CHAPTER 3

NITROGEN APPLICATION AND CRITICAL NITRATE SOIL SOLUTION CONCENTRATIONS FOR YIELD AND QUALITY OF ANNUAL RYEGRASS

3.1 INTRODUCTION

Annual ryegrass is one of the most widely grown irrigated winter pastures in South Africa in the high rainfall areas particularly in the Natal Midlands, the Eastern Highveld, the Eastern Cape and in winter rainfall areas of South Africa (Dickinson *et al*., 2004). It has high nutritional qualities, palatability, digestible energy, protein and mineral contents (Theron and Snyman, 2004) and plays an essential role in supplying good quality grazing between winter and summer (Eckard *et al.,* 1994).

Nitrogen fertiliser is a major input influencing yield and quality of irrigated annual ryegrass in South Africa. Current N recommendations are based on empirical relationships with forage yield, with little focus on pasture quality or losses of N to the atmosphere and groundwater. The high rates of N applied to ensure a maximum forage yield (Eckard *et al.,* 1995), often results in high crude protein (CP) concentration, which is associated with an increase in non-protein N (Reeves *et al*., 1996), nitrate toxicity, imbalances in mineral metabolism and metabolic disorders (Coombe and Hood, 1980; de Villiers and van Ryssen, 2001). It can also reduce non-structural carbohydrates content, forage intake (Marais *et al*., 2003) and milk yields (Tas *et al*., 2006), as energy is used to digest excess protein at the expense of milk production.

There is high potential for N losses in pasture fed dairy production, through the process of ammonia release and leaching of nitrates, with urinary N output accounting for about 65% of N intake for dairy cows feeding on highly fertilised pasture (Peyraud *et al*., 1997). One way to reduce N losses is to reduce CP intake by reducing forage CP concentration, which can be achieved either through reduced N fertilisation or increasing energy intake to balance for ingested CP (Tamminga, 1992;

Hoekstra *et al*., 2007). For indoor ration based dairy production, feed composition can be balanced by mixing diets of herbage with supplements. However, due to the lower cost of inputs in the pasture based systems than a mixed ration system (Gertenbach, 2006), milk production is mainly dependent on pastures. Manipulation of forage quality of the grazing pasture is complex, because high N applications are common for achieving maximum forage yield, while high N application can reduce forage quality and energy value. For example, Nash *et al.* (2008) reported higher energy yield with an application rate of 30 kg N ha^{-1} cycle^{-1} even though the highest biomass yield was obtained at 60 kg ha^{-1} per cycle^{-1}.

In Chapter two, results showed how N fertiliser applications could be reduced using various adaptive strategies based on regular monitoring of soil nitrate using a passive lysimeter. This Chapter extends the work of Chapter two by investigating the nexus between fertiliser, biomass production and quality in more detail. Specifically the objectives of this research are to determine 1) response of annual ryegrass to forage yield and quality to N fertilizer application, 2) critical soil nitrate concentrations for yield and quality and 3) the nature of the trade-off between biomass and quality parameters.

3.2 MATERIALS AND METHODS

3.2.1 Site description and crop management

The experiment was conducted at Cedara, a Department of Agriculture experimental site (altitude 1076 m, 29°32'S; 30°17'E) in 2007 and 2008. The site is located in the midlands of KwaZulu-Natal, one of the main milk producing areas of South Africa. It has a mean annual rainfall of 876 mm and a reference evapotranspiration of 1511 mm (Table 1). Total precipitation over the growing period (March to November) at the study site was 557 mm in 2007 and 441 mm in 2008 (Figure 3.1). Both seasons were drier than the long-term average of 611 mm for this period. Monthly mean minimum and maximum temperatures were similar to the long-term mean values.

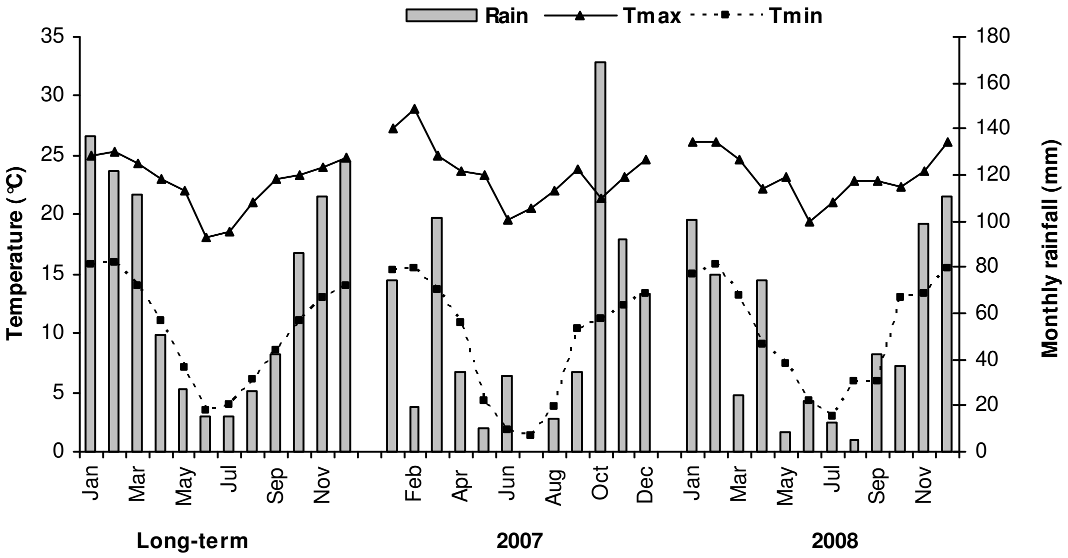

Figure 3.1 Long-term (85 years), 2007 and 2008 total monthly rainfall and mean maximum and minimum temperatures for Cedara

The experimental site has a deep, red, kaolinitic Hutton soil (Soil Classification Working Group, 1991) with a clay loam texture to a depth of 0.4 m, with a heavier clay soil from 0.4 to 1.0 m. In both years, soil core samples were collected to a depth of 1 m at the beginning of the seasons. Soil fertility status was determined prior to planting. Ammonium acetate was used for K, Ca and Mg extraction. Organic carbon and N were estimated by mid-infrared spectroscopy (Ben-Dor and Banin). P measured with Bray I. Nitrate and ammonium N were analysed using 1 M KCl extraction. The soil test results of both years were similar and are presented in Table 2.2. Based on soil fertility status 20 kg P ha^{-1} (super phosphate - 10.5%) was incorporated at planting. Both N (limestone ammonium nitrate - 28%) and K (KCl - 50%) were top-dressed within two days after cutting. The seasonal recommended K (200 kg K ha^{-1}) was divided by the expected number of growth cycles, while the N regime was determined by the treatment.

