels were poorly correlated to mean annual mineral N (r^2 = 0.02, 0.19, 0.10 and 0.11 for summer, autumn, winter and spring, respectively).

Seasonal trends in microbial N indicate that the highest accumulation occurred in summer for all sites, and the lowest in autumn and winter (Fig. 4.10). Mineral N followed the same trends (Fig. 4.3).

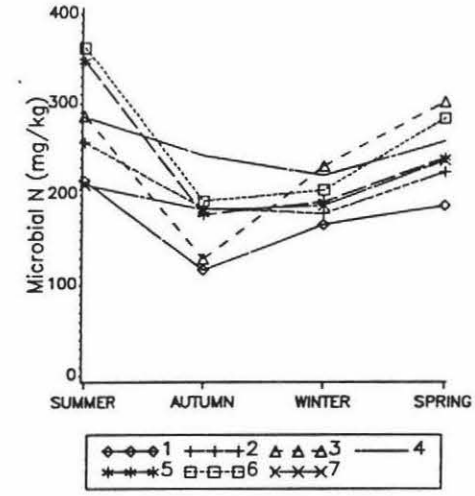


Figure 4.10 Seasonal changes in microbial N (mg N/kg soil).

4.4.3 Microbial C:N ratio

Microbial C:N ratio varied from 3.5 in site 6 to 9.4 in site 3 (Fig. 4.11). However, within each sampling there was not a wide range of ratios across the seven sites (less than 2 fold differences). The highest C:N ratios were measured in autumn.

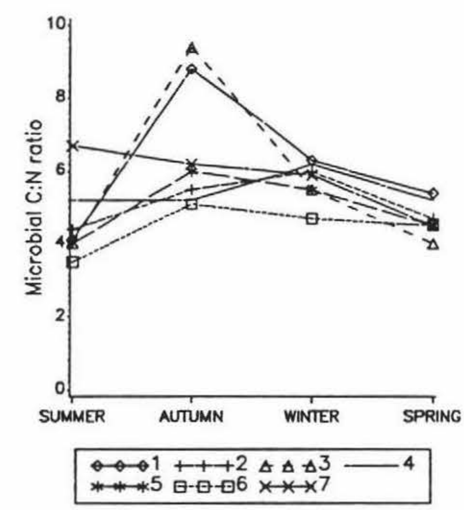
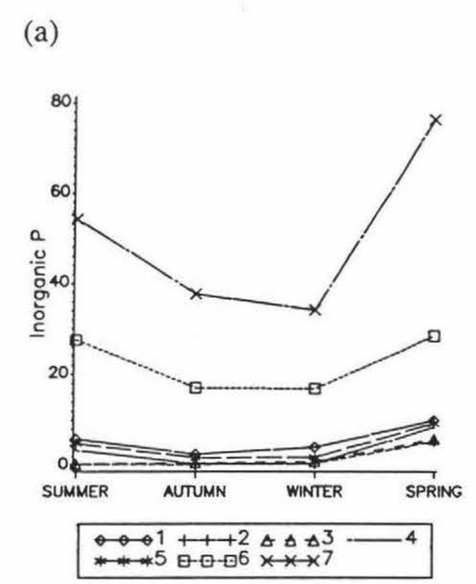


Figure 4.11 Seasonal changes in microbial C:N ratio.

4.4.4 Microbial Phosphorus

The microbial P ranged between 3% and 12% of total P in sites 4 and 1 respectively. There was a wide range in the amounts of microbial P, with 6 times more microbial P in soil at site 7 than at site 4 on average. Site 7 had by far the highest microbial

P content, sites 1, 5 and 6 represented medium microbial P levels and sites 2, 3 and 4 the lowest. The amounts of P contained in the microbial population to 7.5 cm depth varied from 15 kg P/ha on average at site 4 to 82 kgP/ha on average at site 7. Using an overall annual soil microbial turnover rate of about 30% (Sparling *et al* 1994) the estimated values of P turnover in microbial biomass range between 5 and 25 kg P/ha/yr. The microbial P measurements were more closely related to the two indices of P fertility than total P measurements (r^2 values for the linear regression line between Olsen P and microbial P were 0.85, 0.80, 0.82 and 0.90 for summer, autumn, winter and spring measurements, respectively and for Resin P 0.83, 0.79, 0.83 and 0.89 for summer, autumn, winter and spring, respectively).



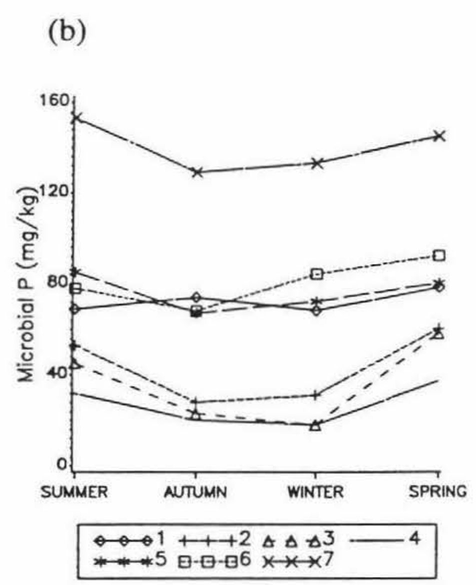


Figure 4.12 (a) seasonal changes in inorganic P and (b) seasonal changes in microbial P (mg P/kg soil).

Seasonal changes within sites showed that the largest contents of microbial P in soils occurred in spring (sites 1, 2, 3 and 4) and in summer (sites 5 and 7) and the lowest in autumn and winter (Fig. 4.12b). Site 1 was the only site that showed a small increase in microbial P in autumn. This might be explained, in part, by the unusually low water status of the soil at this site in summer, which increased in autumn. Tate *et al* (1991), who measured temporal changes in microbial P from two pasture soils reported increases in microbial P in spring and attributed this to incorporation of recently mineralized P from plant, animal and microbial residues. It appears that the amount of microbial P in soil in winter compared to spring-summer decreased as the P fertility of the soils increases. This suggests that the microbial P pool in the low fertility sites is more dependent on fresh inputs of P from plant litter and animal residues than the microbial pool of high fertility sites.

The amounts of microbial P were 2 to 7 times higher than the amounts of P extracted by Olsen or Resin P. However in contrast to these two indices, microbial P showed important changes during the study period (Fig. 4.12). The seasonal patterns of microbial P at sites 5 and 7 which received significant amounts of dung throughout the study, was no different from the pattern of the sites where P inputs came mainly from plant litter and fertiliser. In sharp contrast to the seasonal changes in inorganic P in moist soil and microbial P, Olsen P and Resin P showed no clear seasonal trends. If the amounts of P extracted by the two indices of soil P fertility are examined as a function of microbial P, the amounts extracted by the Resin P technique represented nearly half of the amounts of microbial P in winter, but represented a smaller fraction (25 to 40%) in spring and summer.

In summer and spring there was good agreement between Olsen P determined in a dry soil and the amounts of P extracted by $NaCO_3$ on a field moist soil sample. At both those sampling times moist soil P contents were lower than in the autumn and winter sampling. Sparling *et al* (1987) also reported 14 to 16% increases in Olsen P when soils were air-dried compared to P extracted from moist samples, which they attributed to release of microbial P as a consequence of drying.

4.4.5 Microbial C:P ratio

The microbial C:P ratio decreased (Fig. 4.13) as the P fertility measured by Olsen (Fig. 4.4) or Resin P increased (Fig. 4.6). Microbial C:P ratio was maximum (76) at site 4 in winter and in general greater than 20 at sites 2, 3 and 4 throughout the study. Sites 1, 5 and 6 had soil microbial C:P ratios from 10 to 20 and the lowest ratios were recorded at the high fertility site 7 (less than 10). These values were lower than those found by Tate *et al* (1991) that averaged 28 and 49 for the low and high fertility soils, respectively. Seasonal changes in the ratio reflected the changes in microbial P and inorganic P as the temporal changes in microbial C were smaller.

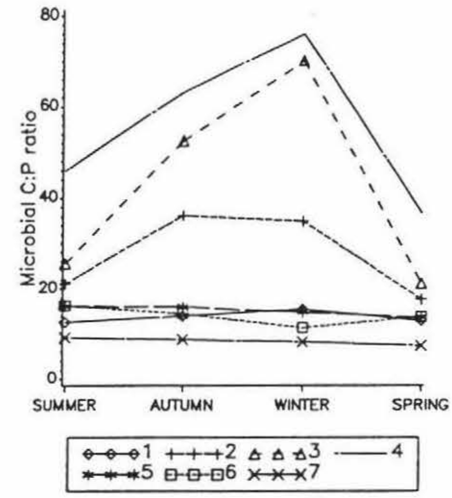


Figure 4.13 Seasonal changes in microbial C:P ratio.

There was an interesting interaction between season, soil fertility and the soil microbial C:P ratio. In addition to a decrease in the ratio as soil P fertility increased, the temporal changes in the microbial C:P ratio also decreased (Fig. 4.13). It appears that at the lowest fertility sites (3 and 4 and to a lesser degree 2), the microbial population becomes increasingly P starved in autumn and winter, whereas at the other sites there was little change in the soil microbial C:P ratio.

4.4.6 Measurements of microbial activity: Metabolic quotient

Metabolic quotient (ml CO_2/h/mg soil microbial biomass) has been used as an indicator of soil microbial activity (Sparling *et al* 1994). Unlikely the microbial P that in general varied more between sites than between seasons for the same site, the estimation of microbial activity seems to have at least similar range of variation within sites as it does across sites.

No clear pattern of activity emerged between sites in respect to metabolic quotient. The activity measurement used in the study does not appear to be related to soil fertility (Fig. 4.14 and Appendix 4). In contrast Tate *et al* (1991) reported higher metabolic activity in a high fertility compared to a low fertility site.

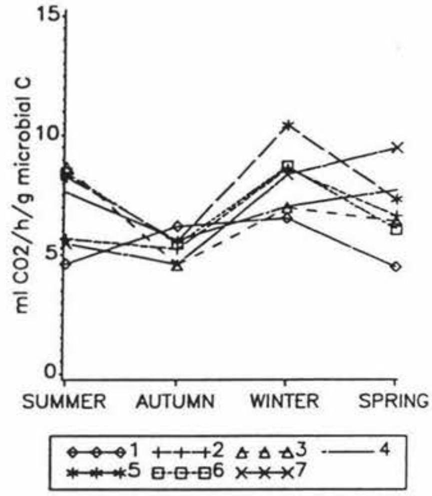


Figure 4.14 Seasonal changes in microbial metabolic quotient (ml CO_2/h/g microbial C).

Metabolic quotients were highest in winter. The increased activity in winter coincides with the lowest microbial P content and the highest microbial C:P ratio in sites 2, 3 and 4. Except at site 1 autumn measurements of metabolic quotient were much lower than the other seasons.

4.4.7 Characteristics of microbial of the seven sites

Of the sites under study it is possible to conclude that both the size and activity of the microbial population in site 1 was limited by water availability. Even though this site had a moderate microbial P content the low metabolic quotient indicates that the cycling of P from the microbial pool was very slow at this site. These characteristics can be contrasted to those of sites 5 and 6, where a similar microbial P pool was cycled faster (higher metabolic quotient). Sites 2, 3 and 4 on the other hand, even though they presented a more dynamic microbial population, were limited by P availability in soil. At these two sites most of the microbial P cycled would return to the microbial pool, with little transfer to plants. The high C:P ratio of these sites seems to confirm the hypothesis that P tends to be immobilized in these soils. The special characteristics of site 7 with no limitation in terms of P availability for the microbial biomass was not reflected in a high metabolic quotient as in sites 5 or 6. The very low C:P ratio of the microbial at this site suggests that C availability might be limiting microbial activity.

4.5 CONCLUSIONS

The soils under study covered a sufficiently diverse range of physical and chemical properties to examine the relationship between soil fertility and seasonality of forage supply and to test the robustness of the soil fertility indices under the range of conditions likely to be found in pastoral systems.

The differences in fertility of the sites was a function of fertiliser history as well as position on the landscape as it affects nutrient transfer and soil-water relationships. This was reflected in total nutrient content of the soils. While there were little differences between sites in terms of soil pH or bulk density, soil C and N and P content were highest at site 7, medium at sites 3, 4, 5 and 6 and lowest at sites 1 and 2.

There was a marked seasonal pattern in soil-water content at all sites with the highest values in late winter-spring and the lowest in summer, despite below average rainfall during most of the studied period. The soil-water content of site 1 was always well below the other sites and for much of the year, pasture at this site was probably under water stress.

Ammonium was the dominant form of soil mineral N at all sites, with the exception of site 7 where plant N uptake was less than inputs allowing nitrification and accumulation of NO_3^-. All sites showed similar seasonal patterns for soil mineral N with the lowest content in winter and the highest in summer. Differences between sites were mainly due to differences in NO_3^- content. There were 3 groups of sites in terms of ranking of mineral N content: 1) sites 1, 2, 3 and 4 showed very low mineral N amounts (specially NO_3^-) at all sampling dates 2) sites 5 and 6 contained medium mineral N amounts and 3) site 7 presented high mineral N levels.

For each site both Olsen P and Resin P tests had similarly small variation throughout the 12 months studied. No apparent seasonal trends in P values could be identified. The sites could be divided into 4 groups (A) sites 2, 3 and 4 had the lowest values for Olsen and Resin P (B) sites 1 and 5 had medium values for both methods (C) site 6 high and (D) site 7 had very high values for both Olsen and Resin P measurements.

There was a good relationship between Olsen P and Resin P measurements (r^2=0.94), indicating that both techniques extracted P proportionally from the same soil pools. Except for site 5 Olsen P ranked the sites in the same order as Resin P test. Temporal changes in P values were small for both methods, however Resin P values tended to drop during the studied period while no clear trend was observed for Olsen P values.

Microbial C and N content and C:N ratio varied little throughout the year. In contrast there was a marked seasonal pattern for P, with microbial P content greater in spring and summer than autumn and winter. There was an interaction between season, soil fertility and microbial P or microbial C:P ratio. In addition to a decrease in microbial C:P ratio as soil fertility increased, the temporal differences in microbial C:P ratios also decreased. No clear seasonal pattern was found for the metabolic quotient of microbial biomass. While the ranking of soils in terms of microbial C varied throughout the studied period, the ranking of soils if microbial P content was considered comprised three groups : 1) sites 2, 3 and 4 had the lowest microbial P contents, 2) sites 1, 5 and 6 had medium microbial P contents, and 3) site 7 had a very high microbial P content.

CHAPTER 5

5.1 INTRODUCTION

In the previous chapter the physical and chemical characteristics of each of the field sites were described and the temporal variation in soil fertility measured by 3 single nutrient indices over 12 months was reported. The sites ranged in soil fertility from an undeveloped low fertility hill pasture to a highly developed well topdressed hill pasture containing ryegrass and white clover.

The purpose of this chapter was to characterise the seasonal patten of pasture growth and the contribution made by individual pasture species to pasture production and to determine the N and P nutrition of the sward as the fertility of the field sites changed.

To examine the interaction between pasture growth and soil fertility further, two cutting regimes (biweekly and 4-weekly) were used to assess pasture growth. Previous workers have indicated that nutrient supply influences the recovery of a sward following defoliation (Frame 1973; Breeze *et al* 1984). Exclusion cages, which allow an assessment of pasture growth under grazing were used.

The objectives of this chapter were to :

1) characterise the seasonal pattern of pasture growth and nutrient uptake and quantify the contribution made by individual species to pasture growth as fertility changes.

2) examine the effect of cutting frequency on pasture production and composition

5.2 PASTURE PRODUCTION

5.2.1 Annual pasture production

Pasture production varied more than 5-fold across the seven sites (Table 5.1). Sites 4 and 2 had the lowest dry matter yields under both cutting regimes followed by sites 3 and 1. Whereas site 3 produced 5% more DM than site 1 under a 2 rather than a 4 weekly cutting regime, site 1 produced 40% more than site 3 under the less frequent cutting regime. Sites 5 and 6 produced much larger amounts of dry matter through the year with growth from site 6 superior to site 5. Pasture growth was extremely high at site 7 reflecting the high nutrient inputs as dung and urine to this site.

Table 5.1 Effect of cutting frequency on annual pasture production (kg/ha) and average pasture growth rates (kg DM/ha/day).

Field site	Cutting frequency			
	Biweekly		4 weekly	
	Pasture production kg/ha	Growth rate kg/ha/day	Pasture production kg/ha	Growth rate kg/ha/day
1	4700	12.8 b	6599	18.2 a
2	4074	11.0 a	4565	12.3 a
3	4868	13.1 a	5117	13.8 a
4	3322	8.9 a	3344	9.0 a
5	10149	27.1 a	10208	27.5 a
6	11180	30.0 a	11598	31.2 a
7	17061	45.9 a	17407	47.1 a

[1] Only pasture growth rate data can be used to compare cutting frequency.
[2] Data used to calculate 2 weekly and 4 weekly yield and growth rate are presented in Appendix 5.1.

5.2.2 Effect of cutting frequency on annual pasture production

Except for site 1, where under a 4 weekly cutting regime pasture growth was near 50% higher than under a biweekly cutting regime, average growth rates were only slightly higher under 4 than 2 weekly cutting regime at all other sites, indicating that pasture growth was on the linear part of the growth curve at most sites throughout the year. Radcliffe (1971) found similar total yields in pastures harvested every 3 and 6 weeks in hill country near Hamilton, she attributed this behaviour to the habit of the species that were able to intercept most of the incident light in three weeks. The absence of any interaction between cutting frequency and soil fertility was somewhat surprising given the more than 5-fold difference in average pasture growth rates between sites.

The marked effect of cutting frequency on pasture growth at site 1 might result from an interaction between cutting frequency and water use efficiency, as cutting frequency did not affect pasture growth rates at the other sites which had higher soil water contents for the twelve months of the study (Fig. 4.2). Site 1 was by far the driest site and had the lowest soil water holding capacity. It is possible that the biweekly cutting regime introduced inefficiencies in water use, and this would have produced an impact at site 1, where soil water appeared to limit pasture growth for most of the twelve months of the study.

The interaction between soil water and pasture growth as it is affected by cutting regime needs to be kept in mind when examining cutting technique for assessing production of hill country pastures that are characterised by sunny, dry, cold and wet aspects. Differences in soil water characteristics between sites are also likely to affect the relationship between soil fertility and pasture growth.

The slope and intercept of the regression lines calculated for each site to study the relationship between pasture accumulated in biweekly and 4-weekly growth periods exhibit a slight deviation from the 1:1 line (Table 5.2). The slope of the regression line was significantly different from the 1:1 line only for site 1. The positive intercept was significantly different from 0 only for site 1 and the total of sites combined.

Table 5.2 Parameters of the linear regression equation of pasture production assessed by biweekly and 4-weekly cutting frequency.

Field site	Intercept	Coefficient DM	r^2
All	68.0 **	0.95 **	0.83
1	102.4 **	1.14 **	0.53
2	12.1 NS	1.08 **	0.74
3	23.3 NS	0.99 **	0.75
4	29.7 NS	0.89 **	0.71
5	103.7 NS	0.87 **	0.77
6	103.8 NS	0.92 **	0.74
7	86.3 NS	0.95 **	0.83

5.3 COMPONENTS OF PASTURE GROWTH

5.3.1 Effect of cutting frequency on botanical composition

It was only possible to assess the effect of cutting frequency on the contribution made by grasses which included high fertility responsive grasses (HFG) plus low fertility adapted grasses (LFG), legume (including white clover plus other legume) and other species (OSPS) to total production. The contribution made by the different species at each cut are presented in Appendix 5.1.

Grasses were the dominant component of all swards. The contribution of other species was higher under the biweekly than for the 4-weekly cutting regime in sites 1 to 5. There was a concomitant higher proportion of grasses in pasture left uncut for 4 weeks at these sites. The reason for this difference in the contribution made by these species is not clear. It is possible that the faster leaf appearance rates and growth habit of broad leaf weeds, with horizontal leaves, makes them more efficient in competition at low pasture heights at low fertility sites. Legumes have been reported as poorer competitors with longer spells between cuts (Brougham 1959; Bland 1967), but this does not seem to be the case in this experiment. Probably this effect is only manifest when differences in cutting frequencies are longer than those used in this experiment.

Table 5.3 Effect of cutting frequency on the contribution made by grass, legumes and other species to annual production[1].

Field site	GRASSES		LEGUMES		OTHER SPECIES	
	2 week	4 week	2 week	4 week	2 week	4 week
1	68.2	73.6	17.0	15.4	14.8	11.0
2	55.5	62.6	3.8	3.3	40.7	34.1
3	74.4	75.5	8.9	9.8	16.7	14.7
4	62.3	65.7	5.2	5.0	32.6	29.3
5	83.7	85.1	10.0	10.6	6.3	4.3
6	81.2	79.7	13.8	15.0	5.0	5.3
7	89.6	89.7	8.3	8.5	2.1	1.8

[1] The dead matter content is not included.

5.3.2 Pasture composition at each field site

The contribution made by individual pasture species to pasture production at each site is discussed briefly.

5.3.2.1 Site 1

The seasonal changes in botanical composition of pasture at site 1 and the contribution made by pasture components to annual production are presented in Figure 5.1 and Appendix 5.1.

High fertility grasses contributed little to pasture production at site 1 (4.9% of a total yield of 6599 kg DM/ha). The contribution this group of pasture species made throughout the year varied from 3.6% in summer to 13.2% in winter. The percentage of low fertility grasses was stable (68.6%). White clover showed the opposite trend to high fertility grasses, with the highest content in summer (15.7%) and the lowest in winter (7.1%) and contributed 13.7% of total pasture production. The content of other legumes was generally low, with the largest contribution in spring (3.1%), and the lowest in autumn (0.2%). Other species (weeds), accounted for 11.0% of total yield, with the highest proportion in summer (12.7%) and the lowest in winter (9.1%). The dominant feature of the sward at this site was the high proportion of white clover and the low proportion of high fertility grasses, characteristics of a site in the initial stages of pasture development, where the low levels of soil N limit grass growth but allow legume production in response to P addition. This site has been fertilised with a maintenance rate of P (125 kg P/ha) for 18 years. The lack of development of pasture at the site despite the regular fertiliser inputs can probably be explained by the lack of soil water at this site (Fig. 4.2). While P from fertiliser has accumulated, N is limiting growth of high fertility responsive grasses.

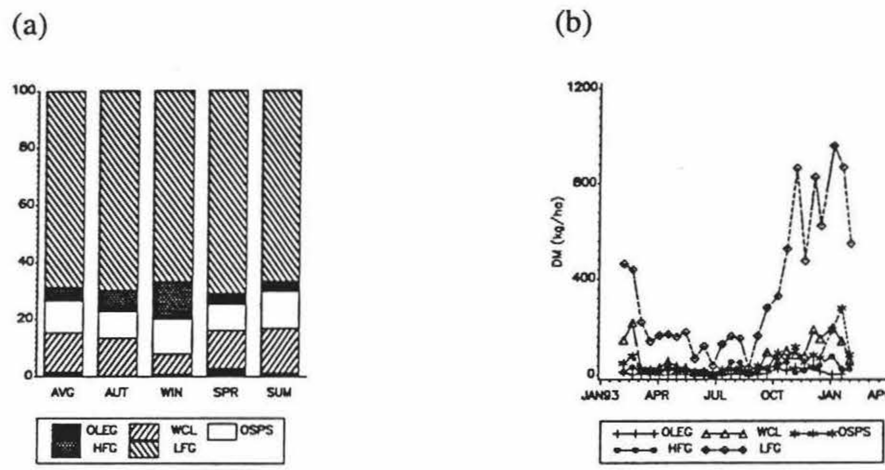


Figure 5.1 (a) The changes in seasonal botanical composition (%) of pasture at site 1 and (b) the contribution (kg DM/ha) made by each pasture components to annual production (b).

5.3.2.2 Site 2

The seasonal changes in botanical composition of pasture at site 2 and the contribution made by pasture components to annual production are presented in Figure 5.2 and Appendix 5.1.

Site 2 contained the lowest HFG content (1.9%) of the total production (4565 kg DM/ha). White clover and other legumes accounted for less than 6% of pasture production. The dominant fraction was LFG (60% of total yield). Weeds were the second most common fraction at this site (34.1% of total yield), being highest in summer (40.8%) and lowest in spring (27.6%). The site has not received fertiliser for 13 years. The feature of the sward at this site is the dominance of LFG and weeds; characteristics of a pasture where nutrition restrictions severely limit pasture growth.

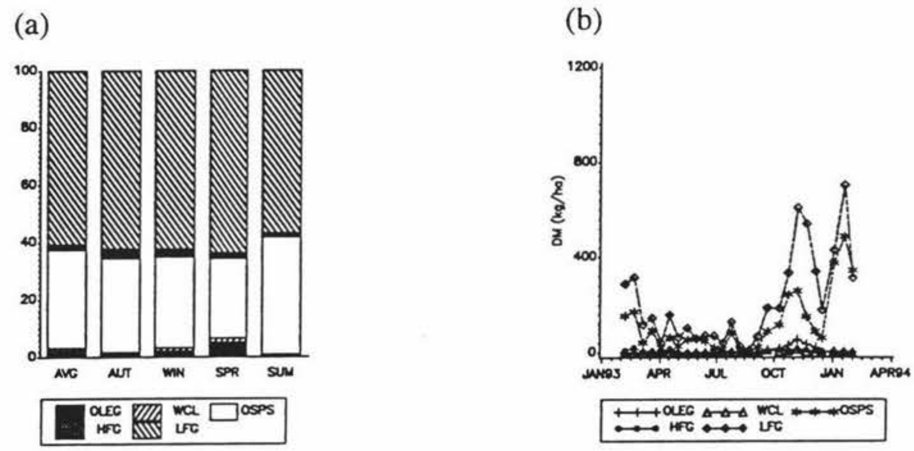


Figure 5.2 (a) The changes in seasonal botanical composition (%) of pasture at site 2 and (b) the contribution (kg DM/ha) made by each pasture components to annual production.

5.3.2.3 Site 3

The seasonal changes in botanical composition of pasture at site 3 and the contribution made by pasture components to annual production are presented in Figure 5.3 and Appendix 5.1.

The proportion of HFG at site 3 was low (8.0% of the 5117 kg DM/ha produced), but it was the highest proportion of this fraction in the low yield group (sites 1 to 4). It ranged between 14.3% in autumn to 6.3% in spring. The majority of dry matter was produced by LFG, fluctuating very little throughout the year (67.5%). White clover growth was in general poor (4.2% of the total yield), being higher for autumn and summer (7.3 and 5.45%, respectively) than for winter and spring (3.0 and 2.3% respectively). The largest proportion of other legumes of all sites was found in site 3 (5.6%). It ranged from 10.4% in spring to 1.2% in autumn. As with site 1 the increase in spring reflected the growth of suckling clover. Weeds accounted for 14.7 of total production being highest in summer (17.3%) and lowest in autumn (10.7%). Site 3 shows the characteristics of a low to medium fertility site, with a small but rather stable proportion of legumes and high fertility grasses. Site 3 differed from sites 2 and 4 more in terms of pasture quality, measured as proportion of HFG and legumes, than in pasture production.

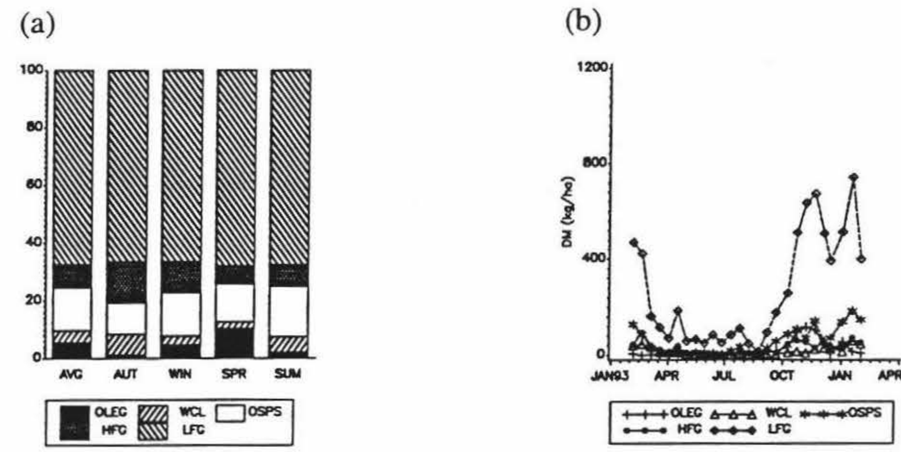


Figure 5.3 (a) The changes in seasonal botanical composition (%) of pasture at site 3 and (b) the contribution (kg DM/ha) made by each pasture components to annual production.

5.3.2.4 Site 4

The seasonal changes in botanical composition of pasture at site 4 and the contribution made by pasture components to annual production are presented in Figure 5.4 and Appendix 5.1.

The contribution from HFG was very small (2.6% of a total of 3344 kg DM/ha produced) as was the contribution of white clover and other legumes that represented only 1.8 and 3.2% of total production respectively. LFG accounted for 63.1% of total production, being highest in autumn (70.6%) while in the other seasons the proportion was slightly lower than the mean. As in site 2 the contribution of OLEG was greater than that of white clover indicating that the nutrient status of the site was insufficient to sustain white clover while lotus, suclking clover and subterranean clover are legumes with lower fertility requirements. Weeds made an important contribution (29.3%) to total dry matter production, being lower in autumn (20.8%) than in the rest of the year. The features of this site are similar to those of site 2. The high weed proportion is indicative of an environment with limited nutrient availability. Like site 2 this flat site had not received fertiliser for 13 years. The similarity of the composition of pastures between these two sites suggests that site

4 may not have received large quantities of nutrients via dung and urine return as was suggested by the soil analysis (Table 4.1).

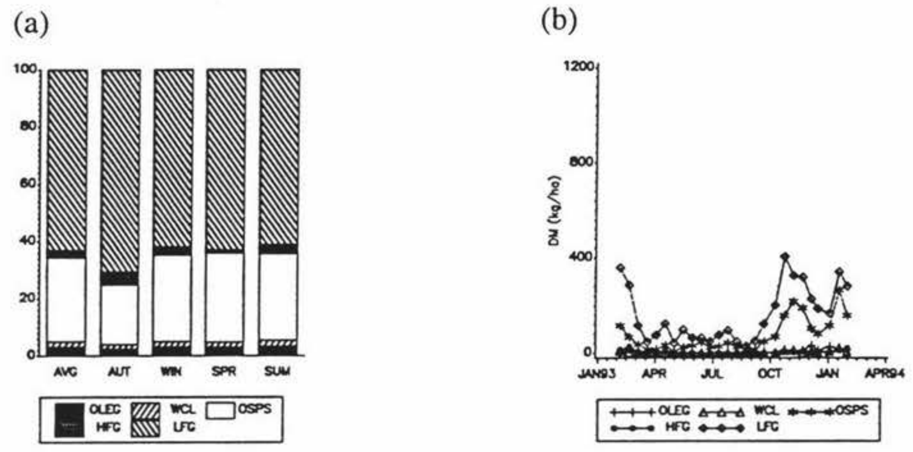


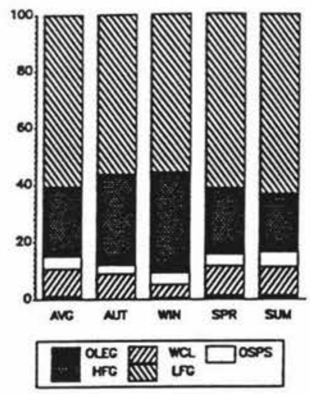
Figure 5.4 (a) The changes in seasonal botanical composition (%) of pasture at site 4 and (b) the contribution (kg DM/ha) made by each pasture components to annual production.

5.3.2.5 Site 5

The seasonal changes in botanical composition of pasture at site 5 and the contribution made by pasture components to annual production are presented in Figure 5.5 and Appendix 5.1.

HFG represented 24.5% of total production of 10208 kg DM/ha at site 5. The highest proportion of this fraction was measured in winter (35.5%) and the lowest in summer (20.5%), while the opposite occurred with low fertility grasses (63.1% in summer and 55.5% in winter). White clover accounted for 9.4% of total production, with higher proportions in summer, spring and autumn (9.8, 10.1 and 8.9% respectively) than in winter (4.6%). The proportion of other legumes was very low (1.2%), while weed production accounted for only 4.3% of the total yield. This site presents the characteristics of a medium fertility site, where the proportion of high quality species (HFG and white clover) represented about one third of total production. Although this site has not received fertiliser for 13 years, because of its location on the landscape it has received regular inputs of nutrients via dung and urine.

(a)



(b)

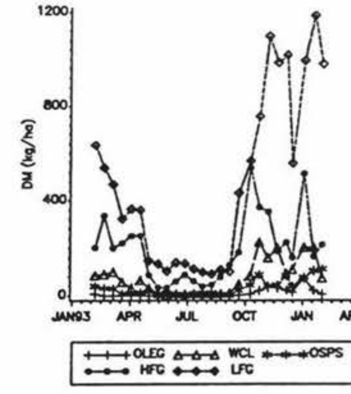


Figure 5.5 (a) The changes in seasonal botanical composition (%) of pasture at site 5 and (b) the contribution (kg DM/ha) made by each pasture components to annual production.

5.3.2.6 Site 6

The seasonal changes in botanical composition of pasture at site 6 and the contribution made by pasture components to annual production are presented in Figure 5.6 and Appendix 5.1.

Nearly 35% of a total pasture production of 11598 kg DM/ha at site 6 was accounted by HFG, with the highest proportion in winter (45.5%) and the minimum in summer (25.9%). The proportion of white clover was highest in summer (21.3%) and lowest in winter (7.7%), with an overall contribution of 14.7%. The seasonal proportion of LFG did not vary markedly about the mean (45%). The contribution from other legume was insignificant (0.3%). Weeds contributed only 5.3% of total production. The high percentage of white clover and high fertility grasses, that represented nearly half of the pasture produced, and the steady proportion of both groups suggests an adequate nutrient supply.

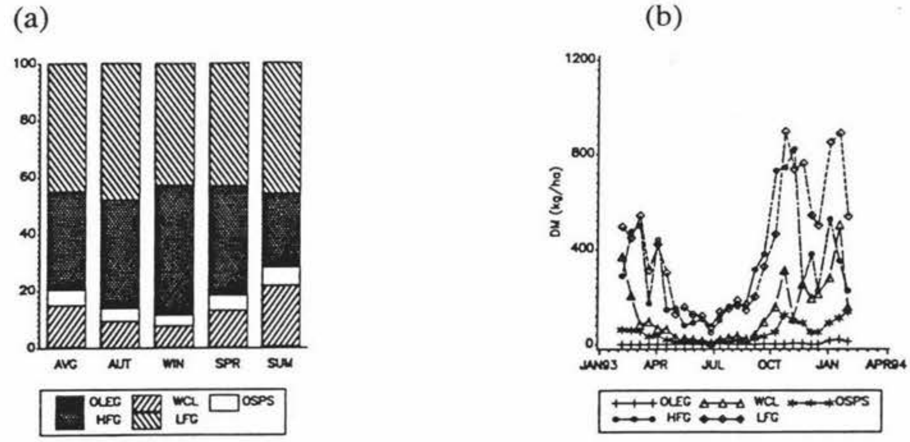


Figure 5.6 (a) The changes in seasonal botanical composition (%) of pasture at site 6 and (b) the contribution (kg DM/ha) made by each pasture components to annual production.

5.3.2.7 Site 7

The seasonal changes in botanical composition of pasture at site 7 and the contribution made by pasture components to annual production are presented in Figure 5.7 and Appendix 5.1.

The predominant fraction in site 7 was HFG with 64.2% of total production of 17407 kg DM/ha ranging from 73.7% in spring to 53.1% in summer. Low fertility grasses presented the opposite pattern, ranging from 32.8% in summer to 17.7% in spring with an average of 25.5%. These proportions coincide with the growth curve of the different species. While poa and ryegrass have maximum growth rates in spring, most low fertility adapted grasses produce maximum growth in late spring-early summer (Lambert *et al* 1986). White clover accounted for 8.5% of total yield, showing the same seasonal pattern as in sites 1, 5 and 6, with 11.9% of summer production and 4.7% of winter production. A similar seasonal pattern for white clover production has been reported by many authors (eg Broughan 1959; Tate *et al* 1991). The contribution from other legume was almost negligible as was the contribution from weeds (1.8%). Site 7 is a site where nutrient supply is nonlimiting. Under these conditions the high fertility responsive grasses demonstrated their competitive ability over those species adapted to low fertility environments (other grasses, other legume and broad leaf weeds). The relatively low percentage contribution of white clover (although in terms of total white clover production this site is only inferior to site 6) may be a consequence of the frequent urine deposition at the site. Stock treading might also reduce legume at the site. Competition for light and space could be an additional factor that limits legume growth. The frequent grazing of the pasture at this site, however suggests that this factor was less important than the ones mentioned previously in determining the low white clover content.

(a) (b)

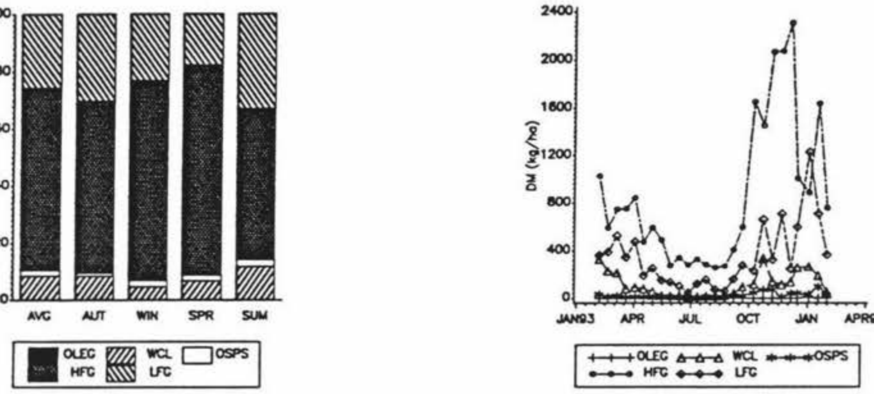


Figure 5.7 (a) The changes in seasonal botanical composition (%) of pasture at site 7 and (b) the contribution (kg DM/ha) made by each pasture components to annual production.

5.3.2.8 Summary of botanical composition

The major features of the sward composition at each of the seven sites is summarized in Table 5.4. Potential productivity the sites can be ranked using species composition in a similar way that soils are ranked on soil fertility indices.

The seven sites fall into two distinct groups. Sites 1 to 4 where HFG contributed less than 10% of total production and where weeds were a significant (more than 10%) component of the sward. These are all features of pastures of both low productivity and poor quality. In sharp contrast sites 5 to 7 represent sites where HFG are a major component of the sward and weeds and low fertility legumes are insignificant components of the sward. These sites can therefore be classified from medium to very high in terms of their potential productivity and quality.

Table 5.4 Pasture production (kg DM/ha) and contribution by each pasture species (% in brackets) and an assessment of the fertility of each site based on botanical composition.

Field site	Pasture species					Fertility assessment
	HFG	LFG	WCL	OLEG	OSPS	
4	86 (2.6)	2110 (63.1)	61 (1.8)	106 (3.2)	981 (29.3)	very low
2	88 (1.9)	2768 (60.7)	40 (0.9)	110 (2.4)	1559 (34.1)	very low
3	412 (8.0)	3455 (67.5)	215 (4.2)	282 (5.6)	753 (14.7)	low
1	327 (4.9)	4531 (68.7)	903 (13.7)	113 (1.7)	725 (11.0)	low
5	2501 (24.5)	6188 (60.6)	960 (9.4)	124 (1.2)	435 (4.3)	medium
6	4023 (34.7)	5223 (45.0)	1708 (14.7)	34 (0.3)	610 (5.3)	high
7	11181 (64.2)	4431 (25.5)	1481 (8.5)	3.5 (0.0)	310 (1.8)	very high

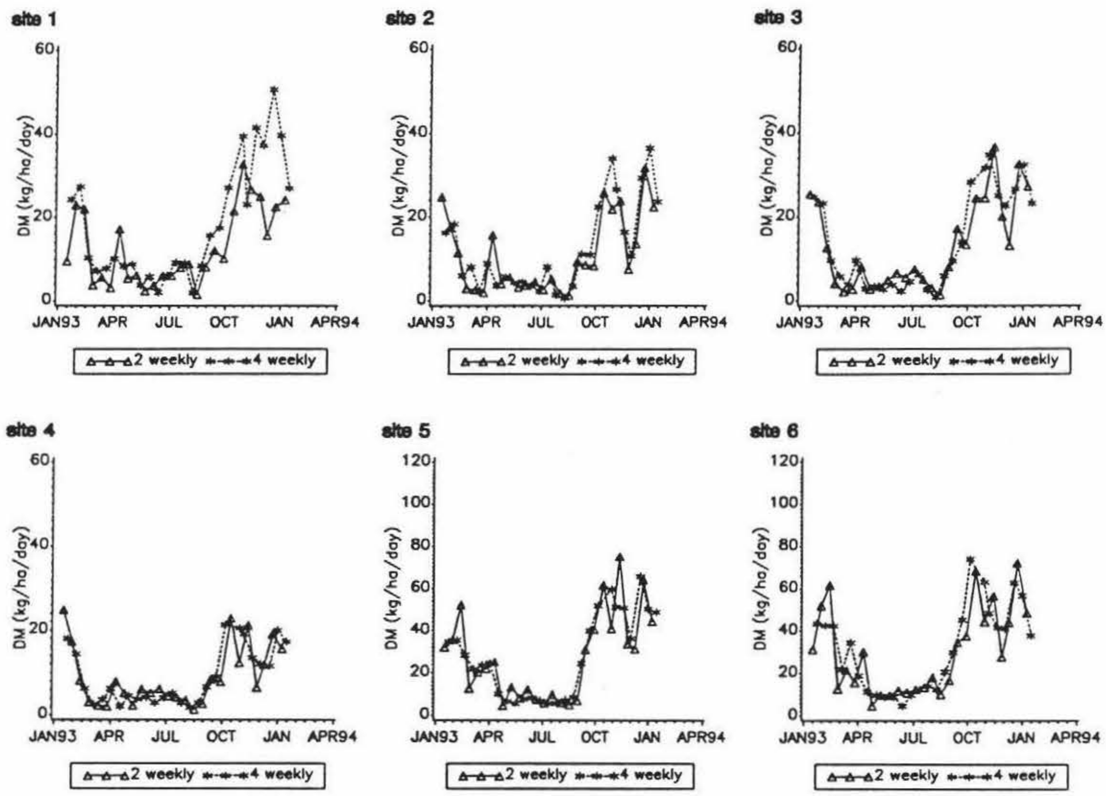
5.4 PATTERN OF PASTURE PRODUCTION

5.4.1 Pattern of pasture growth

Pasture growth rates followed a strong seasonal pattern with the lowest growth rates for late autumn and winter, and the highest for late spring and summer (Fig. 5.8). A pronounced drop in pasture production was recorded at sites 2 to 6 in early summer, probably as a consequence of weather conditions (low temperatures) at that time (Table 3.4).

