THE NITROGEN ECONOMY OF THREE IRRIGATED TEMPERATE GRASS PASTURES WITH AND WITHOUT CLOVER IN NATAL

by

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ABSTRACT

The nitrogen (N) nutritional requirements of three temperate pastures, with and without white clover, were investigated in the Natal midlands. A range of N fertilizer rates, sources and application intervals were applied to annual ryegrass (*Lolium multiflorum* cv. Midmar) in cutting trials, on six sites, between 1985 and 1990. Nitrogen fertilization rates ranged from 0 to 1,080 kg N/ha/yr, applied as limestone ammonium nitrate, urea or ammonium sulphate. Intervals between N applications ranged between four and twelve weeks, including a treatment withholding two winter top-dressings. Treatments were amended over the years as detailed trends emerged.

Resulting from an economic and environmental evaluation of the cutting trial data, more sustainable temperate pasture systems were investigated. Additionally, the applicability of N calibration data evaluated under cutting, to grazed pastures, was questioned.

Irrigated annual ryegrass (*Lolium multiflorum* cv. Midmar), perennial ryegrass (*L. perenne* cv. Yatsyn 1) and tall fescue (*Festuca arundinacea* cv. Demeter) pastures were evaluated, with and without white clover (*Trifolium repens* cv. Ladino). Under intensive sheep grazing, a range of N fertilizer rates were applied to both pure grass (150 to 600 kg N/ha/yr) and grass/clover swards (0 to 450 kg N/ha/yr).

Dry matter (DM) yields of annual ryegrass, with or without white clover, were not restricted by a lack of N at annual applications of 260 to 280 kg N/ha/yr. Four weekly applications of 40 to 50 kg N/ha, between April and October, ensured maximum N efficiency relative to larger, less frequent top-dressings of N. Nitrogen fertilizer, top-dressed to irrigated, winter-dormant pastures was not utilized by the pasture and was lost from the system.

Perennial ryegrass and tall fescue pasture DM yields increased as N fertilizer rates increased to 600 kg N/ha/yr. However, monthly N top-dressings of 45 kg N/ha, applied between April and October, ensured adequate N nutrition for the grass during the cool season (late-autumn, winter and early-spring) of the year. As long as white clover comprised 30% of a grass/clover pasture the grass component was not deficient of N between November and March. However, grown in a pure sward, tall fescue and perennial ryegrass

DM yields responded to monthly N top-dressings of between 45 and 60 kg N/ha over the warm season (November to March).

To maximise the clover component in a N fertilized grass/clover pasture, it is recommended that the clover be established first, then overseeded with grass once the clover has established. If the grass and clover are established together, the pasture should not be fertilized with N until the clover is well established; thereafter, N fertilizer should be applied strategically when clover growth is restricted by low temperatures (April to late September), or when more forage is required from the grass.

Economic evaluation of the three temperate grass pastures revealed maximum profits, for a simulated dairy system, at high rates of N fertilizer, *i.e.* 600 kg N/ha/yr on pure perennial ryegrass pastures. However, a grass/clover pasture, with no N fertilizer applied, resulted in profits equal to those from pastures fertilized with 315 (grass/clover) and 450 kg N/ha/yr (pure grass). Concern was expressed over the nitrate leaching potential following high N fertilizer rates and the degradation of soil structure, resulting from the annual reestablishment of pastures. Recommendations, therefore, included increased emphasis on perennial ryegrass/clover and tall fescue/clover pastures. In addition, N fertilizer may be efficiently and economically top-dressed to grass/clover pastures between April and October, as long as these pastures are not winter-dormant.

DECLARATION

I hereby declare that this thesis and the associated research comprises my own original work, except for the assistance which is acknowledged or where due reference is made in the text. I also declare that the results contained in this thesis have not been previously submitted by me in respect of a degree at any University.

Richard John Eckard

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SECTION I

GENERAL INTRODUCTION

The South African province of Natal is situated on the eastern seaboard of southern Africa. In Natal 4,502,692 hectares of land is devoted to commercial agriculture, including timber. From a pastoral point of view, 3,097,947 hectares are natural rangelands while 175,722 hectares are reported to be under cultivated pasture. Beef enterprises account for 1,330,680 head, sheep for 1,198,500 head and dairy for 195,960 head of animals in Natal (Anon 1991).

The potential of natural rangelands in Natal

The province of Natal encompasses some of the greatest ecological diversity in South Africa (Figure 1). Vegetation ranges from the arid lowveld (Acocks 1988) or arid lowland (Phillips 1973) in the North, to the high rainfall regions (highland sourveld) at the foothills of the Drakensberg mountains (Acocks 1988) and from the coastal lowlands (Phillips 1973) in the east to the montane regions on the upper reaches of the mountains (Phillips 1973). Rainfall is largely summer dominant and varies from as little as 320 mm in the northern lowveld to 3,353mm (6,500 - 11,000 on peaks) at the foot of the Drakensberg mountains (Anon 1991).

In general the soils of Natal are highly weathered and nutritionally poor (Miles 1986). Soils in the arid regions, being subject to less leaching during their development than higher rainfall regions, tend to be of higher nutritional status and less acidic than soil of the higher rainfall regions. The combination of the soil and climatic conditions has resulted in a great diversity of natural grassland communities in Natal, with sweetveld predominating in the arid, frost-free regions and sour grasslands in the higher rainfall regions (Tainton 1981). According the Scott (1947 cited by Tainton 1981), sweetveld is defined as veld that remains palatable and nutritious when mature, whereas sourveld provides palatable material only during the growing season. Grasslands which lie between these two extremes are termed mixed-veld. Given the above, it is not surprising that the estimated grazing capacity of these rangelands varies considerably. Annual grazing capacity may vary from 6 to 15 hectares per animal unit per annum in the arid areas, and 1.75 to 2.5 hectares per animal unit per annum in the higher rainfall regions (Tainton 1981).

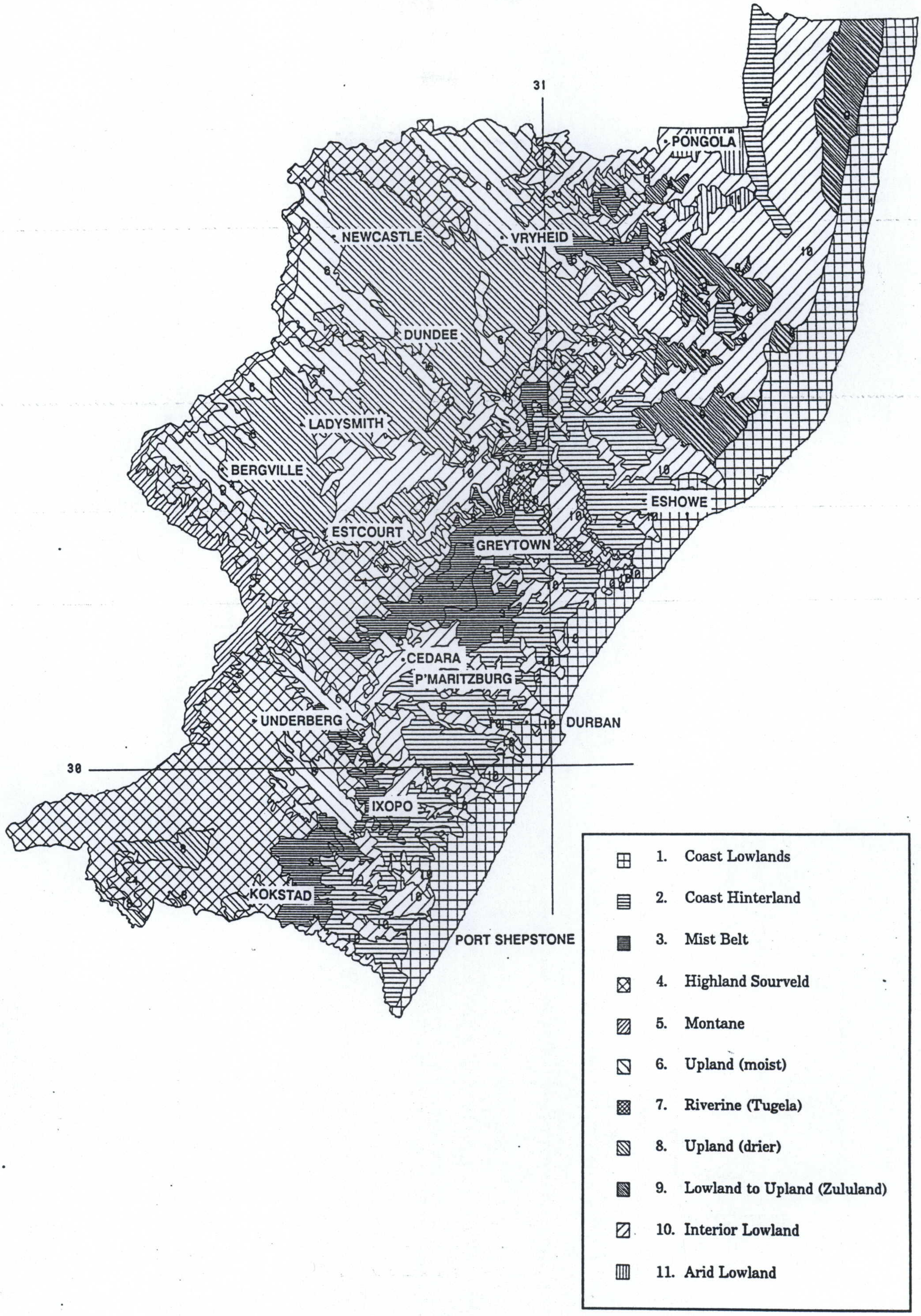

Figure 1. The bioclimatic groups of Natal (Phillips 1973).

Pasture intensification in Natal

In contrast to the low carrying capacities of the natural grasslands, cultivated pastures have resulted in marked increases in grazing capacity and animal production per unit area. Improved productivity is particularly notable in the higher rainfall regions where soil nutrient deficiencies have been corrected by the addition of fertilizer. In these higher rainfall regions a number of cultivated pasture species have proved suitable for replacing natural grasslands. Proven and recommended pasture species include *Lolium multiflorum*, *Lolium perenne* and *Festuca arundinacea*, grown in combination with *Trifolium repens* (Bartholomew 1991; Anon 1993).

In 1975 a locally-bred *Lolium multiflorum* Lam. cultivar, Midmar, was released by plant breeders from Cedara (Rhind & Goodenough 1976). Although Midmar ryegrass has been botanically labelled as a diploid Italian ryegrass (*L. multiflorum*), it has recently been described as a mixture of 60% Westerwold and 40% Italian types (Goodenough 1993 pers. comm.[1]). The term 'annual' ryegrass has long been used to refer to *Lolium rigidum*. However, it appears that the term 'annual' is increasingly being used to refer to Italian and Westerwold ryegrass cultivars, or mixtures of these two ryegrass types. In this dissertation the Midmar cultivar of *Lolium multiflorum* will be referred to as 'annual' ryegrass.

Favourable economic data emerging from trials on adequately fertilized and irrigated pastures have resulted in a rapid increase in the use of intensive, irrigated ryegrass for dairy, beef and sheep systems. The importance of annual ryegrass is amplified by the vital position it is able to occupy in the overall fodder flow, complementing summer pastures like kikuyu (*Pennisetum clandestinum*) (Bartholomew 1985).

Numerous cultivars of perennial ryegrass (*L. perenne*) and tall fescue (*F. arundinacea*) have been available for many years. However, their use in animal production systems has been limited: perennial ryegrass, because of lack of persistence (Fulkerson *et al.* 1993), and tall fescue because of poor palatability (Matches 1979). With the recent introduction of vastly improved cultivars of both these pasture species, there has been a notable increase in their use. However, there is a dearth of information regarding the

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[1]Roodeplaat Grassland Institute, Pasture Breeding, P.Bag X9059, Pietermaritzburg, 3200, South Africa.

fertilization and grazing management requirements of either of these species under local conditions, particularly when grown in association with white clover.

Global trends in the use of nitrogen

Nitrogen (N) fertilizer is recognised world-wide as one of the most effective management tools for manipulating pasture yield within the limitations imposed by the environment (Prins *et al.* 1980). Although much research has been conducted on the use of legumes in grass pastures, partly to provide the N requirements of these pastures, farmers in many countries make extensive use N fertilizer. Netherlands dairy farmers commonly apply 250 kg N/ha/yr to intensive pastures (van Burg *et al.* 1980). In the United Kingdom N rates are commonly in the region of 115 to 135 kg N/ha/yr, ranging between 0 and 450 kg N/ha/yr (Frame 1992). Here rates of 400 kg N/ha/yr are commonly applied on intensive dairy farms (Morrison 1980). In Eastern Australia (Eckard 1992; Fulkerson *et al.* 1993), South Africa (Miles & Bartholomew 1991) and warmer areas of the USA (Matches 1979), N fertilizer rates above 300 kg N/ha/yr are commonly applied to intensive pastures.

New Zealand is one of the few countries where grassland production is sustained largely by N-fixation of clover (Frame 1992). According to Ball (1979), dairy farmers in New Zealand seldom apply as much as 50 kg N/ha/yr, with N application rates of 25 kg N/ha/yr, applied as a single spring dressing, being occasionally applied.

The use of legumes as a source of N in a mixed grass/clover pasture has received much attention worldwide (Wassermann 1979). Perhaps due to the bloat potential and increased complexity of the grazing management required, farmers have been reluctant to include legumes in their pastures. The energy crisis in the early 1970's led to sharp increases in the price of agricultural inputs, in particular N fertilizer. With continued increases in fertilizer prices farming practices require regular economic review, in particular the liberal use of N fertilizer. As a result there has recently been renewed interest in cheaper sources of N for pastures, with legumes being the most obvious low-cost source of N.

Potential improvement from N fertilizer.

Numerous studies world-wide have shown the potential response of grasses to N fertilizer to far exceed that of most crops (Sparrow

1979b). In the absence of N fertilizer annual ryegrass pastures may yield between 3 and 6 t dry matter (DM)/ha/yr (Eckard 1986; Frame 1992). With the addition of N fertilizer these yields can increase by 15 to 25 kg DM/kg N applied (Frame 1992), achieving yields of 11 to 13 t DM/ha/yr (Eckard 1986; Frame 1992). Obviously, most soils do not contain sufficient available N for maximum pasture production (Eckard & Miles 1992).

The high cost of high-potential farm land has forced many farmers to intensify in order to achieve higher profits per hectare. With potential pasture yield increases of the order of 5 to 10 t DM/ha, the use of high N fertilizer rates becomes a highly attractive means of intensification.

Need for and lack of N response data.

Fertilizer Society of South Africa data (Miles 1992) indicate that in 1990, some 121,358 tons of NPK fertilizer were used in Natal alone. The current value of this fertilizer is in excess of R271 million. In the same year fertilizer (NPK) expenditure in the magisterial districts of Mount Currie, Underberg/Polela and Ixopo amounted to R11,9 million, R6,7 million and R11,6 million rands respectively (excluding lime). Estimates are that between 40 and 70% of these fertilizers were applied to pastures. At the individual farm level, an operation involving 160 cows in milk with 80 followers (dry cows and heifers) on kikuyu and irrigated ryegrass pastures would require a minimum annual expenditure of R90,000 on fertilizer and lime. Indications are that on most South African farms, 50 to 80% of pasture costs are attributable to fertilizer (Eckard & Miles 1992). The above costs incurred by the farmer clearly justify accurate calibration of pasture species responses to applied fertilizer and lime.

In Natal, as in many commercial agricultural communities, soil analytical and advisory services exist. Based on a soil analysis, this service aims to provide accurate fertilizer recommendations for each pasture species. These recommendations are based on field trials in which the yield responses of pastures are calibrated against different soil-applied nutrient levels. However, there is a total lack of data relating yield response to N fertilizer levels under grazing.

Reasons for no soil N laboratory analysis.

Commenting on data from N response studies, Miles (1991) noted wide variations in pasture yields achieved in the absence of N fertilizer, with some soils supplying sufficient N to produce 9 tons of DM per hectare per annum. Other than testing for residual nitrate and ammonium nitrogen (Dahnke & Johnson 1990; Miles 1991), no rapid and reliable soil test is available for the prediction of available soil N. This is largely because 97 to 99% of the N in the soil is present in complex organic compounds, becoming available to plants over time through microbial decomposition (Dahnke & Johnson 1990).

The problems of developing a test for available N (after Dahnke & Johnson 1990) are that: (a) the rate at which micro-organisms decompose soil organic matter is dependent on temperature, moisture, aeration, type of organic matter, pH and other factors, and (b) the inorganic forms of N produced are subject to leaching, fixation, denitrification and other losses. Thus it is difficult to predict when N will become available, how much will become available or what will happen to the N once released.

In the absence of a rapid and reliable soil test for the prediction of available soil N, heavy reliance must be placed on field trials. These trials, preferably conducted under a grazing regime (Ball 1979), should include a wide range of N fertilizer rates (Frame 1973) and be conducted on the full range of soil types and climates recommended for the particular pasture (Morrison 1980).

Interpretation of N response curves

The relationship between N fertilizer application rate and yield of a particular crop is usually termed the response curve (Sparrow 1979a). Where N fertilizer is applied to pasture crops, the response curve appears to have three distinct phases:

phase I) a sharply rising portion,
phase II) a turning point, and
phase III) a portion where yield no longer increases, or even slowly decreases (Sparrow 1979a).

The separate phases of the response curve may also be described by one or more regression functions, which in turn describe the observed response. For example, the initial phase (phase I) is usually largely linear, with variable slope (between 16.9 and 39 kg DM/kg N applied, Reid 1970; Darwinkel 1976; Ehlig & Hagemann 1982); phase II is an inflection point in the curve, beginning where the response slopes below 10 kg DM/kg N applied, and phase III, a linear response, with either no slope or a slight negative slope (Sparrow 1979b).

Numerous studies have attempted to fit regression functions to N response curves, with varying degrees of success (Reid 1970; Boyd *et al.* 1976; Sparrow 1979a & b; Eckard 1986). The large number of regression functions listed in Table 1 gives some indication of the variability in the shape of N response curves, with each one of the listed functions being the 'best-fit' option in a particular study.

Table 1. Some regression functions used in the interpretation of the yield response of pasture grasses to applied N.

Polynomials		
linear	$Y = a + bX$	Sparrow 1979a
quadratic	$Y = a + bX + cX^2$	Sparrow 1979a
cubic	$Y = a + bX + cX^2 + dX^3$	Sparrow 1979a
Non-linear functions		
Exponential	$Y = a.exp(bX)$	Smith 1986
Power	$Y = a.X^b$	Smith 1986
Logarithmic	$Y = a + b.\log X$	Smith 1986
Logistic	$Y = a/(1 + bc^X)$	Du Toit & Gonnin 1984
Gompertz	$Y = a.exp(-bc^X)$	Du Toit & Gonnin 1984
Reid's model	$Y = a - (b.exp(-cX^d))$	Reid 1970
Mitscherlich	$Y = a(1- exp(-bX))$	Sparrow 1979b
Inverse polynomial functions		
inverse quadratic	$Y = (a + bX)/(1 + cX + dX^2)$	Sparrow 1979a
inverse linear	$Y = (a + bX)/(1 + cX)$	Sparrow 1979a
inverse linear (with descending asymptote)	$Y = (a + bX + cX^2)/(1 + dX)$	Greenwood *et al.* 1971
Other		
modified exponential	$Y = a - bc^X$	Sparrow 1979a
{with descending asymptote}	$Y = a - bc^X - dX$	Sparrow 1979a
Two intersecting linear functions	$Y = a + bX$ and $Y = d + eX$	Boyd *et al.* 1976

The choice of model depends on a number of factors (after Sparrow 1979a):

(a) the number of nitrogen treatments or rates applied; when few rates are applied it becomes impossible to distinguish between any but the simplest models;

(b) the proximity of the amount of N required for maximum yield to the largest N rate applied: information is required in the region where the model allows yield to change little or to decrease;

(c) the contrast in the rate of response between the three phases (see previous page) of the model, and

(d) the precision of the experiment: a large error variance will make it impossible to discriminate between any but the simplest models.

The major reason for fitting response curves to observed data is to estimate optimal[2] N rates for a particular pasture under a given set of conditions. The main problem encountered, however, is that many regression functions do not describe the observed data adequately in the regions of maximum response to applied nitrogen (Sparrow 1979a & b; Eckard 1986). Therefore, the option of hand-fitting a curve to observed data, although not producing regression statistics, should not be ruled out.

Maximum yield (Y_{max}), where it is assumed that N is not limiting plant growth, is defined as the potential yield under the management imposed for particular conditions of climate and soil (Morrison 1980); the corresponding N fertilizer rate is termed N_{max} or X_{max}. Optimal N rates are usually estimated at Y_{10}, being the yield at which the slope of the response to fertilizer N is 10 kg DM/kg N applied (Sparrow 1979a & b; Morrison 1980), with optimal N rates being estimated from the corresponding N fertilizer rates, N_{10} or X_{10}. An alternative estimate of optimum yield (Y_{90}) may be calculated as 90% of the observed maximum yield, with the estimated optimum N fertilizer rate (X_{90}) being drawn from the fitted curve (Cowling and Lockyer 1970).

Once a "best-fitting" growth function has been selected, based on the significance of the correlation co-efficient and an estimate of error *i.e.* residual or error mean square, residual standard error (not neglecting visual inspection of observed vs estimated data), Y_{max} and optimal yield (Y_{10}) may be calculated from the first differential of the growth function:

$$dY/dX = 0 \text{ for } Y_{max}$$

and $$dY/dX = 10 \text{ for } Y_{10}$$ (Reid 1970).

The use of the Y_{10} estimate for optimal yield is an arbitrarily selected cut-off point, at which the initial steep response slope (as much as 39 kg DM/kg N; Reid 1970) begins a phase of rapid inflection. Prins *et al.* (1980) selected an optimal yield cut-off at $Y_{7.5}$ based on an average of three reviewed studies where optimal yields of $Y_{5.7}$, Y_7 and Y_{10} were used. The Y_{10} estimate thus remains a

[2]In this discussion, 'optimal N' refers to either the X_{10} or X_{90} N fertilizer rates; N fertilizer rates above 'optimal N' are considered inefficient in terms of pasture production.

biological/environmental optimal yield. However, Prins *et al.* (1980) assumed marginal profitability at Y_{10}, an assumption which may lead to erroneous estimates of true profitability as this assumes a static economic climate. The estimation of economic optimum N fertilizer rates will be discussed in a separate chapter.

Overview of thesis and motivation

The data presented in this thesis were drawn from a range of field trials dating from February 1985, with some trials planned to continue until 1996. The earlier trials, conducted under a cutting regime, were aimed at providing the basic information urgently required by the Cedara Fertilizer Advisory Service.

Resulting from information gleaned from the cutting trials and requests from the farming community, further questions were raised. Firstly, the applicability of N response data from cutting trials to the grazed situation was questioned. The effect of the inclusion of clover in the pasture, on both the yield responses to N and pasture quality, also required investigation. Increasing popularity of perennial temperate pastures and the concern over the economic and environmental effects of high input annual pastures, prompted investigation of the N fertilizer responses of perennial ryegrass and tall fescue in association with white clover.

In response to the above questions, further trials were established on Cedara with the objectives of investigating the N fertilizer requirements of grazed *Lolium perenne* and *Festuca arundinacea* pastures, with and without *Trifolium repens*.

A potentially controversial aspect of the grazing trials is the extrapolation of data, derived from a sheep grazed study, to dairy and beef systems. Sheep were used in the grazing trials for both economic reasons (space and animals numbers per replicate) and the more even distribution of dung and urine over the treatments. The main concern, in extrapolating data from a sheep grazed system to a dairy or beef system, would be the defoliation height of the pasture. According to Frame (1992), rotational grazing management should aim to defoliate a pasture to heights of between 4 and 6 cm for sheep, 6 to 8 cm for beef and 7 to 10 cm for dairy cows. In the grazing trials defoliation was purposefully lenient (8cm) in an attempt to compensate for differences between cattle and sheep grazing patterns.

The results of the trials to date are presented.

SECTION II

CUTTING TRIALS ON *Lolium multiflorum* cv. MIDMAR

1 The response of *Lolium multiflorum* to applied nitrogen in the Natal Midlands

1.1 Introduction

1.2 Methods

Site and soil description

Trial design and treatments

Land preparation

Sampling

Analyses

1.3 Results and Discussion

Yield response to N

Effect of residual N

Efficiency of N use

1.4 Conclusions

1 The response of *Lolium multiflorum* to applied nitrogen in the Natal Midlands

1.1 Introduction

Smith (1987) reviewed that annual ryegrass appeared to have an internal N requirement in excess of 400 kg N/ha/yr for maximum yield under South African conditions. However, Ehlig and Hagemann (1982) reported annual ryegrass yield responses, in the Imperial valley (USA), to N rates in excess of 672 kg N/ha/yr. In an extensive study of the N fertilizer requirements of perennial ryegrass (*Lolium perenne* cv. S23) on 21 sites spread over the entire United Kingdom and over four years, the optimum rates of N fertilizer varied between 313 and 530 kg N/ha/yr (Morrison, *et al.* 1980). The work of Bartholomew and Chestnutt (1977) and Prins (1983) showed similar results, with optimum N rates around 400 kg N/ha/yr.

Since N fertilizer is one of the largest input costs on intensive pastures, a sound calibration of N requirement is a prerequisite for efficient and economic ryegrass production. In this study the dry matter yield response of irrigated annual ryegrass to varying rates of N fertilizer is evaluated and discussed.

1.2 Methods

The methods described here relate to all the cutting trials discussed in Section II. However, the results discussed under the separate subsections, in Section II, are extracted from different combinations of the trials discussed below.

Site and soil description

Annual ryegrass (*Lolium multiflorum* Lam. cv. Midmar) trials were established on six sites, four of which were on the Cedara Research Station (altitude 1,076 m, 29°32'S; 30°17'E; mean annual rainfall 885 mm; pan evaporation 1,478 mm) in the Natal mistbelt, and two on the Thabamhlope Research Station (altitude 1,450 m, 29°02'S; 29°39'E; mean annual rainfall 1,166 mm; pan evaporation 1,436 mm) in the highland sourveld (Acocks 1988). Details of the sites and soils associated with the six experimental sites are listed in

Table 1.1. Analyses of the experimental soils, prior to treatment, are listed in Table 1.2.

Table 1.1 Details of sites and soils on which the six trials were established (Soil Classification work group 1991).

Site	Form & Family	Location	Description
C2	Hutton Hayfield	Cedara	Upland, north-facing, old cultivar evaluation land. Orthic A/ red apedal B. Mesotrophic & non-luvic B1 horizon, clay-loam.
C4	Avalon Avondale	Cedara	Mid-slope, level, old hay land. Orthic A/ Yellow-brown apedal B/ soft plinthic B. Mesotrophic, non-luvic B1 horizon, clay-loam.
E4a	Katspruit Lammermoor	Cedara	Seasonally wet bottom-land, old *Paspalum* pasture. Orthic A/ Non-calcareous G horizon, clay.
E4b	Katspruit Lammermoor	Cedara	Seasonally wet bottom-land, old *Paspalum* pasture. Orthic A/ Non-calcareous G horizon, clay.
TH1	Kranskop Fordoun	Thabamhlope	Lower-slope, west facing aspect, old hay land. Thin humic A/ yellow-brown apedal B/ red apedal B. Non-luvic B1 horizon, clay-loam.
TH2	Inanda Himeville	Thabamhlope	Mid-slope, west facing aspect, virgin veld. Thin humic A/ red apedal B. Non-luvic B1 horizon, clay-loam.

Table 1.2 Selected properties of soils on which the six trials were conducted. Soil samples taken to a depth of 15cm and analysed by standard Hunter methods (Farina 1981).

Site	Sample Density	Organic carbon	Clay	P[a]	K	Ca	Mg	Acidity ($Al+H^+$)	Total Cations	Acid Sat	pH (KCl)	Zn[a]
	g/ml	----- % -------		--------- mg/l ---------				--- cmol/l ---		%		mg/l
C2	1.03	2.34	35	8	35	726	132	0.79	5.59	14.1	4.35	0.4
C4	1.03	2.49	43	19	67	389	60	2.18	4.84	45.0	4.00	0.9
E4a	0.79	5.09	58	44	172	1267	222	0.90	9.49	9.4	4.05	3.8
E4b	0.76	5.01	57	47	113	1194	1980	0.90	8.77	10.3	4.04	3.8
TH1	0.98	3.21	36	36	99	275	56	2.06	4.13	49.9	4.21	1.3
TH2	1.05	3.15	32	3	35	88	33	2.24	3.03	74.0	4.10	0.6

a - NH_4HCO_3/EDTA/NH_4F extraction

Trial design and treatments

The trial design on the C2, E4a and TH1 sites was a 3^3 factorial, replicated twice, with a zero N dummy plot included in each replicate. Experimentation was in 1985 and 1986 on the C2 and TH1 sites and 1986 and 1987 on the E4a site.

Treatments included sources of N, intervals between N applications and rates of N application (Table 1.3). The N sources used were urea, limestone ammonium nitrate and ammonium sulphate, while intervals of application were 4, 8 and 12 weeks from April to December, except in 1985. Eckard (1990) reported variations in N source to have no significant effect on dry matter production of *L. multiflorum*; presented data relate, where applicable, to means over the three sources tested.

In the first year of experimentation on the C2 and TH1 sites, N rates were 360, 720 and 1,080 kg N/ha/yr. In the second year of experimentation on the above sites, as well as in the two years on the E4a site, N rates were reduced to 200, 400 and 600 kg N/ha/yr (Table 1.3).

The three remaining trials (C4, E4b & TH2) were first established, using a twice replicated 3^2 factorial design, in 1987 (C4), 1988 (E4b) and 1989 (TH2) (Table 1.3). The treatments were three rates of N fertilizer (200, 300 & 400 kg N /ha/yr) and three N application schedules. The schedules were: N top-dressed on a 4-weekly cycle, a 4-weekly application with no winter N top-dressing (NW) and a 6-weekly cycle. A zero N control plot, used as a reference, was included in each replicate but was not included in the analysis of variance.

Initial N top-dressings were applied, according to their respective rates and schedules, to all plots at seedling emergence (± 2 weeks post planting). For the 4-weekly schedule, N top-dressings were applied subsequent to each harvest. Apart from withholding the two winter top-dressings (May & June) the NW schedule received N top-dressings as per the 4-weekly schedule. The N top-dressings for the 6-weekly schedule were applied at seedling emergence, after the April and July harvests and midway between the May and June and the August and September harvests.

Table 1.3 Details of the N fertilizer treatments applied at the six experimental sites and the years in which they were applied.

Year	Site	Weeks between N applications			N rates kg N/ha/yr
1985	C2, TH1	4	n/a	12	360, 720, 1080
1986	C2, TH1, E4a	4	8	12	200, 400, 600
1987	E4a	4	8	12	200, 400, 600
	C4	4	NW*	6	200, 300, 400
1988	C4, E4b	4	NW	6	200, 300, 400
1989	C4, E4b, TH2	4	NW	6	200, 300, 400
1990	C4, E4b, TH2	4	NW	6	200, 300, 400

NW* = 4-weekly application excluding two winter applications.

Land preparation

All sites were disced for initial land preparation, lime being incorporated where required, and again for the incorporation of basal fertilizer dressings prior to planting. Based on initial soil analyses of the sites (Table 1.2) nutrients, other than N, were supplied in sufficiency to all plots. Additional potassium was top-dressed to all plots midway through the growing season at a rate of 100 kg K/ha (200 kg KCl/ha) to compensate for K removed in the cut herbage.

Following planting, using a Connor-Shea planter (row width and seeding rate settings of 150 mm and 20 to 25 kg seed/ha respectively), the area was rolled with a Cambridge roller. This procedure was repeated for each re-establishment, care being taken to ensure that the same plot boundaries were retained each year. Irrigation, supplemental to rainfall, was supplied to ensure a minimum provision of 25 mm of water per week.

Sampling

Gross plot size was 8.0 x 3.5 m. Samples were cut from a net plot (6.8 x 1.2 m) within the gross plot at intervals of four weeks. All plots were cut, with a reciprocating cutter bar mower, at a height of 5 cm at approximately the same time of day (10h00 to 11h30). Wet herbage weights were recorded and a sub-sample taken from each plot for DM determination (oven dried at 90°C for 24 hrs) and subsequent chemical analysis.

Analyses
The data were subjected to analysis of variance based on the factorial field design. As the zero N control plots were not included in the factorial design, nor in the analysis of variance, significance levels (LSD 5%) are not applicable to comparisons including the zero N treatments.

Data and discussion presented below were drawn from the C2 (1985 & 1986), TH1 (1985 & 1986) and E4a (1986 & 1987) sites (Table 1.3).

1.3 Results and discussion

Yield response to N
Dry matter yield responses to N on three of the sites are presented in Figure 1.1. Maximum cumulative yields (April to December) from individual plots were 13.5, 11.8 and 15.4 t/ha/yr for the C2 (Figure 1.1a), TH1 (Figure 1.1b) and E4a (Figure 1.1c) sites respectively. These yields are in close agreement with the data obtained by [1]Watt-Pringle (pers. comm. 1986) for Cedara (14 t/ha) and [1]Mappledoram (pers. comm. 1986) for Thabamhlope (11 t/ha) in annual ryegrass cultivar evaluation trials.

On the C2 site, responses to N appeared to be greater in 1986 than in 1985, with dry matter production at zero N being markedly higher in the first year. On the TH1 site at Thabamhlope, responses were largely co-incident. On the E4a site, dry matter production in the first year was appreciably higher than in the second, though the pattern of response to N appeared to be essentially similar in both years. A marked response to the first increment of N (360 kg for 1985 and 200

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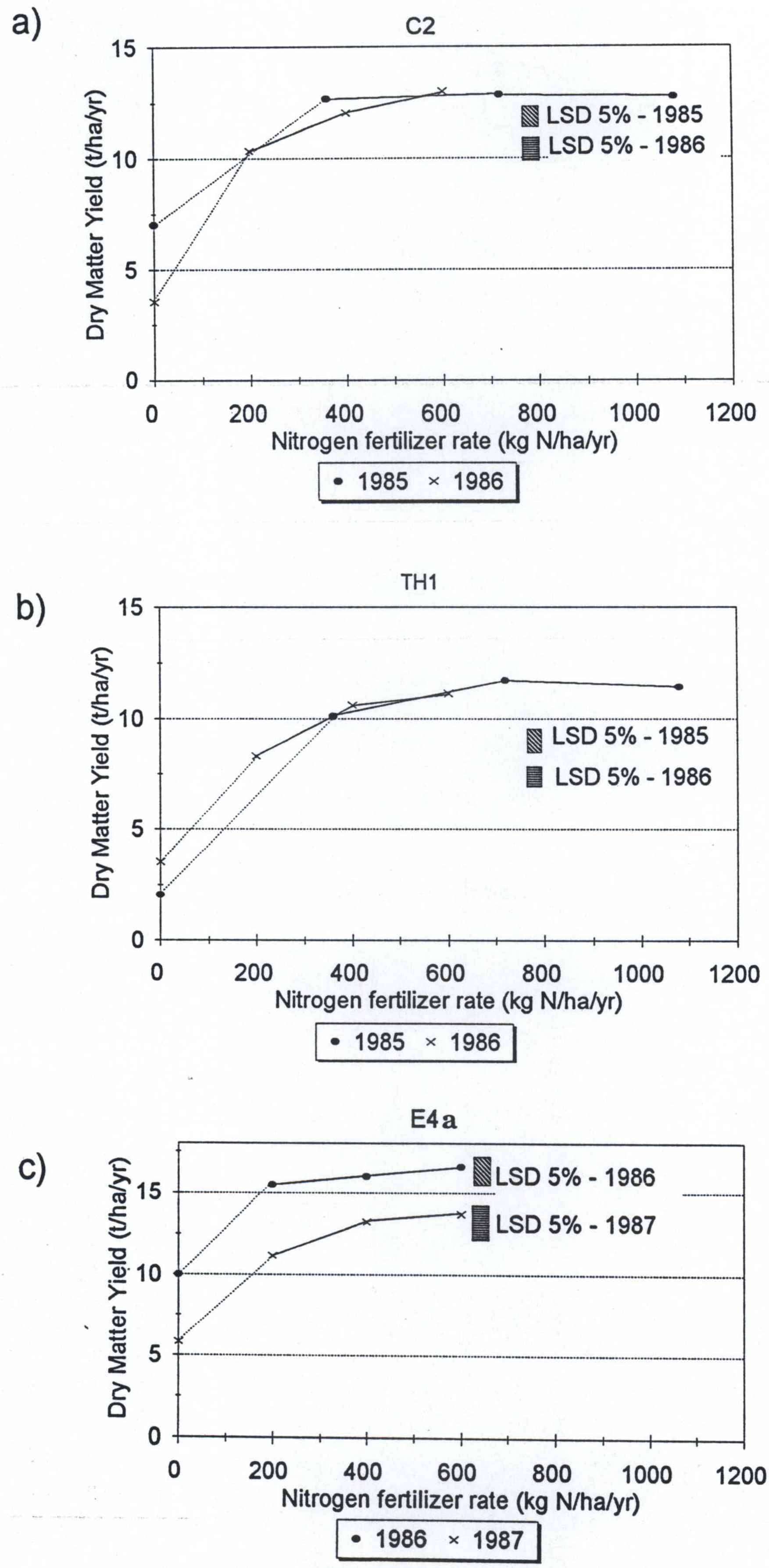

Figure 1.1 The yield response of annual ryegrass to three rates of N fertilizer, with data reported for the C2 (a), TH1 (b) and E4a (c) sites over two years per site. Dotted lines link to zero treatment yields as these were not included in the analysis of variance.

N/ha/yr for 1986 and 1987, Figure 1.1) occurred on all sites in both years. On the C2 and E4a sites, in the first year, the response to the second level of N fertilizer (720 and 400 kg N/ha/yr respectively) was non-significant. On the TH1 site in the first year, however, a significant ($P<0.05$) response occurred between the 360 and 720 kg N/ha/yr rates. The low responses to applied N, on the C2 and E4a sites, are no doubt attributable to the high residual N in the soil, as reflected by the yield at the zero N treatment (the term residual N, in this discussion, refers to the N supplied by the soil from sources other than the current years treatment applications (Morrison, *et al.* 1980)). The residual N in the soil would, therefore, have resulted in the effective N rates (residual plus applied N) being much higher in both the C2 and E4a soils than in the TH1 soil. In the second year a significant response ($P<0.01$, $P<0.01$ and $P<0.05$ for the C2, TH1 and E4a sites respectively) was recorded between the 200 and 400 kg N/ha/yr treatments on all sites. The apparently lower residual N in the second year appeared to result in improved yield responses to higher rates of applied N. In the second year, N applications in excess of 400 kg N/ha/yr proved non-significant on all sites and, in cases where a levelling-off in response was not observed, response patterns suggested that yields at the highest N rates were in close proximity to an asymptote.

Effect of residual N

In order to estimate the N supplied by the soil (residual N) the average N content (3.49 %N) of the herbage from the zero plot on the E4a site was multiplied by the average dry matter yield (9,991 kg/ha/yr) of the same plot. On this basis an estimate of the residual N available to the plant, over the first year, was 350 kg N/ha/yr. The estimates of N supplied by the soil for the C2 and TH1 sites in the first year were 215 and 54 kg N/ha/yr respectively. Although this estimate of residual N may be affected by N immobilised in the roots, stubble and organic matter (Morrison, *et al.* 1980), an indication of relative differences between sites is provided.

The variation in N responses, between years on the E4a site (Figure 1.1c), may be partly attributed to high residual N in the soil in the first year. The dry matter yield achieved on the

E4a site in the first year with no N applied was 10 tons/ha. This yield, when compared with the zero N plots from other sites and from the second year on the same site, suggests that a large amount of residual soil N was supplied to the plant. These data emphasise the need for zero treatment control plots in fertilizer calibration studies.

The residual effect of N on the E4a site may, however, only explain the differential response to N in the two years at the lower N rates. It would appear that other factors also affected the maximum attainable yield in the second year. This was approximately 2 t/ha lower (Figure 1.1c) in the second than in the first year at the E4a site. The reasons for this were not clear, but are most likely due to flooding when the site was water-logged, for approximately 3 weeks, during a peak growth period in the second year.

Efficiency of N use

In order to obtain an estimate of the optimum N fertilizer rate the data, from all years and sites, were compared on a relative yield basis (Figure 1.2). The relative yield was calculated by expressing each observed yield as a percentage of the maximum for that site and year (Y_{MAX}). It is assumed that N is non-limiting at Y_{MAX} which is, therefore, the potential yield under the management imposed for particular conditions of climate or weather and soil (Morrison 1980).

An attempt was made to describe the data in terms of a regression equation, with a number of regression curves being fitted: a linear, a quadratic, a modified logistic, a modified power, a Mitscherlich and an exponential curve (Sparrow 1979a; Morrison *et al.* 1980; Du Toit & Gonin 1984). The regression equations did not, however, describe the observed data adequately in the regions of maximum response to applied nitrogen, a problem encountered in previous N response studies (Sparrow 1979a; Eckard 1986). A second problem encountered was that a number of the curves, although fitting the data, showed a yield depression at higher rates of N application. This trend of yield depression at excessive rates of N fertilizer was not observed in the data. The response curve in Figure 1.2 was therefore fitted by hand.

An estimate of optimum yield (Y_{90}) was calculated as 90% of

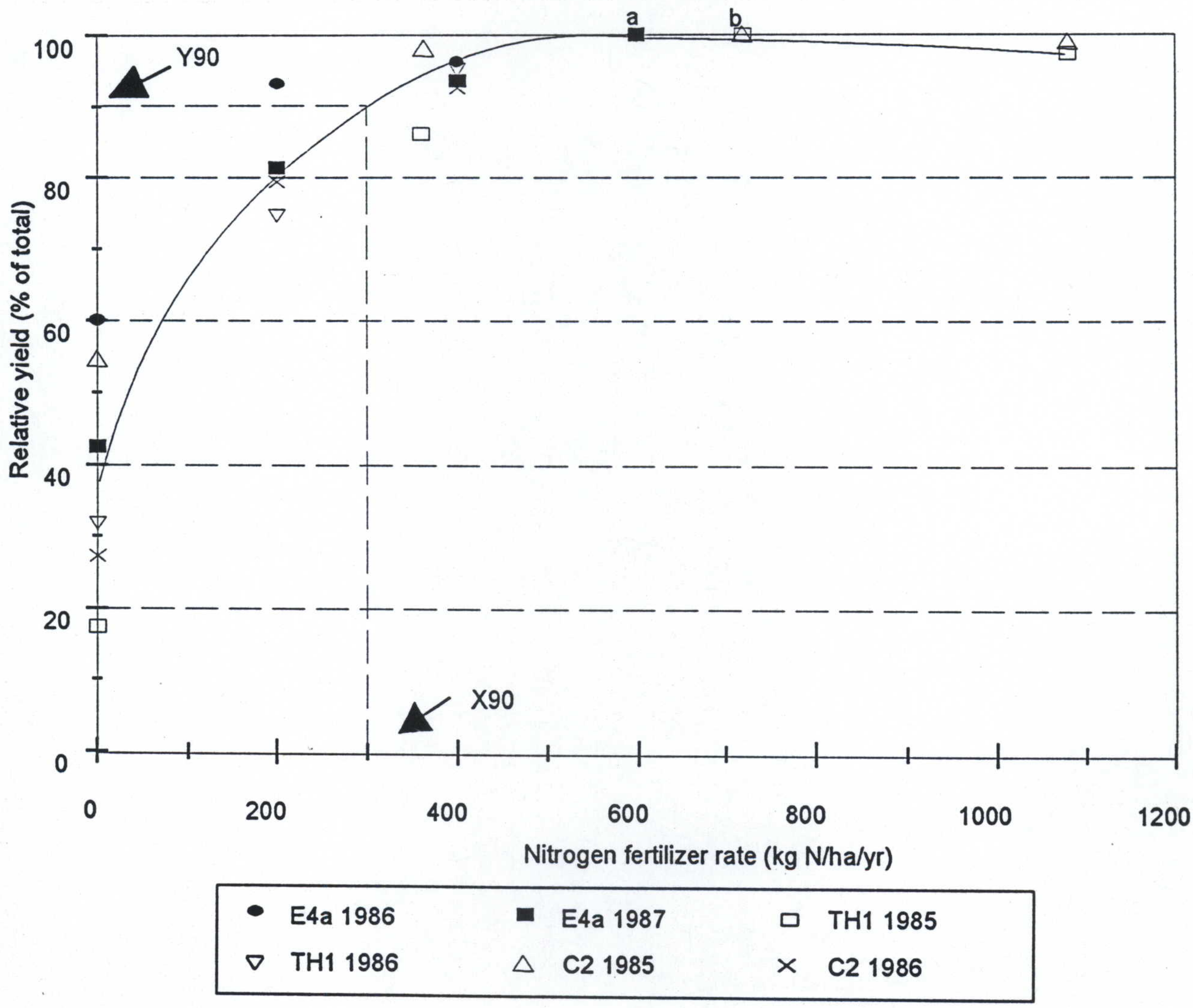

Figure 1.2 The relative yield response of annual ryegrass to varying rates of N fertilizer, expressed as a percent of the highest yield recorded for each year and site. Data reported for three soil sites over two years per site (a = 4 co-incident points; b = 2 co-incident points). Dotted line links 90% of maximum yield (Y_{90}) to the corresponding N fertilizer rate (X_{90}).

Y_{MAX}, as reviewed in the general introduction (Cowling & Lockyer 1970). The dotted line in Figure 1.2 indicates the Y_{90} and corresponding N fertilizer rate (X_{90}). The data presented in Figure 1.2 were initially graphed for each soil type separately, combining two years data per graph (data not shown). The N fertilizer rates (X_{90}) corresponding to the Y_{90} yield values were estimated from the separate fitted curves at 300 kg N/ha/yr for the C2 and E4a sites and 350 kg N/ha/yr for the TH1 site. Morrison *et al.* (1980) reported a lower N requirement for optimum yield where residual soil N was high, which could account for the difference in X_{90} between the C2 and E4a sites compared to the TH1 site. Due to the similarity of the data when compared on a relative yield basis, however, the data from all sites and years were combined (Figure 1.2).