Italian ryegrass cultivar (*Lolium multiflorum*) "Agriton" was planted on the 6th March in 2007 and 25th March 2008 at a seeding rate of 30 kg ha^{-1} and a spacing of 15 mm between rows. A Cambridge roller was used to facilitate good contact between the seed and soil. Two weeks after emergence, 2-4-D amine herbicide was sprayed against broad leaf weeds. Fenoxaprop-p-ethyle 'Puma Super' was also used to control *Eleusine indica* (L.) Gaertn. (goosegrass) which is a common invasive weed of irrigated pastures.

A dragline sprinkler irrigation system with a delivery rate of 4.0 mm h^{-1} and a spacing between sprinklers of 12 m was used. Plots were 12 m wide and 36 m long with a border spacing between plots of 12 m. Each plot had its own sprinkler lines and was irrigated independently by determining the deficit to field capacity using the Diviner-2000 capacitance probe (Sentek®, Australia) to a depth of 0.6 m. Plots were irrigated once a week during autumn, spring and summer, and once every two weeks in winter. Treatments were refilled to field capacity except in summer where some room was left for rain.

3.2.2 Treatments

Experiments were conducted with three levels of N application rates: 0 (N_0), 30 (N_{30}) and 60 kg N ha^{-1} (N_{60}) in 2007. Four fixed rates of N: 0 (N_0), 20 (N_{20}), 40 (N_{40}) and 60 (N_{60}) kg of N ha^{-1} were applied in 2008. The reason for including four application rates in 2008 was to ensure that the yield plateau was determined because from the 2007 data biophysical optimum yield was between 30 and 60 Kg of N ha^{-1}. For all treatments, N was applied at the beginning of each growth cycle except for the first growth cycle in 2008 when no fertiliser N was applied. In both years, treatments were assigned in a complete randomized block design with three replications.

3.2.3 Plant sampling and quality analysis

The pasture was defoliated at the two to three leaf stages. For yield and quality determination, a total of nine samples per treatment (three from each plot) were collected from 1 m^2 quadrants to a stubble height of 50 mm. After taking the samples, the whole field was harvested with a tractor mower to a height of 50 mm. Forage dry matter (DM: t ha^{-1}) was determined by oven drying the samples at 70 °C to constant mass. Samples were milled to pass through a 0.1 mm sieve and were kept in air tight bottles until quality analyses could be performed. Nitrogen was determined by Kjeldahl analysis (AOAC, 2000) and crude protein (CP) was calculated as N x 6.25 (NRC, 2001). True protein (TP) was determined using the trichloroacetic acid (TCA) precipitation method. Non-true protein (NTP, i.e. peptides, free amino acid, nucleic acids, amines, nitrate and ammonia) was calculated by dividing the difference between crude and true protein by 6.25 (NRC, 2001). Neutral detergent fibre (NDF) and acid detergent fibre (ADF) concentrations were determined according to Van Soest *et al.* (1991) method. Metabolisable energy (ME: MJ kg^{-1} DM) content was estimated from CP, NDF and ADF using a relationship developed by Fulkerson *et al.* (1998) using:

$$ME = 16.4 - 0.012\ ADF * NDF + 0.0084\ NDF * CP - 0.315\ CP + 0.01\ (ADF)^2 \qquad (3.1)$$

3.2.4 Soil nitrate sampling and analyses

Wetting front detectors were used to collect soil solution for determining the concentration of nitrate at different depths. They were installed at depths of 0.15, 0.30 and 0.45 m in each plot. Solution sampling from WFDs was conducted a day after an irrigation or a rainfall event. Solutions were kept in a cooler box and nitrate content was estimated using paper colour nitrate test strips (Merck KGaA, Germany). Only nitrate is considered because it is the dominant form of inorganic N (Appendix B1).

3.2.5 Calculations and statistical analysis

Growing degree days (GDD) were calculated by subtracting a base temperature of 4°C from daily average temperature [(maximum + minimum)/2] according to Akmal and Janssens, (2004). Days after emergence, the length of growth cycles in terms of days and GDD are presented in Appendix B2. In pastures, the first week is the most important period in terms of N application (Collins and

Allinson, 2004), and fertiliser is applied at the beginning of each cycle or immediately after each cut. Therefore, measuring soil N during the first week can give a good estimate of N required for the full growth cycle. Mean soil nitrate solution concentrations of all depths from all replications in the first week were used to calculate the critical nitrate levels for various measured and calculated pasture parameters. Biophysical optimum forage yield was expressed relative to the lowest yield that was not statistically significant from the maximum plateau yield for each growth cycle. In case of no plateau, relative yield was calculated using the maximum yield. Therefore, it was easier to compare yields between growth cycles and seasons.

Data were analysed using SAS (SAS, 2002). Forage yield and quality parameters were analysed separately for each growth cycle. Where applicable, significantly different means were separated using Tukey's test at the 95% confidence level. Analyses of variance and regression were performed for yield, N nutrition and crude protein concentration using SAS Proc NLIN (SAS, 2002). Critical levels for biophysical optimum forage yield, optimum (CP_{opt} = 17%) and maximum (CP_{max} = 22%) forage crude protein concentrations (Peyraud and Astigarraga, 1998) were determined using the Cate-Nelson response plateau (CN) model. Error percentages and r^2 were used to show the ability of CN model to express the data (Cate and Nelson, 1971). According to De Jager (1994), for accurate model predictions, error should be less than 20%.

3.3 RESULTS AND DISCUSSION

3.3.1 Forage yield

Forage yield was higher in 2007 than 2008 (Figure 3.2). This was due to early planting and late ending of the 2007 season with longer growing season and greater accumulation of growing degree days (Appendix B1). Forage biomass produced was between 5.9 t ha^{-1} (N_0) and 15.6 t ha^{-1} (N_{60}) (Figure 3.3). The maximum yields were in close agreement with the values reported by Eckard *et al.* (1995) from Cedara, which ranged from 12.5 to 15.4 t ha^{-1}.

