Annual ryegrass dry matter yield and nitrogen responses to fertiliser N applications in southern Brazil

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Abstract

Soil nitrogen (N) is the main factor limiting leaf development, plant growth and nutritive value of annual ryegrass in southern Brazil farming systems. Field research was carried out to monitor and investigate the effects of fertiliser N applications on annual ryegrass dry matter (DM) and pasture N yields in different areas of southern Brazil. Three experiments were carried out with unirrigated annual ryegrass (*Lolium multiflorum* L.) established in different locations of southern Brazil in 2008 and 2009. The experimental design was a randomised block with three replicates, where treatments were four levels of N applied to pasture: 0, 50, 100 and 200 kg fertiliser N ha^{-1} $year^{-1}$. Annual ryegrass DM yield increased ($P<0.001$) with fertiliser N applications at the Embrapa and Unicentro sites, but there was no response observed above 100 kg of N ha^{-1} at UFRGS. Maximum accumulated DM yields were 7.2 t ha^{-1} at Embrapa, 6.0 at UFRGS and 6.4 at Unicentro for 200 kg of N ha^{-1}. Fertiliser N application also increased the number of grazings. Shoot N content increased ($P<0.01$) with fertiliser N applications, but decreased with accumulated biomass. The mean N use efficiency (NUE) for 100 kg N at Embrapa and UFRGS was about 30 kg DM kg^{-1} of N applied and 40 kg DM kg^{-1} of N applied when 50 kg of N was applied at Unicentro. There was an indication that DM and N uptake may continue to increase above 200 kg N ha^{-1} under southern Brazil conditions.

Additional keywords: *Lolium multiflorum*, nitrogen use, N content, nutritive value

Introduction

Annual ryegrass is one of the most important temperate pastures in southern Brazil farming systems. In the three States of southern Brazil, there is an estimated seven million hectares of cultivated pastures with at least 30% of this area occupied by annual ryegrass. Most annual ryegrass is cultivated in mixtures with black oat (*Avena strigosa* Schreb.) or as a single pasture in integrated crop-pasture systems. Despite its wide use, farmers still consider the common variety of annual ryegrass slow to grow in the autumn and usually less productive than black oat in beef, sheep and dairy farming systems. The lack of well adapted and commercial cultivars is another common problem for annual ryegrass in Brazil.

Studies in southern Brazil have shown that soil N is the main factor limiting leaf development, plant growth and nutritive value of annual ryegrass. Low mineralisation rates of organic matter in soils, insufficient fertiliser N applications and inappropriate management practices, result in low N uptake by plants and consequently low productivity and quality of ryegrass pastures in southern Brazil farming systems (Nabinger *et al*., 2000). It has been reported that annual ryegrass yield generally increases with fertiliser N application rates, but optimum N levels differ from site to site (Kemp, 1974; Marino *et al*., 2004; Lippke *et al*., 2006).

Research by Embrapa (The Brazilian Agricultural Research Corporation) and Universities (UFRGS, UFPR and Unicentro) aimed to analyse DM and N yields (N uptake) and NUE of annual ryegrass to different fertiliser N applications in southern Brazil. The data presented here are part of an on-going research programme to develop a database for modelling research on growth of annual ryegrass pastures. However, in this paper the objective is to present an agronomic analysis of annual ryegrass performance at three different experimental sites in southern Brazil. This paper may be of use to New Zealand seed companies wishing to do business in South America and to Brazilian farmers wishing to improve management practices in their farming systems.

Material and Methods

Three experiments were carried out using unirrigated annual ryegrass (*Lolium multiflorum* L.) established at different locations in southern Brazil in 2008 and 2009. The experimental design was the same in all experiments and was a randomised block with three replicates, where the treatments were four levels of fertiliser N applied to annual ryegrass pasture: 0 (0 N), 50 (50 N), 100 (100 N) and 200 (200 N) kg N ha^{-1} $year^{-1}$. Fertiliser N was applied using ammonium sulphate (21% N and 24% S) in Experiments 1 and 2 and urea (44% N) in Experiment 3, with 10% applied at sowing and the rest at early tillering (Griffith *et al*., 1997).