Optimal N rates, estimated by the method of Morrison *et al.* (1980) *i.e.* the yield at which 10 kg of dry matter is produced per kg N applied (cf. General Introduction) compared favourably with the method adopted above.

An indication of the efficiency with which N was utilised may be obtained by calculating the ratio of kg DM produced/kg N applied[2]. These efficiency ratios are reported for some of the sites and years where an N rate of 200 kg N/ha/yr was applied (Table 1.3), in order to compare sites with each other within the region of maximum response to applied N. The efficiency ratios for the C2, TH1 and E4a sites in the 1986 and the E4a site in the 1987 year (0 to 200 kg N/ha/yr), respectively, were 33.9, 23.8, 27.6 and 25.0 kg DM/kg N applied. The data of Ehlig and Hagemann (1982) showed this efficiency ratio of annual ryegrass to be 27.0 for N levels up to 448 kg N/ha/yr. The data of Darwinkel (1976), for Italian ryegrass, showed this ratio at 16.9 for a N level of 600 kg N/ha/yr.

Nitrogen was therefore most efficient at the C2 site and least efficient at the TH1 site. Nitrogen appeared more efficient on the E4a site in the first than in the second year. However, this could be attributed to the same influences that caused the depressed maximum yield in the second year (Figure 1.1c). It appears that N varies in its efficiency at different

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[2] Calculated as follows: (kg DM produced at 200 kg N/ha/yr - kg DM of zero N treatment)/200 kg N/ha/yr.

sites, presumably due to a combination of residual soil N and the environmental factors of climate, weather and soil (Morrison 1980).

1.4 Conclusions

The response pattern to increasing rates of N fertilizer was largely similar on all sites, showing a rapid initial response to N fertilizer with an asymptote being reached or approached at high N fertilizer rates. The site on which the pasture was situated appeared to affect its nitrogen requirements and, as discussed, these are largely due to differences in residual soil N (N mineralization potential), pre-treatment N fertilizer applications and environmental factors (*i.e.* temperature and moisture). Applications of N in excess of 300 to 350 kg N/ha/yr were shown to exceed the N requirements of annual ryegrass for optimum yield (Y_{90}) under the conditions in this study.

It must also be borne in mind that the current investigation was conducted under a cutting regime. Therefore, no account was taken of the N which would be returned to the soil via the excreta in a grazed pasture. In Natal, a reduction of 25% of the first years N rate is advised for subsequent years, to account for the N cycled through the animal and thus carried over in the soil (Miles & Bartholomew 1987). Furthermore, residual soil N appeared to vary markedly between the sites. This investigation highlights the need for a regular soil N test to be included in all fertilizer advisory services, in order to correct recommendations for the residual N available in the soil. The data also emphasise the importance of zero N control treatment in N fertilizer response studies.

The objective of this study was to attempt to calibrate annual ryegrass, in the Natal Midlands, for its nitrogen requirements for optimum yield (Y_{90}). This optimum rate (X_{90}) appeared to be between 300 and 350 kg N/ha/yr for a wide range of sites and soil forms.

2 The relationship between the nitrogen and nitrate content and nitrate and protein toxicity potential of *Lolium multiflorum*

2.1 Introduction

With the increased utilization of N fertilizer on annual ryegrass pastures an increase in the number of animal health problems, attributed to the high N fertility status of the pasture, has occurred. The high nitrate-N (Deinum & Sibma 1980) and N content (Wilman 1970; Bredon unpublished data[3] 1979) of the pastures, resulting from the liberal use of N fertilizer, appear to be the cause of many of these animal health problems.

An investigation of the interrelationships between the N, nitrate-N and dry matter yield of pasture plants was undertaken in order to formulate preventative management recommendations.

2.2 Methods

Data were extracted from selected trials described under Section II, 1.2, namely the C2 (1985), TH1 (1985), E4a (1987) and C4 (1987) sites (Table 1.3, page 14).

All herbage samples were analysed for their N (%) content by Near Infra-Red spectroscopy (NIRS), according to the method of Eckard *et al.* (1988). The NIRS calibration was based on and regularly checked against the standard kjeldahl method (AOAC 1980). Nitrate-N analyses were performed using the standard nitrate electrode technique (Barker 1974; Orion Research Inc. 1979; Carlson & Schneider 1986; Eckard 1986) and reported as nitrate-N (%). All laboratory analyses are reported on a dry matter basis.

The presented data represent the full range of N fertilizer rates, schedules and sources applied at the sites mentioned above.

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[3]Animal Science Section, Department of Agriculture, P.Bag X9059, Pietermaritzburg, 3201.

2.3 Results and discussion

The relationship between herbage N and nitrate-N content of annual ryegrass is illustrated in Figures 1.3 and 1.4, being the mean for the growing season (mean of 9 defoliations) and for selected defoliation dates in each year (April to December), respectively. The relationship between N and nitrate-N in the herbage, presented in Figure 1.3, was best described by the significant exponential model $Y = a.exp\ (X^b)$, where $a = 5.882 \times 10^{-03}$ and $b = 0.987$.

A similar relationship between herbage N and nitrate-N to that presented in Figures 1.3 and 1.4 was found by ap Griffith (1960) for a number of temperate grasses. His findings show a consistent pattern of little or no accumulation of nitrate-N with increasing N levels up to between 3.2 and 3.5% N (20 to 22% crude protein), followed by a sharp (largely linear) increase in nitrate-N with minimal further increase in N content. Darwinkel (1975) reported a similar relationship in Italian ryegrass, with the point of rapid accumulation of nitrate-N varying between 2.0 to 4.0% N, depending on the age of the plant, N application rate and the season of the year.

Darwinkel (1975) attributed the rapid accumulation of nitrate-N, relative to N, to the rate of uptake of nitrate-N exceeding the rate of demand by the plant for protein production. The reasons for this uptake/demand imbalance could be water stress, an excessive supply of N in the soil or the physiological limit of the protein production of the plant being exceeded (Darwinkel 1975; Deinum & Sibma 1980). With one exception (discussed later), water stress was largely avoided in the current investigation by regular irrigation.

The data from the TH1 site (April 1985, Figure 1.4a) show nitrate-N accumulation at lower N levels than the rest of the sites and years. This apparent accumulation of nitrate-N could have resulted from moisture stress at the TH1 site in April 1985. A number of problems were experienced in the initial stages of irrigation management on this site, resulting in a reduced and erratic water supply. Such a low moisture supply would cause a nitrate-N accumulation at a lower than normal N level (Wright & Davison 1964; Deinum & Sibma 1980). As the extent of the moisture deficiency during this period was not

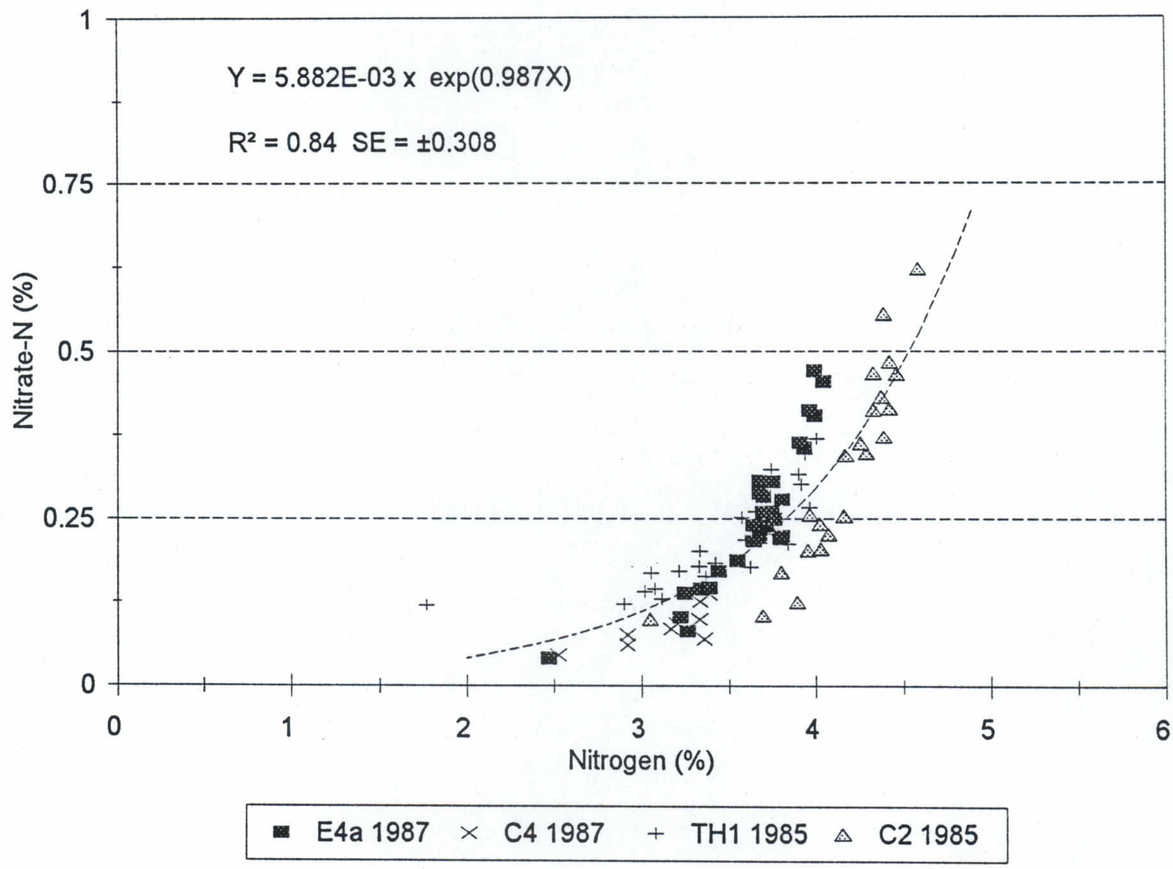

Figure 1.3 The relationship between the annual mean nitrate-N and N contents of annual ryegrass. Data are presented for four soil sites in different years (TH1 1985, C2 1985, C4 1987 and E4a 1987).

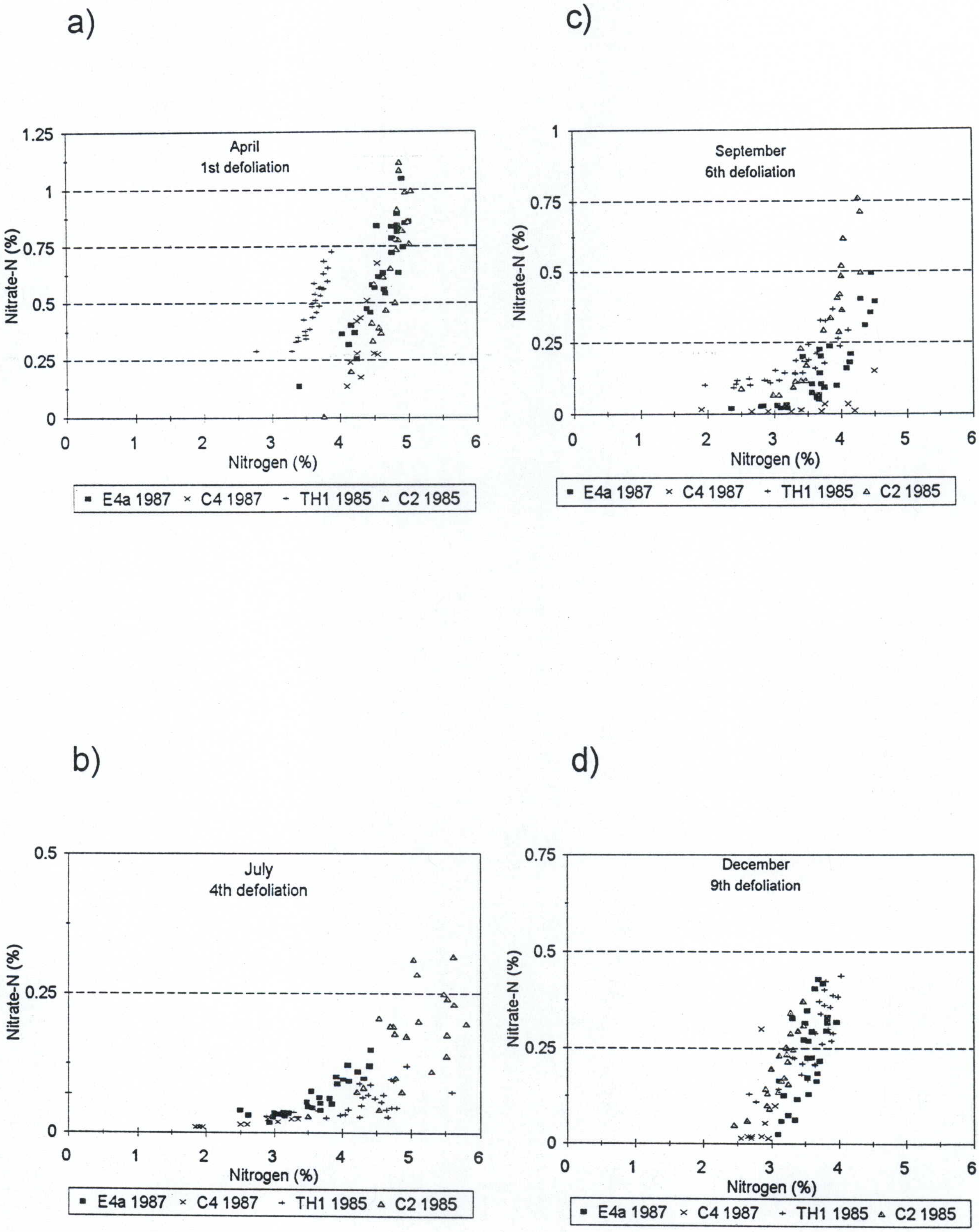

Figure 1.4 The relationship between the nitrate-N and N contents of annual ryegrass at four defoliations dates (April (a), July (b), September (c) and December (d)) over the growing season. Data are presented for four soil sites in different years (TH1 1985, C2 1985, C4 1987 and E4a 1987).

known, reliable conclusions could not be drawn from the data, except to point out the possible effect of moisture stress on promoting nitrate-N accumulation at lower herbage N levels than in the other situations shown.

The data from Figures 1.3 and 1.4 indicate a lower accumulation of nitrate-N in the herbage on the C4 site than on the other sites at all defoliation dates. The C4 site was top-dressed with lower N levels than all the other sites. The highest rate of N fertilizer applied (400 kg N/ha/yr; Table 1.3, page 14) was apparently, therefore, never substantially more than plant requirements.

The data from the July defoliation (Figure 1.4b) show the plants accumulating higher N levels, relative to nitrate-N, than during the rest of the year. Jones *et al.* (1982) demonstrated the preferential uptake of ammonia (70 to 90 % of total N) from the soil, by ryegrass plants, at root temperatures between 3 and 10 ^{0}C. Low temperatures restrict nitrification in the soil and would therefore restrict the uptake of nitrate-N by the plant (Schmidt 1982). With the warming of the season, from September to December, a greatly increased herbage yield of the plant was observed (data not shown), resulting in a relative dilution of the N content of the plant (Figure 1.4c & 1.4d).

The April and September defoliations (Figure 1.4a & 1.4c) appear to be periods when nitrate-N in the plant could reach levels potentially toxic to ruminants. The April defoliation, being the first defoliation of the year, may represent a supply of soil N released in response to the working of the soil at planting. The September defoliation coincides with increased soil temperatures in early spring, leading to increased availability of mineralized soil N.

Nitrate toxicity potential

Although it is generally recognized that nitrate-N accumulated in forages may be potentially toxic to livestock, considerable disagreement exists regarding the concentrations of nitrate-N which result in lethal or sub-clinical toxicity in ruminants. Most literature agrees on a "safe" limit of 0.21 to 0.35% nitrate-N in the dry matter, beyond which toxicity could occur either clinically or sub-clinically (McCreery *et al.* 1966; Lawrence *et al.* 1968; Lovelace *et al.* 1968; White & Halvarson

1980; Olsen & Kurtz 1982). Some reports set these "safe" limits as low as 0.07 to 0.15% nitrate-N (George *et al.* 1973), while more recent investigations indicate that they may be as high as 0.57 to 0.60% nitrate-N (Coombe & Hood 1980; Deinum & Sibma 1980). Sheep grazing annual ryegrass pastures on the Cedara research station, with a nitrate-N content in excess of 1.2 % nitrate-N have shown positive mass gains, with no apparent ill effect (unpublished data 1987). The validity of setting a "safe" limit is questionable as toxicity levels vary widely with the type of animal, quantity of nitrate-N ingested, condition of the animal, previous diet of the animal, carbohydrate content of the diet and other factors (Wright & Davison 1964; George *et al.* 1973).

The most reliable means of expressing toxic, or sub-clinically toxic, nitrate-N levels would be in terms of dietary nitrate-N (g/kg live mass) levels required to produce death in a set percentage of a given animal population. The lethal dose (LD) required to produce death in 50% of the population is called the LD_{50} (Wright & Davison 1964). The LD_{50} for nitrate-N toxicity in ruminants lies between 160 and 224 mg nitrate-N/kg livemass, when nitrate-N is a constituent of the herbage on offer (Wright & Davison 1964). Calculating from the above LD_{50} values (using the daily DM intake requirements for maintenance) the nitrate-N LD_{50} for ruminants on a pure annual ryegrass diet (no supplements), would be between 0.65 and 0.90% nitrate-N. These levels of nitrate-N are well above the critical limit (0.15 to 0.25% nitrate-N) for plant growth, below which dry matter yield is restricted by a lack of N (van Burg 1966; Eckard 1986). Nitrate-N levels in excess of this critical limit (0.15 to 0.25% nitrate-N) will, in any event therefore, indicate a wasteful and uneconomical use of N fertilizer.

Referring to the relationships presented in Figures 1.3 and 1.4, it may be concluded that at N levels of 3.2 to 3.5%, potentially toxic levels of nitrate-N did not appear in the herbage. However, were the pasture was subjected to conditions predisposing the accumulation of high nitrate-N, without increasing the N content *i.e.* moisture stress (TH1 site, Figure 1.4a), potentially toxic levels of nitrate-N could accumulate in the herbage at relatively low N levels. Nitrate-N toxicity in ruminants grazing annual ryegrass pastures should, therefore, occur only under conditions of stress to the pasture and the animal. Stress conditions could occur when animals are in poor condition, starved, unadapted to the pasture, or if N fertilizer were applied at high rates to a stressed pasture (*i.e.* moisture stress), mainly in April or September.

Protein toxicity potential

Of greater importance than nitrate-N appears to be the level of total N in the diet. Wilman (1970), in a review of literature, indicates that N levels above 3% may cause adverse effects in ruminants. This agrees closely with the data of Bredon, Dugmore and Lesch (unpublished data[4] 1979) who set this level at 3.2 to 3.5% N. The adverse effects of high N in the diet may be in the form of bloat (Hegarty 1981), ammonia toxicity with consequent reduced feed intake, or a number of other minor disorders that lead to an unthrifty animal (Hibbit 1984).

The soluble carbohydrate content of the forage is an important factor affecting the susceptibility of ruminants to both high nitrate-N and total N levels in the diet. Ruminants are known to tolerate potentially toxic levels of nitrate-N or N in forages if the energy supply, required to assimilate and metabolise these nitrogenous fractions, is not limiting (Hibbit 1984). Bryant and Ulyatt (1964) produced evidence to show that the soluble carbohydrate content of forages decreases with increasing N fertilization rate and total N in the herbage. If the energy supply is lacking in the diet, rumen function is impaired and the rate of passage through the rumen is slowed, resulting in a reduced voluntary intake (Hibbit 1984). It may be concluded that excessive N (above 3.5%) in the forage is likely to be uneconomical, not only because DM production is not stimulated when levels rise above 3.5 %N (Eckard 1986), but also because of reduced intake and toxicity in the animal, leading to a production loss.

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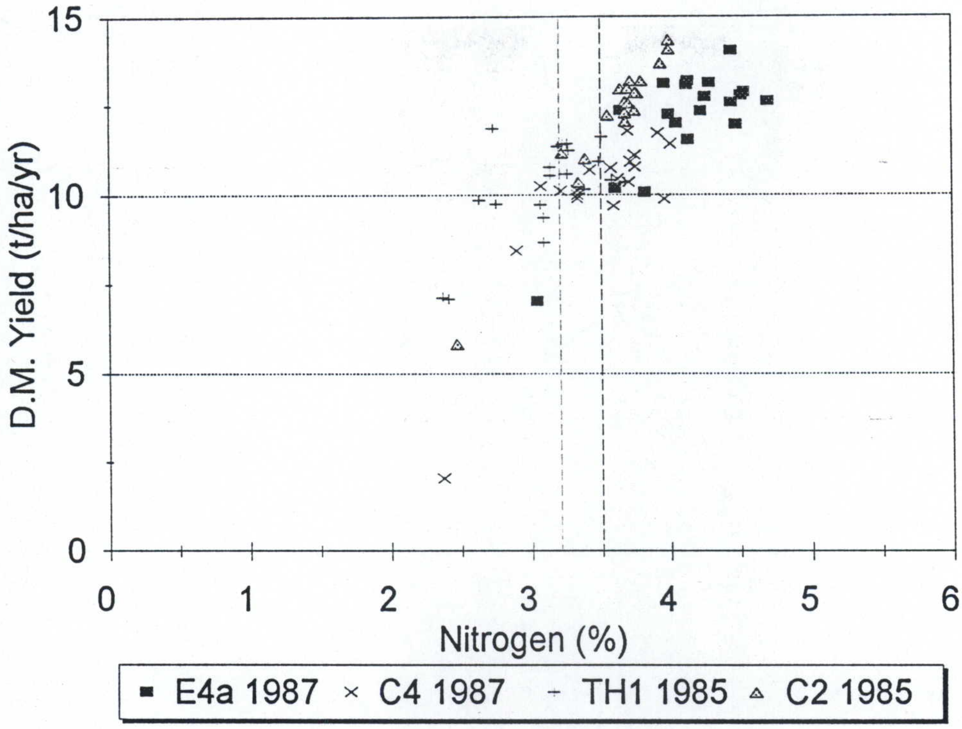

Figure 1.5 The relationship between the annual total dry matter yield and mean N content of annual ryegrass. Data are presented for four soil sites in different years (TH1 1985, C2 1985, C4 1987 and E4a 1987). Vertical lines indicate the 3.2 to 3.5 % N limits.

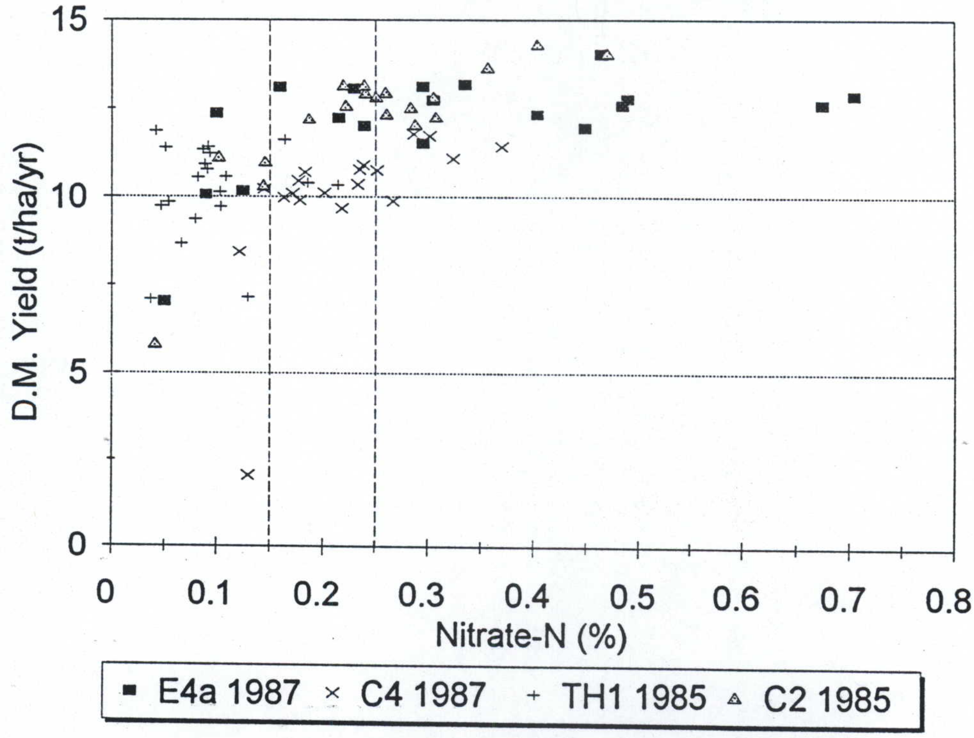

Figure 1.6 The relationship between the annual total dry matter yield and mean nitrate-N content of annual ryegrass. Data are presented for four soil sites in different years (TH1 1985, C2 1985, C4 1987 and E4a 1987). Vertical lines indicate the 0.15 to 0.25 % nitrate-N limits.

DM yield versus N and nitrate-N

In Figures 1.5 and 1.6 the relationship between N and dry matter yield and nitrate-N and dry matter yield are presented respectively. From both Figures 1.5 and 1.6, high DM yields are attained before any appreciable accumulation of N or nitrate-N occurs. The observed data points in the lower DM yield ranges represent herbage samples from the zero N control plots. As there were only two zero N control plots per trial, these few data points were vital in describing the relationships presented.

From the data presented in Figure 1.5, as mentioned earlier, it would appear that N levels in excess of 3.5 to 4.0 % may be in excess of the plants requirement for growth, may be detrimental to the ruminant, and indicate a wasteful use of N fertilizer. The 3.2 to 3.5 % limits are indicated by the vertical dashed lines in Figure 1.5. It is of interest to note that the level of N at which animal health may be adversely affected corresponds to a possible wasteful use of N fertilizer.

As indicated earlier, van Burg (1966) and Eckard (1986) reported that as long as nitrate-N levels of 0.15 to 0.25% or above are maintained in the plant, dry matter yield is not restricted. These limits are indicated by the vertical dashed lines in Figure 1.6. It would appear that above these limits, applied N fertilizer is in excess of the growth requirements of the plant, potentially toxic to ruminants and therefore indicates a wasteful use of N fertilizer.

2.4 Conclusions

From the data presented it is clear that N-related animal health problems, on annual ryegrass pastures, may be attributed to a wasteful use of N fertilizer. A number of poor management practices can predispose ruminants to N-related problems. One of the most common mistakes is to allow unadapted and hungry animals free access to highly fertilized ryegrass pastures, particularly during April and September.

The merit of reducing N fertilizer applications during periods of potentially high nitrate-N and N accumulation requires investigation. Dry matter yields do not appear to be restricted by a reduction in N applications during these periods

(April and September). Livestock and production losses, caused by the build up of toxic nitrogenous compounds during these periods, could be avoided by a more strategic application of N fertilizer.

The reduction of N fertilizer applications in the mid-winter period might represent a cost effective saving in colder areas where no mid-winter growth of annual ryegrass takes place. The merits of the above strategies are discussed in Section II, 4.

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3 The dry matter yield response of *Lolium multiflorum* to varying nitrogen fertilizer application strategies. I. Intervals between nitrogen top-dressings

3.1 Introduction

3.2 Methods

3.3 Results and Discussion

Annual total yields

Monthly yields

3.4 Conclusions

3 The dry matter yield response of *Lolium multiflorum* to varying nitrogen fertilizer application strategies. I. Intervals between nitrogen top-dressings

3.1 Introduction

The timing of N fertilizer applications, over the growing season, greatly affects the seasonal distribution of pasture yield (Wolton *et al.* 1971; Morrison 1980). Higher annual and more uniform seasonal DM yields of perennial ryegrass pastures have been recorded where N fertilizer was applied in frequent small top-dressings, as opposed to fewer heavy applications (Brockman 1966; Castle & Reid 1968; Wolton *et al.* 1971; Anslow & Robinson 1986).

In addition, high rates of N fertilizer, applied in a single application, reportedly favour losses by volatilisation and leaching (Olsen & Kurtz 1982), lead to N uptake surplus to the plant's requirement for growth and may result in herbage N levels (non-protein N or protein) potentially toxic to ruminants (Wright & Davison 1964; Darwinkel 1975; Deinum & Sibma 1980). This implies a reduced efficiency of N utilisation with infrequent N applications, relative to smaller frequent applications.

The aim of this study was to quantify the effect of varying N fertilizer schedules on the DM yield of annual ryegrass pastures under local conditions.

3.2 Methods

Data were extracted from selected trials described under Section II, 1.2, namely the C4 site (1987 to 1990), E4b (1988 to 1990) and TH2 (1989 to 1990) (Table 1.3, page 14). Data were subjected to analysis of variance, based on the factorial design, with years included as an additional factor. Presented data, therefore, represent the means over the years indicated.

3.3 Results and Discussion

Annual total yields

The data presented in Figure 1.7 illustrates the effect of varying the interval of N fertilizer application, at three N fertilizer application rates, on the annual total DM yield of annual ryegrass. Data are presented for each of the three sites and meaned over the years indicated.

At the C4 site (Figure 1.7a) a significantly higher yield ($P<0.05$) was found for the 4-weekly schedule, at 300 kg N /ha/yr, than the 6-weekly schedule. This trend was also evident at 400 kg N /ha/yr for the E4b site (Figure 1.7b). No significant yield differences were noted at the TH2 site (Figure 1.7c).

The data presented in Figure 1.7 show that 4-weekly application intervals produced either higher or equal annual total DM yields, to the 6-weekly schedule. Morrison (1980) and Reid (1984) report the seasonal pattern of N application to have little effect on total yields, particularly at higher levels of application. However, the data of Wolton *et al.* (1971) and Anslow and Robinson (1986) indicate annual total yields to be greater where N was applied in split dressings over the year than when applied as a single dressing. Castle and Reid (1968) report a marked annual total yield advantage to applying the recommended N as 3 or 4 split dressings over the year, as opposed to a single dressing. The above data imply a greater efficiency of N utilization when applied in smaller, but more frequent top-dressings.

Monthly yields

One of the most important factors affecting the relative yields obtained from either single or multiple N schedules is the length of the regrowth period. The longer the regrowth period, the greater would be the response to a single heavy top-dressing (Castle & Reid 1968). According to Brockman (1966), N fertilizer applied to irrigated ryegrass during active pasture growth will have little residual effect after the first subsequent harvest. Excessive free N in the soil may be leached beyond the root profile if irrigation is not carefully managed (Olsen & Kurtz 1982; Anslow & Robinson 1986). Reid (1984) demonstrated,

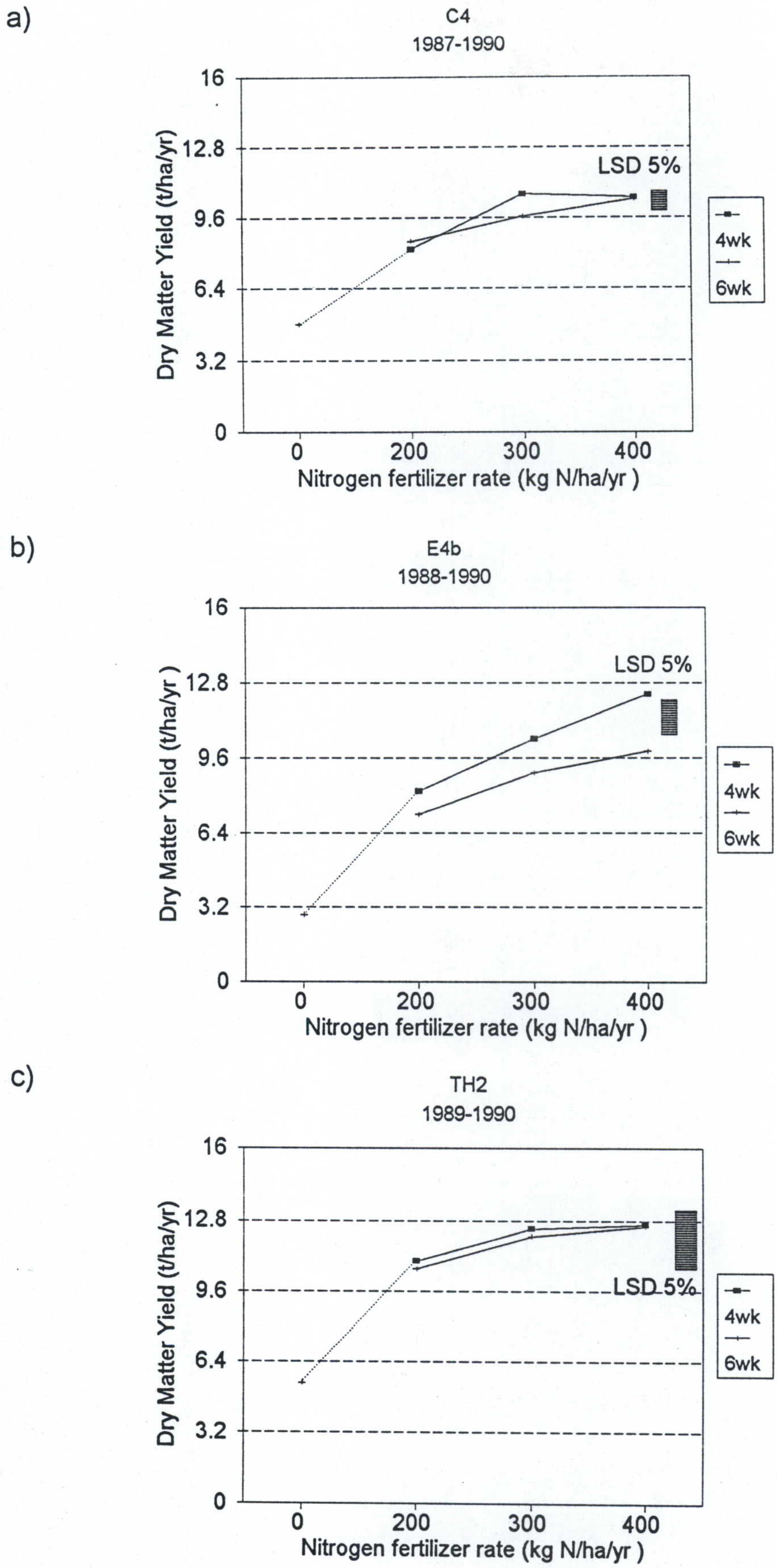

Figure 1.7 The annual total DM yield response (t/ha/yr) of annual ryegrass to N applied at 4 and 6 weekly intervals. Data presented for three sites and meaned over the relevant years. Dotted lines link to zero N level as these were not included in the analysis of variance.

however, that at the harvest immediately after that for which the N was applied, there was a positive residual effect of only 30 to 35% of the size of the direct effect. These findings imply that the optimal N schedule would have to provide sufficient N for each regrowth period in the year separately (Wolton *et al.* 1971). The data of Wolton *et al.* (1971) agree with the observation that most uptake of fertilizer N occurs within four weeks of application (Whitehead 1970 cited by Murtagh 1975).

Figures 1.8, 1.9 and 1.10 illustrate the effect of varying N fertilizer application interval on the monthly yield at three rates of N fertilizer. In Figures 1.8a and c, the 6-weekly (5 applications) schedule produced higher yields in May than the 4-weekly (8 applications) schedule, although this was significant only in Figure 1.8a ($P<0.05$). Apart from Figure 1.9c, this trend was not evident at the higher N application rates (Figures 1.9 & 1.10).

From the data presented it appears that, in addition to a post-emergence N top-dressing, the application of 38 (Figure 1.9) to 40 (Figure 1.8) kg N /ha in April, together with the soil N released at establishment, provided sufficient N for a high level of production in the autumn period (April to June).

No consistent significant ($P>0.05$) differences in yield response between N fertilizer rates were noted during the coldest month, July (Figures 1.8, 1.9 & 1.10), except that the zero N control plots consistently produced inferior DM yields to N fertilized plots. This emphasises the importance of pre-winter N applications in building overall plant vigour before entering the winter period. The earlier spring recovery of N fertilized plots, relative to the zero N plots, may also be attributable to improved plant vigour prior to winter. In most cases, however, the 6-weekly N schedule treatments responded to early spring temperature increases (August) before the 4-weekly treatments. These plots had all received a relatively higher N application in July, thus ensuring the availability of N in the soil in anticipation of early spring temperature increases. As this period is usually the most critical, from a forage production point of view, there appears some justification for a July application of at least 40 to 50 kg N /ha to achieve an early spring (August) response, even at the colder TH2 site. The scheduling of mid-winter N is discussed more fully in Section

a)

b)

c)

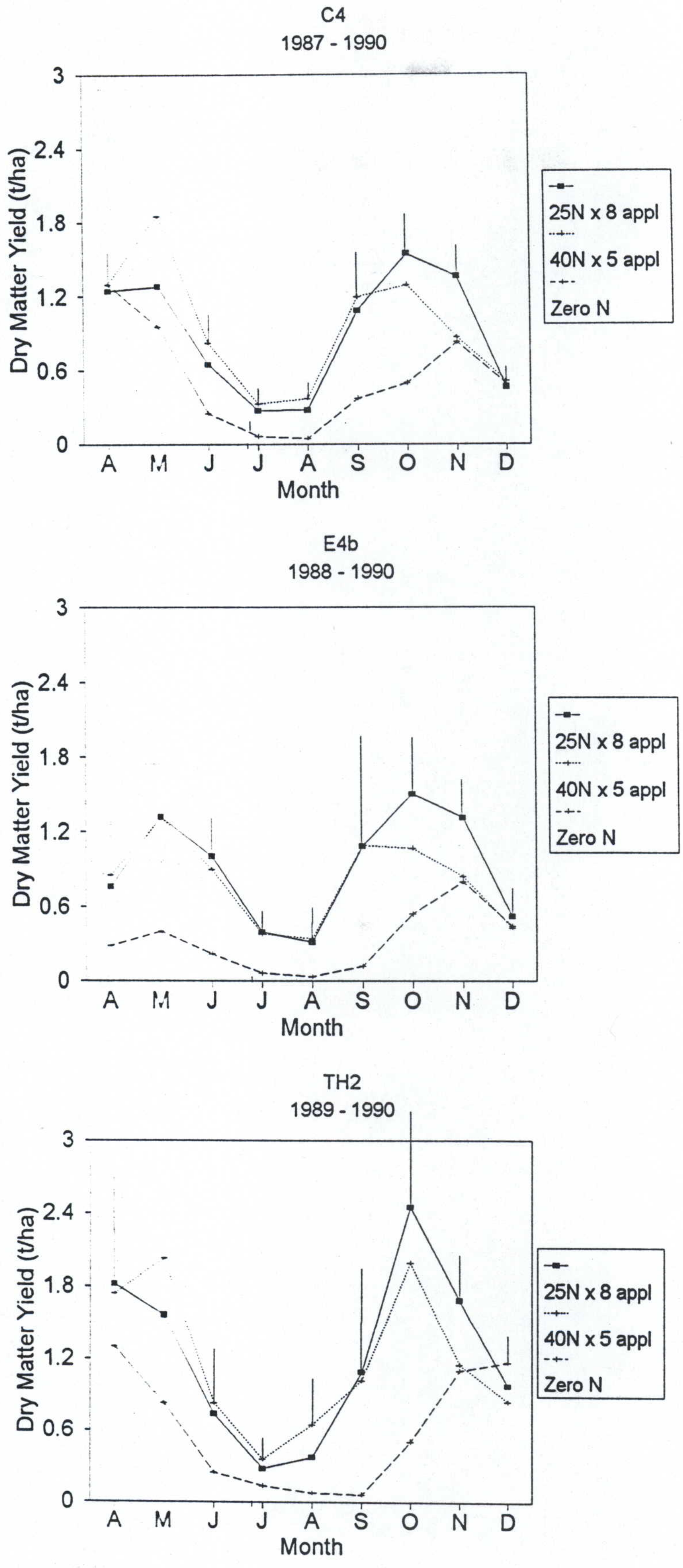

Figure 1.8 The monthly DM yield response of annual ryegrass to varying intervals of N fertilizer application, at an annual N fertilizer rate of 200 kg N /ha/yr. Data are presented for three sites and meaned over the relevant years. Significance levels (LSD 5%), not applicable to the zero N line, are indicated by the vertical bars.

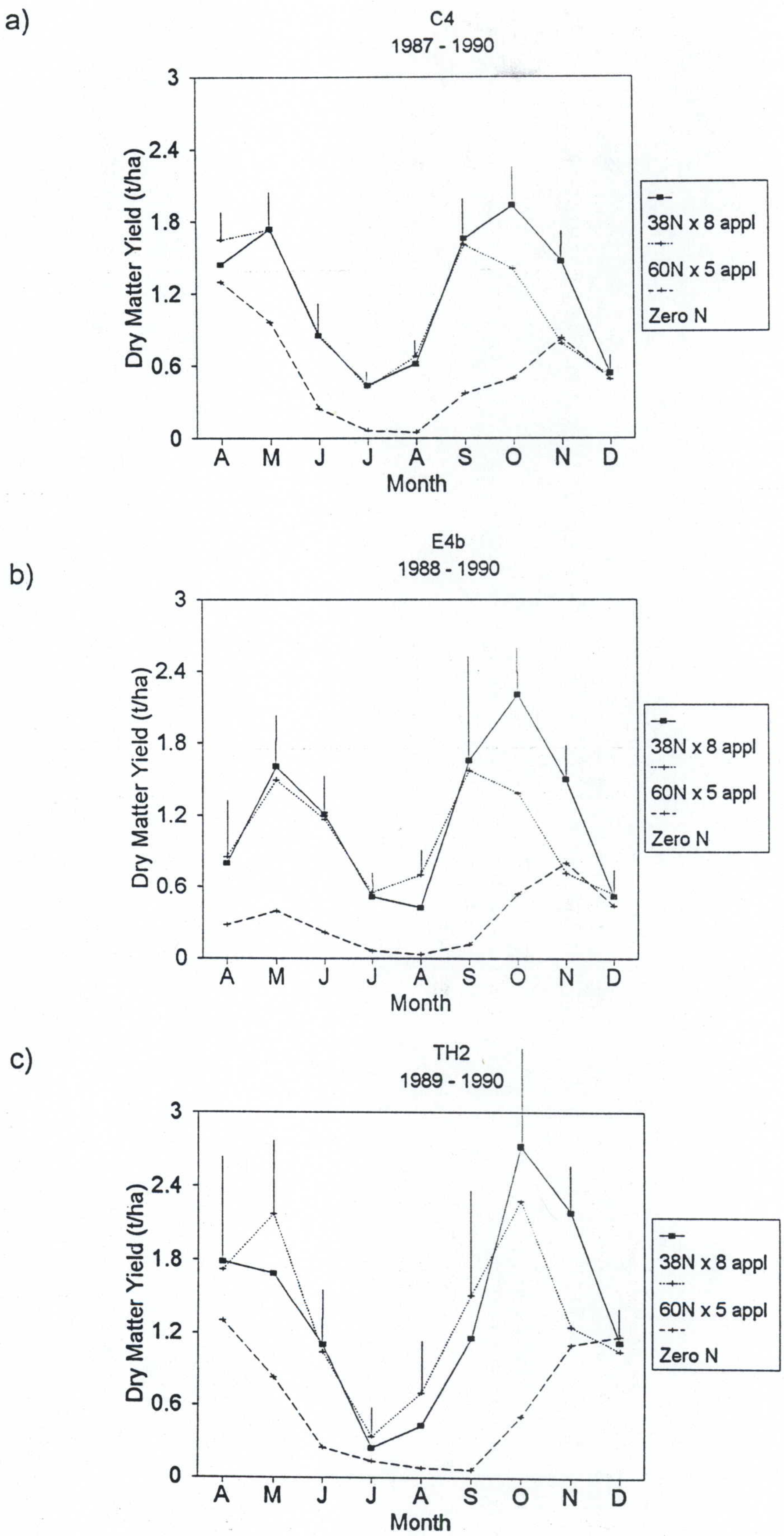

Figure 1.9 The monthly DM yield response of annual ryegrass to varying intervals of N fertilizer application, at an annual N fertilizer rate of 300 kg N /ha/yr. Data are presented for three sites and meaned over the relevant years. Significance levels (LSD 5%), not applicable to the zero N line, are indicated by the vertical bars.