Pasture growth rates for site 1 ranged from 50 kg DM/ha/day in early summer to less than 2 kg DM/ha/day in late winter. At sites 2, 3 and 4 the lowest extreme of the range was no different from site 1 but the highest growth rate recorded was 37 kg DM/ha/day (sites 2 and 3) and 25 kg DM/ha/day (site 4) in summer. The maximum growth rate for sites 5 and 6 were 75 and 72 kg DM/ha/day in summer, respectively, and the minimum about 5 kg DM/ha/day in late winter. Site 7 on the other hand showed a peak of nearly 108 kg DM/ha/day in summer and the lowest growth rate was around 11 kg DM/ha/day in winter.

Autumn pasture growth as a fraction of total growth increased with increases in fertility of the sites, while the contribution of summer production as a fraction of total growth was higher at the low fertility sites (Fig. 5.9). There was no apparent change in winter and spring production as a fraction of total production as fertility increased.



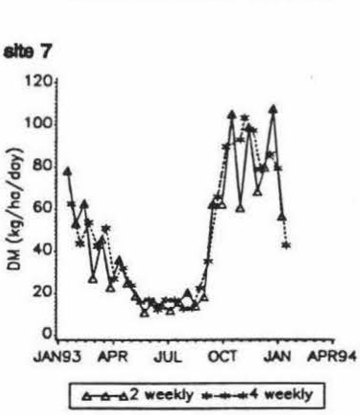


Figure 5.8 Pasture growth rates (kg DM/ha/day) at each site under the two cutting regimes.

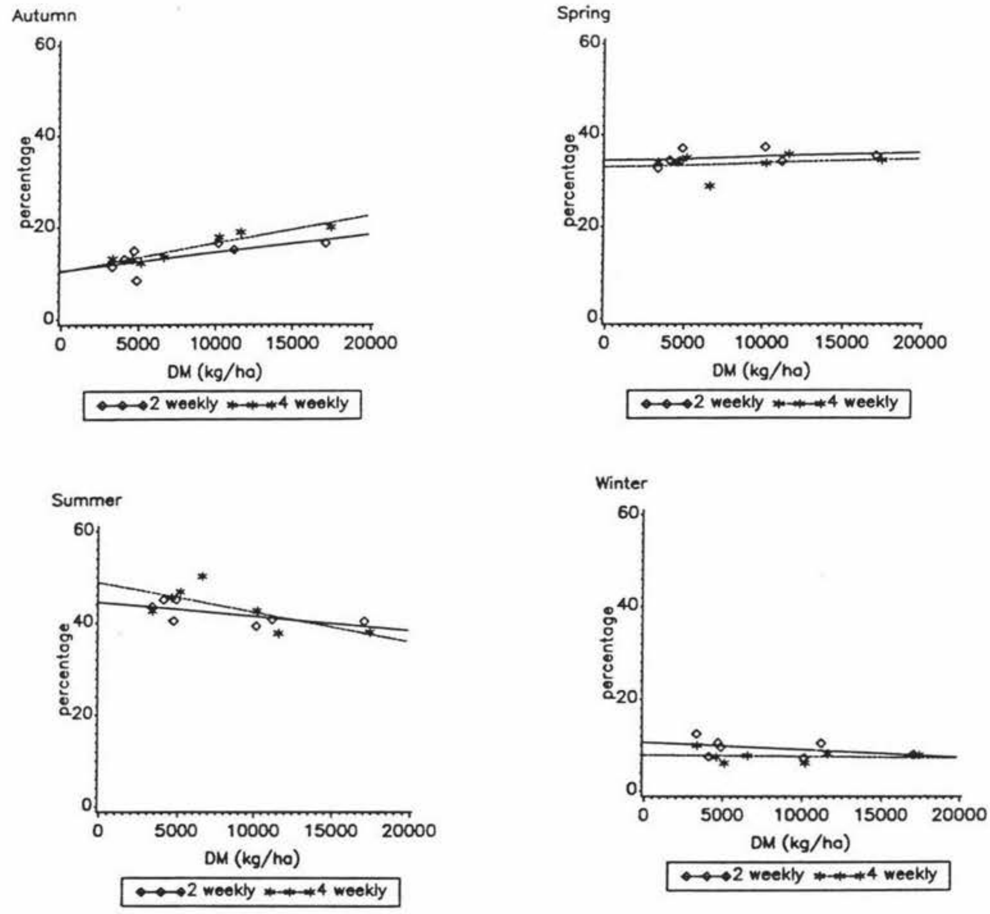


Figure 5.9 Relationship between percentage seasonal production and annual dry matter production.

However the same increase in percentage production represented a large change in the amount of dry matter produced in one season at the different sites. While mean growth rates in winter ranged from 3.3 kg DM/ha/day at site 2 to 15.9 kg DM/ha/day at site 7 mean growth rates in summer ranged from 15.0 kg DM/ha/day at site 4 to 75.6 kg DM/ha/day at site 7 (Fig. 5.10).

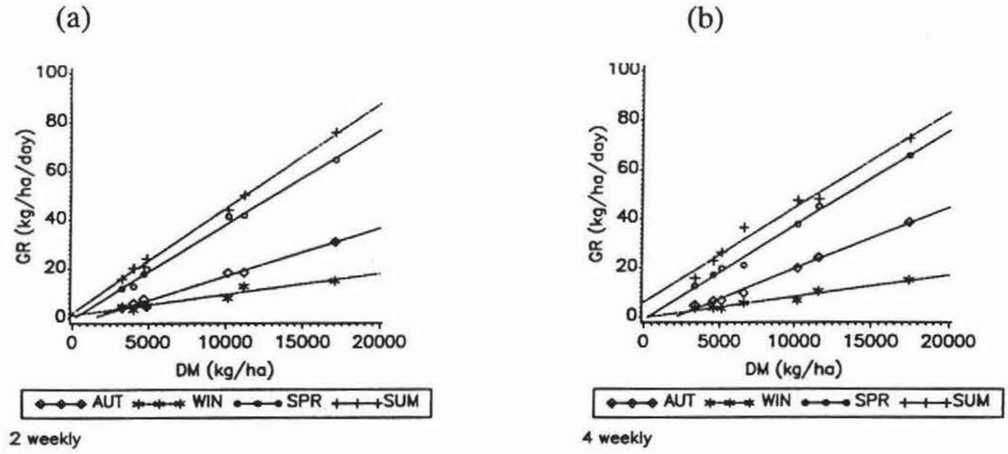


Figure 5.10 Relationship between seasonal growth rate and annual pasture production for a) 2 weekly and b) 4 weekly cutting regime.

5.4.2 Effect of cutting regime on the pattern of pasture production

In contrast to the absence of any differences in cutting regime in total pasture production at all sites except site 1, when the effect of cutting regime on seasonal pattern of pasture growth was examined some small differences were found (Table 5.5).

Pasture growth rates were high when pastures were left uncut for 4 rather 2 weeks in the periods of more rapid pasture growth (autumn and to a lesser extent summer and spring) indicating that at 2 weeks pasture growth was still in the lag phase of the sigmoidal growth curve and at 4 weeks in the exponential part of the pasture growth curve. Again no interaction was found between effect of cutting frequency and soil fertility.

Interestingly the more frequent cutting regime produced higher yields at periods of low pasture growth, when any errors in cutting technique would have its most significant effect on estimation of pasture growth. Errors associated with harvesting and recovery of short pasture is the most likely explanation for higher apparent pasture growth rate with the biweekly cutting in winter.

Table 5.5 Effect of cutting frequency on the seasonal pasture supply (kg/ha) and contribution to annual production (%).

Field Site	Cutting frequency	Season Autumn	Winter	Spring	Summer
1	2 week	696 (14.8%)	495 (10.5%)	1612 (34.3%)	1897 (40.4%)
	4 week	881 (13.4)	510 (7.7)	1903 (28.8)	3307 (50.1)
2	2 week	531 (13.0)	305 (7.5)	1404 (34.5)	1834 (45.0)
	4 week	590 (13.0)	336 (7.4)	1555 (34.1)	2073 (45.5)
3	2 week	407 (8.4)	464 (9.5)	1806 (37.1)	2191 (45.0)
	4 week	622 (12.2)	314 (6.1)	1791 (35.0)	2389 (46.7)
4	2 week	377 (11.4)	413 (12.4)	1087 (32.7)	1444 (43.5)
	4 week	437 (13.1)	333 (9.9)	1141 (34.1)	1434 (42.6)
5	2 week	1666 (16.4)	727 (7.2)	3761 (37.1)	3994 (39.3)
	4 week	1806 (17.7)	624 (6.1)	3428 (33.6)	4327 (42.6)
6	2 week	1672 (15.0)	1165 (10.4)	3792 (33.9)	4551 (40.7)
	4 week	2191 (18.9)	943 (8.1)	4093 (35.5)	4373 (37.7)
7	2 week	2806 (16.5)	1366 (8.0)	5898 (35.2)	6883 (40.3)
	4 week	3487 (20.0)	1364 (7.9)	5961 (34.2)	6596 (37.9)

5.5 LEGUME GROWTH AND BIOLOGICAL NITROGEN FIXATION

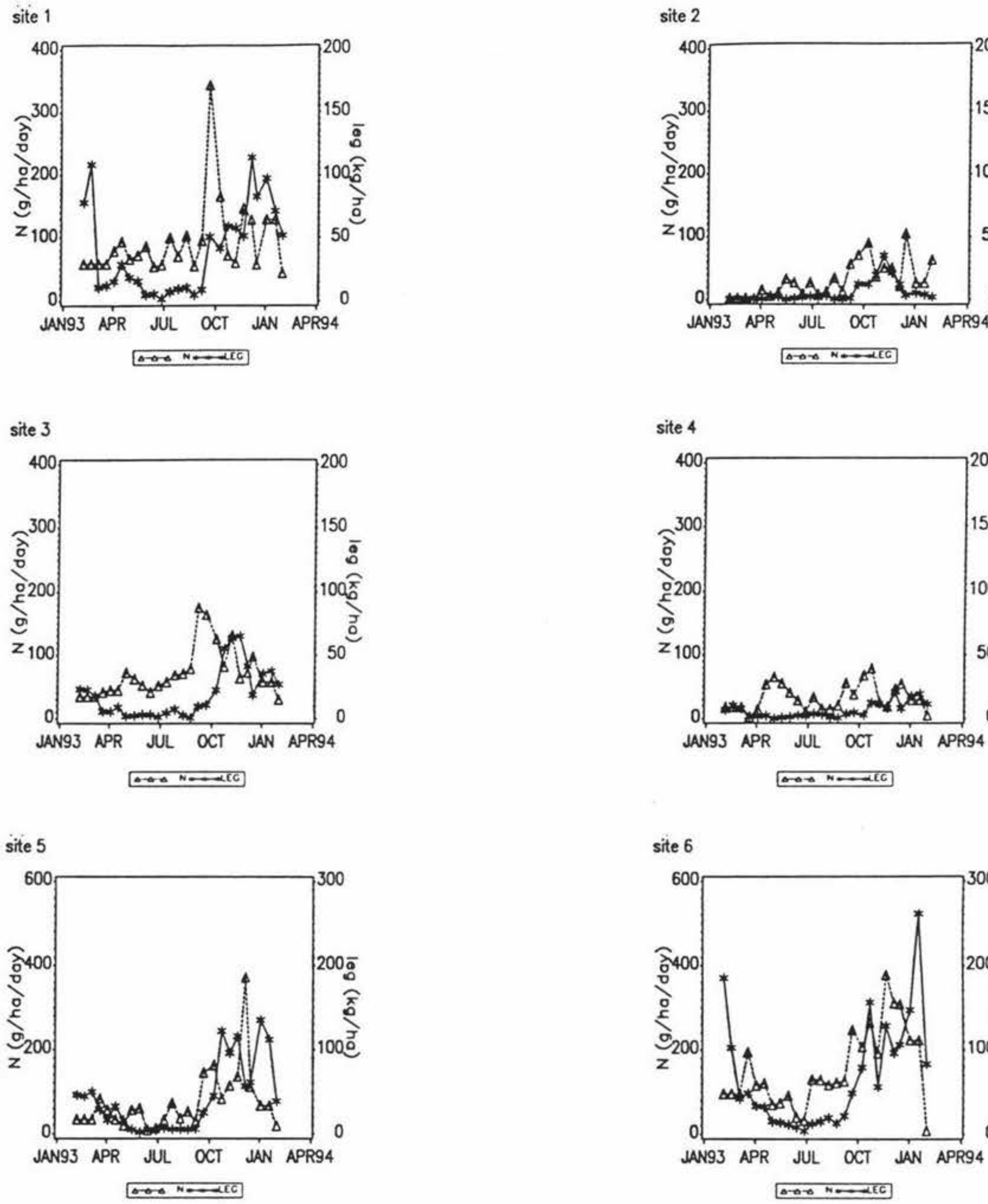
5.5.1 Amounts of nitrogen fixed

The amounts of fixed N in each of the seasons and the total are presented in Table 5.6.

Table 5.6 Seasonal and total amounts of nitrogen fixed (kg/ha) and seasonal proportion of fixed nitrogen (% in brackets) at each site.

Field site	Autumn	Winter	Spring	Summer	Total
1	6.5 (19.0)	7.0 (20.6)	12.4 (36.3)	8.3 (24.1)	34.2
2	0.9 (7.7)	1.9 (17.0)	5.0 (45.6)	3.3 (29.7)	11.0
3	4.5 (17.3)	5.3 (20.6)	11.1 (43.0)	5.0 (19.1)	25.9
4	3.0 (24.9)	2.3 (19.1)	4.3 (35.3)	2.5 (20.7)	12.1
5	4.2 (15.7)	3.5 (13.1)	9.5 (35.1)	9.8 (36.1)	27.0
6	10.3 (18.7)	8.3 (15.0)	19.3 (35.0)	17.3 (31.3)	55.2
7	6.4 (15.3)	2.9 (7.0)	15.6 (37.7)	16.5 (40.0)	41.4

Of all the sites, sites 2 and 4 had the lowest N fixation rates, followed by sites 3, 5 and 1. Sites 7 and 6 fixed the highest amounts. In general the amount of N fixed was lower than has been reported in the past for other regions of New Zealand. Clark *et al* (1979) reported 211 and 242 kg N/ha fixed in two consecutive years in a pasture yielding about 3 tons of legumes and 10 tons of grasses on fertile flatland soils. However previous work in hill country found values comparable to those found in this study. Grant and Lambert (1979) reported annual N fixation amounts between 10 and 65 kg N/ha, while Mackay (pers comm.) measured N fixed between 26 kg N/ha in an untopdressed low fertility site and 87 kg N/ha at a site topdressed with PAPR.



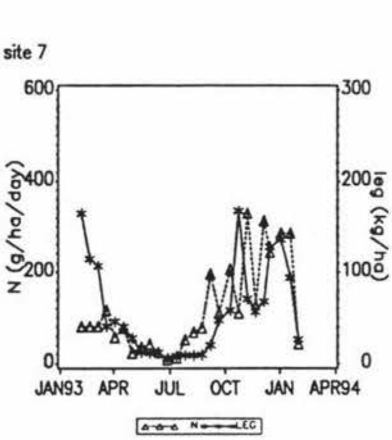


Figure 5.11 Nitrogen fixation (g/ha/day) and legume production during the study period at each site.

Except for site 4 where N fixed in autumn (24.9%) was higher than N fixed in summer (20.7%), autumn and winter accounted for less than 40% of annual fixed N.

The seasonal variation in N fixation rates was less pronounced than in legume yields. The cause of this different behaviour can be related to a higher efficiency of legumes when yields were low or to nonsymbiotic N fixation, that does not depend on legume production. The spring flush in N fixation however preceded the increase in pasture growth in most sites (Table 5.6 and Fig. 5.11).

5.5.2 Relationship between legume production and nitrogen fixation

The methodology used for estimation of N fixation in this experiment was not able to distinguish between symbiotic and nonsymbiotic fixed N. Some legume was present throughout the year in all sites, hence it is not possible to know the amount of non-symbiotic N fixed (in the absence of legumes). Previous estimations of non-symbiotic fixation are between 10 and 21 kg N/ha/year (Grant & Lambert 1979). Probably in this experiment the amount of non-symbiotic fixed N was less than 10 kg because sites 2 and 4 fixed 11.0 and 12.5 kg N/ha respectively. Legume production (monthly harvest) in these sites was 150 and 167 kg/ha respectively, and it is very unlikely that no N was fixed by those legumes.

In general winter showed the highest and summer the lowest efficiency in terms of amount of N fixed per ton of legume (Table 5.7). Similar patterns have been found by Hoglund and Brock (1979) in Palmerston North, Brown *et al* (1979) on the Gisborne Plains and O'Connor *et al* (1979) on the Central Plateau. The higher efficiency in winter and spring was attributed by Clark *et al* (1979) to lower mineral N levels in soil that promote fixation. While this explains the high N fixation efficiency in winter, the low efficiency of N fixation observed in summer in this study can probably be explained more by the low water availability. The effect of water stress on N fixation rates was especially clear in the last sampling of 1994 when the soil was extremely dry and N fixation rates dropped dramatically at all sites.

Table 5.7 Legume produced (kg/ha) and seasonal nitrogen fixation per ton of legume.

Site	Total legume (kg/ha)	Kg N/t legume			
		Autumn	Winter	Spring	Summer
1	1016	61.3	147.2	33.1	16.9
2	150	93.4	167.8	44.4	19.3
3	497	438.2	183.2	43.1	15.1
4	167	186.3	137.7	70.0	33.9
5	1084	28.1	95.1	20.6	22.3
6	1735	52.4	89.0	34.1	15.5
7	1485	22.3	40.3	33.5	25.0

The high urine input received at site 7 and the high mineral N contents found in this site might explain the low fixation efficiency in autumn and winter at this site, but do not appear to have affected spring and summer fixation efficiencies.

5.6 NUTRIENT ABSORPTION BY PASTURE

5.6.1 Nitrogen

5.6.1.1 Nitrogen concentration in mixed pasture

Cutting frequencies had little effect on the concentrations of N in pastures although there was a tendency for the high fertility sites (5 to 7) to have lower concentrations in pastures left uncut for 4 weeks (Table 5.8 and Fig. 5.12). The difference was significantly only for site 7. Lower N concentrations have been observed as the period between cuts increased (Binnie and Chesnut, 1991) as a consequence of dilution, when rates of growth are higher than rates of absorption. This tendency was not often apparent in this experiment, despite the higher pasture growth rates observed at some sites for the 4-week cutting regime in autumn, winter and spring.

Table 5.8 Effect of cutting frequency on the average nitrogen concentration of mixed pasture samples at each site.

Field site	Cutting frequency	
	2 weeks	4 weeks
1	3.2 a	3.2 a
2	2.6 a	2.7 a
3	2.9 a	2.9 a
4	2.3 a	2.4 a
5	3.8 a	3.6 a
6	4.0 a	3.9 a
7	4.4 a	4.2 b

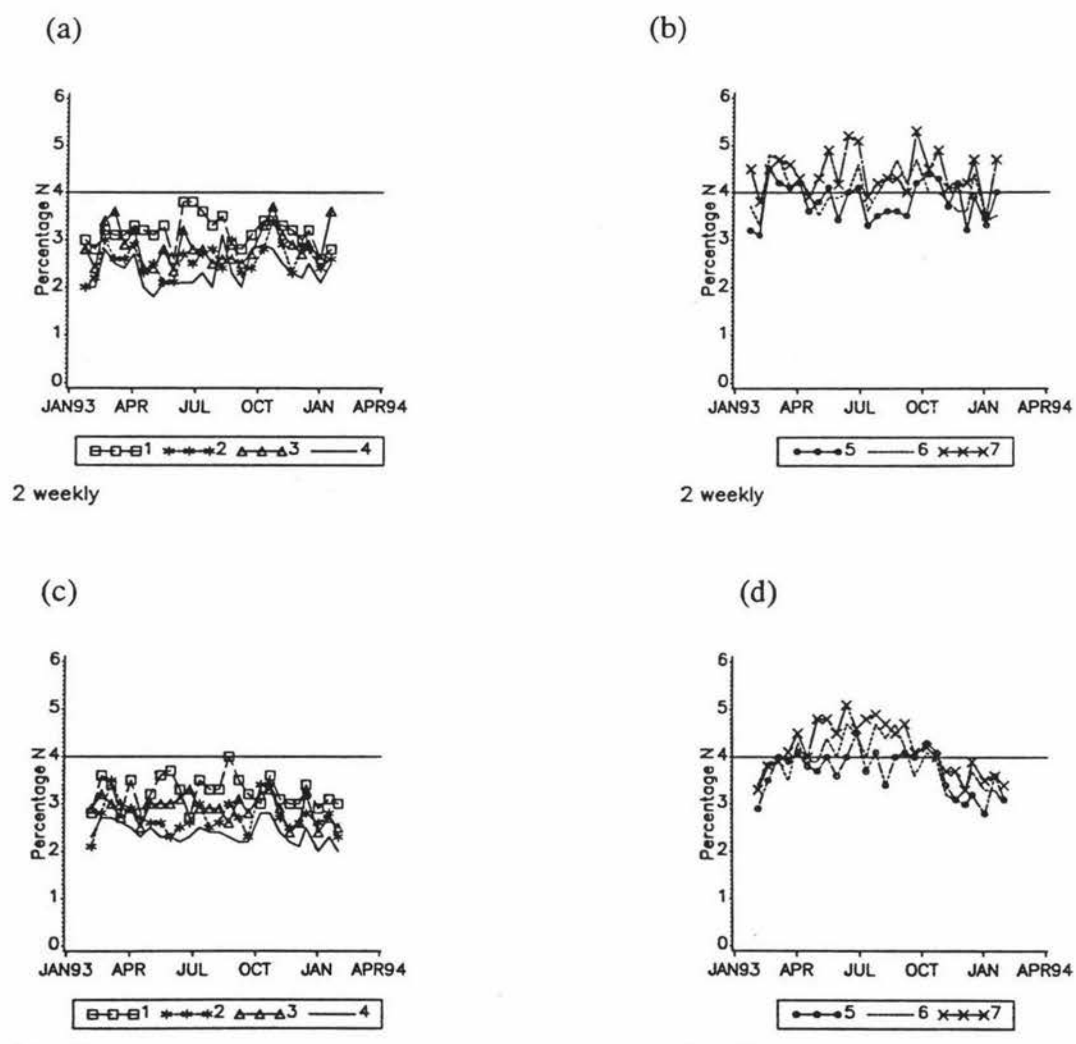


Figure 5.12 Nitrogen concentration of herbage at (a) sites 1 to 4 under biweekly cutting, (b)sites 5 to 7 under biweekly cutting (c) sites 1 to 4 under 4-weekly cutting and (d) sites 5 to 7 under 4-weekly cutting

At all sampling times and frequencies sites 2 and 4 had very low N concentrations. This is consistent with the pasture species found at these two sites, and past fertiliser history. The samples analysed included dead material, that in the cases of sites 1, 2, 3 and 4 represented an important proportion of the sample (10%, 14%, 13% and 20% average of pasture production of sites 1, 2, 3 and 4, respectively). Hence it is possible that the N concentration values presented here for sites 1 to 4 are lower than the active growing component of the pasture. Nevertheless the N concentrations of pastures collected for sites 2 and 4 throughout the study were well below the critical values reported by McNaught (1970) for ryegrass (4.0-4.5%) throughout the study. Sites 1 and 3 also had low N concentrations. This was a little unexpected for site 1 given the appreciable proportion of legumes in the sward at this site. The average N concentration of pastures at site 5 was also below the critical level mentioned above (McNaught 1970) while sites 6 and 7 were in the adequate range. If the ranges reported by Cornforth (1984) are considered, site 5 was in the deficient range for N, site 6 marginal and site 7 had adequate N content. Pasture from site 7 received frequent inputs of readily available N in the form of dung and urine.

There were no clear tendencies in terms of N concentration with season for the biweekly cut pasture nor for the low fertility sites (1, 2, 3 and 4) with 4-weekly cutting. In contrast N concentrations in the 3 high fertility sites (5, 6 and 7) with 4-weekly cutting were lower in summer than during the rest of the year (Fig. 5.12). There was a distinct peak in winter in periods of low growth. These results coincide with those obtained by many authors in New Zealand pastures (Melville & Sears 1953; Metson & Saunders 1978; Hay *et al* 1985).

5.6.1.2 Nitrogen concentration of botanical fractions

The N concentrations in LFG and HFG were not very different at sites 1, 3, 5 and 6, but at sites 4 and 7, LFG contained more N than HFG (Table 5.9). In the case of site 4 this fact can be related to competitive ability of the species adapted to low fertility environments while in the case of site 7 the difference may be due to dilution of absorbed N in the HFG that were growing very fast at this time of the year. It is important to notice however, that N concentrations in the grasses were in the deficiency range (Cornforth 1984) at all sites except site 7.

Legumes had markedly higher N contents than grasses in all sites, having the highest N content of all groups of species. Nevertheless white clover in site 2 was in the range of N deficiency proposed by Cornforth (1984). In the sites where N content of other legumes was analysed, the N content of these species was less than for white clover. It is not possible, however, to know if this result was due to a lower capacity for N fixation of the species other than white clover or to the different parts of the plants that were harvested in both cases (mostly leaves of white clover and more stem material in other legumes).

Nitrogen concentrations in OSPS were similar to those of grasses, particularly LFG, at all sites. The N concentration of dead matter was lower than the other fractions.

Table 5.9 Nitrogen concentrations of high fertility adapted grasses (HFG), low fertility tolerant grasses (LFG), white clover (WCL), other legumes (OLEG), other species (OSPS), dead matter and composite sample taken in early summer (23-12-93) from each site.

Pasture Component	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
HFG	3.2		3.0	3.0	3.2	3.2	3.5
LFG	3.3	3.0	3.2	2.4	3.2	3.4	4.0
WCL	4.4	4.3	4.6		5.3	5.2	5.0
OLEG	3.9	3.2		3.2	4.3		
OSPS	3.3	2.8	3.3	2.5	3.4	3.4	3.9
Dead Matter	2.1	1.6	2.1	1.8	1.8	1.6	2.2
Calculate Composite	3.4	2.7	3.2	2.4	3.4	3.6	3.8
Composite	3.4	2.8	3.2	2.5	3.2	3.7	3.9

5.6.1.3 Nitrogen accumulation by pastures

The total amount of N accumulated by pastures every 2 or 4 weeks is presented in Table 5.10. Original data is presented in Appendix 5.8.

Table 5.10 Effect of cutting frequency on N accumulation (kg N/ha) at each site.

Field site	Cutting frequency	
	2 weeks	4 weeks
1	180.7	234.7
2	128.1	143.4
3	170.8	166.8
4	109.7	98.5
5	430.5	376.9
6	482.9	463.4
7	798.4	720.3

As was explained for pasture dry matter accumulation, fortnightly and monthly N yield are not strictly comparable, since they correspond to different periods, nevertheless it is possible to make some comments for the sites where the differences are substantial.

Greater amounts of N were accumulated under the 4- rather than the 2-weekly cutting regime in sites 1 and 2. This result is consistent with the higher pasture growth obtained with the longer cutting frequency at these sites. At these two sites the N concentrations of pasture under the two cutting frequencies were similar. Amounts of N accumulated in pastures under both cutting frequencies were similar for site 3. Lower amounts of N were obtained in sites 4 to 7 with the longer cutting regime. Considering that these pastures were under grazing during the whole year of the experiment, these results suggest that there is a higher N turnover in the pastures harvested fortnightly than in the pastures harvested monthly. This hypothesis is consistent with the larger differences between cutting frequencies in pasture N yield at sites 5 and 7 than in the other sites.

The small amount of N accumulated at sites 4 and 2 is consistent with their poor production of pasture and the low N content at these two sites. Sites 1 accumulated more N than site 3 when the pastures were cut every 4 weeks but less when the pastures were cut every 2 weeks. This result is in part a consequence of the higher

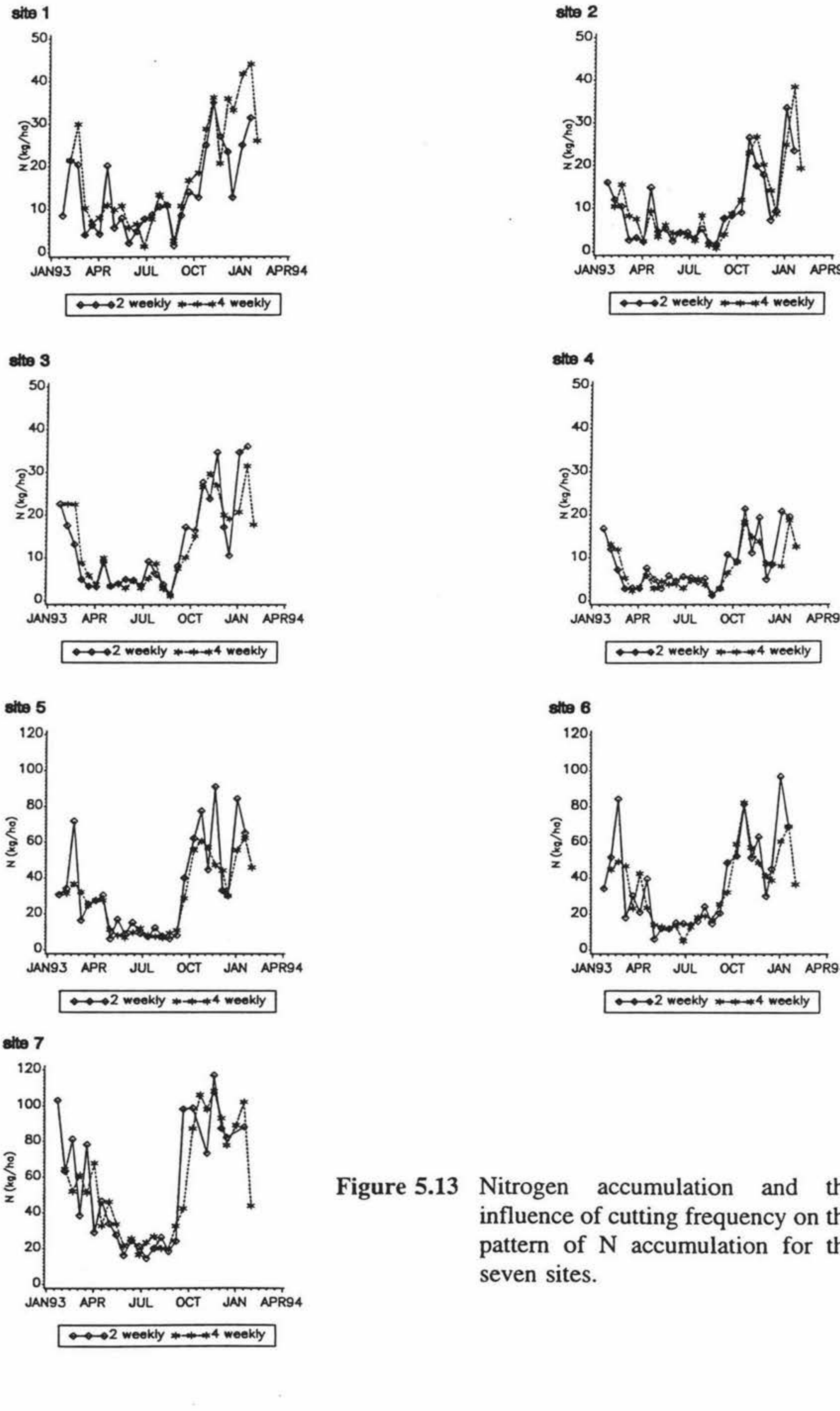


Figure 5.13 Nitrogen accumulation and the influence of cutting frequency on the pattern of N accumulation for the seven sites.

legume content of pastures at site 1. Accumulation of N at site 6 was greater than at site 5. While an important proportion of pasture N in site 6 came from legume-fixed N, most N at site 5 would have been derived from N inputs as dung and urine. Site 7 accumulated large amounts of N (798 and 720 kg for 2-weekly and 4-weekly cuts, respectively). This is consistent with the large amount of urine and dung deposition observed at this site throughout the trial. The amount of accumulated N measured at site 6 (between 460 and 480 kg N/ha) was comparable to that reported by Brock and Hoglund (1979) for a similar yielding pasture (462 and 472 kg N/ha for two years). Ruiz (1992) reported a N yield of 534 kg N/ha for a grass pasture comparable to site 7, yielding about 16000 kg.

Nitrogen accumulation rates throughout the year tracked pasture growth (Fig. 5.13) with accumulation rates from as low as 0.1 kg N/ha/day for winter in site 1 to 25 kg N/ha/day in late spring at site 7.

5.6.2 Phosphorus accumulation by pasture

5.6.2.1 Phosphorus concentration

Average P concentrations in pastures harvested either biweekly or 4-weekly are presented in Table 5.11. The complete data set is presented in Appendix 5.3.

Table 5.11 Effect of cutting frequency on the average phosphorus content of mixed pasture samples.

Field site	Cutting frequency	
	2 weeks	4 weeks
1	0.31 b	0.32 a
2	0.18 a	0.18 a
3	0.22 a	0.23 a
4	0.19 a	0.19 a
5	0.36 a	0.35 a
6	0.46 a	0.47 a
7	0.49 a	0.49 a

The P concentrations of pasture across the seven sites were not affected by cutting frequency apart from site 1 where the mean P concentration of pasture cut biweekly was significantly lower than pasture cut 4-weekly. Average P concentrations of pasture at sites 2, 3 and 4 were below the critical levels (0.28-0.36% for ryegrass and 0.30-0.40% for white clover) reported by McNaught (1970) for adequate pasture growth. As was explained for N concentrations, the higher content of dead material in the samples from these 3 sites would tend to lower the P content of the mixed pasture sample. Sites 1 and 5 had medium P concentrations, with site 1 at the lower extreme of the adequate range. The P concentrations of pastures at sites 6 and 7 were higher than the optimum range of P content reported by McNaught (1970) for ryegrass-white clover pastures.

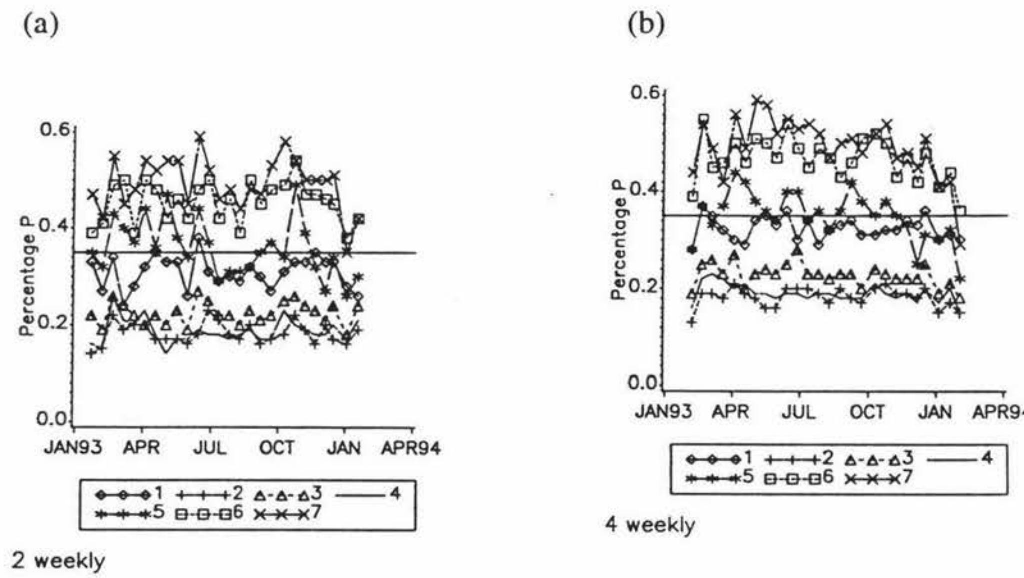


Figure 5.14 Phosphorus concentration of mixed pasture form each site cut (a) biweekly and (b) 4-weekly.

The P concentrations in mixed pasture from biweekly and 4 weekly harvested pastures followed the same seasonal trends (Fig. 5.14). The P concentrations of herbage were lower in late spring and summer than for the rest of the year at most sites. This is probably due to a dilution effect, since maximum growth rates were measured during this period.

Application of P fertiliser to sites 1, 3, 6 and 7 in mid spring had little if any effect on the P content of pasture. In herbage from biweekly harvests an increase in P concentration was observed in spring at all sites, not only those that were fertilised. For herbage from 4-weekly cuts the only feature that can be mentioned is that the seasonal drop in P concentrations for the fertilised sites was delayed compared to the drop in P concentrations at site 5 (not fertilised).

5.6.2.2 Phosphorus content of pasture components

Table 5.12 shows the P concentrations measured in the different fractions of the monthly harvest on 23-12-93. Except for site 3 where the HFG P content (0.19%) was lower than that of LFG (0.27%), the HFG and LFG had similar P concentrations at the other 6 sites. In most sites the P concentration of grasses was close to but slightly higher than the P composition of the composite sample, reflecting the dominance of these species in all sites. The P concentration of LFG was similar to the P concentration of the composite sample.

Table 5.12 Phosphorus concentration of high fertility adapted grasses (HFG), low fertility tolerant grasses (LFG), white clover (WCL), other legumes (OLEG), other species (OSPS), dead matter and composite sample taken in early summer (23-12-93) from each site.

Pasture Component	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
HFG	0.38		0.19	0.24	0.33	0.54	0.53
LFG	0.40	0.21	0.27	0.22	0.34	0.51	0.53
WCL	0.30	0.23	0.27		0.32	0.40	0.40
OLEG	0.33	0.19		0.17	0.33		
OSPS	0.33	0.26	0.26	0.23	0.33	0.46	0.52
Dead Matter	0.23	0.09	0.22	0.12	0.21	0.25	0.32
Calculated Composite[1]	0.37	0.20	0.26	0.20	0.33	0.48	0.51
Composite	0.36	0.20	0.25	0.20	0.31	0.48	0.51

[1] weighted mean

Legumes (WCL and OLEG) had lower P concentrations than grasses in sites 1, 4, 6 and 7, while in the other sites P concentrations in grasses and legumes were similar. The higher P content of grasses at sites 1, 4, 6 and 7 reflected the better competitive ability of grasses, due to their larger root system, for P absorption.

However the reason for the similar P content in grasses and legumes in sites 2, 3 and 5 is not clear.

The P concentrations of OSPS were similar to grasses in sites 3, 4, 5 and 7, between grasses and legumes in site 6, lower than grasses in site 1 and higher than grasses in site 2. The P concentration in OSPS in site 2 was higher than the P concentration in any other fraction. This result can be related to the extremely high proportion of other species in site 2, showing a possible advantage of the weeds in terms of P accumulation in an extremely P deficient site.

The concentration of P in dead matter was lower than in any other fraction in all sites. But it was unexpected that only in sites 2, 4 and 6 was the P concentration of this fraction about 50% lower than in grasses. Probably the cause of the relatively high P concentration in dead matter of most sites was that this fraction was composed of senescent leaves, as well as material from pre-trimming.

For sites 2, 3 and 4 the P concentration of all pasture fractions were well below the critical level for adequate growth proposed by Cornforth (1984). Pasture components at sites 1, 5, 6 and 7 were above this level with the exception of dead matter. Hence for these sites at this harvest date, the P concentration of the composite sample was able to give acceptable information on the P status of this pastures.