Experiment 1 was located at Embrapa Southern Animal Husbandry in Bage, Rio Grande do Sul State (31° 21’ 09” S, 54° 01’ 00” W at 226 m altitude). The soil is a Plainsoil with a texture of 14 ± 0.9% clay. Soil chemical samples were collected from each treatment area (35 x 80 m paddock) prior to sowing date at 0-300 mm depth. The results showed a mean pH of 5.1± 0.1 (low), an organic matter content of 2.5 ± 0.3% (low), extractable P of 33 ± 16 ppm (medium), K of 77 ± 29 ppm (high), a total CEC of 11.1 ± 0.9 $cmol_c$ dm^{-3} (medium) and Al of 0.4±0.2 cmol dm^{-3} (low). Limestone was applied at 5 t ha^{-1} four months prior to establishment. Basal fertiliser applications of 31-44 kg ha^{-1} P and 58-83 kg ha^{-1} K were applied in April 2008 prior to ryegrass sowing, depending on paddock soil analysis. The climate is classified as cold subtropical with frequent winter frosts and warm summer temperatures. Historical meteorological data shows a mean monthly air temperature varying from 12 to 24^{o}C in a year and a total annual rainfall of 1,470 mm.

Experiment 2 was carried out at the Federal University of Rio Grande do Sul (UFRGS), Arroio dos Ratos, Rio Grande do Sul State (30° 05’ 27” S, 51° 40’ 18” W, and 46 m altitude). This soil has a sandy texture with 21 ± 3 % clay. Soil chemical samples were collected from each treatment area (7 x 15 m paddock) from 0-300 mm prior to sowing and showed a mean pH of 5.3 ± 0.2 (low), organic matter content of 1.9 ± 0.2 % (low), extractable P of 8 ± 2 ppm (medium), K of 110 ± 23 ppm (high), total CEC of 7.4 ± 2.1 $cmol_c$ dm^{-3} (medium) and Al of 0.3 ± 0.2 cmol dm^{-3} (low). Fertiliser P and K applications followed the same method as in experiment 1 with 35 kg ha^{-1} P and 33 kg ha^{-1} K applied in April 2008 prior to sowing. Climate is classified as cold, humid subtropical with warm temperatures in summer. The mean annual temperature varies from 9 to 25°C and total annual rainfall is 1,440 mm.

Experiment 3 was located at the University of Center-West Parana (Unicentro), Guarapuva, Parana State (25° 23' 01" S, 51° 29' 46" W and 1,024 m altitude). This was part of a pasture-crop system experiment. After annual ryegrass, a maize crop (*Zea mays* L.) was grown in rotation in this experimental area. The soil has a clay texture with 35% clay. Soil chemical samples were collected from each treatment area (7 x 15 m paddock) from 0-200 mm depth prior to sowing date and showed a mean pH in $CaCl_2$ of 5.1 ± 0.2 (low), organic matter content of 3.5% ± 0.2 % (medium), extractable P of 6 ppm (low), K of 152 ppm (high), total CEC of 11.5 $cmol_c$ dm^{-3} (medium) and Al of 0 cmol dm^{-3}. Basal applications of 16 kg ha^{-1} P and 96 kg ha^{-1} K were applied in April 2009, prior to sowing. The climate is classified as humid subtropical with mild summer temperatures. Mean annual temperature varies from 10.5 to 22°C and total annual rainfall is 1,961 mm. Figure 1 shows the average climate conditions for all three experiments.