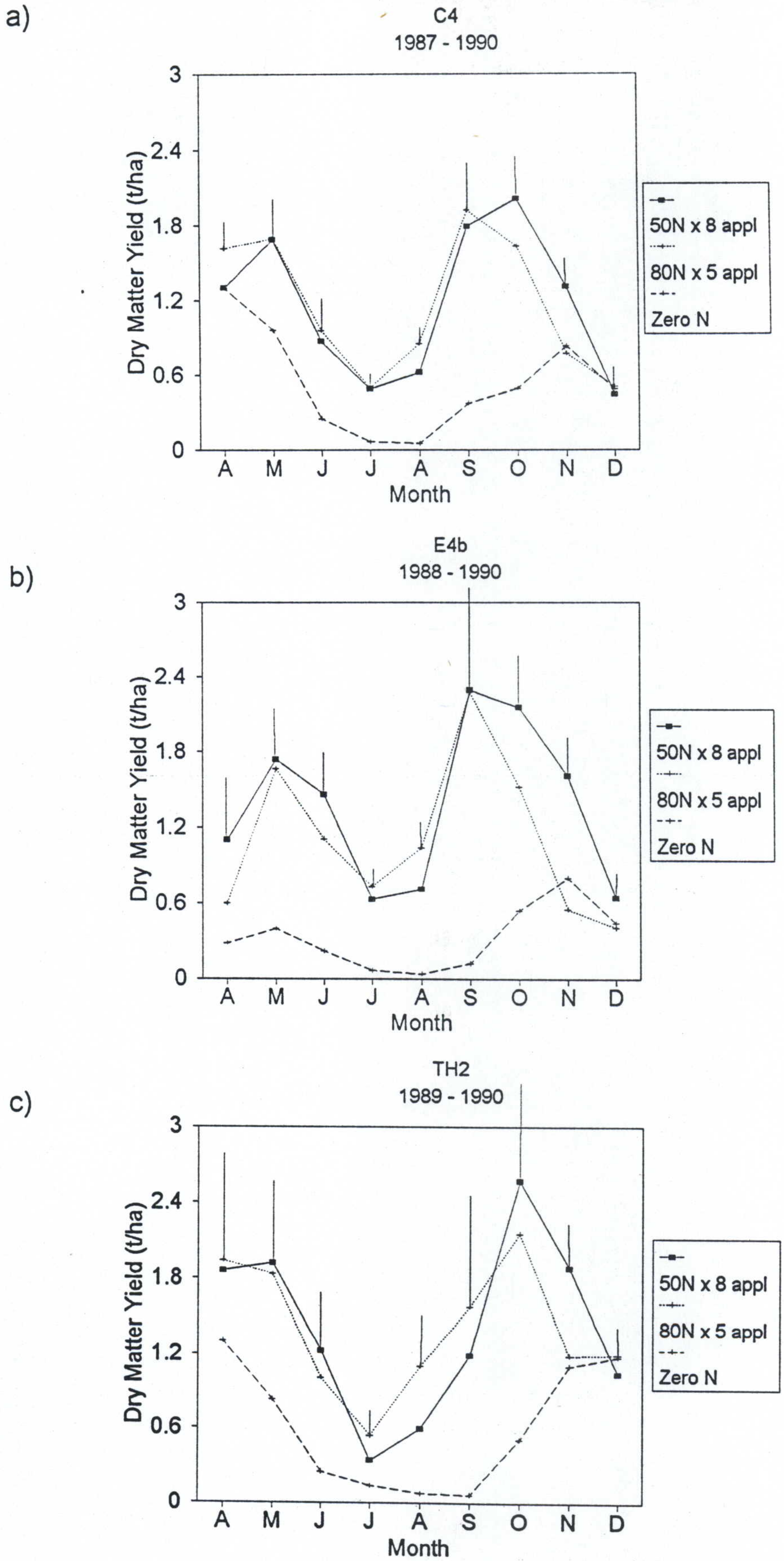

Figure 1.10 The monthly DM yield response of annual ryegrass to varying intervals of N fertilizer application, at an annual N fertilizer rate of 400 kg N /ha/yr. Data are presented for three sites and meaned over the relevant year. Significance levels (LSD 5%), not applicable to the zero N line, are indicated by the vertical bars.

II, 4.

In late spring (October and November), the 4-weekly schedule produced superior yields on all sites and over all N rates (Figures 1.8, 1.9 & 1.10). These differences were significant ($P<0.05$) in many cases. The above trends may be explained by the specific timing of N fertilizer top-dressings. The last two N top-dressings of the 6-weekly N schedule (5 applications), were applied in July and 6 weeks before the seasonal peak (between August and September). It would appear, therefore, that the last 6-weekly N top-dressing (2 weeks before the September harvest) did not have sufficient residual effect after the September harvest to promote the level of regrowth achieved by the 4-weekly schedule. This evidence further supports the earlier statement that N fertilizer, applied to irrigated ryegrass during active pasture growth, will have little residual effect after the first post-application harvest (Brockman 1966), with excessive free N in the soil being lost from the root profile, mainly by leaching, or being bound up in the soil organic matter (Olsen & Kurtz 1982; Anslow & Robinson 1986).

In comparing the N schedules over the three rates of N (Figures 1.8, 1.9 & 1.10) in the spring period, applications between 38 (Figure 1.9) and 50 (Figure 1.10) kg N/ha produced high DM yields. It would appear, therefore, that to optimise spring production, N must be applied after each harvest (4-weekly) and at rates not exceeding 50 kg N/ha per application.

3.4 Conclusions

The results highlight the need for careful planning of N application schedules for irrigated annual ryegrass pastures, in order to economically justify management decisions.

From the data presented it is recommended that, to ensure that annual ryegrass yields are not restricted by a lack of N, 40 kg N /ha be applied at seedling emergence (±2 weeks post-planting), with a second application 4 to 6 weeks later. Thereafter, 40 to 50 kg N /ha should be applied on a 4-weekly cycle from July till October. This schedules compliments the 28 day recommended grazing cycle for annual ryegrass (8 camps system, 3.5 days in each camp; Bartholomew 1985). Nitrogen fertilizer applied in excess of these rates appears to be lost, perhaps through leaching, and may be cause for both environmental and economic concern. In addition, excess N taken up by the pasture may be toxic to ruminants (cf. Section II, 2).

With the increase in environmental concern over nitrate leaching from intensive pastures and the potential toxicity of the herbage to livestock, the application of large infrequent N top-dressings is questionable.

4 The dry matter yield response of midmar ryegrass (*Lolium multiflorum*) to varying nitrogen fertilizer application strategies II. The efficiency of winter nitrogen top-dressings

4.1 Introduction

Annual ryegrass (*Lolium multiflorum* Lam. cv. Midmar) pastures are widely utilized by livestock farmers in Natal to supply winter forage. In the case of annual ryegrass N fertilizer and irrigation remain the only management options available to increase cool season production. In contrast to temperate climates, where most pasture production ceases through the winter period (Anslow & Green 1967), annual ryegrass pastures are grazed throughout the winter period under the sub-tropical conditions of Natal. At higher altitudes, however, these pastures may be dormant for a period of up to 6 to 8 weeks during winter (June and July).

Where pasture growth is restricted by low temperatures in winter, the reduction or complete withholding of N fertilizer applications, during the mid-winter period, might be cost-effective. In addition, the application of N fertilizer to an irrigated pasture in excess of the plants immediate regrowth requirements, may result in substantial losses of N due to leaching (Olsen & Kurtz 1982; Anslow & Robinson 1986). This will not only reduce the profitability of these pastures, but will increase the possibility of a proportion of the N reaching ground waters (Miles & Manson 1992). It is important, therefore, that research provide the producer with guidelines to assist N fertilizer management planning.

In Section II, 3.3 (page 31) a marked yield response was noted in early spring (August) where N fertilizer was top-dressed in late July. By contrast, unfertilized treatments appeared to respond later, presumably in response to increased N mineralization, induced by increasing soil temperatures (Olsen & Kurtz 1982). These data emphasise the importance of applying N fertilizer in anticipation of the rise in early spring temperatures, while ensuring that this application is not so premature that N is lost through leaching before being utilized by the pasture.

The obvious questions that remain, therefore, are: with the onset of winter, when should N fertilizer applications cease and, in anticipation of spring, when should the first spring dressing of N fertilizer be applied? The aim of the current investigation was to provide winter N fertilizer management guidelines for annual ryegrass pastures.

4.2 Methods

Data were extracted from selected trials described under Section II, 1.2, namely the C4 site (1987 to 1990), E4b (1988 to 1990) and TH2 (1989 to 1990) (Table 1.3; page 14). Data were subjected to analysis of variance, based on the factorial design, with years included as an additional factor. Presented data, therefore, represent the means over the years indicated.

4.3 Results and discussion

Annual total yields

The effect of withholding N fertilizer top-dressings in May (for June growth) and June (for July growth) on the annual total DM yield of annual ryegrass is presented in Table 1.4. Although the trend was for lower yields from the NW treatments at the E4b site, this was not significant. The NW treatment at the colder, higher altitude site (TH2) produced a consistently higher yield, although non-significantly ($P>0.05$) so, than the 4-weekly treatment at all N rates. These trends would be expected, as low temperatures at the TH2 site would limit growth for a longer period during winter than at the Cedara sites (C4 & E4b). As the ryegrass at the Cedara sites (E4b & C4) was able to grow during the winter period, the withholding of two N top-dressings was reflected in reduced annual total yields (Table 1.4).

Table 1.4. The effect of withholding winter N top-dressings on the annual total DM yield (t/ha) of annual ryegrass at three sites. Significance levels (LSD's) are not applicable to comparisons with the zero N level

Site	N rate (kg N /ha/yr)	N Schedule 4-weekly	NW[1]	LSD 5%	1%
C4 1987/90				0.880	1.280
	Zero	4.95			
	200	8.16	8.67		
	300	10.65	9.63	*	
	400	10.50	10.73		
E4b 1988/90					
	Zero	2.89		1.520	2.300
	200	8.20	7.04		
	300	10.43	9.95		
	400	12.33	10.46	*	
TH2 1989/90				2.386	3.958
	Zero	5.44			
	200	10.98	11.95		
	300	11.31	12.72		
	400	11.02	11.87		

NW[1] = 4-weekly application excluding two winter applications

The data in Figures 1.11a, b and c show the effect of withholding N applications during the winter months on the seasonal DM yield response of annual ryegrass at the C4, E4b and TH2 sites, respectively, for the higher N application rates. The data are shown for the zero N, 4-weekly at 400 kg N/ha/yr (50 kg N/ha/application), NW at 300 kg N/ha/yr (50 kg N/ha/application) and NW at 400 kg N/ha/yr (67 kg N/ha/application) treatments, thus allowing direct comparison of equal annual and equal per-application N rates to the 4-weekly rates (Table 1.3, page 14).

Winter yields

Where N was not top-dressed during June and July, significantly ($P<0.05$) lower yields were obtained at both Cedara sites (C4 & E4b, Figure 1.11). At 400 kg N /ha/yr on the C4 site the yield reduction resulting from no winter N applications, relative to the 4-weekly schedule, was 290 and 384 kg DM/ha, for June and July respectively. At 400 kg on the E4b site, withholding N during the winter resulted in yield reductions of 876 and 526 ($P<0.05$) kg DM /ha in June and July respectively. No significant yield differences ($P>0.05$) were noted between the treatments in the TH2 site through the winter, although the June yields were 429 kg DM /ha greater at the 400 kg N /ha/yr rate

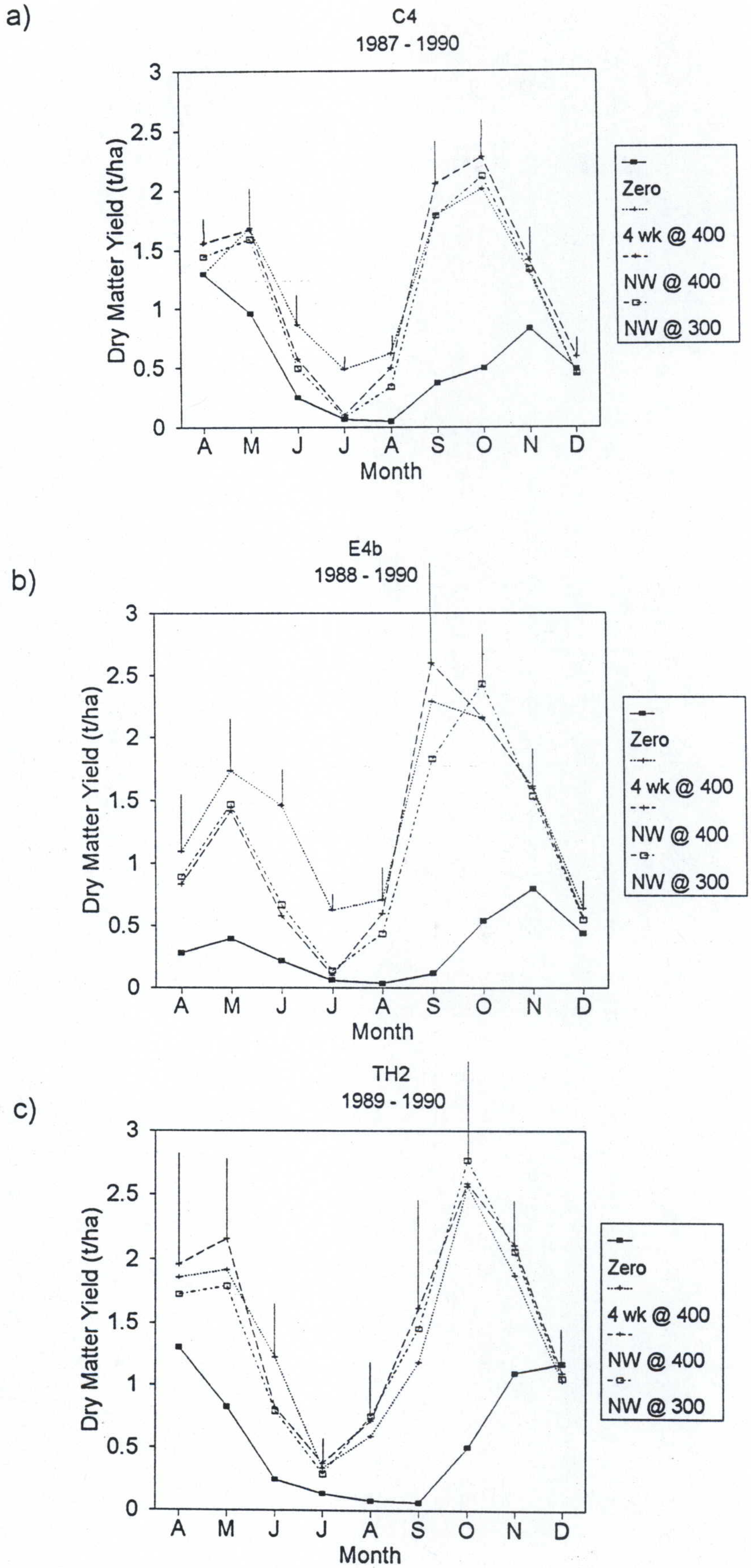

Figure 1.11 The monthly DM yield response of annual ryegrass to N fertilizer top-dressed 4-weekly (4WK @ 400 kg N /ha/yr = 50 kg N /ha/application), or 4-weekly with no winter (NW @ 300 kg N /ha/yr = 50 kg N /ha/application & NW @ 400 kg N /ha/yr = 67 kg N /ha/application) (May & June) top-dressings. Data are presented for three sites and meaned over the relevant years. Significance levels (LSD 5%), not applicable to the zero N line, are indicated by the vertical bars.

where N was top-dressed in May (4-weekly), relative to treatments receiving no N fertilizer.

The above data show that winter N top-dressings on annual ryegrass pastures at Cedara may provide between 674 (C4) to 1,402 (E4b) kg DM per hectare over the June/July period. This extra DM produced through winter may prove vital to the winter fodder supply.

On the other hand, the application of winter (July) N fertilizer at the Thabamhlope site would be wasteful, particularly in the absence of any 'carry-over' effect on spring growth (Figure 1.11c). Nitrogen top-dressed in the winter period must have been lost from the system, possibly through leaching of N beyond the root profile by the continued irrigation (Olsen & Kurtz 1982). This loss of N has important bearing on economic use of N in cold sites and on the potential nitrate pollution hazard of applying N that is not utilized by the pasture. The precise fate of N fertilizer applied under these conditions requires further investigation.

To illustrate the efficacy of mid-winter N top-dressings, N fertilizer response curves for the June and July months are presented in Figure 1.12. At both the Cedara sites (C4 & E4b; Figures 1.12a, b, c & d) the 4-weekly N schedule produced higher yields in both June and July, significant ($P<0.05$) in all but the 200 kg N /ha rate in June on the C4 site. Although non-significant, the June harvest of the TH2 site (Figure 1.12e) showed a potentially important response to increasing rates of N fertilizer, with the NW schedule yielding 429 kg DM /ha less than the 4-weekly schedule at 400 kg N/ha/yr. In contrast, however, low mid-winter temperatures (Figure 1.13) would have reduced soil temperatures substantially by July, thus being an over-riding factor limiting growth at the TH2 site (Figure 1.12f), resulting in a total lack of yield response to the application of N fertilizer in July.

Although the E4b site was considered to be colder than the C4 site at Cedara, it remained the more responsive through the winter period, perhaps due to a higher water table of this bottomland (poorly drained) soil. Nitrogen was possibly less subject to leaching and moisture conditions were better at this site than at the upland (C4) site. These data emphasise the importance of identifying differences between sites and the need to optimise N management accordingly *i.e.* due to the greater N

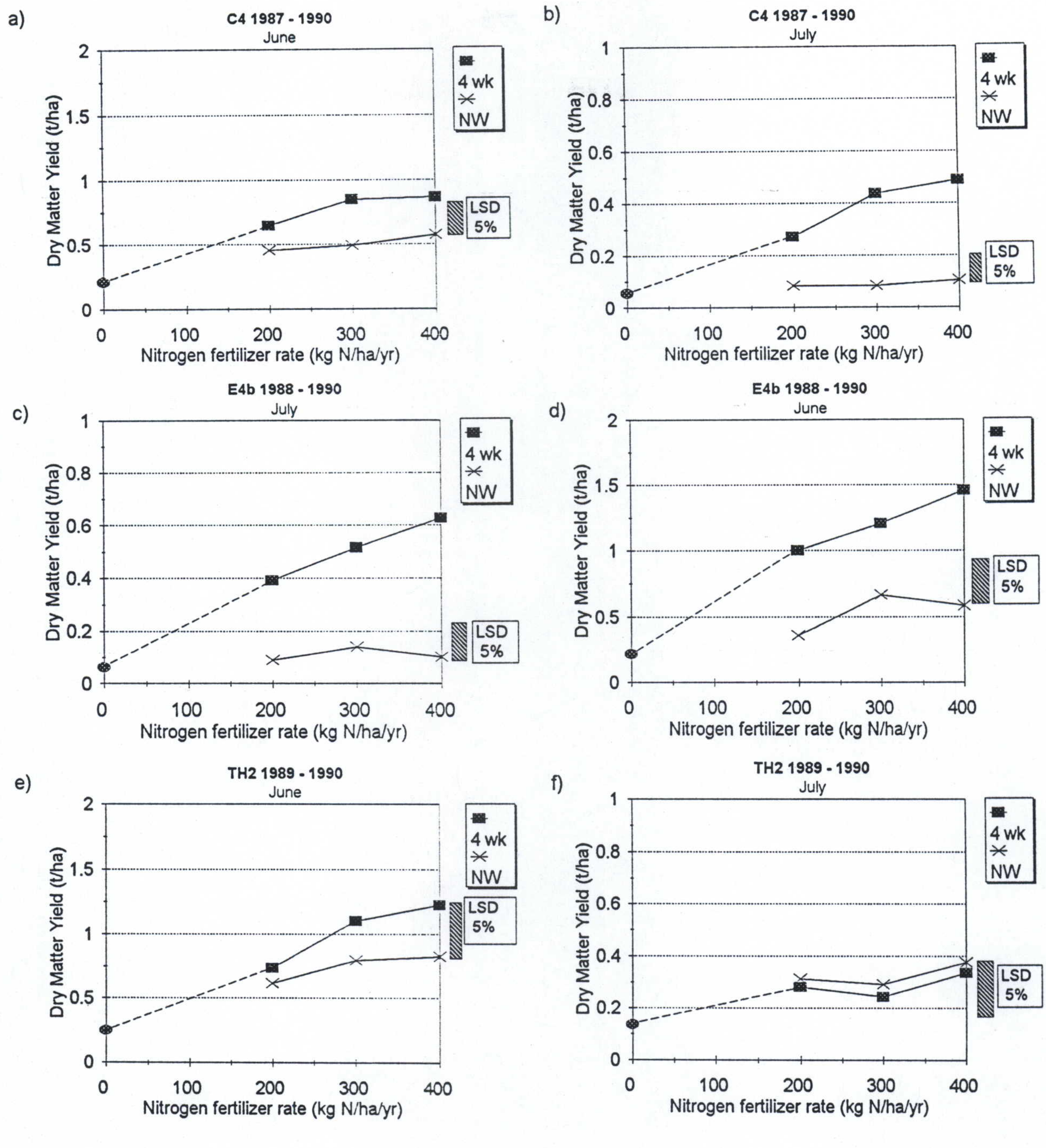

Figure 1.12 The June and July DM yield response of annual ryegrass to varying rates of N fertilizer top-dressed in June (a, c & e) and July (b, d & f). Data are presented for three sites (C4:a & b; E4b: c & d; TH2: e & f) and meaned over the relevant years. Dotted lines link to zero N level as these were not included in the analysis of variance.

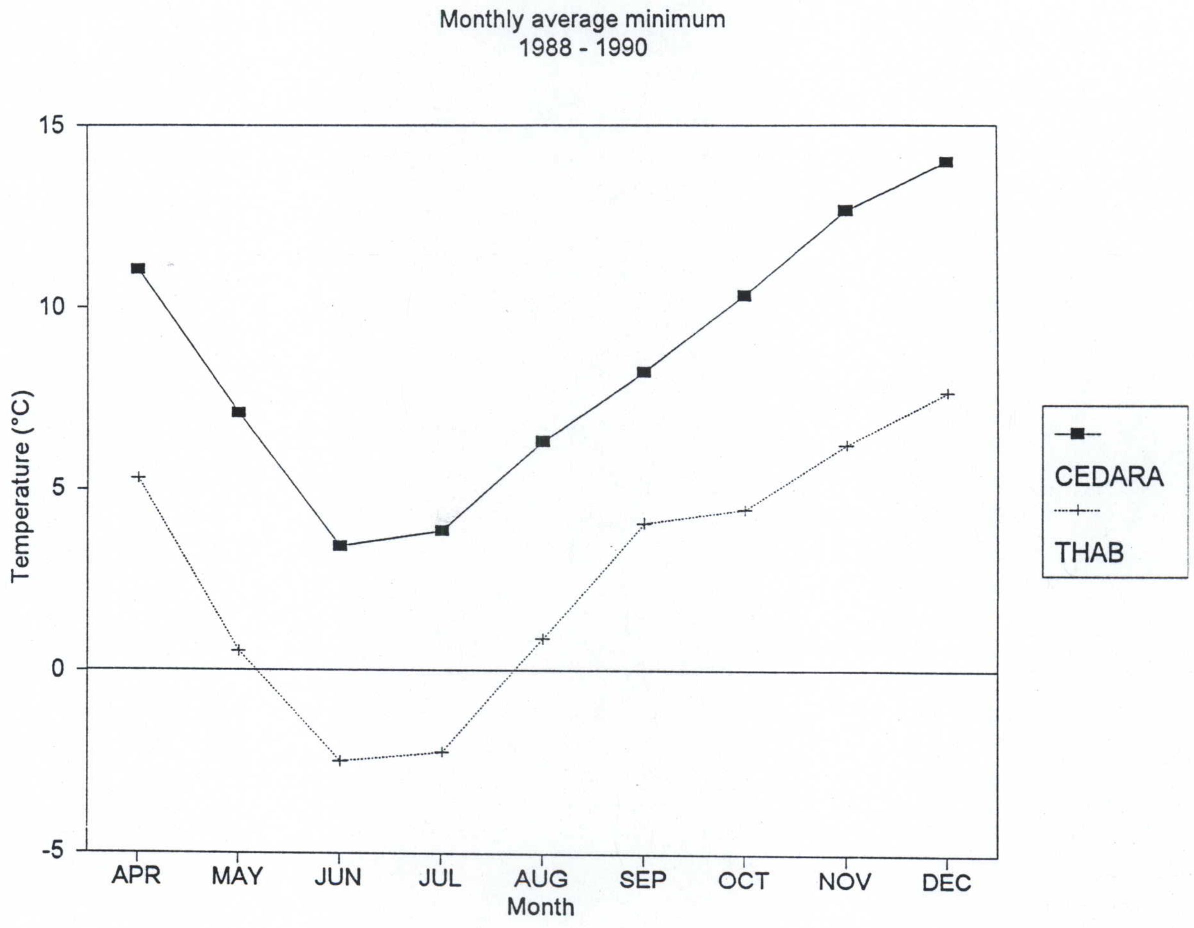

Figure 1.13 The monthly average minimum (Stevenson screen) air temperatures recorded at the Cedara and Thabamhlope research stations, meaned over the years for which trials were conducted.

response observed at the E4b site, it may be more economical to apply 50 kg N /ha to the E4b site in June, than 25 kg N /ha to each of the C4 and E4b sites.

From the data presented in Figure 1.12, it appears that somewhere between the two Cedara sites (C4 & E4b) and the Thabamhlope site (TH2) is a mid-winter (July) temperature 'cut-off' point, below which annual pastures are no longer able to respond to top-dressed N. Based on a subjective comparison between the monthly average minimum air temperatures (Stevenson screen, Figure 1.13) and the seasonal growth patterns presented in Figure 1.11, it appears that annual ryegrass pastures no longer respond to N fertilizer once the minimum air temperatures are consistently (5 to 7 days) below approximately 0°C. This result may provide farmers in these colder regions with a simple method by which to determine a N fertilizer 'cut-off' date.

Early spring yields

Treatments receiving N fertilizer from July onwards produced noticeably higher yields in early spring than the zero N control (Figure 1.11). As early spring is usually a period of critical forage shortage, the timing of this N application is critical. If free N is not available in the soil, this early growth potential may be lost. However, if this N fertilizer is top-dressed too early it may be leached (van Burg *et al.* 1980; Olsen & Kurtz 1982). In order to ensure efficient use of N fertilizer the producer would need some means of ensuring that this late-winter/early-spring N is applied at the correct time.

Numerous researchers in temperate regions of the northern hemisphere have reported that grass begins growth in spring when the sum of the average daily temperatures above 0°C, recorded from the 1st January, reaches 200. This technique is referred to as Temperature-sum 200 (T-sum 200) (Garstang 1980, Postmus & Schepers 1980, Sandford 1980, van Burg *et al.* 1980). Located in the southern hemisphere, the T-sum was calculated for each experimental site from the 1st of July. The average T-sum (200) dates for Cedara and Thabamhlope were the 18th (range: 17th to 19th) and 27th (range: 25th to 30th) of July, respectively. For the Thabamhlope site, this matches closely the date derived from the data in Figure 1.11 when ryegrass begins to respond to N fertilizer in early spring. The T-sum calculation is not applicable to the Cedara sites as the pastures were not dormant through the winter period.

4.4 Conclusions

The data presented emphasise the importance of judicious planning of winter N fertilizer management in order to maximise winter pasture growth, while reducing N fertilizer wastage. To achieve this a producer should attempt to identify lands of high or low yield potential and winter temperature extremes, based *inter alia* on historical records, aspect, slope, altitude and soil type.

Where the minimum air temperatures (Stevenson screen) are consistently (5 to 7 days) below 0°C, there appears to be no yield benefit to top-dressing N fertilizer to irrigated annual ryegrass pastures. Nitrogen fertilizer top-dressed to winter-dormant pastures is likely to be to leached and thus potentially wasteful. In the light of increased environmental concern, with regard to nitrate leaching into ground waters, and the high cost of N fertilizer, such N fertilizer applications should be avoided.

However, where annual ryegrass pastures are not dormant during the winter months (Cedara sites) they will respond to top-dressed N fertilizer in the middle of winter (June or July). These sites would generally be those on which the weekly average minimum air temperatures remain above 0°C. On these sites, annual ryegrass appears to respond to N fertilizer up to an application rate of 37.5 kg N/ha. On more productive sites, such as wet bottomlands, the pasture may respond to still higher levels of top-dressed N (50 kg N/ha), provided that temperatures remain above 0°C.

The T-sum (200) technique may provide a useful guide for the determination of the date for the first post-winter N top-dressing for winter-dormant pastures. Based on the T-sum calculation, the last week in July (27th) appears to be a reliable recommendation for the colder, higher altitude regions of Natal. The T-sum technique warrants further investigation and validation.

SECTION III

GRAZING TRIALS ON IRRIGATED *Lolium multiflorum*, *L. perenne* AND *Festuca arundinacea*, WITH AND WITHOUT *Trifolium repens*

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1 The nitrogen requirements of grazed annual ryegrass (*Lolium multiflorum* cv. Midmar)/clover (*T.repens*) pastures

1.1 Introduction

Annual ryegrass/clover

Irrigated annual ryegrass has the potential to produce up to 1,400 kg beef per ha over a 210 day period (Bartholomew 1985), 16 kg of 4% fat corrected milk per day and 27 kg of 4% fat corrected milk per day by the addition of 10kg of concentrates (Bredon & Stewart 1978).

However, it is expected that even higher levels of animal production may be achieved by the addition of a clover component to the pasture (Bartholomew 1985; Smith 1987). Besides the improved animal performance obtained from the inclusion of a clover component, clover could prove valuable in extending the grazing season into mid-summer and in improving the declining animal performance recorded as the annual ryegrass goes to seed (Bartholomew 1985). Subsequent to the study by Bartholomew (1985), these suggestions have been proven in grazing trials on Cedara (unpublished data; [1]Bartholomew pers. comm. 1993). White clover sown with annual ryegrass makes very little initial contribution to the overall pasture, particularly at higher rates of N fertilizer. However, once the annual ryegrass sets seed (November/December), the clover tends to predominate through the summer, thus extending the potential grazing season through the provision of high quality forage.

Nitrogen inputs through symbiotic N fixation vary appreciably with locality. In swards managed to maintain a high legume content estimates of symbiotic N inputs range from 74 to 280 kg N/ha/yr for lowland sites in the United Kingdom and from 85 to 342 kg N/ha/yr for pastures in New Zealand (Ball & Ryden 1984). These data appear to concur with local data, where estimates range between 100 to 200 kg legume-derived N/ha/yr for white clover, with red clover estimates more in the region of 100 kg legume-derived N/ha/yr (Cross 1980).

A problem associated with high inputs of N fertilizer is the

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[1]Cedara Agricultural Development Institute, P. Bag X9059, Pietermaritzburg, 3200.

suppression of the clover component (Strijdom 1979; Mundy & Jones 1984; Ball & Field 1987). This suppression of clover appears to be less severe in New Zealand than in Europe (Ball & Field 1987). However, due to the differences in the literature cited from New Zealand and Europe, these suppressive effects of N on clover need to be quantified under local conditions.

Cutting trials versus grazing trials

To date most pasture fertility studies in Natal have been conducted under a cutting regime, with results being used in grazing system recommendations (Bartholomew & Miles 1984; Miles, Eckard & de Villiers 1991; Section II). Relative to mechanical harvesting, grazing animals exert a variety of influences on pastures, both beneficial and deleterious. Due to the significant effect of animal dung and urine, selective grazing and trampling on the growth of a pasture, it is important that N calibration trials be conducted under grazing where applicable (Ball 1979). Jackson and Williams (1979) reported that, "cutting experiments cannot be used to predict herbage yields and responses to fertilizer N under grazing conditions". Estimates vary between 100 kg N ha/yr (Baker 1986) and 200 kg N ha/yr (Jackson & Williams 1979) more N required under cutting than under grazing. The differences between cutting and grazing have been extensively reviewed (Ball 1979; Baker 1986).

N fertilization strategies for grass/clover pastures

In a mixed grass/legume sward the clover N contribution is generally insufficient to achieve maximum grass production (Miles & Bartholomew 1991). In a review of New Zealand grasslands, Ball and Field (1987) stated that in the absence of N fertilizer inputs, temperate perennial grass/clover pastures would be in a negative N balance. This negative N balance would be due to both the high N requirements of the grass and the seasonal growth pattern of white clover. In Natal white clover exhibits a bimodal seasonal growth pattern. White clover yields are highest in spring, followed by a mid-summer yield depression, with yields rising through the autumn (Brockett *et al.* 1979). With the winter production of white clover being negligible, N-fixation potential is limited to the warm season of the year. The producer thus has three options:

a) plan for a low or zero N pasture system (*i.e.* legume based), accepting lower grass production and thus lower animal production per hectare;

b) aim for maximum grass production through adequate N fertilization, disregarding the N contribution of the clover, or

c) strategically supplement the pasture, at selected times of the year, with sufficient N to cover the N shortfall, yet hopefully not suppressing the ability of the clover to fix N.

Of these three options, the third option appears to be the most profitable and promising. In order to plan the N fertilizer management it is necessary to identify N deficient periods. A model of the potentially N-deficient periods of the year is presented in Figure 2.1. These data are based on perennial ryegrass growth curve data (unpublished data) and the hypothetical supply of N from clover.

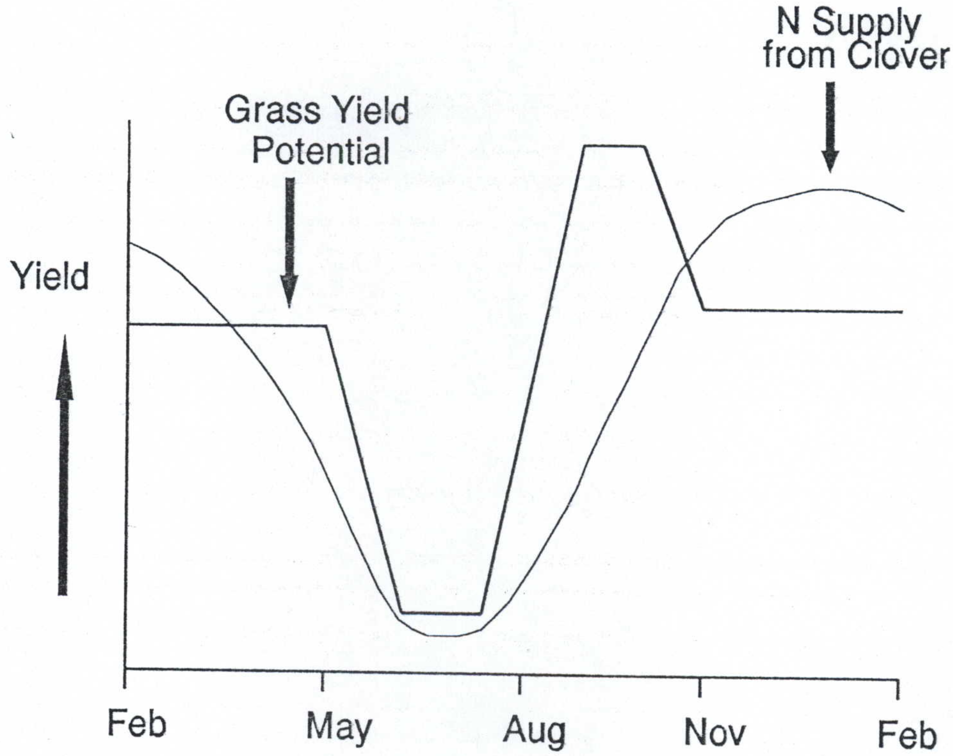

Figure 2.1 The potential seasonal nitrogen supply from white clover when grown in combination with a temperate grass.

Using the model in Figure 2.1 as a basis in order to implement option c) above, N fertilizer should be applied only between April and October *i.e.* the cool season when clover growth is limited by lower temperatures.

The objectives of the current investigation were: to determine the nitrogen requirements of grazed annual ryegrass (*Lolium multiflorum*), with and without white clover (*Trifolium repens*), and to estimate the contribution of the clover component to overall pasture yield and quality.

1.2 Methods

The methods described in this section apply to all the grazing trials mentioned in Section III, namely *Lolium multiflorum, L. perenne* and *Festuca arundinacea,* in combination with *Trifolium repens*.

Site and soil description

Two grazing trials were located on a level, midslope site on the Cedara Research Station (29°32'S & 30°17'E; altitude 1,067m, mean annual rainfall 885mm and pan evaporation 1,478mm) in the Natal Mistbelt (Phillips 1973). A perennial ryegrass (*Lolium perenne* cv. Yatsyn 1) /clover (*Trifolium repens* cv. Ladino) and a fescue (*Festuca arundinacea* cv. Demeter) /clover pasture were established on adjacent lands, referred to as C4a and C4b respectively. The entire C4 land was previously an *Eragrostis curvula* hay pasture. The C4a land was planted to an annual ryegrass cutting trial and Jap radish for one year each prior to experimentation, during which time the C4b land was used for Midmar ryegrass (*Lolium multiflorum* cv. Midmar) breeder seed production.

The soils were predominantly of the Bainsvlei form (orthic A/ red apedal B/ soft plinthic B) and Brandkraal family (mesotrophic, non-luvic B1 horizon; clay-loam) according to the Soil Classification Work Group (1991) system. Soil nutrient (P, K, Ca, Mg, $Al+H^+$ and Zn) status and pH were analysed by standard Hunter methods (Farina 1981). Clay content was determined by the pipette method after dispersion with an ultrasonic homogeniser. Soil nitrogen was analysed by kjeldhal (AOAC 1980) and organic carbon by the Walkley-Black method. Results of the analysis of the experimental soils prior to establishing the trials are listed in Table 2.1.

Table 2.1 Selected soil properties of the lands prior to establishment. Sites 1 and 2 represent samples taken from half of each trial site. Samples were taken to a depth of 15cm.

Trial	Sample density	Organic carbon	Clay	P[a]	K	Ca	Mg	Acidity (Al+H)	Total cations	Acid Sat	pH (KCl)	Zn[a]
	g/ml	---- % ----		-------- mg/l --------				--- cmol/l --		- % -		mg/l
C4a												
site 1	0.95	2.49	43	6	49	1042	310	0.06	7.93	0.8	5.30	1.7
site 2	1.01	2.18	39	10	80	958	198	0.25	6.86	3.6	4.60	0.8
C4b												
site 1	0.97	2.44	42	11	182	763	201	0.22	6.14	3.6	4.66	0.5
site 2	0.99	2.30	41	13	176	778	189	0.32	6.20	5.2	4.51	0.9

a - NH_4HCO_3/EDTA/NH_4F extraction

Land preparation

The sites were disced for initial preparation, lime being incorporated where recommended, and again for the incorporation of basal fertilizer dressings prior to planting. Based on initial soil analyses of the sites (Table 2.1), nutrients, other than N, were supplied in sufficiency to all plots. Initial N dressings were applied, according to treatment, at seedling emergence. Soil nutrient status was monitored every 6 months, with deficiencies being corrected, on an individual plot basis, according to the Cedara Fertilizer Advisory Service.

The lands were planted and subsequently rolled with a Cambridge roller. On the 6th of March 1991 the seed was planted using a Connor-Shea planter, with row width and seeding rate settings of 150mm and 20-25 kg seed/ha, respectively, for both the perennial ryegrass and tall fescue. The white clover (*Trifolium repens* cv. Ladino) was planted on the same day as the grass seed, using a broadcast-roller (Brillion), at 3 kg seed/ha.

Irrigation, supplemental to rainfall, was supplied to ensure a minimum application of 25mm of water per week.

Trial design and treatments

Subsequent to planting and prior to seedling emergence, the trials were laid out on the land. Treatments were based on a completely randomised design, with four replications of each treatment. In the first year (1991) four nitrogen treatments were imposed on a mixed grass/clover pasture, as detailed in Table 2.2a. In addition a zero N pure clover and a 450 kg N/ha/yr pure grass treatment were included in each replicate. The grass/clover plots received 6 equal top-dressings of N (25, 50 and 75 kg N/ha/application for the three N fertilizer rates respectively) from seedling emergence (25/03/91) to October, while the pure grass received an additional two N top-dressings through the summer period (75 kg N/ha/application x 8 = 600 kg N/ha/yr). The C4b (tall fescue) trial failed to establish due to the successful germination of a heavy seed load of annual ryegrass remaining from the breeder seed unit. Annual ryegrass was assessed as making up more than 90% of the grass component. It was, therefore, decided to conduct the trial on an annual ryegrass/clover sward for one year (1991) and to re-establish the trial to tall fescue for the next year. For the purpose of this investigation the data from the pure clover (N0C) and pure grass (N450G) treatments were excluded.

Table 2.2a Treatment combinations and designations for the perennial ryegrass (C4a) and annual ryegrass (C4b) trials for the 1991 growing season.

Nitrogen rate	Pasture composition		
(kg N/ha/yr)	Pure clover	Grass/clover	Pure grass
0	N0C	N0M	
150		N150M	
300		N300M	
450		N450M	N450G

Nitrogen top-dressings, in the form of limestone ammonium nitrate (28% N), were applied every 28 days on the C4b trial (both Midmar ryegrass and tall fescue) and every 35 days on the C4a trial, as these cycles complimented the animal grazing cycles (detailed later).

In the spring of 1991, the treatments were reviewed. The revised treatments are detailed in Table 2.2b. The revised treatments allowed N rates on the pure grass sward to be directly compared with those applied to the grass/clover swards for the March to October period. The pure grass plots then received the balance of their N top-dressing through the summer period. In Figure 2.2 the specific top-dressings applied to the N420M and N600G are presented as an example.

Table 2.2b Nitrogen topdressing combinations and treatment designations for the C4a and b trials, based on 7 equal applications (March to October) for the mixed grass/clover and 10 equal applications (March to February) for the pure grass sward.

Mixed Grass/Clover			Pure grass		
Treatment	(kg N/ha/yr)	N rate per application	Treatment	(kg N/ha/yr)	N rate per application
N0M	0	0			
N105M	105	15	N150G	150	15
N315M	315	45	N450G	450	45
N420M	420	60	N600G	600	60

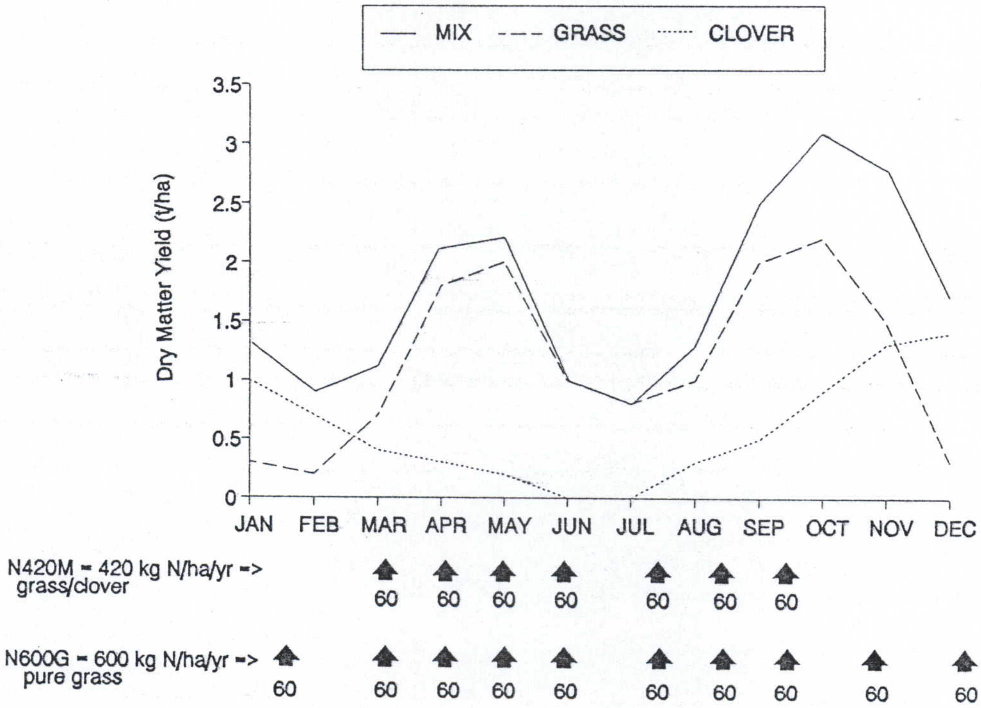

Figure 2.2 A diagrammatic representation of the nitrogen fertilizer application strategies, applied to ensure monthly as well as annual comparisons between N fertilizer rates. The arrows indicate the N fertilizer application times. Dry matter yield data represent the mean of numerous previous studies at Cedara (unpublished data).

The revised treatments were imposed on the C4a trials in spring (1991), and the C4b trial when it was reestablished to tall fescue on the 5th March 1992. The physical layout of the two sites is detailed in Appendix 1 and 2, with a map of the area in Appendix 3. The area of land planted, based on 5 sheep per treatment, was 140 x 106m (14,865 m^2) and 109 x 86m (9,422 m^2) for the ryegrass and fescue sites, respectively.

Camp sizes were designed to accommodate a minimum of five mature merino weathers per camp, using the replicates as camps in a rotationally grazed system. Animal numbers were adjusted at the start of each grazing cycle to ensure even pasture utilization over all treatments (approximately 8cm pasture height at the end of each grazing). At the start of each grazing cycle animals entered a 'pre-conditioning' replicate, thus ensuring that their rumens reflected the N status of the treatment. All sheep were colour coded, as were the treatments, to ensure that groups remained with their respective N treatment throughout the grazing cycle. Animals remained in each replicate for 3.5 days, thus allowing all sampling on either a Monday afternoon of Friday morning. Using the 17.5 day cycle recommended for perennial ryegrass (C4a), animals were able to remain on the trial for most of the year. However, the C4b trial (both the annual ryegrass and tall fescue) were grazed on a 28 cycle; animals were thus off the trial for 3 sets of 3.5 days before re-entering the preconditioning camps. All sheep were weighed (non-starved) at the start and end of each grazing cycle.

Total sheep grazing days were calculated, for each treatment and grazing cycle, as the product of the number of animals (corrected to a 60kg average) and the number of days spent grazing each hectare (Edwards 1981). Total grazing days represents the sum of the grazing days for each grazing cycle over the year.

Weed invasion was controlled by spraying 2*l* Basagran (Bendioxide; post-emergence) herbicide per hectare. Turfweeder (2,4-D: Dicamba: MCPA at 5*l*/ha) herbicide was sprayed, prior to animals entering the trial, in order to eradicate clover from the pure grass treatments.

Sampling

Herbage on offer and apparent intake was estimated using the pasture disc meter (Bransby & Tainton 1977). Fifty disc recordings were taken when animals entered a camp and again when they left a camp (3.5 days). The disk meter was calibrated by harvesting the herbage under every 10th recording. These cut samples were weighed before being separated into grass, clover and weed fractions. Each fraction was weighed before and after oven drying (90°C for 24hrs). All herbage samples were milled (1mm sieve) and stored in sealed plastic packets in preparation for chemical analysis.

Dry matter yield estimates were based on linear regressions between the disc meter and the herbage harvested from each plot. Due to the large sets of data collected, regressions were performed on numerous combinations of data sets, grouped largely on season and nitrogen treatment. The regressions used in the final estimates were based on grouping all data from all plots for each grazing cycle separately, as these proved to be the most homogeneous data sets.

Soil samples, to a depth of 15cm, were taken seasonally (4 per year) from all plots.

Analyses

Estimated DM consumed was calculated from the yield estimate (disc meter regression) as animals entered a camp, minus the yield remaining as the animals left that camp. Unfortunately, some of these estimates resulted in negative yields *i.e.* more yield remaining after grazing than before. However, it was decided to use these data based on the assumption that treatment differences would remain relative.