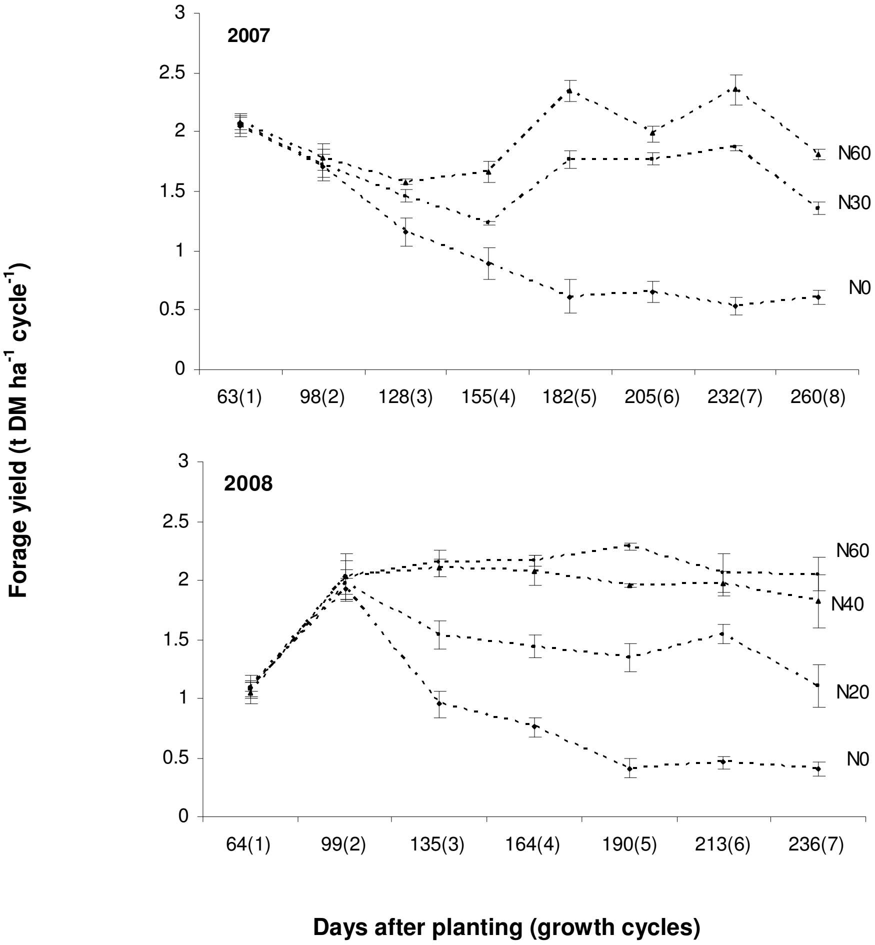

Figure 3.2 Forage yield of annual ryegrass under a range of N application rates for eight growth cycles in 2007 (0, 30, 60 kg ha^{-1} cycle^{-1} for N_0, N_{30}, N_{60}) and seven growth cycles in 2008 (0, 20, 40 60 kg ha^{-1} cycle^{-1} for N_0, N_{20}, N_{40}, N_{60})

Biophysical optimum forage yields (the lowest yield that is not statistically significant from the maximum yield) were observed between N_{30} and N_{60} in 2007 and between N_{40} and N_{60} in 2008 (Figure 3.2 and Figure 3.3). Nitrogen fertiliser application was not effective in the first 2 - 3 growth cycles. This could be due to high initial soil inorganic N and high rates of N mineralisation after tillage in autumn and in spring. This suggests over-fertilisation for the first 2-3 growth cycles, because farmers usually apply equal amount of N (i.e. 50 kg ha^{-1} cyle^{-1}) for all growth cycles.

Reduction of N fertiliser for these growth cycles could help increase profitability and reduce risk of N loss.

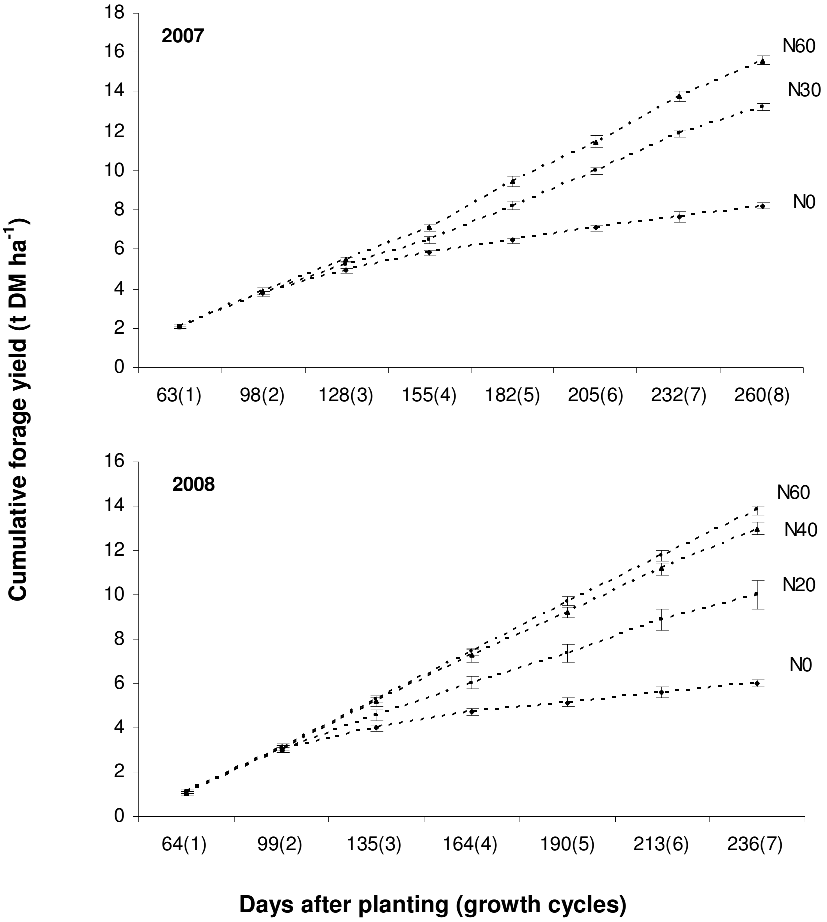

Figure 3.3 Cumulative forage yield of annual ryegrass under a range of N application rates for eight growth cycles in 2007 (0, 30, 60 kg ha^{-1} cycle^{-1} for N_0, N_{30}, N_{60}) and seven growth cycles in 2008 (0, 20, 40 60 kg ha^{-1} cycle^{-1} for N_0, N_{20}, N_{40}, N_{60})

3.3.2 Forage quality

3.3.2.1 Crude protein, true protein and non-true protein

In both years, CP concentrations of N_{60} treatment were above the CP_{max} for all growth cycles (Figure 3.4). CP_{opt} was attained only in few cycles for N_0 and N_{30} in 2007, and in N_0 and N_{20} in 2008. At the biophysical optimum forage growth, CP concentrations exceed the recommended concentrations for reasonable levels of milk production (NRC, 2001). In general, although the CP was dependent on the soil N availability, N applications between 30-40 kg ha^{-1} cycle^{-1} generally produce CP concentrations between CP$_{opt}$ and CP$_{max}$. However, N applications above 40 kg ha^{-1} cycle^{-1} will most likely produce CP concentrations above the maximum limit of 22%.