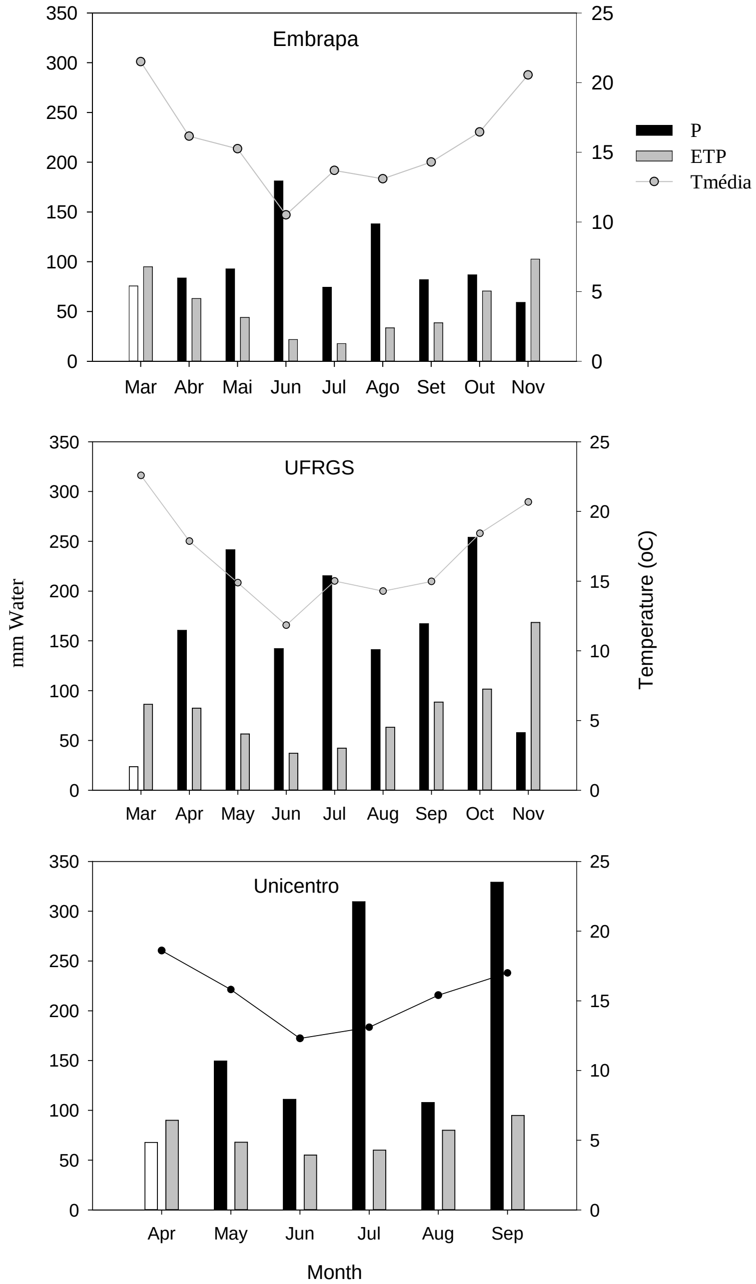

Figure 1: Total monthly rainfall (P) and Penman's evapotranspiration (ETP) and monthly mean air temperature (T) measured at the three experimental sites in southern Brazil in 2008 (Embrapa and UFRGS) and 2009 (Unicentro).

In all three experiments, annual ryegrass was cultivated as a single pasture species sown at 40 kg ha^{-1} in the autumn. Seeds used were a CPPSUL Embrapa variety of annual ryegrass produced in 2007 at Embrapa Southern Animal Husbandry Research Unit. Paddocks were sown on 14 April 2008 in experiment 1, 26 April 2008 in experiment 2 and 17 April 2009 in experiment 3. Final sampling dates were 5 and 12 November 2008 in experiments 1 and 2 respectively, and 27 September 2009 in experiment 3. Annual ryegrass plots were grazed with heifers whenever canopy cover reached 95% interception of photosynthetically active radiation interception (PARi). Data for PARi were collected weekly above and below the canopy, using a Ceptometer AccuPAR 80. Animals grazed the paddocks for 4 ± 2 days or until mean residual pasture height reached 120 mm. Because this study was designed to collect data for a modelling study, N cycling through excreta was minimised and livestock were only allowed to graze the plots only from 10 am to noon and from 2 to 4 pm daily. The aim was to evaluate plant potential response to mineral N fertiliser only as a first modelling stage, minimising N cycling in the plots. Therefore, livestock were allowed to rest outside the experiment most of the day and part of the N was exported to a nearby area, decreasing total N cycling in the experimental plots.

Data analysed in this experiment were accumulated shoot dry matter yield (kg DM ha^{-1}), total N uptake (kg N ha^{-1}) and N use efficiency (NUE) for each rotation, i.e. for each growth or grazing period. In experiments 1 and 2, samples were collected from the vegetative to the reproductive stage (50% flowering). In experiment 3, annual ryegrass was measured until the early flowering stage (30% flowering) to allow a soybean (*Glycine max* L.) crop to be sown in the same experimental area. Five herbage samples per treatment were randomly collected using a 0.25 m^2 quadrat. Samples were dried at 65°C to a constant weight and then the dry matter (DM) yield was measured. Sub-samples were taken for plant N analysis at the Animal Nutrition Laboratory of Embrapa. Annual NUE was calculated according to the following equation:

$$NUE=\frac{\text{kg DM yield with fertiliser N application - kg DM yield without fertiliser N application}}{\text{kg fertiliser N applied}}$$

Results for DM, N uptake and NUE were analysed using a randomised block analysis of variance (ANOVA), where treatments were 4 levels of fertiliser N: 0, 50, 100 and 200 kg ha^{-1} $year^{-1}$. Differences between means were tested using Fisher's protected Least Significant Difference test (LSD) at the 5% level.