Using the Statgraphics 6.0+ software package, analysis of variance was used to identify significant treatment effects. Other comparisons were analysed and assessed by regression analysis. While presented LSD's (5%) relate to differences between treatment means, regression statistics apply to data points from each replicate *i.e.* n=16 for the grass/clover plots, and n=12 for the pure grass plots.

1.3 Results and discussion

Annual total yield

The response of a Midmar ryegrass/white clover pasture to varying N fertilizer treatments, under intensive sheep grazing, is presented in Figure 2.3. The estimated DM yield, removed by sheep from the grass/clover pasture, increased linearly ($P<0.05$) up to the 300kg N/ha/yr (April to October) rate, with a non-significant DM yield response to an additional 150 kg N/ha/yr (450 kg N/ha/yr).

The relationship between N fertilizer rate and estimated DM was best described by the quadratic function indicated on Figure 2.3, the curve-fitting problems encountered in Section II not being encountered in this case. However, due to the nature of a quadratic curve, the function should not be used to extrapolate beyond the

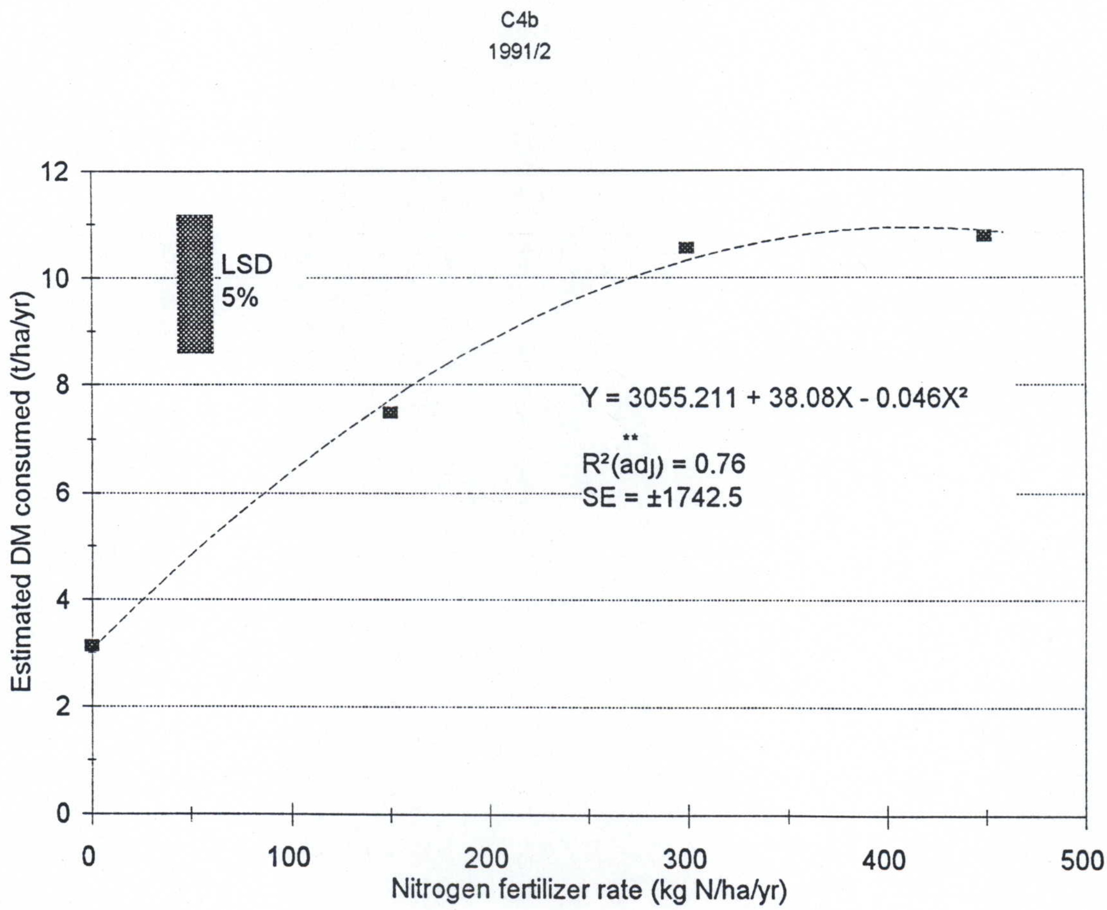

Figure 2.3 The annual total yield (estimated DM consumed) response of a grazed annual ryegrass/white clover pasture to increasing rates of N fertilizer. The dotted line represents the quadratic funtion.

observed maxima.

To determine the Y_{max} and Y_{10}, the integral of the quadratic function at 0 (Y_{max}) and 10 (Y_{10}) was calculated as follows:

$Y = aX^2 + bx + c$ ($a = -0.046$, $b = 38.08$ and $c = 3055.211$)

$dY/dX = 2ax + b$

Y_{max} is the point at which $dY/dX = 0$ and thus $X = -b/2a$

Y_{10} is the point at which $dY/dX = 10$ and thus $X = (10-b)/2a$

Using the above equations Y_{max} was estimated at 10.31 t DM/ha/yr, corresponding to an X_{max} of 381 kg N/ha/yr. The optimal N rate (X_{10}) was estimated at 281 kg N/ha/yr, corresponding to a yield of 9.81 t DM/ha. Using the technique employed in Section II (page 17 & 18), an X_{90} value of 260 kg N/ha/yr was estimated, corresponding to a Y_{90} of 9.7 t DM/ha/yr.

The average slope of the curve below the X_{10} point provides an estimated response of 25.2 kg DM/kg N applied. The slope of the curve provides an indication of the efficiency of N utilization, comparing favourably with the range of slopes calculated from the cutting trials (Section II, page 18; Eckard 1986). The data of Ehlig and Hagemann (1982) showed Italian ryegrass efficiency ratios of 27 kg DM/kg N for N rates up to 448 kg N/ha/yr.

The X_{10} data presented above provide estimates for optimal N fertilizer rates dissimilar to those derived from cutting trials (Section II). In Section II (page 18), optimal N rates from a cut annual ryegrass pasture were estimated to be between 300 and 350 kg N/ha/yr. Based on the difference between the cut and grazed studies, a cutting regime appears to over-estimate the optimal N application rate (X_{10}) by 30 to 90 kg N/ha/yr. However, the data in Figure 2.3 represents only the first year of a grazing regime and should be interpreted as such. It would be expected that, after a few years of intensive grazing, optimal N rates would be lower than 300 to 350 kg N/ha/yr. In practice it is recommended that, after a few years grazing, N rates be lowered by between 15 and 30% of the rate applied in the first year, to account for the N cycled through the grazing animal back to the pasture (cf. section II, page 19; Miles & Bartholomew 1987).

The data from the current trial emphasise the need for N fertilizer response studies to be conducted under a long-term grazing regime, treatments being re-imposed on identical plots regardless of annual re-establishment. However, cognizance must be taken of the limitations of data from one years (especially the first year) results from grazing trials.

Animal grazing days

Total sheep (corrected to 60 kg) grazing days per hectare were calculated for each N fertilizer treatment (Section III, 1.2, page 45) and are presented in Figure 2.4. A largely linear increase in grazing days/ha was noted, with the number of grazing days more than doubling from the 0 to the 450 kg N/ha/yr fertilizer rates.

Edwards (1981) warned that, unless linked to animal performance, grazing days may be of little value in evaluating pasture performance *i.e.* animals may have been losing weight at the 450 kg N/ha/yr rate while gaining weight at the lower N rates. Although the trial design provided no estimate of animal performance, the sheep maintained mass on all treatments over the duration of the trial.

The marked increase in grazing days, attainable by the addition of N fertilizer, further justifies the use of high rates of N fertilizer by the farming community as a means of pasture intensification.

Monthly yields

The estimated monthly DM consumed from an annual ryegrass/clover pasture is presented in Figure 2.5. Apart from the flush of growth in the spring period (September), the pasture responded positively to incremental rates of N fertilizer, significantly ($P<0.05$) so in many cases. This response was greatest during the peak growth periods (autumn and spring) and lowest in late winter (July) and the end of the growing season (October). In the spring period (September) no significant differences were noted between treatments receiving N fertilizer, although all the N fertilized treatments out-yielded the zero N (N0M) treatment (significant ($P<0.05$) in September). The clover content of the N0M treatment appeared to make little contribution to pasture yields at this stage. The application of 450 kg N/ha/yr (N450M), in six equal top-dressings of 75 kg N/ha, appeared to produce maximum DM yields from April to late-July. Over the month of August N applications of 50 kg N/ha/28 days (N300M) produced significantly ($P<0.05$) greater DM yields than 25 kg N/ha/28 days (N150M).

The grazing management of the trial required even pasture

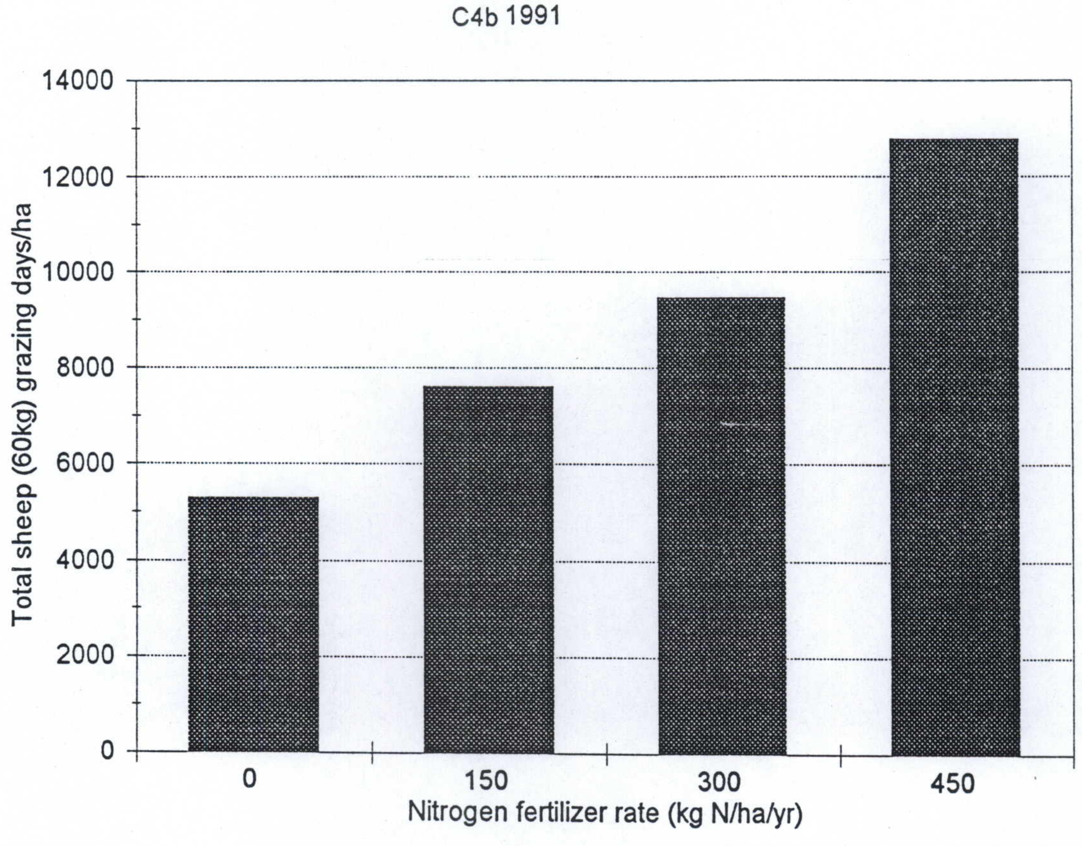

Figure 2.4 The effect of N fertilizer rates on total sheep (corrected to 60kg) grazing days per hectare, on an annual ryegrass/clover pasture.

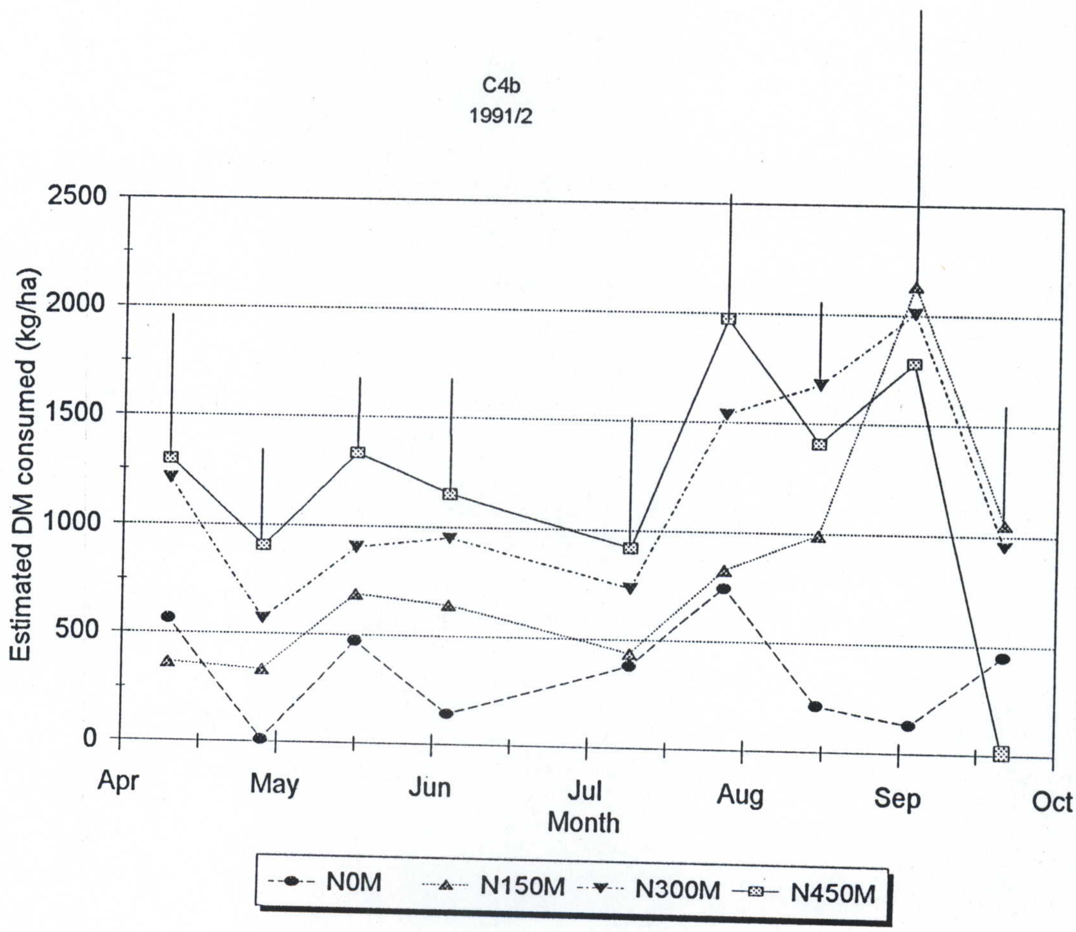

Figure 2.5 The monthly yield response (estimated DM consumed) of an annual ryegrass/clover pasture to increasing rates of N fertilizer. Vertical bars indicate the 5% LSD level.

utilization over all treatments at the end of each grazing cycle. Even utilization was achieved by adjusting animal numbers above a 'core-group' number. As a result, the number of sheep required to graze the early spring growth led to excessive treading damage of the pasture in certain replicates, particularly at the higher N rates. Excessive trampling was evidenced by the reduced yields recorded from the N450M treatment subsequent to August (Figure 2.5). The high LSD value for the September grazing resulted from a trampled camp (one replicate) being excluded from grazing and thus the analysis of variance.

The September peak noted for the N150M treatment, could have been due to the combined effect of spring soil-N mineralisation, fertilizer N and low animal numbers (which would not have trampled the pasture to the extent that they did at the two higher N rates). The drop in yield at the end of the growing season is, nonetheless, expected as the Midmar ryegrass matures with the onset of flowering.

Figures 2.6a, b and c provide some indication of the relative contribution of the various components of the sward to the overall yield. As expected in a newly sown pasture, the grass component (Figure 2.6a) predominated in most treatments. Subsequent to winter the proportion of grass in the N0M treatment began to decline, with a concomitant rise in clover content (Figure 2.6b). A clear suppression of N fertilizer on the production of clover, in a mixed sward, was observed at N fertilizer rates from 150 to 450 kg N/ha/yr. Weed invasion of the trial remained low (Figure 2.6c), particularly subsequent to winter frosting, with highest weed content initially following planting. However, broad-leaf weeds were controlled with Basagran (bendioxide) at about 4 weeks post-planting.

The effect of N fertilizer on the ratio of grass to clover will be discussed in more detail in a Section III, 5.2. However, the data presented concur with many other local studies which show that increasing rates of N fertilizer results in a reduced clover component (Strijdom 1979; Van den Berg & Kruger 1989; van den Berg *et al.* 1990). In addition, the clear trend of clover increasing in proportion from early spring onwards corroborates the suggestion of Bartholomew (1985) that this change in pasture composition could play an important role in the finishing of animals on annual ryegrass/clover pastures.

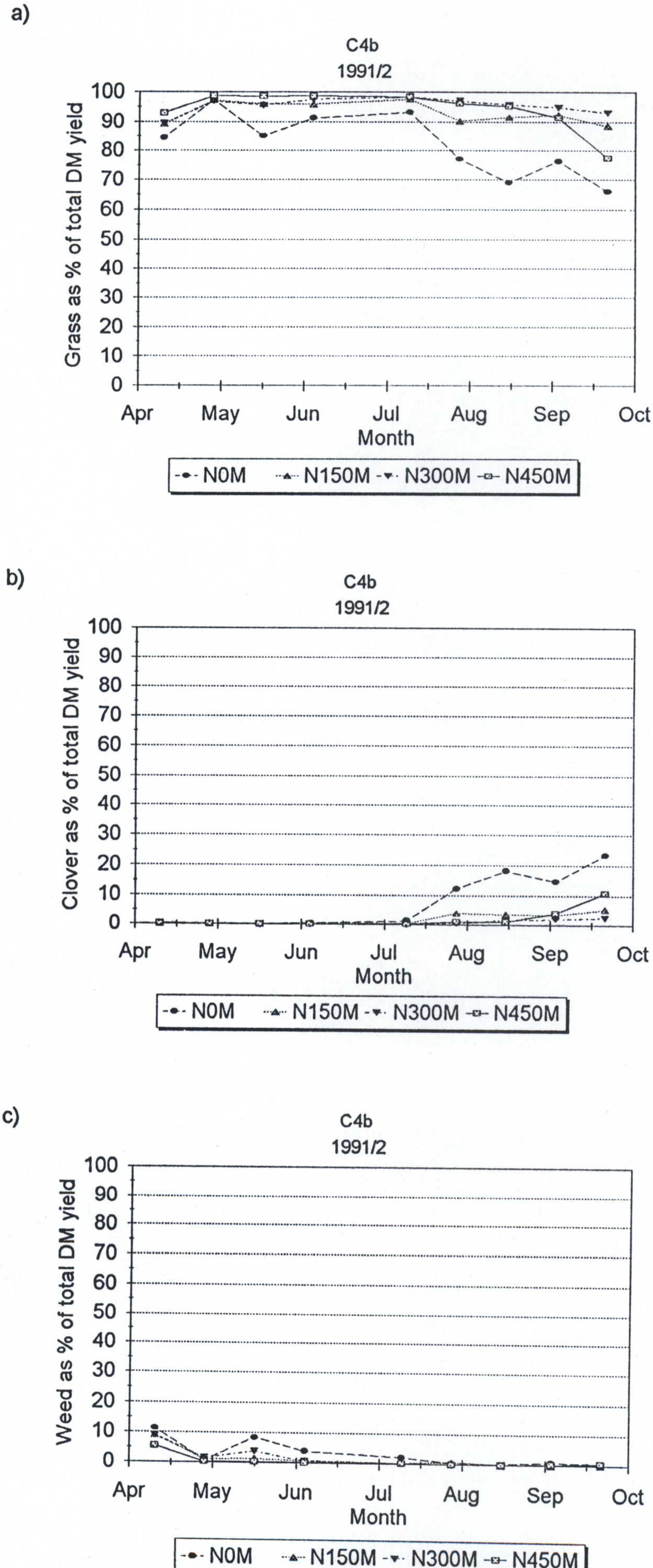

Figure 2.6 The effect of N fertilizer rates on the seasonal species composition of an annual ryegrass/clover pasture. The proportion (% of total yield) of the grass (a), clover (b) and weed (c) components are presented.

1.4 Conclusions

Optimum yields (Y_{10}) on grazed annual ryegrass/clover pastures may be achieved at a N fertilizer rate of 281 kg N/ha/yr, with maximum yields being recorded at 381 kg N/ha/yr. Maximum monthly yields were achieved by the application of between 50 and 75 kg N/ha/application (28 days) from April to late-July; thereafter, 50 kg N/ha/application appeared to be sufficient for maximum yield. The monthly (28 days) N applications, advocated from the grazing trials, are higher than those estimated from cutting trials in Section II, 1.3 and 1.4.

Due to the differences between optimal N fertilizer rates estimated from this grazing trial (C4b), and those from the cutting trials (Section II), it is important that investigations of N fertilizer response studies be conducted under a grazing regime. It must be emphasised that the current data represent results from a single year. Ideally, N response trials should be conducted for at least 3 to 4 years, on identical treatment plots, in order to quantify yield responses and account for N returned via dung and urine.

2 Economic and environmental considerations in the future use of nitrogen fertilizer on intensive annual pastures

2.1 Introduction

In intensive pasture systems, two input costs have consistently emerged as major negative factors to overall economic sustainability; namely, those of fertilizer and machinery inputs. More specifically within these two categories are the cost of annual re-establishment and the price of nitrogen fertilizer. In an attempt to combat these two input costs, farmers in Natal have shown a renewed interest in perennial pasture systems *i.e.* kikuyu (*Pennisetum clandestinum*), perennial ryegrass (*Lolium perenne*) and tall fescue (*Festuca arundinacea*), in combination with clovers (*Trifolium repens*) where possible.

At this point in the dissertation it would be important to review the data presented on the N responses of annual ryegrass pastures, in the light of current and future trends in economics and environmental considerations.

2.2 Economic review of annual ryegrass pastures

Current market prices

The following data, extracted from Combud (1993; Appendix 4), Bredon and Stewart (1978) and local fertilizer suppliers, provide the reader with some idea of current N fertilizer costs:

at the currently recommended N application rate of 350 kg N/ha/yr (1250 kg LAN/ha/yr; 28%N), N fertilizer costs R728.75/ha, excluding delivery. Nitrogen fertilizer, applied at the above recommended rate, accounts for 26 % of estimated total costs on an annual ryegrass/clover pasture (R3078.41/ha/yr; Appendix Table 4).

Economic assessment of optimal N fertilizer rates

Most N response studies estimate optimal N rates as either a percentage of the maximum observed yield (Cowling & Lockyer 1970), or the point at which the slope of the response curve declines below a defined value, usually 10 kg DM/kg N applied (Sparrow 1979a & b). However, these estimates remain biologically and climatically based and may have little relevance to current economics.

The Law of Diminishing Returns states that "If increasing amounts of one input are added to a production process, while all other inputs are held constant, the amount of output added per unit of variable input will eventually decrease" (Doll & Orazem 1984). In other words, the yield response and the economic response curves will appear similar in shape, except that the slope and inflection points may differ.

In order to calculate an economic optimum N fertilizer rate it is important to define a number of terms relating to production-function economics (after Doll & Orazem 1984):

MPP = Marginal Physical Product = Δ in yield (litres or kg beef/ha)/Δ in N fertilizer applied (kg N/ha). MPP is the change resulting from a unit increment or unit change in variable input. It measures the amount that total output increases or decreases as input increases. Geometrically, MPP represents the slope of the production function;

APP = Average Physical Product = total yield/total N fertilizer applied. APP is obtained by dividing the total output by the total variable input. APP is defined geometrically in terms of the slope of a particular straight line. That slope represents the average rate at which the input **X**, is transformed into the product **Y**. The straight line (ray) must always pass through the origin and intersect of the production function;

TVP = Total Value of Product = the currency value of an enterprise = Py x **Y** {Py = price per unit of output & **Y** = amount of output};

TC = Total Cost of product = sum of total variable costs and total fixed costs of production;

Px = Unit cost of input (*i.e.* unit price of N fertilizer) = a constant, being the slope of the TC curve assuming no other variable inputs;

VMP = Value of Marginal Product = Py x MPP = the slope of the TVP curve. Profits are maximized when VMP = Px

Profit = TVP - TC

The above terms were calculated for a typical dairy system (Appendix 7) and a system of fattening beef steers (Appendix 8), both on an annual ryegrass/clover pasture over a range of N fertilization rates. Pasture yields were estimated using the quadratic function fitted to the data of Figure 2.4.

Based on the financial data of Combud (1993), with dairy data from Bredon and Stewart (1978) and beef data from van Ryssen (1992), the following inputs were assumed:

Milk value (R/*l* as at 10/93)	0.89
Beef price (R/kg dressed, as at 10/93)	5.92
Dressing % (Steer):	53
N cost (R/t of LAN):	641
Total pasture costs (per ha):	3,078.41
Total pasture yield (t DM/ha):	12.5
Growing season (months):	9
Pasture wastage - dairy (%):	30
Pasture wastage - beef (%):	20

Assumption: A 500 kg Friesland cow requires 14.50 kg DM/day and can produce 16*l*/day off an annual ryegrass/clover pasture. Milk production potential of the forage produced is thus:

(litres produced/kg DM intake) x (DM yield - wastage)

Assumption: A 280 to 300 kg medium framed beef steer requires 7.2 kg DM/day and can produce 1 kg/day (ADG) off an annual ryegrass/clover pasture. Beef production potential of the forage produced is thus:

(kg beef produced/kg DM intake) x (DM yield - wastage)

Doll and Orazem (1984) suggest three methods of determining optimum inputs in a production system:

a) The first method involves a graphical comparison between the TVP (Rands) and TC (Rands) of an enterprise plotted against the variable input (X), being N fertilizer rates in this case (Figure 2.7a & 2.8a). Profits are maximized in the graph when TVP exceeds TC and the vertical distance between the two is a maximum. In Figure 2.7a this optimum point occurred fractionally below 360 kg N/ha/yr.

b) A second method considers profit as a direct function of input. The optimum amount of input occurs where profit is a maximum; again fractionally below 360 kg N/ha/yr (Figure 2.7b).

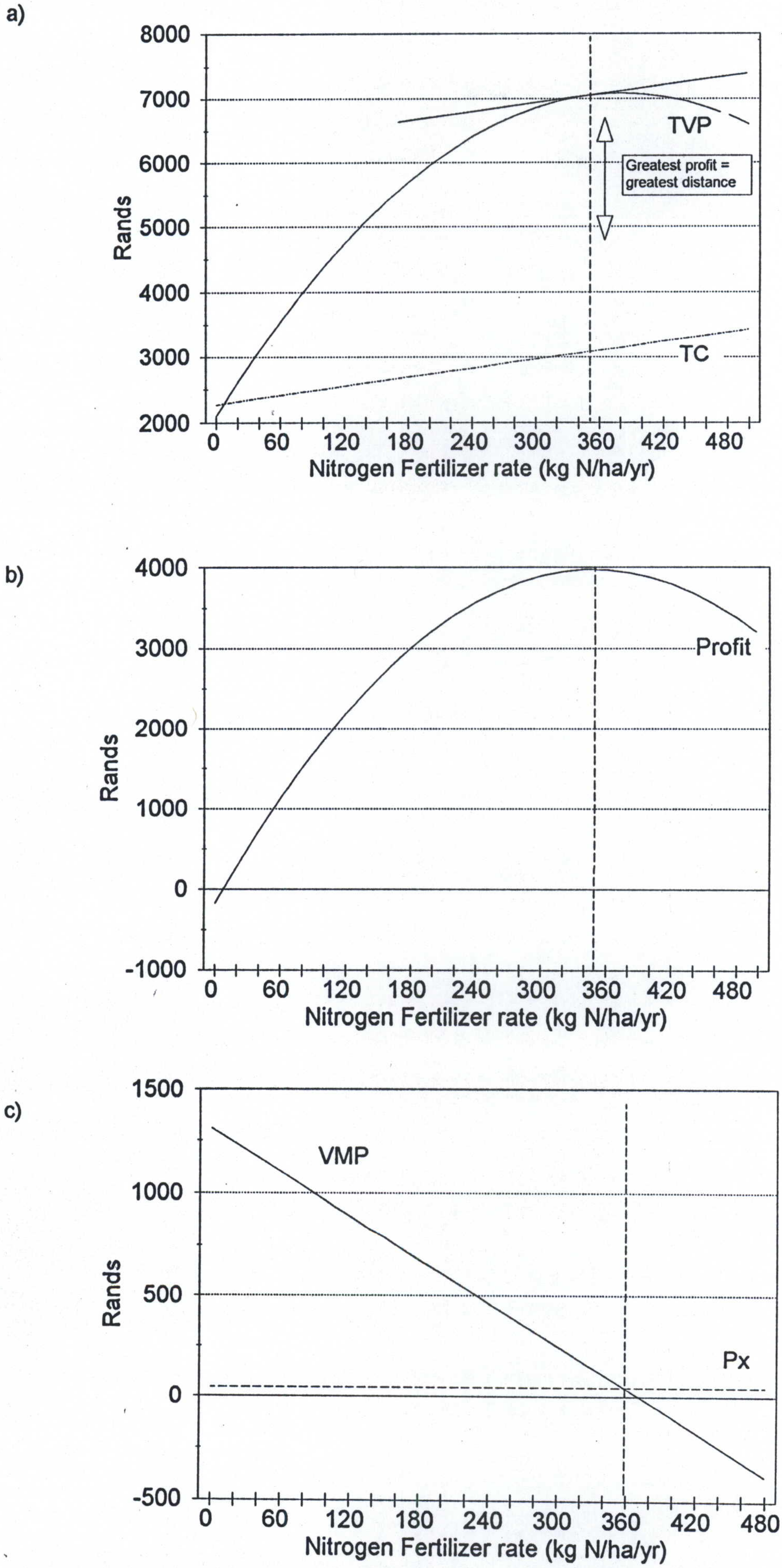

Figure 2.7 Economic optimum N fertilization rates for dairy production on annual ryegrass clover pastures. Optima calculated according to the a) TVP vs TC, b) Profit and c) VMP vs Px methods.

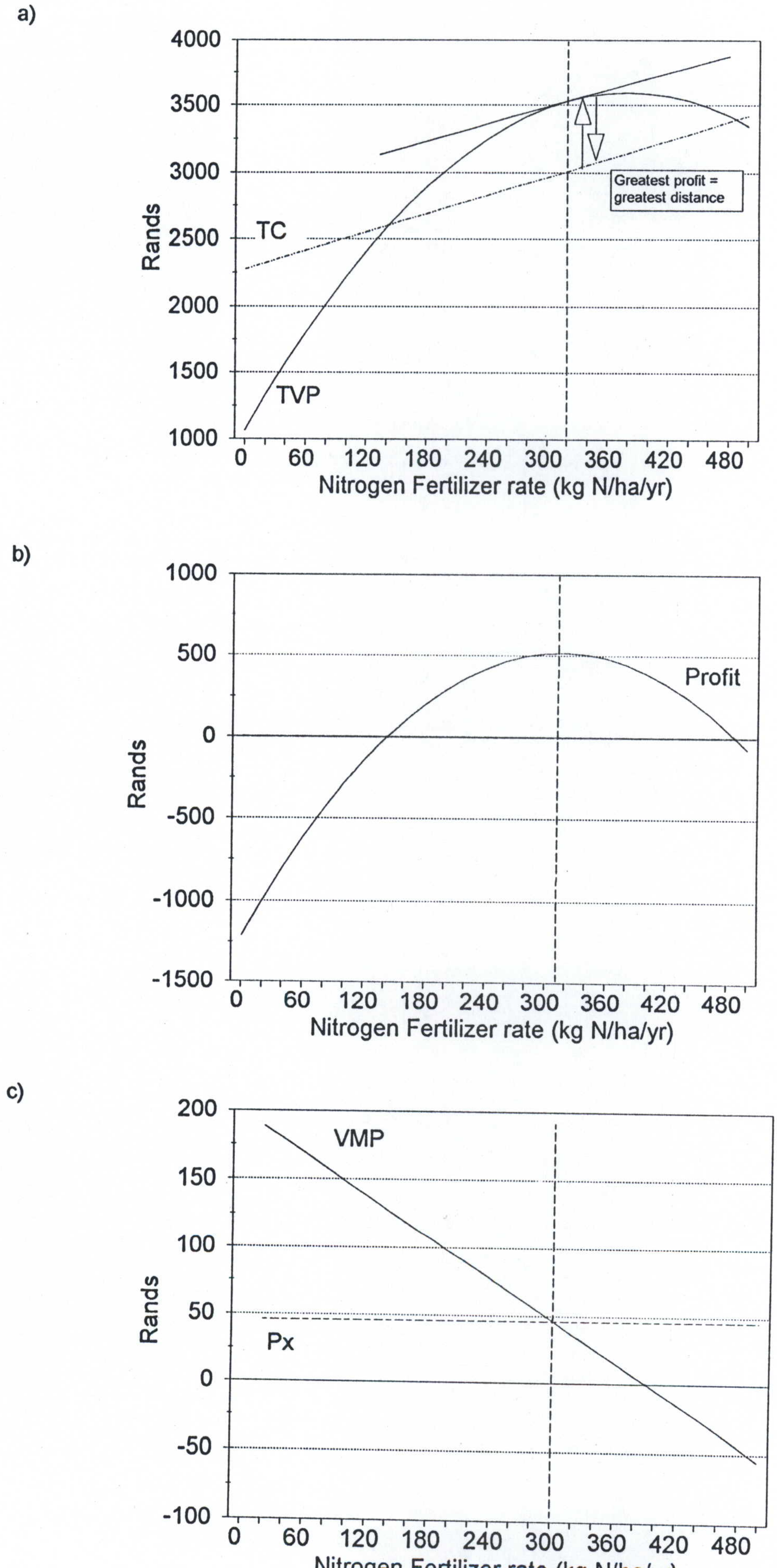

Figure 2.8 Economic optimum N fertilization rates for beef production on annual ryegrass clover pastures. Optima calculated according to the a) TVP vs TC, b) Profit and c) VMP vs Px methods.

c) The third method involves the comparison of the slopes of the TVP (VMP) and TC (Px) curves (Figure 2.7c & 2.8c). Profits will be maximized when the TVP and Tc lines are equal *i.e.* where VMP and Px intersect. As this method is essentially the same as the first, the economic optimum rate of input remains the same.

Assuming the above examples to represent a specific farm, the dairy farmer will continue to show an economic return to the application of up to 350 to 360 kg N/ha/yr on his annual ryegrass/clover pasture (Figure 2.7). The beef farmer on the other hand would maximize profits at 300 to 318 kg N/ha/yr (Figure 2.8).

If the economic optimum N application rate is lower than the (ecological/environmental) X_{10} optimum N rate the producer will be forced to consider the economics of the entire enterprise. The first priority would be to attempt to reduce the input costs, without reducing the output volume. A second consideration would be to increase the value of the output *i.e.* better markets, higher prices or processing the output further. If neither option exists the producer must either consider a totally different enterprise, or carefully balance the effect of reduced N fertilizer (thus reduced yield) on the volume of output produced.

Although the above examples show both enterprises to remain profitable, at currently recommended N fertilization rates, these margins may change markedly with changes in input costs and market prices. With inflation and price structures at present rates of increase, modern farmers would be well advised to set up a spreadsheet, similar to those in Appendix 4, 5, 6, 7 and 8, based on actual on-farm costs and prices. In this way the options may be investigated by simply varying the input costs and market prices. As a management tool such a scenario planner is extremely valuable.

The options presented above all assumed Px to be ever increasing, with no allowance being made for alternative, cheaper sources of Px (N fertilizer in this case). It is in this exact situation that pasture legumes have a potential role to play.

In the introduction to Section III, three N fertilization strategies were presented. Assuming the high N fertilizer application strategy to be uneconomic and the total reliance on clover-N to reduce yields to uneconomic levels, a reduction in N application rates may be achieved by strategic, seasonal N top-dressings. Based on the conceptual model presented in Figure 2.1 of Section III (page 44), a potential saving of N fertilizer may be effected over the warmer months of the growing season. The modified treatments, in the second year of the perennial ryegrass/clover trial (C4a) and the tall fescue/clover (C4b) (Table 2.2b; Section III, page 48), are based on the principle of strategic N applications.

Economics of re-establishment of annual ryegrass pastures

As discussed in Section II, 2.1, the cost of annual re-establishment of pastures may require closer economic examination as this may be a reducible input cost. The estimated allocated costs (after Combud 1993, Appendix 5 & 6) of a perennial ryegrass/clover pasture are R4,013.40/ha and R1,854.08/ha for the establishment and maintenance years respectively; a potential saving of R2,159.32/ha per maintenance year. If the perennial ryegrass/clover pasture requires replanting every three years, total allocated costs would be R7,721.56/ha, as opposed to R9,235.23/ha for three years of annual ryegrass/clover pastures (Appendix 4, 5 & 6). A potential savings of R1,513.67/ha over three years (R504.56/ha/year) could justify the replacement of annual ryegrass/clover pastures with perennial ryegrass/clover pastures in many cases.

2.3 Environmental review of annual ryegrass pastures

Long-term soil structure

The organic matter (OM) content of a soil plays a vital role in the moisture and nitrogen retention in the root profile (Miles & Manson 1992). The use of pastures to increase soil organic N and organic carbon (OC) levels has long been recognised (Packer & Hamilton 1987; Miles & Manson 1992). However, Ball and Field (1987) show evidence that the efficiency of pastures, in building soil N and OC levels, depends on the intensity of utilization of such pastures; they concluded that "there are modern farming systems, involving intensive utilization of permanent grassland, which are mining soil organic matter and its contained nutrients just as surely as does cropping, although much less spectacularly".

The N in urine patches is generally deposited at rates greater than the immobilisation capacity of the soil profile (Ball & Field

1987). Soils rich in organic matter content, in addition to their higher inorganic N content, are able to store more free N (from urine patches) than soils deficient in organic matter.

The shift towards conservation tillage has received much research attention, particularly in the field of annual cropping (Packer & Hamilton 1987). Soil cultivation is the major factor promoting organic matter and total nitrogen depletion under annual pasture systems (Packer & Hamilton 1987; Miles & Manson 1992). However, organic matter conservation, by conservation tillage practices in annual pasture systems, has received little attention in South Africa.

In response to the above understanding, soil samples were taken from all lands adjacent to the C4 site and analysed for their soil physical and chemical properties (Table 2.3). Soil samples were also taken from other sites on Cedara, where recommended management systems are imposed, and used for comparison. In the undisturbed sites, listed in Table 2.3, years refer to the number of years since the last recorded soil disturbance. In the disturbed sites the years refer to the number of years of consecutive soil preparation.

Table 2.3 The effect of various management systems on selected topsoil properties (0 - 15 cm). Data represent a single analysis of a composite sample (15+ cores from each site).

Site & Management	Yrs	Total N	Organic Carbon	Clay	C:N ratio	Texture class
		%	%	%		
Undisturbed						
C4: under fence line	21+	0.34	3.47	34	10.21	Sandy Clay Loam
C4: waterway kikuyu pasture	21+	0.43	3.95	46	9.19	Clay
SF: under fence line	21+	0.31	3.24	38	10.35	Sandy Clay
Disturbed:						
C4: Midmar breeder seed unit	5	0.177	2.29	36	12.94	Sandy Clay
C4: Maize lands	30+	0.235	2.55	29	10.85	Sandy Clay Loam
SF: Midmar ryegrass pasture	12	0.227	2.15	36	9.47	Sandy Clay

The 'C4: under fence line' and 'SF: under fence line' soil samples, taken from under permanent fences, should represent the soil status if the lands had remained as undisturbed natural grassland. These areas under the fence lines are trimmed annually. The 'C4:waterway kikuyu pasture' is an opportunistically grazed kikuyu (*Pennisetum clandestinum*) pasture, in a slight depression (not waterlogged), designed to slow stormwater run-off from the adjacent roadway. The 'C4:Midmar breeder seed unit', on the other hand, has been under annual cultivation for 5 years subsequent to being a hay land. All the C4 sites were within a few meters of the C4 grazing trial.

Assuming the 'C4:fence line' sample to represent the stable state of the soil, a potential improvement in total N and OC may be affected by the introduction of permanent, lightly utilized pasture *i.e.* kikuyu. In contrast to this, the 'C4: Midmar breeder seed unit' and 'C4: Maize lands' samples, being under annual cultivation (discing to +15cm) for 5 and more than 30 years respectively, show much lower total N and OC levels. The higher total N in the 'C4: maizelands' sample, relative to the 'C4: breeder seed unit', could be attributed to the purposeful return of stubble and trash into the soil profile.

The other comparison made was between an intensively grazed and fertilized Midmar ryegrass pasture (SF: Midmar ryegrass pasture), after 12 years of annual cultivation, and under the undisturbed, adjacent fence line (SF: under fence line). Here too a reduction in total N and OC levels was noted with annual soil cultivation. In recent years a progressive decline in annual yields were recorded from this pasture, attributed largely to the effects of long-term annual cultivation ([2]Bartholomew pers.comm.).

Annual soil cultivation appears to be a major factor affecting soil total N and OC levels. According to Haynes (1986 cited by Miles & Manson 1992) cultivation promotes oxidation in the soil as it exposes fresh soil to the atmosphere and promotes aeration. Seedbed preparation of annual ryegrass pastures usually occurs in mid- to late- summer (February) when soil temperatures are high, thereby favouring the oxidation process (Miles & Manson 1992).

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[2]Pastures Section, Department of Agriculture, P.Bag X9059, Pietermaritzburg, 3200.

Soil surface compaction, due to sheep hoof action, is a major setback for effective water infiltration on intensively grazed annual pastures. This effect has certainly been noted in the C4 grazing trials, where irrigation puddling becomes progressively worse as the year progresses. In an attempt to combat this effect, the Cedara Agricultural Development Institute recommends the annual use of a pasture aerator (a straight, cutting coulter followed by a narrow tipped spring-tine), preferably in early spring, to improve water infiltration (Macdonald 1991).

The use of a pasture aerator provides, however, only a short-term solution to a problem requiring long-term action. Although perennial ryegrass/clover and tall fescue/clover pastures produce less winter forage than annual ryegrass, increased emphasis on these perennial pastures may be one of the few practical means of promoting sustainability. Research efforts on annual pastures should concentrate on minimum tillage re-seeding techniques and techniques for maximizing the re-incorporation of unutilized forage into the soil.

Nitrate leaching

Nitrate leaching from intensive pastures has been the subject of much controversy and debate in recent years, particularly in developed countries where 'green' lobbyist groups have a strong influence (Dowdell, 1986; Magdorf 1992; Miles & Manson 1992). These pressures have resulted in numerous studies aimed at quantifying and/or reducing nitrate leaching (Steele *et al.* 1984; Cameron & Scotter 1987; Schofield *et al.* 1991; Magdorf 1992).

Nitrate losses from extensive pasture are generally low (Cameron & Scotter 1987). Intensively grazed pastures, on the other hand, may lose appreciable quantities of nitrate via leaching, particularly where high rates of N fertilizer are commonly applied (Ball & Ryden 1984; Cameron & Scotter 1987). In Section II, 3 and 4, evidence was presented suggesting that injudicious use of N fertilizer may result in substantial losses of N fertilizer.

The high concentration of N in urine patches appears to be the main path for N losses (Ball 1979; Steele *et al.* 1984; Cameron & Scotter 1987). Urine patches may contain the equivalent of 950 kg N/ha for cattle and 500 kg N/ha/yr for sheep (Steele 1982 cited by Cameron & Scotter 1987). Ball and Ryden (1984) recorded leaching losses of between 140 and 190 kg N/ha/yr from an intensively grazed pasture. In addition, irrigated pastures have a higher potential for nitrate leaching than do dryland pastures, due to both the concomitant higher stocking rate and greater volume of through drainage (Turner 1976 & Burden 1982, both cited by Cameron & Scotter 1987).

Pasture systems, where the soil profile is disturbed annually (low OM content), may show greater nitrate leaching losses than perennial pasture systems (Cameron & Scotter 1987; Miles & Manson 1992). Nitrate leaching losses may, therefore, also be lower with direct drilling than ploughing for the re-introduction of fresh seed to a pasture.

As yet, South African farmers have not had to face the magnitude of pressure imposed on farmers in more developed countries. However, this should not be used as an excuse to ignore the potential problems. In the short term, however, the ever increasing cost of N fertilizer will most likely be the deciding factor limiting excessive N fertilizer use.

2.4 Conclusions

Whether it be environmental or economic constraints that place restrictions on farmers, futuristic scenarios suggest ever-increasing pressure on farmers to reduce N fertilizer usage on intensive pastures in South Africa. Future research efforts should, therefore, aim to provide alternative solutions for the farmers, with research having to quantify the production potential and economics of each recommended alternative.

The inclusion of clovers, as a source of symbiotic N in intensive pastures, is thus becoming more prevalent and essential, not only to reduce the overall N requirement of the pasture but to increase the quality of the overall pasture.

Research is urgently required on minimum tillage re-establishment of annual pastures and its effect on annual pasture production. Research is also required on the effects of reincorporation of unutilized forage at the end of the year on soil total N and OC.

The data and discussion above appear to justify a closer investigation of the N requirement of alternative temperate perennial pastures, in combination with a perennial legume like white clover. Not only will temperate perennial grass/clover pastures effect savings on re-establishment costs and N fertilizer, but they are likely to improve the soil environment and thus sustained productivity.

3 The nitrogen requirements of grazed perennial ryegrass (*Lolium perenne* cv. Yatsyn 1) pastures, with and without white clover (*Trifolium repens* cv. Ladino)

3.1 Introduction

In recent years perennial ryegrass (*Lolium perenne*) and tall fescue (*Festuca arundinacea*), in conjunction with white clover (*Trifolium repens*), have assumed an increasingly important role as perennial pastures in the livestock industry in Natal.