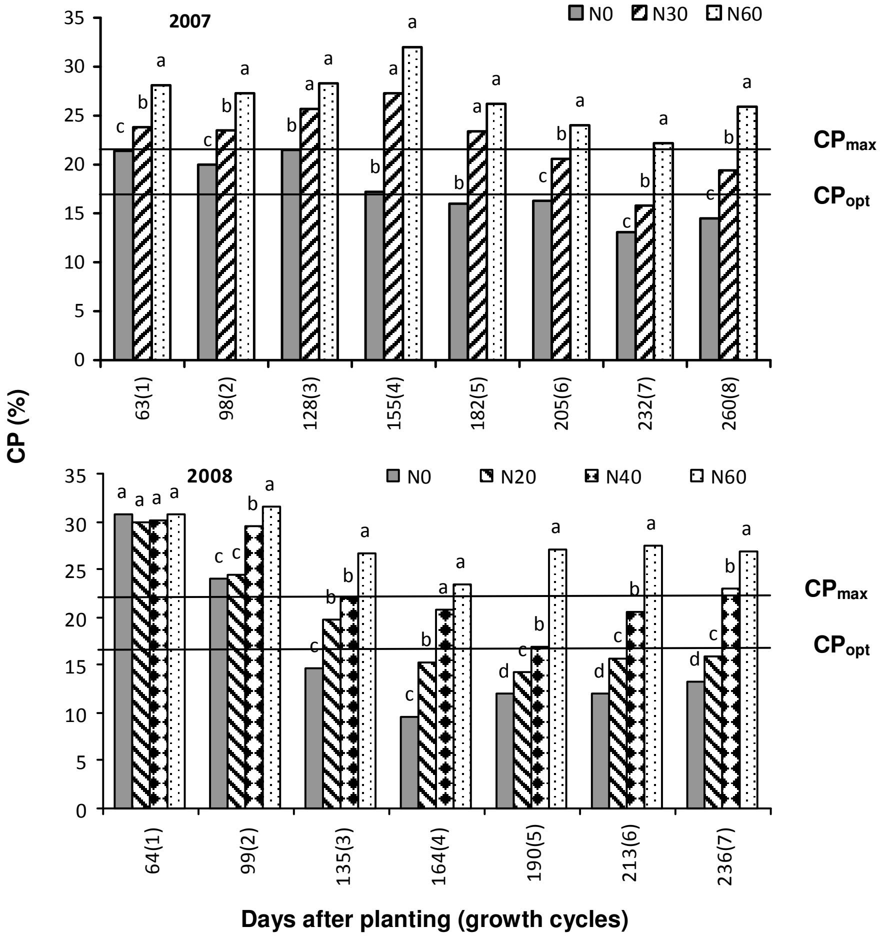

Figure 3.4 Crude protein (CP) concentrations of annual ryegrass under a range of N application rates for eight growth cycles in 2007 (0, 30, 60 kg ha^{-1} cycle^{-1} for N_0, N_{30}, N_{60}) and seven growth cycles in 2008 (0, 20, 40 60 kg ha^{-1} cycle^{-1} for N_0, N_{20}, N_{40}, N_{60})

Nitrogen fertilisation has a direct effect on proportion of protein (true or non-true protein). At high N levels the percentage of TP to CP decreased significantly in most of the growth cycles (Appendix B2), which reduces the proportion of true protein while increasing the non-true protein portion (Figure 3.5).

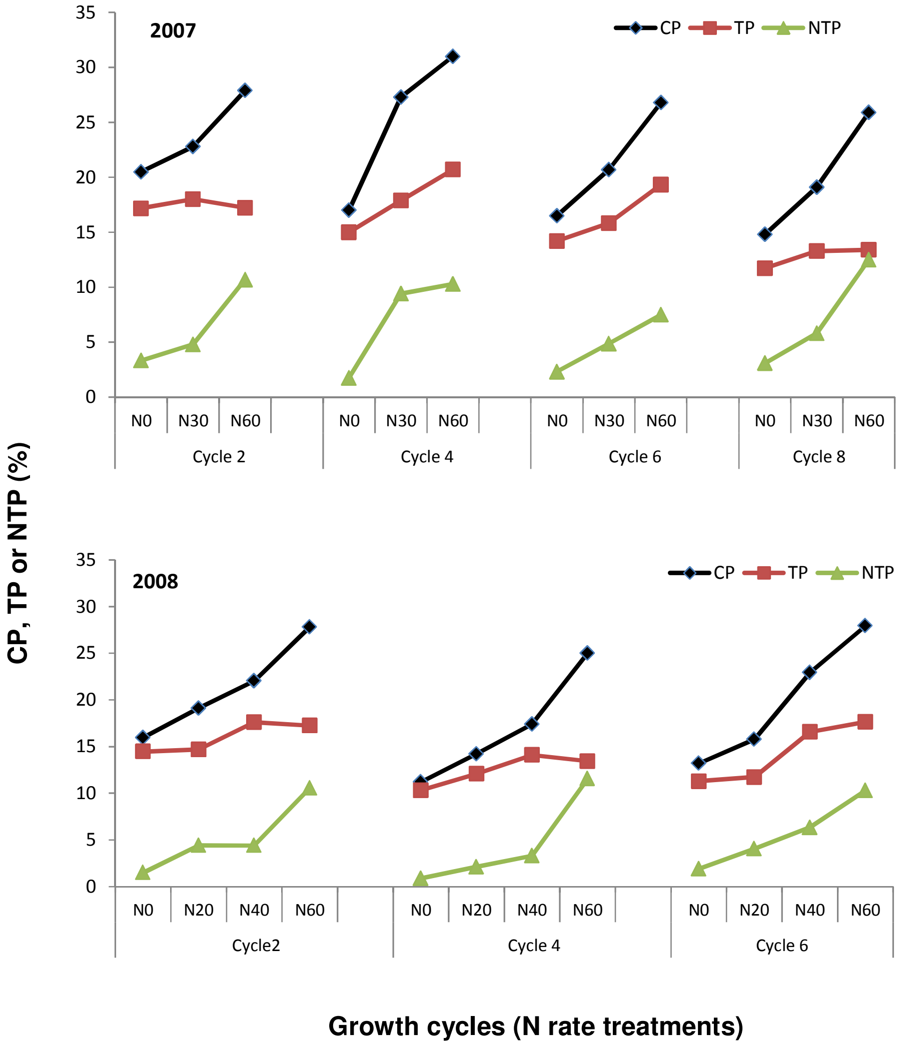

Figure 3.5 Crude protein (CP), true protein (TP) and non-true protein (NTP) concentrations of annual ryegrass under a range of N application rates for four growth cycles in 2007 (0, 30, 60 kg ha^{-1} cycle^{-1} for N_0, N_{30}, N_{60}) and three growth cycles in 2008 (0, 20, 40 60 kg ha^{-1} cycle^{-1} for N_0, N_{20}, N_{40}, N_{60})

The majority of true protein and non-true protein entering the rumen is broken down to ammonia, which bacteria require for synthesising their own body protein. Ammonia, in excess of that used by the micro-organisms, is absorbed through the rumen wall into the blood, carried to the liver and converted to urea, in which the greater part is excreted in the urine (only small portion is lost by belching). An increase in non-true protein usually leads to nitrate accumulation in the plant, where in the rumen the nitrate is converted to nitrite and then to ammonia. Generally, when N application exceeds the pasture requirement (20-22% CP), the increase in CP was mostly in the form of non-true protein, with a negligible increase in true protein. True protein only increases up to certain level (20-22% CP optimum for growth), however, above this CP is stored in non-true protein (largely in the form of peptides, free amino acid and nitrates) form (Van Soest, 1994; Marais *et al.,* 2003). Animal performance and milk production may, however, significantly be affected when the CP concentrations significantly drop below the minimum requirement of 8 -11% (Hoekstra *et al*., 2007).