Results

Annual ryegrass DM yield increased (P<0.001) with N in experiments 1 (Embrapa) and 3 (Unicentro). However, in experiment 2 (UFRGS), the DM response was greater (P<0.001) for 100 and 200 kg N ha^{-1} than for 0 and 50 kg N ha^{-1}. Asymptotic functions were fitted to the DM yields against N level at the three experimental sites (Figure 2a). The maximum accumulated ryegrass DM production was 7,190 kg DM ha^{-1} with 200 kg N ha^{-1} at Embrapa and the minimum was 1,193 kg DM ha^{-1} with no N applied at Unicentro. Mean annual growth rates increased (P<0.05) with fertiliser N applications with averages ranging from 16 to 36 kg DM ha^{-1} d^{-1} at Embrapa, 14 to 30 kg DM ha^{-1} d^{-1} at UFRGS and 11 to 51 kg DM ha^{-1} d^{-1} at Unicentro from 0 N to 200 N, respectively, during the experimental period. Control treatments (0 N) limited ryegrass DM yield in all experiments and never reached the criteria of 95% of PARi for grazing, so these plots were never grazed during the experimental period and plants were allowed to reach the full flowering stage. Treatments with 100 and 200 N had a higher number of grazings than 0 N and 50 N (Table 1).

Plant N content increased (P<0.001) with N fertiliser applications and decreased with plant maturity (Table 1). Nitrogen uptake increased (P<0.001) with increasing N applications at Embrapa and Unicentro (Figure 2b), but at UFRGS the N uptake was greater for 100 (167 kg N ha^{-1}) and 200 N (189 kg N ha^{-1}) than for 0 N (31 kg N ha^{-1}) and 50 N (73 kg N ha^{-1}). The Maximum accumulated shoot N uptake was 248 kg N ha^{-1} at 200 N in the clay soil of Unicentro and the minimum was 16 kg N ha^{-1} with 0 N, at the same site. The highest mean NUE was about 30 kg DM per kg N applied for 100 N at Embrapa and UFRGS and about 40 kg DM per kg N applied for 50 N (P<0.05) in Unicentro. The lowest mean NUE (P<0.05) was <28 kg DM per kg N applied at the 200 N level at all three sites.