In Natal no data are available on the nitrogen management of grass/clover pastures on which to base recommendations to farmers. Another alarming point is that there are numerous private pasture consultants offering farmers advice on the management and fertilisation of these perennial pastures, with no locally applicable data on which to base such advice. Pasture advisers are recommending that no nitrogen fertilizer need be applied to temperate perennial pastures if they are planted in combination with clover. Such recommendations could lead to a serious mid-winter fodder flow problem.

Research trials using Ariki ryegrass (*Lolium perenne* crossed with *Lolium multiflorum*, back-crossed to *Lolium perenne*) showed a decline in grass production of 33%, 61% and 67% in the second, third and fourth years of production, respectively (Cross & Bartholomew 1971). However, individual farmers in Natal have successfully cultivated perennial ryegrass pastures for a number of years (Twiddy 1989). In a survey of perennial ryegrass production in Natal, Twiddy (1989) highlighted some important common factors contributing to pasture perenniality.

The discrepancy between the lack of perenniality of Ariki ryegrass in field trials and farmers successfully using Ellett ryegrass requires urgent attention. In addition, the effect of perennial pastures, as opposed to annual pastures, on the soil organic matter status and nutrient content requires investigation locally under grazing.

Fertilizer nitrogen (N) is applied to grasslands to increase the profitability of a livestock enterprise through the production of either more feed or a cheaper feed source than can be bought or grown elsewhere (Baker 1986). In overseas countries the level of N fertilizer applied to intensive pastures has steadily risen over the past 20 years, with rates in excess of 400 kg N/ha/yr regularly being applied to perennial ryegrass pastures (Ball & Ryden 1984).

It is important, therefore, that the correct N requirements of these pastures be determined, and that this information be made available to the fertilizer advisory service and the Natal Extension service.

3.2 Methods

Data were extracted from the C4a site, in the 1991/2 and 1992/3 years, described under Section III, 1.2 (Table 2.2, pages 47 & 48). The procedures followed are described in Section III, 1.2 (page 45), with the trial design and layout detailed in Appendix 1, 2 and 3.

3.3 Results and discussion

Annual total yield

The DM yield response of a perennial ryegrass/clover pasture to varying N fertilizer treatments, under intensive sheep grazing, is presented in Figure 2.9. Dry matter yields of the grass/clover pasture increased linearly ($P<0.05$) up to the 300 kg N/ha/yr level, with a non-significant ($P>0.05$) yield increase from a further 150 kg N/ha/year. The average slope of the response below X_{10} ($dY/dX=10$; cf. General Introduction) was 25.71 kg DM/kg N. The DM yield response to increasing N fertilizer rates was best represented by the following quadratic function:

$$Y = 2{,}094.41 + 36.51X - 0.04X^2$$

$$(R^2(adj)=0.85;\ SE= \pm1{,}477.67)$$

$$Y_{max} = 10{,}425.54 \text{ and } X_{max} = 456.38$$

$$Y_{10} = 9{,}800.59 \text{ and } X_{10} = 331.38$$

As N fertilizer was applied only between April and October, allowing the clover component to maximise its contribution over the summer months, the response curves for the two periods April to October and November to March, were plotted separately; these are presented in Figures 2.10 and 2.11, respectively. The average slope of the response below X_{10} was 14.67 and 11.96 for the period April to October (Figure 2.10) and November to March (Figure 2.11),

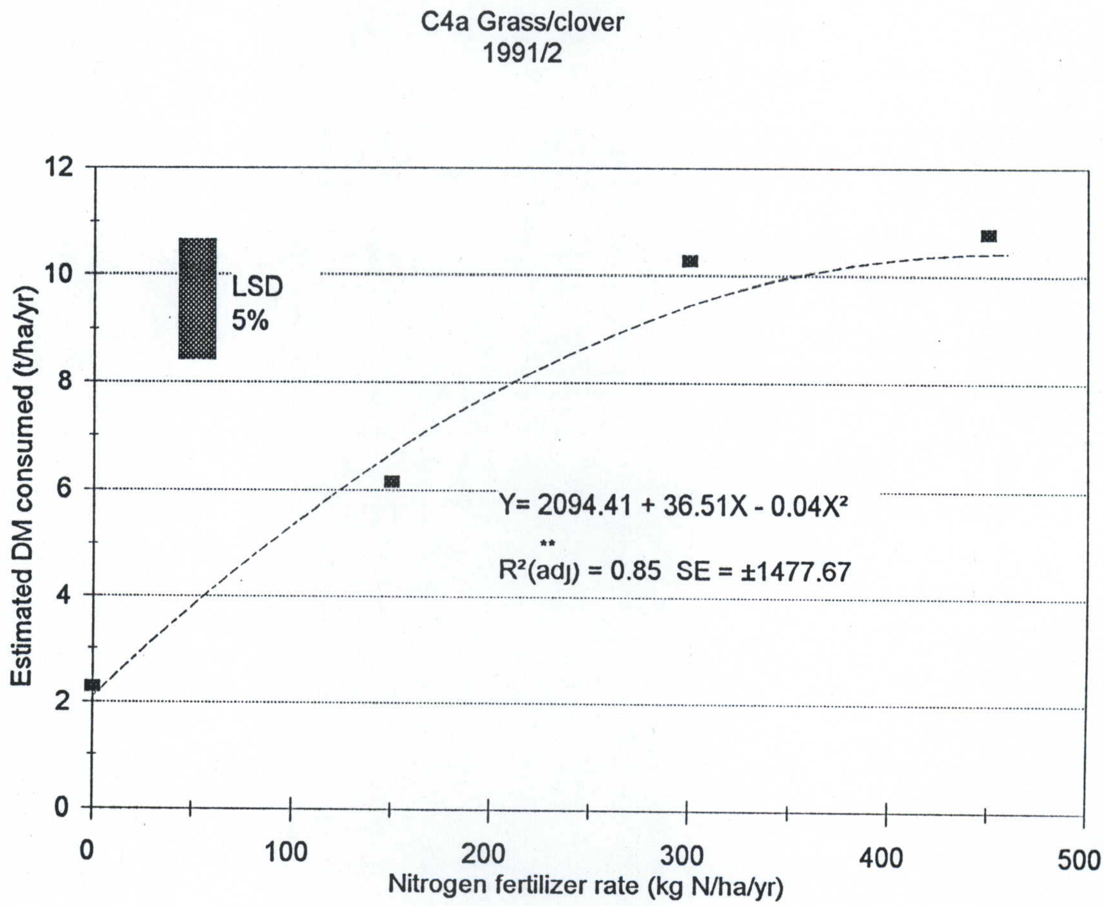


Figure 2.9 The annual total yield (estimated DM consumed) response of a grazed perenial ryegrass/white clover pasture to increasing rates of N fertilizer.

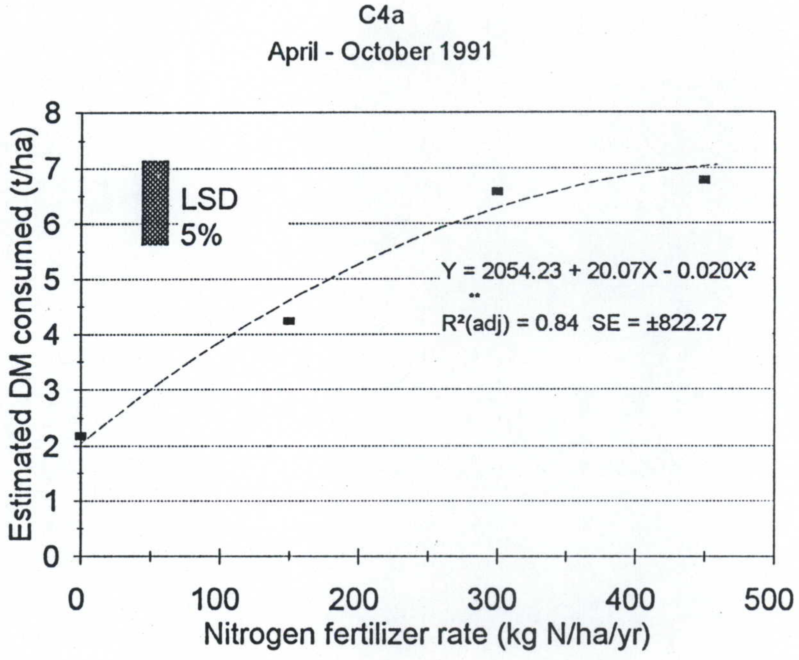


Figure 2.10 The effect of increasing rates of N fertilizer on the estimated total ammount of DM removed by sheep from a perennial ryegrass/clover pasture, over the period for which N fertilizer was top-dressed (April - October).

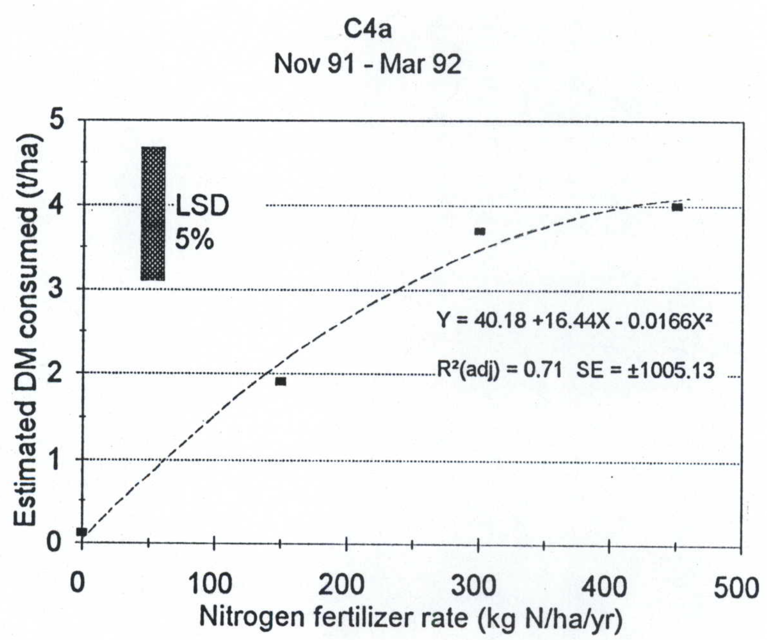


Figure 2.11 The effect of increasing rates of N fertilizer on the estimated total DM yield removed by sheep from a perennial ryegrass/clover pasture, over the period for which N fertilizer was not top-dressed (November - March).

respectively. The DM yield responses to increasing N fertilizer rate, for both periods, were best represented by the following quadratic functions:

April to October 1991 (Figure 2.10):

$$Y = 2054.23 + 20.07X - 0.02X^2$$
$$(R^2(adj)=0.84;\ SE = \pm 822.27)$$
$$Y_{max} = 7{,}089.29 \text{ and } X_{max} = 501.75$$
$$Y_{10} = 5{,}839.29 \text{ and } X_{10} = 251.75$$

November 1991 to March 1992 (Figure 2.11):

$$Y = 40.18 + 16.44X - 0.0166X^2$$
$$(R^2(adj)=0.71;\ SE = \pm 1005.13)$$
$$Y_{max} = 4{,}110.57 \text{ and } X_{max} = 495.18$$
$$Y_{10} = 2{,}604.58 \text{ and } X_{10} = 193.98$$

At present the Cedara fertilizer advisory service recommends that between 400 and 450 kg N/ha/yr be applied to perennial ryegrass pastures in order to achieve optimal (Y_{10}) production. Based on the data of Figure 2.9, it would appear that this recommendation should rather be in the region of 330 kg N/ha/yr (X_{10}; Figure 2.9) for the establishment year. In addition, with a clover component in the sward, most of this N should be applied during the cool season, *i.e.* April to October at a rate of ± 250 kg N/ha (X_{10}; Figure 2.10), or 50 kg N in 5 top-dressings between April and October.

Over the summer period (November to March) the perennial ryegrass/clover pasture continued to respond to the prior N applications. A quadratic function, similar to that derived for the April to October period, aptly described the DM yield response for the November to March period (Figure 2.11); this despite the fact that no N fertilizer was applied over the November to March period. Applying the Y_{10} calculation to the regression function presented in Figure 2.11, the DM yield response was equivalent to the addition of ±194 kg N/ha (X_{10}).

In the second year (92/93) the perennial ryegrass/clover pastures were compared with a pure perennial ryegrass pasture at equivalent N rates (cf. Figure 2.2 and Table 2.2b, Section III, 1.2, page 48). Figure 2.12 illustrates the DM yield response of both the pastures to increasing N fertilizer rates.

Apart from the NOM plots, both the pure grass and grass/clover

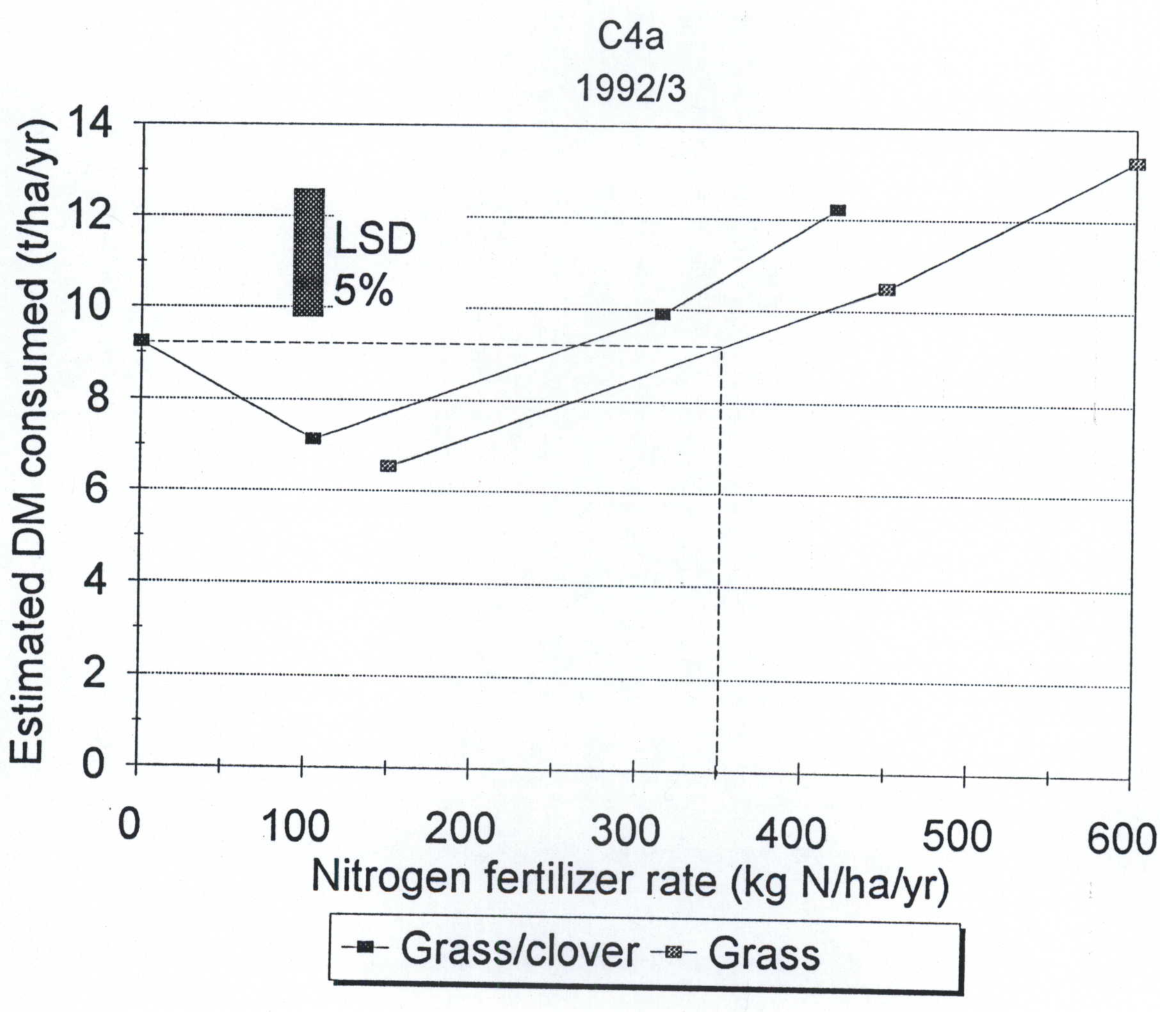


Figure 2.12 The effect of increasing rates of N fertilizer on the estimated annual total ammount of DM removed by sheep from a perennial ryegrass/clover pasture. Data are presented for three rates of N on a pure grass pasture and four rates on a mixed grass/clover pasture.

treatments appeared to respond linearly to increasing rates of N fertilizer, the former up to as high as 600 kg N/ha/yr. Frame (1973) reported similar trends, with the N response of grass/clover swards being rectilinear at N rates above the contribution of the clover. Due to the nature of the responses observed in Figure 2.12, and the lack of an observed maximum inflection point, regression functions were not fitted to the data.

There was a clear suppression of the clover contribution to the pasture DM yield with increasing applications of N. The zero N (N0M) treatment out-yielded (non-significant) treatments receiving 105 (N105M) and 150 (N150G) kg N/ha/yr. An important result was the lack of significant differences between the N0M and the N315M and N450G treatments. The suppression of clover by applied N fertilizer will be dealt with in more detail in a following section. However, equating the DM yields at the N0M treatment to yields achieved from the pure grass treatments (dotted line in Figure 2.12), implies that the clover component of the perennial ryegrass/clover pasture, receiving no N fertilizer, may provide the equivalent of ±350 kg N/ha/yr.

The marked difference in annual total yield response to N fertilizer between the first (Figure 2.9) and second years data (Figure 2.12) is cause for concern. A possible explanation for this may be the trampling damage caused to the N450M plots in the first year (cf. Section III, 1.3, page 50). The implication is, therefore, that in the absence of treading damage linear yield responses, up to 450 kg N/ha/yr, may have been noted in the data of Figures 2.9, 2.10 and 2.11. In support of this explanation, the yield response in the second year, when the damaged camps had recovered, was positive up to 600 kg N/ha/yr (N600G). A concern here is, therefore, that the experimental N rates were not high enough to enable an assessment of optimum N application rates.

As the mixed grass/clover plots (N x M plots) received their N only between April and October, the data in Figure 2.12 were plotted for the separate response periods, April to October (Figure 2.13) and November to March (Figure 2.14). The N0M plots out-yielded plots receiving 105 (N105M, 15 kg/ha - Figure 2.13) and 150 (N150G, 45 kg N/ha -Figure 2.14) kg N/ha/yr. The yields of the N0M plots were also not significantly (P>0.05) different from the N315M and N450G treatments in both periods (Figures 2.13 & 2.14). The data in Figure 2.13 show a possible Y_{max} being approached at the

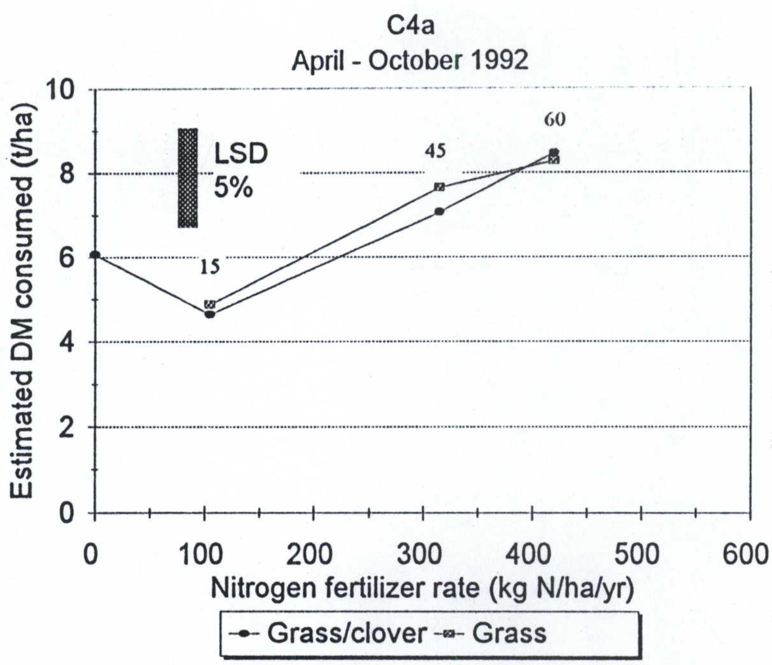


Figure 2.13 The effect of increasing rates of N fertilizer on the estimated DM yield removed by sheep from a perennial ryegrass/clover pasture, from April to October 1992. Data are presented for three rates of N on a pure grass pasture and four rates on a mixed grass/clover pasture. Values printed on the graph indicate the quantity of N applied at each topdressing.

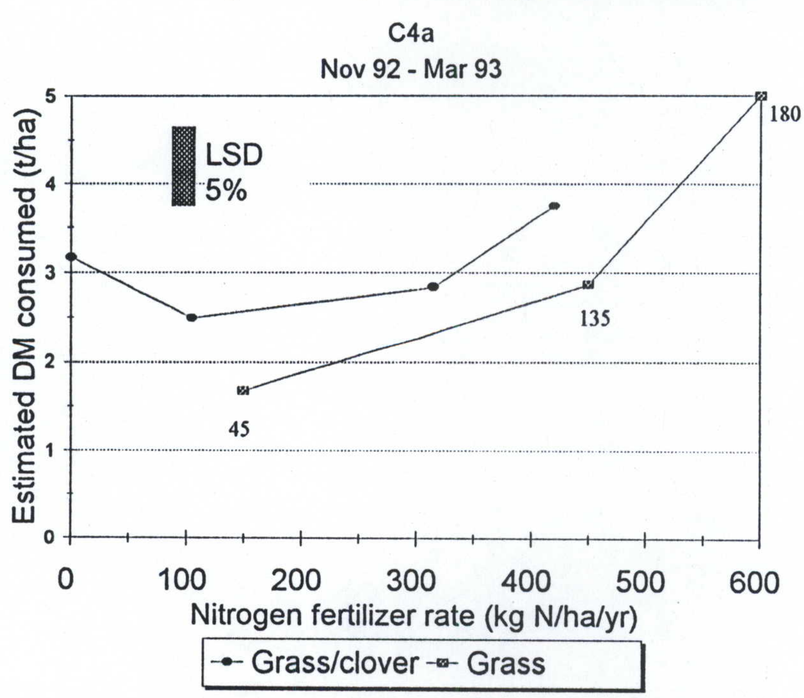


Figure 2.14 The effect of increasing rates of N fertilizer on the estimated DM yield removed by sheep from a perennial ryegrass/clover pasture, from November 1992 to March 1993. Data are presented for three rates of N on a pure grass pasture and four rates on a mixed grass/clover pasture (no N fertilizer applied). Values printed on the graph indicate the total N applied, to the pure grass treatments, over the period (November

highest N fertilizer rate (N600G) on the pure grass treatments.

The data in Figure 2.14 show a marked response to increasing rates of N fertilizer on the pure grass plots, apparently in excess of 180 kg N/ha over the summer (60 kg N/ha/application, N600G). Due to the lack of a maximum yield inflection in the N responses observed (Figures 2.13 and 2.14), optimum (X_{10}) N fertilizer rates could not be estimated.

Economic optimum N rates

The data in Figures 2.9 and 2.12 were subjected to economic evaluation according to the procedures described in Section III, 2.2 (page 56). Based on the quadratic response curve in Figure 2.9 and the dairy system described in section III, 2.2 (page 56), economic optimum N rates were estimated between 400 and 430 kg N/ha/yr. Beef production, according to the system described in Section III, 2.2 was uneconomic regardless of the rate of N fertilizer applied.

More important than the above is an economic evaluation of the N responses observed from the second year (Appendix 9), where the clover component made more of a contribution at the lower N rates. An evaluation, as conducted in Section III, 2.2 and presented in Appendix 7 and 8, was not possible due to the lack of a fitted response curve. The actual data were, therefore, used in the economic calculation presented in Appendix 9.

Highest economic returns were estimated at the N600G and the N420M rates, showing profits (TVP-TC) of R6,510.43/ha and R6,372.54/ha, respectively. The N0M treatment was comparable to the N450G and N315M treatments, with profits of R5,271.69/ha, R5,135.20/ha and R5,066.12/ha, respectively. The lower N rates of N105M and N150G were the least profitable at R3,599.12/ha and R2,934.70/ha, respectively.

Current price structures in South Africa appear to favour the use of high rates of N fertilizer. However, with the potential de-regulation of dairy control boards, international competition for markets and N fertilizer price increases, the N0M treatment could well emerge as the only economic solution.

Animal grazing days

Total sheep (corrected to 60 kg) grazing days per hectare were calculated for each N fertilizer treatment (Section III, 1.2) and presented for the 1991 (Figure 2.15a) and 1992 (Figure 2.15b) years. A largely linear increase in grazing days/ha was noted, with the number of grazing days more than doubling between the N0M to the highest fertilizer rates in all cases. In the 1992 year (Figure 2.15b) more grazing days were achieved from the N105M (grass/clover) plots than the N150G pure grass treatment. The extra grazing days from the grass/clover plots would be expected due to the higher DM yields of the grass/clover plots, relative to the pure grass plots at equivalent N fertilizer rates.

Edwards (1981) warned that, unless linked to animal performance, grazing days may be of little value in evaluating pasture performance *i.e.* animals may have been losing weight at the 450 kg N/ha/yr rate while gaining weight at the lower N rates. Although the trial design provided no estimate of animal performance, the sheep maintained mass on all treatments over the duration of the trial.

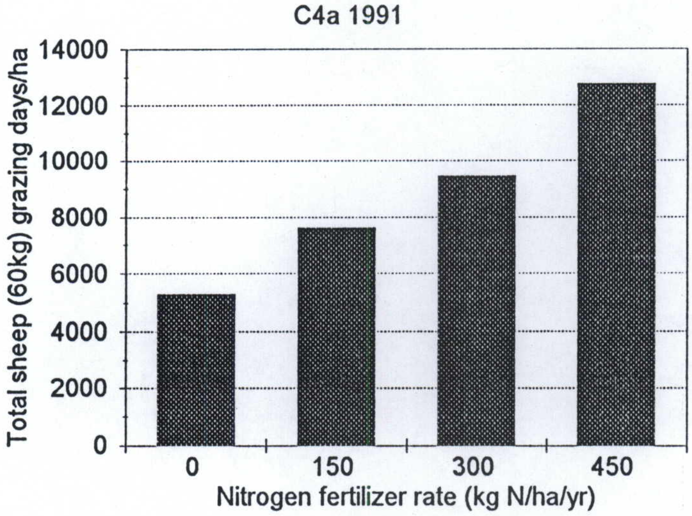
The marked increase in grazing days, attainable by the addition of N fertilizer, defends the use of high rates of N fertilizer as a means of pasture intensification. The addition of white clover to a perennial ryegrass pasture is further justified by the increase in grazing days achieved, particularly at lower rates of N application.

Monthly yields

The estimated monthly DM consumed from the C4 pasture is presented in Figures 2.16, 2.17 and 2.18, for perennial ryegrass/clover over the 1991/2 and 1992/3 years and pure ryegrass over the 1992/3 year, respectively.

The data in Figure 2.16 show a positive response to increasing rates of N fertilizer for most of the year. These responses, in particular that to N450M, were significant ($P<0.05$) in many cases. Through the spring period (August to October) significant ($P<0.05$) yield differences were evident between the three lower N rates (N0M, N150M and N300M), with the N300M rate showing a marked response in the 'spring flush' period (September). As mentioned in Section III, 2.3, the grazing management of the trial required even pasture utilization at the end of each grazing cycle. To achieve even pasture utilization animal numbers were adjusted above a 'core-group' (5 sheep) number. As a result of the number of sheep required to graze the early spring growth in the N450M treatments,

a)



b)

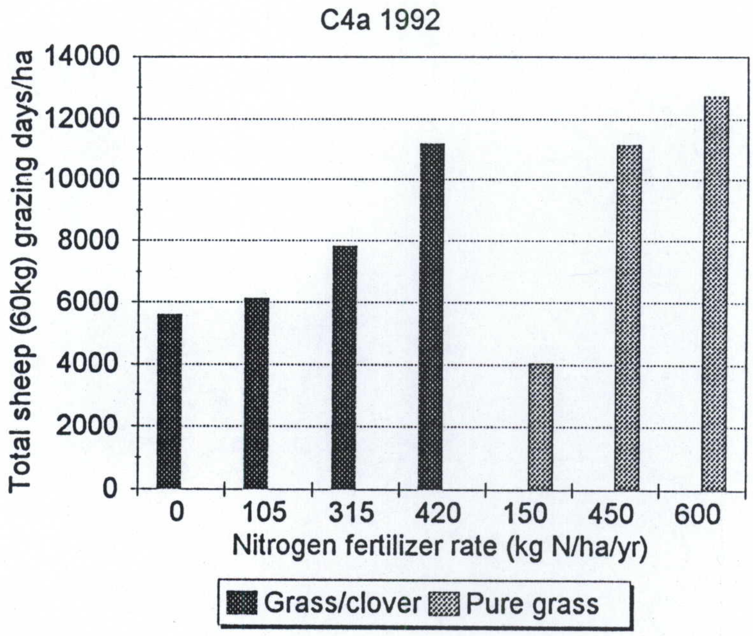


Figure 2.15 The effect of N fertilizer rates on total sheep (corrected to 60kg) grazing days per hectare, on a perennial ryegrass/clover pasture, in the a) 1991/2 and b) 1992/3 years.

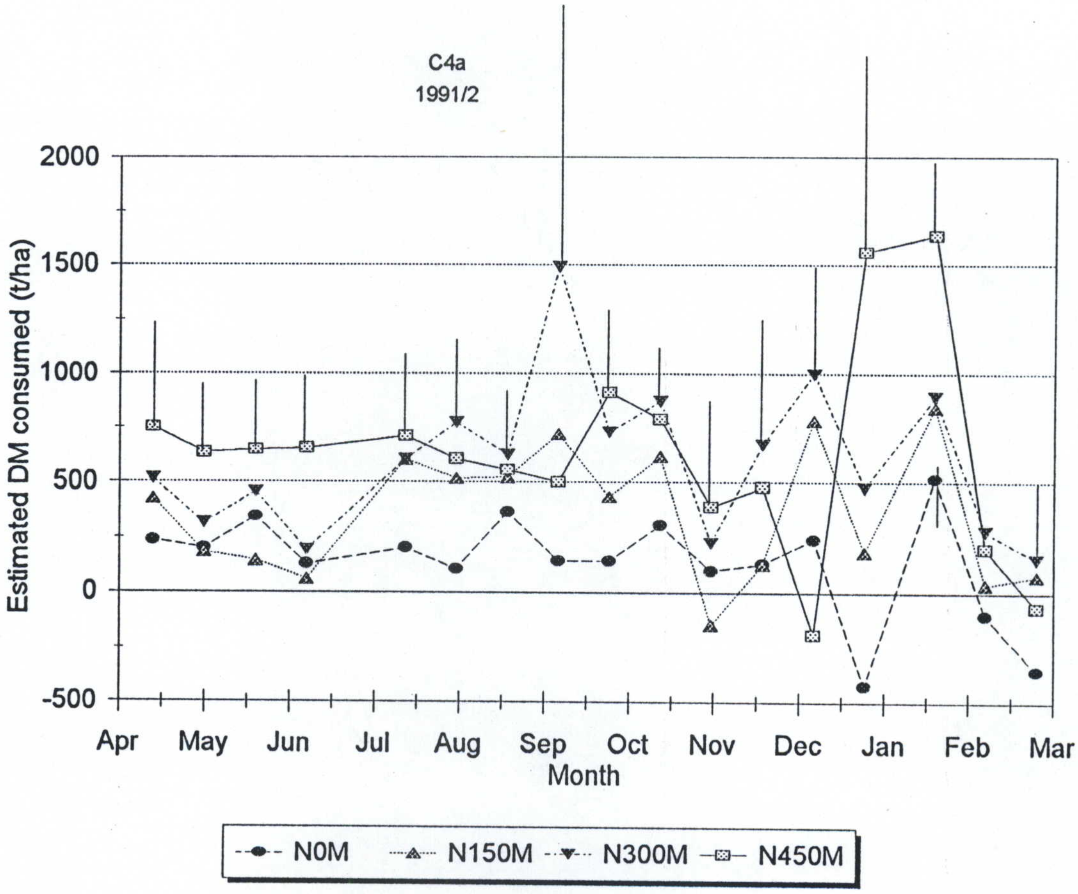


Figure 2.16 The monthly yield response (estimated DM consumed by sheep) of a perennial ryegrass/clover pasture to increasing rates of N fertilizer (kg N/ha/yr). Vertical bars indicate the 5% LSD level.

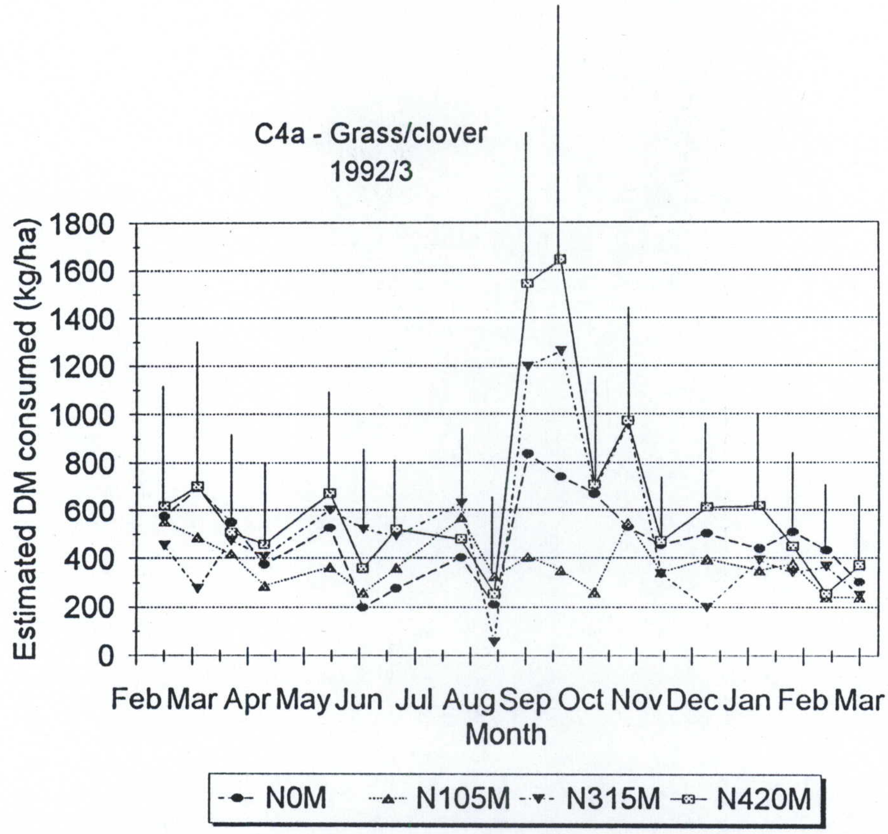


Figure 2.17 The monthly yield response (estimated DM consumed by sheep) of a perennial ryegrass/clover pasture to increasing rates of N fertilizer (kg N/ha/yr). Vertical bars indicate the 5% LSD level.

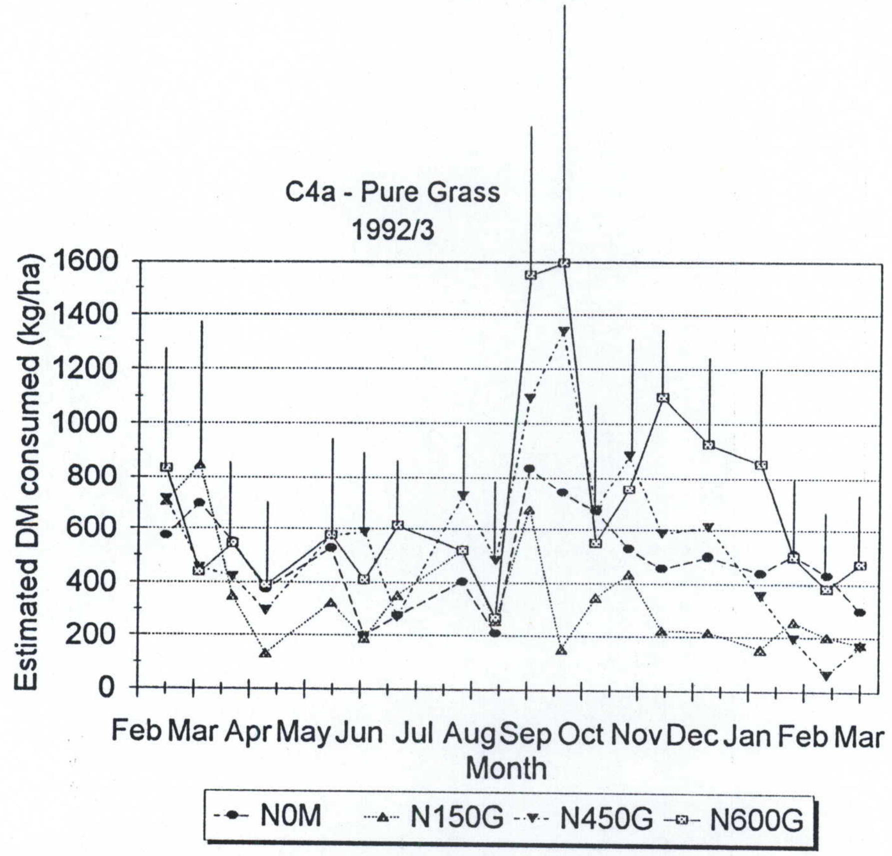


Figure 2.18 The monthly yield response (estimated DM consumed by sheep) of a pure perennial ryegrass pasture to increasing rates of N fertilizer (kg N/ha/yr). Vertical bars indicate the 5% LSD level. The N0M treatments are included for comparison.

the pasture was damaged due to excessive treading. The high LSD in the September grazing resulted from a damaged camp being excluded from grazing, resulting in a missing plot in the analysis of variance. In addition, the sheep missed a grazing replicate during this period due to annual shearing. As a result of treading damage the N450M plots were grazed leniently through most of the spring and summer. This period of lenient grazing could explain the marked recovery of the N450M plots in January and February. Subsequent to the termination of N fertilizer applications (October), trends across treatments were less evident (Figure 2.16).

Dry matter yield response to applied N were less marked during the 1992/3 (Figure 2.17) year, than in 1991/2, with few significant ($P>0.05$) differences noted between treatments. However, the N0M treatments yielded marginally higher than the N105M treatments for most of the year, and particularly in spring (September). Significant ($P<0.05$) differences in yield were noted between both the N0M and N105M and the N420M rates, and between the N105M and N315M rates, during the flush of growth in the spring period (September to October). The important contribution of the clover component was particularly evident from spring (September) onwards, with the N0M treatment being comparable to most of the treatments receiving N fertilizer.

In the pure grass treatments (Figure 2.18), consistent significant ($P<0.05$) treatment effects were noted only from spring (September) onwards. The N0M treatments (included in Figure 2.18 for comparative purposes) yielded marginally higher than the N150G treatments for most of the year, and particularly after September (Figure 2.18). Through the summer period there appeared little or no benefit to the application of up to 450 kg N/ha/yr (135 kg N/ha/application; N450G). However, where N was top-dressed at 600 kg N/ha/yr (60 kg N/ha/application), significantly ($P<0.05$) greater yields were noted through the summer period (December to January), than from lower N applications.

Figures 2.19 and 2.20 indicate the relative contribution of the various components of the sward to the overall DM yield. As expected in a newly sown pasture, the grass component (Figure 2.19a) predominated in most treatments. Subsequent to winter, a change in pasture composition was noted in the N0M plots, with grass proportions decreasing (Figure 2.19a) as clover content increased (Figure 2.19b). The decline in grass proportion at the

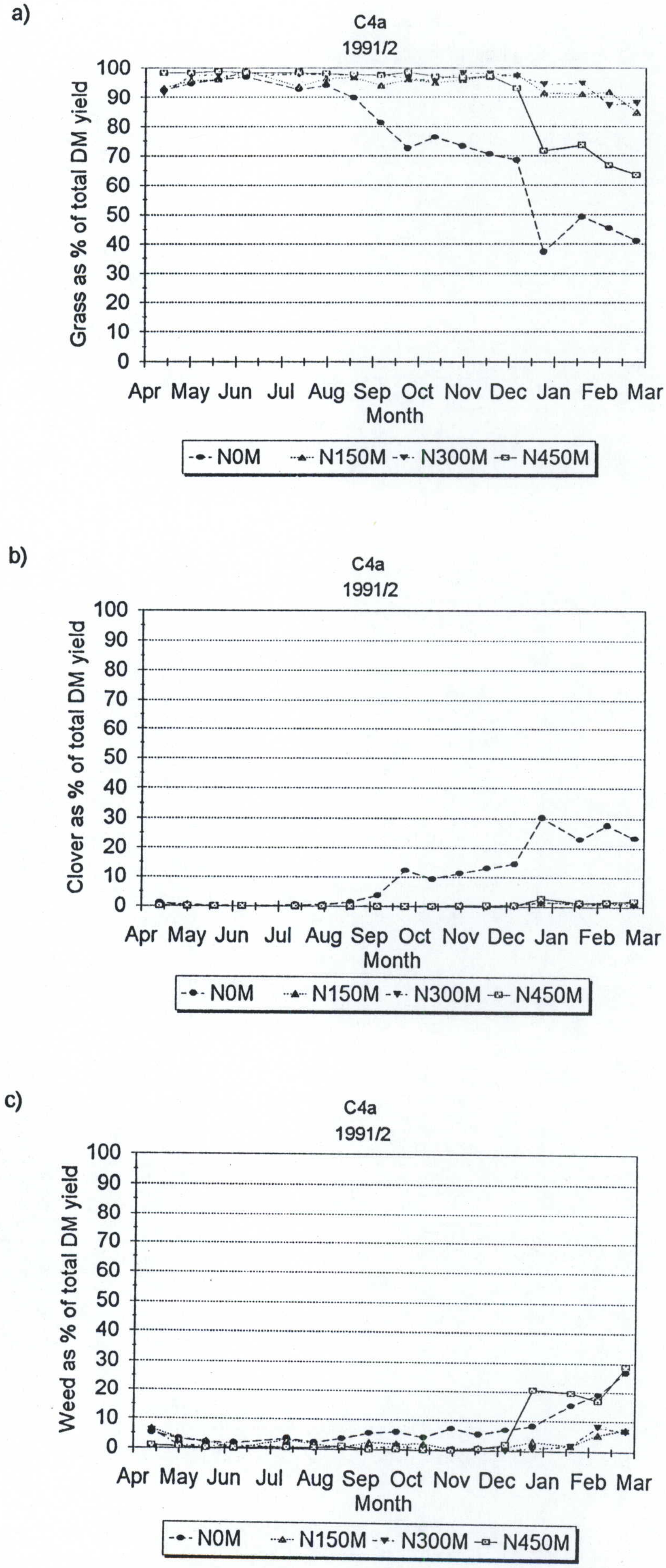


Figure 2.19 The effect of N fertilizer rates on the seasonal species composition of a perennial ryegrass/clover pasture (establisment year, 1991/2). The proportion (% of total yield) of the grass (a), clover (b) and weed (c) components are presented.

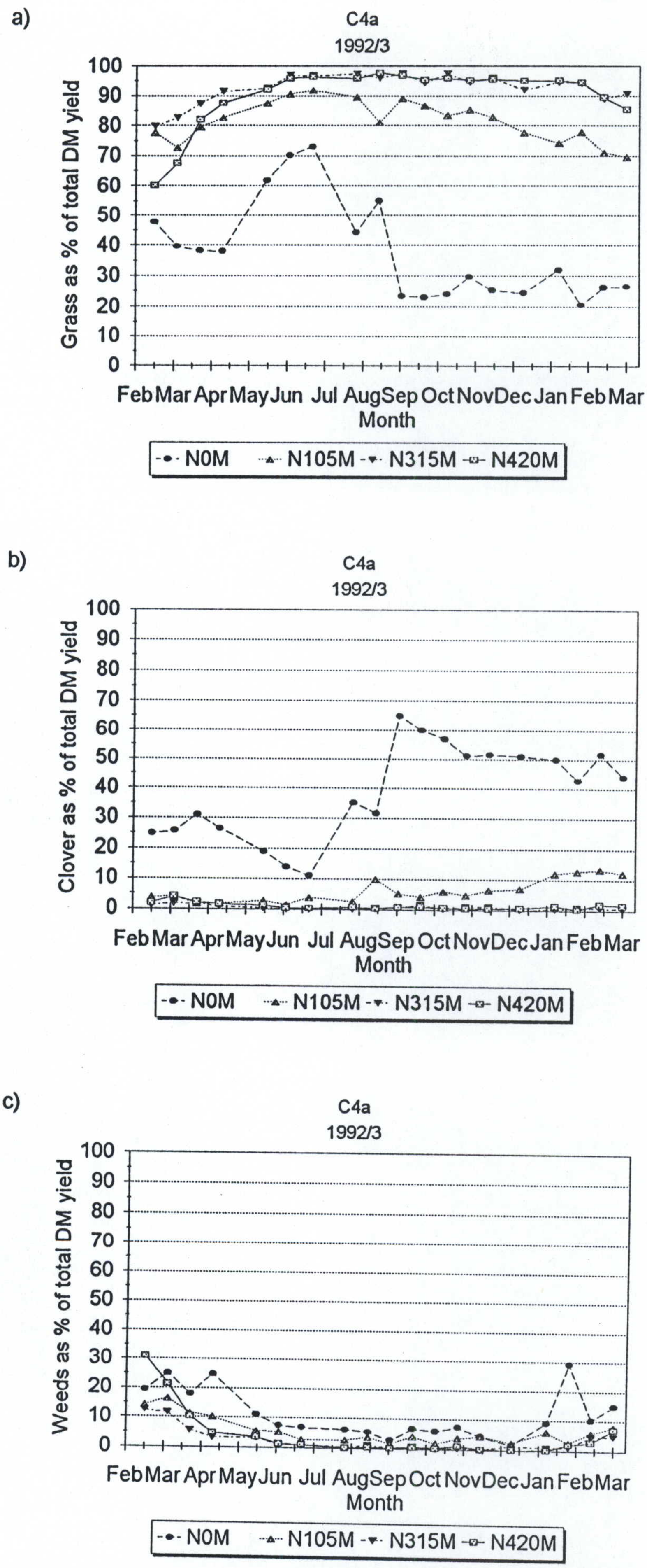


Figure 2.20 The effect of N fertilizer rates on the seasonal species composition of a perennial ryegrass/clover pasture (second year, 1992/3). The proportion (% of total yield) of the grass (a), clover (b) and weed (c) components are presented.

end of the 1991/2 year in the N450M treatments (Figure 2.19a) was most likely due to sward damage from overstocking (trampling). The damaged to the grass component resulted in bare patches in the pasture which were invaded by weeds (Figures 2.19c).