3.3.2.2 Fibre

Expressing the fibre requirement as NDF is superior to ADF because it measures most of the structural components of the plant cell (i.e. cellulose, hemicellulose and lignin) while NDF does not include hemicellulose (NRC, 2011). Therefore, in this study only NDF (Figure 3.6) is discussed but ADF values are also presented in Appendix B3. Neutral detergent fibre is closely associated to rumen fill or intake (Allen, 1996). The slow digestion of the NDF in the herbage may have a large influence on passage rate and therefore the NDF fraction is believed to have a direct effect on rumen fill. Increased NDF reduces digestibility and intake by increasing the residence time of the course material in the rumen and therefore, reduce the nutritional status of a high producing dairy cow.

Neutral detergent fibre was the least affected quality parameters (Figure 3.6). It was more affected by the plant growth stage of maturity than by N fertiliser (Peyraud and Astigarraga, 1998). In general, the NDF values were higher than the minimum requirements for dairy cows of 25-28% (NRC, 2001). Lower values of NDF usually correspond to high nutritive value, however, excessively low NDF values than the recommended requirement can cause digestive problems due to fast passage through the rumen (Redfearn *et al*., 2002). Towards the end of the season, the NDFs were high and may show a reduced intake (Hopkins *et al.,* 2002).

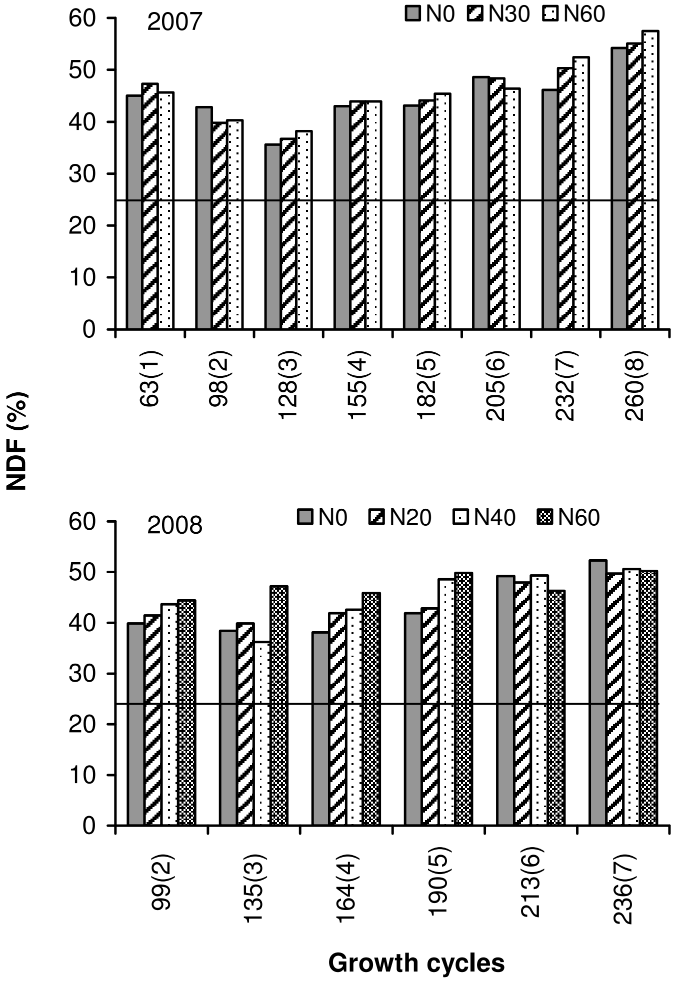

Figure 3.6 Neutral detergent fibre (NDF) of annual ryegrass under a range of N application rates for eight growth cycles in 2007 (0, 30, 60 kg ha^{-1} cycle^{-1} for N_0, N_{30}, N_{60}) and seven growth cycles in 2008 (0, 20, 40 60 kg ha^{-1} cycle^{-1} for N_0, N_{20}, N_{40}, N_{60}). Horizontal line is minimum NDF requirement for dairy cows

3.3.2.3 Metabolisable energy

Metabolisable energy was calculated from NDF, ADF and CP concentrations using an empirical relationship developed by Fulkerson *et al.* (1998). The calculated ME values are in the range of typical annual ryegrass reported in literature (Fulkerson *et al.,* 1998; Meeske *et al.*, 2006). In most cases (Figure 3.7), ME contents of all N rate treatments were within the acceptable rages of 10 - 12 MJ kg^{-1} DM (Fulkerson *et al.,* 1998), except end of the season when the NDF values were high.

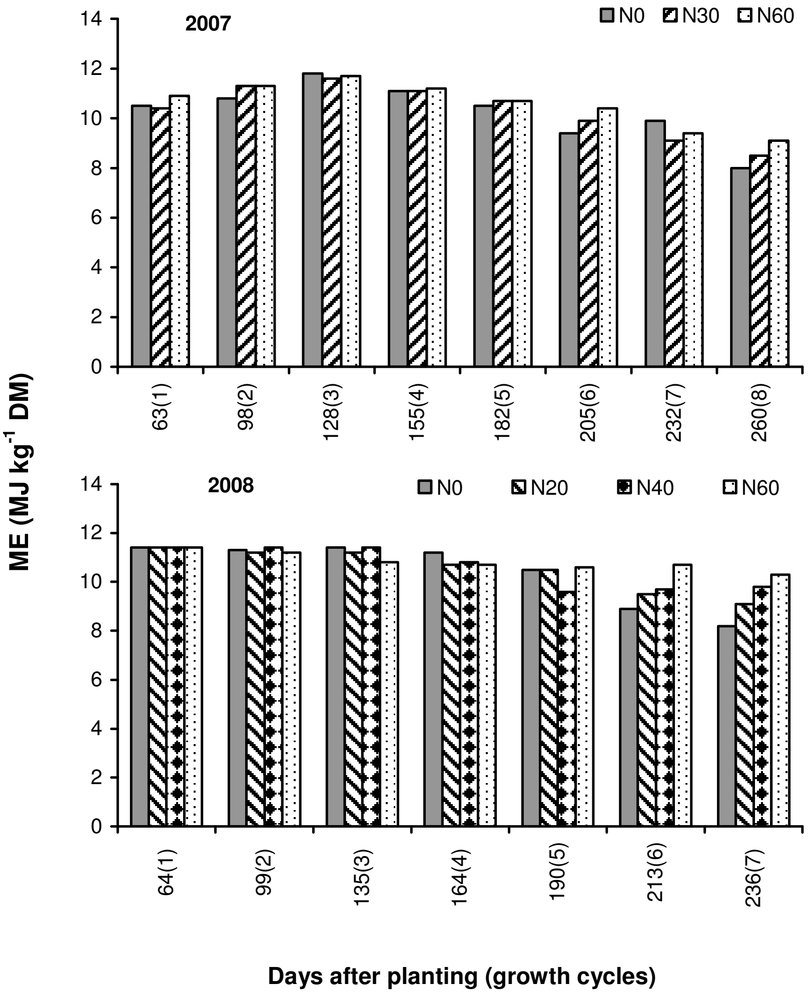

Figure 3.7 Metabolisable energy (ME) content of annual ryegrass under a range of N application rates for eight growth cycles in 2007 (0, 30, 60 kg ha^{-1} cycle^{-1} for N_0, N_{30}, N_{60}) and seven growth cycles in 2008 (0, 20, 40 60 kg ha^{-1} cycle^{-1} for N_0, N_{20}, N_{40}, N_{60})