5.6.3 Phosphorus uptake by pasture

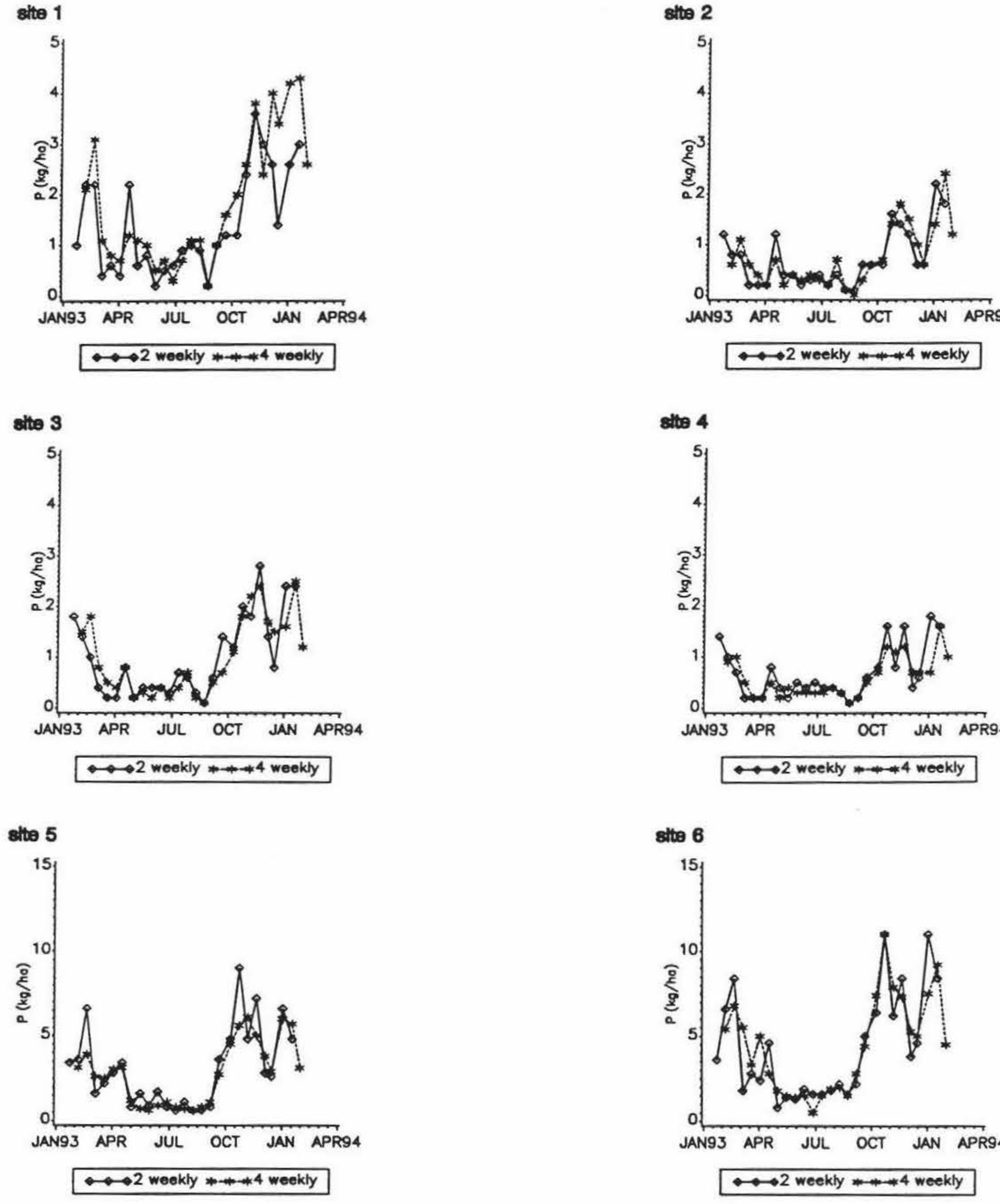
Accumulated P uptake for both cutting frequencies are presented in Table 5.13 and Fig. 5.15. Complete data are presented in Appendix 5.3.

Apart from site 1 where 4-weekly-harvested pasture took up 30% more P than fortnightly-harvested pasture, cutting frequency had little effect on P uptake by pasture. The greater uptake at site 1 was as a consequence of the higher growth rates found at site 1 under the 4-weekly than the biweekly cutting regime. The slightly, but significantly (P=0.05) higher P concentration of pasture from the 4-weekly than biweekly cutting regime at site 1 (Table 5.13) would also have contributed to the greater P uptake under the 4-weekly cutting regime.

Table 5.13 Effect of cutting regime on phosphorus uptake (kg P/ha) for seven sites.

Field site	Cutting frequency	
	2 weeks	4 weeks
1	18.3	23.8
2	9.2	9.5
3	13.0	12.8
4	8.8	7.7
5	39.7	36.0
6	55.5	57.1
7	88.6	87.1

Phosphorus uptake differences between sites reflect, and in some cases magnify, the differences in pasture yields between the 7 sites. Sites 2 and 4 had extremely low P uptake (less than 10 kg/ha/year) demonstrating the extremely P deficient nature of these two sites. The difference in P uptake between site 3 and 1 are far greater than differences in pasture production (Table 5.1). This suggests that pasture growth at site 1 is limited more by factors other than P supply. Similarly at sites 5 and 6, the difference in P uptake was more marked than the difference in pasture yields. The greater uptake of P at site 6 reflects the higher soil P availability. Phosphorus uptake by pasture at site 7 was nearly 10 times higher than the P taken up on the low production sites (Table 5.13), reflecting the high inputs of P in fertiliser and dung.



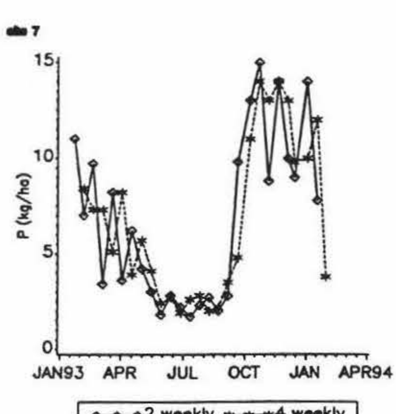


Figure 5.15 Phosphorus uptake by pasture at each site and the influence of cutting frequency on the pattern of P uptake for the seven sites.

5.6.4 Nitrogen:phosphorus ratio of pasture

Cutting frequency had little or no effect on the N:P ratio of pastures. The highest N:P ratios were found at sites 2, 3 and 4. These sites were deficient in both N and P (Table 5.14), but these ratios suggest that P was more strongly limiting growth than N. Jones *et al* (1990), established a critical P:N ratio (corresponding to 95% relative yield) of 0.083, equivalent to a N:P ratio of 12.05:1. However in this experiment the only sites that showed a ratio near this value were clearly deficient in both nutrients. Sites 1 and 5 had very similar ratios. At site 1 this resulted more from an elevated P status than a low N status and the low yields at this site are not related solely to N deficiency but also to water stress. Sites 6 and 7 had very low N:P ratios; well below the 12:1 for optimum plant growth mentioned above. These two sites were not likely to have suffered nutrient shortages and the low ratio probably reflected the uptake and assimilation characteristics of both nutrients. While N absorption is closely related to photosynthesis and protein build up, it has been found that plants can accumulate P beyond their needs. It is possible then that the low ratio for sites 6 and 7 is more influenced by a luxury P consumption than by shortage of N.

Table 5.14 Effect of cutting frequency on mean N:P ratio in samples from mixed pastures for seven sites.

Field site	Cutting frequency	
	2 weeks	4 weeks
1	10.3	10
2	14.2	14.9
3	12.7	12.7
4	12.6	12.5
5	10.9	10.7
6	8.9	8.3
7	9.0	8.6

There were no clear seasonal patterns in the N:P ratios of mixed pastures through the year (Fig. 5.16).

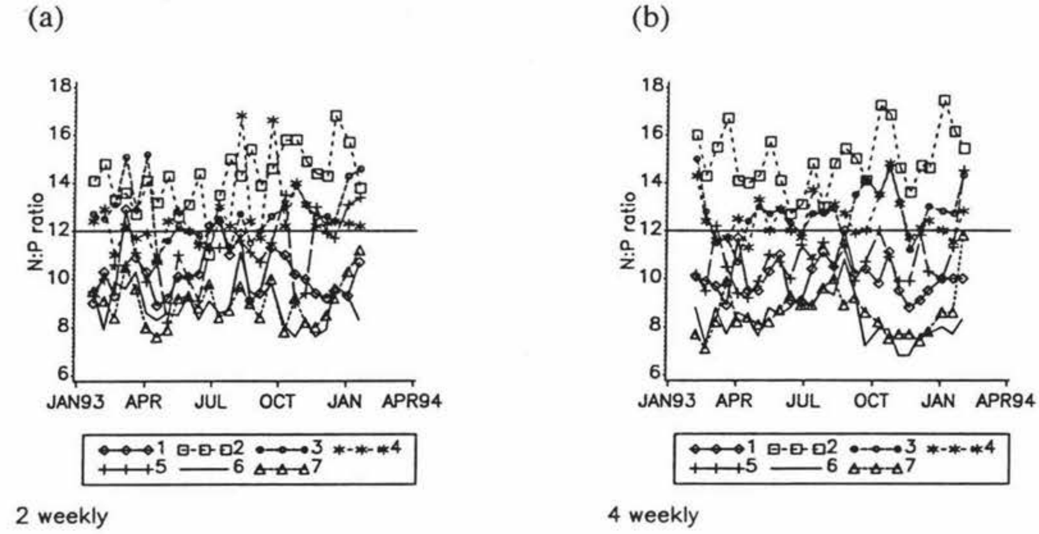


Figure 5.16 The N:P ratio of mixed pasture as influenced by site and cutting frequency (a) biweekly and (b) 4-weekly cut.

5.7 CONCLUSIONS

Annual pasture production varied more than 5-fold across the 7 field sites used to examine the relationship between soil fertility and pasture growth. It is possible to place the field sites into 4 broad groups based on pasture production:

(a) sites 2 and 4 represent very low production sites with 3300 to 4500 kg DM/ha,

(b) sites 1 and 3 represented low production sites with 5000 to 6600 kgDM/ha,

(c) sites 5 and 6 represented medium production sites with 10200 to 11600 kg DM/ha, and

(d) site 7 represented a high production site with 17000 kg DM/ha.

Grasses adapted to low fertility environments were the dominant botanical fraction of pasture at all sites with the exception of site 7. High fertility responsive grass production followed the same trend as pasture production being almost negligible for soils from group A. Legume production was extremely low at sites from group A but did not follow the same trend as pasture production, being maximum at one of the medium production sites. Weeds accounted for a significant proportion of total production only at pastures from sites of group A.

Seasonal patterns of pasture production were similar for all sites with spring and summer production representing more than 70% of annual production. The lowest pasture growth rates (less than 3 kgDM/ha/day) were recorded in late winter at all sites and the highest growth rates were recorded in mid summer (105 kg DM/ha/day). Interestingly pasture growth increased to a similar extent in each season as soil fertility increased, so that while winter pasture growth rates ranged from 3.3 to 15.9 kg DM/ha/day as soil fertility increased, a similar percentage increase occurred in the other seasons.

When the seasonal pattern of pasture growth was examined there was higher production under the 4-weekly cutting regime at all sites in autumn and greater growth in spring or summer. No interaction was found between pasture growth, cutting frequency and soil fertility.

Only at one site (site 1) where soil water limited pasture growth for much of the year did cutting frequency influence annual pasture yields. The literature reviewed (Brougham, 1959, Alberda, 1964, Parsons *et al*, 1983) is consistent in describing a sigmoid curve of pasture accumulation after defoliation. Based on such a model the pasture accumulation rates increase with time until a plateau is reached. The results presented here however do not follow this model since growth rates under a 4-weekly cutting frequency were not significantly higher than growth rates under a biweekly cutting regime indicating that the slope of the growth curve was constant until 4 weeks growth. One possible explanation for this behaviour is that the two cutting periods were too close. It is surprising, however that during the fast growth periods (late spring and summer), when the pasture growth curve is steepest (Brougham, 1959, Alberda, 1964 and Hongwen *et al*, 1990) there were no differences in growth rates between cutting frequencies. These data suggest that 4-weekly cutting frequency throughout the year is as reliable for estimation of pasture growth than biweekly cutting frequency. This finding has practical implications for the assessment of pasture growth in hill country pastures under set stocking since less frequent cutting up to 4 weeks enables a simpler experimental management.

Except for site 7, pasture N concentration was below critical levels, being extremely low in pastures from sites in group 1 and 2. Except at sites 1 and 2 where pasture production assessed in the 4-weekly cutting regime was higher than pasture production assessed biweekly, the biweekly cut pasture had higher N accumulation than the 4-weekly cut pasture.

No interaction was found between N-accumulation, soil fertility and cutting regime despite marked differences in the mineral soil N pool.

Phosphorus concentrations were within the adequate range for most sites, however P concentrations in pasture were well below the critical level for sites in group 1 and one of the sites in group 2. Differences in P uptake by pasture were far greater (nearly 10 fold) than differences in pasture production. With the exception of site 1 where P uptake under 4-weekly cutting regime accumulated larger amounts of P than 2-weekly cut pastures, there were no differences between biweekly and 4-weekly harvested pastures in terms of P accumulation.

CHAPTER 6

6.1 INTRODUCTION

By selecting field sites that differed in fertility, as a result of not only differences in fertiliser inputs, but also as a result of differential dung and urine return and soil water availability, the field sites encompassed the major variables that influence nutrient supply to grazed pasture. The sites varied in soil fertility using - Olsen P, as a single nutrient-index of fertility, from 7 to 47 μg/cc and potential productive capability, using the content of high fertility responsive grasses that ranged from less than 2 to 50%.

The objective of this chapter of the study was to: examine the relationship between the seasonality of and components of pasture growth and soil fertility represented by the 3 single-nutrient indices: mineral N, Olsen P and Resin P.

6.2 SOIL MEASUREMENTS

There was a very close relationship between the total C, N and P content of the seven soils (Table 6.1). These results are consistent with the build up of fertility that has been observed following pasture development (Walker, 1960, Jackman, 1964 and Nguyen and Goh, 1990). There were good correlations between total nutrient content (%C, %N, %P) and the 3 nutrient indices (mineral N, Olsen P, Resin P). There was also a good correlation between average mineral N and the two indices of available P indicating that the build up in available P could have caused an increase in the N fertility of the systems as a consequence of biological N fixation. As was mentioned earlier both measurements of P availability were very closely related.

Table 6.1 Correlation coefficients for total carbon, nitrogen and phosphorus, available phosphorus and mineral nitrogen measurements.

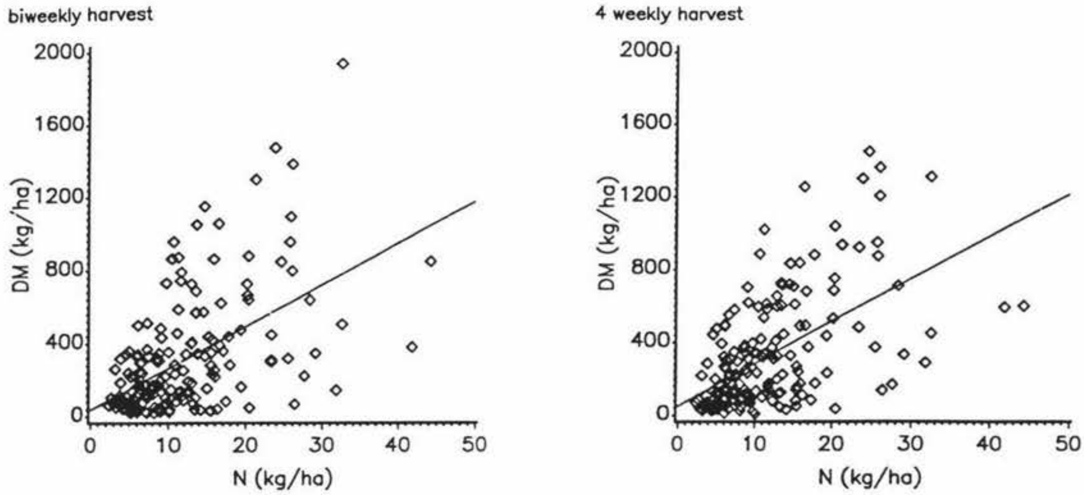
	C (%)	N (%)	P (μg/g)	Min N (μg/g)	Olsen P (μg/g)	Resin P (μg/g)
C (%)	1					
N (%)	0.95	1				
P (μg/g)	0.94	0.97	1			
Min N (μg/g)	0.73	0.74	0.79	1		
Olsen P (μg/g)	0.70	0.68	0.77	0.97	1	
Resin P (μg/g)	0.70	0.70	0.78	0.97	0.99	1

6.3 RELATIONSHIP BETWEEN SEASONAL PATTERNS OF PASTURE GROWTH AND THE COMPONENTS OF PASTURE YIELD AND SOIL FERTILITY INDICES

6.3.1 Mineral N content of soil

There was a very poor relationship between either 2- or 4-weekly pasture growth through the year and mineral N levels at the beginning of each growth period (Fig. 6.1). These results indicate that mineral N alone does not control pasture growth rates, so that at any time factors other than mineral N must also be considered when using this soil index as an assessment of soil fertility and likely pasture growth.

(a) (b)



$Y = 103^{NS} + 37x^{**}$ $r^2=0.29$ $Y=38^{NS} + 47x^{**}$ $r^2=0.32$

Figure 6.1 Relationship between pasture growth assessed by (a) biweekly or (b) 4 weekly cutting and mineral nitrogen at the beginning of each growth period.

6.3.1.1 Monthly soil mineral N levels

Except for May (r^2 = 0.03 and 0.08), and to a lesser extent August (r^2=0.57 and 0.57), the monthly mean of mineral N was strongly related to annual pasture production assessed by either biweekly or 4-weekly cutting (r^2 from 0.70 to 0.98) (Fig. 6.2). Parameters for the regression lines are presented in Appendix 6.1.

The closest relationships were found for spring (r^2 from 0.95 to 0.97) and summer months (r^2 from 0.76 to 0.97). However the slope and the intercept of the regression lines varied widely throughout the year, without any definitive seasonal pattern to the variation.

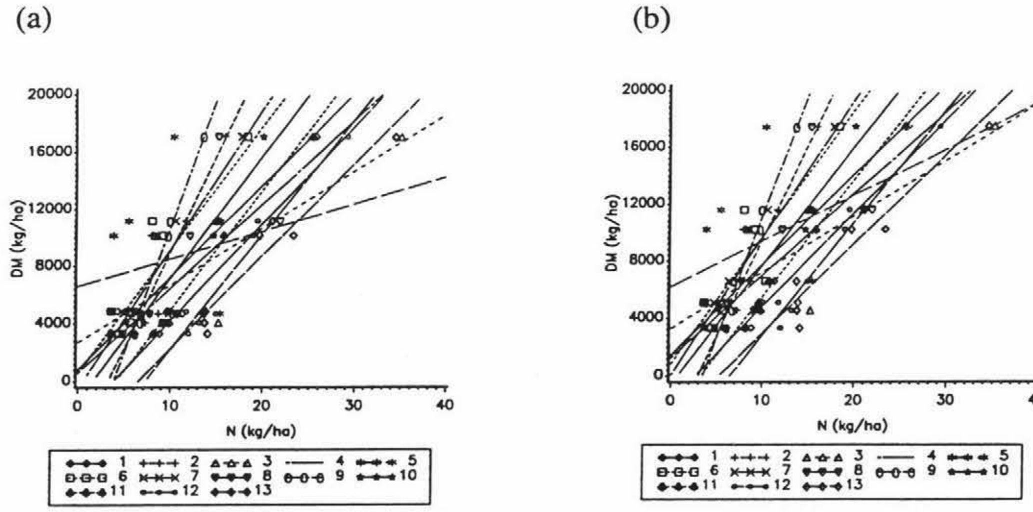


Figure 6.2 Relationships between average seasonal mineral N level (kg/ha) annual pasture production (kg/ha) under (a) biweekly or (b) 4-weekly cutting.

6.3.1.2 Seasonal soil mineral N levels

When average seasonal mineral N levels and seasonal pasture production were related a good relationship was found in each season (Table 6.2 and Fig. 6.3). The slope of the regression line followed a predictable seasonal pattern with the steepest slope in spring and summer and the lowest slope in winter when temperature limits pasture growth and when mineral N levels were at their lowest (Fig. 4.3). Mineral N levels were highest in spring and summer (Fig. 4.3) at a time when pasture growth rates were highest. In none of the 4 seasons, was there any suggestion that soil mineral N levels were approaching a level that no longer limited pasture growth. Even at site 7 where soil mineral N levels were as high as 50 μg/g of soil in spring, pasture growth was still increasing in a linear manner.

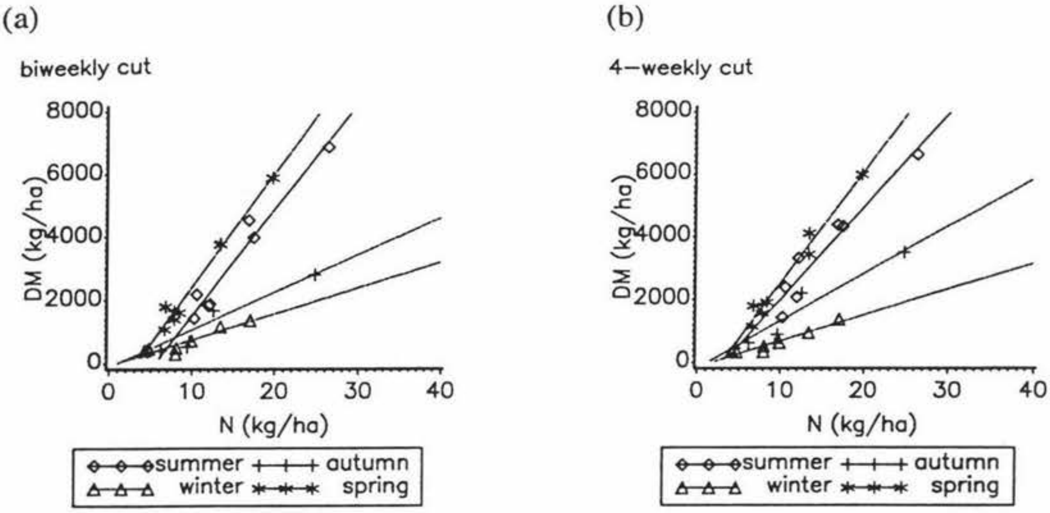


Figure 6.3 Relationship between average seasonal mineral N level and seasonal pasture production assessed by (a) biweekly and (b) 4 weekly cutting.

Table 6.2 Parameters of the linear regression of average seasonal mineral N levels (kg/ha) and seasonal pasture production (kg/ha) under two cutting regimes

	Intercept	Linear coef.	r^2
Summer biweekly	-1983 *	339 **	0.95
Summer 4 weekly	-971 NS	296 **	0.93
Autumn biweekly	-113 NS	119 **	0.76
Autumn 4 weekly	-186 NS	150 **	0.80
Winter biweekly	-62 NS	82 **	0.85
Winter 4 weekly	-141 NS	82 **	0.93
Spring biweekly	-1194 **	357 **	0.97
Spring 4 weekly	-1054 *	363 **	0.97

The relationships (Fig. 6.4) between mean seasonal mineral N levels and annual pasture production were very close with the highest r^2 in spring and summer (0.96 and 0.98 respectively) and the lowest in autumn and winter, indicating that if soil mineral N is used as an index of soil fertility the predictability of the index is greatest in spring or summer.

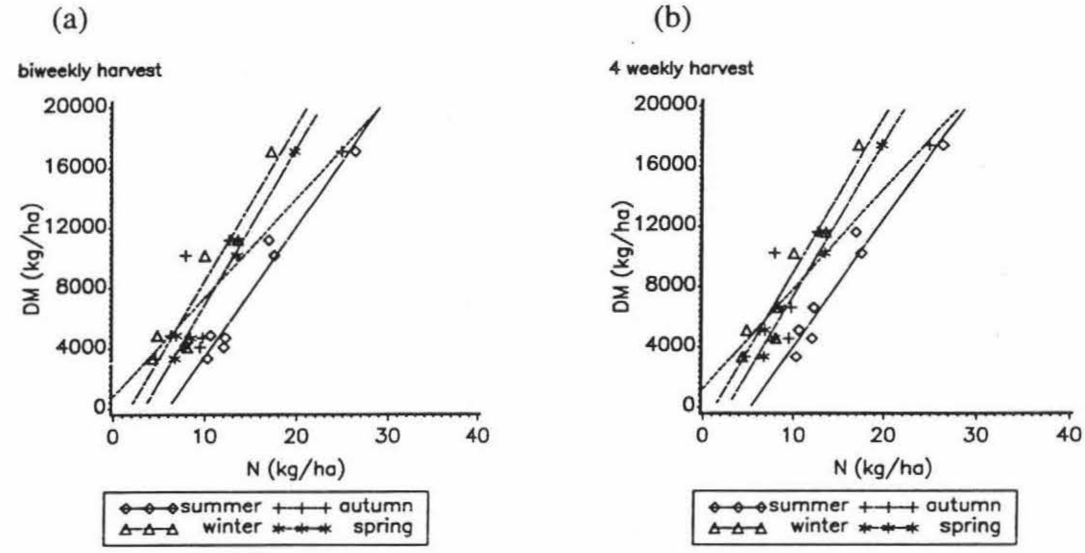


Figure 6.4 Relationship between mean seasonal mineral N levels and annual pasture production assessed by (a) biweekly or (b) 4 weekly cuts.

The relationship between mean annual soil mineral N and annual pasture growth (Fig. 6.5) was similar to that found when spring or summer mean soil mineral N were used as indices of pasture growth (intercepts= -2754 and -4447 for spring and summer, respectively, and -1934 for annual mean, linear coefficients = 1046 and 852 for spring and summer, respectively, and 868 for annual mean). This is not surprising given that the bulk of pasture growth occurs during these two seasons. The strong linear nature of the relationship between soil mineral N and pasture growth, even when average soil mineral N levels were as high as 26 μg/g at site 7 and pasture growth exceeded 17000 kg DM/ha indicates that mineral N limited pasture growth at all sites. Sakadevan 1991 also found a strong positive relationship between mineral N and pasture growth. As with the present study, these authors found little data to suggest that N was becoming non-limiting.

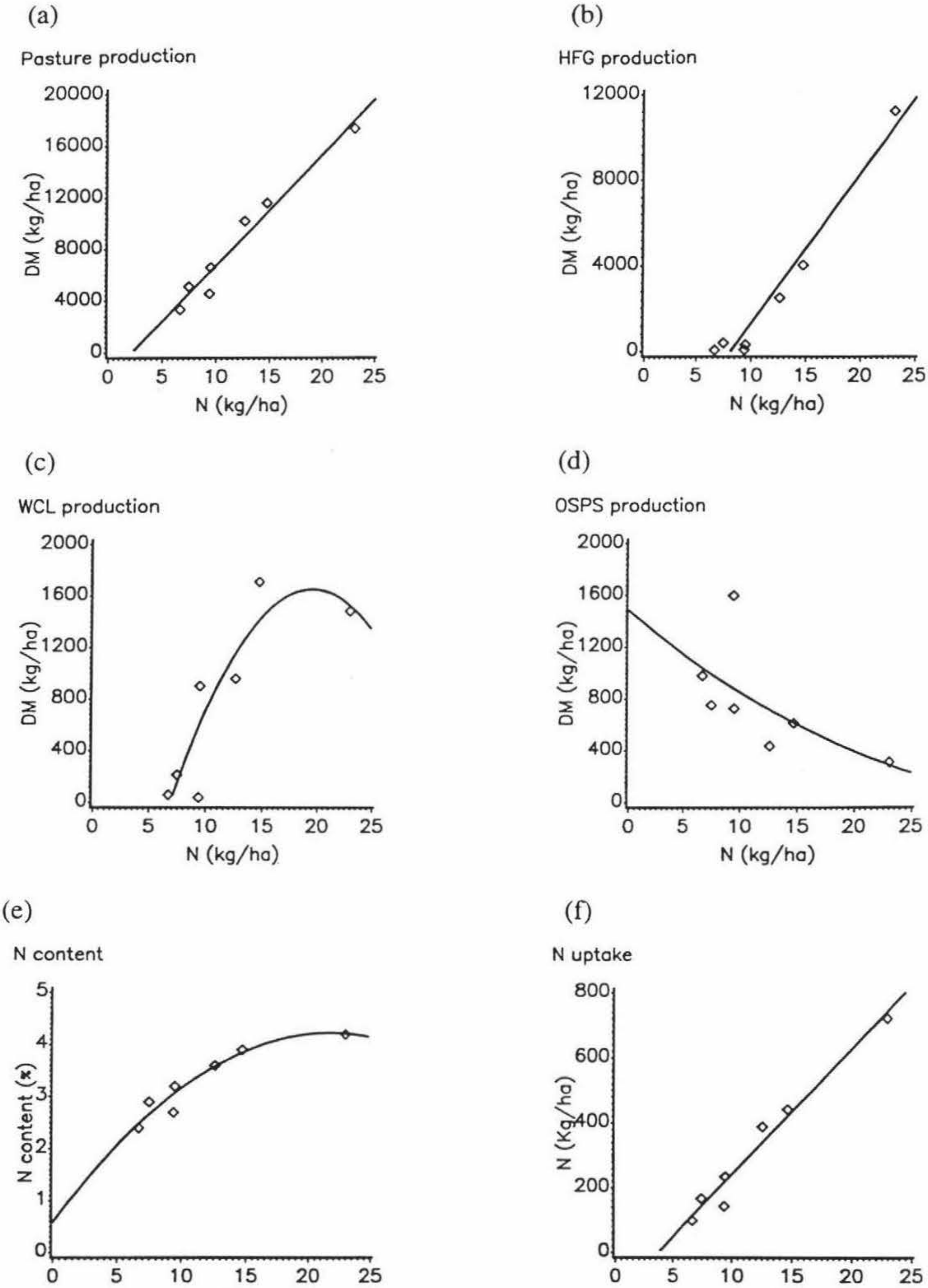


Figure 6.5 Relationship between mean annual mineral N and (a) annual pasture production, (b) HFG production, (c) white clover production (d) OSPS production, (e) N content and (f) N accumulation by pasture assessed by 4 weekly cutting. Parameters of the linear and quadratic regressions are given in Appendix 6.2.

Close relationships were found between mean annual mineral N levels in soil, which ranged from less than 10 to nearly 25 kg N/ha in the upper 75 mm of soil and HFG production, N concentration and N accumulation (Fig. 6.5). Despite the high mineral N contents measured at site 7, the only suggestion that N was becoming non-limiting was found in the N concentration of pasture which reached a peak (4.0 to 4.2% of N) at sites 6 and 7. The shape of the regression curve between mineral N levels and white clover production was probably related to the high mineral N levels in site 7, that had a negative effect on white clover.

The increase in the HFG content of pasture as mineral N levels increase was paralleled by a decline in the contribution of OSPS. At the high fertility sites where the N concentration of the pasture reached a maximum (4.2% N), the increase in HFG content continued to lift the productive capability of the sward and total N accumulation.

6.3.2 Olsen and Resin P as indices of soil fertility

6.3.2.1 Monthly Olsen P and Resin P levels

Since the temporal differences in both Olsen and Resin P were relatively small a close relationship was found between monthly Olsen and Resin P and annual pasture production assessed by either 2 or 4-weekly cuts. (Appendix 6.3 and Fig. 6.6). Since results for both cutting regimes were similar only 4-weekly pasture production is presented. With the exception of October and November (when fertiliser was applied), parameters of the regression lines for mean monthly Olsen P values on annual pasture production did not differ greatly. Since the Resin P was less affected by fertiliser than Olsen P the relationship between mean monthly Resin P and annual pasture production was similar in all months. Except for the months immediately following topdressing, there does not appear to be any time during the year when indices used for assessing soil fertility status are more sensitive.

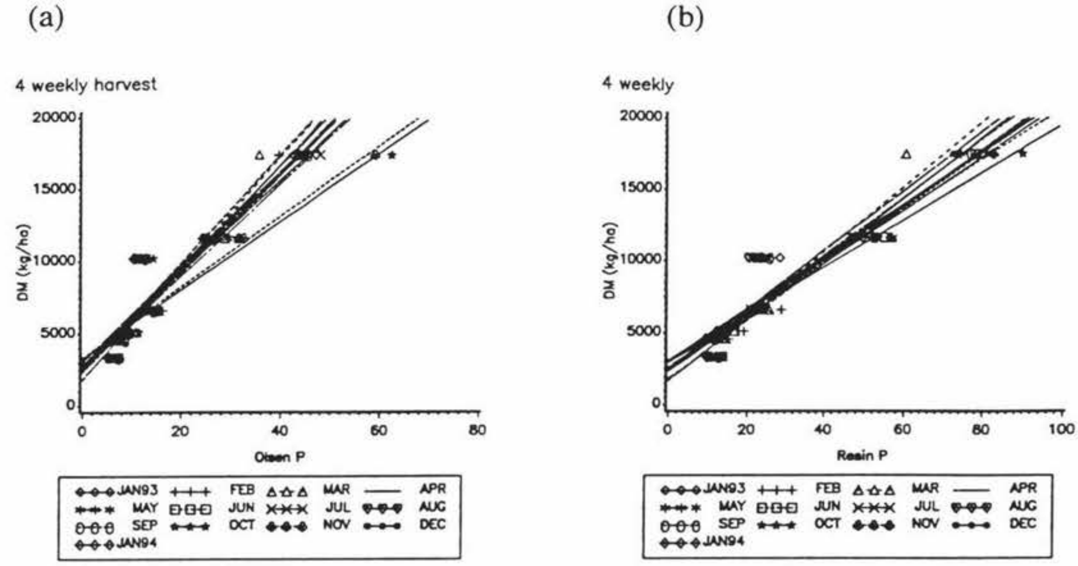


Figure 6.6 Relationship between (a) monthly Olsen P level and (b) monthly Resin P level and annual pasture production.

6.3.2.2 Mean seasonal Olsen P and Resin P levels

Relationships between mean seasonal Olsen and Resin P means and annual pasture growth show the same characteristics as the monthly means. The relationships (r^2) did not improve with the use of seasonal means instead of monthly means as had occurred with mineral N measurements (Appendix 6.4).

Table 6.3 Parameters for the regressions between seasonal Olsen and Resin P, (kg/ha) and annual pasture yields assessed by 4 weekly cuts.

	Intercept		**Linear coef**		**r^2**	
	Olsen	**Resin**	**Olsen**	**Resin**	**Olsen**	**Resin**
Summer	1503 *	1501 NS	120 **	65 **	0.84	0.86
Autumn	-30 NS	-90 NS	85 **	48 **	0.87	0.89
Winter	149 *	148 *	27 **	16 **	0.96	0.98
Spring	1015	894 *	91 **	62 **	0.87	0.91

In contrast to the strong linear relationship found between soil mineral N and annual pasture production, fitting of a quadratic or exponential function ($y=A * (1-e^{-cx})$ where "A" is the asymptote and "c" the curvature coefficient) to the soil P indices of soil fertility and pasture growth improved the fit (linear r^2 0.88 and 0.91; quadratic $r^2=0.89$ and 0.91; and exponential $r^2= 0.93$ and 0.94 for Olsen and Resin P, respectively). While the differences in the goodness of fit between the models are not significant, the quadratic and exponential models appear to better describe the changes in pasture growth and soil P levels of the systems under investigation. This tendency is particularly clear in spring and summer (Fig. 6.7) indicating that at least in spring and summer, soil P was not limiting further increases in pasture growth at the most fertile sites. In winter, however, a strong linear regression explained most of the variation between Olsen and Resin P as indices of fertility and pasture production, suggesting that winter growth was limited by available P at all sites. Assessment of pasture growth at this time of the year would appear to provide a more sensitive indicator of soil nutrient availability than the use of pasture growth responses at other times of the year. The absolute pasture growth response to Olsen and Resin P was greatest in spring and summer and least in autumn and winter (Fig. 6.7).

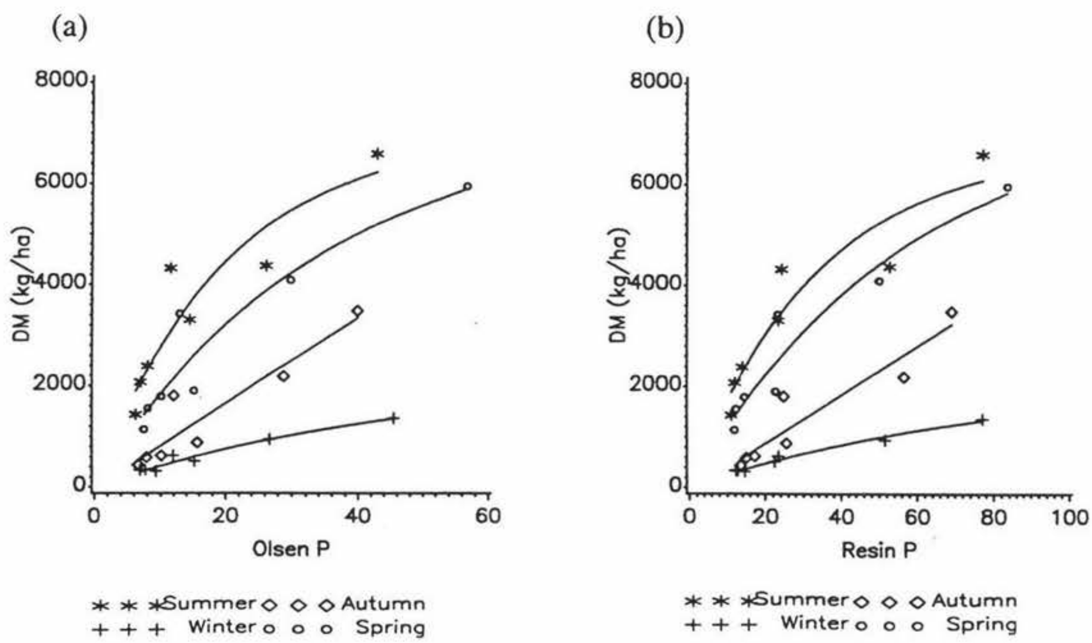


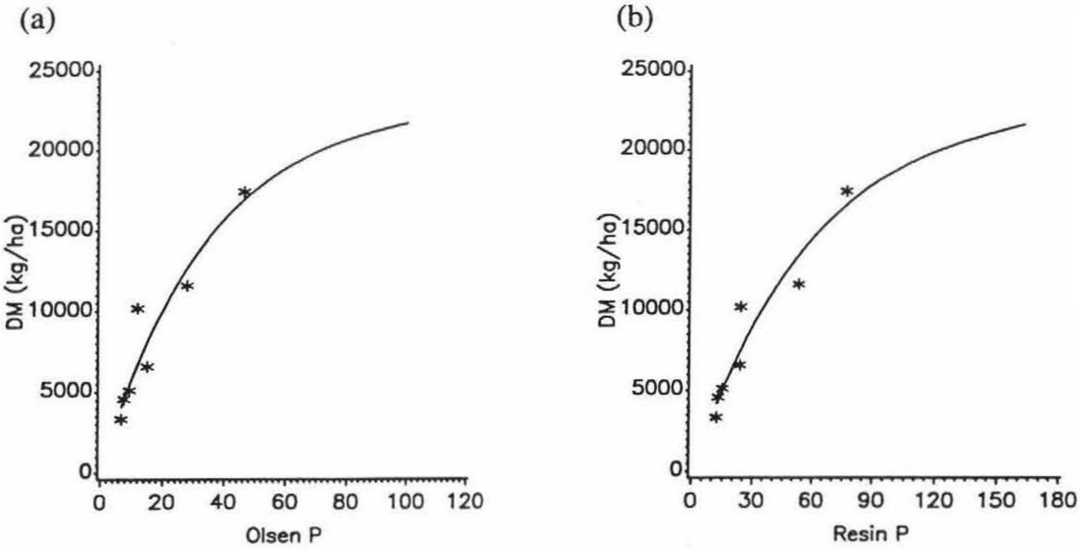
Figure 6.7 Relationship between (a) mean seasonal Olsen P level and (b) mean seasonal Resin P and seasonal pasture production.

The critical Olsen P value for 95% of maximum growth in winter, spring and summer were 143, 103 and 60 μg/cc of soil, respectively, based on the exponential equation. The equivalent values for Resin P were 250, 176 and 100. If site 7 was removed from the analysis then the Olsen P values for 95% of maximum yield were 230, 125, 83 and 36 in autumn, winter, spring and summer, respectively. It is likely, however, that at these sites (particularly the campsites) there is a strong interaction between available N and P which makes it difficult to dissociate the effect of both nutrients on plant growth. Considering that New Zealand pastures have been reported as N deficient once P limitation is removed (Smith and Cornforth 1981) the 5000 kg DM/ha increase in annual pasture production from site 6 (Olsen P=27.9 μg/cc) to site 7 (Olsen P=46.3 μg/cc) may not reflect a response to P availability, but to a combined effect of N and P availability. Therefore the critical values for Olsen and Resin P mentioned above appear to be unrealistic and mainly due to the interaction between N and P that occurs in soils following pasture development. However for the conditions of this study the critical Olsen P value of 20 μg/g soil does not seem to be adequate.

6.3.2.3 Mean annual Olsen and Resin P values

The relationship between mean annual Olsen and Resin P and annual pasture production could be described by a exponential function. Using this exponential function the Olsen P value for 95% of a maximum yield of 23030 kg/ha (Fig. 6.8) was 103. For Resin P the equivalent value was 187 μg/cc of soil. For pastures on a sedimentary soil (low P retention capacity) the Olsen P for 95% of maximum pasture production is set at 20 μg/g of soil (Morton *et al*, 1994). The unrealistically high maximum yield predicted by the exponential function contributed to the very high critical soil test levels.