In the second year (Figure 2.20a) grass proportions increased with the onset of the cool season and declined marginally after the winter period. A clear suppression by N fertilizer on the spread of clover in a mixed sward was observed in the both years. In the absence of N fertilizer (N0M), the clover component remained in roughly equal proportion to the grass in the second year (Figures 2.20 a & b). As expected, grass:clover ratios, in the N0M plots, changed marginally through the season, with grass predominating in the cool season and clover in the warmer.

Weed invasion of the trial remained low (Figures 2.19c & 2.20c), particularly subsequent to winter frosting, with highest weed invasions occurring during the warm seasons. Weeds were controlled with Basagran (bendioxide) about 4 weeks post-planting.

The effect of N fertilizer on grass:clover rations will be discussed in more detail in a separate section. However, the data above concur with many other local studies, where increasing rates of N fertilizer result in a reduced clover component (Strijdom 1979; van den Berg & Kruger 1989; van den Berg *et al.* 1990).

3.4 Conclusions

The data presented clearly show the benefits on including clover in a pasture. Not only were yields consistently higher in grass/clover plots than at equivalent N fertilizer rates on pure grass pastures, but pasture quality would have been improved. An important observation was the lack of significant yield difference between the N0M and N315M treatments. The implication is that as long as clover is present in the pasture in sufficient quantity, a savings of about 350 kg N/ha/yr may be effected by total reliance on the N contribution from the clover. However, as a greater number of animal grazing days were achievable by the addition of high rates of N fertilizer, the final choice of N fertilizer rate must be based on economics.

At current market prices, the yield difference between the N600G and N420M treatments was sufficient to result in the N600G being R137.89/ha more profitable. The economic evaluation data suggest that, for a dairy system, N fertilizer rates of 400 to 430 kg N/ha/yr should be recommended for a perennial ryegrass/clover pasture. However, economic trends should be carefully monitored for each situation, as the economics of the NOM treatments was equivalent to reasonably high rates of N fertilizer. In addition, the economics of the NOM treatments may change with different pasture management and animal production systems (viz. the extrapolation of data from the sheep-grazed pastures in the current study to a dairy economic evaluation).

The N fertilizer demand of perennial ryegrass was highest in spring, with pasture yields responding positively to N fertilizer rates up to 60 kg N/ha/application. Without clover, perennial ryegrass yields continued to respond to monthly N top-dressings of 60 kg N/ha between December and January. The trampling damage, noted at the higher N fertilizer rates in spring, may be avoided by careful grazing management, or by harvesting selected camps for grass silage. Alternatively, if the additional forage is not required, reducing N fertilizer applications during the early spring period will result in lower yields.

4 The nitrogen requirements of grazed tall fescue (*Festuca arundinacea* cv. Demeter) pastures, with and without white clover (*Trifolium repens* cv. Ladino)

4 The nitrogen requirements of grazed tall fescue (*Festuca arundinacea* cv. Demeter) pastures, with and without white clover (*Trifolium repens* cv. Ladino)

4.1 Introduction

The first commercial tall fescue (*Festuca arundinacea* Schreb.) cultivars, Kentucky 31 and Alta fescue, were released in the USA in 1943 and 1940, respectively (Buckner *et al.* 1979). Soon after its release Kentucky 31 became a popular pasture in the higher potential areas of South Africa (Scott 1967).

Tall fescue, in its natural state, is found growing in damp pastures and wet areas throughout Europe and North Africa (Buckner *et al.* 1979). Consequently, tall fescue pastures are usually recommended for low lying sites, where soils tend to be poorly drained (Bartholomew 1991).

Tall fescue has, however, been associated with low palatability (Cross 1987) attributed to the presence of alkaloids, mainly *perloline,* in the plant (Gentry *et al.* 1969). Gentry *et al.* (1969) also reported significant increases in perloline content with N fertilizer use. However, the alkaloid content of tall fescue was notably reduced in older plants and in tall fescue hay. Perhaps, as a result of these findings, tall fescue is traditionally planted for dryland foggage or hay in Natal.

Gentry *et al.* (1969) reported sufficient genetic variability within tall fescue to facilitate genetic selection. Since these early years plant breeders have paid much attention to improving both the physical and chemical (alkaloid) palatability of this grass (Buckner *et al.* 1979; Asay *et al.* 1979). Modern cultivars of tall fescue have shown marked improvements in overall acceptability to livestock, with a large number of farmers in the higher rainfall areas of Natal successfully using grazed tall fescue pastures in their animal production systems. In South Africa only two cases of endophyte fungus (*Acremonium coenophialum*) infection have been reported in tall fescue pastures. The seed used in the current investigation, and certainly that sold on the open market in South Africa, must be certified endophyte free by law.

Tall fescue has long been known for its compatibility with white and red clovers (Scott 1967; Matches 1979). Due to the greatly improved animal production potential from modern cultivars of tall fescue (Matches 1979) and their long-term perenniality, tall fescue pastures are gaining popularity as an alternative to annual ryegrass, particularly on heavy bottom-land soils.

The N requirements of tall fescue and tall fescue/clover pastures are poorly researched in Natal. In the USA, positive yield responses of a tall fescue pasture have been shown up to N fertilizer rates of 896 kg/ha/yr, although the last increment of 448 kg N/ha produced only an additional 890 kg DM/ha (Jensen 1970 cited by Matches 1979). Most of the studies reviewed by Matches (1979) report maximum DM yields of between 9.4 and 15.5 t/ha/yr, at N fertilizer rates of between 358 and 448 kg N/ha/yr.

Total dry matter yields and protein content of all fescue pasture increase when grown in combination with clover (Matches 1979). However, the addition of N fertilizer has frequently resulted in a reduction in the clover component of the pasture, particularly at higher rates of N fertilizer (Frame 1973).

The study reported on here had the objective of providing quantitative data on the N fertilizer response of a sheep-grazed tall fescue pasture, with and without white clover.

4.2 Methods

Data were extracted from selected trials described under Section III, 1.2 (page 45), namely the C4b site in the 1991/2 year (Table 2.2, page 47 & 48). The procedures followed are described in Section III, 1.2, with the trial design and layout detailed in Appendix 2 and 3.

4.3 Results and discussion

Annual total yield

The data in Figure 2.21 show the effect of the N fertilizer treatments on the quantity of DM removed by sheep from a tall fescue pasture, with and without clover. The yield responses observed in Figure 2.21 show a largely linear response to increasing rates of N fertilizer, in both the pure grass and the mixed grass/clover treatments. Optimal N fertilizer rates (X_{10}) were not calculated, as no indication of maximum attainable yield could be gained from the data. The linear regression fitted to the mixed grass/clover response was non-significant ($P>0.05$; $n=16$) and should be viewed with due caution. The regressions presented in Figure 2.21 were based on four replicates of each data point presented in the graph.

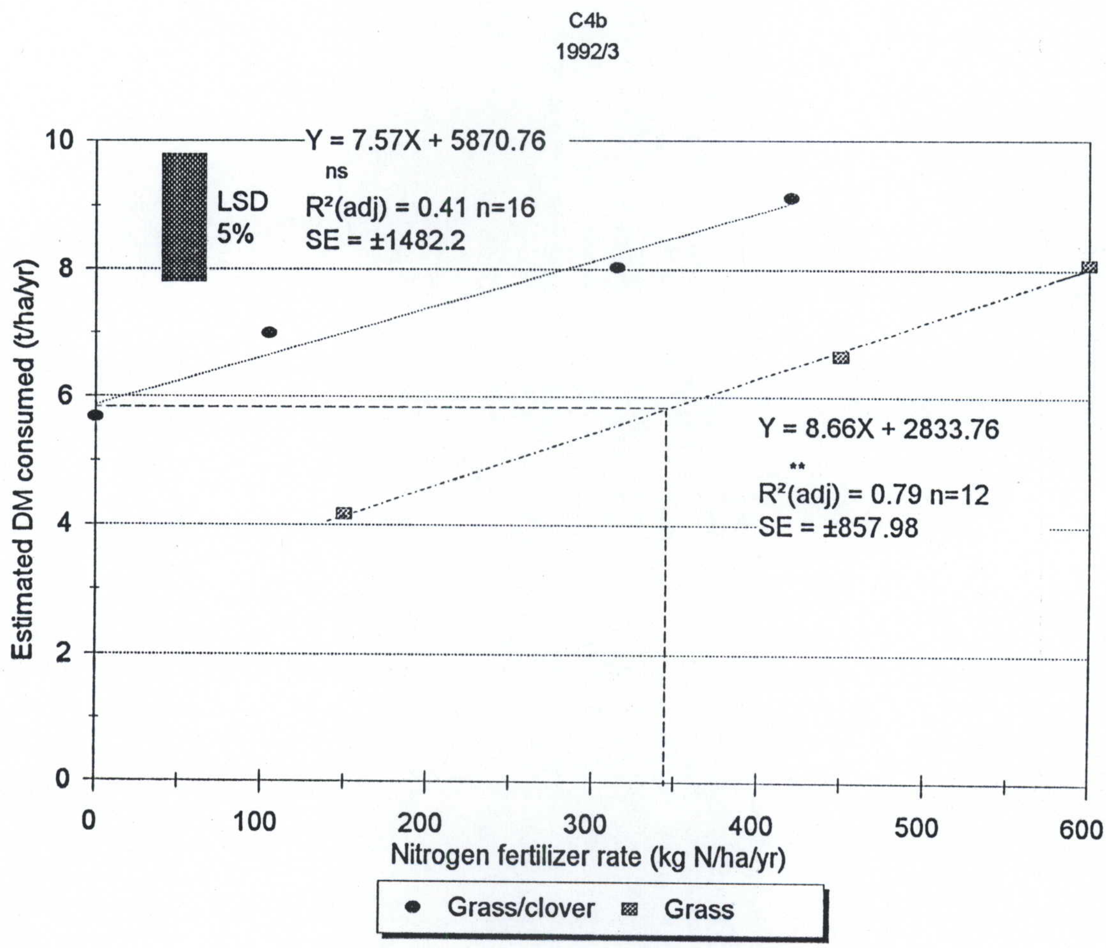


Figure 2.21 The effect of increasing rates of N fertilizer on the estimated annual total ammount of DM removed by sheep from a tall fescue pasture. Data are presented for three rates of N on a pure grass pasture and four rates on a mixed grass/clover pasture.

The linear regression fitted to the pure grass pasture data (Figure 2.21), although significant ($P<0.01$; $n=12$), has a limited range of applicability; extrapolation outside this range would be questionable. The slope and intercept of the linear regressions remained unaltered, irrespective of fitting through the means, as presented in Figure 2.21, or through the individual data points.

The slope of the yield response was low for both the pure grass (8.7) and the grass/clover (7.6; Figure 2.21) treatments. The steeper response in the pure grass plots, relative to the grass/clover plots, could be due to a high clover N contribution at the lower N rates and lower N contribution at higher rates in the grass/clover plots. Consequently, the Y intercept would be greater (5.9 t/ha) in the grass/clover pasture than in the pure grass pasture (2.8 t/ha), suggesting a DM yield response of 3.1 t/ha to the clover N. Frame (1973) reported maximum N response slopes, from a tall fescue/clover pasture, of between 13.0 and 17.9 kg DM/kg N in the first year.

Of particular relevance to the study were the greater yields achieved from mixed grass/clover plots than the equivalent pure grass treatments, even at the higher rates of N application; these trends were noted in the reviews of Matches (1979) and the data of Frame (1973). As this trend was not as evident in the perennial ryegrass trial (C4a), it could be concluded that the more tufted and upright growth habit of tall fescue allows greater compatibility with clover, thus allowing clover to contribute to the overall yield even at high N rates. This will be discussed in more detail later. In order to estimate the contribution of the clover to the overall pasture, the X-intercept of the grass/clover regression (5871 kg DM/ha/yr) was used as the Y value for the pure grass regression (*i.e.* dotted line in Figure 2.21). From the above calculation the inclusion of white clover in the tall fescue pasture (no N fertilizer) was equivalent to the addition of 351 kg N/ha/yr as fertilizer N.

As in the perennial ryegrass trial, the data were divided into the April to October and November to March response periods; these are presented in Figure 2.22 and 2.23, respectively. In Figure 2.22 a linear response to increasing rates of N fertilizer is once again observed from the mixed grass/clover plots. The pure grass plots exhibited a quadratic yield response, indicating a possible Y_{max} at the N600G rate; effectively 420 kg N/ha over the April to October period.

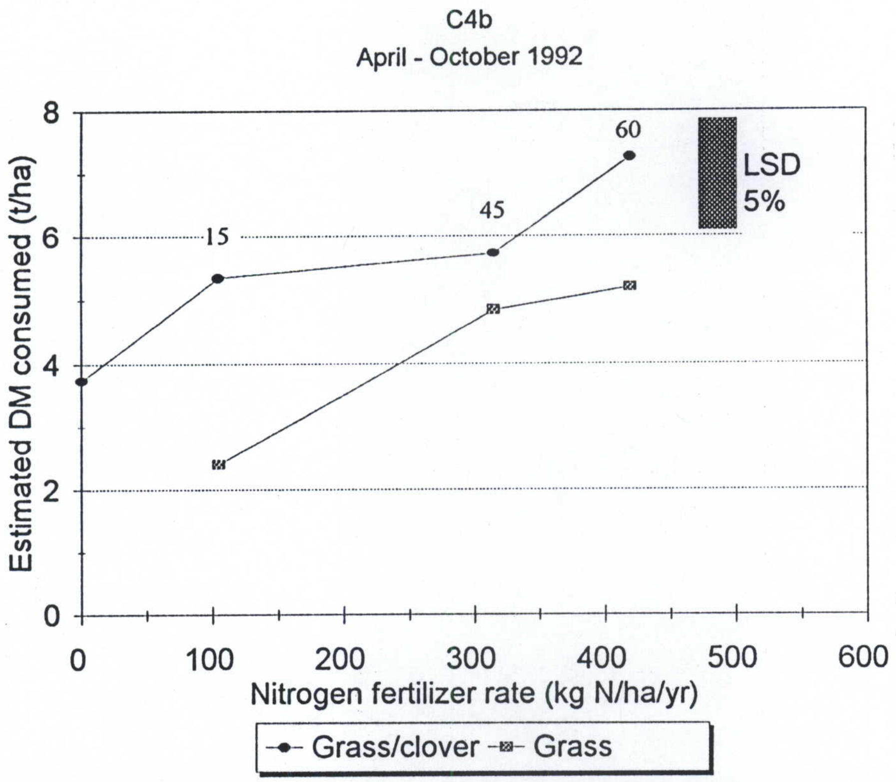


Figure 2.22 The effect of increasing rates of N fertilizer on the estimated DM yield removed by sheep from a tall fescue pasture, from April to October 1992. Data are presented for three rates of N on a pure grass pasture and four rates on a mixed grass/clover pasture. Values printed on the graph indicate the quantity of N applied at each topdressing.

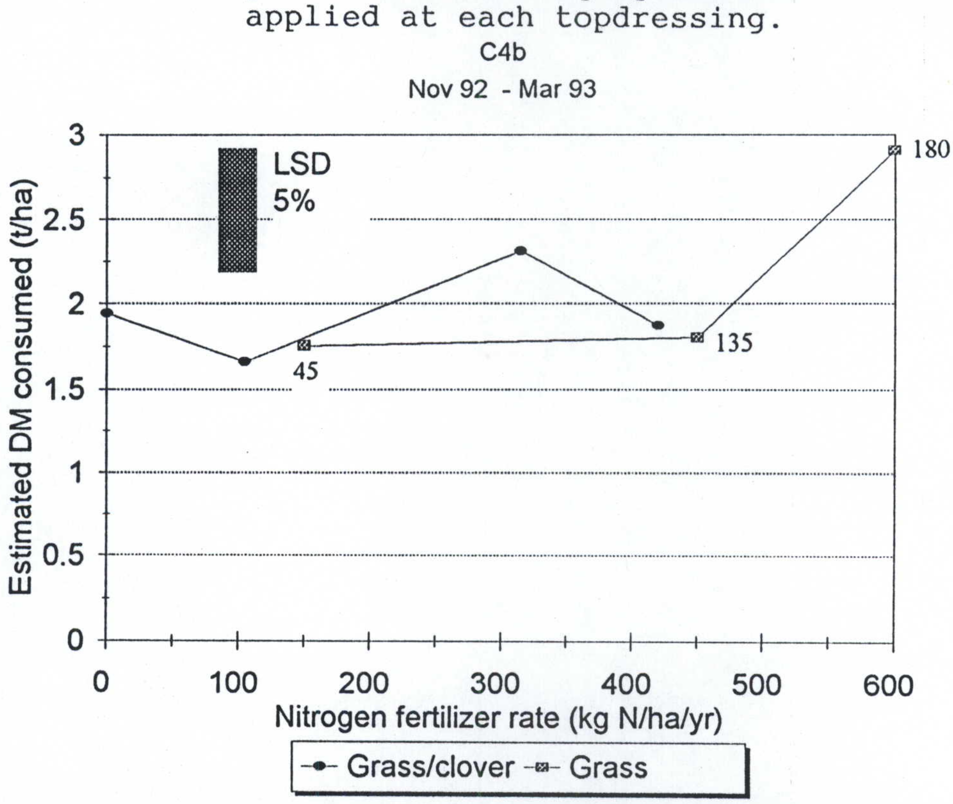


Figure 2.23 The effect of increasing rates of N fertilizer on the estimated DM yield removed by sheep from tall fescue and tall fescue/clover pastures, from November 1992 to March 1993. Data are presented for three rates of N on a pure grass pasture and four rates on a mixed grass/clover pasture (no N fertilizer applied). Values printed on the graph indicate the total N applied over the period (November to March), applied in three equal top-dressings.

Over the summer period (November to March; Figure 2.23) there were no significant yield differences between the mixed grass/clover treatments (receiving no N fertilizer). The pure grass plots showed no significant yield differences between plots receiving 45 kg N/ha (3 dressings of 15) and 135 kg N/ha (3 dressings of 45) between November and March. However, a significant ($P<0.05$) yield response was noted when a further 45 kg N/ha (3 dressings of 60) was applied. This trend was also noted in the perennial ryegrass trial (C4a; Figure 2.14), indicating a high N demand in the pure grass sward over this growing period.

Economic optimum N rates

In subjecting the data in Figure 2.21 to economic evaluation, actual yields were used as regression equations were not considered to provide accurate predictions. The economic data and calculations are presented in Appendix 10.

Highest economic returns were estimated at the N420M N rate, showing profits (TVP-TC) of R2,564.50/ha, with profits of R2,099.76/ha at the N315M rate. The N0M treatment was comparable to the N600G and N105M treatments, with profits of R1,303.97/ha, R1,484.60/ha and R1,914.61/ha, respectively. In general, the pure grass treatments were least profitable (N450G = R894.06/ha), with the N150G making a loss of R-10.64/ha.

Beef production, determined according to the system described in Section III, 2.2 (page 56), remained uneconomic.

These profit structures would, however, be expected to change as the clover component increases with time. An improved contribution from the clover would favour the clover-based pasture; a trend noted in the second year of the perennial ryegrass trial (C4a).

Animal grazing days

Total sheep (corrected to 60 kg) grazing days per hectare were calculated for each N fertilizer treatment (Section III, 1.2, page 45) and presented for the 1992 year (Figure 2.24). A largely exponential increase in grazing days/ha was noted, with the number of grazing days little different at the lower N fertilizer rates. A marked increase in grazing days was noted between the highest fertilizer rates and all lower rates of N application, in both the pure grass and grass/clover plots. At the lower N fertilization rates, higher grazing days were achieved from the mixed

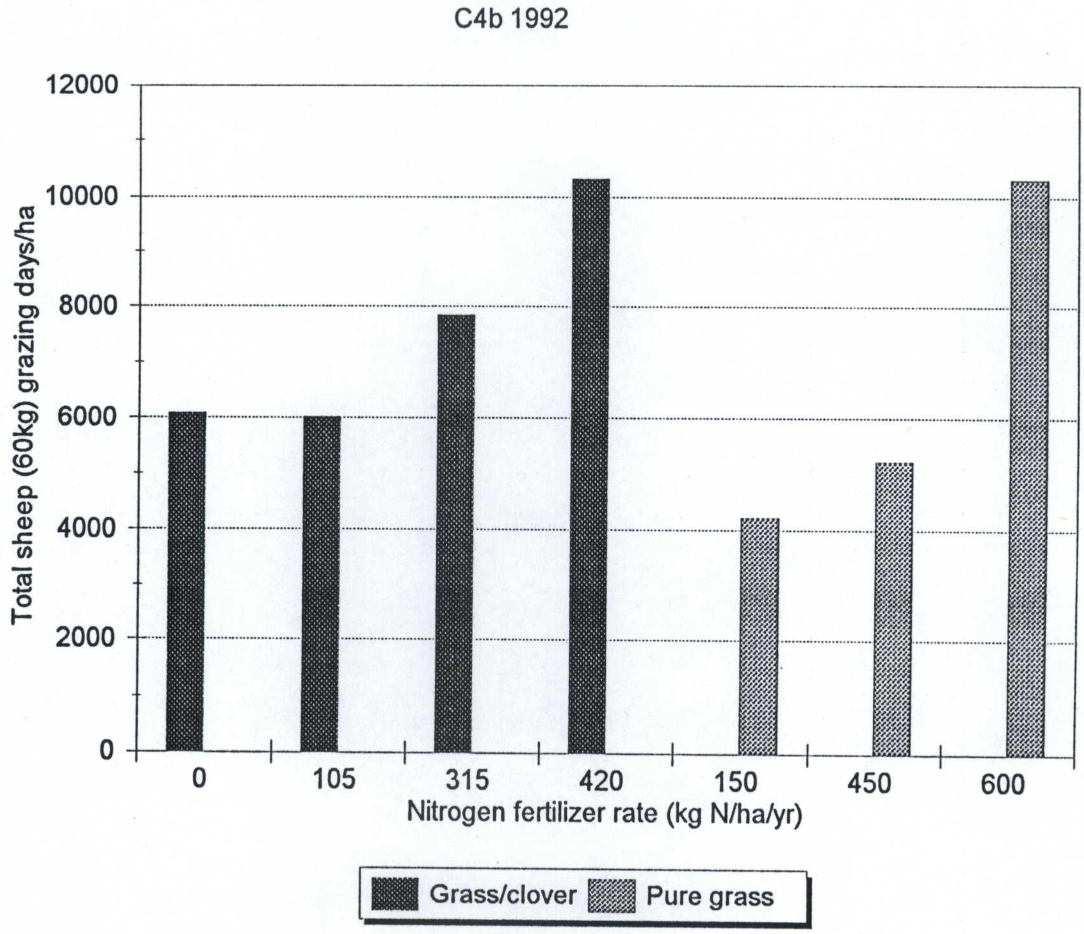


Figure 2.24 The effect of N fertilizer rates on total sheep (corrected to 60kg) grazing days per hectare, on a tall fescue/clover pasture.

(grass/clover) plots than the equivalent N rates on the pure grass plots. The extra grazing days from the grass/clover plots would be expected based on the higher DM yields from these grass/clover plots, relative to the pure grass plots at equivalent N fertilizer rates.

Edwards (1981) warned that, unless linked to animal performance, grazing days may be of little value in evaluating pasture performance *i.e.* animals may have been losing weight at the 450 kg N/ha/yr rate while gaining weight at the lower N rates. Although the trial design provided no estimate of animal performance, the sheep maintained mass on all treatments over the duration of the trial.

The marked increase in grazing days, attainable by the addition of N fertilizer, justifies the use of high rates of N fertilizer on tall fescue pastures as a means of pasture intensification. The addition of white clover to a tall fescue pasture is further justified by the increase in grazing days achieved, particularly at lower rates of N application.

Monthly yields

The estimated monthly DM consumed from a tall fescue/clover and pure tall fescue pasture is presented, for the 1992/3 year, in Figures 2.25 and 2.26, respectively.

The data in Figure 2.25 show little yield response to increasing rates of N fertilizer for much the year. However, during the peak growth period in spring (September to October) a marked yield response was noted. In August the N315M plots yielded significantly ($P<0.05$) higher than the N0M plots. In mid-September the N420M treatment yielded significantly ($P<0.05$) higher than both the N0M and N315M treatments and the N0M and N105M treatments in mid-October. Little difference was noted between the N105M and N315M rates during the spring period. During the summer period (November to February) treatment effects appeared minimal, with no significant differences noted. The high LSD's in September were as a result of the sheep missing two grazing replicates due to annual shearing.

In the pure grass treatments (Figure 2.26) there were significant ($P<0.05$) differences in yield response between the N600G rate and the N150G rate in April, May and mid-October. The N450G treatment was significantly higher than the N150G and N0M

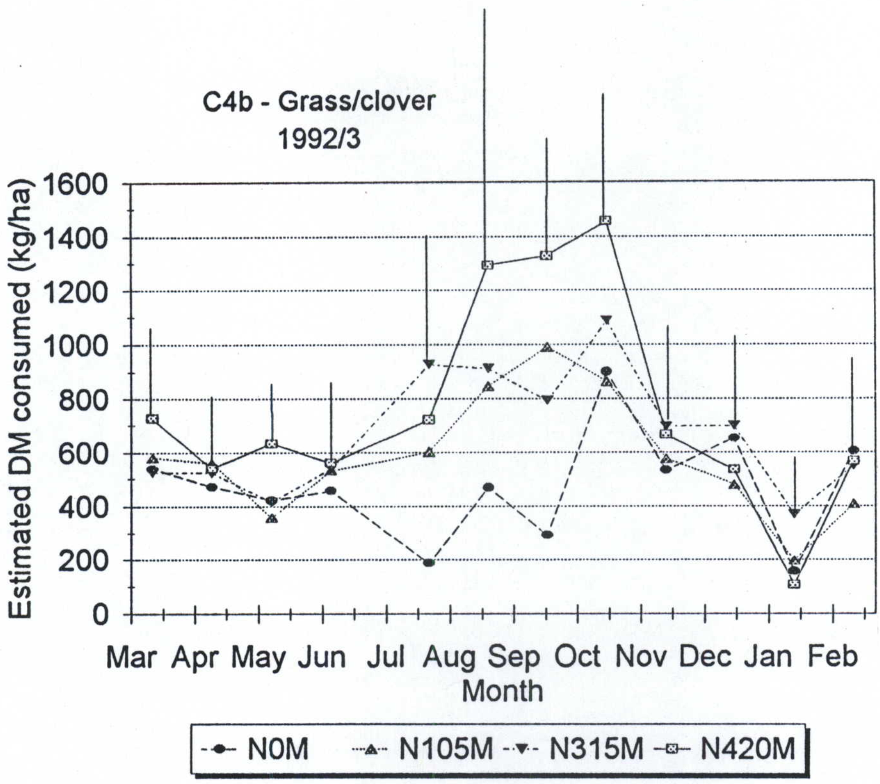


Figure 2.25 The monthly yield response (estimated DM consumed by sheep) of a tall fescue/clover pasture to increasing rates of N fertilizer (kg N/ha/yr). Vertical bars indicate the 5% LSD level.

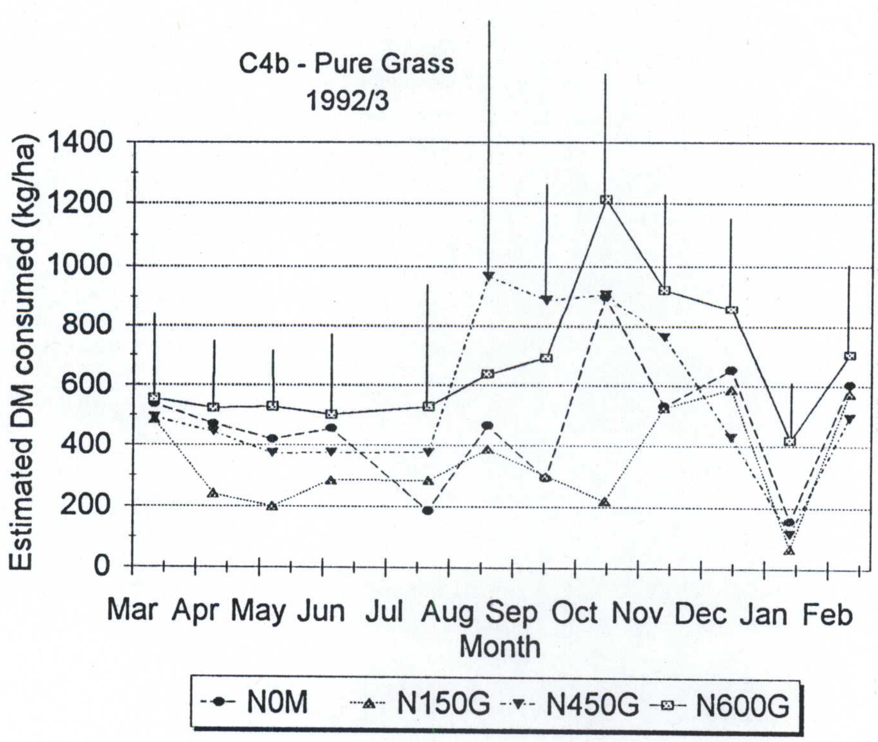


Figure 2.26 The monthly yield response (estimated DM consumed by sheep) of a pure tall fescue pasture to increasing rates of N fertilizer (kg N/ha/yr). Vertical bars indicate the 5% LSD level. The N0M treatments are included for comparison.

treatments in mid-September. Through the summer period no significant ($P<0.05$) differences were noted between the lower N rates. However, yields from the N600G plots were consistently higher than all other treatments for most of the late-spring and summer (October to February), significant ($P<0.05$) in November (N0M and N150G), December (N450G) and January (all other treatments).

Tall fescue pastures appear able to respond to high N rates through the warmer seasons on the year (three applications of 60kg N/ha). In most months the N0M treatment out-yielded the N150G treatment, emphasising the positive influence of clover on pasture yields.

Figures 2.27 a, b and c provide some indication of the relative contribution of the various components of the grass/clover sward to the overall yield. In contrast to the data of Figure 2.19, a clearer effect of increasing N fertilizer rates on increased grass proportions (Figure 2.27a) and decreased clover proportions (Figure 2.27b) proportions, was noted. As tall fescue tends to grow in a more upright and open sward than perennial ryegrass, particularly under intensive sheep grazing, more space may exist for white clover to establish itself between the grass tufts. The differences between these pastures and their compatibility with clover will be discussed in more detail in Section III, 5.2.

The contrast between the effect of N fertilizer on tall fescue:clover (Figure 2.27) proportions and perennial ryegrass:clover (Figure 2.19) proportions, could be that the white clover in the tall fescue trials was a year older than the tall fescue. As discussed in the description of methods (Section III, 1.2, page 45), with the initial establishment of tall fescue and white clover (C4b site) the trial was completely overrun with annual ryegrass in the 1991/2 year. Once the annual ryegrass had seeded, tall fescue was seeded back into the same plots which, now a year later, contained reasonable proportions of clover in all plots.

Weed invasion (Figure 2.27c) was greatest immediately after the re-introduction of tall fescue seed (April). However, these weeds were soon suppressed by a combination of the successful establishment of tall fescue and frost.

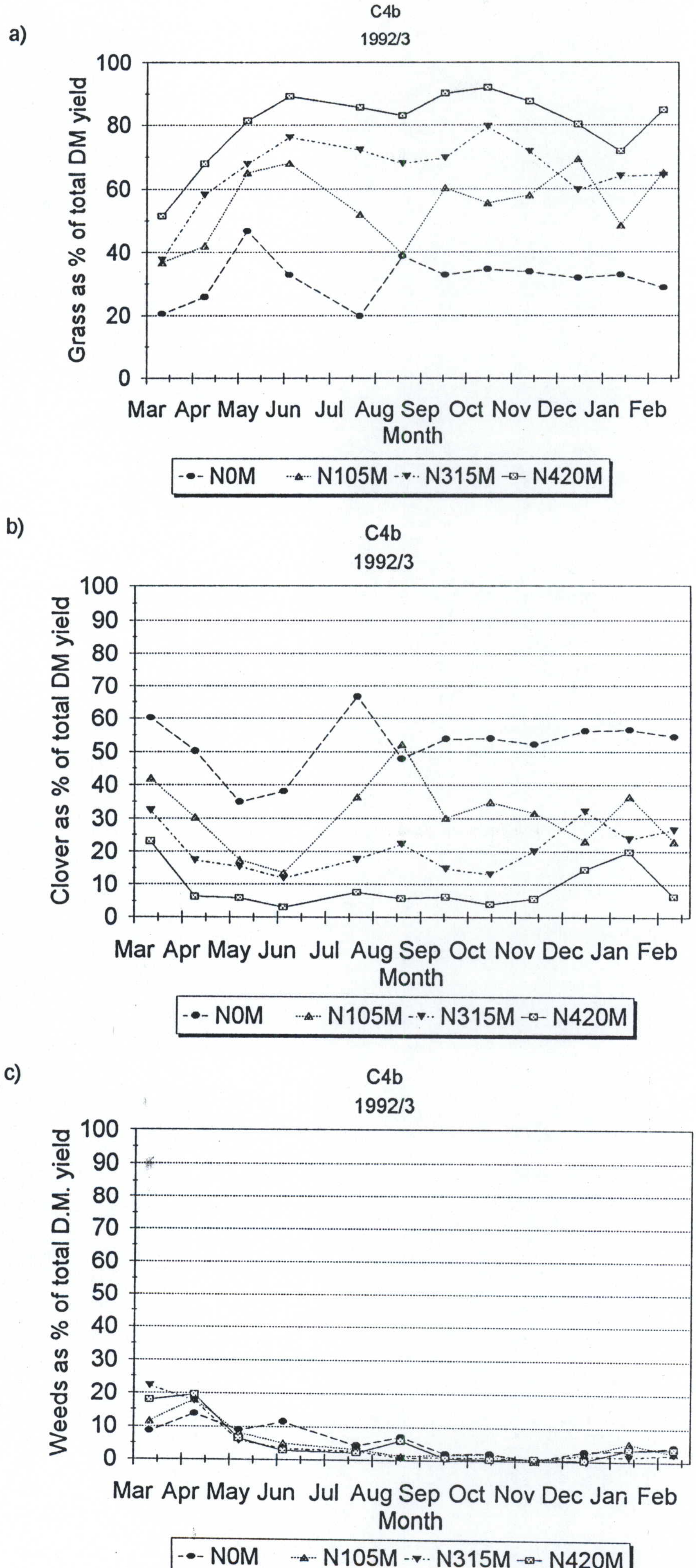


Figure 2.27 The effect of N fertilizer rates on the seasonal species composition of a tall fescue/clover pasture (establisment year, 1992/3). The proportion (% of total yield) of the grass (a), clover (b) and weed (c)

4.4 Conclusions

Tall fescue and tall fescue/clover pasture responded positively to N fertilizer rates up to 600 kg N/ha/yr. However, the slope of the yield response, in the C4b trial, was particularly low relative to published work. Reasons for this low response are not clear, but may relate to a particularly dry year with restricted irrigation.

Tall fescue appears to have a high demand for N fertilizer between mid-August and mid-October (spring). Dry matter yield responses were noted, during this spring period, to N fertilizer rates of 60 kg N/ha applied every 28 days. However, for most of the 1992/3 year, excluding spring, yield responses to N fertilizer on the mixed grass/clover sward were negligible. In contrast, pure tall fescue pastures yield positively to monthly N top-dressings of between 45 and 60 kg N/ha, with the highest N demand in spring.

Economic data support reasonably high rates of N fertilizer (315 to 450 kg N/ha/yr) for a dairy system. These high rates may decline as clover begins to make a more significant contribution at the lower N rates. The trial should be repeated for at least 3 to 4 years in order to investigate these trends more thoroughly.

Tall fescue appears highly compatible with white clover, even at reasonably high rates of N fertilizer; this, together with the perenniality of tall fescue, makes it a highly recommended pasture for livestock production, particularly in association with white clover.

SECTION III

GRAZING TRIALS (contd.)

5 The effect of nitrogen fertilizer management on sward dynamics in grazed temperate perennial pastures

5.1 The effect of N fertilizer rate on perennial ryegrass tuft diameters

Introduction

Methods

Results and Discussion

Conclusions

5.2 The effect of N fertilizer rate on clover stolon spread

Introduction

Methods

Results and discussion

Conclusions

5.3 The effect of N fertilizer rate on the N content of grass and clover roots

Introduction

Methods

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5 The effect of nitrogen fertilizer management on sward dynamics in grazed temperate perennial pastures

5.1 The effect of N fertilizer rate on perennial ryegrass tuft diameter

Introduction

One of the main drawbacks to the use of perennial ryegrass is the lack of true perenniality exhibited by the pasture (Bartholomew 1991; Eckard 1993). This lack of perenniality has been reported from both temperate (Mathew *et al.* 1991; Eckard 1992) and tropical climates (Eckard 1992; Eckard 1993; Fulkerson *et al.* 1993). The perenniality of perennial ryegrass results from the development of daughter tillers on mature parent tillers (Eckard 1992). Any factor leading to a reduction in the development of new tillers would obviously affect the perenniality of the grass. Increasing tuft diameter may be an important feature in the pereniality of perennial ryegrass, as tuft bases increase as new tillers develop (Frame 1992).

In an attempt to investigate the effect of the various N fertilizer treatments on the vigour of a perennial ryegrass pasture, tuft diameters were measured, under grazing, over a range of N fertilization levels. It was hoped that these would provided some index of tillering.

Methods

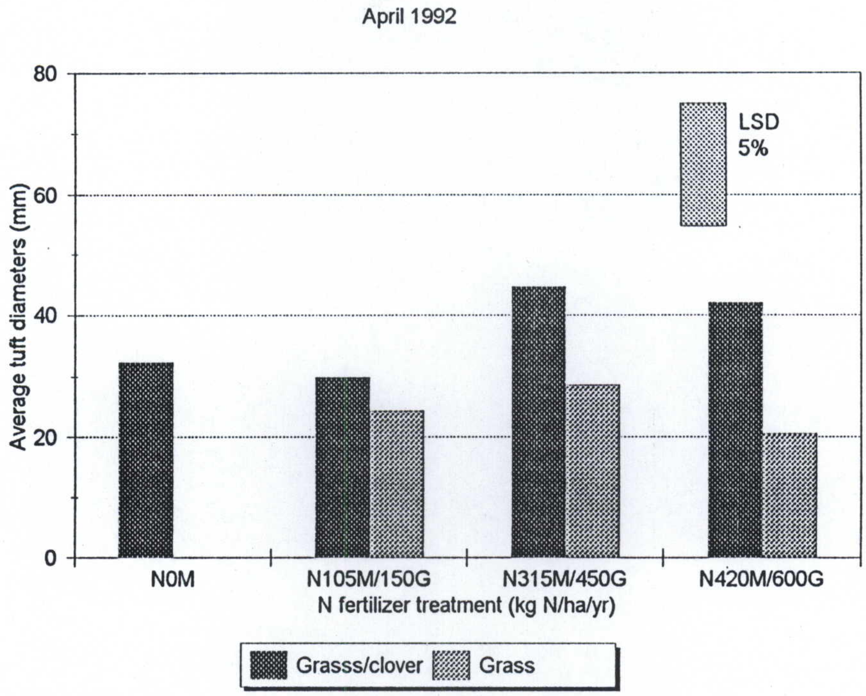
Data were extracted from selected trials described under Section III, 1.2 (page 45), namely the C4a site (Table 2.2, page 47 & 48).

The tuft diameter (average of the diameter in two directions) of twenty randomly selected perennial ryegrass plants, from each treatment in the C4a trial, was measured. Based on the trial design (detailed in Section III, 1.2, page 46) average tuft diameters (cm), sampled in April 1992 and October 1993, were subjected to an analysis of variance.

Results and Discussion

Figures 2.28a and b show the effect of the various N fertilizer rates on the average perennial ryegrass tuft diameter (mm), measured 13 and 31 months after establishment. Thirteen months after planting (Figure 2.28a), the N600G treatments had

a)



b)

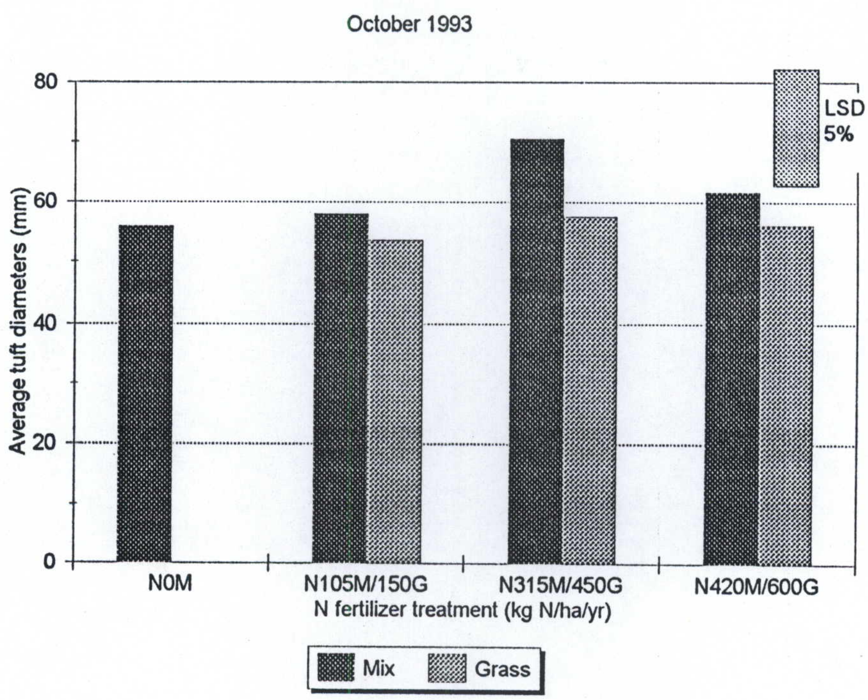


Figure 2.28 The effect of varying N fertilizer treatments on average grass tuft diameters in a sheep-grazed perennial ryegrass pasture with and without white clover. Data are presented for the April 1992 (a) and October 1993 (b) measurements.

significantly ($P<0.05$) smaller grass tuft diameters than the N315M and N420M treatments. Although there were no other significant differences in tuft diameter between treatments, the data indicate certain trends. Increasing the level of applied N resulted in increased tuft diameters up to the N315M and N450G rates, following which additional N resulted in reduced tuft diameters.

Furthermore, at 'comparable' N levels the perennial ryegrass had larger tuft diameters when grown with clover, than when grown alone. Although these differences were not as marked, these trends of increased grass tuft diameter in grass/clover pastures were still noted 31 months after planting (Figure 2.28b).

A marked increase in tuft diameters was noted, over all treatments (Table 2.4), as the pasture aged from 13 months (Figure 2.28a) to 31 months (Figure 2.28b). Largest increases in tuft diameters were noted from the pure grass treatments, particularly at the N600G fertilizer rate (Table 2.4). However, in the grass/clover plots greater increases in grass tuft diameters were noted at the lower N fertilizer rates (N0M and N105M). Differences between the grass tuft diameters from the grass/clover plots and the pure grass plots were greater in April 1992 than in October 1993. Perhaps due to larger inter-tuft spaces, grass tufts from the grass/clover plots may have been closer to their physiological size limit than tuft bases from the pure grass plots.

Table 2.4 The percentage increase in perennial ryegrass tuft diameters (cm) from 13 months to 31 months post-planting.

treatment	grass/clover %	treatment	pure grass %
N0M	42.1		
N105M	48.6	N150G	54.7
N315M	36.8	N450G	50.3
N420M	32.0	N600G	63.2

Conclusions

The trends observed, although largely non-significant, indicate possible N fertilizer effects on perennial ryegrass tuft diameters. The smaller tuft diameters observed in certain treatments could be due to plant competition, with tuft diameters being lower or higher than required for maximum yield at the lowest and highest N rates, respectively.

Higher grass tuft diameters in the mixed grass/clover treatments, may be due a combination of; a) greater spaces between grass tufts due to the growth of clover, and b) the higher overall N status of the grass/clover treatments, than their corresponding pure grass treatments, due to the N contribution of the clover component.

The data, although largely non-significant, indicate a possible effect of N fertilizer and clover on perennial ryegrass tuft size (diameter). Larger grass tuft bases in the grass/clover plots, particularly at moderate N fertilization rates, may be important factors in the maintenance of perenniality in perennial ryegrass pastures. The data highlight a need for an investigation of the effects of N fertilizer on tiller size, tiller number and tiller density of perennial ryegrass and perennial ryegrass/clover pastures, fertilized at varying rates of N.

5.2 The effect of N fertilizer rate on clover stolon spread

Introduction

As a general rule in mixed grass/clover pastures, clover proportions tend to decline with increasing rate of applied N fertilizer (Matches 1979; Strijdom 1979; Booysen 1981; Frame 1987; Smith 1987; Van den Berg & Kruger 1989; van den Berg *et al.* 1990; Section III, 1.3, 3.3 & 4.3). The application of N fertilizer to a grass/clover pasture does not suppress the clover component *per se*, but intensifies competition to the clover from the grass. Relative to clovers, grasses tend to show a steeper yield response to N fertilizer, thus allowing them to out-compete clovers during peak response periods (Frame 1987; Eckard 1992). It is generally agreed that the major effect of fertilizer N on a grass/clover pasture is to confer a competitive advantage for light, moisture and nutrients to the grass since growth of the upright deeper-rooting grass is stimulated more by N than the prostrate, shallow-rooting white clover (Frame 1973).

Ideally grass/clover pastures should contain sufficient clover to improve the quality of the herbage without detracting too much from the yield. On this basis, optimal grass/clover ratios are suggested at 60:40 (Booysen 1981). Roberts *et al.* (1989) reported that a minimum of 30% clover was required, in a grass/clover pasture, for clover to make a significant nutritional impact on livestock and N fixation by the pasture.