ME values were similar for the first five growth cycles for different N rate treatments (Figure 3.7). However, high N rate treatment tends to produce higher ME towards end of the season. This could be due to the depletion of N in the low rate fertiliser treatments which leads to low CP than the N required for pasture growth. Generally, N application rate has no effect on ME content (Figure 3.7). This implies that at the high N rate treatment milk production is likely to be reduced due consumption of high CP. The decrease in milk production would be due to a higher energy required for metabolising the excess CP.

3.3.3 Critical soil nitrate concentrations for yield and quality

The critical soil solution concentration is a concept widely accepted for interpreting soil nitrate for optimum growth/yield/quality (Cate and Nelson, 1971). Values lower than the critical concentrations indicate a high potential response in growth to N application. Above the critical value, the biomass response to an increase in the availability of N is negligible and the forage quality may be reduced. In all Cate-Nelson (CN) figures, the vertical line which intersects the x axis indicates the critical soil solution nitrate concentration for yield or quality parameters (Van Biljon *et al.,* 2008). The CN partitions the data into four groups. Horizontal and vertical lines are plotted to maximise points in the upper right (non-responsive) and lower left (responsive) and minimise points at the upper left (over-prediction) and lower right (under-prediction) quadrants (Cate and Nelson, 1971).

In Chapter 2, the thresholds for the adaptive management treatments were somewhat arbitrarily selected in the knowledge that they would be improved with experience. In this study, optimum soil solution nitrate concentration ranges for yield and quality were developed using statistical models. Critical mean nitrate concentration was 28 mg L^{-1} for biophysical optimum forage yield, 20 mg L^{-1} for CP_{opt} and 41 mg L^{-1} for CP_{max} (Figure 3.8). These ranges can be used by trading of forage yield with a good forage quality, whilst also minimising N leaching. All the relationships between soil nitrate solution measured at the first week and crop parameters were significant at 99% level of confidence and the total error was within an acceptable range (De Jager, 1994). In the Cate-Nelson model, error I showed that the parameters reached optimum while the soil solution nitrates were below optimum value which may result in yield/quality reduction because no N fertiliser application is required. On the other hand, error II showed that the critical nitrate level reached optimum but the crop N was in deficit, in which case N would have been applied and would lead to leaching.

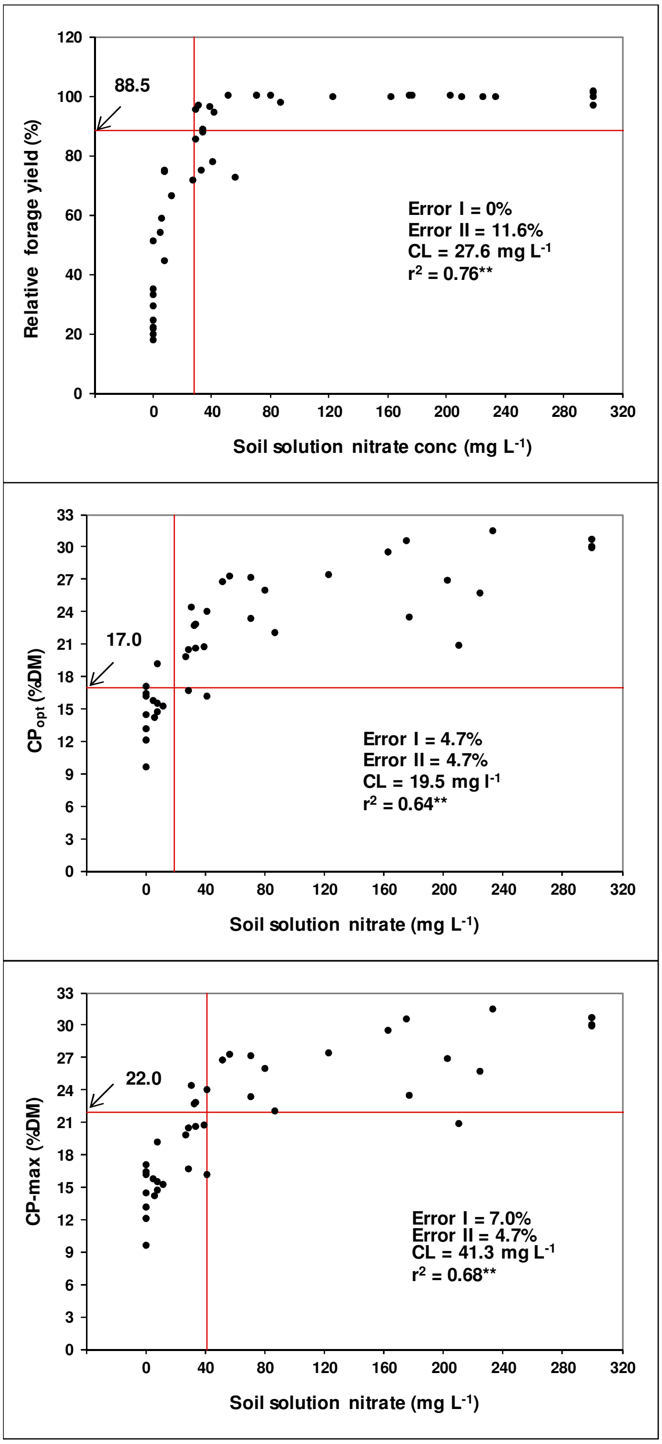

Figure 3.8 Critical soil solution nitrate concentration for biophysical optimum forage yield, optimum (CP_{opt}) and maximum (CP_{max}) crude protein concentrations using Cate-Nelson model. Critical soil solution nitrate concentration (CL), coefficient of determination (r^2), number of observations (n = 43), error I upper left side of the quadrant (I) and error II lower right side of the quadrant (II)

In Chapter 2 (Fessehazion *et al.,* 2011), 50 mg L^{-1} (mean of all WFD that responded) was used. In this study, the values are slightly lower than the 50 mg L^{-1} (when critical levels were determined statistically). However, considering the variability of the pooled data, growth cycles and averages of nitrate from the WFDs, a range of critical mean nitrate concentration between 20 and 41 mg L^{-1} could be used as better estimates of the critical nitrate soil solution concentration. However, since the nitrate test strips used in the experiment were in a range of 0, 10, 25, 50, 100, 250 and 500 mg L^{-1}, a range of soil nitrates between 25 to 50 ppm would be an appropriate value for yield and quality whilst also minimising N leaching.