Only in spring and summer, and only when site 7 was excluded did the Olsen P value for 95% maximum yield approach the value of 20 μg/g, the value at which pastures are thought to reach 95% of maximum yield for sedimentary soils in the lower half of the North Island of New Zealand (Morton *et al*, 1994). When site 7 was excluded critical Olsen P value for 95% of maximum yield was 54 μg/cc (Fig. 6.9).



$Y = 23027\ (1-e^{-0.029x})$ $Y = 23131\ (1-e^{-0.016x})$

Figure 6.8 Relationship between annual pasture production and (a) annual mean for Olsen P and (b) annual mean for Resin P.

When the exponential model was fitted for legume growth, P levels for 95% of maximum legume production were lower than those calculated for total production (73 and 138 µg/cc for Olsen and Resin P, respectively).

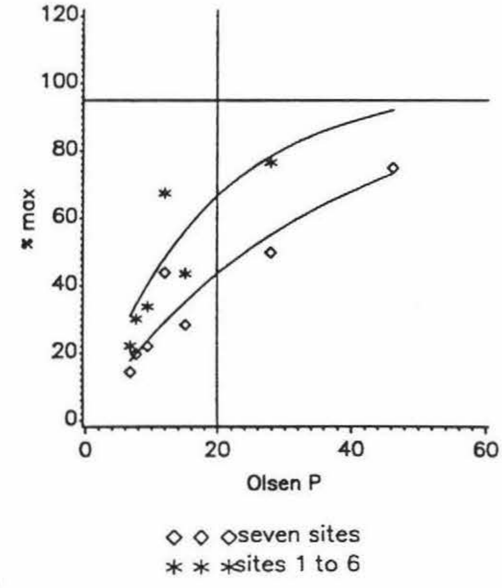


Figure 6.9 Relationship between Olsen P and relative pasture production.

A good linear relationship was found between high fertility responsive grass (HFG) production and soil P status (r^2=0.93 and 0.91 for Olsen and Resin P, respectively) and the proportion of HFG in the sward (r^2=0.93 and 0.91 for Olsen and Resin P, respectively) (Fig. 6.10 and Appendix 6.5). There was no suggestion that HFG production reached a plateau at site 7, but rather that further increases in P availability would result in further increase in the contribution made by HFG to total production (Fig. 6.10). At sites 6 and 7 the HFG component accounted for 35 and 64% of total production, indicating that there was considerable scope for further increases in pasture growth. The non linear relationship between white clover production and available P (r^2= 0.95 and 0.99 for Olsen and Resin P, respectively) (Fig. 6.10) was a function of not only the high soil mineral N levels at site 7, but also of the effect of competition from HFG for light and space. The Olsen and Resin P values calculated at maximum legume yields were 34 and 56 µg/cc of soil, respectively. The negative relationship that was found between OSPS and Olsen and Resin P can be related to the ability of these species to colonize sites when the productive pasture species are under nutrient stress.

A non-linear relationship was found between Olsen and Resin P and P% in the pasture (Fig. 6.11), indicating that as available P increased the P concentration of pastures reached a maximum. In many calibration experiments (eg Grigg, 1967 and Mackay *et al,* 1984) indices of P availability are commonly regressed against P uptake, as uptake data appears to be less affected by environmental factors than pasture yield, and is thus more sensitive in assessment of the effectiveness of indices for forecasting the size of the available P pool. The results from this experiment support this view, since Olsen and Resin P values were more highly correlated with P uptake by pasture than with annual pasture production (r^2=0.94 and 0.97 for Olsen and Resin P, respectively). The linear regression between both indices (Fig. 6.11) and P uptake suggests that further increases in soil fertility would result in greater uptake and growth of high fertility responsive grasses.

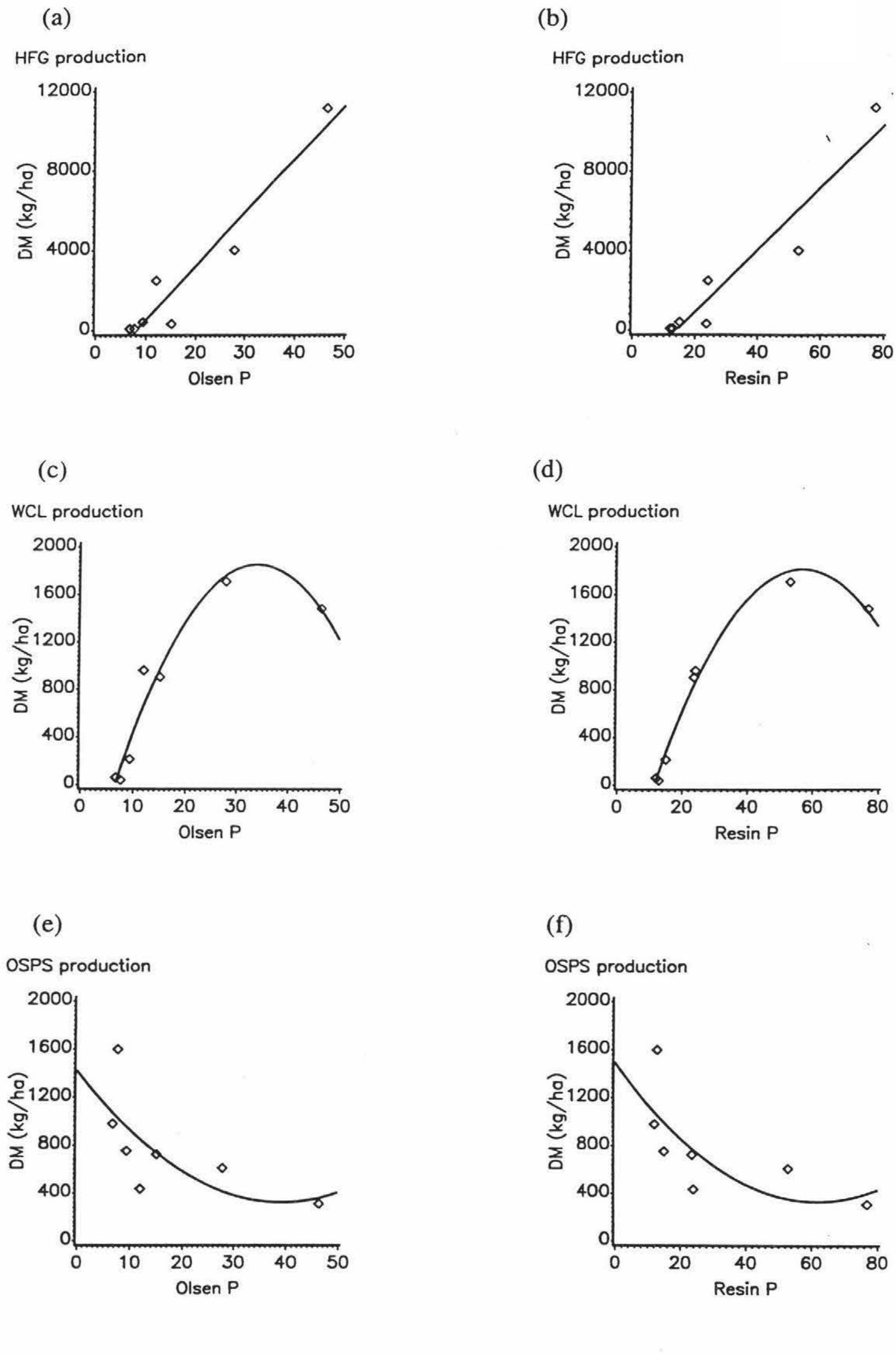


Figure 6.10 Relationship between (a) Olsen P and HFG production, (b) Resin P and HFG production, (c) Olsen P and WCL production, (d) Resin P and WCL production, (e) Olsen P and OSPS production and (f) Resin P and OSPS production.

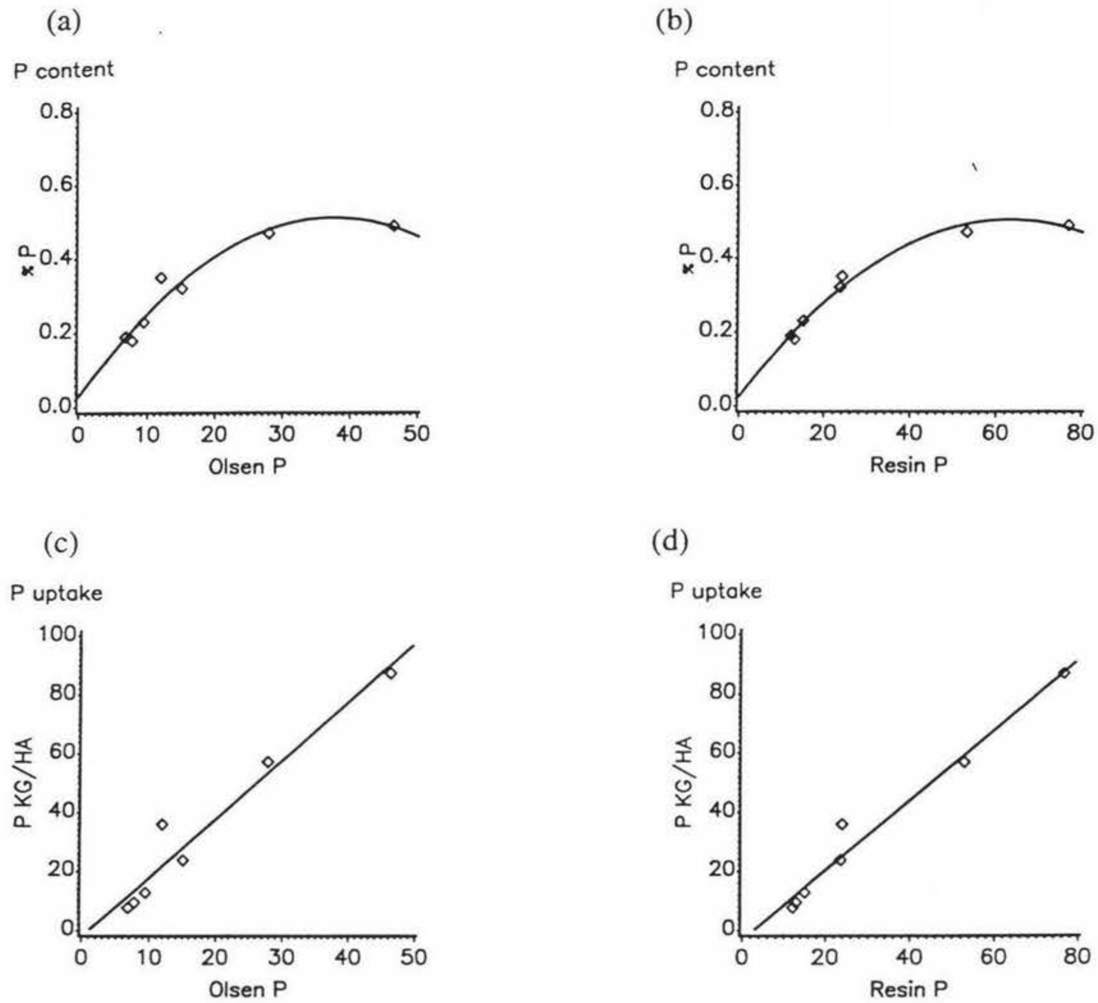


Figure 6.11 Relationship between (a) Olsen P and pasture P content, (b) Resin P and pasture P content, (c) Olsen P and P uptake and (f) Resin P and P uptake.

6.3.3 Relationship between Nitrogen fixation and soil Phosphorus

The close quadratic relationship between fixed N and available soil P (for both Olsen and Resin P) of the different soils (Table 6.4 and Fig 6.12) indicates that although N fixation was highly dependent on P availability at low P levels, there was a threshold at high P levels where P was no longer limiting biological N fixation. However, it is not possible to establish a causal relationship between high P levels and the drop in N fixation because the drop in N fixation that occurred in site 7 was probably a response to the effect of other associated factors on legume growth (high N inputs, competition from HFG, treading) rather than P availability.

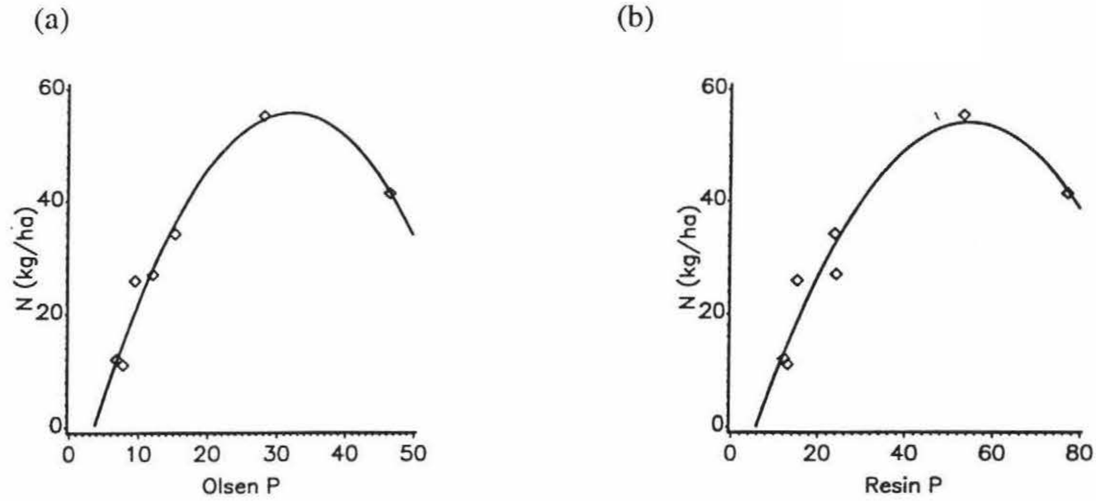


Figure 6.12 Relationship between (a) Olsen P and (b) Resin P and the biological fixation of N.

Table 6.4 Relationship between Olsen P (μg/cc) and Resin P (μg/cc) and fixed N (kg/ha) for the seven sites.

	Intercept	Linear coef	Quadratic coef.	r^2
Olsen P	-15.4 *	4.45 **	-0.07 **	0.96
Resin P	-14.4 NS	2.53 **	-0.02 **	0.93

6.4 PLANT MEASUREMENTS

6.4.1 Plant analysis

Plant analysis for P was at least as effective as available soil P for predicting pasture production. While the N content of pastures accounted for less of the variation in pasture growth (r^2 =0.92) than soil mineral N levels, this was counteracted by the much lower variation in plant N content through the year (coefficients of variation from 10.0% in site 1 to 13.4% in site 6) than in soil mineral N (coefficients of variation from 35.9% in site 2 to 50.0% in site 4).

While it was expected the relationship between N concentration and pasture yield would follow a straight line because the N concentrations of pastures at all sites were in the deficient and low ranges (Cornforth, 1984), it was unexpected that the P concentrations in pastures would be linearly related to pasture growth, since only three sites were in the deficient region for P and two of them had values over the optimum (Table 6.5 and Fig. 6.13).

Table 6.5 Relationship between pasture yield (kg/ha) and mean annual N and P concentrations mixed pasture.

	Intercept	Linear coef.	r^2
N content (%)	-15444 **	7290.4 **	0.92
P content (%)	-3283 NS	37000 **	0.88

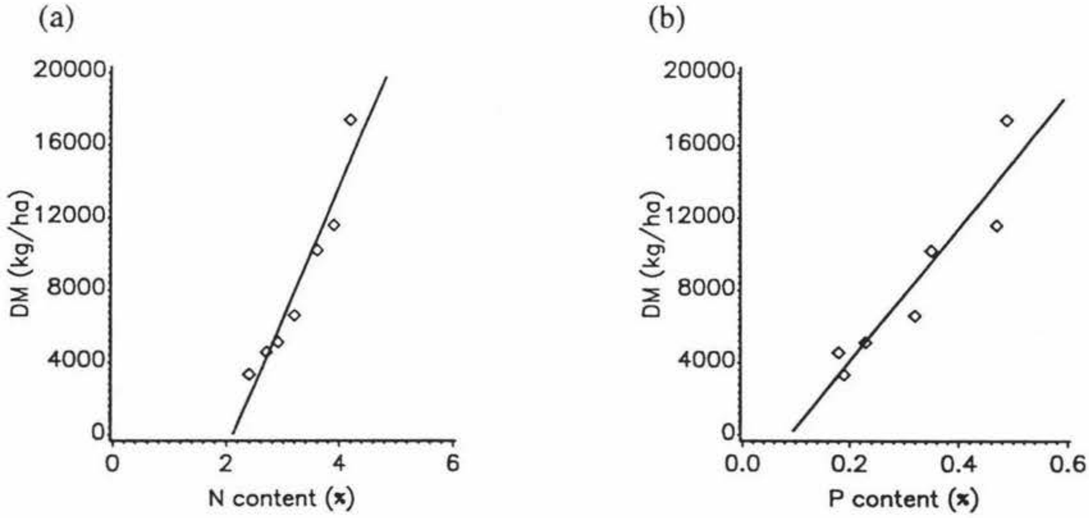
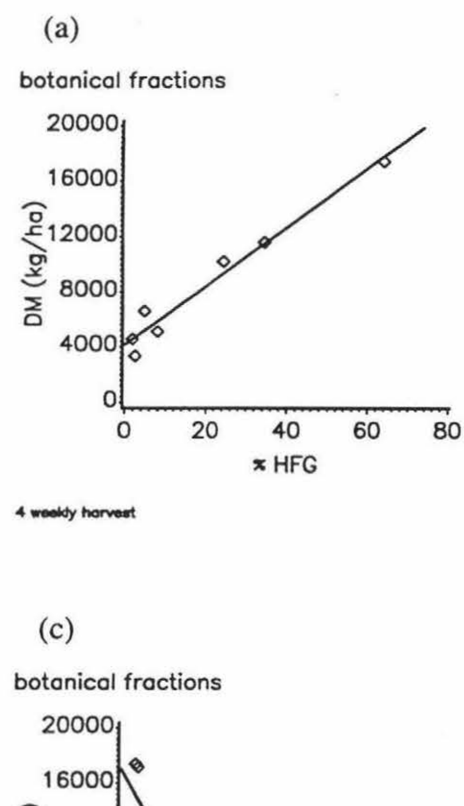
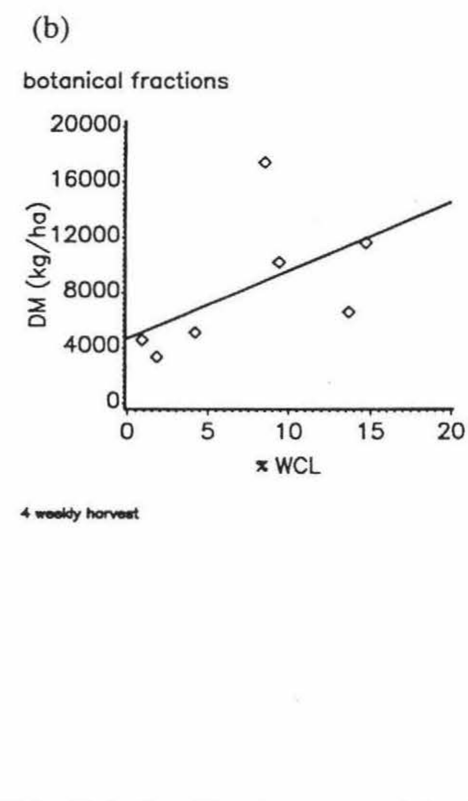


Figure 6.13 Relationship between pasture production and (a) pasture N and (b) pasture P content.

6.4.2 Relationship between components of pasture growth and annual pasture production

Of the pasture components separated in the 4-weekly cuts, the closest relationship between pasture components and annual pasture growth corresponded to HFG proportion (r^2=0.96) (Fig. 6.14 and Table 6.6). The HFG component of the sward, which was made up mainly of ryegrass and poa in this study provides a simple and quick method for assessing the productive capacity of the sward. In conjunction with indices of soil fertility, a measure of the productive capability of the sward using indicator species offers another index of the productive capability of a sward of unknown history. A strong negative relationship was found when OSPS proportion was used to assess the changes in pasture production (Fig 6.14).





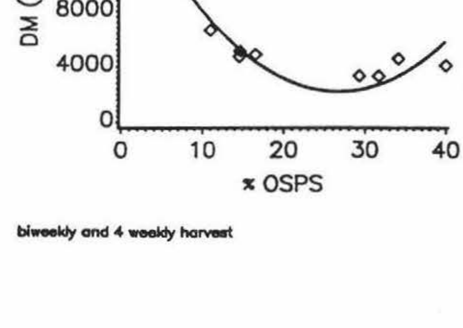


Figure 6.14 Relationship between (a) % HFG, (b) % WCL and (c) % OSPS and annual pasture production.

Table 6.6 Relationship between pasture production (kg/ha) and pasture botanical composition (%).

Pasture component	Intercept	Linear coef.	Quadratic coef.	r^2
HFG %	4.14 **	0.21 **		0.96
WCL %	4.7 NS	0.49 NS		0.29
OSPS %	17.7 **	-1.3 **	0.03 **	0.93

6.5 CONCLUSIONS

There was a strong positive relationship between soil total nutrient content (%C, %N, %P) of the soils and the indices of soil fertility (mineral N, Olsen P and Resin P). Mean seasonal mineral soil N was closely related to seasonal pasture growth in all seasons, except autumn. Mean monthly and seasonal mineral soil N values were also closely related to annual pasture production, however, the intercept and slope of the linear regressions varied widely between the different measurements, with spring and summer measurements being the most reliable predictors of annual production. The strong linear nature of the relationship between pasture production and mineral N indicated that N was limiting pasture growth over the range of soils studied. Soil mineral N was also related to pasture composition, with a strong positive linear relationship between this index and high fertility responsive grasses production and content and a negative relationship with weeds production and content. Soil mineral N was not related to white clover production or content.

There were no important differences between the two soil P indices studied (Olsen P and Resin P) when the relationships of these indices and pasture parameters was examined. Soil P fertility indices were strongly related to pasture growth. Due to the small variability of these indices throughout the year, relationships between Olsen and Resin P and total pasture production were in general independent from the sampling time, with the exception of the sampling immediately following P fertiliser application. In contrast to mineral N that was linearly related to pasture growth, P indices showed a tendency for decreasing responses at high P levels in spring and summer and in annual pasture production.

Estimated P levels for 95% of maximum growth were extremely high (103 and 187 μg/cc for Olsen and Resin P respectively). These values are well above the commonly used critical Olsen P level for these soils (20 μg/g). However, the shape of the response curve in this study may be affected by the combined effect of available P and N at the high fertility sites. Indices of P fertility were also related to pasture composition, with a strong positive linear relationship with high fertility grass production, aquadratic relationship with white clover production and negative relationships with weed production and content.

This study suggests that in hill country pastures Olsen P and Resin P values may be satisfactory indicators of pasture productivity for animal production models. However, pasture production will continue to increase to much higher P levels than are normally associated with maximum production in conventional P fertiliser trials. This is because of the linkage of N and P in animal excreta resulting in a high nitrogen status in those areas of hill country that also have high P.

Both N and P content of the mixed pasture samples were strongly linearly related to pasture production. While this was expected with N, because the N contents of pastures at all sites were in the deficient and low range, it was unexpected with P, as only 3 sites were in the deficient region for P and the P concentration values at two of the sites were in the optimum range. The use of N and P concentrations in mixed pasture samples appears to be a valuable tool for predicting pasture production since N and P concentrations varied very little throughout the year.

Pasture botanical composition, particularly the high fertility responsive grasses percentage of the sward, was a good indicator of nutrient status of the different sites, being strongly related to total pasture production.

CHAPTER 7

SUMMARY & CONCLUSIONS

1) Single nutrient indices of soil fertility have been used extensively as tools for assessing nutrient requirements and for predicting annual pasture production. Use of such indices for examining how the components of and seasonality of pasture growth change with changing nutrient status has received little if any attention. Establishing the relationship between soil fertility and the seasonality of forage supply is becoming increasingly important with the increasing use of models such as Stockpol, that match pasture growth and livestock production, for decision making in the pastoral sector.

2) Seven hill country pasture sites varying in fertilizer history and position on the landscape were used to examine the relationship between soil fertility, measured using a number of indices, and the components of and seasonality of forage supply of grazed hill pastures. The effect of time of sampling, fertilizer history, and position on the landscape, as it influences nutrient return in dung and urine on the ability of soil (mineral nitrogen, Olsen and Resin P) and plant indices (herbage N and P concentrations and the proportions of botanical fractions) to assess nutrient supply was also studied.

3) The sites varied from an undeveloped, unfertilized hill pasture containing only low fertility adapted grasses and weeds (sites 2 and 4) to a highly productive sward with a high proportion of high fertility responsive grasses and white clover (sites 6 and 7). The total C content of the soils varied from 4.7 to 7.2%, N content varied from 0.43 to 0.70% and P content from 517 to 1361 mg l^{-1}. The soils under study covered a sufficiently diverse range of physical and chemical properties to examine the relationship between soil fertility and seasonality of forage supply and to test the robustness of the soil fertility indices under the range of conditions likely to be found in pastoral systems.

4) Soils of the seven sites were sampled biweekly for determination of mineral N (NO_3^-– NH_4^+) and Olsen and Resin P for 12 months starting in January 1993. In each season microbial C, N and P was also measured at each site. The seasonality of pasture growth and the components of pasture growth at each site, were assessed by both biweekly and 4-weekly cuts throughout the 12 months of measurements, as were the N and P concentrations of mixed pasture.

5) Ammonium was the dominant form of soil mineral N at all but one of the sites. The exception was the site with the highest overall soil fertility. All sites showed similar seasonal patterns for soil mineral N, with the lowest content in winter and the highest in summer. Differences between sites were mainly due to differences in NO_3^- content.

6) There was a good relationship between Olsen P and Resin P measurements (r^2 = 0.94), indicating that both techniques extracted P proportionally from the same soil pools. Olsen P values at the seven sites ranged from 7.7 to 46.3 and Resin P values from 12.2 to 76.7. Temporal changes in Olsen and Resin P values were small with no apparent seasonal pattern to the changes.

7) Microbial C and N content and the microbial C:N ratio varied little throughout the year. In contrast there was a marked seasonal pattern for microbial P with microbial P content being greater in spring and summer than in autumn and winter. There was an interaction between season, soil fertility and microbial P and the microbial C:P ratio. In addition to a decrease in microbial C:P ratio as soil fertility increased, the temporal differences in microbial C:P ratios also decreased with increasing fertility. No clear seasonal pattern was found for the metabolic quotient of the microbial population. While the ranking of soils in terms of microbial C varied throughout the studied period, the ranking of soils if microbial P content was considered comprised three groups: 1) sites 2, 3 and 4 showed the lowest microbial P contents, 2) sites 1, 5 and 6 showed medium microbial P contents and 3) site 7 showed very high microbial P content.

8) Annual pasture production varied more than 5-fold across the 7 field sites used to examine the relationship between soil fertility and pasture growth. Actual production ranged from 3300 to 17000 kg DM/ha. There was little difference in annual pasture production between 2- and 4-weekly cutting regimes at most of the sites. This has important implications to the conduct of field trials where it is desired to assess pasture production under continuous grazing. The results of this study suggest that cutting cages at 4-weekly intervals may be as good as a more labour-intensive biweekly cutting regime.

9) Grasses adapted to low fertility environments were the dominant botanical fraction of pasture at all sites with the exception of site 7. High fertility responsive grass production followed the same trend as pasture production being almost negligible at sites 2 and 4. Legume production was extremely low at sites 2 and 4 but did not follow the same trend as pasture production, reaching a maximum at one of the medium production sites. Weeds accounted for a significant proportion of total production only at pastures from sites 2 and 4.

10) Seasonal patterns of pasture production were similar for all sites with spring and summer production representing more than 70% of annual production. The lowest pasture growth rates (less than 3 kg DM/ha/day) were recorded in late winter and the highest growth rates were recorded in mid summer (105 kg DM/ha/day). Seasonality of pasture growth was not affected by cutting frequency. Interestingly, pasture growth increased to a similar extent in each season as soil fertility increased, so that while winter pasture growth rates ranged from 3.3 to 15.9 kg DM/ha/day as soil fertility increased, a similar percentage increase occurred in the other seasons.

11) Pasture N concentrations, followed the same trends as pasture growth, being highest at sites with high pasture production. The herbage N concentrations were below critical levels in most sites. While biweekly-cut pastures tended to accumulate more N, no significant interaction was found between N accumulation, soil fertility and cutting regime.

12) Phosphorus concentrations were within the adequate range for most sites, and were generally higher at sites with high pasture production and lower at sites with low pasture production. There were no differences in P accumulation between the 2 cutting frequencies. Differences in P uptake by pasture were far greater (nearly 10-fold) than differences in pasture production.

13) There was a strong positive relationship between total nutrient content (%C, %N, %P) of the soils and the soil indices of fertility (mineral N, Olsen P and Resin P).

14) Except in autumn, mean seasonal mineral soil N values were closely related to seasonal pasture growth. Mean monthly and seasonal mineral soil N values were closely related to annual pasture production measurements, with spring and summer measurements being the most reliable predictors of annual production. The strong linear nature of the relationship between pasture production and mineral N indicated that N was limiting pasture growth over the range of soils studied. Soil mineral N was also related to pasture composition, with a strong positive linear relationship between this index and high fertility responsive grasses production and content and a negative relationship with weeds production and content. Soil mineral N was not related to white clover production or content.

15) Soil P fertility indices were strongly related to pasture growth although pasture growth appeared to be reaching a plateau at high P levels. Due to the small variability of these indices throughout the year, relationships between Olsen P and Resin P and total pasture production were independent of sampling time, with the exception of the sampling immediately following P fertiliser application. In contrast to mineral N that was linearly related to pasture growth, P indices showed a tendency for decreasing responses at high P levels in spring and summer and in annual pasture production.

16) Estimated P levels for 95% of maximum growth were extremely high (103 and 187 μg/cc for Olsen P and Resin P, respectively). These indices are much greater than the commonly used critical level for Olsen P in these soils (20 μg/g). However, the shape of the response curve in this study may be affected by the combined effect of available P and N at the high fertility sites. Indices of P fertility were also related to pasture composition, with a strong positive linear relationship with high fertility responsive grass production, a quadratic relationship with white clover production and a negative relationship with weed production and content.

17) This study suggests that in hill country pastures, Olsen P and Resin P values may be satisfactory indicators of pasture productivity for animal production models. However, pasture production will continue to increase to much higher P levels than are normally associated with maximum production in conventional P fertiliser trials. This is because of the linkage of N and P in animal excreta resulting in a high nitrogen status in those areas of hill country that also have high P.

18) Both N and P content of the mixed pasture samples were strongly linearly related to pasture production, although N content was in the deficiency range and P content at adequate levels at most sites.

19) Pasture botanical composition was a good indicator of nutrient status of the different sites, particularly the high fertility responsive grass production that was strongly related to total pasture production.

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Appendix 4.2: Gravimetric soil water content (g water/100g soil) at each site at each sampling date 1=22/1/93 2= 5/2/93 3=19/2/93 4=5/3/93 5=19/3/93 6=2/4/93 7=16/4/93 8=30/4/93 9=14/5/93 10=28/5/93 11=11/6/93 12=25/6/93 13=9/7/93 14=23/7/93 15=6/8/93 16=20/8/93 17=3/9/93 18=17/9/93 19=1/10/93 20=18/10/93 21=1/11/93 22=15/11/93 23=29/11/93 24=13/12/93 25=23/12/93 26=10/1/94 27=25/1/94

site	date	g w/100 g
1	1	22.57
1	2	19.45
1	3	16.26
1	3	16.26
1	4	25.71
1	5	24.00
1	6	27.02
1	7	30.78
1	8	27.16
1	9	31.93
1	4	25.71
1	5	24.00
1	6	27.02
1	7	30.78
1	8	27.16
1	9	31.93
1	10	32.27
1	11	37.22
1	12	31.58
1	13	39.28
1	14	32.21
1	15	34.93
1	16	33.15
1	17	30.66
1	18	36.33
1	19	34.89
1	20	23.80
1	21	26.49
1	22	16.39
1	23	29.64
1	24	28.87
1	25	28.87
1	26	25.99
1	27	20.42
1	28	22.08
2	1	45.75
2	2	42.07
2	3	28.99
2	4	48.31
2	5	58.38
2	6	41.63
2	7	51.69
2	8	53.99
2	9	49.67
2	10	43.69
2	11	56.27
2	12	51.29

2	13	61.09
2	14	59.65
2	15	55.50
2	16	59.97
2	17	46.22
2	18	53.63
2	19	57.78
2	20	53.28
2	21	40.84
2	22	41.46
2	23	56.27
2	24	54.99
2	25	54.62
2	26	35.31
2	27	32.41
3	1	36.80
3	2	31.20
3	3	28.38
3	4	40.86
3	5	46.95
3	6	45.46
3	7	52.62
3	8	50.59
3	9	50.54
3	10	37.66
3	11	51.83
3	12	54.00
3	13	45.03
3	14	53.14
3	15	53.10
3	16	56.19
3	17	48.90
3	18	55.85
3	19	54.37
3	20	52.14
3	21	40.85
3	22	37.25
3	23	52.66
3	24	46.34
3	25	39.60
3	26	29.72
3	27	32.59
4	1	52.00
4	2	40.33
4	3	40.79
4	4	59.54
4	5	71.06
4	6	50.62
4	7	62.91
4	8	65.19
4	9	62.96
4	10	47.51
4	11	68.56
4	12	67.18
4	13	74.56
4	14	78.87

4	15	68.97
4	16	70.59
4	17	66.64
4	18	70.00
4	19	71.49
4	20	68.45
4	21	64.31
4	22	53.26
4	23	64.72
4	24	63.26
4	25	69.92
4	26	39.61
4	27	43.62
5	1	40.66
5	2	31.74
5	3	31.01
5	4	47.74
5	5	50.82
5	6	36.70
5	7	52.91
5	8	55.66
5	9	51.05
5	10	40.12
5	11	60.15
5	12	50.46
5	13	51.81
5	14	63.64
5	15	60.50
5	16	62.11
5	17	57.36
5	18	62.22
5	19	63.66
5	20	59.56
5	21	49.73
5	22	49.74
5	23	57.03
5	24	52.38
5	25	45.35
5	26	29.94
5	27	31.53
6	1	30.91
6	2	28.19
6	3	24.57
6	4	38.98
6	5	38.80
6	6	34.05
6	7	45.34
6	8	44.42
6	9	46.07
6	10	37.04
6	11	51.58
6	12	52.53
6	13	52.20
6	14	50.10
6	15	50.48
6	16	55.44

6	17	43.44
6	18	50.66
6	19	53.61
6	20	46.13
6	21	38.48
6	22	33.92
6	23	45.85
6	24	42.81
6	25	41.73
6	26	26.15
6	27	29.53
7	1	43.58
7	2	38.64
7	3	35.00
7	4	47.98
7	5	54.10
7	6	36.58
7	7	58.12
7	8	60.61
7	9	56.42
7	10	47.90
7	11	63.86
7	12	70.32
7	13	67.62
7	14	71.42
7	15	62.79
7	16	71.36
7	17	65.08
7	18	66.82
7	19	66.99
7	20	67.70
7	21	67.53
7	22	52.61
7	23	59.20
7	24	56.75
7	25	48.20
7	26	33.66
7	27	36.84

Appendix 4.3: Mineral N. (Ammonium N (μg/g), nitrate N (μg/g), total mineral N (μg/g), ammonium (kg/ha), nitrate (kg/ha) and total mineral N (kg/ha))at each site at each sampling date. Samping date 1= 5/2/93 2=19/2/93 3=5/3/93 4=19/3/93 5=2/4/93 6=16/4/93 7=30/4/93 8=14/5/93 9=28/5/93 10=11/6/93 11=25/6/93 12=9/7/93 13=23/7/93 14=6/8/93 15=20/8/93 16=3/9/93 17=17/9/93 18=1/10/93 19=18/10/93 20=1/11/93 21=15/11/93 22=29/11/93 23=13/12/93 24=23/12/93 25=10/1/94 26=25/1/94 27=712194

site	date	NH_4 (μg/g)	NO_3 (μg/g)	Min N (μg/g)	NH_4 kg/ha	NO_3 kg/ha	Min N kg/ha
1	1	14.4	2.5	16.9	12.2	2.1	14.3
1	2	10.5	2.4	12.8	8.9	2.0	10.9
1	3	11.9	1.2	13.1	10.1	1.0	11.0
1	4	9.7	2.8	12.4	8.2	2.3	10.5
1	5	5.6	2.4	7.9	4.7	2.0	6.8
1	6	10.2	2.9	13.0	8.6	2.5	11.1
1	7	7.8	2.3	10.1	6.6	2.0	8.6
1	8	5.4	2.5	7.9	4.6	2.1	6.7
1	9	4.0	1.3	5.3	3.4	1.1	4.5
1	10	21.8	1.3	23.1	18.4	1.1	19.5
1	11	4.6	0.4	5.0	3.9	0.3	4.2
1	12	24.7	1.3	26.0	20.9	1.1	22.0
1	13	5.9	1.7	7.7	5.0	1.4	6.4
1	14	11.2	0.0	11.2	9.5	0.0	9.5
1	15	12.1	0.0	12.1	10.2	0.0	10.2
1	16	11.0	0.0	11.0	9.3	0.0	9.3
1	17	10.1	1.3	11.4	8.5	1.1	9.6
1	18	9.2	0.0	9.2	7.7	0.0	7.7
1	19	12.5	0.7	13.2	10.5	0.6	11.1
1	20	9.9	0.0	9.9	8.3	0.0	8.3
1	21	12.8	3.8	16.6	10.8	3.2	14.0
1	22	10.9	0.0	10.9	9.2	0.0	9.2
1	23	20.7	0.0	20.7	17.5	0.0	17.5
1	24	18.2	4.2	22.4	15.3	3.5	18.8
1	25	16.6	2.8	19.4	14.0	2.3	16.4
1	26	21.7	3.8	25.5	18.3	3.2	21.5
1	27	17.4	3.1	20.4	14.7	2.6	17.3
2	1	20.0	1.5	21.5	17.6	1.4	19.0
2	2	8.3	1.6	9.9	7.4	1.4	8.8
2	3	11.5	1.3	12.8	10.1	1.1	11.3
2	4	23.1	2.5	25.7	20.4	2.2	22.6
2	5	11.1	11.1	22.2	9.8	9.8	19.7
2	6	11.3	2.8	14.2	10.0	2.5	12.5
2	7	5.7	2.5	8.2	5.0	2.2	7.2
2	8	12.5	2.3	14.8	11.0	2.0	13.1
2	9	6.4	1.5	7.9	5.6	1.4	7.0
2	10	7.5	0.7	8.2	6.6	0.6	7.2
2	11	6.6	3.1	9.8	5.9	2.7	8.6
2	12	6.6	1.5	8.1	5.9	1.4	7.2
2	13	13.0	0.8	13.8	11.5	0.7	12.2
2	14	15.4	0.0	15.4	13.6	0.0	13.6
2	15	15.9	0.0	15.9	14.0	0.0	14.0
2	16	12.8	0.0	12.8	11.3	0.0	11.3
2	17	9.9	0.0	9.9	8.7	0.0	8.7

2	18	11.1	0.0	11.1	9.8	0.0	9.8
2	19	14.2	0.0	14.2	12.5	0.0	12.5
2	20	7.8	0.0	7.8	6.9	0.0	6.9
2	21	11.4	2.1	13.5	10.1	1.9	11.9
2	22	11.0	0.7	11.7	9.7	0.6	10.3
2	23	19.1	2.0	21.1	16.9	1.8	18.7
2	24	15.7	4.3	19.9	13.9	3.8	17.7
2	25	16.2	5.0	21.3	14.3	4.4	18.8
2	26	18.3	4.7	23.0	16.1	4.1	20.3
2	27	16.2	4.0	20.2	14.3	3.5	17.9
3	1	15.4	1.4	16.8	14.6	1.4	16.0
3	2	8.5	1.6	10.2	8.1	1.5	9.6
3	3	10.9	1.3	12.2	10.4	1.2	11.6
3	4	7.4	1.6	8.9	7.1	1.5	8.6
3	5	7.3	2.6	9.9	6.9	2.5	9.4
3	6	14.3	2.9	17.2	13.6	2.8	16.4
3	7	5.7	2.3	8.0	5.4	2.2	7.6
3	8	6.0	16.6	22.6	5.7	15.8	21.5
3	9	33.1	1.5	34.6	31.4	1.4	32.9
3	10	5.5	0.7	6.2	5.3	0.7	5.9
3	11	4.4	0.8	5.2	4.2	0.8	5.0
3	12	6.2	0.8	6.9	5.9	0.8	6.6
3	13	3.4	1.1	4.5	3.2	1.1	4.3
3	14	8.0	3.1	11.1	7.6	2.9	10.5
3	15	10.3	0.0	10.3	9.8	0.0	9.8
3	16	9.4	0.8	10.2	8.9	0.8	9.7
3	17	7.8	0.0	7.8	7.4	0.0	7.4
3	18	11.3	0.0	11.3	10.7	0.0	10.7
3	19	8.5	1.2	9.6	8.1	1.1	9.2
3	20	7.8	0.0	7.8	7.4	0.0	7.4
3	21	10.3	0.0	10.3	9.8	0.0	9.8
3	22	11.0	1.4	12.4	10.4	1.4	11.8
3	23	26.1	0.0	26.1	24.8	0.0	24.8
3	24	15.7	5.1	20.8	14.9	4.9	19.8
3	25	15.4	3.5	18.8	14.6	3.3	17.9
3	26	17.5	4.5	22.1	16.7	4.3	20.9
3	27	19.6	5.3	24.9	18.6	5.0	23.6
4	1	14.2	1.7	15.9	14.4	1.7	16.1
4	2	7.4	1.4	8.8	7.5	1.4	8.9
4	3	11.8	1.5	13.3	11.9	1.5	13.4
4	4	6.1	1.4	7.4	6.2	1.4	7.6
4	5	6.8	2.6	9.4	6.9	2.6	9.5
4	6	10.2	2.6	12.8	10.4	2.6	13.0
4	7	6.7	1.8	8.5	6.8	1.8	8.6
4	8	5.8	1.7	7.4	5.9	1.7	7.6
4	9	3.9	24.0	27.9	4.0	24.3	28.3
4	10	6.0	0.7	6.7	6.1	0.7	6.8
4	11	4.6	0.8	5.5	4.7	0.8	5.5
4	12	7.9	2.5	10.4	8.0	2.6	10.6
4	13	3.5	0.9	4.4	3.5	0.9	4.4
4	14	8.9	0.0	8.9	9.0	0.0	9.0
4	15	8.0	0.0	8.0	8.1	0.0	8.1
4	16	9.4	0.0	9.4	9.5	0.0	9.5
4	17	9.2	2.1	11.2	9.3	2.1	11.4
4	18	10.6	0.0	10.6	10.7	0.0	10.7
4	19	12.9	0.9	13.7	13.1	0.9	14.0