In order to maximise the N contribution of the clover component in the pasture, while still not restricting grass growth, N fertilizer would have to be applied in small applications and during periods of restricted clover growth (Booysen 1981; Frame 1987). One of the objectives of the C4 grazing trials was to establish a N fertilization rate, or strategy, at which both grass and clover growth may be optimised.

Methods

Data were extracted from selected trials described under Section III, 1.2, namely the C4a and C4b sites (Table 2.2, page 47 & 48).

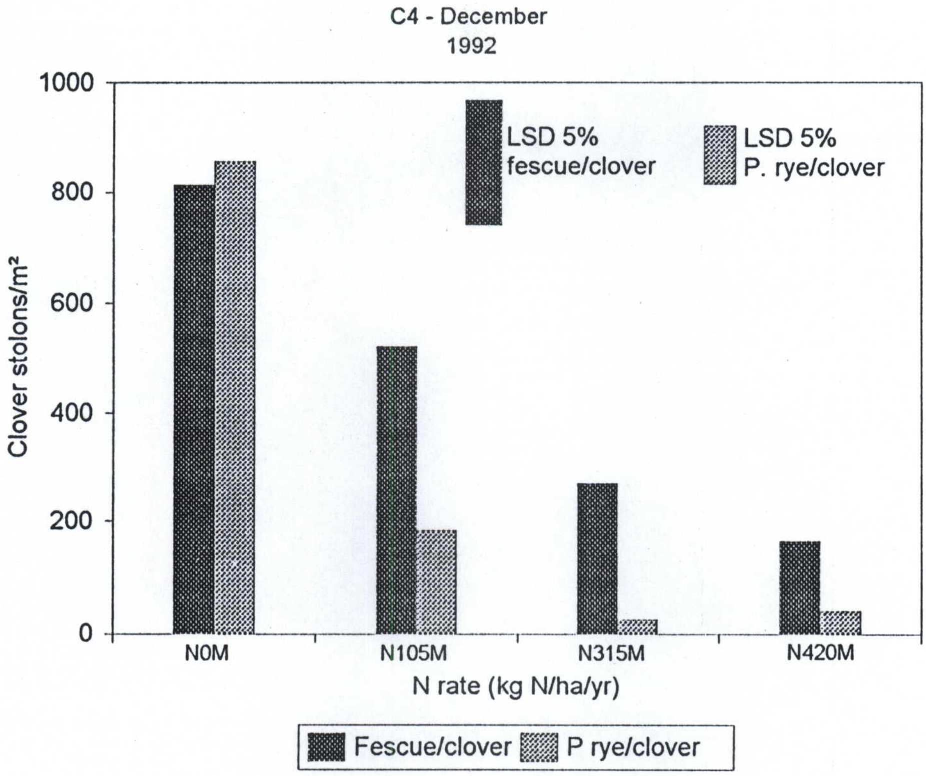
Clover stolon spread was measured in all grass/clover plots in the perennial ryegrass (C4a) and tall fescue (C4b) trials. The number of clover stolons per m^2 was estimated from five randomly placed quadrates (10 cm x 10 cm) per camp. Each quadrate was divided into 4 equal sub-quadrates, with clover stolons being counted crossing the sides of each quadrate (4 internal and 8 external sides). Data were converted to clover stolons per m^2, meaned for each camp (mean of 5 quadrates) and subjected to analysis of variance based on the design of the C4 trial.

Results and discussion

Figures 2.29a and b show the effect of the N fertilizer treatments on the number of white clover stolons per square meter, in December 1992 and May 1993, respectively. Data are presented for both the perennial ryegrass/clover (C4a) and tall fescue/clover (C4b) trials.

The data show a significant ($P<0.05$) decline in white clover stolons per square meter with increasing N fertilizer rate in all cases. In both the perennial ryegrass/clover and tall fescue/clover trials, in December 1992 (Figure 2.29a) and May 1993 (Figure 2.29b), the N0M plots contained significantly ($P<0.05$) more clover stolons per square meter than all other treatments, except for the N105M treatment in May 1993. In December 1992, the N105M treatments contained significantly ($P<0.05$) more clover stolons per square meter, in both the fescue/clover and perennial ryegrass/clover trials, than the N315M and N420M treatments. In May 1993, the N105M treatment of the fescue/clover trial contained significantly ($P<0.05$) more clover stolons per square meter than the N420M treatment.

a)



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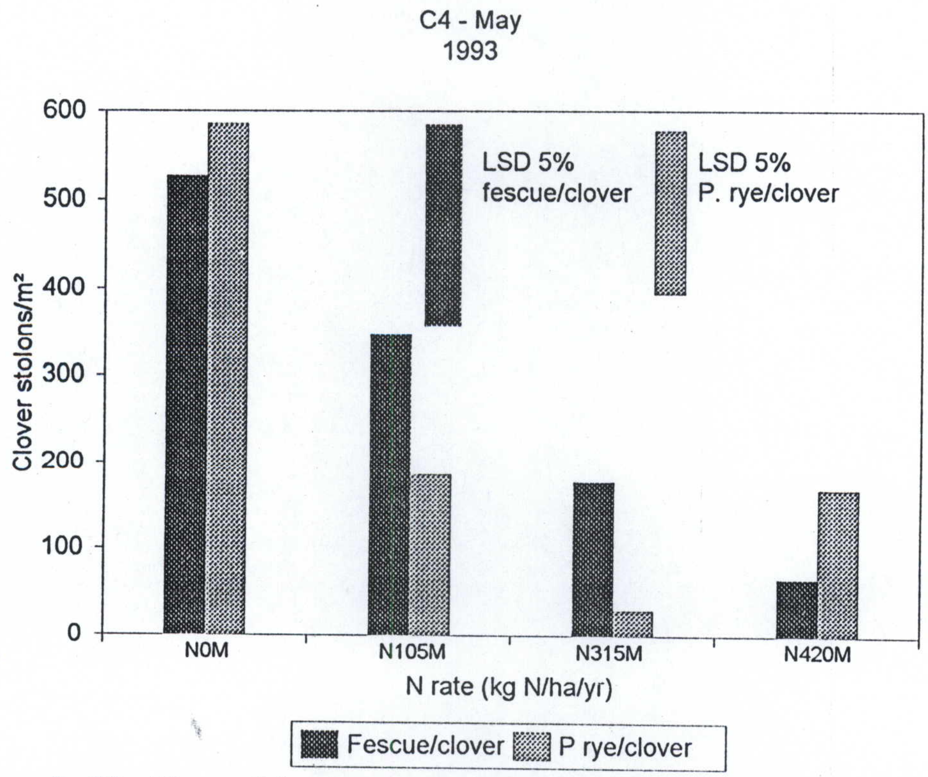


Figure 2.29 The effect of N fertilizer treatment on the number of clover stolons/m^2 under a sheep grazed perennial ryegrass/clover and tall fescue/clover pasture. Data are presented for sampling dates 21 (December 1992: 2a) and 26 (May 1993:2b) months after initial establishment (P.rye/clover = perennial ryegrass/clover).

Tall fescue appears to be more compatible with clover than perennial ryegrass at high rates of N fertilizer. In general, grass species and varieties which create densely tillered, close-knit swards are the least conducive to clover stolon proliferation and plant development, due to inhibition of the growth of clover growing points by shading at ground level (Frame 1992). The tufted upright growth habit of a tall fescue pasture appears to allow the spread of white clover to a greater extent than a N fertilized perennial ryegrass pasture. This effect may be more marked under sheep grazing than cattle, as the perennial ryegrass forms a more densely matted pasture under intensive sheep grazing. Frame (1992) reported marked differences between grass species in their compatibility with clover, reporting perennial ryegrass to be of 'intermediate compatibility'.

The increase in clover stolons/m^2 from the N315M to the N420M treatments in the perennial ryegrass trial in May 1993, although non-significant, could be due to clover invading bare patches resulting from the trampling damage (cf. *monthly yields*, Section III, 3.3, page 72). This may support the observation that N fertilizer does not suppress clover growth *per se*, but stimulates the grass component, which ultimately out-competes and shades the clover component (Frame 1987; Eckard 1992).

Further discussion is presented below on the grass and clover proportion data presented in Section III, 1, 3 and 4 (Figures 2.6, 2.19, 2.20 & 2.27 on pages 53a, 73a, 73b & 82a):

In the annual ryegrass clover trial (Figure 2.6b; C4b 1991/2; page 53a), clover proportions remained negligible for most of the year. In the absence of N fertilizer (N0M) clover proportions increased after the winter, peaking as the grass began seeding in October. However, clover never comprised more than 25% of total yield, even in the absence of N fertilizer (N0M).

In Figure 2.19b (C4a 91/2, perennial ryegrass/clover, page 73a) clover content in the N0M plots rose to just below 30% between January and March, a year after establishment. In the second year (Figure 2.20b, page 73b), clover proportions, in the N0M plots, dropped through the winter and rose to above 60% in September, dropping to about 45% in the March of 1993. In the N105M plots clover proportions increased marginally (above 10%) after January 1993. .

In the tall fescue/clover trial (C4b 1992/3, Figure 2.27, page

82a) clover proportions in the N0M and N105M plots were above 30% for most of the year, dropping below 30% through the winter period (Figure 2.27b). At the higher N rates (N315M and N420M) clover proportion remained below 30% for most of the year, peaking through the summer period. The more linear decline in clover proportions with increasing N fertilizer rate (Figure 2.27b), relative to the annual (Figure 2.6b) and perennial ryegrass (Figure 2.19b) data, could be attributed to both a) the greater compatibility of fescue with white clover, and b) the tall fescue having been oversown into a year old clover sward.

These data emphasise the need to determine management strategies which result in higher ratios of clover to grass. The ideal grass/clover ratios of 60:40 (Booysen 1981), or 30% clover in the pasture (Roberts *et al.* 1989), were seldom achieved.

From observations around the perennial ryegrass trials (C4a; border rows and passages), clover appears to remain in high proportion, even at high rates of N fertilizer application. However, these areas were N fertilized only three months after establishment, as and when the grazing was required. It would appear, therefore, that as long as the clover is given an initial establishment advantage (*i.e.* no N fertilizer for the grass), the application of subsequent strategic N top-dressings may have a greatly reduced adverse effect on clover proportions.

Conclusions

Perhaps due its more upright, tufted growth habit, tall fescue is more compatible with white clover than is perennial ryegrass. In general, however, higher rates of N fertilizer have a negative effect on white clover proportions in a grass/clover pasture.

Based on the above data and other observations, in order to maximise the clover component in an N fertilized grass/clover pasture the clover should be established first, then overseeded with grass once the clover has established. If the grass and clover are established together, then the pasture should not be fertilized with N until the clover is well established. Thereafter, N fertilizer should be applied strategically *i.e.* when clover growth is restricted by low temperatures, or if more forage is required.

5.3 The effect of N fertilizer rate on the N content of grass and clover roots

Introduction

One of the main mechanisms for the transfer of legume N, from the clover to the grass, is from nodules sloughing off clover roots. These nodules break down in the soil, releasing their N for uptake by the grass (Frame 1992).

In order to investigate the effect of N fertilizer on the N produced by root nodules, and on total N in grass roots, roots were analysed for their N content.

Methods

Root cores were taken in March and October 1993, from a single replicate in both the C4a and C4b trials. Cores (3cm diameter) were sampled, to a depth of 15cm, through the centre of grass tufts and clover plants. All soil was washed from the roots, roots were dried, milled and analysed for their N content by the Kjeldhal (AOAC 1980) method. As the samples were taken only from a single replicate, no analysis of variance was conducted. Data represent the mean of the five samples taken from a single replicate.

Results and discussion

In Figures 2.30 and 2.31 the N content of the grass and clover roots are presented for the perennial ryegrass (C4a) and tall fescue (C4b) trials respectively. No definite trends emerged in the data. However, the N content of grass roots from pure grass plots appeared to increase between the N150G and N450G treatments.

In general, the N content of clover roots was considerably higher than that of grass roots. This trend is expected due to the N fixing nodules present on the clover roots. Mytton *et al.* (1993) showed higher N levels in the soil cores taken from clover pastures than from pure grass pastures grown at low rates of N fertilizer.

Conclusions

The N content of the roots analysed appears low compared to herbage N content (cf. Section III, 6.3). Although there was no definite evidence of N fertilizer rates affecting N content of grass or clover roots, clover roots generally (excluding N420M, Figure 3.30b) contained higher N levels than the grass at all N rates.

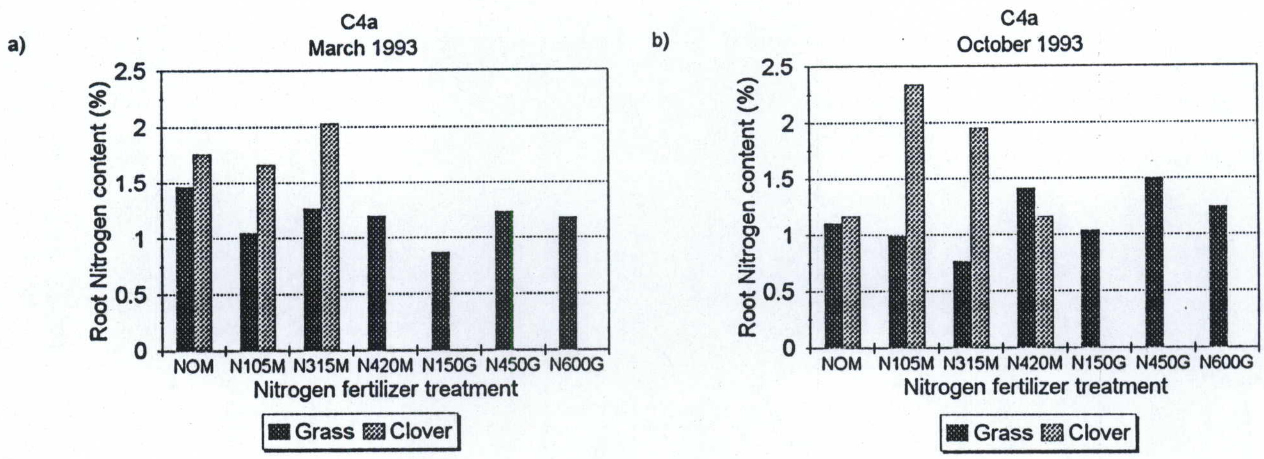


Figure 2.30 The N content of perennial ryegrass and white clover roots from a pasture fertilized at varying N fertilizer rates, sampled in a) March and b) October 1993 .

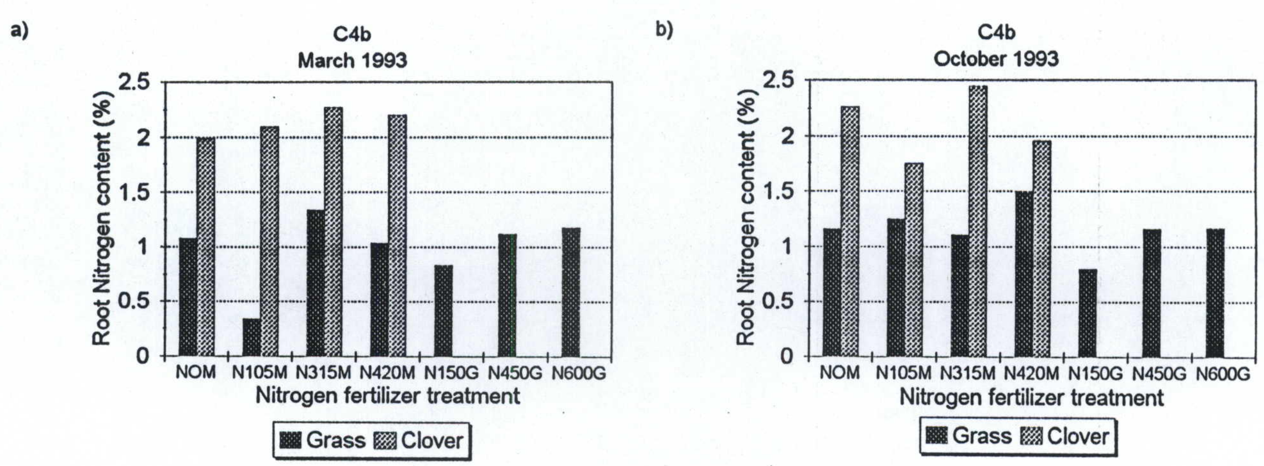


Figure 2.31 The N content of tall fescue and white clover roots from a pasture fertilized at varying N fertilizer rates, sampled in a) March and b) October 1993.

Assuming a large proportion of this N to be symbiotically fixed, particularly at the lower N fertilization rates, clover has valuable potential in building soil total N.

6 The effect of nitrogen fertilizer management on the herbage N content of three temperate grass/clover pastures

6.1 Introduction

The purpose of introducing clover into a grass pasture is both to supply 'free' N to the grass, and to provide superior protein in the clover herbage to livestock (Frame 1992). From the data presented in Section II, 2.3 and many other studies (Wilman 1970; Bartholomew & Chestnutt 1977; Ball 1979; Ehlig & Hagemann 1982; Anslow & Robinson 1986, Eckard 1993), N fertilizer appears to increase the N content of grasses in much the same way as yield is increased. White clover N content, however, shows little response to increasing rates of N fertilizer (Ball 1979). Attributed largely to a less efficient root system, temperate legumes tend to be less effective in taking up available soil N than are grasses (Vallis 1978).

The addition of increasing rates of N fertilizer to grass/clover pastures results in a linear decrease in clover N yield (Ball 1979). However, grass and total N yields (kg N/ha) from grass/clover pastures increase linearly with increasing N fertilizer rate (Ball 1979). Apparent N recovery from grazed grass/clover swards decreases quadratically with increasing N fertilizer rate (Baker 1986).

Seasonal variation in herbage N content is noted in most grasses. Matches (1979) reported highest N content, in tall fescue, in spring and autumn, with lowest herbage N levels in summer. Similar trends in herbage N levels were noted in annual ryegrass (Eckard 1986). In contrast to grasses, white clover N content does not vary greatly over the year, although slight increases in N content are noted in early spring (Ball 1979). The N content of clover is generally higher than that of grasses, although the addition of high rates of N fertilizer to the grass may result in grass N levels equal to those of clover (Frame 1992).

The amount of N fertilizer required by a pure grass sward to match the production of a grass/clover sward is in the region of 180 to 250 kg N/ha (van den Berg & Kruger 1989; Frame 1991), depending on management and environmental constraints. Estimates of biological N-fixation vary appreciably, but values between 100 to 200 kg N/ha/yr appear realistic (Strijdom 1979; Ball & Field

1987; van den Berg & Kruger 1989).

The objectives of the current investigation were: to determine the N fertilizer requirements, in terms of herbage N content (%) and N yield (kg N/ha), of annual ryegrass, perennial ryegrass and tall fescue pastures, grown alone or in combination with white clover.

6.2 Methods

Data were extracted from selected trials described under Section III, 1.2 (page 45), namely the C4a and C4b sites for the 1991/2 and 1992/3 years (Table 2.2, page 47 & 48).

All grass samples were analysed for their total N (%, DM basis) content, using the Near Infra Red Spectrophotometer (NIRS) technique of Eckard *et al.* (1988). The NIRS technique was calibrated, using samples from the C4a and C4b trials, against analyses using the standard Kjeldhal technique (AOAC 1980). Separate NIRS calibrations were developed for the annual ryegrass, perennial ryegrass and tall fescue pastures. White clover samples were analyzed by the standard Kjeldhal technique. Total N yield was calculated as the product of the annual total DM yield and mean N% content of the herbage. The efficiency of N usage was estimated by expressing the N yield in the herbage (kg N/ha/yr) as a percentage of N applied (kg N/ha/yr).

The grass N content data were subjected to analysis of variance based on the trial design. Due to the low clover content of most treatments, clover samples had to be combined over replicates to provide sufficient herbage for chemical analysis. Clover N content was, therefore, not analysed statistically, with presented data relating to means of duplicate analyses where possible.

6.3 Results and discussion

Average N content

The average N content of both annual ryegrass and clover (Figure 2.32) increased linearly as N fertilizer rate increased. Annual ryegrass N content was significantly ($P<0.05$) different between all treatments. The N content of the white clover, grown in association with annual ryegrass, responded positively to increasing rates of N fertilizer, indicating the ability of white clover to utilize

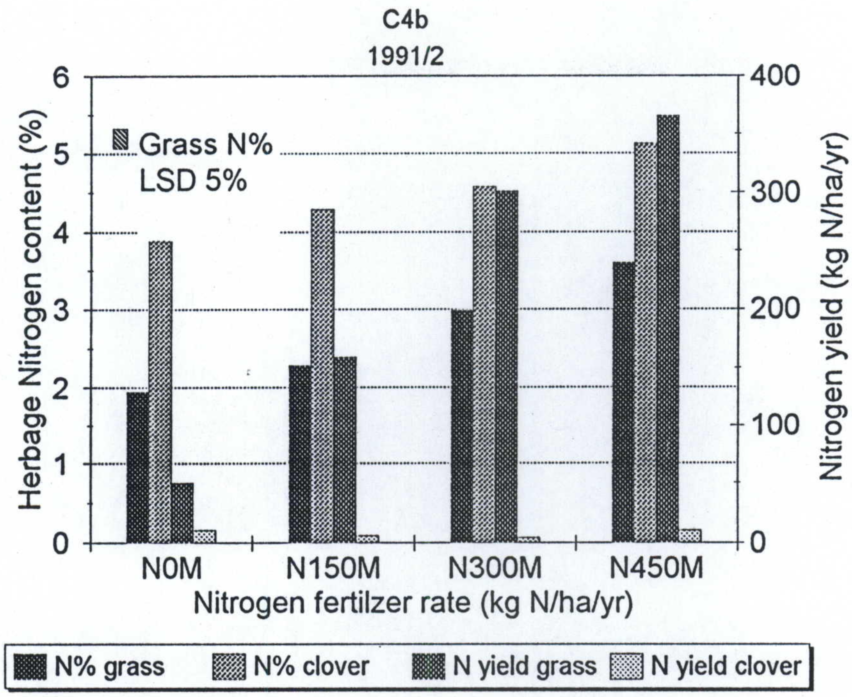


Figure 2.32 The mean herbage N content (%) and total N yield (kg N/ha/yr) response of annual ryegrass and white clover to increasing rates of N fertilizer (kg N/ha/yr). Vertical bars indicate the 5% LSD level, applicable to the grass N content only (see 6.2 in text).

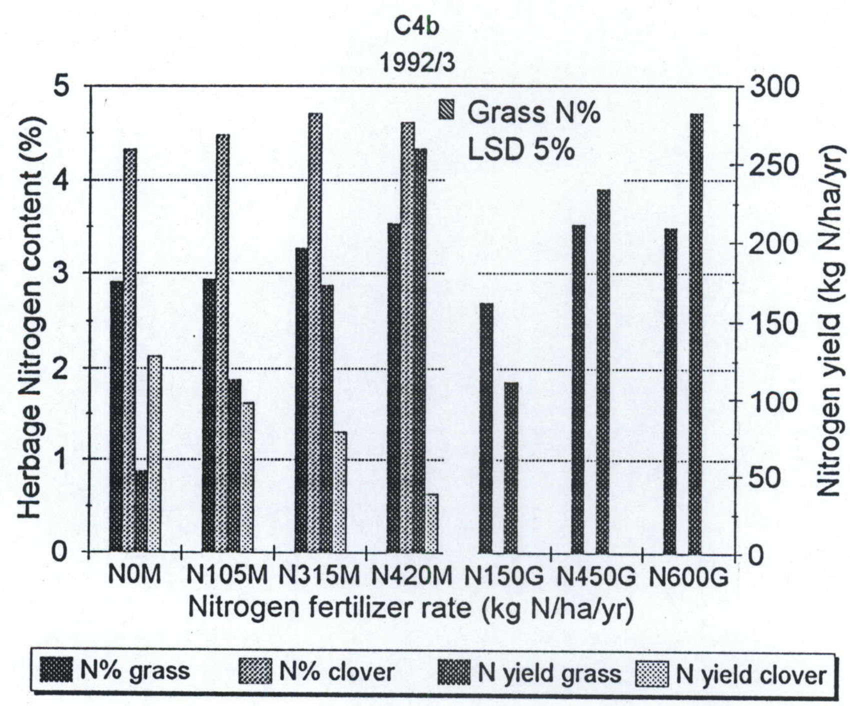


Figure 2.33 The mean herbage N content (%) and N yield (kg N/ha/yr) response of tall fescue and white clover to increasing rates of N fertilizer (kg N/ha/yr). Vertical bars indicate the 5% LSD level, applicable to the grass N content only (see 6.2 in text).

fertilizer N.

Grown in association with white clover, the average N content of tall fescue (Figure 2.33) and perennial ryegrass (Figure 2.34) increased significantly ($P<0.05$) as N fertilizer rate increased from the lowest (N105M; Figures 2.33 & 2.34b and N150M; Figure 2.34a) to the highest N application rates (N420M; Figures 2.33 & 2.34b and N450M; Figure 2.34a). No significant differences, in N content of tall fescue or perennial ryegrass, were noted between the N0M treatments and the first increment of N fertilizer, indicating a possible N contribution from the clover to the grass at the N0M treatment. The N content of white clover, grown in association with tall fescue (Figure 2.33), increased marginally between the N0M and N315M treatment, above which no further increase in N content was noted. Similar marginal increases in clover N content were noted in the clover grown in association with perennial ryegrass (Figure 2.34).

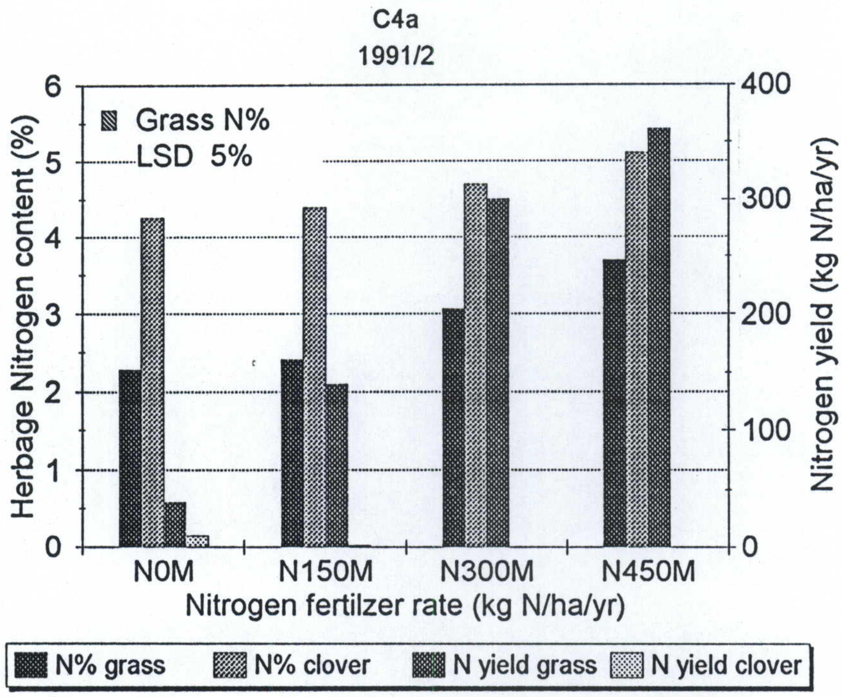
The average herbage N content of pure tall fescue (Figure 2.33) and pure perennial ryegrass (Figure 2.34b) increased significantly ($P<0.05$) between the N150G and N450G treatments. No further increase in tall fescue N content was noted as the N rate increased to the N600G treatment (Figure 2.33). However, the N content of the pure perennial ryegrass (Figure 2.34b) dropped significantly ($P<0.05$) as N fertilizer was increased from the N450G to the N600G treatments. At comparable N fertilizer rates, the N content of tall fescue (Figure 2.33) and perennial ryegrass (Figure 2.34b) was not notably different when grown in a pure sward or with white clover.

The N content of the white clover was markedly higher than that of annual ryegrass, tall fescue and perennial ryegrass in all cases (Figures 2.32, 2.33 & 2.34), emphasising the quality (protein) contribution of white clover to the overall grass/clover pasture.

Total N yield

As expected, based on the DM yield responses presented earlier, total N yields (kg N/ha/yr) of annual ryegrass (Figure 2.32), tall fescue (Figure 2.33) and perennial ryegrass (Figure 2.34) increased linearly with increasing N fertilizer rate. Due to the low proportion of clover in the treatments, clover N yield remained negligible over all treatments in the annual ryegrass (Figure 2.32) and perennial ryegrass (Figure 2.34) trials. Resulting from the higher clover proportions in the tall fescue/clover trial (C4b,

a)



b)

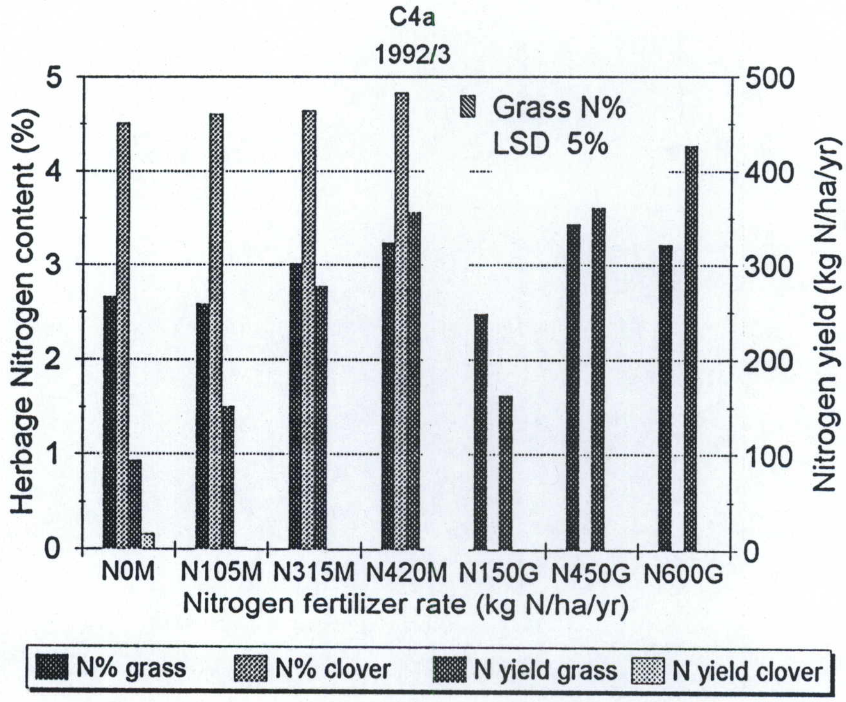


Figure 2.34 The average herbage N content (%) and total N yield (kg N/ha/yr) response of perennial ryegrass and white clover to increasing rates of N fertilizer (kg N/ha/yr), for the 1991/2 (a) and 1992/3 (b) years. Vertical bars indicate the 5% LSD level, applicable to the grass N content only (see 6.2 in text).

Figure 2.33), a negative linear effect of N fertilizer on clover N yield was noted. This negative effect of N fertilizer on clover N yields corroborates the trends observed in clover stolon spread (Section III, 5.2).

An indication of the efficiency (apparent N recovery) of applied N fertilizer was estimated (Table 2.5) by expressing the total N yield (kg N/ha/yr) as a percentage of the N fertilizer applied (kg N/ha/yr). Although the data presented in Table 2.5 ignore the contribution of soil N and N supplied by the clover, an indication of the relative N efficiency of treatments may be made.

Table 2.5 The efficiency of N fertilizer (kg N yield in herbage/kg N applied x 100) applied to three temperate pastures, with and without white clover.

	Perennial ryegrass/clover 1991/2			Annual ryegrass/clover 1991/2		
N rate	Grass	Clover	Total	Grass	Clover	Total
	%					
N150M	93.0	0.8	93.8	106.0	4.1	110.1
N300M	100.0	0.1	100.1	100.0	1.4	101.4
N450M	80.0	0.1	80.1	81.0	2.4	83.4
	Perennial ryegrass/clover 1992/3			Tall fescue/clover 1992/3		
N105M	143.0	1.9	144.9	108.0	92.0	200.0
N315M	88.0	0.1	88.1	55.0	25.0	80.0
N420M	85.0	0.2	85.2	62.0	9.0	71.0
N150G	108.0		108.0	75.0		75.0
N450G	80.0		80.0	52.0		52.0
N600G	71.0		71.0	47.0		47.0

Nitrogen recovery in the herbage of the annual and perennial ryegrass trials was approximately equal to applied N at the lower N fertilizer rates (N150M, N300M, N150G). However, as N fertilizer rates increased, to the maximum applied in each case, N recovery dropped by between 20 and 53% (Table 2.5). A higher clover content in the N105M plots of the tall fescue (31% clover; 1992/3) and perennial ryegrass trials (6% clover; 1992/3), resulted in N recoveries of 1.4 and 2 times the amount of N applied, respectively. The total N efficiency of the N105M treatment on the perennial ryegrass/clover (145%) and tall fescue/clover (200%) (bottom half of Table 2.5, in 1992/3) was also far greater than the equivalent N rate (N150G; refer to Section III, 1.2, Table 2.2b, page 48) applied to a pure grass pasture.

Nitrogen recovery by white clover, when grown in association with annual and perennial ryegrass, was negligible due largely to the low clover DM yields. However, the high N recovery by the clover when grown in association with the tall fescue, at low N fertilizer rates (92%; Table 2.5), provides some indication of the potential N contribution of clover to the overall pasture.

Seasonal N content

Annual ryegrass

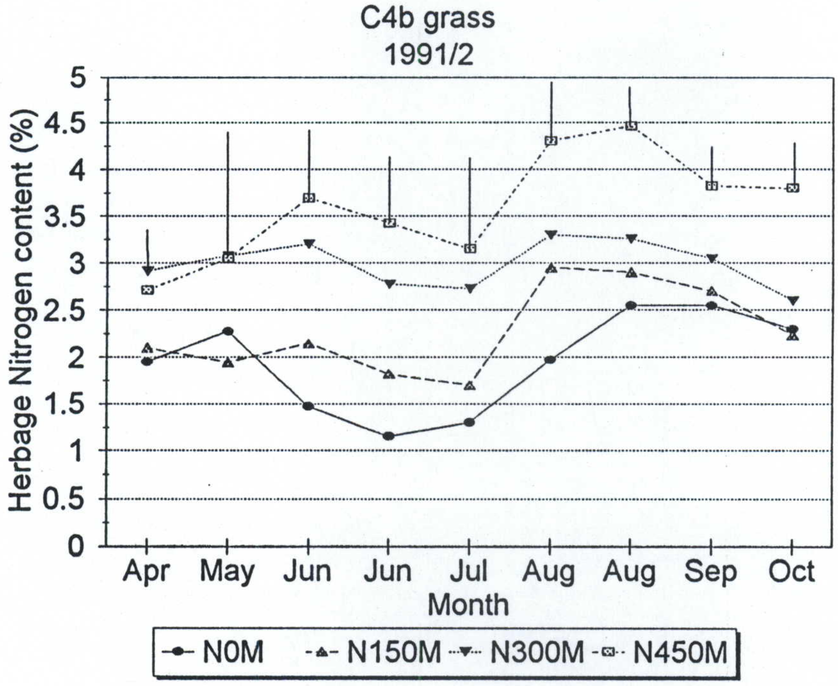
The seasonal N content of annual ryegrass, grown in association with white clover, increased significantly ($P<0.05$) with increasing N fertilizer rate (Figure 2.35a). With the exception of May, when there was no significant difference between treatments, the N content of the annual ryegrass from the N450M treatment was significantly ($P<0.05$) higher than both the N0M and N150M treatments, indicating a high N demand by the grass for N fertilizer. In addition, annual ryegrass from the N450M plots contained significantly ($P<0.05$) higher N levels than all other treatments between August and October (Figure 2.35a). The N content of the annual ryegrass (Figure 2.35a) was lowest in April and mid-winter (June and July), and highest in the spring period. The lack of significant difference, in annual ryegrass N content, between the N150M and N300M rates and the N0M plots from mid-August to October suggests a positive contribution by clover to the N content of the grass at lower N fertilizer rates at this time. Earlier data (Section III, 1.3, Figure 2.6c, page 53a) indicated increasing clover percentages, relative to annual ryegrass, from early August. The data presented in Figure 2.35b will be discussed under the sub-section dealing with white clover.

Tall fescue

Tall fescue N content, from pure grass plots (Figure 2.36a), was significantly ($P<0.05$) lower at the N150G rate than both the N450G and N600G rates in all months except spring (August to October; Figure 2.36a). No significant differences were noted in tall fescue N content between the N450G and N600G rates over the year.

The N content of tall fescue, when grown in association with white clover (Figure 2.36b), was significantly ($P<0.05$) higher at the N420M treatment than at the N0M and N105M treatments from May

a)



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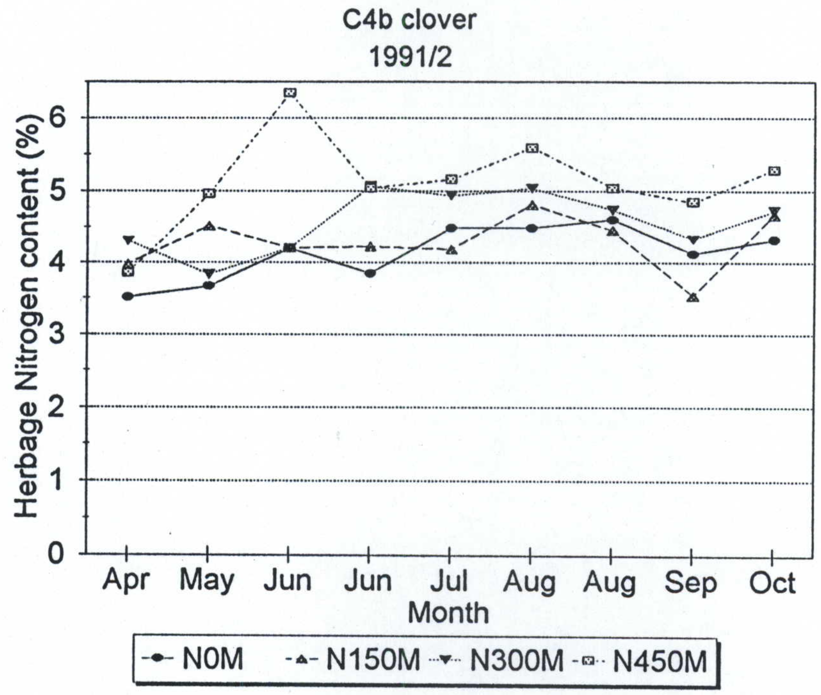


Figure 2.35 The seasonal herbage N (%) response of annual ryegrass (a) and white clover (b) to increasing rates of N fertilizer (kg N/ha/yr). Vertical bars indicate the 5% LSD level, applicable to the grass N content only (see 6.2 in text).

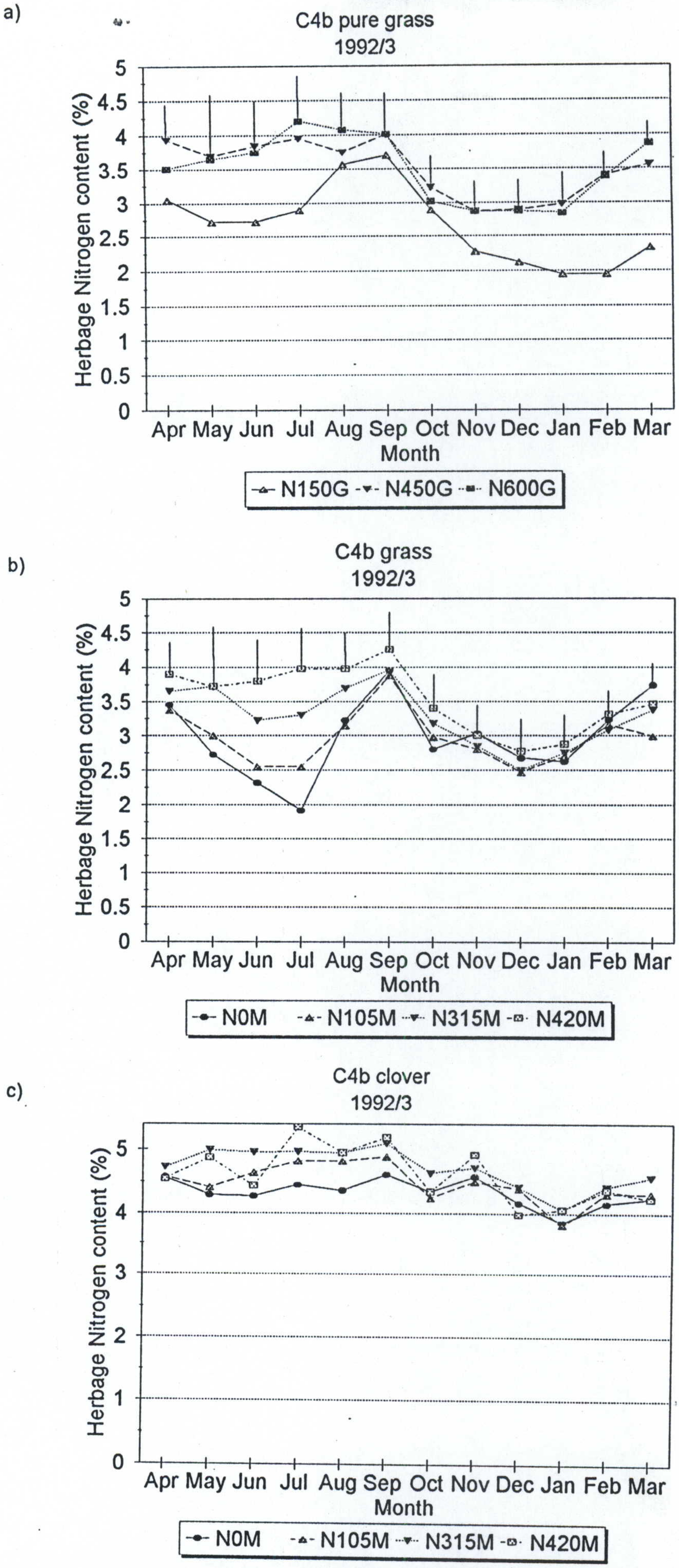


Figure 2.36 The seasonal herbage N (%) response of: (a) tall fescue grown alone; (b) tall fescue when grown with clover, and (c) clover when grown with tall fescue, to increasing rates of N fertilizer (kg N/ha/yr). Vertical bars indicate the 5% LSD level, applicable to the grass N content only (see 6.2 in text).

to August. Apart from June and July, when the N420M treatment had a significantly ($P<0.05$) higher N content than the N315M treatment, there were no significant differences in N content between the N420M and N315M treatments.

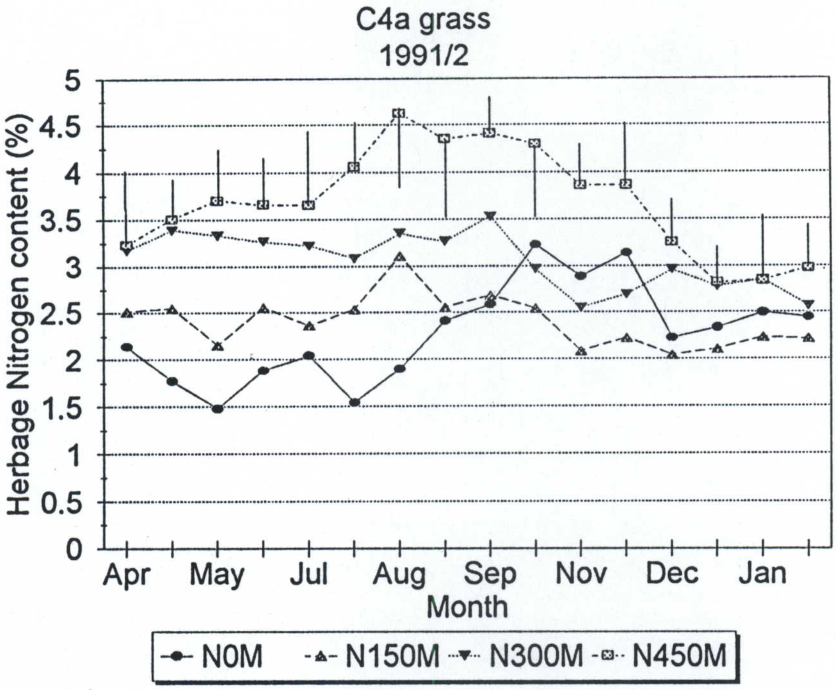
From mid-September to the end of the growing season (March), no significant differences were noted between the N0M, N105M, N315M and N420M treatments (Figure 2.36b). This lack of significant difference is attributed to the N contribution from the white clover at the lower N rates (N0M and N105M). The N contribution of clover to the grass is further confirmed by the low N content of the N150G through the warm season (Figure 2.36a). The data presented in Figure 2.36c will be discussed under the sub-section dealing with white clover.

<u>Perennial ryegrass</u>

In the first year of the perennial ryegrass/clover trial, grass N content (Figure 2.37a) was significantly ($P<0.05$) higher in the N450M treatments than in the N0M and N150M treatments for most of the year; the exceptions were April (N150M) and January (N0M) when no significant differences were noted between these treatments. In addition, the N content of the perennial ryegrass was significantly ($P<0.05$) higher from the N450M plots than the N300M plots between late-winter (mid-July) and early-summer (mid-November). The N content of the pasture declined through the summer (December and January), with no significant treatments effects noted during this period. The data presented in Figure 2.37b will be discussed under the sub-section dealing with white clover.