Critical soil nitrate levels developed in this study can be used in the following strategies. First, to apply part of the recommended N at the beginning of the growth cycle and supplement the rest as necessary based on the WFD nitrate concentration. This can be more practical in winter when intervals of the growth cycles are 35 to 60 days and there is enough time to apply N fertiliser once or twice especially for farmers who fertigate their pasture where a small amount of N can be applied. Secondly, critical soil nitrate is a guide for how much N to apply for the next growth cycle based on nitrate soil solution from the last irrigation of the previous growth cycle. This would be more suitable during the short growth cycle intervals and/or when tractors are used for fertiliser application. In autumn, spring and early summer when the growth cycles are between 21 and 28 days, there may not be enough time to apply N based on the nitrate levels from the same growth cycle. Therefore, soil solution nitrate concentrations from the last irrigation of the previous growth cycle can be used as a guide for the next growth cycle (as reported in Chapter 2). Finally, critical soil nitrate values can be used for integrated adaptive N and irrigation management because the WFD shows the depth the wetting front has passed and the concentration of nutrients at that particular soil depth.

There was a significant exponential relationship between N application rate and soil solution nitrate concentrations collected from the WFDs (Figure 3.9). The reciprocal of the graph would give some indication on the amount of N required to reach a target soil solution nitrate concentration for yield or quality. For example, N application of 35 - 48 kg ha^{-1} cycle^{-1} is required to reach mean nitrate concentrations of 25 to 50 mg L^{-1}. To attain critical mean nitrate concentration of 28 mg L^{-1} (biophysical optimum forage yield), 20 mg L^{-1} (CP$_{opt}$) and 41 mg L^{-1} (CP$_{max}$), N application rates of 31, 37 and 43 kg ha^{-1} cycle are required, respectively. Because the data are averaged across sampling dates over two years and the solutions are affected by plant uptake, rate of mineralisation and initial soil inorganic concentrations, the relationship (in Figure 3.9) may not hold for all growth cycles and years.

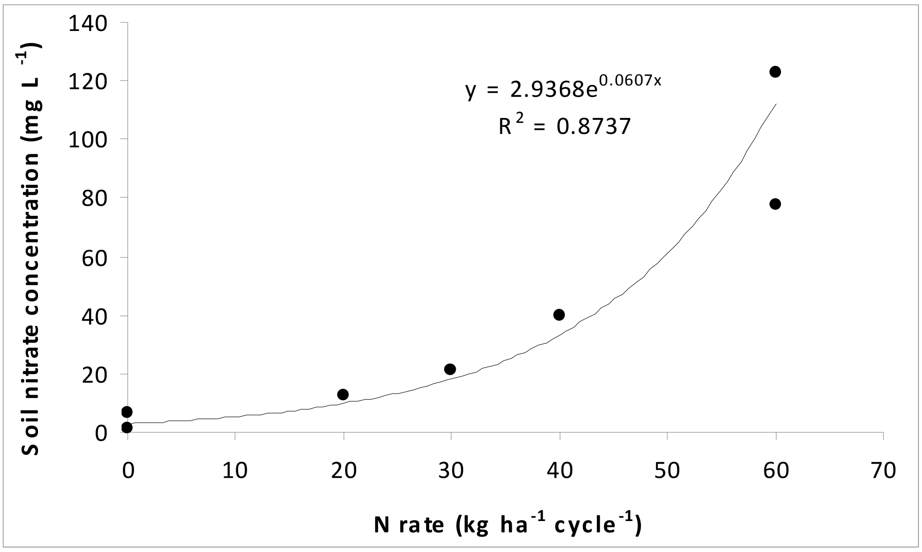

Figure 3.9 Exponential equation used to show the relationship between N application rates and mean soil solution nitrate concentrations. Data pooled from range of N application rates in 2007 (0, 30, 60 kg ha^{-1} cycle^{-1} for N_0, N_{30}, N_{60}) and in 2008 (0, 20, 40 60 kg ha^{-1} cycle^{-1} for N_0, N_{20}, N_{40}, N_{60})

3.3.4 Nature of the trade-off between yield and quality parameters

Neutral detergent fibre and ME were the least affected quality parameters by N application rate treatments. As a result, CP was used for balancing forage biomass yield and to determine the nature of trade-off between yield and quality. This was because CP represents the overall forage quality and is also the most affected quality parameter. Forage CP (or N) is the most important forage quality parameter that can be easily analysed. It can also be used as a good indicator for other quality parameters which can be affected directly or indirectly by N application.

Both metabolisable energy yield (MJ ha^{-1}) for individual growth cycles (Appendix B4) and seasonal cumulative (Figure 3.10) showed similar trends to forage yield. Similar to forage yield, though not always significant, the highest ME yields were observed from the highest N rate treatment. As a result optimum ME yield was obtained at N rate between N_{30} to N_{60} in 2007 and at N_{40} in 2008 (Figure 3.10).