4	20	7.0	0.0	7.0	7.1	0.0	7.1
4	21	11.1	0.0	11.1	11.3	0.0	11.3
4	22	11.5	0.0	11.5	11.6	0.0	11.6
4	23	21.4	0.0	21.4	21.7	0.0	21.7
4	24	16.3	4.9	21.2	16.5	5.0	21.5
4	25	17.2	4.7	21.8	17.4	4.8	22.2
4	26	22.9	5.4	28.3	23.2	5.5	28.7
4	27	16.5	6.1	22.6	16.7	6.2	22.9
5	1	21.5	15.1	36.5	19.0	13.4	32.3
5	2	7.4	2.2	9.6	6.5	2.0	8.5
5	3	11.3	3.9	15.2	10.0	3.5	13.4
5	4	6.3	3.6	9.9	5.6	3.2	8.7
5	5	5.7	11.3	17.0	5.0	10.0	15.0
5	6	10.0	3.8	13.8	8.9	3.4	12.2
5	7	6.9	17.4	24.2	6.1	15.4	21.5
5	8	5.4	9.3	14.8	4.8	8.2	13.0
5	9	3.8	2.3	6.0	3.4	2.0	5.4
5	10	4.6	1.4	6.0	4.1	1.2	5.3
5	11	6.2	7.4	13.5	5.5	6.5	12.0
5	12	11.7	3.3	15.1	10.4	2.9	13.3
5	13	5.7	1.5	7.2	5.0	1.4	6.4
5	14	12.5	7.0	19.5	11.0	6.2	17.2
5	15	8.4	8.8	17.3	7.4	7.8	15.2
5	16	8.9	11.8	20.7	7.9	10.4	18.3
5	17	10.2	5.9	16.1	9.0	5.2	14.2
5	18	14.2	0.0	14.2	12.5	0.0	12.5
5	19	11.0	10.2	21.3	9.7	9.0	18.7
5	20	11.4	13.4	24.8	10.1	11.9	21.9
5	21	10.7	12.1	22.8	9.5	10.7	20.1
5	22	13.5	7.8	21.3	11.9	6.9	18.8
5	23	25.5	4.7	30.2	22.5	4.1	26.6
5	24	29.6	6.9	36.5	26.1	6.1	32.2
5	25	14.5	8.4	23.0	12.8	7.4	20.3
5	26	26.5	5.2	31.7	23.4	4.6	28.0
5	27	18.3	11.8	30.1	16.1	10.4	26.6
6	1	18.8	4.8	23.6	16.4	4.2	20.6
6	2	14.4	5.6	20.1	12.5	4.9	17.4
6	3	14.0	2.2	16.1	12.2	2.0	14.2
6	4	6.6	4.1	10.6	5.8	3.6	9.4
6	5	10.8	25.3	36.1	9.5	22.1	31.5
6	6	11.7	3.2	14.9	10.2	2.8	13.0
6	7	7.1	17.1	24.2	6.2	14.9	21.2
6	8	17.0	23.8	40.8	14.9	20.8	35.6
6	9	7.3	10.7	18.0	6.4	9.3	15.7
6	10	7.6	0.7	8.3	6.6	0.6	7.2
6	11	5.5	9.2	14.8	4.8	8.0	12.8
6	12	8.4	1.5	9.9	7.4	1.3	8.6
6	13	8.2	4.2	12.4	7.1	3.7	10.8
6	14	13.1	7.1	20.3	11.4	6.2	17.6
6	15	11.7	6.8	18.4	10.2	5.9	16.1
6	16	33.4	15.9	49.4	29.1	13.9	43.0
6	17	10.0	6.8	16.9	8.7	5.9	14.6
6	18	13.9	0.0	13.9	12.2	0.0	12.2
6	19	24.2	7.3	31.5	21.1	6.4	27.5
6	20	10.4	6.0	16.4	9.1	5.3	14.3
6	21	12.7	13.2	25.9	11.1	11.5	22.6

6	22	14.7	3.3	18.1	12.8	2.9	15.7
6	23	23.1	2.6	25.7	20.2	2.3	22.4
6	24	18.9	8.6	27.5	16.5	7.5	24.0
6	25	21.8	11.0	32.8	19.0	9.6	28.6
6	26	27.1	4.1	31.2	23.6	3.6	27.2
6	27	29.2	4.9	34.1	25.5	4.3	29.8
7	1	25.8	18.2	44.0	24.8	17.5	42.3
7	2	13.5	6.2	19.8	13.0	5.9	18.9
7	3	16.5	18.2	34.8	15.9	17.5	33.4
7	4	14.8	56.7	71.5	14.3	54.5	68.8
7	5	6.2	42.1	48.3	5.9	40.5	46.4
7	6	19.3	24.2	43.5	18.5	23.3	41.8
7	7	7.1	48.4	55.5	6.8	46.6	53.4
7	8	7.6	42.2	49.8	7.3	40.6	47.9
7	9	3.9	1.6	5.5	3.8	1.6	5.3
7	10	5.8	11.8	17.6	5.6	11.3	16.9
7	11	6.4	40.7	47.1	6.2	39.2	45.3
7	12	6.0	9.4	15.3	5.8	9.1	14.9
7	13	6.3	26.8	33.1	6.1	25.8	31.9
7	14	12.9	14.5	27.4	12.4	14.0	26.3
7	15	9.4	21.2	30.5	9.1	20.4	29.5
7	16	9.0	12.4	21.4	8.6	11.9	20.6
7	17	10.3	16.9	27.2	9.9	16.3	26.2
7	18	13.3	5.8	19.2	12.8	5.6	18.4
7	19	9.6	18.4	28.0	9.2	17.7	26.9
7	20	9.5	31.0	40.5	9.2	29.8	38.9
7	21	14.3	27.6	42.0	13.7	26.6	40.3
7	22	9.7	34.5	44.2	9.3	33.2	42.5
7	23	26.3	17.4	43.6	25.3	16.7	42.0
7	24	24.3	19.9	44.2	23.4	19.1	42.5
7	25	14.9	40.4	55.3	14.3	38.9	53.2
7	26	38.1	37.4	75.5	36.6	35.9	72.5
7	27	21.3	20.7	42.0	20.5	19.9	40.4

Appendix 4.4: Olsen P values expressed as μg/g and μg/cc at each site at each sampling date. Sample date 1=22/1/93 2=5/2/93 3=19/2/93 4=5/3/93 5=19/3/93 6=2/4/93 7=16/4/93 8=30/4/93 9=14/5/93 10=28/5/93 11=11/6/93 12=25/6/93 13=9/7/93 14=23/7/93 15=6/8/93 16=20/8/93 17=3/9/93 18=17/9/-93 19=1/10/93 20=18/10/93 21=1/11/93 22=15/11/93 23=29/11/93 24=13/12/93 25=23/12/93 26=10/1/94 27=7/2/94

field site	date	Olsen P μg/g	Olsen P μg/g
1	1	14.84	13.21
2	1	7.85	6.67
3	1	10.42	8.23
4	1	7.85	5.81
5	1	13.44	11.43
6	1	30.68	26.39
7	1	54.45	42.47
1	2	18.57	16.53
2	2	8.32	7.07
3	2	9.02	7.12
4	2	8.55	6.33
5	2	12.05	10.24
6	2	30.22	25.99
7	2	43.73	34.11
1	3	18.3	16.32
2	3	6.9	5.87
3	3	13.3	10.53
4	3	8.8	6.52
5	3	12.6	10.73
6	3	26.2	22.52
7	3	57.6	44.94
1	4	18.3	16.32
2	4	8.8	7.49
3	4	11.7	9.22
4	4	7.6	5.64
5	4	14.8	12.55
6	4	35.2	30.3
7	4	46.2	36.03
1	5	16.9	15.05
2	5	10.5	8.9
3	5	15.7	12.41
4	5	7.6	5.64
5	5	14.8	12.55
6	5	38.1	32.76
7	5	45	35.1
1	6	16	14.24
2	6	9.8	8.33
3	6	11.7	9.24
4	6	10.5	7.77
5	6	16.9	14.37
6	6	34.5	29.67
7	6	54.5	42.51
1	7	18.1	16.11
2	7	9.5	8.08
3	7	12.4	9.8
4	7	10.7	7.92

5	7	14.3	12.16
6	7	32.9	28.29
7	7	48.6	37.91
1	8	18.19	16.19
2	8	11.01	9.36
3	8	13.4	10.59
4	8	9.09	6.73
5	8	12.92	10.98
6	8	31.59	27.17
7	8	55.04	42.93
1	9	17.23	15.33
2	9	8.14	6.92
3	9	11.01	8.7
4	9	8.62	6.38
5	9	12.44	10.58
6	9	35.89	30.87
7	9	50.73	39.57
1	10	16.27	14.48
2	10	8.62	7.32
3	10	12.44	9.83
4	10	8.62	6.38
5	10	13.88	11.8
6	10	32.07	27.58
7	10	60.3	47.04
1	11	17.23	15.33
2	11	8.14	6.92
3	11	10.53	8.32
4	11	9.09	6.73
5	11	12.44	10.58
6	11	31.59	27.17
7	11	47.86	37.33
1	12	17.71	15.76
2	12	9.57	8.14
3	12	11.01	8.7
4	12	9.09	6.73
5	12	13.4	11.39
6	12	34.94	30.05
7	12	63.65	49.65
1	13	16.75	14.91
2	13	10.05	8.54
3	13	12.44	9.83
4	13	11.01	8.15
5	13	16.75	14.24
6	13	30.63	26.34
7	13	70.83	55.25
1	14	18.19	16.19
2	14	9.57	8.14
3	14	13.4	10.59
4	14	9.09	6.73
5	14	13.88	11.8
6	14	29.19	25.11
7	14	52.17	40.69
1	15	16.75	14.91
2	15	8.62	7.32
3	15	11.01	8.7
4	15	9.09	6.73

5	15	13.4	11.39
6	15	27.76	23.87
7	15	55.52	43.3
1	16	17.23	15.33
2	16	9.57	8.14
3	16	11.49	9.07
4	16	10.05	7.44
5	16	13.4	11.39
6	16	29.67	25.52
7	16	65.09	50.77
1	17	15.79	14.06
2	17	11.49	9.76
3	17	12.25	9.68
4	17	9.53	7.05
5	17	13.61	11.57
6	17	31.59	27.17
7	17	70.83	55.25
1	18	16.75	14.91
2	18	9.09	7.73
3	18	12.44	9.83
4	18	10.53	7.79
5	18	16.27	13.83
6	18	30.15	25.93
7	18	45.47	35.46
1	19	15.79	14.06
2	19	10.05	8.54
3	19	12.44	9.83
4	19	8.62	6.38
5	19	14.84	12.61
6	19	32.54	27.99
7	19	62.7	48.9
1	20	19.14	17.03
2	20	11.01	9.36
3	20	16.75	13.23
4	20	11.97	8.85
5	20	19.14	16.27
6	20	39.72	34.16
7	20	97.15	75.78
1	21	19.62	17.46
2	21	7.72	6.56
3	21	13.4	10.59
4	21	9.09	6.73
5	21	16.27	13.83
6	21	44.03	37.87
7	21	111.51	86.98
1	22	15.43	13.73
2	22	7.72	6.56
3	22	10.89	8.6
4	22	11.35	8.4
5	22	12.71	10.8
6	22	34.49	29.66
7	22	56.73	44.25
1	23	17.25	15.35
2	23	9.98	8.49
3	23	12.25	9.68
4	23	10.44	7.72

5	23	17.25	14.66
6	23	34.49	29.66
7	23	58.54	45.66
1	24	14.98	13.33
2	24	10.44	8.87
3	24	12.25	9.68
4	24	9.53	7.05
5	24	14.07	11.96
6	24	27.23	23.42
7	24	57.18	44.6
1	25	15.79	14.06
2	25	7.22	6.14
3	25	9.02	7.13
4	25	8.12	6.01
5	25	13.09	11.12
6	25	29.33	25.22
7	25	59.56	46.46
1	26	16.7	14.86
2	26	6.77	5.75
3	26	9.48	7.49
4	26	7.67	5.68
5	26	13.99	11.89
6	26	33.39	28.72
7	26	63.17	49.27
1	27	15.79	14.06
2	27	7.22	6.14
3	27	9.02	7.13
4	27	6.77	5.01
5	27	10.38	8.82
6	27	27.98	24.06
7	27	48.28	37.66

Appendix 4.5: Resin P values expressed as μg/g and μg/cc at each site at each sampling date. Sampling, date 1=22/1/93 2=5/2/93 3=19/2/93 4=5/3/93 5=19/3/93 6=2/4/93 7=16/4/93 8=30/4/93 9=14/5/93 10=28/5/93 11=11/6/93 12=25/6/93 13=9/7/93 14=6/8/93 15=20/8/93 16=3/9/93 17=17/9/93 18=1/10-/93 19=18/10/93 20=1/11/93 21=15/11/93 22=29/11/93 23=13/12/-93 24=23/12/93 25=10/1/94

field site	date	Resin P ug/g	Resin P ug/cc
1	1	27.14	24.15
2	1	14.74	12.53
3	1	19.19	15.16
4	1	17.84	13.2
5	1	33.72	28.66
6	1	61.43	52.83
7	1	105.41	82.22
1	2	35.84	31.9
2	2	18.32	15.57
3	2	23.74	18.75
4	2	17.48	12.94
5	2	27.71	23.55
6	2	66.93	57.56
7	2	96.13	74.98
1	3	29.55	26.3
2	3	17.82	15.15
3	3	24.73	19.54
4	3	19.72	14.59
5	3	26.83	22.81
6	3	64.71	55.65
7	3	94.44	73.66
1	4	30.21	26.89
2	4	16.44	13.97
3	4	22.07	17.44
4	4	14.35	10.62
5	4	31.67	26.92
6	4	69.01	59.35
7	4	83.2	64.9
1	5	28.12	25.03
2	5	17.9	15.21
3	5	20.4	16.12
4	5	18.11	13.4
5	5	24.37	20.71
6	5	63.17	54.33
7	5	71.72	55.94
1	6	22.43	19.96
2	6	17.61	14.97
3	6	20.34	16.07
4	6	17.41	12.88
5	6	33.73	28.67
6	6	64.5	55.47
7	6	83.34	65.01
1	7	26.66	23.73
2	7	14.56	12.38
3	7	20.19	15.95
4	7	17.07	12.63

5	7	30.63	26.04
6	7	58.37	50.2
7	7	85.28	66.52
1	8	32.49	28.92
2	8	19.14	16.27
3	8	23.87	18.86
4	8	19.97	14.78
5	8	31.87	27.09
6	8	68	58.48
7	8	107.83	84.11
1	9	31.67	28.19
2	9	19.56	16.63
3	9	21.2	16.75
4	9	20.58	15.23
5	9	25.3	21.51
6	9	72.72	62.54
7	9	95.31	74.34
1	10	24.89	22.15
2	10	13.03	11.08
3	10	16	12.64
4	10	14.94	11.06
5	10	27	22.95
6	10	59.81	51.44
7	10	94.52	73.73
1	11	26.74	23.8
2	11	16.27	13.83
3	11	23.04	18.2
4	11	19.97	14.78
5	11	29	24.65
6	11	60.82	52.31
7	11	95.51	74.5
1	12	26.41	23.5
2	12	15.94	13.55
3	12	19.5	15.41
4	12	17.2	12.73
5	12	25.57	21.73
6	12	67.64	58.17
7	12	104.28	81.34
1	13	23.53	20.94
2	13	16.86	14.33
3	13	16.86	13.32
4	13	17.69	13.09
5	13	30	25.5
6	13	54.62	46.97
7	13	104.69	81.66
1	14	24.25	21.58
2	14	12.4	10.54
3	14	17.27	13.64
4	14	13.03	9.64
5	14	26.16	22.24
6	14	56.63	48.7
7	14	94.52	73.73
1	15	25.73	22.9
2	15	14.09	11.98
3	15	15.57	12.3
4	15	12.82	9.49

5	15	21.92	18.63
6	15	58.96	50.71
7	15	109.97	85.78
1	16	23.27	20.71
2	16	14.68	12.48
3	16	20.75	16.39
4	16	19.5	14.43
5	16	29.13	24.76
6	16	55.08	47.37
7	16	113.07	88.19
1	17	25.1	22.34
2	17	13.46	11.44
3	17	16.63	13.14
4	17	15.36	11.37
5	17	32.08	27.27
6	17	54.52	46.89
7	17	83.93	65.47
1	18	25.52	22.71
2	18	12.61	10.72
3	18	15.78	12.47
4	18	14.94	11.06
5	18	27.42	23.31
6	18	51.55	44.33
7	18	83.51	65.14
1	19	28.18	25.08
2	19	16.27	13.83
3	19	21.4	16.91
4	19	18.32	13.56
5	19	32.49	27.62
6	19	72.93	62.72
7	19	147.24	114.85
1	20	24.62	21.91
2	20	12.8	10.88
3	20	16.29	12.87
4	20	13.77	10.19
5	20	23.65	20.1
6	20	68.6	59
7	20	143.19	111.69
1	21	25.78	22.94
2	21	16.99	14.44
3	21	21.8	17.22
4	21	17.2	12.73
5	21	24.94	21.2
6	21	46.29	39.81
7	21	69.11	53.91
1	22	20.55	18.29
2	22	11.83	10.06
3	22	13.96	11.03
4	22	12.8	9.47
5	22	28.11	23.89
6	22	67.24	57.83
7	22	105.6	82.37
1	23	26.36	23.46
2	23	17.45	14.83
3	23	16.87	13.33
4	23	14.16	10.48

5	23	30.04	25.53
6	23	52.9	45.49
7	23	91.46	71.34
1	24	22.88	20.36
2	24	10.86	9.23
3	24	16.48	13.02
4	24	13.58	10.05
5	24	24.23	20.6
6	24	58.72	50.5
7	24	94.36	73.6
1	25	25.2	22.43
2	25	11.06	9.4
3	25	15.51	12.25
4	25	13.38	9.9
5	25	27.72	23.56
6	25	61.62	52.99
7	25	100.56	78.44

Appendix 5.1a: Pasture DM production (kg/ha), pasture growth rate (kg/ha/day) grass production (kg/ha) legume production (kg/ha) osps production (kg/ha) dead matter production (kg/ha) at each site at each biweekly harvest. Samping dates 1= 5/2/93 2=19/2/93 3=5/3/93 4=19/3/93 5=2/4/93 6=16/4/93 7=30/4/93 8=14/5/93 9=28/5/93 10=11/6/93 11=25/6/93 12=9/7/93 13=23/7/93 14=6/8/93 15=20/8/93 16=3/9/93 17=17/9/93 18=1/10/93 19=18/10/93 20=1/11/93 21=15/11/93 22=29/11/93 23=13/12/93 24=23/12/93 25=10/1/94 26=25/1/94.

site	bl	date	DM	GR	grass	legume	osps	dead mat.
1	1	1	128	9.1	112	10	6	8
1	2	1	186	13.3	112	54	20	14
1	3	1	91	6.5	47	30	14	9
1	1	2	287	20.5	182	57	48	66
1	2	2	337	24.1	221	62	55	60
1	3	2	340	24.3	215	99	27	80
1	1	3	268	19.2	181	41	46	10
1	2	3	290	20.7	219	50	22	19
1	3	3	364	26.0	278	36	50	7
1	1	4	24	1.7	22	1	1	11
1	3	4	82	5.9	77	4	1	16
1	1	5	32	2.3	86	51	13	27
1	2	5	150	10.7	33	9	11	17
1	3	5	52	3.7	22	2	7	14
1	1	6	26	1.9	33	0	12	28
1	2	6	46	3.3	35	22	5	14
1	3	6	62	4.4	17	6	4	15
1	1	7	162	11.5	78	59	24	81
1	2	7	279	19.9	201	43	35	74
1	3	7	283	20.2	237	42	3	39
1	1	8	37	2.6	21	12	3	13
1	2	8	94	6.7	52	26	16	15
1	3	8	96	6.8	77	14	5	25
1	1	9	96	6.8	67	3	25	71
1	2	9	70	5.0	38	9	23	23
1	3	9	95	6.8	68	19	7	12
1	1	10	22	1.6	13	2	7	25
1	2	10	18	1.3	10	2	6	10
1	3	10	60	4.3	36	14	10	20
1	1	11	57	4.1	30	11	16	14
1	2	11	50	3.5	34	10	5	19
1	3	11	47	3.4	32	7	8	10
1	1	12	43	3.1	25	6	12	33
1	2	12	133	9.5	116	10	6	2
1	3	12	75	5.4	58	10	7	8
1	1	13	9	0.6	6	2	1	4
1	2	13	64	4.6	30	13	21	32
1	3	13	180	12.9	167	10	3	28
1	1	14	68	4.8	45	9	13	22
1	2	14	115	8.2	63	28	24	56
1	3	14	149	10.6	108	15	25	72
1	1	15	47	3.3	22	14	11	15
1	2	15	25	1.8	21	1	4	10
1	3	15	299	21.3	212	38	49	34
1	1	16	10	0.7	6	0	4	5
1	2	16	18	1.3	13	3	2	5
1	3	16	35	2.5	20	9	6	8
1	1	17	74	5.3	49	17	8	45
1	2	17	172	12.3	126	15	31	24
1	3	17	94	6.7	56	19	19	43
1	1	18	103	7.4	77	15	11	35
1	2	18	293	20.9	227	34	32	58
1	3	18	109	7.8	51	28	30	38
1	1	19	118	6.9	96	11	11	8
1	2	19	263	15.4	208	38	17	16
1	3	19	134	7.9	82	26	27	20
1	1	20	388	27.7	117	47	223	109

site	bl	date	DM	GR	grass	legume	osps	dead mat.
1	2	20	143	10.2	103	24	17	27
1	3	20	367	26.2	266	69	32	43
1	1	21	164	11.7	92	16	56	47
1	2	21	353	25.2	224	110	19	7
1	3	21	857	61.2	693	117	47	53
1	1	22	79	5.7	52	15	13	5
1	2	22	309	22.1	229	58	22	26
1	3	22	723	51.6	495	191	37	34
1	1	23	337	24.1	224	65	48	22
1	2	23	288	20.6	178	49	62	50
1	3	23	419	29.9	365	40	14	31
1	1	24	107	10.7	75	12	20	46
1	2	24	189	18.9	124	45	20	40
1	3	24	174	17.4	144	18	11	45
1	1	25	422	23.4	242	95	85	91
1	2	25	521	29.0	290	163	69	84
1	3	25	264	14.7	128	35	101	63
1	1	26	356	23.8	242	34	81	330
1	2	26	332	22.2	154	96	82	112
1	3	26	395	26.3	257	74	64	212
2	1	1	366	26.1	229	38	99	49
2	2	1	292	20.9	172	3	117	60
2	3	1	384	27.4	269	14	101	61
2	1	2	242	17.3	152	1	89	73
2	2	2	248	17.7	143	0	106	9
2	3	2	247	17.6	133	0	113	10
2	1	3	220	15.7	137	8	75	26
2	2	3	158	11.3	91	4	64	9
2	3	3	104	7.4	49	1	54	18
2	1	4	33	2.3	21	1	11	13
2	2	4	31	2.2	20	0	11	6
2	3	4	63	4.5	32	2	29	11
2	1	5	50	3.6	29	1	21	7
2	2	5	43	3.1	28	0	15	19
2	3	5	17	1.2	9	1	7	7
2	1	6	43	3.1	35	0	8	19
2	2	6	7	0.5	5	0	1	3
2	3	6	32	2.3	17	2	13	6
2	1	7	260	18.6	98	7	155	97
2	2	7	323	23.1	253	6	64	306
2	3	7	79	5.6	48	2	29	27
2	1	8	10	0.7	5	0	5	7
2	2	8	118	8.4	87	1	29	67
2	3	8	43	3.0	19	2	22	22
2	1	9	76	5.5	42	1	34	57
2	2	9	73	5.2	47	0	26	31
2	3	9	95	6.8	25	2	68	55
2	1	10	20	1.4	16	0	4	3
2	2	10	28	2.0	18	0	10	14
2	3	10	92	6.5	46	4	42	26
2	1	11	48	3.4	19	2	27	41
2	2	11	59	4.2	36	1	22	30
2	3	11	49	3.5	29	1	20	26
2	1	12	40	2.8	23	2	15	12
2	2	12	135	9.7	63	8	65	54
2	3	12	20	1.4	9	0	10	14
2	1	13	32	2.3	15	5	11	15
2	2	13	57	4.1	38	0	19	22
2	3	13	22	1.6	16	1	6	16
2	1	14	93	6.6	46	11	35	58
2	2	14	23	1.6	11	1	11	7
2	3	14	104	7.4	49	8	47	29
2	1	15	32	2.3	9	2	21	16
2	2	15	26	1.9	18	0	8	22
2	3	15	16	1.1	9	1	6	10
2	1	16	21	1.5	9	2	11	9

site	bl	date	DM	GR	grass	legume	osps	dead mat.
2	3	16	18	1.3	9	1	8	7
2	1	17	150	10.7	47	19	84	32
2	2	17	89	6.3	51	3	35	23
2	3	17	153	10.9	75	4	74	66
2	1	18	132	9.5	67	2	63	64
2	2	18	132	9.4	67	14	50	43
2	3	18	96	6.8	42	8	45	37
2	1	19	80	4.7	26	1	53	16
2	2	19	86	5.0	47	1	38	5
2	3	19	256	15.1	113	18	126	8
2	1	20	475	33.9	281	28	165	27
2	2	20	356	25.4	267	4	85	30
2	3	20	251	17.9	107	34	109	36
2	1	21	314	22.4	220	9	85	49
2	2	21	328	23.4	202	12	113	51
2	3	21	273	19.5	204	2	67	20
2	1	22	405	28.9	209	12	183	97
2	2	22	463	33.1	287	36	140	66
2	3	22	132	9.5	66	7	60	16
2	1	23	68	4.9	53	0	15	12
2	2	23	147	10.5	103	7	37	16
2	3	23	99	7.1	63	3	33	25
2	1	24	110	11.0	77	6	27	44
2	2	24	148	14.8	73	3	73	27
2	3	24	151	15.1	111	3	37	24
2	1	25	429	23.8	317	13	98	134
2	2	25	649	36.0	306	14	329	67
2	3	25	634	35.2	287	26	320	134
2	1	26	263	17.5	152	7	104	62
2	2	26	345	23.0	135	4	206	97
2	3	26	394	26.3	141	12	241	219
3	1	1	399	28.5	328	26	45	33
3	2	1	362	25.8	302	31	29	63
3	3	1	307	21.9	229	13	65	54
3	1	2	331	23.7	266	29	37	13
3	2	2	331	23.6	199	17	8	98
3	3	2	327	23.4	277	28	22	7
3	1	3	221	15.8	167	21	33	23
3	2	3	191	13.7	150	12	29	19
3	3	3	115	8.2	82	19	13	7
3	1	4	102	7.3	95	3	4	18
3	2	4	22	1.6	13	2	6	5
3	3	4	49	3.5	41	2	6	5
3	1	5	33	2.3	26	2	4	19
3	2	5	51	3.6	38	5	8	18
3	3	5	10	0.7	8	1	1	9
3	1	6	44	3.2	41	1	2	23
3	2	6	17	1.2	11	1	5	6
3	3	6	57	4.1	53	2	2	7
3	1	7	137	9.8	82	9	45	146
3	2	7	101	7.2	63	10	28	50
3	3	7	104	7.4	85	10	8	40
3	1	8	43	3.1	27	2	14	43
3	2	8	10	0.7	6	0	3	23
3	3	8	63	4.5	46	7	9	30
3	1	9	48	3.4	25	2	21	23
3	2	9	50	3.6	38	4	8	34
3	3	9	48	3.4	34	6	7	19
3	1	10	8	0.5	5	1	2	4
3	2	10	72	5.1	52	2	18	81
3	3	10	125	8.9	103	1	20	43
3	1	11	58	4.2	40	8	10	30
3	2	11	115	8.2	69	24	22	22
3	3	11	104	7.4	76	12	15	31
3	1	12	90	6.4	64	10	16	15
3	2	12	71	5.0	69	1	1	19

site	bl	date	DM	GR	grass	legume	osps	dead mat.
3	3	12	76	5.4	74	2	1	31
3	1	13	80	5.7	64	5	12	76
3	2	13	87	6.2	61	8	18	54
3	3	13	151	10.8	117	14	20	48
3	1	14	72	5.1	48	8	16	65
3	2	14	101	7.2	72	7	22	65
3	3	14	46	3.3	31	3	12	27
3	1	15	19	1.3	12	4	3	21
3	2	15	65	4.6	39	12	13	21
3	3	15	51	3.7	31	6	15	40
3	1	16	8	0.6	5	0	3	6
3	3	16	34	2.4	26	2	5	5
3	1	17	102	7.3	54	33	15	83
3	2	17	94	6.7	71	7	16	38
3	3	17	143	10.2	115	6	23	49
3	1	18	157	11.2	114	9	34	45
3	2	18	100	7.1	62	8	30	55
3	3	18	468	33.4	326	75	68	73
3	1	19	166	9.8	122	9	35	17
3	2	19	299	17.6	200	47	52	27
3	3	19	216	12.7	154	30	32	16
3	1	20	228	16.3	170	21	37	11
3	2	20	537	38.3	401	80	57	43
3	3	20	263	18.8	207	16	39	27
3	1	21	388	27.7	295	60	33	49
3	2	21	347	24.8	272	12	63	23
3	3	21	293	21.0	193	49	51	31
3	1	22	330	23.6	217	45	69	49
3	2	22	737	52.7	568	84	85	174
3	1	22	474	33.9	346	63	65	52
3	1	23	334	23.9	266	21	47	35
3	2	23	333	23.8	263	27	43	56
3	3	23	182	13.0	138	7	37	25
3	1	24	82	8.2	59	10	13	66
3	2	24	182	18.2	160	10	12	61
3	3	24	131	13.1	99	18	14	32
3	1	25	316	17.6	227	6	84	51
3	2	25	788	43.8	593	29	166	58
3	3	25	660	36.7	438	107	116	111
3	1	26	438	29.2	310	19	109	144
3	2	26	222	14.8	149	7	67	84
3	3	26	568	37.9	409	38	121	60
4	1	1	311	22.2	234	29	48	71
4	2	1	414	29.6	264	34	115	62
4	3	1	319	22.8	217	13	90	88
4	1	2	223	15.9	178	6	39	59
4	2	2	224	16.0	224	7	99	96
4	3	2	277	19.8	211	2	65	23
4	1	3	106	7.6	77	6	23	18
4	2	3	128	9.2	80	5	43	2
4	3	3	111	7.9	86	6	19	16
4	1	4	30	2.2	23	1	6	10
4	2	4	41	2.9	33	3	5	10
4	3	4	59	4.2	51	1	8	16
4	1	5	14	1.0	8	1	5	6
4	2	5	48	3.4	36	2	10	20
4	3	5	36	2.6	19	0	16	21
4	1	6	27	1.9	20	7	1	1
4	2	6	47	3.4	43	0	4	26
4	3	6	11	0.8	5	1	5	10
4	1	7	120	8.5	72	0	47	118
4	2	7	115	8.2	67	6	42	66
4	3	7	96	6.8	40	14	41	65
4	1	8	138	9.8	93	3	42	100
4	2	8	75	5.4	53	0	23	112
4	3	8	4	0.3	3	0	1	8

site	bl	date	DM	GR	grass	legume	osps	dead mat.
4	1	9	19	1.4	12	1	6	22
4	2	9	18	1.3	11	1	6	30
4	3	9	58	4.1	47	1	10	39
4	1	10	99	7.1	51	3	45	51
4	2	10	115	8.2	62	2	51	48
4	3	10	44	3.1	24	1	19	55
4	1	11	70	5.0	42	6	22	36
4	2	11	79	5.7	44	7	28	35
4	3	11	69	4.9	53	5	11	42
4	1	12	59	4.2	35	8	16	29
4	2	12	114	8.1	43	4	67	48
4	3	12	88	6.3	60	7	21	52
4	1	13	72	5.1	39	3	30	73
4	2	13	83	6.0	44	6	34	61
4	3	13	33	2.4	22	3	8	26
4	1	14	54	3.8	21	4	29	49
4	2	14	61	4.4	22	4	35	47
4	3	14	63	4.5	36	1	27	57
4	1	15	44	3.2	21	0	24	30
4	2	15	52	3.7	26	2	24	43
4	3	15	51	3.6	28	5	17	45
4	1	16	13	0.9	7	1	4	8
4	2	16	30	2.1	17	2	11	10
4	3	16	11	0.8	8	0	3	7
4	1	17	42	3.0	28	1	13	26
4	2	17	19	1.3	13	1	5	23
4	3	17	55	3.9	28	2	25	45
4	1	18	138	9.8	72	6	59	81
4	2	18	108	7.7	80	0	28	103
4	3	18	109	7.8	44	11	53	32
4	1	19	132	7.8	88	6	38	43
4	2	19	128	7.5	77	5	45	26
4	3	19	139	8.2	61	15	63	18
4	1	20	347	24.8	259	19	69	69
4	2	20	274	19.6	121	20	134	36
4	3	20	339	24.2	223	26	90	54
4	1	21	213	15.2	137	11	66	39
4	2	21	104	7.4	48	4	52	23
4	3	21	198	14.2	110	7	81	84
4	1	22	294	21.0	166	8	119	60
4	2	22	179	12.8	87	14	78	82
4	3	22	416	29.7	237	33	146	212
4	1	23	105	7.5	72	4	30	27
4	2	23	73	5.2	42	8	23	15
4	3	23	94	6.7	50	4	40	31
4	1	24	86	8.6	60	5	21	57
4	2	24	158	15.8	109	4	45	69
4	3	24	109	10.9	88	5	16	37
4	1	25	199	11.1	95	14	90	118
4	2	25	408	22.7	239	36	133	228
4	3	25	426	23.7	278	23	124	118
4	1	26	142	9.5	96	16	29	148
4	2	26	197	13.1	151	10	36	148
4	3	26	362	24.1	197	10	155	176
5	1	1	445	31.8	422	6	17	64
5	2	1	388	27.7	223	151	14	18
5	3	1	514	36.7	415	96	3	25
5	1	2	476	34.0	350	102	24	26
5	2	2	420	30.0	352	52	17	47
5	3	2	606	43.3	577	0	28	78
5	1	3	562	40.1	342	208	12	16
5	2	3	299	21.4	222	61	17	6
5	3	3	1334	95.3	1194	137	3	9
5	1	4	221	15.8	179	31	10	35
5	2	4	97	7.0	83	3	12	3
5	3	4	215	15.4	159	34	23	4

site	bl	date	DM	GR	grass	legume	osps	dead mat.
5	1	5	373	26.6	348	21	4	40
5	2	5	153	10.9	121	12	20	7
5	3	5	333	23.8	298	35	0	18
5	1	6	386	27.6	350	15	21	3
5	2	6	194	13.9	188	5	1	8
5	3	6	344	24.6	295	32	17	27
5	1	7	629	44.9	472	150	6	140
5	2	7	153	11.0	123	9	21	41
5	3	7	277	19.8	196	77	4	24
5	1	8	105	7.5	93	6	6	17
5	2	8	11	0.8	9	0	2	4
5	3	8	82	5.9	73	5	5	7
5	1	9	316	22.6	282	29	5	25
5	2	9	61	4.3	56	4	1	9
5	3	9	189	13.5	174	4	11	9
5	1	10	110	7.9	95	9	7	13
5	2	10	99	7.1	89	4	5	11
5	3	10	140	10.0	125	6	9	11
5	1	11	123	8.8	116	5	2	24
5	2	11	175	12.5	152	20	3	8
5	3	11	218	15.6	199	13	5	18
5	1	12	133	9.5	118	5	11	7
5	2	12	58	4.2	55	3	1	3
5	3	12	122	8.7	107	8	7	8
5	1	13	63	4.5	49	6	9	28
5	2	13	124	8.9	94	4	26	37
5	3	13	57	4.1	50	3	4	14
5	1	14	62	4.4	46	3	13	46
5	2	14	241	17.2	163	25	53	18
5	3	14	110	7.9	92	4	15	17
5	1	15	69	4.9	56	4	8	17
5	2	15	131	9.4	107	11	13	26
5	3	15	51	3.6	45	3	3	9
5	1	16	81	5.8	71	5	5	7
5	2	16	41	2.9	33	2	6	12
5	3	16	95	6.8	74	8	12	20
5	1	17	65	4.7	47	7	11	14
5	2	17	103	7.3	83	8	11	7
5	3	17	130	9.3	114	6	10	15
5	1	18	413	29.5	332	65	16	31
5	2	18	270	19.3	252	6	12	18
5	3	18	619	44.2	609	2	8	42
5	1	19	771	45.4	672	80	18	7
5	2	19	652	38.3	560	68	24	14
5	3	19	642	37.8	552	88	2	17
5	1	20	901	64.4	865	36	0	27
5	2	20	795	56.8	704	81	10	36
5	3	20	897	64.1	666	121	110	61
5	1	21	592	42.3	425	160	8	33
5	2	21	618	44.1	576	22	20	45
5	3	21	512	36.6	414	72	26	19
5	1	22	1424	101.7	1264	133	27	19
5	2	22	914	65.3	797	95	23	31
5	3	22	819	58.5	706	83	31	36
5	1	23	357	25.5	292	38	27	13
5	2	23	577	41.2	461	46	70	20
5	3	23	491	35.1	378	87	26	23
5	1	24	319	31.9	268	38	13	68
5	2	24	449	44.9	330	114	6	75
5	3	24	171	17.1	147	22	3	38
5	1	25	1165	64.7	902	126	136	42
5	2	25	1684	93.6	1405	179	101	85
5	3	25	609	33.9	457	119	33	51
5	1	26	945	63.0	830	75	41	108
5	2	26	733	48.9	509	82	142	77
5	3	26	319	21.3	286	14	19	250

site	bl	date	DM	GR	grass	legume	osps	dead mat.
6	1	1	330	23.6	241	64	25	10
6	2	1	507	36.2	402	90	15	16
6	3	1	476	34.0	387	67	21	24
6	1	2	579	41.4	491	54	34	49
6	2	2	730	52.1	549	166	14	17
6	3	2	873	62.4	614	174	85	118
6	1	3	1038	74.1	980	31	27	15
6	2	3	672	48.0	480	164	27	16
6	3	3	884	63.1	716	140	28	0
6	1	4	21	1.5	18	1	2	3
6	2	4	317	22.7	293	15	10	8
6	3	4	197	14.1	150	43	4	4
6	1	5	204	14.6	181	15	8	35
6	2	5	568	40.6	503	52	14	53
6	3	5	134	9.6	102	21	11	44
6	1	6	102	7.3	92	9	1	19
6	2	6	356	25.4	296	39	22	11
6	3	6	209	15.0	159	22	28	20
6	1	7	354	25.3	328	16	10	26
6	2	7	164	11.7	118	33	13	51
6	3	7	751	53.6	485	216	50	37
6	1	8	58	4.2	51	5	2	8
6	2	8	29	2.1	22	2	5	8
6	3	8	118	8.4	100	16	2	18
6	1	9	191	13.6	164	23	4	2
6	2	9	144	10.3	126	16	2	16
6	3	9	85	6.1	72	7	5	7
6	1	10	145	10.3	132	7	5	9
6	2	10	139	10.0	130	7	3	9
6	3	10	129	9.2	118	9	2	21
6	1	11	135	9.7	117	10	9	14
6	2	11	116	8.3	105	8	3	9
6	3	11	257	18.3	248	7	2	13
6	1	12	122	8.7	110	6	6	4
6	2	12	134	9.6	124	9	1	12
6	3	12	209	14.9	197	11	1	1
6	1	13	155	11.1	140	8	7	29
6	2	13	269	19.2	254	11	5	29
6	3	13	99	7.1	89	8	3	13
6	1	14	186	13.3	141	14	31	15
6	2	14	174	12.4	145	27	2	12
6	3	14	202	14.4	145	22	35	13
6	1	15	204	14.6	165	16	24	11
6	2	15	232	16.5	212	16	3	24
6	3	15	328	23.4	244	40	43	44
6	1	16	258	18.4	248	9	1	6
6	2	16	98	7.0	82	11	5	6
6	3	16	81	5.8	62	15	4	3
6	1	17	99	7.0	85	11	2	7
6	2	17	396	28.3	278	40	78	9
6	3	17	210	15.0	195	14	1	8
6	1	18	336	24.0	319	10	7	14
6	2	18	440	31.5	314	112	15	32
6	3	18	679	48.5	522	143	14	9
6	1	19	577	33.9	438	115	24	20
6	2	19	687	40.4	450	179	58	24
6	3	19	657	38.6	423	216	17	14
6	1	20	873	62.3	763	97	12	34
6	2	20	972	69.4	721	205	46	38
6	3	20	1033	73.8	795	169	69	81
6	1	21	745	53.2	636	64	44	44
6	2	21	394	28.2	282	92	19	21
6	3	21	726	51.9	623	90	13	60
6	1	22	585	41.8	469	66	50	43
6	2	22	627	44.8	379	159	89	97
6	3	22	1164	83.2	957	184	23	82

site	bl	date	DM	GR	grass	legume	osps	dead mat.
6	1	23	421	30.1	345	33	43	33
6	2	23	417	29.8	268	138	11	11
6	3	23	330	23.6	248	74	7	20
6	1	24	302	30.2	250	22	30	43
6	2	24	460	46.0	351	99	11	70
6	3	24	557	55.7	380	156	21	61
6	1	25	889	49.4	714	135	40	106
6	2	25	1331	73.9	683	610	38	95
6	3	25	1684	93.5	1210	296	178	110
6	1	26	578	38.5	492	44	42	322
6	2	26	598	39.9	455	132	11	204
6	3	26	1009	67.2	726	220	62	235
7	1	1	973	69.5	850	112	11	63
7	2	1	1057	75.5	807	208	42	21
7	3	1	1260	90.0	1126	134	1	79
7	1	2	815	58.2	616	180	19	162
7	2	2	691	49.4	436	244	11	45
7	3	2	725	51.8	570	155	0	93
7	1	3	1004	71.7	901	70	33	3
7	2	3	835	59.7	704	125	6	34
7	3	3	800	57.1	619	149	32	19
7	1	4	593	42.4	565	25	3	19
7	2	4	256	18.3	233	19	4	19
7	3	4	294	21.0	257	37	0	11
7	1	5	772	55.2	623	50	99	177
7	2	5	345	24.6	290	48	7	302
7	3	5	800	57.2	735	65	0	143
7	1	6	196	14.0	163	31	2	12
7	2	6	379	27.1	353	23	3	5
7	3	6	386	27.5	356	26	3	29
7	1	7	584	41.7	504	63	17	105
7	2	7	405	29.0	353	50	2	98
7	3	7	529	37.8	489	40	0	49
7	1	8	431	30.8	401	26	4	33
7	2	8	361	25.8	353	8	0	42
7	3	8	255	18.2	234	21	0	50
7	1	9	264	18.9	249	9	6	17
7	2	9	306	21.8	288	17	1	17
7	3	9	220	15.7	212	9	0	10
7	1	10	159	11.3	141	5	12	58
7	2	10	131	9.4	128	3	0	25
7	3	10	163	11.7	156	7	0	49
7	1	11	203	14.5	195	7	1	9
7	2	11	198	14.1	183	14	1	4
7	3	11	270	19.3	241	8	21	21
7	1	12	207	14.8	200	4	2	12
7	2	12	182	13.0	169	12	2	2
7	3	12	213	15.2	203	1	8	13
7	1	13	188	13.4	162	4	22	25
7	2	13	201	14.4	187	15	0	10
7	3	13	104	7.4	90	10	4	19
7	1	14	204	14.5	193	9	1	23
7	2	14	238	17.0	213	20	5	16
7	3	14	218	15.6	207	9	2	18
7	1	15	274	19.5	243	22	9	22
7	2	15	322	23.0	303	10	10	26
7	3	15	260	18.5	247	3	10	16
7	1	16	114	8.1	89	20	5	11
7	2	16	143	10.2	136	6	1	12
7	3	16	327	23.3	310	10	6	21
7	1	17	171	12.2	146	17	7	28
7	2	17	429	30.7	371	49	9	17
7	3	17	170	12.2	132	32	6	22
7	1	18	792	56.6	746	20	27	39
7	2	18	890	63.6	830	58	2	20
7	3	18	937	66.9	861	53	23	88

site	bl	date	DM	GR	grass	legume	osps	dead mat.
7	1	19	877	51.6	780	43	54	34
7	2	19	1232	72.5	1076	145	11	20
7	3	19	1066	62.7	934	109	23	23
7	1	20	1008	72.0	856	79	73	24
7	2	20	1676	119.7	1531	104	42	52
7	3	20	1740	124.3	1623	113	4	26
7	1	21	581	41.5	514	58	9	30
7	2	21	1033	73.8	963	70	0	26
7	3	21	932	66.6	859	70	3	19
7	1	22	1102	78.7	1018	63	22	53
7	2	22	1580	112.9	1394	176	10	59
7	3	22	1474	105.3	1331	138	4	29
7	1	23	636	45.4	540	72	24	25
7	2	23	1176	84.0	1129	48	0	15
7	3	23	1059	75.6	923	124	12	90
7	1	24	844	84.4	601	174	68	88
7	2	24	925	92.5	871	54	0	52
7	3	24	629	62.9	545	73	11	72
7	1	25	1794	99.7	1539	120	136	48
7	2	25	1868	103.8	1598	264	5	114
7	3	25	2157	119.8	2047	96	15	37
7	1	26	972	64.8	912	7	52	77
7	2	26	739	49.2	593	144	2	60
7	3	26	838	55.9	731	107	0	96