In the second year, perennial ryegrass N content, from pure grass plots (Figure 2.38a), was significantly ($P<0.05$) lower at the N150G rate than the N600G rate in all months, except in mid-September. Apart from the first grazing in March, no significant differences were noted in perennial ryegrass N content between the N450G and N600G rates. The N content of the perennial ryegrass from the mixed grass/clover plots (Figure 2.38b) showed similar trends to the pure grass treatments, with the higher N rates (N315M and N420M) resulting in significantly ($P<0.05$) higher grass N content, than the N0M and N105M treatments, between mid-March and September. No significant differences, in grass N content, were noted between the N0M and N105M treatments, nor between the N315M and N420M treatments. From mid-September to the end of the growing season

a)



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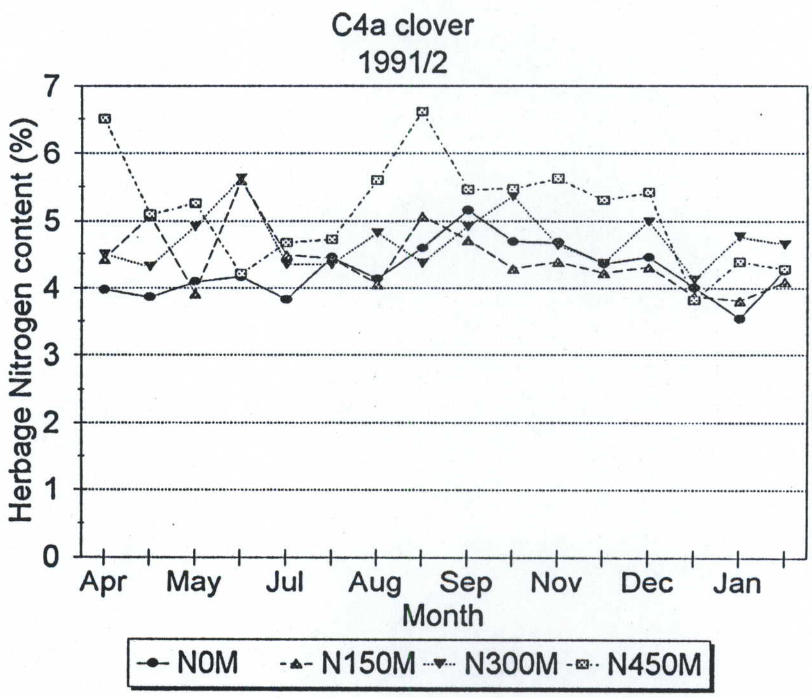

Figure 2.37 The seasonal herbage N (%) response of perennial ryegrass (a) and white clover (b) to increasing rates of N fertilizer (kg N/ha/yr). Vertical bars indicate the 5% LSD level, applicable to the grass N content only (see 6.2 in text).

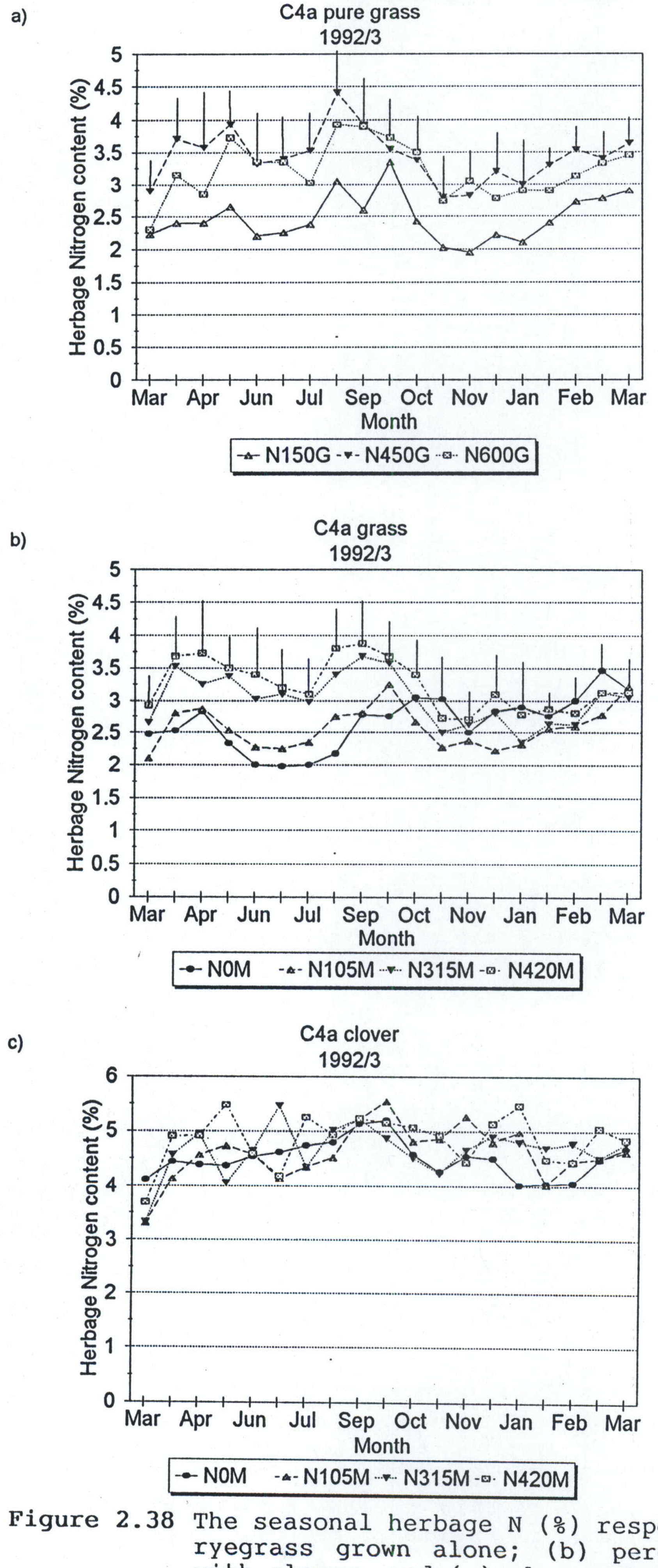

Figure 2.38 The seasonal herbage N (%) response of: (a) perennial ryegrass grown alone; (b) perennial ryegrass grown with clover, and (c) clover when grown with perennial ryegrass, to increasing rates of N fertilizer (kg N/ha/yr). Vertical bars indicate the 5% LSD level, applicable to the grass N content only (see 6.2 in text).

(March), no significant differences were noted between the N0M, N105M, N315M and N420M treatments (Figure 2.38b), presumably because of the N contribution of the clover to the grass N content of the lower N treatments (N0M and N105M). The data presented in Figure 3.38c will be discussed under the sub-section dealing with white clover.

White clover

There were no clear seasonal trends in the N content of white clover grown in association with annual ryegrass (Figure 2.35b), tall fescue (Figure 2.36c) and perennial ryegrass (Figures 2.37b & 2.38c). However, clover N content appeared to increase marginally in early spring (August), declining as the year progressed through the summer. The summer decline in clover N content corresponds with increasing clover growth rates, indicating a possible dilution of herbage N with the increasing DM yield. Although largely negligible, a trend of increasing N content, with increasing N fertilizer rate, was noted for most of the year. Occasional peak N contents in the clover data *eg.* the N450M rate in June (Figure 2.35b), were attributed to laboratory error resulting from excessively small sample sizes.

6.4 Conclusions

The N content and N yield of annual and perennial ryegrass and tall fescue increased linearly with increasing N fertilizer rate. White clover showed an ability to utilize N fertilizer, although N content responses were less marked in clover than in the grasses investigated. The N yield of clover declined with increasing N fertilizer rate, a trend which confirms previous findings on the suppression of clover growth by N fertilizer when grown in a mixed grass/clover sward. Without N fertilizer, grass/clover pastures produced grass N contents equal to the application of between 105 and 150 kg N/ha/yr.

The N content of white clover remained higher than all the grasses investigated, irrespective of N fertilizer application rate. This higher protein content of clover is a major motivating factor for the inclusion of clover in grass pastures.

In general, N fertilizer rates of 420 to 600 kg N/ha/yr were less efficient, in terms of apparent recovery in the herbage, than lower N fertilizer rates, *i.e.* 105 to 150 kg N/ha/yr. White clover proportions, as low as 6% in grass/clover pastures, were sufficient to ensure a greater apparent recovery at low rates of N fertilizer. However, clover proportions of 31% in a grass/clover sward, doubled the apparent recovery of N fertilizer in a tall fescue/clover pasture. These findings are further supported by Roberts *et al.* (1989), who reported that a minimum of 30% clover was required, in a grass/clover pasture, for clover to make a significant nutritional impact on livestock and N fixation by the pasture.

The ability of annual ryegrass (April to October) and perennial ryegrass to assimilate N remained high for most of the year. Tall fescue appeared to have a high N demand during most months of the year except in spring (August to October). In general, grass N content declined through the summer, corresponding to reduced DM yields during this warm period. All the grasses investigated showed positive N content responses to monthly N applications of 45 kg N/ha (N315M and N450G), except tall fescue in spring.

White clover grown in association with the grasses investigated appeared to be capable of meeting the high N content requirement of the grass through the warm season (October to March).

To maximise the N content of the pastures investigated, monthly top-dressings of 45 kg N/ha should be applied. In tall fescue pastures these N applications may be reduced between August and October. If grass/clover proportions are managed to ensure a minimum clover content of 31%, the clover appears to provide sufficient N for the grass over the warm season of the year (October to March), thus obviating the need to apply N fertilizer at this time.

The data emphasize the valuable contribution of white clover to a grass pasture. Not only would the protein content of the pasture be improved, but a saving of N fertilizer, through the warm season, may be effected.

N fertilizer requirements
White clover
Efficiency of N fertilizer
Livestock health
Economics of N fertilizer
Environmental issues
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GENERAL DISCUSSION AND CONCLUSIONS

Nitrogen fertilizer remains an effective tool for manipulating pasture yield and protein quality. Data from the current study show annual ryegrass DM yields and herbage nitrate-N content increasing as much as five fold with the addition of N fertilizer. Similarly, the herbage N content of annual ryegrass was more than doubled with increasing N nutrition. However, for the pasture manager to maximize the advantages of these responses, quantification of the relationships between N fertilizer, yield and quality of the herbage produced is required.

The N nutritional management of pastures is further complicated by the potential availability of N from legumes. White clover, grown in association with grass, has the potential to supply some of the N requirements of the grass (Wasserman 1979; Frame 1992). However, due to the seasonal growth pattern of white clover, the supply of symbiotically-fixed N to the grass is limited to the warmer season of the year (Miles & Bartholomew 1991). The grass component of a zero N fertilizer, mixed grass/clover pasture will, therefore, be short of N for certain periods of the year. It is in this precise situation that a sound understanding of the N nutritional requirements of these grass/clover pastures is required.

Nitrogen fertilizer applied injudiciously to a grass/clover pasture will result in a suppression of clover growth. However, strategic applications of N fertilizer during the cooler season of the year will result in marked increases in grass yield, at a time when DM is most required. As white clover is largely dormant during the cooler months (April to September), strategic N applications during this cool season are expected to have minimal negative effects on clover growth.

Based on the results of the trials presented, the following discussion and conclusions attempt to provide the information required to optimize N fertilizer use on intensive pastures in the Natal midlands. In this discussion, 'optimal' N implies that the pasture is in no way restricted by a shortage of N.

N fertilizer requirements

Annual ryegrass pasture yield responses, both economically and biologically, were recorded for N fertilizer rates up to 360 kg

N/ha/yr. However, when grown in association with white clover, N fertilizer rates of 260 to 280 kg N/ha/yr ensured that DM yields were not restricted by a lack of N. Monthly applications of between 40 and 50 kg N/ha, applied on a four weekly cycle from seedling emergence (April) until October, were required to ensure optimal DM yields. In the Natal midlands, annual ryegrass pastures showed little response to N fertilizer from October onwards, *i.e.* from the inception of flowering.

Since the perennial ryegrass and tall fescue pastures responded to N fertilizer rates in excess of the maximum evaluated (600 kg N/ha/yr), biological optimum N fertilization rates could not be established. Although tall fescue responded to high rates of N fertilizer, the DM yield produced per unit of N applied was lower than for either annual or perennial ryegrass. This lower efficiency of DM production in tall fescue requires further investigation, as the data were only drawn from a single season. The tall fescue trials will, therefore, be continued for as least three to four years.

The N fertilizer demand of perennial ryegrass and tall fescue was highest in spring, although pasture yields responded positively to N fertilizer rates up to 45 kg N/ha/application for most of the season. Grown in a pure sward, perennial ryegrass and tall fescue yields continued to respond positively to monthly N top-dressings of as much as 60 kg N/ha through December and January.

To meet the N nutritional requirements of the pastures investigated, therefore, monthly top-dressings of between 45 and 50 kg N/ha should be applied for most of the season. For the perennial grasses, these monthly top-dressings may be increased to 60 kg N/ha/month over the summer, if the additional forage is required at this time. However, if the grass/clover pastures are managed to ensure a minimum clover content of 31%, the clover could provide sufficient N for the grass during the warm season of the year (October to March).

Generally, the principle of "less N more often" should apply to N fertilizer top-dressing strategies. For example, 45 kg N/ha applied every four to six weeks is more efficient than 90 kg N/ha applied every eight to twelve weeks. Studies reporting only the annual N requirements of pastures, without detailing the specific N fertilizer requirements for each regrowth period or grazing cycle, are largely meaningless.

The ability of annual ryegrass (April to October) and perennial ryegrass to assimilate N remained high for most of the season. Tall fescue appeared to assimilate high N levels in most months of the year except in spring (August to October). All the grasses investigated showed a positive increase in N content in response to monthly N applications of 45 kg N/ha (N315M and N450G); the exception being tall fescue in spring.

White clover

The benefits of including white clover in a grass pasture are many and largely undisputed. The N content of white clover remained higher than that of all the grasses investigated, irrespective of N fertilizer application rate. This higher protein content of clover is a major motivating factor for the inclusion of clover in grass pastures. Although white clover utilized N fertilizer, increases in N content of clover, in response to applied N, were less than in the grasses investigated.

Total pasture DM yields were increased by the inclusion of clover in the grass pasture. Without N fertilizer, grass/clover pastures produced grass N (%) levels equal to the application of between 105 and 150 kg N/ha/yr. Furthermore, the inclusion of a clover component resulted in DM yields equal to the application of 350 kg N/ha/yr to a pure grass pasture. White clover, grown in association with the grasses investigated, appeared able to supply sufficient N to maintain the N content of the grass through the warm season (October to March). However, for the balance of the season, N fertilizer applications were necessary to provide high pasture DM yields. It is through this period (April to late-September) that strategic N top-dressings of 45 to 50 kg N/ha/month are recommended if additional forage is required.

Increasing the rate of N application affected white clover proportions negatively in all the pastures investigated. Irrespective of N fertilizer rate, tall fescue appeared to be more compatible with white clover than perennial ryegrass. This is probably the result of the more upright and tufted growth habit of tall fescue, compared with the more 'prostrate', densely tufted growth habit of perennial ryegrass. An investigation of the relative rooting depths of tall fescue, perennial ryegrass and white clover (C4, unpublished data) showed tall fescue to be deeper rooted (30 to 45 cm) than both perennial ryegrass (10 to 15 cm) and white clover (10 to 15 cm). The deeper rooting depth of the tall fescue pasture may have resulted in less competition with white clover for water and nutrients, than in the perennial ryegrass/clover pasture.

To maximise the clover component in a N fertilized grass/clover pasture it is recommended that the clover be established first. Once the clover has become established the grass may be overseeded into the clover sward. If the grass and clover are established together, then the pasture should not be fertilized with N until the clover is well established. Once the clover is established, N fertilizer may be applied strategically *i.e.* when clover growth is restricted by low temperatures (April to late September), or when additional forage is required.

Efficiency of N fertilizer

The efficiency of N fertilizer, in terms of apparent recovery in the herbage, declines with increasing N fertilizer rate. Low rates of N fertilizer (105 to 150 kg N/ha/yr), applied to grass/clover pastures, are more efficient than when applied to pure grass pastures. White clover proportions as low as 6% in grass/clover pastures are sufficient to ensure a greater apparent recovery of N at low rates of N fertilizer, than the same rate of N fertilizer on pure grass pastures. However, clover proportions of 31% in a grass/clover sward resulted in a 200% apparent recovery of N fertilizer in a tall fescue/clover pasture.

Data from the trials reported on here emphasize the valuable contribution that white clover may make to the N nutrition of the grass component of a grass/clover pasture. Not only is the protein content of the pasture increased, but a saving of N fertilizer may be effected, particularly during the warm season .

Livestock health

Based on the N content of the pasture species analysed, highly N-fertilized annual ryegrass appears to hold the greatest threat to animal health. However, the potential for protein and nitrate toxicity from perennial ryegrass and tall fescue pastures cannot be ruled out. However, nitrate and protein toxicity problems may be greatly reduced by both careful livestock management and strategic N fertilization. Under normal circumstances, N top-dressings of 50 kg N/ha/application or lower do not produce toxic quantities of nitrogenous compounds in annual ryegrass herbage. As a rule, however, starved or unadapted animals should never be given unrestricted access to N-fertilized annual ryegrass pastures.

Economics of N fertilizer

Although the economic evaluations, presented in Section III, are extrapolations from a sheep-grazed pasture, they provide some indication of the relative differences between pasture types. A sound understanding of the economic methods employed is important to the farmer, as the economics of high N applications require constant review as price structures change.

An economic comparison of the three grass pastures, for a dairy production system, shows highest profits per hectare from perennial ryegrass pastures fertilized at 600 kg N/ha/yr (R6,510.43/ha). However, these profits may be lower if averaged over the life expectancy of the pasture *i.e.* the high cost in the establishment year and the declining productivity as the pasture ages.

Annual ryegrass/clover pastures remain profitable for dairy production, with maximum profits of R3,971.83/ha being realized from the application of 340 kg N/ha/yr. Of the three pastures, tall fescue/clover pastures provided the lowest profits. Maximum profits for tall fescue/clover were R2,564.50/ha at a N rate of 420 kg N/ha/yr. However, of the three grass pastures evaluated, tall fescue is reported to be the most perennial (Cross & Bartholomew 1971). If the above profits were spread over the life expectancy of the pasture, profits from the tall fescue/clover pasture may be far higher than indicated.

As the clover content of the grass/clover pastures increases with time, it may be found that highest profits are achieved at low N rates due to the significant yield and quality contribution of the clover. Ideally, N calibration trials should be conducted over a range of grass/clover ratios and for at least three to four seasons on the same site, to thoroughly investigate the N contribution from the clover component.

A summary of the economic optimum N fertilizer rates, based on the hypothetical dairy system presented, follows:

(a) annual ryegrass/clover pastures at 360 kg N/ha/yr (R3,971.83);

(b) pure perennial ryegrass pastures at 600 kg N/ha/yr (R6,510.43);

(c) perennial ryegrass/clover pastures at 420 kg N/ha/yr, applied between April and October (R6,372.54);

(d) tall fescue/clover pastures at 315 kg N/ha/yr, applied between April and October (R2,099.76), and

(e) pure tall fescue pastures at 450 kg N/ha/yr (R894.06).

Apart from the application of 600 kg N/ha/yr to a pure perennial ryegrass pasture, the economic N fertilizer recommendations presented are not at disparity with the biological optimum N fertilizer rates recommended in this study. The additional management and labour involved, in applying N fertilizer at regular intervals throughout the season, should be carefully weighed against a less intensive policy of strategic N applications to grass/clover pastures.

Environmental issues

Whether it be environmental or economic constraints that place restrictions on farmers, futuristic scenarios suggest ever-increasing pressure on farmers to reduce N fertilizer usage on intensive pastures in South Africa. Future research efforts should, therefore, aim to provide alternative solutions to the farmers, with research quantifying the production potential and economics of each alternative recommended.

The inclusion of clovers, as a source of symbiotic N in intensive pastures, will become more prevalent and essential, not only to reduce the total fertilizer N requirement of the pasture but to improve pasture quality.

Alternative solutions to annual ploughing, for the reestablishment of annual ryegrass, are urgently required. Data are required on minimum tillage reestablishment techniques for annual pastures and the effects of minimum tillage on pasture yields and long-term soil structure. In addition, research is required on pasture reestablishment techniques that maximize organic matter returns to the soil *i.e.* the incorporation of unutilized forage into the soil at the end of the season.

The loss of N fertilizer applied to irrigated, winter-dormant pastures infer the leaching of nitrates. The precise pathway of N loss requires further clarification to improve management recommendations for improved N fertilizer efficiency. A useful suggestion, in designing an irrigated pasture system, would be to locate pastures so that any leachate ultimately flows into the irrigation storage reserves. In this way nutrient losses from pasture systems, as a whole, may be reduced. Under these conditions, irrigation water should be analysed for its nutrient content, with fertilization strategies being amended to compliment nutrients recycled to the pasture.

Identification of colder or warmer sites, based on minimum air temperatures, may assist in the planning of winter N top-dressings to reduce N losses. Until research can provide more specific information, it is recommended that N fertilizer not be top-dressed to annual ryegrass pastures where average minimum air temperatures are below 0°C. As annual ryegrass was the most 'winter active' of the species evaluated, a 0°C minimum temperature 'cut-off' could safely be applied to the other pastures studied. Additionally, the use of the T-sum 200 technique for the timing of spring N applications appears to have merit and, therefore, requires further research and local validation for each pasture type.

Sward dynamics

Perennial ryegrass tufts were larger in the grass/clover plots, than in the pure grass plots, particularly at moderate N fertilization rates. The combination of N fertilizer and/or the inclusion of clovers may be important management factors in the maintenance of perenniality in perennial ryegrass pastures. The data highlight a need for research on the effects of N fertilizer on tiller size, number and density of perennial ryegrass and perennial ryegrass/clover pastures fertilized at varying rates of N.

Soil effects

The high residual soil N, noted from the zero N control plots of the annual ryegrass cutting trials (Section II), emphasises the need for research on predicting plant-available N in soils. Until a reliable test for residual soil N is available, farmers could save on N fertilizer by identifying lands with high residual N content. Alternatively, an analysis of the organic matter content of the soil may be useful as an indicator of the N mineralisable potential of the soil.

Cutting versus grazing

The extrapolation of data from cutting trials to grazed pastures remains questionable. Due to the differences between optimal N fertilizer rates estimated from the grazing trials (Section III, C4b) and the cutting trials (Section II), it is important that N fertilizer response studies be conducted under a grazing regime.

Limitations of the current study

It must be emphasised that some of the data presented represent results from a single season. Ideally, N response trials should be conducted for at least three to four seasons to quantify yield responses, account for N returned via dung and urine and establish trends in grass/clover proportions. However, N fertilizer responses in the establishment year of perennial pastures are also vital to N fertilizer management.

Although the grazing management used in the grazing trials attempted to simulate the more lenient utilization expected under a dairy system, the use of data from sheep grazed pastures in a dairy economic evaluation may require validation. Similarly, although care was exercised to ensure that the economic evaluations presented represented local farms, these remain theoretical economic models. It remains strongly advised, however, that the methods followed in evaluating the economics of each enterprise be used by farmers and advisors before making changes to any enterprise.

Final conclusions

The original objectives of the trials reported in this study were the provision of N fertilizer management guidelines for the various pastures, or combinations of pastures, investigated. Based on the results presented, many options are available to the producer, depending on his preference, animal production system, available capital, etc. To recommend one annual rate of N fertilizer for each pasture type would be to ignore the varying demands of each individual system.

The proven positive contribution of white clover, in a grass pasture, needs to be repeatedly emphasised to the farming community. Specific grass/clover management guidelines, particularly the strategic use of N fertilizer and management to maximize white clover proportions, need to be conveyed to farmers.

All the pasture species studied remain important in the higher rainfall areas of Natal. The data of this study show that these pastures may be highly profitable for milk production, particularly at high N fertilizer rates. At current market prices, the economics of beef or sheep production from these intensive pastures remains questionable and each enterprise would have to be carefully costed.

In terms of future trends, each of these pastures still has a definite role to play in Natal *i.e.* annual ryegrass will out-produce perennial ryegrass and tall fescue in mid-winter and tall fescue pastures are best suited to lowland, wet sites. However, the discussion presented suggests the need for a shift in emphasis towards more economically and environmentally sustainable pasture systems. Due largely to the success of the annual ryegrass cultivar Midmar, there has perhaps been an overemphasis on annual ryegrass pastures, particularly at high N fertilization rates. Perhaps the time has now come for farmers in these higher rainfall areas to re-evaluate their temperate pasture systems and, while not excluding annual ryegrass, decrease their use on lands better suited to strategically N-fertilized perennial temperate grass/clover pastures.

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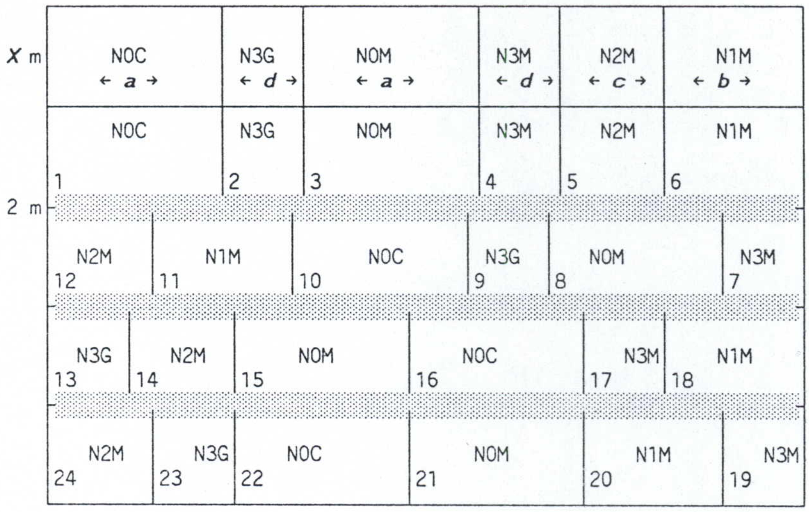
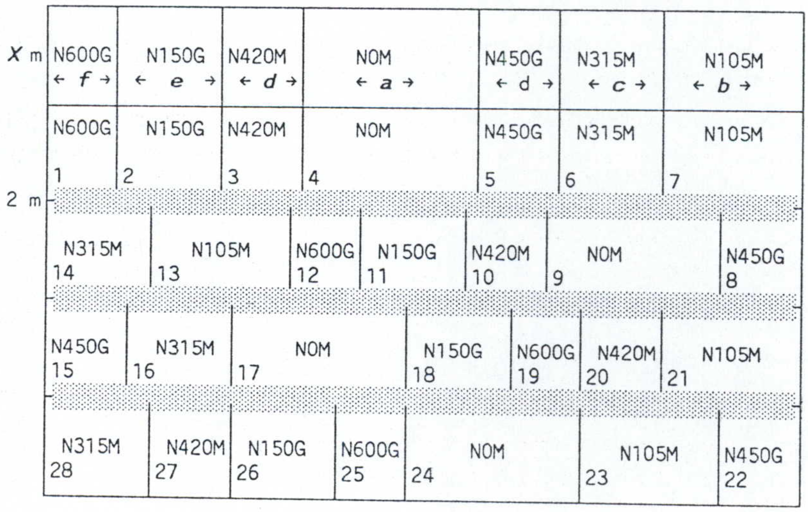
APPENDIXES

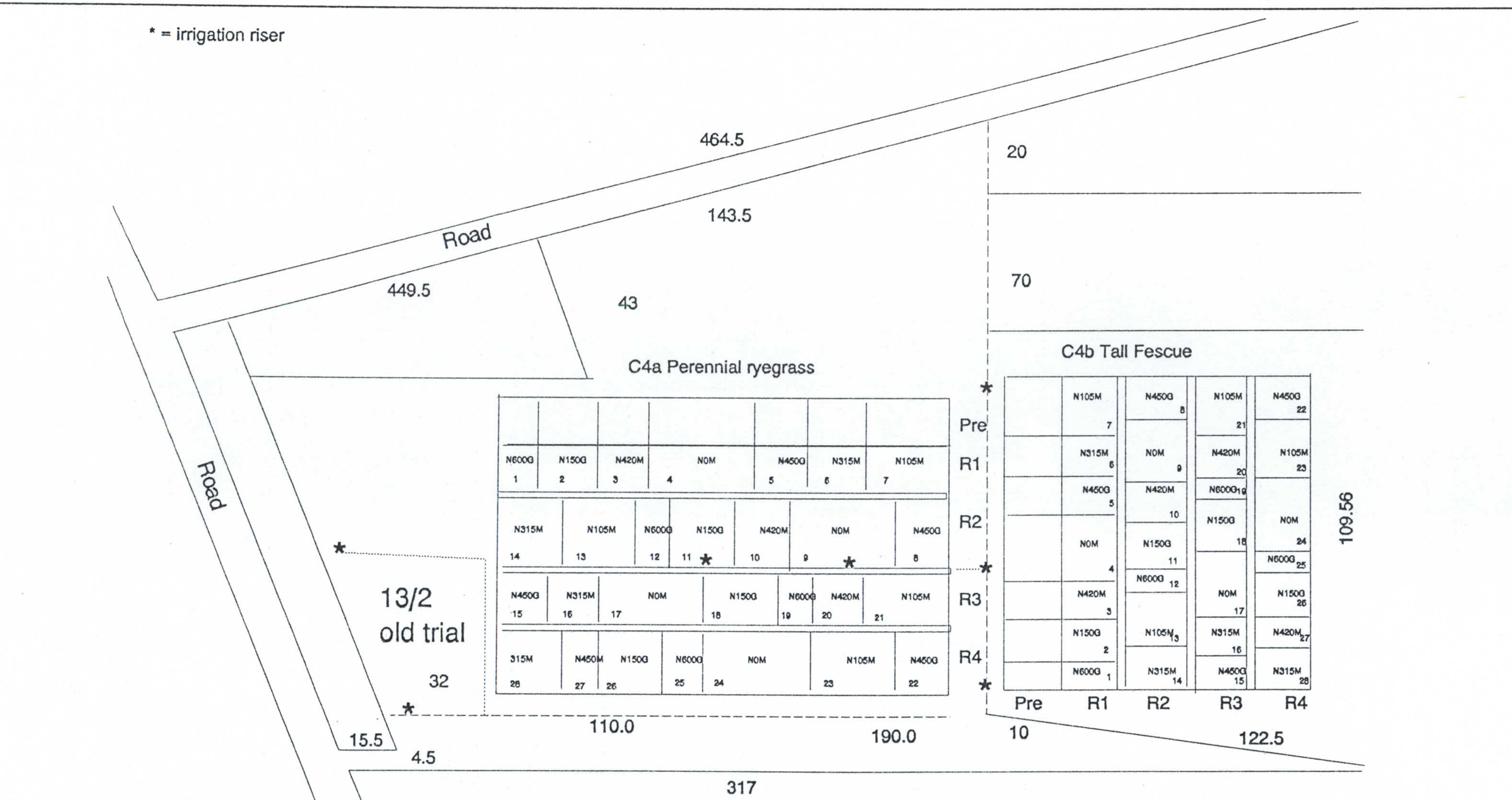
Appendix 1. The experimental layout for the C4a (perennial ryegrass/clover) and the C4b (annual ryegrass/clover) experiments in the 1991/2 year. For the ryegrass trial x = 20 m, a = 33.33 m, b = 25 m, c = 20 m and d = 14.29. For the fescue trial x = 16 m, a = 26.04 m, b = 19.53 m, c = 15.63 m and d = 11.16. ░ = Passages.



Appendix 2. The experimental layout for the C4a (perennial ryegrass/clover) and the C4b (fescue/clover) experiments in the 1992/3 year. For the ryegrass trial x = 20 m, a = 33.33 m, b = 25 m, c = 20 m, d = 14.29, e = 22.22 m and f = 11.11. For the fescue trial x = 16 m, a = 26.04 m, b = 19.53 m, c = 15.63 m, d = 11.16, e = 17.36 and f = 8.68 . ░ = Passages.



endix 3. Diagrammatic map of the C4 land on which the grazing trials were conducted (Section III). Lines in the experimental area represent permanent electric fencing.



Appendix 4. Allocated costs of an annual ryegrass/clover pasture (adjusted from Combud 1993).

Annual ryegrass/clover pastures: Red soils; Natal mistbelt				
Allocated costs	unit	Price or cost/unit	Qty	Value/ cost/ha
grass seed	kg	7.850	25	196.25
clover seed	kg	19.95	3	59.85
lime	kg	0.101	2000	202.00
inoculant	unit	5.175	1	5.18
LAN (28)	kg	0.583	1250	728.75
Superphosphate (10.5)	kg	0.539	475	256.03
KCl (50)	kg	0.728	500	364.00
delivery (30km)	ton	20.000	4.225	84.50
machinery (fuel-lube-repairs)	ha			285.65
implements (repairs-lube)	ha			37.06
equip. & irrig. system repairs	ha			15.15
irrigation (power)	mm	0.555	700	388.50
irrig. motor & pump repairs	mm	0.0198	700	13.89
machinery labour	hr	1.650	20.507	33.84
machine crew labour	hr	1.400	14.676	20.55
irrigation labour	hr	1.400	144	201.60
interest on operating capital	R	0.182	1019.887	185.62
Total allocated costs/ha				3078.41

Assumed soil status: P 9 mg/l; K 80 mg/l; Acid Saturation 35%; N rate 350 kg/ha/yr.

Appendix 5. Allocated costs of a perennial ryegrass/clover pasture in the establishment year (adjusted from Combud 1993).

Perennial ryegrass/clover pastures: Red soils; Natal mistbelt				
Allocated costs	unit	Price or cost/unit	Qty	Value/ cost/ha
grass seed	kg	9.98	25	249.50
clover seed	kg	19.95	3	59.85
lime	kg	0.101	8500	858.50
inoculant	unit	5.175	1	5.18
LAN (28)	kg	0.583	892.86	520.54
Superphosphate (10.5)	kg	0.539	475	256.03
KCl (50)	kg	0.728	500	364.00
delivery (30km)	ton	20.000	10.01	200.20
machinery (fuel-lube-repairs)	ha			277.92
implements (repairs-lube)	ha			33.86
equip.& irrig. system repairs	ha			15.15
irrigation (power)	mm	0.555	840	466.20
irrig. motor & pump repairs	mm	0.0198	840	16.63
machinery labour	hr	1.650	18.000	29.70
machine crew labour	hr	1.400	10.403	14.56
irrigation labour	hr	1.400	144	201.60
interest on operating capital	R	0.182	2439.517	443.99
Total allocated costs/ha				4013.40

Assumed soil status: P 9 mg/l; K 80 mg/l; Acid Saturation 35%; N rate 250 kg/ha/yr.

Appendix 6. Allocated costs of a perennial ryegrass/clover pasture in the maintenance year (adjusted from Combud 1993).

Perennial ryegrass/clover pastures: Red soils; Natal mistbelt				
Allocated costs	unit	Price or cost/unit	Qty	Value/ cost/ha
lime	kg	0.101	750	75.75
LAN (28)	kg	0.583	714.29	416.43
Superphosphate (10.5)	kg	0.539	200	107.80
KCl (50)	kg	0.728	200	145.60
delivery (30km)	ton	20.000	2.05	41.00
machinery (fuel-lube-repairs)	ha			157.91
implements (repairs-lube)	ha			21.10
equip.& irrig. system repairs	ha			15.50
irrigation (power)	mm	0.555	840	466.20
irrig. motor & pump repairs	mm	0.0198	840	16.63
machinery labour	hr	1.650	11.892	19.62
machine crew labour	hr	1.400	11.892	16.65
irrigation labour	hr	1.400	144	201.60
interest on operating capital	R	0.182	838.683	152.64
Total allocated costs/ha				1854.08

Assumed soil status: P 9 mg/l; K 80 mg/l; Acid Saturation 35%; N rate 200 kg/ha/yr.

pendix 7. Profitability estimates of a typical dairy system on an annual ryegrass/clover pasture (calculations after Doll & Orazem 1984).

fert rate g/ha/yr)	DM Yield (kg/ha/yr)	Milk prod (l/ha)	Pn (N cost)	TVP	TC	PROFIT/ha (TVP-TC)	MPP	APP	Px	VMP
0	3055.17	2359.86	0.00	2100.27	2277.16	-176.89				
20	3796.77	2932.68	45.79	2610.08	2322.95	287.14	28.64	146.63	45.79	1311.35
40	4498.37	3474.60	91.57	3092.40	2368.73	723.67	27.10	86.87	45.79	1240.62
60	5159.97	3985.63	137.36	3547.21	2414.52	1132.70	25.55	66.43	45.79	1169.89
80	5781.57	4465.76	183.14	3974.53	2460.30	1514.23	24.01	55.82	45.79	1099.16
100	6363.17	4915.00	228.93	4374.35	2506.09	1868.26	22.46	49.15	45.79	1028.43
120	6904.77	5333.34	274.71	4746.67	2551.87	2194.80	20.92	44.44	45.79	957.70
140	7406.37	5720.78	320.50	5091.50	2597.66	2493.84	19.37	40.86	45.79	886.97
160	7867.97	6077.33	366.29	5408.82	2643.45	2765.38	17.83	37.98	45.79	816.24
180	8289.57	6402.98	412.07	5698.65	2689.23	3009.42	16.28	35.57	45.79	745.51
200	8671.17	6697.73	457.86	5960.98	2735.02	3225.96	14.74	33.49	45.79	674.77
220	9012.77	6961.59	503.64	6195.81	2780.80	3415.01	13.19	31.64	45.79	604.04
240	9314.37	7194.55	549.43	6403.15	2826.59	3576.56	11.65	29.98	45.79	533.31
260	9575.97	7396.61	595.21	6582.98	2872.37	3710.61	10.10	28.45	45.79	462.58
280	9797.57	7567.78	641.00	6735.32	2918.16	3817.16	8.56	27.03	45.79	391.85
300	9979.17	7708.05	686.79	6860.16	2963.95	3896.22	7.01	25.69	45.79	321.12
320	10120.77	7817.42	732.57	6957.51	3009.73	3947.77	5.47	24.43	45.79	250.39
340	10222.37	7895.90	778.36	7027.35	3055.52	3971.83	3.92	23.22	45.79	179.66
360	10283.97	7943.48	824.14	7069.70	3101.30	3968.39	2.38	22.07	45.79	108.93
380	10305.57	7960.16	869.93	7084.55	3147.09	3937.46	0.83	20.95	45.79	38.19
400	10287.17	7945.95	915.71	7071.90	3192.87	3879.02	-0.71	19.86	45.79	-32.54
420	10228.77	7900.84	961.50	7031.75	3238.66	3793.09	-2.26	18.81	45.79	-103.27
440	10130.37	7824.84	1007.29	6964.11	3284.45	3679.66	-3.80	17.78	45.79	-174.00
460	9991.97	7717.94	1053.07	6868.96	3330.23	3538.73	-5.35	16.78	45.79	-244.73
480	9813.57	7580.14	1098.86	6746.32	3376.02	3370.30	-6.89	15.79	45.79	-315.46
500	9595.17	7411.44	1144.64	6596.18	3421.80	3174.38	-8.43	14.82	45.79	-386.19

d on the financial data of Combud (1993) and local suppliers with animal data from Bredon & Stewart (1978).
ts assumed:

Milk value (R/*l* as at 10/93)	0.89
N cost (per ton of LAN):	0.641
Total pasture costs (per ha):	3078.41
Total pasture yield (t DM/ha):	12.5
Growing season (months):	9
Pasture wastage (%):	30

A 500 kg cow requires 14.50 kg DM/day and can produce 16*l*/day off an annual ryegrass pasture. Milk production potential of the forage produced is thus: (litres produced/kg DM intake) x (DM yield - wastage)

Pn = N fertilizer cost
TVP = Total Value of Product
TC = Total Costs
MPP = Marginal Physical Product
APP = Average Physical Product
Px = Unit cost of input
VMP = Value of Marginal Product

pendix 8. Profitability estimates of a typical intensive beef steers system on an annual ryegrass/clover pasture (calculations after Doll & Orazem (1984).

fert rate g/ha/yr)	DM Yield (kg/ha/yr)	Total beef (kg/ha)	Pn (N cost)	TVP	TC	PROFIT/ha (TVP-TC)	MPP	APP	Px	VMP
0	3055.17	339.46	0.00	1065.10	2277.16	-1212.06				
20	3796.77	421.86	45.79	1323.64	2322.95	-999.31	4.12	21.09	45.79	188.64
40	4498.37	499.82	91.57	1568.23	2368.73	-800.50	3.90	12.50	45.79	178.46
60	5159.97	573.33	137.36	1798.88	2414.52	-615.64	3.68	9.56	45.79	168.29
80	5781.57	642.40	183.14	2015.58	2460.30	-444.72	3.45	8.03	45.79	158.11
100	6363.17	707.02	228.93	2218.34	2506.09	-287.75	3.23	7.07	45.79	147.94
120	6904.77	767.20	274.71	2407.16	2551.87	-144.72	3.01	6.39	45.79	137.76
140	7406.37	822.93	320.50	2582.03	2597.66	-15.63	2.79	5.88	45.79	127.59
160	7867.97	874.22	366.29	2742.95	2643.45	99.50	2.56	5.46	45.79	117.41
180	8289.57	921.06	412.07	2889.93	2689.23	200.70	2.34	5.12	45.79	107.24
200	8671.17	963.46	457.86	3022.96	2735.02	287.95	2.12	4.82	45.79	97.07
220	9012.77	1001.42	503.64	3142.05	2780.80	361.25	1.90	4.55	45.79	86.89
240	9314.37	1034.93	549.43	3247.20	2826.59	420.61	1.68	4.31	45.79	76.72
260	9575.97	1064.00	595.21	3338.40	2872.37	466.02	1.45	4.09	45.79	66.54
280	9797.57	1088.62	641.00	3415.65	2918.16	497.49	1.23	3.89	45.79	56.37
300	9979.17	1108.80	686.79	3478.96	2963.95	515.01	1.01	3.70	45.79	46.19
320	10120.77	1124.53	732.57	3528.33	3009.73	518.59	0.79	3.51	45.79	36.02
340	10222.37	1135.82	778.36	3563.75	3055.52	508.23	0.56	3.34	45.79	25.84
360	10283.97	1142.66	824.14	3585.22	3101.30	483.92	0.34	3.17	45.79	15.67
380	10305.57	1145.06	869.93	3592.75	3147.09	445.66	0.12	3.01	45.79	5.49
400	10287.17	1143.02	915.71	3586.34	3192.87	393.46	-0.10	2.86	45.79	-4.68
420	10228.77	1136.53	961.50	3565.98	3238.66	327.32	-0.32	2.71	45.79	-14.85
440	10130.37	1125.60	1007.29	3531.67	3284.45	247.23	-0.55	2.56	45.79	-25.03
460	9991.97	1110.22	1053.07	3483.42	3330.23	153.19	-0.77	2.41	45.79	-35.20
480	9813.57	1090.40	1098.86	3421.23	3376.02	45.21	-0.99	2.27	45.79	-45.38
500	9595.17	1066.13	1144.64	3345.09	3421.80	-76.71	-1.21	2.13	45.79	-55.55

d on the financial data of Combud (1993) and local suppliers with animal data from van Ryssen (1992).
price (R/kg dressed, as at 10/93) 5.92 Pasture wastage (%): 20
st (per ton of LAN): 0.641 Dressing % (Steer): 53
l pasture costs (per ha): 3078.41 Growing season (months): 9
l pasture yield (t DM/ha): 12.5
) - 300 kg medium framed beef steer requires 7.2 kg DM/day and can produce 1 kg/day (ADG) off an annual ryegrass/clover pasture.
production potential of the forage produced is thus: (kg beef produced/kg DM intake) x (DM yield - wastage)

pendix 9. Profitability estimates of a typical dairy system on a perennial ryegrass/clover pasture (calculations after Doll & Orazem 1984).

fert rate g/ha/yr)	DM Yield (t/ha/yr)	Milk prod (l/ha)	Pn (N cost)	TVP	TC	PROFIT/ha (TVP-TC)
N0M	9.2	7106.21	0.00	6324.52	1052.83	5271.69
N105M	7.1	5484.14	240.38	4880.88	1281.76	3599.12
N150G	6.3	4866.21	343.39	4330.92	1396.22	2934.70
N315M	9.9	7646.90	721.13	6805.74	1739.62	5066.12
N420M	12.2	9423.45	961.50	8386.87	2014.33	6372.54
N450G	10.5	8110.34	1030.18	7218.21	2083.01	5135.20
N600G	13.0	10041.38	1373.57	8936.83	2426.40	6510.43

ed on the financial data of Combud (1993) and local suppliers with animal data from Bredon & Stewart (1978). Symbols used are
iled in Appendix 7.
ts assumed:
value (R/*l* as at 10/93) 0.89
st (per ton of LAN):0.641
l pasture costs (per ha):1854.08
l pasture yield (t DM/ha):13.0
ing season (months):12
ure wastage (%):30

0 kg cow requires 14.50 kg DM/day and can produce 16*l*/day off a perennial ryegrass pasture. No was account made for superior
production from the clover component. Milk production potential of the forage produced is thus: (litres produced/kg DM intake)
M yield - wastage)

pendix 10. Profitability estimates of a typical dairy system on a tall fescue/clover pasture (calculations after Doll & Orazem (1984).

fert rate kg/ha/yr)	DM Yield (t/ha/yr)	Milk prod (l/ha)	Pn (N cost)	TVP	TC	PROFIT/ha (TVP-TC)
N0M	5.68	4098.52	0.00	3647.69	2343.72	1303.97
N105M	7.00	5054.73	240.38	4498.71	2584.10	1914.61
N150G	4.16	3007.27	343.39	2676.47	2687.11	-10.64
N315M	8.04	5802.93	721.13	5164.61	3064.85	2099.76
N420M	9.13	6595.19	961.50	5869.72	3305.22	2564.50
N450G	6.64	4795.45	1030.18	4267.95	3373.90	894.06
N600G	8.09	5844.82	1373.57	5201.89	3717.29	1484.60

ed on the financial data of Combud (1993) and local suppliers with animal data from Bredon & Stewart (1978). Symbols used are
ailed in Appendix 7.
uts assumed:
k value (R/*l* as at 10/93) 0.89
ost (per ton of LAN):0.641
al pasture costs (per ha): R3144.97
al pasture yield (t DM/ha):9.132
wing season (months):12
ture wastage (%):30

00 kg cow requires 14.50 kg DM/day and can produce 14.96*l*/day off a tall fescue pasture. No was account made for superior milk duction from the clover component. Milk production potential of the forage produced is thus: (litres produced/kg DM intake) x yield - wastage)