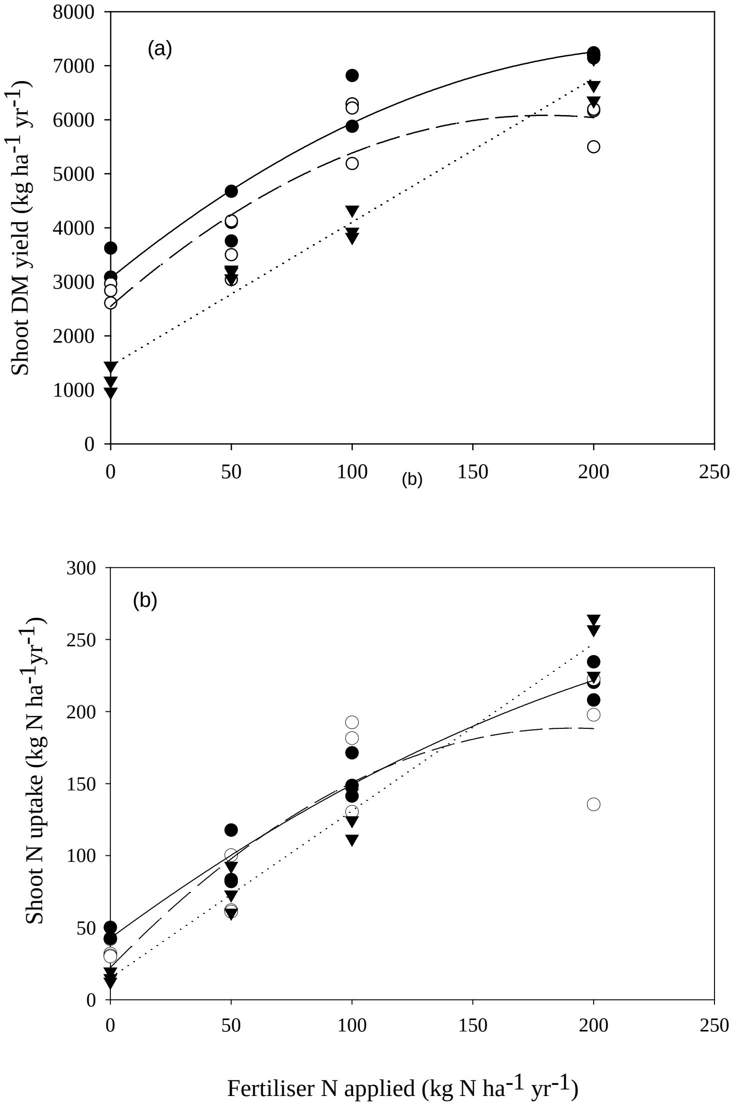

Figure 2: Shoot accumulated dry matter yield (a) and N uptake (b) during the experimental periods at Embrapa (DM LSD = 690 and N LSD = 28), UFRGS (DM LSD= 875 and N LSD=45) and Unicentro (DM LSD = 508 and N LSD = 30) in southern Brazil.

Table 1: Mean shoot dry matter yield (kg DM ha^{-1}) at the end of each growing rotation at Embrapa and UFRGS (2008 season) and at Unicentro (2009 season) in southern Brazil. Values in parenthesis are mean shoot N content (%). Final DM and % N samples for each treatment were collected when ryegrass plants were at the flowering stage.

Nitrogen Applied (kg N ha^{-1} yr^{-1})	Rotation 1[1]	Rotation 2	Rotation 3	Rotation 4	Rotation 5	Total DM yield[2]
	kg DM ha^{-1}					
EMBRAPA						
0	3262 (1.5)	-	-	-	-	3262 d
50	1770 (3.8)	2406 (1.6)	-	-	-	4176 c
100	1191 (4.8)	2133 (2.6)	3004 (1.4)	-	-	6328 b
200	1304 (5.1)	2168 (3.9)	3718 (1.9)	-	-	7190 a
UFRGS						
0	2801 (1.5)	-	-	-	-	2801 b
50	1156 (3.9)	2398 (1.3)	-	-	-	3554 b
100	1498 (5.6)	1823 (2.9)	2576 (1.7)	-	-	5897 a
200	1644 (5.2)	1865 (3.8)	2440 (2.3)	-	-	5949 a
UNICENTRO						
0	1193 (1.3)	-	-	-	-	1193 d
50	1300 (3.8)	1917 (1.1)	-	-	-	3217 c
100	1065 (4.7)	1250 (3.1)	1795 (1.2)	-	-	4110 b
200	1372 (5.1)	1091 (4.3)	1412 (4.0)	1480 (3.5)	1057 (2.4)	6412 a

[1]First grazing.

[2]Values followed by the same letter are not different by LSD at 5%.

Discussion

Annual ryegrass DM yield responded to increasing fertiliser N applications at all three sites (Figure 2a and Table 1). Favourable climate conditions for annual ryegrass in southern Brazil with mild temperatures and appropriate rainfall usually allow high pasture growth rates, especially in the late winter and spring seasons. In this study, for example, the annual ryegrass DM yield over the nil control increased by 3.9 t DM ha^{-1} yr^{-1} at Embrapa and 5.5 t DM ha^{-1} yr^{-1} at Unicentro when 200 N was applied. However, the mean DM yields observed in this study were below those reported by Thom and Prestidge (1996) for Concord annual ryegrass in New Zealand. They found a maximum accumulated DM yield of 10-13 t ha^{-1} yr^{-1} with three applications of 25 kg N ha^{-1} yr^{-1} each. In addition, Craighead *et al*. (1998) reported DM yields greater than 9,500 kg ha^{-1} yr^{-1} and peak growth rates of 70-80 kg DM ha^{-1} d^{-1} in autumn and early spring for the Corvette or Cordura cultivars (Wrightson Seeds, New Zealand) in southern Canterbury, but this was obtained after applying about 150 kg N fertiliser ha^{-1} and under irrigated conditions.