Appendix 5.1b: Pasture DM production (kg/ha), pasture growth (kg/ha/day), HFG, LFG, WCL, OLEG, OSPS and DEAD MATTER production (kg/ha) at each site at each 4-weekly harvest sampling dates 1= 5/2/93 2=19/2/93 3=5/3/93 4=19/3/93 5=2/4/93 6=16/4/93 7=30/4/93 8=14/5/93 9=28/5/93 10=11/6/93 11=25/6/93 12=9/7/93 13=23/7/93 14=6/8/93 15=20/8/93 16=3/9/93 17=17/9/93 18=1/10/93 19=18/10/93 20=1/11/93 21=15/11/93 22=29/11/93 23=13/12/93 24=23/12/93 25=1/10/94 26=25/1/94 27=7/2/94.

site	B	date	DM	GR	HFG	LFG	WCL	OLEG	OSPS	DE.MA
1	1	2	615	22.0	12	457	91	33	22	137
1	2	2	784	28.0	11	444	263	0	66	39
1	3	2	639	22.8	10	490	81	0	58	105
1	1	3	712	25.4	17	537	108	0	51	75
1	2	3	896	32.0	59	464	242	0	132	59
1	3	3	690	24.7	24	315	300	0	51	39
1	1	4	225	8.0	26	153	12	0	33	15
1	2	4	354	12.7	20	267	39	8	20	25
1	3	4	286	10.2	9	238	5	0	33	40
1	2	5	226	8.1	11	169	35	0	11	48
1	3	5	173	6.2	6	123	34	1	10	53
1	1	6	178	6.4	11	137	31	0	0	10
1	2	6	137	4.9	4	114	13	0	7	19
1	3	6	327	11.7	35	241	48	0	4	9
1	1	7	188	6.7	6	112	32	0	37	92
1	2	7	234	8.4	15	155	30	0	35	112
1	3	7	432	15.4	38	239	111	0	44	116
1	1	8	120	4.3	1	85	19	0	14	22
1	2	8	318	11.3	31	192	67	1	26	59
1	3	8	261	9.3	33	196	25	0	7	119
1	1	9	199	7.1	2	133	24	0	39	79
1	2	9	435	15.5	42	322	56	0	15	27
1	3	9	106	3.8	5	78	14	0	8	7
1	1	10	54	1.9	0	27	3	0	25	65
1	2	10	57	2.0	6	37	8	0	6	17
1	3	10	208	7.4	48	137	17	1	6	37
1	1	11	166	5.9	8	128	10	0	20	53
1	2	11	150	5.3	43	76	15	1	15	41
1	3	11	171	6.1	6	152	6	0	8	17
1	1	12	14	0.5	0	9	1	2	3	15
1	2	12	83	3.0	0	67	6	0	10	22
1	1	13	76	2.7	0	52	4	4	16	25
1	2	13	112	4.0	1	75	17	0	18	33
1	3	13	324	11.6	19	255	15	2	32	25
1	1	14	157	5.6	0	86	22	0	50	169
1	2	14	186	6.7	11	132	20	2	22	96
1	3	14	431	15.4	152	267	12	0	0	84
1	1	15	102	3.7	4	77	5	0	16	31
1	2	15	189	6.8	3	119	15	5	48	85
1	3	15	473	16.9	149	259	32	6	26	63
1	1	16	10	0.3	0	7	1	0	1	3
1	2	16	51	1.8	3	33	7	1	7	19
1	3	16	99	3.6	21	50	18	1	10	18
1	1	17	80	2.8	3	48	4	3	22	102
1	2	17	382	13.7	29	277	13	6	58	13
1	3	17	240	8.6	15	162	26	0	37	75
1	1	18	191	6.8	5	138	30	1	17	51
1	2	18	774	27.7	57	485	204	0	29	64
1	3	18	342	12.2	23	215	51	17	36	44
1	1	19	212	6.8	4	128	30	12	38	28
1	2	19	1173	37.8	99	725	85	63	201	65
1	3	19	232	7.5	11	130	58	1	32	18
1	1	20	494	15.9	5	387	50	14	39	24
1	2	20	737	23.8	43	642	10	22	20	28
1	3	20	1036	33.4	111	548	243	15	119	55
1	1	21	1226	43.8	0	1036	66	15	109	90
1	2	21	623	22.2	0	513	0	73	37	37

site	B	date	DM	GR	HFG	LFG	WCL	OLEG	OSPS	DE.MA
1	3	21	1456	52.0	29	1038	184	8	198	41
1	1	22	469	16.7	0	369	26	8	66	40
1	2	22	763	27.3	13	583	92	37	39	35
1	3	22	700	25.0	36	470	119	25	50	52
1	1	23	1070	38.2	4	864	143	15	45	47
1	2	23	1150	41.1	23	691	297	83	56	37
1	3	23	1260	45.0	58	917	123	22	140	56
1	1	24	1131	47.1	42	672	287	22	108	72
1	2	24	589	24.6	10	458	71	9	41	63
1	3	24	960	40.0	67	730	93	13	57	62
1	1	25	1080	38.6	32	655	166	0	227	43
1	2	25	1291	46.1	54	895	223	2	117	28
1	3	25	1869	66.8	144	1313	193	0	220	116
1	1	26	1314	39.8	33	904	127	4	245	172
1	2	26	904	27.4	8	556	147	2	192	74
1	3	26	1703	51.6	35	1132	147	0	390	66
1	1	27	454	16.2	0	355	35	0	64	161
1	2	27	875	31.3	13	566	97	118	82	94
1	3	27	929	33.2	53	715	61	0	101	126
2	1	2	454	16.2	13	352	1	0	88	5
2	2	2	319	11.4	0	156	0	0	163	81
2	3	2	584	20.9	13	357	0	2	212	13
2	1	3	533	19.0	42	311	0	5	175	70
2	2	3	497	17.7	8	308	0	0	180	31
2	3	3	504	18.0	13	328	1	1	162	57
2	1	4	141	5.0	9	106	0	3	23	17
2	2	4	195	7.0	3	132	0	0	60	13
2	1	5	176	6.3	7	141	0	0	28	16
2	3	5	325	11.6	8	151	5	0	162	37
2	1	6	109	3.9	3	81	3	0	22	22
2	2	6	23	0.8	1	17	0	0	6	5
2	3	6	67	2.4	1	31	0	0	35	19
2	1	7	228	8.1	18	146	3	2	58	78
2	2	7	375	13.4	25	263	4	3	80	191
2	3	7	141	5.0	11	68	1	3	56	44
2	1	8	131	4.7	8	82	5	4	33	40
2	2	8	76	2.7	2	61	0	0	12	21
2	3	8	95	3.4	0	51	2	3	38	34
2	1	9	149	5.3	0	74	0	1	75	67
2	2	9	229	8.2	0	185	0	0	43	72
2	3	9	104	3.7	2	53	0	1	48	53
2	1	10	82	2.9	1	32	1	1	47	50
2	2	10	118	4.2	2	81	0	1	34	44
2	3	10	172	6.1	1	68	3	1	99	103
2	1	11	94	3.4	0	46	1	0	46	19
2	2	11	144	5.2	1	97	0	4	44	66
2	3	11	145	5.2	3	78	2	3	58	39
2	1	12	68	2.4	0	60	0	1	8	41
2	2	12	150	5.3	1	119	0	1	28	30
2	3	12	82	2.9	2	36	14	0	30	24
2	1	13	86	3.1	4	57	2	3	20	31
2	2	13	31	1.1	2	22	0	1	6	17
2	3	13	76	2.7	7	42	2	1	23	12
2	1	14	316	11.3	10	136	1	4	165	264
2	2	14	202	7.2	6	139	1	7	50	71
2	3	14	160	5.7	1	111	0	6	42	66
2	1	15	30	1.1	8	17	0	1	4	17
2	2	15	32	1.2	1	22	0	0	9	6
2	3	15	67	2.4	2	45	0	3	17	13
2	1	16	19	0.7	0	12	0	0	6	6
2	2	16	11	0.4	0	9	0	0	3	3
2	3	16	24	0.9	1	15	0	2	6	9
2	1	17	128	4.6	5	97	0	4	21	52
2	2	17	44	1.6	1	27	0	0	16	14
2	3	17	123	4.4	2	80	1	2	37	67
2	1	18	233	8.3	0	114	12	4	102	28

site	B	date	DM	GR	HFG	LFG	WCL	OLEG	OSPS	DE.MA
2	2	18	362	12.9	15	238	18	20	71	61
2	3	18	338	12.1	11	211	4	17	95	106
2	1	19	314	10.1	4	194	0	3	114	35
2	2	19	253	8.2	5	179	0	3	65	9
2	3	19	448	14.4	26	186	19	49	167	6
2	1	20	691	22.3	2	252	11	32	394	34
2	2	20	630	20.3	18	471	0	8	133	29
2	3	20	561	18.1	12	277	13	55	204	37
2	1	21	833	29.8	28	631	3	35	136	50
2	2	21	783	28.0	22	552	7	4	199	18
2	3	21	1241	44.3	0	639	33	129	439	36
2	1	22	1067	38.1	9	857	17	56	128	123
2	2	22	585	20.9	4	456	0	14	110	41
2	3	22	586	20.9	23	306	0	40	217	23
2	1	23	381	13.6	0	328	0	6	47	71
2	2	23	516	18.4	10	355	0	52	99	87
2	3	23	484	17.3	14	332	4	12	122	74
2	1	24	242	10.1	17	142	7	4	72	56
2	2	24	300	12.5	4	225	2	9	60	51
2	3	24	220	9.2	0	168	0	0	53	49
2	1	25	662	23.6	0	406	17	12	227	26
2	2	25	1016	36.3	0	350	3	0	663	178
2	3	25	783	28.0	18	533	0	1	232	152
2	1	26	1371	41.6	0	824	1	1	544	213
2	2	26	1025	31.1	8	560	4	0	452	150
2	3	26	1212	36.7	7	720	7	12	466	148
2	1	27	1018	36.3	4	428	4	0	583	193
2	2	27	560	20.0	0	296	0	1	263	108
2	3	27	406	14.5	3	212	0	7	184	84
3	1	2	924	33.0	70	566	47	3	238	76
3	2	2	558	19.9	14	445	36	14	48	130
3	3	2	592	21.1	50	401	36	4	101	12
3	1	3	638	22.8	105	402	64	0	68	46
3	2	3	645	23.0	118	389	34	0	104	63
3	3	3	668	23.9	64	478	38	0	88	33
3	1	4	338	12.1	38	214	50	5	31	29
3	2	4	220	7.9	32	128	16	0	45	9
3	3	4	256	9.2	56	145	36	1	19	23
3	1	5	188	6.7	33	137	9	1	9	66
3	2	5	176	6.3	27	108	16	0	25	20
3	3	5	134	4.8	14	103	8	0	10	63
3	1	6	92	3.3	7	71	8	0	5	23
3	2	6	153	5.5	25	93	13	3	19	28
3	3	6	76	2.7	12	50	8	0	6	23
3	1	7	397	14.2	57	274	20	4	43	210
3	2	7	311	11.1	41	217	8	14	31	142
3	3	7	109	3.9	26	68	8	0	7	30
3	1	8	56	2.0	1	42	2	0	9	36
3	2	8	19	0.7	2	13	1	0	4	20
3	3	8	168	6.0	29	122	8	1	8	24
3	1	9	71	2.5	5	50	1	0	14	28
3	2	9	124	4.4	20	83	3	2	15	39
3	3	9	95	3.4	13	67	4	3	9	30
3	1	10	6	0.2	1	5	0	0	0	7
3	2	10	84	3.0	9	49	6	1	19	23
3	3	10	138	4.9	13	97	9	3	16	36
3	1	11	146	5.2	2	123	1	6	14	46
3	2	11	109	3.9	9	80	2	4	14	52
3	3	11	69	2.5	6	53	6	0	3	32
3	1	12	68	2.4	0	60	3	0	5	45
3	2	12	56	2.0	6	40	3	0	7	16
3	3	12	71	2.5	8	57	1	1	5	14
3	1	13	156	5.6	13	119	3	10	12	49
3	2	13	129	4.6	22	70	0	6	30	51
3	3	13	92	3.3	5	65	2	5	15	54
3	1	14	168	6.0	11	123	3	7	24	153

site	B	date	DM	GR	HFG	LFG	WCL	OLEG	OSPS	DE.MA
3	2	14	176	6.3	16	107	6	7	40	120
3	3	14	193	6.9	23	105	11	11	43	102
3	1	15	25	0.9	3	16	1	3	3	19
3	2	15	76	2.7	9	52	5	0	9	23
3	3	15	113	4.0	19	76	2	5	10	30
3	1	16	4	0.1	0	3	0	0	1	2
3	2	16	38	1.4	8	24	3	0	3	20
3	3	16	36	1.3	8	24	1	0	3	11
3	1	17	95	3.4	4	58	2	15	17	61
3	2	17	175	6.2	16	100	4	5	49	86
3	3	17	234	8.3	52	126	9	22	24	54
3	1	18	284	10.1	5	179	2	28	70	207
3	2	18	334	11.9	7	230	6	13	77	61
3	3	18	181	6.5	16	123	6	10	26	48
3	1	19	525	16.9	66	308	8	30	113	50
3	2	19	360	11.6	45	201	6	38	71	22
3	3	19	429	13.8	32	267	18	35	78	17
3	1	20	502	16.2	70	264	14	82	73	16
3	2	20	1048	33.8	66	680	6	105	191	39
3	3	20	824	26.6	47	590	27	97	63	47
3	1	21	719	25.7	64	444	8	104	100	168
3	2	21	1241	44.3	63	913	3	179	83	115
3	3	21	700	25.0	37	549	16	69	29	70
3	1	22	794	28.4	30	509	20	94	142	166
3	2	22	788	28.2	28	610	16	42	93	147
3	3	22	1351	48.3	35	902	37	182	195	96
3	1	23	640	22.8	56	485	46	28	26	46
3	2	23	833	29.7	64	562	30	82	95	38
3	3	23	633	22.6	41	476	11	51	54	86
3	1	24	486	20.2	30	393	9	0	53	13
3	2	24	736	30.7	63	466	82	14	111	47
3	3	24	404	16.8	30	318	2	5	48	76
3	1	25	612	21.8	14	371	17	60	149	127
3	2	25	829	29.6	18	633	18	11	150	120
3	3	25	804	28.7	46	539	7	99	114	84
3	1	26	1121	34.0	15	859	9	40	198	191
3	2	26	894	27.1	78	618	90	7	101	59
3	3	26	1204	36.5	125	747	79	0	254	86
3	1	27	622	22.2	8	416	9	0	189	61
3	2	27	524	18.7	17	356	74	11	66	78
3	3	27	809	28.9	131	424	57	11	186	33
4	1	2	464	16.6	5	388	10	0	61	108
4	2	2	507	18.1	1	310	12	6	178	105
4	3	2	540	19.3	40	379	8	3	110	40
4	1	3	374	13.4	23	275	2	24	51	34
4	2	3	434	15.5	20	284	13	9	108	41
4	3	3	401	14.3	45	298	1	13	45	50
4	1	4	152	5.5	7	103	2	12	28	16
4	2	4	153	5.5	11	105	13	1	23	11
4	3	4	225	8.1	8	141	3	18	56	42
4	1	5	54	1.9	1	36	1	2	13	11
4	2	5	20	0.7	0	13	1	0	6	10
4	3	5	142	5.1	10	93	4	3	31	36
4	1	6	45	1.6	0	32	0	4	9	15
4	2	6	158	5.6	0	127	3	0	27	28
4	3	6	97	3.5	7	72	1	2	16	29
4	1	7	271	9.7	21	188	7	3	53	150
4	2	7	111	4.0	5	87	0	0	19	71
4	3	7	141	5.0	9	100	1	2	29	50
4	1	8	76	2.7	4	64	0	0	8	43
4	2	8	74	2.6	3	57	0	0	14	37
4	3	8	14	0.5	0	9	0	0	4	10
4	1	9	133	4.8	1	107	0	3	22	96
4	2	9	189	6.7	8	151	0	1	30	66
4	3	9	68	2.4	2	40	0	1	24	36
4	1	10	113	4.0	3	72	0	4	34	92

site	B	date	DM	GR	HFG	LFG	WCL	OLEG	OSPS	DE.MA
4	2	10	86	3.1	1	54	0	1	30	69
4	3	10	113	4.0	10	69	3	0	31	37
4	1	11	81	2.9	2	45	1	3	31	38
4	2	11	190	6.8	0	110	3	5	72	99
4	3	11	83	3.0	3	42	1	2	35	71
4	1	12	67	2.4	1	46	0	3	17	70
4	2	12	101	3.6	3	54	2	0	41	32
4	3	12	78	2.8	5	49	6	0	17	44
4	1	13	130	4.6	5	96	2	6	21	81
4	2	13	143	5.1	4	89	1	1	48	88
4	3	13	73	2.6	0	43	0	13	16	32
4	1	14	177	6.3	0	122	0	2	53	66
4	2	14	88	3.1	0	52	1	4	31	34
4	3	14	176	6.3	3	115	5	8	46	94
4	1	15	58	2.1	0	34	0	3	20	41
4	2	15	80	2.9	4	44	1	1	30	31
4	3	15	107	3.8	9	67	1	1	29	78
4	1	16	82	2.9	0	49	0	2	31	28
4	2	16	25	0.9	1	14	1	0	9	15
4	3	16	47	1.7	2	30	0	0	13	21
4	1	17	72	2.6	3	48	8	0	14	68
4	2	17	93	3.3	6	63	1	4	20	42
4	3	17	75	2.7	10	42	2	6	15	52
4	1	18	265	9.5	7	181	5	6	66	139
4	2	18	111	4.0	0	71	0	3	37	70
4	3	18	177	6.3	3	117	7	7	43	133
4	1	19	333	10.8	2	255	0	6	71	48
4	2	19	269	8.7	0	213	3	1	52	60
4	3	19	235	7.6	7	138	4	3	83	21
4	1	20	430	13.9	6	300	9	0	115	75
4	2	20	743	24.0	10	504	8	16	204	51
4	3	20	613	19.8	2	413	15	27	156	31
4	1	21	445	15.9	4	297	1	21	123	74
4	2	21	647	23.1	9	366	4	0	268	62
4	3	21	626	22.4	0	317	37	8	263	47
4	1	22	415	14.8	6	250	6	10	143	55
4	2	22	594	21.2	6	368	0	14	206	91
4	3	22	592	21.1	8	341	3	17	223	138
4	1	23	359	12.8	3	192	13	73	78	26
4	2	23	260	9.3	3	148	6	17	87	33
4	3	23	512	18.3	4	345	6	10	146	43
4	1	24	317	13.2	0	233	3	15	66	54
4	2	24	239	10.0	2	151	4	13	70	30
4	3	24	304	12.7	8	177	0	13	106	106
4	1	25	343	12.2	6	182	5	4	145	89
4	2	25	233	8.3	3	114	14	13	89	84
4	3	25	388	13.9	3	207	5	66	109	52
4	1	26	682	20.7	10	318	20	20	313	154
4	2	26	527	16.0	5	302	10	6	204	128
4	3	26	774	23.4	26	407	37	24	280	139
4	1	27	532	19.0	14	297	11	16	194	129
4	2	27	561	20.0	47	359	2	0	153	151
4	3	27	359	12.8	5	189	10	29	126	148
5	1	2	706	25.2	200	412	39	23	32	100
5	2	2	1074	38.4	142	768	99	0	64	126
5	3	2	1122	40.1	260	725	115	0	23	76
5	1	3	1103	39.4	494	521	59	0	30	65
5	2	3	667	23.8	169	342	121	0	35	35
5	3	3	1215	43.4	347	753	86	0	29	31
5	1	4	951	34.0	235	628	66	0	22	5
5	2	4	555	19.8	55	341	113	0	47	2
5	3	4	880	31.4	307	434	119	0	19	4
5	1	5	729	26.0	249	399	60	0	21	54
5	2	5	734	26.2	331	334	69	0	0	33
5	3	5	365	13.1	81	237	44	0	4	6
5	1	6	686	24.5	312	334	36	0	4	23

site	B	date	DM	GR	HFG	LFG	WCL	OLEG	OSPS	DE.MA
5	2	6	704	25.1	291	360	37	0	15	20
5	3	6	590	21.1	149	401	25	0	15	9
5	1	7	930	33.2	278	508	142	0	3	21
5	2	7	715	25.5	386	280	38	0	12	44
5	3	7	424	15.2	92	291	14	0	28	15
5	1	8	281	10.0	89	136	48	0	9	26
5	2	8	285	10.2	84	142	27	0	32	21
5	3	8	285	10.2	87	163	22	1	12	20
5	1	9	244	8.7	36	184	18	0	6	15
5	2	9	171	6.1	23	125	7	0	15	9
5	3	9	146	5.2	47	92	6	0	1	8
5	1	10	141	5.1	41	84	6	0	9	20
5	2	10	112	4.0	20	84	1	0	7	30
5	3	10	212	7.6	40	142	5	0	25	22
5	1	11	203	7.2	32	140	12	2	16	22
5	2	11	193	6.9	53	126	8	0	7	31
5	3	11	251	9.0	94	150	8	0	0	6
5	1	12	119	4.2	30	77	5	0	7	52
5	2	12	209	7.5	60	132	14	0	4	33
5	3	12	374	13.4	173	196	4	0	2	13
5	1	13	180	6.4	53	98	11	5	13	21
5	2	13	214	7.6	69	127	6	6	6	19
5	3	13	198	7.1	62	112	13	0	11	20
5	1	14	146	5.2	42	93	1	1	10	20
5	2	14	212	7.6	45	121	18	1	27	30
5	3	14	122	4.4	29	82	7	4	0	11
5	1	15	80	2.9	16	52	7	1	5	37
5	2	15	190	6.8	36	115	16	5	18	19
5	3	15	211	7.5	84	105	3	0	19	21
5	1	16	97	3.5	34	47	7	0	8	13
5	2	16	307	11.0	136	149	16	0	6	28
5	3	16	205	7.3	65	131	7	0	2	24
5	1	17	313	11.2	138	149	21	0	5	53
5	2	17	267	9.6	169	88	7	0	3	10
5	3	17	146	5.2	76	64	6	0	1	12
5	1	18	554	19.8	148	310	78	5	14	20
5	2	18	900	32.2	193	645	29	2	32	19
5	3	18	598	21.4	204	336	34	1	22	20
5	1	19	1454	46.9	829	521	91	0	13	6
5	2	19	642	20.7	177	345	43	21	56	18
5	3	19	1610	51.9	605	831	114	0	60	19
5	1	20	1274	41.1	355	598	111	13	197	10
5	2	20	1611	52.0	410	824	294	49	34	21
5	3	20	1473	47.5	345	836	264	0	29	23
5	1	21	1907	68.1	479	1304	79	18	27	18
5	2	21	1337	47.8	364	796	168	0	9	25
5	3	21	1769	63.2	208	1169	225	84	84	10
5	1	22	1662	59.3	353	808	482	0	18	61
5	2	22	1080	38.6	69	868	25	12	106	35
5	3	22	1572	56.1	132	1258	88	86	8	36
5	1	23	1470	52.5	354	844	200	37	35	13
5	2	23	1160	41.4	93	859	51	5	151	26
5	3	23	1650	58.9	219	1327	19	26	59	94
5	1	24	768	32.0	145	505	63	27	29	61
5	2	24	892	37.2	162	539	123	0	67	56
5	3	24	962	40.1	165	625	140	13	19	54
5	1	25	1547	55.3	331	877	137	175	28	59
5	2	25	1994	71.2	539	1183	177	20	76	132
5	3	25	1986	70.9	666	901	286	16	116	129
5	1	26	1511	45.8	190	794	331	58	138	58
5	2	26	2121	64.3	195	1799	47	0	81	148
5	3	26	1359	41.2	101	939	224	9	86	141
5	1	27	2031	72.5	419	1292	126	0	194	111
5	2	27	1247	44.5	129	1073	30	0	15	90
5	3	27	831	29.7	86	551	59	16	119	94
6	1	2	701	25.0	229	301	155	0	16	40

site	B	date	DM	GR	HFG	LFG	WCL	OLEG	OSPS	DE.MA
6	2	2	1452	51.9	269	484	589	0	110	95
6	3	2	1501	53.6	368	705	368	0	61	121
6	1	3	1503	53.7	839	522	38	0	104	62
6	2	3	961	34.3	243	375	324	0	19	83
6	3	3	1118	39.9	352	456	252	0	57	65
6	1	4	1450	51.8	640	641	71	0	98	35
6	2	4	1207	43.1	416	613	117	0	60	17
6	3	4	906	32.4	451	381	63	0	11	13
6	1	5	177	6.3	17	114	20	0	26	17
6	2	5	465	16.6	95	261	71	0	37	69
6	3	5	1207	43.1	406	565	200	0	37	65
6	1	6	1022	36.5	479	411	62	0	70	8
6	2	6	1044	37.3	522	441	74	0	7	29
6	3	6	838	29.9	325	416	64	0	33	39
6	1	7	350	12.5	93	190	52	0	14	18
6	2	7	711	25.4	192	453	63	0	2	93
6	3	7	538	19.2	151	264	80	0	43	91
6	1	8	298	10.6	161	100	20	0	17	29
6	2	8	339	12.1	140	155	38	0	5	75
6	3	8	317	11.3	155	125	34	0	3	12
6	1	9	186	6.6	60	106	10	0	9	12
6	2	9	212	7.6	45	132	24	0	12	12
6	3	9	431	15.4	134	233	51	0	12	2
6	1	10	406	14.5	181	203	20	0	3	20
6	2	10	122	4.4	44	53	11	0	14	64
6	3	10	223	8.0	47	122	38	0	17	29
6	1	11	123	4.4	42	58	8	0	15	18
6	2	11	228	8.2	77	119	23	0	9	8
6	3	11	404	14.4	198	180	19	0	8	8
6	1	12	128	4.6	49	74	1	0	4	10
6	2	12	96	3.4	32	50	11	0	4	5
6	3	12	178	6.3	69	95	11	0	2	9
6	1	13	257	9.2	117	98	22	7	13	39
6	2	13	280	10.0	63	165	24	0	28	61
6	3	13	298	10.6	126	150	20	0	2	25
6	1	14	422	15.1	205	171	30	0	16	18
6	2	14	399	14.3	213	158	22	0	5	10
6	3	14	225	8.0	62	118	37	0	9	69
6	1	15	490	17.5	184	249	24	0	33	44
6	2	15	369	13.2	183	145	35	0	5	29
6	3	15	343	12.3	110	163	56	1	14	13
6	1	16	164	5.8	64	85	11	0	4	9
6	2	16	491	17.5	265	199	21	5	0	12
6	3	16	397	14.2	194	149	40	0	14	11
6	1	17	831	29.7	486	296	35	0	13	11
6	2	17	529	18.9	224	216	50	0	39	17
6	3	17	392	14.0	237	92	44	2	17	16
6	1	18	741	26.4	330	295	90	4	20	28
6	2	18	1222	43.6	605	407	136	0	74	95
6	3	18	556	19.9	206	281	58	3	8	22
6	1	19	1697	54.7	1339	316	12	0	30	21
6	2	19	1071	34.6	239	482	257	4	89	26
6	3	19	1445	46.6	611	596	202	0	35	18
6	1	20	2251	72.6	481	1360	178	4	228	23
6	2	20	1610	51.9	340	772	460	0	37	26
6	3	20	2361	76.2	1407	553	297	0	104	52
6	1	21	1299	46.4	601	572	14	17	95	17
6	2	21	2306	82.3	901	1046	206	0	154	38
6	3	21	1702	60.8	961	586	100	0	55	38
6	1	22	1227	43.8	239	719	151	13	104	213
6	2	22	1180	42.1	88	696	298	0	97	128
6	3	22	1672	59.7	422	865	310	0	74	204
6	1	23	1128	40.3	350	482	257	0	39	31
6	2	23	816	29.2	91	488	162	0	75	192
6	3	23	1555	55.5	699	657	159	0	40	31
6	1	24	761	31.7	214	384	78	0	86	74

site	B	date	DM	GR	HFG	LFG	WCL	OLEG	OSPS	DE.MA
6	2	24	1148	47.8	279	575	248	0	46	23
6	3	24	1051	43.8	179	540	311	0	20	45
6	1	25	1591	56.8	536	812	118	42	82	113
6	2	25	1464	52.3	289	894	234	0	47	30
6	3	25	2221	79.3	753	838	486	4	140	62
6	1	26	1407	42.6	138	901	146	3	218	161
6	2	26	2043	61.9	278	1016	689	60	0	227
6	3	26	2156	65.3	635	741	670	0	110	194
6	1	27	958	34.2	246	549	87	32	44	297
6	2	27	997	35.6	135	445	148	3	266	68
6	3	27	1231	44.0	293	616	230	0	93	121
7	1	2	1361	48.6	897	183	231	0	50	312
7	2	2	1873	66.9	1076	401	350	0	46	114
7	3	2	2014	71.9	1103	499	407	0	5	122
7	1	3	1162	41.5	483	508	148	0	24	130
7	2	3	1186	42.4	477	423	275	0	12	121
7	3	3	1317	47.0	816	237	263	0	0	132
7	1	4	1926	68.8	1425	334	139	0	28	69
7	2	4	1269	45.3	524	583	160	0	3	22
7	3	4	1319	47.1	292	659	341	0	26	28
7	1	5	1389	49.6	956	373	45	0	14	86
7	2	5	843	30.1	459	311	70	0	2	54
7	3	5	1327	47.4	846	352	128	0	1	0
7	1	6	1365	48.7	1018	300	23	0	23	23
7	2	6	1782	63.7	920	703	151	0	8	54
7	3	6	1130	40.4	593	428	102	0	7	75
7	1	7	825	29.5	522	190	96	0	17	34
7	2	7	600	21.4	382	149	61	0	7	68
7	3	7	824	29.4	512	227	84	0	0	62
7	1	8	861	30.8	515	299	42	0	5	42
7	2	8	838	29.9	676	101	52	0	8	54
7	3	8	1016	36.3	590	354	72	0	0	103
7	1	9	780	27.8	609	125	35	0	10	93
7	2	9	751	26.8	573	159	15	0	4	8
7	3	9	484	17.3	288	169	23	0	4	8
7	1	10	559	20.0	304	237	12	0	7	0
7	2	10	383	13.7	283	53	22	0	25	29
7	3	10	382	13.6	231	112	32	0	7	26
7	1	11	373	13.3	317	41	8	0	7	4
7	2	11	574	20.5	354	202	19	0	0	70
7	3	11	466	16.6	351	65	43	0	7	7
7	1	12	388	13.9	341	26	9	0	13	15
7	2	12	265	9.5	238	13	14	0	0	11
7	3	12	371	13.3	258	103	11	0	0	14
7	1	13	508	18.1	253	237	8	0	9	21
7	2	13	494	17.6	447	35	10	0	1	15
7	3	13	403	14.4	285	85	29	0	3	19
7	1	14	317	11.3	172	121	16	0	7	126
7	2	14	756	27.0	476	223	32	0	25	20
7	3	14	333	11.9	198	120	6	0	9	40
7	1	15	341	12.2	316	0	14	0	10	147
7	2	15	440	15.7	269	136	31	0	4	28
7	3	15	277	9.9	182	77	8	0	10	36
7	1	16	327	11.7	239	61	19	0	9	25
7	2	16	400	14.3	342	40	19	0	0	133
7	3	16	338	12.1	227	80	18	0	13	99
7	1	17	819	29.3	575	188	24	0	32	106
7	2	17	516	18.4	390	67	47	0	11	33
7	3	17	535	19.1	258	218	47	0	12	29
7	1	18	843	30.1	563	189	77	0	14	27
7	2	18	1268	45.3	848	248	153	0	18	59
7	3	18	843	30.1	380	389	53	0	22	14
7	1	19	1901	61.3	1631	135	104	0	31	34
7	2	19	2243	72.4	1661	341	169	0	73	19
7	3	19	1967	63.5	1656	211	74	0	26	29
7	1	20	2043	65.9	1367	572	60	0	44	57

site	B	date	DM	GR	HFG	LFG	WCL	OLEG	OSPS	DE.MA
7	2	20	2828	91.2	2169	366	294	0	0	60
7	3	20	2658	85.7	809	1040	649	0	160	169
7	1	21	1777	63.5	918	514	151	0	194	42
7	2	21	3545	126.6	3064	334	131	0	16	32
7	3	21	2481	88.6	2214	120	141	0	6	186
7	1	22	2797	99.9	1691	1027	66	0	14	38
7	2	22	3319	118.6	2350	832	128	0	9	24
7	3	22	2575	92.0	2169	263	143	0	0	45
7	1	23	2901	103.6	2591	258	23	0	30	61
7	2	23	2964	105.9	2730	73	161	0	0	53
7	3	23	2305	82.3	1595	403	222	0	85	60
7	1	24	1454	60.6	848	432	127	0	47	40
7	2	24	2462	102.6	1481	740	241	0	0	66
7	3	24	1771	73.8	679	614	398	0	80	88
7	1	25	2118	75.6	768	1105	177	0	69	177
7	2	25	2811	100.4	1175	1429	206	0	0	122
7	3	25	2302	82.2	705	1138	411	20	28	25
7	1	26	1889	57.2	665	934	225	0	65	163
7	2	26	3212	97.3	2753	282	118	0	59	270
7	3	26	2762	83.7	1479	900	219	0	164	191
7	1	27	1198	42.8	282	825	24	0	67	87
7	2	27	1035	37.0	883	52	97	0	3	113
7	3	27	1367	48.8	1104	215	36	0	13	68

Appendix 5.3: Percentages of N and P in herbage, N and P yields and N/P ratio at each site at each sampling date 1= 5/2/93 2=19/2/93 3=5/3/93 4=19/3/93 5=2/4/93 6=16/4/93 7=30/4/93 8=14/5/93 9=28/5/93 10=11/6/93 11=25/6/93 12=9/7/93 13=23/7/93 14=6/8/93 15=20/8/93 16=3/9/93 17=17/9/93 18=1/10/93 19=18/10/93 20=1/11/93 21=15/11/93 22=29/11/93 23=13/12/93 24=23/12/93 25=1/10/94 26=25/1/94 27=7/2/94. Fortnightly harvest is indicated as week=2 and monthly harvest as week=4.