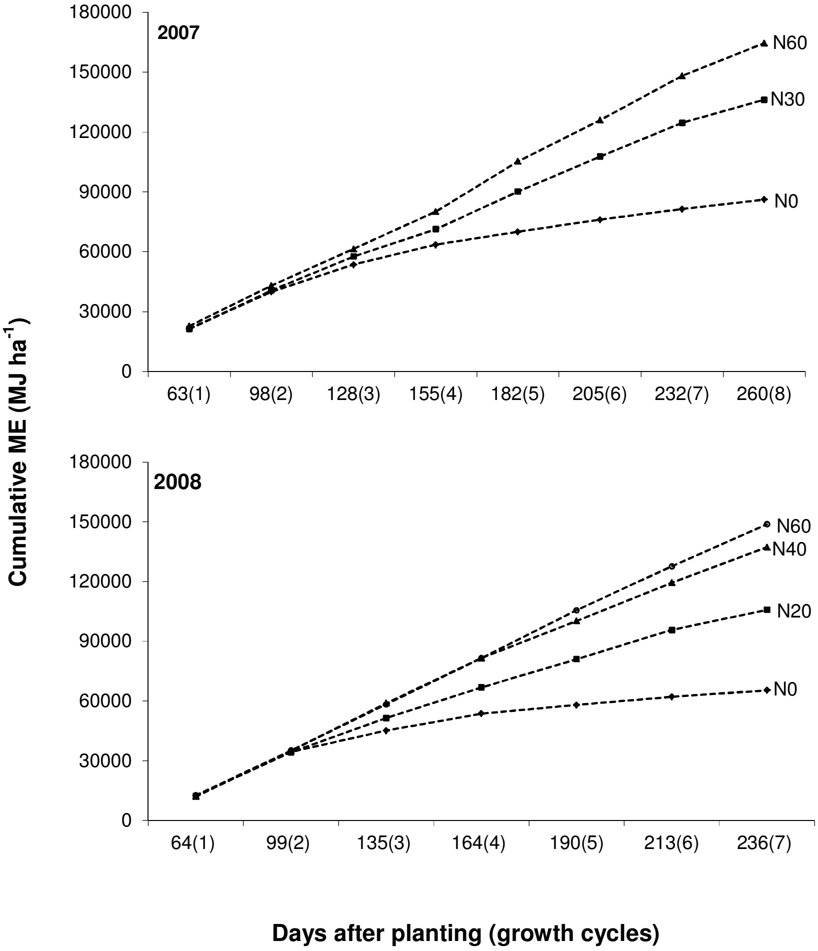

Figure 3.10 Cumulative metabolisable energy (ME) of annual ryegrass under a range of N application rates for eight growth cycles in 2007 (0, 30, 60 kg ha^{-1} cycle^{-1} for N_0, N_{30}, N_{60}) and seven growth cycles in 2008 (0, 20, 40 60 kg ha^{-1} cycle^{-1} for N_0, N_{20}, N_{40}, N_{60})

Critical CP concentrations required for biophysical optimum relative yields (which are also similar for ME yield) developed using the Cate-Nelson model was 18.1% (Figure 3.11). This value is slightly higher than the optimum CP (CP_{opt}) concentration of 17% but lower than the maximum CP (CP_{max}) of 22%. Nitrogen fertiliser required for achieving a maximum forage yield/ME yield and CP varies amongst growth cycles (Appendix B5) depending on soil N availability. As a result, N fertiliser application for the first two to three cycles not only reduced forage quality (high CP) but also did not improve forage and ME yields.

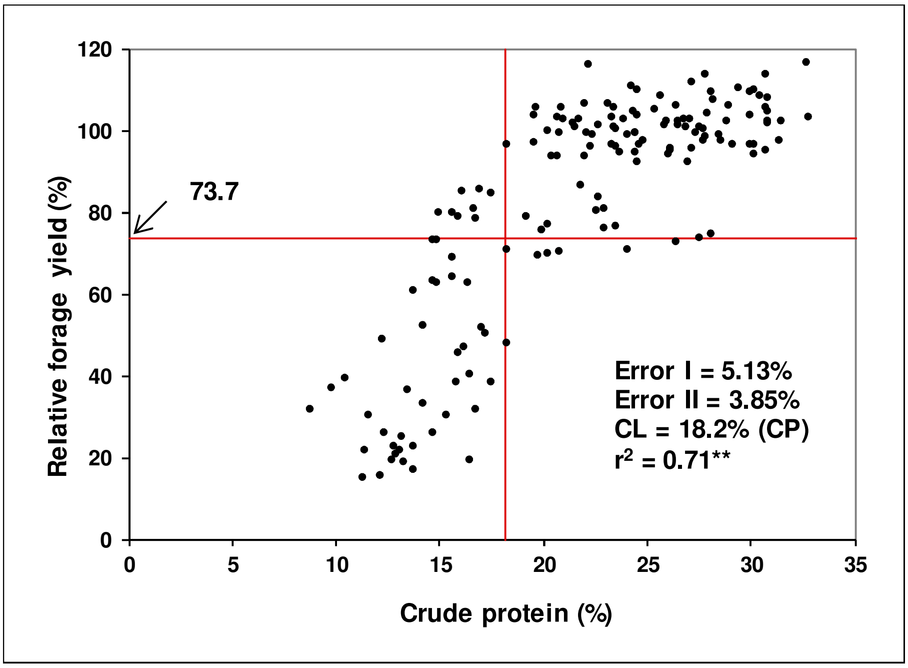

Figure 3.11 Critical crude protein concentration (%) for biophysical optimum relative forage yield (%) using Cate-Nelson model. Critical crude protein concentration (CL), coefficient of determination (r^2), number of observations, error I upper left side of the quadrant (I) and error II lower right side of the quadrant (II)

Generally, the current study showed that the biophysical optimum N application per cycle (the highest non- significant forage and ME yields) was between 30-60 kg N ha^{-1} in 2007 and 40 kg N ha^{-1} in 2008. Hence, N application rate of around 30-40 kg N ha^{-1} per growth cycle could be biophysical optimum yield to slightly lower forage and ME yield, but with CP concentrations ranging between CP_{opt} and CP_{max}. This may not be applicable for the first 2-3 growth cycles, where there is excessive CP concentrations, however, this can be managed by considering soil N (as presented in Chapter 2).

3.4 CONCLUSIONS

Generally, for most growth cycles, the highest forage yields were produced when N application rates ranged between 30 to 60 kg N ha^{-1} $cycle^{-1}$, except for the first growth cycles when there was high soil N carryover. The amount of N fertiliser required for achieving a maximum forage yield and optimum quality varies widely among growth cycles depending on soil N availability. As a result, N fertiliser application for the first two to three cycles did not improve forage yield (and the N nutrition) but reduced quality (high CP). Consequently, the current farmers' recommendation (fixed N application rate of 50 kg ha^{-1} per growth cycle) based on target yield may give the highest biomass but not optimal quality and hence may not improve animal performance (for all growth cycles). It could also increase N leaching as a result of high CP which most likely will result in high urinary excretion. Therefore, similar overall animal performance or milk yield can be achieved by applying less N fertiliser and compensating the reduced yield with an improved quality of forage (lower CP), while also minimising environmental impact. However, farmers who use a pasture based system have only limited options for managing N by integrating both yield and quality whilst minimising leaching, because balancing rations for pasture based dairy production is difficult.

Generally, the current study showed that the optimum N application per cycle (the highest non-significant forage and ME yields) was between 30-60 kg N ha^{-1} in 2007 and 40 kg N ha^{-1} in 2008. Hence, N application rate of around 30-40 kg N ha^{-1} per growth cycle could give biophysical optimum forage yield (or slightly lower) and ME yield and but with CP concentrations with the boundaries of CP_{opt} and CP_{max}. This may not be applicable for the first 2-3 growth cycles, where there is excessive CP concentrations, however, this can be managed by considering soil N (as presented in Chapter 2).

The trade-off between yield and quality will depend on the management of pasture, whether for pasture based systems or indoor ration based dairy production (feed composition can be balanced by mixing diets of herbage with supplements). For pasture based systems due to difficulty in manipulation of all parameters of pasture quality, trading-off forage yield for better forage quality may be required. However, for indoor ration based dairy production, targeting maximum biomass yield would be better because the feed can be supplemented with low-cost roughages.