In 2008 and 2009, the three experimental sites received an excess of rainfall between autumn and early spring and this might have affected the ryegrass potential yield in the experiments because of N leaching in soil and water runoff. For example, on the sandy soil at UFRGS, the amount of rainfall was 1,380 mm for the seven month growth period which is near the historical annual rainfall for this location (Figure 1). Possibly, because of this excess N was leached before N uptake occurred, at this site, an increase in annual ryegrass DM yield above applications of 100 kg N ha^{-1} was not observed. In other studies, annual ryegrass DM yields were reported to increase with fertiliser N application and potential yields were usually higher (Lemaire and Salette, 1984; Lippke *et al*., 2006; Agusdei *et al*., 2008) or similar (Kemp, 1974; Marino *et al*., 2004) than those found in this study. Finally, N applications increased the number of growing rotations (i.e. grazings) because canopy net photosynthesis, leaf expansion and growth rates were usually accelerated (Chapman and Lemaire, 1993; Lippke *et al*., 2006).

As expected, shoot N content (%) increased linearly with fertiliser N applications at the end of each rotation and during late vegetative stages (Table 1). The dilution effect of N in plants was observed in all experiments (Table 1) as pasture approached the flowering stage. Low levels of shoot N were observed in all treatments at the final rotations as a consequence of leaf senescence and a low leaf to stem ratio when samples were collected at the advanced flowering stage. This explains the asymptotic responses observed for ryegrass N uptake in all experiments (Figure 2b). The maximum accumulated N uptake in annual ryegrass observed (248 kg N ha^{-1} with 200 N) in this study was greater than those reported by Marino *et al*. (2004) in Argentina for fertiliser applications of 100 and 200 kg N ha^{-1}, but similar to those for 0 and 50 kg N ha^{-1}. In southern Canterbury, New Zealand, de Ruiter (2009) reported an accumulated N uptake of 274 kg N ha^{-1} for Italian ryegrass cv. Feast II grown from June to September, but this was with a fertiliser applications of 100 kg N ha^{-1}. The indication was that NUE was highest at fertiliser N rates of 100 N at Embrapa and UFRGS, but 50 N at the Unicentro site. However, excess rainfall and N losses in Unicentro, particularly in the winter and early spring, may have affected N uptake by ryegrass plants at the 100 and 200 N fertiliser rates. Using this data, this means that the best economic response of all treatments for unirrigated annual ryegrass in southern Brazil was about USD 3-4c or NZD 4-5c kg^{-1} DM when applying fertiliser at 100 kg N ha^{-1} (current cost of USD 1.17 or NZD 1.64 kg^{-1} of N from urea in southern Brazil). Conversely, in southern Canterbury, Craighead *et al*. (1998) found about 60-80 kg of DM kg^{-1} of N for irrigated annual ryegrass which resulted in NZD 1.8-2c kg^{-1} DM when applying fertiliser at 140-160 kg N ha^{-1} (current cost of NZD 1.41 kg^{-1} N from urea in Canterbury).

Overall, based on the DM and N yield responses measured in these experiments, the indication was that the optimum fertiliser N application for annual ryegrass was never reached. Other factors such as the timing of applied N, the optimum grazing stage and variable weather conditions would also influence annual ryegrass responses (Griffith *et al*., 1997). For example, Craighead *et al*. (1998) reported greater annual ryegrass DM and N yields than those found in this study by building up a bank of feed supply in early autumn (40-80 kg N ha^{-1}), using strategic fertiliser N applications in mid- to late-autumn and in winter and applying good feed management such as strip grazing, the use of front and back fences and monitoring herbage quality. In fact, ryegrass growers could potentially increase N use efficiency and economic results by more effectively matching timing and amount of N applied to crop demand. In these experiments, all N fertiliser was applied up to early tillering stage which, because of the high rainfall observed in southern Brazil, may have limited the annual ryegrass in expressing its potential yield with increased fertiliser N application.

Finally, high fertiliser N applications may consistently increase DM and N yields in intensive farming systems, but long term environmental effects may result from them, such as:

(1) increased use of synthetic fertilisers based on fossil fuels,
(2) contributing to increased fossil fuel energy inputs into farms and,
(3) increased environmental pressures because of the effects of N leachate on waterways and groundwater (MFE, 2007).

Conclusion

Annual Ryegrass dry matter yield and N uptake increased consistently with N fertiliser applications and shoot N content decreased with accumulated DM yield and plant maturity (dilution effect). None of the fertiliser N levels applied could be recommended as the optimum N dosage for annual ryegrass in southern Brazil as there is indication that N uptake could continue to increase above 200 Kg N ha^{-1} under southern Brazilian conditions.

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