site	block	date	N %	N(kg/ha)	P %	P(kg/ha)	N/P	week
1	1	1	2.8	3.8	0.30	0.41	9.2	2
1	2	1	3.0	6.1	0.37	0.74	8.3	2
1	3	1	3.1	3.1	0.32	0.33	9.5	2
1	1	2	2.8	9.9	0.24	0.85	11.7	2
1	2	2	2.9	11.4	0.30	1.20	9.5	2
1	3	2	2.6	11.0	0.27	1.14	9.6	2
1	1	3	3.1	8.7	0.32	0.90	9.7	2
1	2	3	3.3	10.1	0.35	1.07	9.4	2
1	3	3	3.2	11.9	0.36	1.35	8.8	2
1	2	4	3.1	1.1	0.24	0.08	12.9	2
1	3	4	3.1	3.0	0.24	0.24	12.9	2
1	1	5	2.5	1.1	0.24	0.11	10.4	2
1	2	5	3.5	6.2	0.33	0.58	10.8	2
1	3	5	3.2	2.2	0.28	0.20	11.4	2
1	1	6	2.6	1.0	0.25	0.10	10.4	2
1	2	6	3.6	2.6	0.33	0.24	10.9	2
1	3	6	3.7	2.8	0.39	0.30	9.5	2
1	1	7	2.0	4.8	0.23	0.57	8.5	2
1	2	7	3.8	13.4	0.41	1.47	9.2	2
1	3	7	3.7	12.0	0.41	1.31	9.1	2
1	1	8	2.6	1.3	0.29	0.14	9.0	2
1	2	8	3.5	3.9	0.35	0.38	10.1	2
1	3	8	3.1	3.7	0.37	0.44	8.4	2
1	1	9	2.5	4.2	0.25	0.42	10.0	2
1	2	9	2.9	2.7	0.33	0.31	8.7	2
1	3	9	4.6	5.0	0.40	0.43	11.5	2
1	1	10	2.2	1.0	0.24	0.11	9.4	2
1	2	10	2.6	0.7	0.26	0.07	10.1	2
1	3	10	3.0	2.3	0.28	0.22	10.7	2
1	1	11	3.2	2.3	0.30	0.21	10.8	2
1	2	11	3.8	2.6	0.43	0.29	9.0	2
1	3	11	4.3	2.5	0.40	0.23	10.8	2
1	1	12	2.6	2.0	0.28	0.21	9.3	2
1	2	12	4.5	6.1	0.30	0.40	15.1	2
1	3	12	4.3	3.6	0.35	0.29	12.3	2
1	1	13	3.6	0.5	0.29	0.04	12.4	2
1	2	13	2.9	2.8	0.29	0.28	10.0	2
1	3	13	4.3	8.9	0.29	0.60	14.8	2
1	1	14	3.4	3.0	0.30	0.26	11.5	2
1	2	14	3.6	6.1	0.31	0.52	11.8	2
1	3	14	3.0	6.6	0.30	0.67	9.8	2
1	1	15	3.0	1.8	0.28	0.17	10.9	2
1	2	15	3.3	1.2	0.28	0.10	12.0	2
1	3	15	4.0	13.4	0.32	1.05	12.7	2
1	1	16	2.9	0.4	0.32	0.05	9.1	2
1	2	16	2.9	0.7	0.32	0.07	9.1	2
1	3	16	2.9	1.2	0.32	0.14	9.1	2
1	1	17	2.6	3.1	0.29	0.34	9.0	2
1	2	17	3.3	6.5	0.36	0.70	9.3	2
1	3	17	2.5	3.4	0.26	0.35	9.8	2
1	1	18	2.8	3.8	0.25	0.34	11.2	2
1	2	18	3.8	13.4	0.31	1.08	12.4	2
1	3	18	2.6	3.8	0.25	0.36	10.4	2
1	1	19	3.2	4.1	0.31	0.39	10.5	2
1	2	19	3.7	10.2	0.30	0.85	12.1	2
1	3	19	3.2	4.9	0.31	0.47	10.5	2
1	1	20	3.7	18.2	0.34	1.70	10.7	2
1	2	20	3.1	5.2	0.29	0.49	10.7	2

site	block	date	N %	N(kg/ha)	P %	P(kg/ha)	N/P	week
1	3	20	3.4	14.0	0.37	1.50	9.3	2
1	1	21	2.7	5.6	0.26	0.54	10.4	2
1	2	21	3.4	12.2	0.34	1.22	10.0	2
1	3	21	3.8	34.6	0.40	3.60	9.6	2
1	1	22	3.0	2.5	0.29	0.25	10.3	2
1	2	22	2.9	9.9	0.37	1.23	8.0	2
1	3	22	3.7	28.0	0.38	2.88	9.7	2
1	1	23	2.9	10.2	0.31	1.13	9.1	2
1	2	23	2.8	9.4	0.33	1.10	8.5	2
1	3	23	3.4	15.4	0.34	1.54	10.0	2
1	1	24	2.6	4.0	0.29	0.45	9.0	2
1	2	24	3.3	7.5	0.33	0.75	10.0	2
1	3	24	3.6	7.8	0.37	0.81	9.6	2
1	1	25	2.4	12.5	0.26	1.32	9.4	2
1	2	25	2.8	16.8	0.26	1.59	10.6	2
1	3	25	2.5	8.2	0.31	1.03	8.0	2
1	1	26	2.6	17.5	0.24	1.62	10.8	2
1	2	26	3.1	13.6	0.29	1.30	10.5	2
1	3	26	2.6	16.0	0.24	1.48	10.8	2
1	1	2	2.4	18.4	0.27	2.03	9.1	4
1	2	2	2.8	23.4	0.31	2.55	9.2	4
1	3	2	3.0	22.3	0.25	1.85	12.0	4
1	1	3	3.1	24.6	0.30	2.34	10.5	4
1	2	3	4.0	38.0	0.45	4.26	8.9	4
1	3	3	3.7	27.2	0.36	2.61	10.4	4
1	1	4	4.0	9.5	0.43	1.02	9.3	4
1	2	4	3.2	12.3	0.32	1.21	10.2	4
1	3	4	2.9	9.5	0.31	1.00	9.5	4
1	2	5	2.8	7.7	0.33	0.90	8.5	4
1	3	5	2.8	6.4	0.31	0.69	9.2	4
1	1	6	3.5	6.6	0.30	0.57	11.5	4
1	2	6	3.2	5.0	0.28	0.44	11.4	4
1	3	6	3.8	12.7	0.31	1.03	12.3	4
1	1	7	2.4	6.8	0.26	0.73	9.4	4
1	2	7	2.8	9.8	0.31	1.06	9.2	4
1	3	7	3.0	16.3	0.30	1.66	9.8	4
1	1	8	2.8	4.0	0.28	0.40	10.0	4
1	2	8	3.6	13.6	0.43	1.64	8.3	4
1	3	8	3.2	12.1	0.31	1.17	10.3	4
1	1	9	3.2	9.0	0.31	0.87	10.3	4
1	2	9	4.3	19.7	0.40	1.83	10.8	4
1	3	9	3.4	3.8	0.35	0.39	9.9	4
1	1	10	2.4	2.8	0.27	0.32	8.9	4
1	2	10	3.9	2.9	0.37	0.27	10.5	4
1	3	10	4.8	11.8	0.35	0.86	13.7	4
1	1	11	3.0	6.6	0.33	0.73	9.1	4
1	2	11	3.9	7.4	0.41	0.79	9.4	4
1	3	11	3.0	5.6	0.34	0.65	8.7	4
1	1	12	2.7	0.8	0.30	0.09	9.0	4
1	2	12	2.7	2.9	0.30	0.32	9.0	4
1	1	13	2.8	2.8	0.39	0.39	7.2	4
1	2	13	3.0	4.4	0.30	0.43	10.2	4
1	3	13	4.5	15.8	0.33	1.16	13.7	4
1	1	14	2.1	6.9	0.23	0.76	9.1	4
1	2	14	2.9	8.2	0.31	0.87	9.4	4
1	3	14	4.9	25.2	0.33	1.69	14.9	4
1	1	15	3.5	4.6	0.28	0.38	12.2	4
1	2	15	2.7	7.4	0.27	0.74	10.0	4
1	3	15	3.8	20.4	0.42	2.23	9.2	4
1	1	16	4.0	0.5	0.33	0.04	12.0	4
1	2	16	3.5	2.4	0.35	0.24	10.0	4
1	3	16	4.4	5.2	0.32	0.37	14.0	4
1	1	17	2.7	4.9	0.31	0.57	8.6	4
1	2	17	4.2	16.6	0.37	1.44	11.5	4
1	3	17	3.5	11.0	0.33	1.03	10.6	4
1	1	18	3.0	7.2	0.28	0.67	10.7	4

site	block	date	N %	N(kg/ha)	P %	P(kg/ha)	N/P	week
1	2	18	3.7	31.3	0.36	3.05	10.3	4
1	3	18	3.0	11.5	0.29	1.14	10.2	4
1	1	19	2.7	6.5	0.29	0.69	9.5	4
1	2	19	3.4	41.5	0.37	4.58	9.1	4
1	3	19	3.0	7.6	0.28	0.70	10.9	4
1	1	20	3.3	16.9	0.30	1.56	10.8	4
1	2	20	3.8	29.3	0.31	2.41	12.2	4
1	3	20	3.7	40.2	0.36	3.91	10.3	4
1	1	21	2.8	36.7	0.27	3.61	10.2	4
1	2	21	2.9	19.3	0.33	2.17	8.9	4
1	3	21	3.5	52.6	0.37	5.55	9.5	4
1	1	22	2.6	13.2	0.29	1.47	9.0	4
1	2	22	2.9	23.5	0.35	2.82	8.3	4
1	3	22	3.4	25.6	0.37	2.78	9.2	4
1	1	23	2.8	31.1	0.33	3.72	8.4	4
1	2	23	3.0	36.0	0.32	3.83	9.4	4
1	3	23	3.1	40.6	0.33	4.32	9.4	4
1	1	24	3.6	43.4	0.34	4.10	10.6	4
1	2	24	3.1	19.9	0.39	2.57	7.8	4
1	3	24	3.6	36.3	0.35	3.53	10.3	4
1	1	25	2.9	32.7	0.33	3.65	9.0	4
1	2	25	3.1	40.7	0.36	4.80	8.5	4
1	3	25	2.6	51.5	0.21	4.08	12.6	4
1	1	26	3.1	45.7	0.32	4.79	9.5	4
1	2	26	2.8	27.4	0.33	3.26	8.4	4
1	3	26	3.3	58.9	0.28	4.93	11.9	4
1	1	27	3.0	18.4	0.35	2.14	8.6	4
1	2	27	3.2	30.6	0.28	2.72	11.3	4
1	3	27	2.7	29.0	0.27	2.84	10.2	4
2	1	1	2.0	8.3	0.15	0.63	13.2	2
2	2	1	2.1	7.5	0.14	0.49	15.4	2
2	3	1	1.8	8.1	0.13	0.59	13.7	2
2	1	2	2.2	6.8	0.15	0.48	14.2	2
2	2	2	2.1	5.5	0.15	0.37	14.7	2
2	3	2	2.2	5.7	0.14	0.36	15.5	2
2	1	3	2.9	7.1	0.22	0.54	13.1	2
2	2	3	2.9	4.8	0.22	0.37	12.9	2
2	3	3	3.1	3.8	0.22	0.27	13.9	2
2	1	4	2.6	1.2	0.20	0.09	13.0	2
2	2	4	2.6	1.0	0.19	0.07	13.6	2
2	3	4	2.6	1.9	0.18	0.13	14.2	2
2	1	5	2.8	1.6	0.22	0.12	13.0	2
2	2	5	2.4	1.5	0.19	0.12	12.3	2
2	3	5	2.6	0.6	0.20	0.05	12.7	2
2	1	6	3.2	2.0	0.22	0.14	14.4	2
2	2	6	2.9	0.3	0.20	0.02	14.1	2
2	3	6	2.6	1.0	0.19	0.07	13.7	2
2	1	7	2.1	7.3	0.16	0.56	13.1	2
2	2	7	1.9	11.9	0.17	1.06	11.2	2
2	3	7	2.9	3.0	0.19	0.20	15.3	2
2	1	8	2.5	0.4	0.17	0.03	14.3	2
2	2	8	2.7	5.1	0.18	0.34	15.0	2
2	3	8	2.2	1.4	0.16	0.11	13.6	2
2	1	9	2.2	2.9	0.15	0.19	14.8	2
2	2	9	2.2	2.3	0.21	0.22	10.2	2
2	3	9	1.8	2.7	0.14	0.21	12.8	2
2	1	10	2.1	0.5	0.16	0.04	13.1	2
2	2	10	2.0	0.8	0.15	0.06	13.3	2
2	3	10	2.3	2.7	0.18	0.21	12.8	2
2	1	11	2.0	1.7	0.16	0.14	12.5	2
2	2	11	3.2	2.9	0.21	0.18	15.7	2
2	3	11	2.8	2.1	0.18	0.14	15.1	2
2	1	12	2.0	1.1	0.19	0.10	10.5	2
2	2	12	2.5	4.6	0.22	0.42	11.1	2
2	3	12	3.0	1.0	0.26	0.09	11.5	2
2	1	13	2.8	1.3	0.19	0.09	15.0	2

site	block	date	N %	N(kg/ha)	P %	P(kg/ha)	N/P	week
2	2	13	2.8	2.3	0.27	0.21	10.6	2
2	3	13	2.4	0.9	0.16	0.06	14.8	2
2	1	14	2.2	3.4	0.17	0.26	13.1	2
2	2	14	3.6	1.1	0.20	0.06	18.5	2
2	3	14	2.4	3.2	0.18	0.24	13.2	2
2	1	15	2.0	1.0	0.16	0.08	12.5	2
2	2	15	3.0	1.4	0.17	0.08	17.7	2
2	3	15	2.3	0.6	0.18	0.05	12.7	2
2	1	16	3.0	0.9	0.20	0.06	15.4	2
2	3	16	3.0	0.8	0.20	0.05	15.4	2
2	1	17	2.2	4.0	0.16	0.30	13.6	2
2	2	17	2.6	2.9	0.18	0.20	14.4	2
2	3	17	2.0	4.4	0.15	0.32	13.7	2
2	1	18	2.6	5.0	0.17	0.32	15.5	2
2	2	18	2.5	4.4	0.17	0.30	14.7	2
2	3	18	2.2	2.9	0.16	0.22	13.6	2
2	1	19	2.4	2.3	0.16	0.15	15.0	2
2	2	19	3.0	2.7	0.16	0.15	18.2	2
2	3	19	3.2	8.4	0.22	0.59	14.2	2
2	1	20	3.2	16.3	0.23	1.15	14.2	2
2	2	20	3.4	13.1	0.19	0.74	17.7	2
2	3	20	3.6	10.2	0.23	0.66	15.5	2
2	1	21	2.7	9.8	0.20	0.72	13.5	2
2	2	21	3.0	11.4	0.19	0.72	15.9	2
2	3	21	2.9	8.6	0.19	0.56	15.4	2
2	1	22	1.8	9.2	0.13	0.67	13.7	2
2	2	22	2.6	13.6	0.17	0.89	15.3	2
2	3	22	2.5	3.8	0.18	0.27	14.1	2
2	1	23	2.8	2.2	0.19	0.15	15.0	2
2	2	23	3.0	5.0	0.22	0.35	14.1	2
2	3	23	2.9	3.6	0.21	0.26	13.8	2
2	1	24	2.3	3.6	0.17	0.26	13.5	2
2	2	24	3.0	5.3	0.16	0.29	18.5	2
2	3	24	3.1	5.4	0.17	0.29	18.2	2
2	1	25	2.3	12.7	0.16	0.89	14.2	2
2	2	25	2.7	19.3	0.17	1.19	16.2	2
2	3	25	2.4	18.1	0.14	1.10	16.6	2
2	1	26	2.8	9.1	0.20	0.64	14.2	2
2	2	26	3.0	13.1	0.22	0.95	13.8	2
2	3	26	2.1	13.0	0.16	0.97	13.4	2
2	1	2	1.9	8.9	0.13	0.62	14.4	4
2	2	2	2.2	8.8	0.14	0.56	15.7	4
2	3	2	2.3	13.5	0.13	0.76	17.7	4
2	1	3	2.6	15.8	0.20	1.19	13.3	4
2	2	3	2.6	13.8	0.20	1.04	13.3	4
2	3	3	3.0	17.0	0.19	1.04	16.3	4
2	1	4	2.8	4.4	0.19	0.30	15.0	4
2	2	4	4.1	8.5	0.20	0.42	20.2	4
2	1	5	2.7	5.7	0.17	0.36	15.7	4
2	2	5	3.6	6.9	0.21	0.40	17.4	4
2	3	5	2.7	9.8	0.16	0.58	16.9	4
2	1	6	3.0	4.0	0.23	0.30	13.3	4
2	2	6	2.6	0.7	0.20	0.06	12.7	4
2	3	6	3.0	2.6	0.18	0.16	16.5	4
2	1	7	2.3	7.2	0.19	0.58	12.4	4
2	2	7	2.7	15.5	0.19	1.08	14.4	4
2	3	7	2.9	5.4	0.19	0.36	15.1	4
2	1	8	2.4	4.1	0.21	0.35	11.7	4
2	2	8	3.1	3.0	0.18	0.18	16.8	4
2	3	8	2.4	3.1	0.16	0.21	14.5	4
2	1	9	2.3	4.9	0.17	0.36	13.6	4
2	2	9	3.3	9.8	0.18	0.53	18.6	4
2	3	9	2.3	3.6	0.15	0.24	14.8	4
2	1	10	2.1	2.7	0.14	0.19	14.5	4
2	2	10	2.9	4.8	0.20	0.32	15.0	4
2	3	10	1.8	5.0	0.14	0.39	12.8	4

site	block	date	N %	N(kg/ha)	P %	P(kg/ha)	N/P	week
2	1	11	2.4	2.7	0.17	0.19	13.8	4
2	2	11	2.4	5.1	0.19	0.39	13.0	4
2	3	11	2.8	5.2	0.25	0.45	11.4	4
2	1	12	2.0	2.2	0.18	0.20	11.1	4
2	2	12	2.8	5.1	0.21	0.37	13.8	4
2	3	12	3.1	3.3	0.22	0.23	14.3	4
2	1	13	2.4	2.8	0.19	0.22	12.6	4
2	2	13	3.2	1.5	0.20	0.09	16.4	4
2	3	13	3.5	3.1	0.23	0.20	15.3	4
2	1	14	1.9	11.2	0.16	0.95	11.8	4
2	2	14	2.9	7.8	0.24	0.66	11.9	4
2	3	14	2.7	6.0	0.17	0.39	15.4	4
2	1	15	2.1	1.0	0.17	0.08	11.9	4
2	2	15	3.1	1.2	0.16	0.06	19.1	4
2	3	15	2.5	2.0	0.19	0.15	13.4	4
2	1	16	3.0	0.7	0.20	0.05	15.4	4
2	2	16	3.0	0.4	0.20	0.03	15.4	4
2	3	16	3.0	1.0	0.20	0.06	15.4	4
2	1	17	2.6	4.6	0.18	0.33	14.1	4
2	2	17	2.6	1.5	0.17	0.10	15.3	4
2	3	17	2.9	5.5	0.19	0.35	15.7	4
2	1	18	2.4	6.2	0.16	0.41	15.0	4
2	2	18	2.4	10.0	0.17	0.73	13.7	4
2	3	18	2.3	10.0	0.17	0.73	13.6	4
2	1	19	2.8	9.9	0.18	0.64	15.4	4
2	2	19	3.8	10.0	0.17	0.46	22.0	4
2	3	19	3.5	15.8	0.25	1.12	14.2	4
2	1	20	3.6	26.2	0.23	1.63	16.0	4
2	2	20	3.2	21.0	0.18	1.20	17.6	4
2	3	20	3.5	21.2	0.21	1.25	16.9	4
2	1	21	2.6	23.3	0.20	1.72	13.5	4
2	2	21	3.0	23.8	0.19	1.55	15.4	4
2	3	21	2.6	32.6	0.17	2.19	14.9	4
2	1	22	2.3	27.6	0.19	2.23	12.4	4
2	2	22	2.7	16.8	0.19	1.19	14.2	4
2	3	22	2.6	15.9	0.18	1.12	14.2	4
2	1	23	2.7	12.2	0.20	0.89	13.8	4
2	2	23	2.6	15.5	0.19	1.14	13.7	4
2	3	23	2.6	14.6	0.16	0.88	16.6	4
2	1	24	2.9	8.6	0.16	0.49	17.6	4
2	2	24	2.7	9.6	0.21	0.72	13.3	4
2	3	24	2.8	7.7	0.22	0.59	12.9	4
2	1	25	2.7	18.6	0.16	1.11	16.7	4
2	2	25	2.8	33.6	0.15	1.83	18.4	4
2	3	25	2.4	22.2	0.14	1.29	17.1	4
2	1	26	2.6	41.9	0.17	2.64	15.9	4
2	2	26	2.9	34.4	0.19	2.18	15.8	4
2	3	26	2.8	38.3	0.17	2.31	16.6	4
2	1	27	2.6	32.0	0.17	2.08	15.4	4
2	2	27	2.4	16.2	0.15	1.01	16.0	4
2	3	27	2.0	9.6	0.13	0.65	14.8	4
3	1	1	3.1	13.5	0.21	0.92	14.7	2
3	2	1	2.6	10.9	0.19	0.82	13.3	2
3	3	1	2.7	9.6	0.26	0.95	10.2	2
3	1	2	2.5	8.7	0.19	0.67	13.0	2
3	2	2	2.2	9.3	0.18	0.77	12.2	2
3	3	2	2.5	8.4	0.20	0.68	12.2	2
3	1	3	3.7	9.1	0.25	0.61	14.8	2
3	2	3	3.3	6.9	0.26	0.55	12.6	2
3	3	3	3.2	3.8	0.27	0.33	11.8	2
3	1	4	4.1	4.9	0.23	0.28	17.4	2
3	2	4	3.6	0.9	0.24	0.06	15.1	2
3	3	4	3.0	1.6	0.24	0.13	12.7	2
3	1	5	3.0	1.6	0.21	0.11	14.2	2
3	2	5	2.7	1.9	0.23	0.16	11.7	2
3	3	5	2.9	1.0	0.22	0.08	12.9	2

site	block	date	N %	N(kg/ha)	P %	P(kg/ha)	N/P	week
3	1	6	2.3	1.5	0.17	0.11	13.8	2
3	2	6	3.2	0.8	0.20	0.05	15.2	2
3	3	6	4.0	2.6	0.24	0.16	16.7	2
3	1	7	2.1	6.0	0.21	0.60	10.0	2
3	2	7	2.1	3.2	0.19	0.28	11.3	2
3	3	7	3.0	4.3	0.26	0.38	11.3	2
3	1	8	2.1	1.8	0.18	0.16	11.7	2
3	2	8	2.4	0.8	0.20	0.07	11.6	2
3	3	8	2.6	2.4	0.23	0.21	11.5	2
3	1	9	2.3	1.7	0.20	0.14	11.8	2
3	2	9	2.9	2.5	0.26	0.22	11.3	2
3	3	9	3.0	2.0	0.22	0.15	13.6	2
3	1	10	2.3	0.3	0.20	0.02	12.0	2
3	2	10	2.2	3.4	0.19	0.28	11.9	2
3	3	10	2.5	4.2	0.20	0.34	12.1	2
3	1	11	3.3	2.9	0.27	0.23	12.3	2
3	2	11	3.2	4.3	0.27	0.37	11.8	2
3	3	11	3.1	4.2	0.28	0.37	11.3	2
3	1	12	3.1	3.3	0.28	0.29	11.2	2
3	2	12	2.4	2.2	0.21	0.19	11.4	2
3	3	12	2.8	3.0	0.25	0.26	11.3	2
3	1	13	2.6	4.1	0.23	0.37	11.3	2
3	2	13	2.7	3.8	0.24	0.33	11.5	2
3	3	13	2.9	5.9	0.20	0.40	14.6	2
3	1	14	2.3	3.2	0.22	0.31	10.4	2
3	2	14	2.6	4.4	0.22	0.36	12.1	2
3	3	14	2.5	1.8	0.22	0.16	11.4	2
3	1	15	2.3	0.9	0.18	0.07	12.4	2
3	2	15	3.0	2.6	0.23	0.20	13.2	2
3	3	15	2.5	2.3	0.20	0.18	12.5	2
3	2	16	2.6	0.4	0.23	0.03	11.5	2
3	3	16	2.6	1.0	0.23	0.09	11.5	2
3	1	17	2.1	3.8	0.18	0.32	11.7	2
3	2	17	2.9	3.8	0.24	0.31	12.3	2
3	3	17	2.5	4.8	0.21	0.40	12.0	2
3	1	18	2.6	5.3	0.22	0.43	12.3	2
3	2	18	2.5	3.9	0.20	0.32	12.2	2
3	3	18	3.0	16.5	0.23	1.22	13.5	2
3	1	19	3.0	5.6	0.24	0.43	12.9	2
3	2	19	3.4	11.2	0.27	0.89	12.5	2
3	3	19	3.3	7.7	0.25	0.58	13.4	2
3	1	20	3.9	9.2	0.28	0.67	13.8	2
3	2	20	3.9	22.7	0.26	1.53	14.8	2
3	3	20	3.3	9.5	0.25	0.72	13.1	2
3	1	21	3.1	13.7	0.27	1.16	11.8	2
3	2	21	3.3	12.3	0.23	0.84	14.7	2
3	3	21	3.0	9.6	0.23	0.75	12.8	2
3	1	22	3.1	11.7	0.23	0.87	13.4	2
3	2	22	2.8	25.6	0.22	2.02	12.7	2
3	3	22	2.8	14.6	0.24	1.25	11.7	2
3	1	23	3.0	11.2	0.25	0.93	12.0	2
3	2	23	2.3	8.9	0.17	0.65	13.6	2
3	3	23	2.8	5.7	0.23	0.47	12.2	2
3	1	24	2.9	4.3	0.23	0.35	12.5	2
3	2	24	2.7	6.6	0.23	0.56	11.7	2
3	3	24	3.1	5.1	0.24	0.39	12.9	2
3	1	25	2.7	9.9	0.18	0.66	15.0	2
3	2	25	2.7	22.8	0.18	1.56	14.6	2
3	3	25	2.5	19.3	0.19	1.46	13.2	2
3	1	26	3.3	19.5	0.22	1.31	14.9	2
3	2	26	3.5	10.8	0.25	0.76	14.2	2
3	3	26	3.8	23.9	0.26	1.64	14.6	2
3	1	2	3.5	35.1	0.18	1.80	19.5	4
3	2	2	2.5	17.0	0.18	1.26	13.5	4
3	3	2	2.6	15.7	0.22	1.30	12.0	4
3	1	3	3.7	25.4	0.26	1.78	14.2	4

site	block	date	N %	N(kg/ha)	P %	P(kg/ha)	N/P	week
3	2	3	2.9	20.8	0.22	1.56	13.3	4
3	3	3	3.0	21.2	0.28	1.99	10.7	4
3	1	4	3.2	11.8	0.28	1.04	11.4	4
3	2	4	2.8	6.4	0.25	0.57	11.2	4
3	3	4	3.0	8.5	0.25	0.71	12.0	4
3	1	5	3.1	7.9	0.24	0.62	12.7	4
3	2	5	2.5	4.8	0.22	0.42	11.4	4
3	3	5	2.6	5.1	0.23	0.46	11.0	4
3	1	6	3.1	3.5	0.33	0.38	9.4	4
3	2	6	2.7	4.9	0.24	0.44	11.2	4
3	3	6	2.9	2.9	0.25	0.25	11.6	4
3	1	7	2.5	15.0	0.20	1.24	12.1	4
3	2	7	2.6	11.6	0.23	1.04	11.1	4
3	3	7	2.4	3.4	0.17	0.24	14.0	4
3	1	8	2.5	2.3	0.22	0.20	11.6	4
3	2	8	2.8	1.1	0.23	0.09	12.4	4
3	3	8	3.6	6.9	0.24	0.46	15.0	4
3	1	9	3.3	3.2	0.25	0.25	12.9	4
3	2	9	2.8	4.5	0.23	0.37	12.2	4
3	3	9	3.1	3.9	0.24	0.30	12.9	4
3	1	10	3.0	0.4	0.23	0.03	12.9	4
3	2	10	2.6	2.8	0.23	0.24	11.3	4
3	3	10	3.4	5.9	0.23	0.41	14.5	4
3	1	11	3.3	6.3	0.26	0.49	12.7	4
3	2	11	2.9	4.7	0.25	0.41	11.5	4
3	3	11	3.3	3.3	0.26	0.26	12.7	4
3	1	12	3.0	3.4	0.25	0.28	12.0	4
3	2	12	3.9	2.8	0.32	0.23	12.2	4
3	3	12	3.1	2.6	0.26	0.22	11.7	4
3	1	13	3.0	6.2	0.25	0.52	12.0	4
3	2	13	3.0	5.5	0.22	0.40	13.8	4
3	3	13	2.8	4.0	0.22	0.32	12.4	4
3	1	14	2.4	7.8	0.20	0.65	12.0	4
3	2	14	3.0	9.0	0.23	0.67	13.5	4
3	3	14	3.1	9.2	0.25	0.73	12.5	4
3	1	15	2.7	1.2	0.24	0.11	11.5	4
3	2	15	2.8	2.8	0.20	0.20	14.3	4
3	3	15	3.0	4.4	0.24	0.34	12.9	4
3	1	16	2.6	0.2	0.23	0.01	11.5	4
3	2	16	2.6	1.5	0.23	0.13	11.5	4
3	3	16	2.6	1.2	0.23	0.11	11.5	4
3	1	17	3.1	4.8	0.26	0.41	11.9	4
3	2	17	3.0	7.8	0.21	0.55	14.2	4
3	3	17	3.3	9.5	0.23	0.66	14.5	4
3	1	18	2.6	12.7	0.19	0.96	13.2	4
3	2	18	2.8	11.2	0.20	0.77	14.5	4
3	3	18	2.9	6.6	0.20	0.45	14.6	4
3	1	19	3.1	17.7	0.25	1.43	12.4	4
3	2	19	3.3	12.7	0.23	0.87	14.6	4
3	3	19	3.3	14.9	0.25	1.11	13.4	4
3	1	20	3.5	18.2	0.24	1.25	14.6	4
3	2	20	3.0	32.2	0.19	2.11	15.3	4
3	3	20	3.3	29.0	0.24	2.09	13.9	4
3	1	21	3.0	26.8	0.24	2.11	12.7	4
3	2	21	3.0	40.7	0.22	2.93	13.9	4
3	3	21	2.8	21.4	0.21	1.63	13.1	4
3	1	22	2.4	23.0	0.21	2.02	11.4	4
3	2	22	2.6	24.2	0.21	1.96	12.3	4
3	3	22	2.3	33.2	0.23	3.32	10.0	4
3	1	23	2.7	18.3	0.21	1.43	12.8	4
3	2	23	2.7	23.7	0.23	2.02	11.7	4
3	3	23	2.5	18.0	0.21	1.54	11.6	4
3	1	24	3.1	15.3	0.24	1.18	12.9	4
3	2	24	3.5	27.8	0.25	1.98	14.0	4
3	3	24	3.0	14.3	0.25	1.20	11.9	4
3	1	25	2.3	17.2	0.21	1.53	11.2	4

site	block	date	N %	N(kg/ha)	P %	P(kg/ha)	N/P	week
3	2	25	2.4	22.6	0.16	1.54	14.7	4
3	3	25	2.5	22.4	0.20	1.81	12.4	4
3	1	26	2.4	31.7	0.22	2.84	11.1	4
3	2	26	2.7	25.5	0.21	2.03	12.6	4
3	3	26	2.9	37.2	0.20	2.58	14.4	4
3	1	27	2.6	17.7	0.19	1.27	13.9	4
3	2	27	2.7	16.2	0.19	1.15	14.1	4
3	3	27	2.3	19.6	0.16	1.32	14.8	4
4	1	1	2.2	8.5	0.16	0.62	13.6	2
4	2	1	2.0	9.4	0.16	0.77	12.1	2
4	3	1	1.8	7.5	0.16	0.64	11.6	2
4	1	2	1.9	5.5	0.16	0.45	12.2	2
4	2	2	2.0	6.6	0.15	0.50	13.2	2
4	3	2	2.0	6.0	0.15	0.45	13.3	2
4	1	3	2.7	3.3	0.23	0.29	11.5	2
4	2	3	2.8	3.7	0.25	0.33	11.4	2
4	3	3	2.9	3.7	0.28	0.36	10.2	2
4	1	4	2.5	1.0	0.21	0.08	12.2	2
4	2	4	2.6	1.3	0.20	0.10	12.4	2
4	3	4	2.5	1.9	0.21	0.16	11.9	2
4	1	5	2.4	0.7	0.21	0.06	11.7	2
4	2	5	2.7	1.8	0.23	0.16	11.5	2
4	3	5	2.1	1.2	0.18	0.10	12.0	2
4	1	6	2.7	0.8	0.24	0.07	11.3	2
4	2	6	2.7	2.0	0.22	0.16	12.4	2
4	3	6	2.7	0.0	0.23	0.00	11.9	2
4	1	7	2.1	4.9	0.19	0.45	10.8	2
4	2	7	2.1	3.8	0.19	0.33	11.4	2
4	3	7	1.8	2.8	0.18	0.28	10.0	2
4	1	8	1.8	4.4	0.15	0.36	12.3	2
4	2	8	1.7	3.2	0.14	0.26	12.5	2
4	3	8	1.8	0.0	0.14	0.02	12.4	2
4	1	9	2.1	0.9	0.16	0.07	12.7	2
4	2	9	1.8	0.9	0.14	0.07	13.2	2
4	3	9	2.5	2.4	0.20	0.20	12.5	2
4	1	10	2.2	3.4	0.18	0.27	12.4	2
4	2	10	2.0	3.2	0.18	0.28	11.4	2
4	3	10	2.0	2.0	0.16	0.16	12.1	2
4	1	11	2.0	2.1	0.18	0.19	11.1	2
4	2	11	2.1	2.4	0.18	0.20	11.7	2
4	3	11	2.3	2.6	0.20	0.22	11.5	2
4	1	12	2.1	1.8	0.18	0.16	11.7	2
4	2	12	2.0	3.3	0.17	0.28	12.0	2
4	3	12	2.3	3.2	0.18	0.25	12.8	2
4	1	13	2.5	3.7	0.18	0.25	14.4	2
4	2	13	2.2	3.1	0.17	0.25	12.6	2
4	3	13	2.2	1.3	0.19	0.11	11.8	2
4	1	14	2.1	2.2	0.16	0.17	12.7	2
4	2	14	1.9	2.1	0.15	0.16	12.7	2
4	3	14	2.0	2.4	0.18	0.22	11.1	2
4	1	15	5.8	4.3	0.21	0.16	27.3	2
4	2	15	1.9	1.8	0.16	0.15	12.2	2
4	3	15	1.7	1.6	0.16	0.15	10.9	2
4	1	16	2.6	0.5	0.23	0.04	11.5	2
4	2	16	2.3	0.9	0.19	0.07	12.4	2
4	3	16	2.5	0.4	0.21	0.03	12.0	2
4	1	17	2.1	1.5	0.18	0.12	11.6	2
4	2	17	2.1	0.8	0.17	0.07	12.1	2
4	3	17	1.9	1.9	0.16	0.16	11.5	2
4	1	18	3.9	8.4	0.16	0.35	24.1	2
4	2	18	2.2	4.5	0.17	0.36	12.6	2
4	3	18	2.3	3.2	0.17	0.24	13.1	2
4	1	19	2.8	4.8	0.23	0.40	11.9	2
4	2	19	2.7	4.2	0.25	0.38	11.0	2
4	3	19	3.1	4.8	0.22	0.35	13.8	2
4	1	20	3.0	12.5	0.22	0.91	13.7	2

site	block	date	N %	N(kg/ha)	P %	P(kg/ha)	N/P	week
4	2	20	2.5	7.8	0.17	0.53	14.9	2
4	3	20	3.0	11.8	0.22	0.87	13.6	2
4	1	21	2.4	6.2	0.18	0.47	13.2	2
4	2	21	2.4	3.1	0.19	0.24	13.2	2
4	3	21	2.6	7.4	0.20	0.57	13.0	2
4	1	22	2.1	7.5	0.19	0.66	11.4	2
4	2	22	2.1	5.5	0.17	0.45	12.3	2
4	3	22	2.5	16.0	0.20	1.23	13.0	2
4	1	23	2.2	3.0	0.19	0.24	12.1	2
4	2	23	2.4	2.1	0.19	0.17	12.6	2
4	3	23	1.9	2.4	0.16	0.24	12.1	2
4	1	24	2.6	3.7	0.19	0.27	13.6	2
4	2	24	2.4	5.6	0.19	0.44	12.6	2
4	3	24	2.3	3.4	0.21	0.31	11.0	2
4	1	25	2.2	6.9	0.16	0.52	13.2	2
4	2	25	2.0	12.9	0.16	1.04	12.4	2
4	3	25	2.1	11.4	0.18	1.00	11.4	2
4	1	26	2.6	7.5	0.22	0.64	11.7	2
4	2	26	2.4	8.2	0.19	0.65	12.6	2
4	3	26	2.5	13.7	0.21	1.13	12.1	2
4	1	2	2.1	11.7	0.16	0.89	13.1	4
4	2	2	2.0	12.2	0.16	0.96	12.8	4
4	3	2	2.7	15.7	0.16	0.93	17.0	4
4	1	3	2.8	11.2	0.22	0.88	12.8	4
4	2	3	2.4	11.5	0.20	0.94	12.2	4
4	3	3	2.9	12.9	0.24	1.07	12.1	4
4	1	4	2.7	4.6	0.23	0.39	11.7	4
4	2	4	2.6	4.3	0.23	0.37	11.5	4
4	3	4	2.6	7.1	0.23	0.61	11.5	4
4	1	5	2.8	1.8	0.24	0.15	11.9	4
4	2	5	2.6	0.5	0.22	0.04	11.7	4
4	3	5	2.4	4.2	0.21	0.37	11.4	4
4	1	6	2.5	1.5	0.21	0.13	11.9	4
4	2	6	2.7	5.0	0.19	0.36	13.8	4
4	3	6	2.4	3.0	0.20	0.26	11.7	4
4	1	7	2.0	8.4	0.19	0.82	10.3	4
4	2	7	2.4	4.3	0.23	0.41	10.4	4
4	3	7	2.6	5.0	0.20	0.38	13.3	4
4	1	8	2.3	2.8	0.20	0.23	11.8	4
4	2	8	2.7	2.9	0.18	0.20	14.7	4
4	3	8	2.5	0.6	0.19	0.05	13.3	4
4	1	9	2.2	5.1	0.18	0.42	12.2	4
4	2	9	2.4	6.0	0.19	0.48	12.6	4
4	3	9	2.2	2.3	0.19	0.20	11.3	4
4	1	10	2.0	4.0	0.16	0.33	12.2	4
4	2	10	1.9	3.0	0.14	0.22	13.4	4
4	3	10	2.9	4.4	0.22	0.34	13.1	4
4	1	11	2.3	2.8	0.18	0.21	13.1	4
4	2	11	1.7	4.9	0.15	0.43	11.3	4
4	3	11	2.7	4.1	0.23	0.35	11.5	4
4	1	12	2.3	3.1	0.20	0.28	11.3	4
4	2	12	2.1	2.8	0.17	0.23	12.0	4
4	3	12	2.4	3.0	0.20	0.25	12.0	4
4	1	13	2.6	5.4	0.20	0.42	13.0	4
4	2	13	2.4	5.6	0.19	0.45	12.6	4
4	3	13	2.5	2.6	0.16	0.17	15.6	4
4	1	14	2.4	5.8	0.19	0.46	12.6	4
4	2	14	2.3	2.8	0.18	0.22	12.8	4
4	3	14	2.5	6.9	0.19	0.52	13.1	4
4	1	15	2.5	2.5	0.20	0.20	12.8	4
4	2	15	2.5	4.6	0.18	0.33	13.8	4
4	3	15	2.3	4.2	0.18	0.33	12.8	4
4	1	16	2.1	2.3	0.17	0.18	12.3	4
4	2	16	2.3	0.9	0.18	0.07	12.7	4
4	3	16	2.5	1.7	0.19	0.13	13.1	4
4	1	17	2.1	3.0	0.18	0.25	12.0	4

site	block	date	N %	N(kg/ha)	P %	P(kg/ha)	N/P	week
4	2	17	2.4	3.3	0.20	0.27	12.3	4
4	3	17	2.0	2.5	0.18	0.22	11.4	4
4	1	18	2.2	9.0	0.19	0.76	11.8	4
4	2	18	2.1	3.8	0.17	0.30	12.6	4
4	3	18	2.2	6.7	0.19	0.58	11.6	4
4	1	19	2.9	10.9	0.20	0.75	14.5	4
4	2	19	2.6	8.5	0.21	0.68	12.6	4
4	3	19	3.0	7.6	0.22	0.57	13.3	4
4	1	20	2.9	14.6	0.18	0.93	15.7	4
4	2	20	2.9	22.7	0.20	1.55	14.6	4
4	3	20	2.7	17.5	0.19	1.24	14.1	4
4	1	21	2.5	13.1	0.20	1.02	12.8	4
4	2	21	2.4	17.1	0.16	1.17	14.7	4
4	3	21	2.1	14.4	0.18	1.21	11.9	4
4	1	22	2.2	10.4	0.18	0.86	12.1	4
4	2	22	2.1	14.1	0.18	1.21	11.7	4
4	3	22	2.3	17.1	0.21	1.50	11.4	4
4	1	23	2.3	8.9	0.20	0.76	11.8	4
4	2	23	1.9	5.5	0.16	0.46	11.9	4
4	3	23	2.1	11.8	0.17	0.93	12.6	4
4	1	24	2.7	9.9	0.20	0.76	13.1	4
4	2	24	2.5	6.8	0.20	0.54	12.4	4
4	3	24	2.3	9.5	0.20	0.81	11.7	4
4	1	25	1.6	7.0	0.13	0.57	12.2	4
4	2	25	2.0	6.3	0.16	0.52	12.1	4
4	3	25	2.5	11.0	0.22	0.95	11.6	4
4	1	26	2.5	21.0	0.20	1.65	12.7	4
4	2	26	2.3	14.9	0.20	1.33	11.2	4
4	3	26	2.2	20.3	0.21	1.90	10.7	4
4	1	27	2.1	14.2	0.18	1.19	11.9	4
4	2	27	2.2	15.4	0.15	1.07	14.3	4
4	3	27	1.6	8.2	0.13	0.67	12.2	4
5	1	1	2.7	13.7	0.25	1.27	10.8	2
5	2	1	3.6	14.5	0.35	1.41	10.3	2
5	3	1	3.3	17.8	0.45	2.42	7.3	2
5	1	2	3.2	16.3	0.33	1.68	9.7	2
5	2	2	3.0	14.2	0.25	1.17	12.2	2
5	3	2	3.0	20.7	0.37	2.55	8.1	2
5	1	3	4.2	24.5	0.44	2.54	9.7	2
5	2	3	4.0	12.2	0.38	1.15	10.6	2
5	3	3	5.3	70.9	0.46	6.21	11.4	2
5	1	4	4.3	11.0	0.43	1.10	10.0	2
5	2	4	4.0	4.0	0.33	0.33	12.1	2
5	3	4	4.4	9.6	0.45	0.99	9.7	2
5	1	5	4.3	17.7	0.36	1.50	11.8	2
5	2	5	4.1	6.6	0.38	0.61	10.9	2
5	3	5	3.9	13.7	0.37	1.28	10.7	2
5	1	6	4.1	15.8	0.47	1.83	8.6	2
5	2	6	4.0	8.1	0.50	1.01	8.1	2
5	3	6	4.5	16.9	0.35	1.30	13.0	2
5	1	7	3.6	27.4	0.47	3.63	7.6	2
5	2	7	3.3	6.4	0.22	0.44	14.7	2
5	3	7	3.9	11.7	0.39	1.17	10.0	2
5	1	8	4.4	5.4	0.52	0.64	8.5	2
5	2	8	3.8	0.6	0.47	0.07	8.2	2
5	3	8	3.3	2.9	0.41	0.37	7.9	2
5	1	9	4.1	14.1	0.42	1.44	9.8	2
5	2	9	3.6	2.5	0.38	0.26	9.6	2
5	3	9	4.4	8.8	0.33	0.65	13.5	2
5	1	10	3.6	4.5	0.40	0.49	9.1	2
5	2	10	3.1	3.4	0.29	0.32	10.7	2
5	3	10	3.5	5.3	0.34	0.52	10.3	2
5	1	11	3.4	5.0	0.36	0.53	9.4	2
5	2	11	4.3	7.8	0.46	0.84	9.3	2
5	3	11	4.3	10.1	0.51	1.20	8.4	2
5	1	12	3.6	5.0	0.30	0.41	12.0	2

site	block	date	N %	N(kg/ha)	P %	P(kg/ha)	N/P	week
5	2	12	4.6	2.8	0.37	0.23	12.3	2
5	3	12	4.3	5.6	0.45	0.59	9.6	2
5	1	13	3.3	3.0	0.30	0.28	11.0	2
5	2	13	3.4	5.4	0.28	0.46	11.9	2
5	3	13	3.1	2.2	0.29	0.20	10.9	2
5	1	14	2.5	2.7	0.27	0.29	9.3	2
5	2	14	4.2	10.8	0.35	0.90	12.0	2
5	3	14	3.8	4.8	0.30	0.38	12.6	2
5	1	15	3.4	2.9	0.31	0.26	11.0	2
5	2	15	4.2	6.6	0.32	0.51	13.1	2
5	3	15	3.2	1.9	0.30	0.18	10.8	2
5	1	16	3.8	3.4	0.31	0.27	12.4	2
5	2	16	3.4	1.8	0.31	0.16	11.1	2
5	3	16	3.4	3.9	0.35	0.40	9.7	2
5	1	17	3.3	2.7	0.28	0.22	12.1	2
5	2	17	3.5	3.8	0.29	0.32	12.1	2
5	3	17	3.8	5.4	0.47	0.68	8.0	2
5	1	18	4.0	17.7	0.46	2.06	8.6	2
5	2	18	3.7	10.7	0.27	0.79	13.6	2
5	3	18	4.8	31.4	0.38	2.53	12.4	2
5	1	19	4.8	37.5	0.40	3.13	12.0	2
5	2	19	4.6	30.7	0.26	1.75	17.5	2
5	3	19	3.8	25.1	0.35	2.28	11.0	2
5	1	20	4.7	43.3	0.56	5.23	8.3	2
5	2	20	4.1	33.8	0.36	2.97	11.4	2
5	3	20	4.1	39.3	0.56	5.39	7.3	2
5	1	21	3.6	22.4	0.39	2.46	9.1	2
5	2	21	3.9	26.2	0.38	2.52	10.4	2
5	3	21	3.5	18.4	0.41	2.15	8.6	2
5	1	22	4.4	63.4	0.35	5.08	12.5	2
5	2	22	3.8	36.2	0.33	3.11	11.6	2
5	3	22	4.3	36.9	0.29	2.50	14.7	2
5	1	23	2.5	9.3	0.22	0.82	11.3	2
5	2	23	3.9	23.5	0.31	1.84	12.8	2
5	3	23	3.3	16.9	0.28	1.46	11.6	2
5	1	24	4.1	15.7	0.29	1.13	13.9	2
5	2	24	4.2	22.2	0.42	2.20	10.1	2
5	3	24	3.4	7.1	0.31	0.65	10.9	2
5	1	25	3.2	38.3	0.23	2.78	13.8	2
5	2	25	3.9	68.6	0.31	5.49	12.5	2
5	3	25	3.0	19.6	0.23	1.51	13.0	2
5	1	26	4.1	43.0	0.30	3.15	13.7	2
5	2	26	4.2	34.4	0.27	2.21	15.5	2
5	3	26	3.6	20.5	0.33	1.88	10.9	2
5	1	2	2.7	21.6	0.25	2.00	10.8	4
5	2	2	2.8	33.1	0.31	3.72	8.9	4
5	3	2	3.3	39.0	0.30	3.55	11.0	4
5	1	3	3.8	43.9	0.38	4.44	9.9	4
5	2	3	3.3	23.3	0.33	2.33	10.0	4
5	3	3	3.5	43.1	0.40	4.93	8.7	4
5	1	4	4.1	39.5	0.30	2.89	13.7	4
5	2	4	3.5	19.5	0.34	1.90	10.3	4
5	3	4	4.3	37.6	0.34	2.98	12.6	4
5	1	5	4.0	31.6	0.38	2.97	10.6	4
5	2	5	3.6	27.4	0.43	3.31	8.3	4
5	3	5	4.0	14.8	0.31	1.16	12.7	4
5	1	6	3.9	27.7	0.42	2.94	9.4	4
5	2	6	4.3	31.3	0.50	3.62	8.6	4
5	3	6	4.0	23.8	0.39	2.35	10.1	4
5	1	7	4.0	37.8	0.52	4.94	7.6	4
5	2	7	3.9	29.7	0.36	2.71	11.0	4
5	3	7	3.4	15.1	0.38	1.67	9.1	4
5	1	8	4.2	12.9	0.43	1.31	9.9	4
5	2	8	3.0	9.0	0.26	0.78	11.5	4
5	3	8	3.9	12.0	0.47	1.42	8.4	4
5	1	9	4.5	11.8	0.37	0.96	12.3	4

site	block	date	N %	N(kg/ha)	P %	P(kg/ha)	N/P	week
5	2	9	3.7	6.7	0.35	0.63	10.6	4
5	3	9	3.7	5.7	0.36	0.55	10.3	4
5	1	10	3.6	5.9	0.32	0.51	11.4	4
5	2	10	3.3	4.7	0.30	0.43	10.8	4
5	3	10	4.0	9.3	0.40	0.93	10.0	4
5	1	11	3.8	8.6	0.36	0.80	10.7	4
5	2	11	3.6	8.0	0.39	0.72	9.0	4
5	3	11	4.6	11.9	0.44	1.14	10.4	4
5	1	12	4.5	7.7	0.35	0.60	12.7	4
5	2	12	4.3	10.4	0.38	0.92	11.3	4
5	3	12	4.6	17.8	0.45	1.75	10.2	4
5	1	13	2.9	5.8	0.26	0.52	11.2	4
5	2	13	4.2	9.9	0.35	0.81	12.2	4
5	3	13	3.9	8.6	0.43	0.93	9.2	4
5	1	14	4.2	7.0	0.36	0.59	11.8	4
5	2	14	3.8	9.3	0.36	0.88	10.5	4
5	3	14	4.4	5.8	0.36	0.48	12.1	4
5	1	15	3.1	3.7	0.30	0.36	10.3	4
5	2	15	3.6	7.5	0.34	0.71	10.6	4
5	3	15	3.5	8.1	0.33	0.76	10.7	4
5	1	16	3.4	3.7	0.29	0.31	11.8	4
5	2	16	4.2	14.1	0.42	1.39	10.1	4
5	3	16	4.4	10.0	0.36	0.83	12.1	4
5	1	17	4.0	14.6	0.40	1.48	9.9	4
5	2	17	4.1	11.3	0.44	1.21	9.3	4
5	3	17	4.3	6.8	0.41	0.65	10.5	4
5	1	18	3.6	21.0	0.33	1.87	11.2	4
5	2	18	4.4	40.7	0.36	3.29	12.4	4
5	3	18	3.9	24.2	0.46	2.82	8.6	4
5	1	19	4.8	69.4	0.37	5.33	13.0	4
5	2	19	3.6	23.5	0.32	2.12	11.1	4
5	3	19	4.5	73.5	0.38	6.15	11.9	4
5	1	20	3.8	49.2	0.40	5.11	9.6	4
5	2	20	3.9	64.0	0.33	5.36	11.9	4
5	3	20	4.6	69.0	0.42	6.23	11.1	4
5	1	21	3.5	67.6	0.46	8.88	7.6	4
5	2	21	3.5	47.2	0.30	4.04	11.7	4
5	3	21	3.2	56.3	0.30	5.36	10.5	4
5	1	22	3.5	59.7	0.43	7.48	8.0	4
5	2	22	2.7	30.6	0.29	3.28	9.3	4
5	3	22	3.2	51.2	0.26	4.18	12.3	4
5	1	23	3.2	47.1	0.30	4.41	10.7	4
5	2	23	2.7	31.6	0.21	2.50	12.6	4
5	3	23	3.1	53.8	0.25	4.44	12.1	4
5	1	24	2.8	23.6	0.29	2.44	9.7	4
5	2	24	3.5	33.2	0.33	3.13	10.6	4
5	3	24	3.3	33.3	0.31	3.13	10.6	4
5	1	25	2.5	40.7	0.20	3.26	12.5	4
5	2	25	3.3	70.1	0.42	9.03	7.8	4
5	3	25	2.7	56.0	0.27	5.71	9.8	4
5	1	26	3.5	54.9	0.31	4.86	11.3	4
5	2	26	3.1	70.5	0.33	7.50	9.4	4
5	3	26	4.1	61.8	0.32	4.73	13.1	4
5	1	27	3.1	66.4	0.19	4.07	16.3	4
5	2	27	3.2	43.3	0.21	2.80	15.5	4
5	3	27	3.0	28.1	0.26	2.39	11.7	4
6	1	1	3.4	11.6	0.36	1.21	9.6	2
6	2	1	3.6	19.0	0.38	1.98	9.6	2
6	3	1	4.1	20.6	0.45	2.23	9.2	2
6	1	2	3.0	19.0	0.41	2.56	7.4	2
6	2	2	3.8	28.2	0.41	3.08	9.2	2
6	3	2	3.1	30.4	0.42	4.18	7.3	2
6	1	3	5.1	54.0	0.43	4.56	11.8	2
6	2	3	4.5	31.3	0.56	3.86	8.1	2
6	3	3	4.7	41.1	0.48	4.20	9.8	2
6	1	4	4.7	1.1	0.50	0.12	9.6	2

site	block	date	N %	N(kg/ha)	P %	P(kg/ha)	N/P	week
6	2	4	5.5	17.7	0.46	1.50	11.8	2
6	3	4	4.0	8.1	0.54	1.09	7.4	2
6	1	5	3.8	9.1	0.36	0.86	10.5	2
6	2	5	4.8	30.0	0.42	2.63	11.4	2
6	3	5	3.5	6.3	0.39	0.70	9.0	2
6	1	6	4.2	5.1	0.46	0.56	9.1	2
6	2	6	4.6	17.0	0.56	2.05	8.3	2
6	3	6	4.1	9.5	0.49	1.13	8.4	2
6	1	7	3.7	14.2	0.50	1.88	7.5	2
6	2	7	3.5	7.5	0.42	0.90	8.3	2
6	3	7	4.8	37.8	0.53	4.16	9.1	2
6	1	8	2.9	1.9	0.27	0.18	10.7	2
6	2	8	3.3	1.2	0.43	0.16	7.6	2
6	3	8	4.3	5.9	0.56	0.77	7.6	2
6	1	9	5.0	9.7	0.47	0.90	10.8	2
6	2	9	3.2	5.1	0.43	0.68	7.6	2
6	3	9	3.5	3.2	0.48	0.44	7.3	2
6	1	10	4.7	7.3	0.40	0.62	11.7	2
6	2	10	2.9	4.3	0.39	0.58	7.5	2
6	3	10	4.0	5.9	0.45	0.68	8.8	2
6	1	11	2.9	4.3	0.34	0.51	8.4	2
6	2	11	4.1	5.1	0.49	0.62	8.3	2
6	3	11	5.0	13.5	0.61	1.64	8.2	2
6	1	12	4.6	5.8	0.50	0.63	9.2	2
6	2	12	4.4	6.5	0.49	0.72	9.0	2
6	3	12	4.7	9.9	0.52	1.10	9.0	2
6	1	13	3.6	6.6	0.39	0.73	9.1	2
6	2	13	3.5	10.3	0.42	1.26	8.2	2
6	3	13	3.7	4.2	0.43	0.48	8.6	2
6	1	14	4.0	8.0	0.46	0.93	8.6	2
6	2	14	3.9	7.3	0.47	0.87	8.4	2
6	3	14	4.0	8.7	0.45	0.97	9.0	2
6	1	15	4.2	9.1	0.39	0.85	10.8	2
6	2	15	4.4	11.2	0.44	1.12	10.0	2
6	3	15	4.3	15.9	0.34	1.28	12.4	2
6	1	16	5.4	14.2	0.58	1.52	9.3	2
6	2	16	4.3	4.5	0.45	0.46	9.7	2
6	3	16	4.3	3.6	0.46	0.39	9.4	2
6	1	17	3.7	3.9	0.44	0.46	8.4	2
6	2	17	4.2	17.2	0.44	1.80	9.6	2
6	3	17	4.6	10.0	0.47	1.03	9.7	2
6	1	18	4.0	14.0	0.47	1.66	8.5	2
6	2	18	4.8	22.8	0.41	1.93	11.8	2
6	3	18	5.2	36.0	0.57	3.94	9.1	2
6	1	19	3.7	22.0	0.45	2.71	8.1	2
6	2	19	3.9	28.0	0.47	3.37	8.3	2
6	3	19	4.2	28.4	0.53	3.57	8.0	2
6	1	20	4.2	38.0	0.48	4.38	8.7	2
6	2	20	3.9	39.6	0.53	5.32	7.5	2
6	3	20	4.0	44.5	0.60	6.67	6.7	2
6	1	21	4.3	33.9	0.46	3.63	9.3	2
6	2	21	3.6	15.0	0.43	1.77	8.5	2
6	3	21	3.6	28.2	0.51	4.04	7.0	2
6	1	22	3.5	21.6	0.45	2.79	7.8	2
6	2	22	3.6	26.2	0.45	3.27	8.0	2
6	3	22	3.8	47.0	0.53	6.55	7.2	2
6	1	23	3.4	15.7	0.45	2.04	7.7	2
6	2	23	3.9	16.7	0.49	2.10	8.0	2
6	3	23	3.6	12.5	0.45	1.58	7.9	2
6	1	24	3.8	13.2	0.40	1.38	9.5	2
6	2	24	5.0	26.3	0.47	2.50	10.5	2
6	3	24	4.5	28.0	0.48	2.98	9.4	2
6	1	25	3.4	33.7	0.33	3.32	10.1	2
6	2	25	3.6	51.2	0.44	6.31	8.1	2
6	3	25	3.4	60.4	0.35	6.31	9.6	2
6	1	26	2.9	26.0	0.34	3.05	8.5	2

site	block	date	N %	N(kg/ha)	P %	P(kg/ha)	N/P	week
6	2	26	4.0	31.9	0.47	3.74	8.5	2
6	3	26	3.6	45.4	0.46	5.76	7.9	2
6	1	2	3.1	22.8	0.29	2.13	10.7	4
6	2	2	3.8	58.8	0.46	7.04	8.4	4
6	3	2	3.2	52.6	0.43	7.04	7.5	4
6	1	3	4.0	62.2	0.45	6.99	8.9	4
6	2	3	3.9	41.1	0.59	6.11	6.7	4
6	3	3	3.8	44.4	0.61	7.16	6.2	4
6	1	4	4.0	59.1	0.45	6.72	8.8	4
6	2	4	3.5	43.3	0.50	6.09	7.1	4
6	3	4	4.1	37.8	0.39	3.60	10.5	4
6	1	5	3.4	6.7	0.40	0.77	8.6	4
6	2	5	3.4	18.3	0.42	2.26	8.1	4
6	3	5	3.5	44.5	0.55	7.00	6.4	4
6	1	6	4.2	42.8	0.54	5.51	7.8	4
6	2	6	4.6	49.4	0.48	5.15	9.6	4
6	3	6	4.1	35.5	0.48	4.21	8.4	4
6	1	7	3.9	14.4	0.47	1.73	8.3	4
6	2	7	4.4	35.1	0.48	3.83	9.2	4
6	3	7	3.3	21.0	0.44	2.75	7.6	4
6	1	8	3.7	12.2	0.49	1.59	7.7	4
6	2	8	3.8	15.6	0.52	2.16	7.2	4
6	3	8	4.3	14.3	0.54	1.77	8.1	4
6	1	9	4.2	8.2	0.46	0.90	9.1	4
6	2	9	4.0	9.0	0.48	1.08	8.4	4
6	3	9	4.9	21.4	0.56	2.41	8.8	4
6	1	10	4.5	19.0	0.48	2.05	9.3	4
6	2	10	4.0	7.4	0.50	0.92	8.1	4
6	3	10	3.5	8.9	0.44	1.10	8.1	4
6	1	11	4.0	5.7	0.46	0.65	8.8	4
6	2	11	4.6	10.9	0.52	1.24	8.8	4
6	3	11	5.6	22.9	0.63	2.58	8.9	4
6	1	12	4.5	6.2	0.45	0.62	10.0	4
6	2	12	4.5	4.5	0.49	0.49	9.3	4
6	3	12	4.5	8.4	0.52	0.97	8.6	4
6	1	13	3.7	11.0	0.44	1.31	8.4	4
6	2	13	3.9	13.3	0.41	1.40	9.5	4
6	3	13	4.2	13.7	0.51	1.64	8.3	4
6	1	14	4.7	20.8	0.44	1.93	10.8	4
6	2	14	5.4	22.1	0.58	2.37	9.3	4
6	3	14	4.0	11.8	0.45	1.34	8.8	4
6	1	15	4.8	25.5	0.48	2.57	9.9	4
6	2	15	4.1	16.2	0.45	1.80	9.0	4
6	3	15	4.2	15.0	0.48	1.70	8.8	4
6	1	16	4.5	7.8	0.47	0.80	9.7	4
6	2	16	4.9	24.6	0.45	2.24	11.0	4
6	3	16	4.6	18.6	0.39	1.60	11.6	4
6	1	17	4.7	39.4	0.53	4.44	8.9	4
6	2	17	3.7	20.4	0.34	1.85	11.0	4
6	3	17	4.2	16.9	0.50	2.04	8.3	4
6	1	18	3.8	28.8	0.50	3.87	7.5	4
6	2	18	3.6	47.1	0.48	6.34	7.4	4
6	3	18	3.5	20.5	0.53	3.09	6.6	4
6	1	19	4.3	74.1	0.50	8.60	8.6	4
6	2	19	3.6	39.9	0.54	5.91	6.8	4
6	3	19	4.3	63.3	0.52	7.57	8.4	4
6	1	20	4.1	94.2	0.47	10.76	8.8	4
6	2	20	4.2	69.5	0.49	8.09	8.6	4
6	3	20	3.5	83.3	0.54	13.09	6.4	4
6	1	21	3.1	40.4	0.34	4.49	9.0	4
6	2	21	3.1	73.0	0.46	10.78	0.7	4
6	3	21	3.3	58.2	0.49	8.55	6.8	4
6	1	22	2.8	40.1	0.45	6.48	6.2	4
6	2	22	3.4	44.1	0.43	5.64	7.8	4
6	3	22	3.3	61.3	0.51	9.66	6.3	4
6	1	23	3.3	38.7	0.42	4.89	7.9	4

site	block	date	N %	N(kg/ha)	P %	P(kg/ha)	N/P	week
6	2	23	3.1	30.8	0.40	4.07	7.6	4
6	3	23	3.5	54.7	0.45	7.06	7.8	4
6	1	24	3.4	28.6	0.49	4.12	6.9	4
6	2	24	4.0	46.9	0.48	5.67	8.3	4
6	3	24	3.7	40.9	0.48	5.22	7.8	4
6	1	25	3.0	50.3	0.37	6.23	8.1	4
6	2	25	3.6	53.1	0.47	7.07	7.5	4
6	3	25	3.4	78.1	0.40	9.18	8.5	4
6	1	26	3.2	49.8	0.37	5.83	8.6	4
6	2	26	3.5	80.4	0.48	10.90	7.4	4
6	3	26	3.2	76.3	0.46	10.75	7.1	4
6	1	27	3.6	45.1	0.46	5.81	7.8	4
6	2	27	2.9	31.3	0.30	3.23	9.7	4
6	3	27	2.5	33.4	0.33	4.41	7.6	4
7	1	1	4.6	47.3	0.48	4.94	9.6	2
7	2	1	4.5	48.9	0.46	4.95	9.9	2
7	3	1	4.3	57.7	0.48	6.49	8.9	2
7	1	2	3.4	33.1	0.42	4.12	8.0	2
7	2	2	4.4	32.6	0.42	3.08	10.6	2
7	3	2	3.6	29.1	0.41	3.38	8.6	2
7	1	3	5.1	51.1	0.46	4.66	11.0	2
7	2	3	4.7	40.7	0.59	5.10	8.0	2
7	3	3	3.7	30.0	0.59	4.83	6.2	2
7	1	4	5.3	32.5	0.42	2.59	12.6	2
7	2	4	4.5	12.4	0.45	1.24	10.0	2
7	3	4	4.2	12.8	0.47	1.42	9.0	2
7	1	5	4.8	45.9	0.43	4.11	11.2	2
7	2	5	4.4	28.2	0.46	2.95	9.6	2
7	3	5	4.6	43.1	0.56	5.33	8.1	2
7	1	6	4.3	8.9	0.52	1.09	8.2	2
7	2	6	4.4	16.9	0.54	2.09	8.1	2
7	3	6	4.2	17.6	0.55	2.27	7.7	2
7	1	7	4.0	27.5	0.56	3.84	7.2	2
7	2	7	3.7	18.5	0.43	2.17	8.5	2
7	3	7	4.1	23.7	0.57	3.30	7.2	2
7	1	8	4.9	22.9	0.62	2.87	8.0	2
7	2	8	4.3	17.3	0.52	2.10	8.3	2
7	3	8	3.6	10.9	0.48	1.47	7.4	2
7	1	9	5.2	14.7	0.54	1.53	9.6	2
7	2	9	5.0	16.0	0.61	1.95	8.2	2
7	3	9	4.6	10.6	0.47	1.08	9.8	2
7	1	10	4.1	8.8	0.42	0.91	9.6	2
7	2	10	4.2	6.7	0.43	0.68	9.8	2
7	3	10	4.2	8.9	0.49	1.04	8.6	2
7	1	11	5.3	11.2	0.54	1.14	9.8	2
7	2	11	5.2	10.6	0.61	1.23	8.6	2
7	3	11	5.0	14.7	0.63	1.82	8.0	2
7	1	12	4.9	10.8	0.53	1.15	9.3	2
7	2	12	5.3	9.7	0.50	0.92	10.5	2
7	3	12	5.0	11.4	0.53	1.20	9.4	2
7	1	13	3.8	8.0	0.46	0.98	8.2	2
7	2	13	4.2	9.0	0.47	1.00	9.0	2
7	3	13	3.7	4.5	0.46	0.56	8.1	2
7	1	14	4.4	9.8	0.51	1.15	8.5	2
7	2	14	4.2	10.8	0.45	1.14	9.4	2
7	3	14	4.0	9.5	0.49	1.16	8.2	2
7	1	15	3.6	10.7	0.37	1.09	9.9	2
7	2	15	4.7	16.2	0.48	1.67	9.7	2
7	3	15	4.5	12.4	0.48	1.31	9.5	2
7	1	16	4.0	5.0	0.46	0.57	8.7	2
7	2	16	4.4	6.8	0.50	0.77	8.8	2
7	3	16	4.5	15.7	0.48	1.65	9.5	2
7	1	17	3.6	7.1	0.43	0.84	8.5	2
7	2	17	4.9	22.1	0.53	2.36	9.4	2
7	3	17	3.5	6.8	0.47	0.91	7.5	2
7	1	18	4.6	38.0	0.48	4.01	9.5	2

site	block	date	N %	N(kg/ha)	P %	P(kg/ha)	N/P	week
7	2	18	6.0	54.8	0.59	5.38	10.2	2
7	3	18	5.3	54.3	0.51	5.27	10.3	2
7	1	19	4.5	41.2	0.52	4.75	8.7	2
7	2	19	4.7	58.9	0.63	7.83	7.5	2
7	3	19	4.4	47.7	0.61	6.62	7.2	2
7	1	20	4.8	49.6	0.49	5.07	9.8	2
7	2	20	4.9	84.2	0.57	9.89	8.5	2
7	3	20	5.0	88.6	0.55	9.64	9.2	2
7	1	21	3.6	21.7	0.51	3.08	7.0	2
7	2	21	4.1	43.4	0.47	5.02	8.6	2
7	3	21	4.7	44.8	0.52	4.96	9.0	2
7	1	22	3.6	41.2	0.51	5.84	7.1	2
7	2	22	4.2	68.3	0.49	7.97	8.6	2
7	3	22	4.4	66.5	0.52	7.85	8.5	2
7	1	23	3.5	23.4	0.47	3.13	7.5	2
7	2	23	4.7	56.4	0.52	6.18	9.1	2
7	3	23	4.4	50.9	0.50	5.72	8.9	2
7	1	24	4.5	42.3	0.57	5.27	8.0	2
7	2	24	5.1	50.2	0.50	4.92	10.2	2
7	3	24	4.3	30.5	0.47	3.29	9.3	2
7	1	25	3.4	61.8	0.38	7.09	8.7	2
7	2	25	4.0	78.8	0.39	7.78	10.1	2
7	3	25	3.1	67.5	0.26	5.66	11.9	2
7	1	26	5.2	54.1	0.44	4.58	11.8	2
7	2	26	4.3	34.2	0.45	3.62	9.5	2
7	3	26	4.7	43.7	0.38	3.54	12.3	2
7	1	2	3.3	56.0	0.51	8.57	6.5	4
7	2	2	3.5	69.0	0.39	7.77	8.9	4
7	3	2	3.2	68.1	0.42	8.90	7.6	4
7	1	3	3.3	42.7	0.58	7.45	5.7	4
7	2	3	4.2	55.2	0.56	7.29	7.6	4
7	3	3	4.0	57.6	0.49	7.17	8.0	4
7	1	4	4.3	84.9	0.40	7.89	10.8	4
7	2	4	4.2	54.1	0.57	7.32	7.4	4
7	3	4	3.3	44.1	0.50	6.71	6.6	4
7	1	5	4.2	62.2	0.37	5.48	11.4	4
7	2	5	4.0	35.8	0.45	4.07	8.8	4
7	3	5	4.2	55.3	0.43	5.72	9.7	4
7	1	6	4.6	64.2	0.53	7.38	8.7	4
7	2	6	4.8	87.6	0.57	10.50	8.3	4
7	3	6	4.3	51.2	0.57	6.81	7.5	4
7	1	7	3.9	33.9	0.46	3.94	8.6	4
7	2	7	4.0	26.5	0.45	3.02	8.8	4
7	3	7	4.2	37.4	0.55	4.89	7.7	4
7	1	8	5.1	45.7	0.64	5.82	7.8	4
7	2	8	4.8	42.4	0.52	4.67	9.1	4
7	3	8	4.5	50.0	0.60	6.67	7.5	4
7	1	9	4.4	38.8	0.59	5.13	7.6	4
7	2	9	5.2	39.4	0.59	4.47	8.8	4
7	3	9	4.7	23.0	0.56	2.76	8.3	4
7	1	10	5.3	29.8	0.53	2.98	10.0	4
7	2	10	5.0	20.6	0.52	2.16	9.5	4
7	3	10	3.2	13.1	0.49	2.01	6.5	4
7	1	11	5.1	19.3	0.55	2.06	9.4	4
7	2	11	5.4	35.0	0.55	3.56	9.8	4
7	3	11	4.7	22.4	0.54	2.57	8.7	4
7	1	12	4.8	19.4	0.47	1.90	10.2	4
7	2	12	4.6	12.7	0.55	1.51	8.4	4
7	3	12	4.5	17.4	0.56	2.15	8.1	4
7	1	13	4.6	24.3	0.53	2.80	8.7	4
7	2	13	5.3	27.1	0.56	2.86	9.5	4
7	3	13	4.5	19.0	0.53	2.25	8.4	4
7	1	14	4.6	20.5	0.56	2.47	8.3	4
7	2	14	5.4	42.2	0.51	3.99	10.6	4
7	3	14	4.7	17.6	0.48	1.77	9.9	4
7	1	15	4.7	23.0	0.50	2.42	9.5	4

site	block	date	N %	N(kg/ha)	P %	P(kg/ha)	N/P	week
7	2	15	4.9	23.0	0.49	2.30	10.0	4
7	3	15	4.4	13.7	0.42	1.32	10.4	4
7	1	16	4.4	15.6	0.51	1.80	8.6	4
7	2	16	4.8	25.7	0.52	2.78	9.2	4
7	3	16	4.1	18.0	0.47	2.04	8.8	4
7	1	17	5.2	48.3	0.52	4.83	10.0	4
7	2	17	4.3	23.8	0.51	2.78	8.6	4
7	3	17	4.6	25.6	0.50	2.79	9.2	4
7	1	18	3.8	32.9	0.50	4.31	7.6	4
7	2	18	4.5	59.4	0.46	6.08	9.8	4
7	3	18	4.0	34.4	0.49	4.16	8.3	4
7	1	19	4.0	76.5	0.49	9.46	8.1	4
7	2	19	4.1	93.8	0.48	10.83	8.7	4
7	3	19	4.6	91.2	0.58	11.60	7.9	4
7	1	20	3.7	77.4	0.48	10.18	7.6	4
7	2	20	4.3	123.4	0.55	15.82	7.8	4
7	3	20	4.2	117.9	0.58	16.39	7.2	4
7	1	21	3.6	65.2	0.48	8.70	7.5	4
7	2	21	3.2	113.9	0.45	16.02	7.1	4
7	3	21	4.3	114.5	0.50	13.31	8.6	4
7	1	22	3.7	106.0	0.48	13.60	7.8	4
7	2	22	3.6	118.7	0.45	15.04	7.9	4
7	3	22	3.7	98.1	0.51	13.43	7.3	4
7	1	23	3.0	88.2	0.41	12.05	7.3	4
7	2	23	3.8	114.3	0.49	14.89	7.7	4
7	3	23	3.2	76.4	0.45	10.57	7.2	4
7	1	24	3.5	52.9	0.56	8.30	6.4	4
7	2	24	4.1	103.3	0.43	10.95	9.4	4
7	3	24	4.1	76.6	0.54	10.04	7.6	4
7	1	25	3.2	72.4	0.42	9.69	7.5	4
7	2	25	3.7	108.8	0.41	11.89	9.2	4
7	3	25	3.7	85.8	0.40	9.38	9.1	4
7	1	26	3.4	69.7	0.49	9.96	7.0	4
7	2	26	3.8	133.4	0.38	13.17	10.1	4
7	3	26	3.5	104.0	0.40	11.85	8.8	4
7	1	27	3.5	44.9	0.39	5.00	9.0	4
7	2	27	2.8	32.1	0.25	2.82	11.4	4
7	3	27	3.8	53.9	0.25	3.57	15.1	4

Appendix 6.1: Parameters of the linear regression of average monthly and seasonal mineral N levels (kg/ha) and pasture production (kg/ha) under the 2 cutting regimes.

	Intercept		Linear coef.		r^2	
	2w	4w	2w	4w	2w	4w
Jan93	-2597NS	-1729NS	681*	657**	0.78	0.76
Feb	-4374NS	-3964NS	1341**	1350**	0.84	0.89
Mar	2714NS	3298NS	399**	393**	0.70	0.70
Apr	583NS	1261NS	590**	575**	0.92	0.91
May	6600NS	6231NS	193NS	320NS	0.03	0.08
Jun	612NS	879NS	859*	886**	0.71	0.78
Jul	-514NS	74NS	973**	962**	0.81	0.82
Aug	844NS	1466NS	643*	632*	0.57	0.57
Sep	-6761**	-5944**	1757**	1718**	0.97	0.96
Oct	-1342NS	-630NS	854**	834**	0.95	0.95
Nov	-3399*	-2692*	837**	822**	0.96	0.96
Dec	-5787**	-5138**	803**	794**	0.95	0.97
Jan94	-4176*	-3322NS	647**	628**	0.94	0.92

Appendix 6.2: Parameters of the linear and quadratic regression of average mineral N levels (kg/ha) and annual pasture production (kg/ha), pasture components proportion and N content and uptake assessed by 4 weekly cutting.

	Intercept	linear coef.	quadratic coef.	r^2
DM yield (kg/ha)	-1934 NS -5311NS	867.8 ** 1410*	 -18NS	0.96 0.97
HFG yield (kg/ha)	-5720 **	703 **		0.96
HFG %	-27.5 **	4.0 **		0.95
OSPS yield (kg/ha)	1323 **	-46.2 NS		0.37
OSPS %	33.7 * 58.7NS	-1.5 NS -5.7NS	 0.14NS	0.47 0.56
N content (%)	2.01 ** 0.58NS	0.10 ** 0.33**	 -0.008NS	0.82 0.92
N yield (kg/ha)	-144.8 *	38.4 **		0.97

Appendix 6.3a: Parameters of the linear regression of average monthly and seasonal Olsen P levels (µg/cc) and annual pasture production (kg/ha) under 2 cutting frequencies.

	intercept		linear coef		r^2	
	2 week	4 week	2 week	4 week	2 week	4 week
Jan93	2192 NS	2688 NS	350 **	350 **	0.86	0.90
Feb	1910 NS	2314 NS	373 **	379 **	0.80	0.86
Mar	1310 NS	1743 NS	384 **	389 **	0.79	0.83
Apr	1357 NS	1824 NS	371 **	373 **	0.84	0.88
May	2103 NS	2575 NS	334 **	336 **	0.83	0.87
Jun	2119 NS	2576 NS	334 **	336 **	0.82	0.87
Jul	1981 NS	2470 NS	323 **	324 **	0.85	0.88
Aug	2322 NS	2800 NS	320 **	322 **	0.83	0.87
Sep	1779 NS	2281 NS	343 **	342 **	0.86	0.89
Oct	2714 NS	3241 *	239 **	239 **	0.85	0.85
Nov	2815 NS	3328 *	246 **	246 **	0.85	0.88
Dec	2309 NS	2806 NS	333 **	333 **	0.85	0.88
Jan94	2567 NS	3029 *	330 **	332 **	0.83	0.88
Summer	2132 NS	2605 NS	347 **	349 **	0.85	0.89
Autumn	1489 NS	1938 NS	371 **	374 **	0.83	0.87
Winter	2061 NS	2357 NS	332 **	333 **	0.84	0.88
Spring	2664 NS	3178 *	261 **	261 **	0.85	0.87

Appendix 6.3b: Parameters of the linear regression of average monthly and seasonal Resin P levels (µg/cc) and annual pasture production (kg/ha) under 2 cutting frequencies.

	intercept		linear coeficient		r2	
	2w	4week	2 week	4 week	2w	4 w
Jan93	2551 *	2964 *	179 **	179 **	0.84	0.88
Feb	1345NS	1818NS	198 **	199 **	0.82	0.87
Mar	1156NS	1627NS	225 **	225 **	0.79	0.83
Apr	1136NS	1676NS	212 **	211 **	0.89	0.92
May	1868NS	2368NS	192 **	192 **	0.84	0.87
Jun	1808NS	2342NS	190 **	189 **	0.86	0.89
Jul	2038NS	2596 *	190 **	188 **	0.90	0.92
Aug	2556NS	3067 *	182 **	181 **	0.87	0.90
Sep	1769NS	2324 *	203 **	202 **	0.92	0.93
Oct	2396NS	2929 *	166 **	165 **	0.89	0.92
Nov	2517NS	3052 *	176 **	175 **	0.88	0.90
Dec	1956NS	2476 *	207 **	206 **	0.90	0.92
Jan94	1334NS	2095 *	194 **	191 **	0.98	0.99
Summer	2044NS	2563 *	191 **	190 **	0.89	0.92
Autumn	1200NS	1708NS	212 **	211 **	0.85	0.88
Winter	1962NS	2496NS	195 **	193 **	0.88	0.91
Spring	2312NS	2842 *	179 **	178 **	0.88	0.91

Appendix 6.4: Parameters of the linear regression of mean seasonal Olsen P levels (µg/cc) and seasonal pasture production (kg/ha) under 2 cutting frequencies.

	intercept		linear coeficient		r2	
	2week	4week	2week	4week	2week	4week
Summer	955 NS	1501 NS	75 **	65 **	0.90	0.86
Autumn	-18 NS	-90 NS	37 **	48 **	0.81	0.89
Winter	214 *	148 *	16 **	16 **	0.94	0.98
Spring	861 NS	894 *	61 **	62 **	0.84	0.91

	A		Curvature coef		r^2	
	Olsen	Resin	Olsen	Resin	Olsen	Resin
total DM	23.03	23.13	0.029	0.164		
Summer	7.06	6.76	0.017	0.30	0.97	0.98
Winter						
Spring						

Appendix 6.5a: Parameters of the linear and quadratic regression of average Olsen P levels (μg/cc) and annual pasture production (kg/ha) under 2 cutting frequencies, pasture components proportion and P content and accumulation across the 7 sites.

	Intercept	linear coef.	quadratic coef.	r^2
DM yield (kg/ha) (Biweekly)	2117 NS 1751NS	323.7 ** 367NS	 -0.8NS	0.84 0.85
DM yield (kg/ha) (4 weekly)	2600 NS 1455NS	324.6 ** 461.4NS	-2.6NS	0.88 0.89
HFG yield (kg/ha) 4 weekly	-2167 *	269.9 **		0.93
HFG % 4 weekly	-7.1 ns	1.51 **		0.90
WCL yield (kg/ha) 4 weekly	-1012 *	168.8 **	-2.49 **	0.95
WCL % 4 weekly	-9.0 *	1.78 **	-0.03 **	0.89
OSPS yield (kg/ha) 4 weekly	1106 **	18.6 NS		0.40
OSPS % 4 weekly	25.1 ** 41.7*	-0.60 NS -2.6NS	0.04NS	0.46 0.70
P content (g/kg) (biweekly)	36.2 NS	24.5 **	-0.32 NS	0.92
P content (g/kg) (4 weekly)	28.6 NS	25.7 **	-0.34 *	0.95
P yield (kg/ha) (biweekly)	-2.33 NS	1.99 **		0.92
P yield (kg/ha) (4 weekly)	-2.06 NS	1.98 **		0.94

Appendix 6.5b: Parameters of the linear and quadratic regression of average Resin P levels (µg/cc) and annual pasture production (kg/ha) under 2 cutting frequencies, pasture components proportion and P content and accumulation across the 7 sites.

	Intercept	linear coef.	quadratic coef.	r^2
DM yield (kg/ha) (biweekly)	1856 NS 1524NS	194.8 ** 218NS	 -0.27NS	0.88 0.88
DM yield (kg/ha) (4 weekly)	2379 NS 1404NS	193.9 ** 264NS	 -0.81NS	0.91 0.91
HFG yield (kg/ha) (4 weekly)	-2240 *	157.7 **		0.91
HFG % (4 weekly)	-8.0 NS	0.91 **		0.93
WCL yield (kg/ha) (4 weekly)	-1060 **	101.5 **	-0.90 **	0.99
WCL % (4 weekly)	-9.7 *	1.09 **	-0.01 **	0.88
OSPS yield (kg/ha) (4 weekly)	1122 **	-11.2 NS		0.42
OSPS % (4 weekly)	25.7 ** 43.7*	-0.37 NS -1.65NS	 0.01NS	0.50 0.70
P content (g/kg) (biweekly)	28.4 NS	14.7 **	-0.11 *	0.97
P content (g/kg) (4 weekly)	24.9 NS	15.2 **	-0.12 **	0.98
P yield (kg/ha) (biweekly)	-3.76 NS	1.19 **		0.95
P yield (kg/ha) (4 weekly)	-3.38 NS	1.18 **		0.97