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Revisiting Nitrogen Fertilisation Rates of Kikuyu and Kikuyu-Ryegrass Pastures

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Revisiting nitrogen fertilisation rates of kikuyu and kikuyu-ryegrass pastures

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Key words: Dry matter production; crude protein; total mineral soil nitrogen

Abstract

Irrigated pastures are used for dairy production in South Africa. Minimum-tillage and nitrogen (N) fertilisation are important management practices for kikuyu (*Pennisetum clandestinum*) and ryegrass (*Lolium* spp.) pastures. Nitrogen fertiliser application rates as high as 500 kg N ha^{-1} year^{-1} have been reported. Conventional tillage as well as cutting and removal of herbage material (opposed to removal through grazing) are the basis on which these fertiliser guidelines were developed. The current management practices have substantially changed the soil organic carbon and N stoichiometry. The aim of this study was to determine an optimum rate of N application of kikuyu and kikuyu-ryegrass pastures. Five fixed N fertiliser rates (0, 20, 40, 60 and 80 kg N ha^{-1} grazing cycle^{-1}) were evaluated. Soil characteristics and pasture performance were monitored over a two year period. Nitrate concentrations and total mineral soil N were substantial, compared to the control, when more than 40 kg N ha^{-1} grazing cycle^{-1} were applied, leading to potential losses to the environment. Differences in biomass production were mostly due to seasonal variation, while N treatment effects within a season were generally small. As N treatments increased on both the study sites, the self-sown clover component decreased. Agronomic nitrogen use efficiency was similar across treatments and seasons on both sites, with the exception of winter in the first year on the kikuyu-ryegrass site. The results indicate that the soil could be saturated with N, at least to a point where herbage production response is minimal. A positive response in terms of crude protein was observed in some of the higher N treatments, but up to a point where it was no longer favourable for milk production. It is therefore concluded that the current N guidelines needs to be revisited as they pose a risk to the environment and farm economics.

Introduction

Kikuyu has undesirable characteristics for dairy production which include low winter and spring production, low nutritional quality and mineral imbalances (Marais 2001). However, as it has hardy rhizomes and stolons, no cost effective method was found to eradicate kikuyu and research rather attempted to incorporate it into pasture systems (Botha 2009). The effort to remove kikuyu exposed its value as a pasture base due to its tolerance to trampling from grazing. Kikuyu is an important pasture base in dairy producing systems in the southern Cape region of South Africa, as well as in other pasture dairy producing areas of the world (Garcia et al. 2014). Nitrogen, together with irrigation when rainfall is insufficient, and a temperate climate is conducive to kikuyu growth. During times of low productivity in autumn and winter, ryegrass is often sown into the kikuyu base.

To obtain high yields from the kikuyu-ryegrass pasture, N is often applied in excess of 500 kg N ha^{-1} year^{-1}, which is a large financial input. Previous N fertilisation research were performed on conditions that are dissimilar to current management practices. Historically, pasture soils were conventionally tilled compared to current no-tillage. Past research was also based on small plot trials, where herbage material was cut and removed, as opposed to situations where herbage is removed through grazing and nutrients returned through excreta. Under the current management practices, organic carbon and N the soil have changed substantially (Swanepoel et al. 2017). Dairy cows excrete a considerable amount of N and therefore applying the current N guidelines might lead to N losses. The aim of this study was to revisit the current guidelines and to determine an optimum rate of N application of kikuyu and kikuyu-ryegrass pastures.

Methods and Study Site

The study site, located on the Outeniqua Research farm, near George in the Western Cape of South Africa, has a temperate climate with rainfall (long-term average of 728 mm) distributed throughout the year. Winter months were June, July and August. Spring months were September, October and November. Summer included the months of December, January and February, while autumn was characterised as March, April and May.

Two distinct trials were conducted on separate pasture sites from April 2016 until March 2018. Past management on both sites consisted of a kikuyu base over sown with ryegrass by means of minimum tillage practices and receiving approximately 40 kg N ha^{-1} after each grazing. The first trial was comprised of long term established kikuyu (local strain) (KLS) only, which was slashed with a mower in autumn each year to keep the pasture from becoming fibrous. The second trial site consisted of kikuyu over sown with 25 kg ha^{-1} annual ryegrass (*Lolium multiflorum* cv. Barmultra II) (KRB) in autumn, on 4 April 2016 and again on 17 March 2017.

Both trials were conducted in a randomised block design consisting of four blocks allocated five N treatments each. Jersey cows grazed the pasture sites approximately once a month, resulting in approximately 11 grazing cycles within a production year. The treatments were applied as limestone ammonium nitrate at rates of 0, 20, 40, 60 and 80 kg N ha^{-1} after every grazing event (approximately 0, 220, 440, 660 and 880 kg N ha^{-1} $year^{-1}$). Irrigation scheduling was done according to tensiometers.

Soil samples were taken before grazing from each plot to a depth of 100 mm to determine mineral N content (Keeney and Nelson 1982; Cataldo et al. 1975). Five rings (0.0985 m^2) were used to cut pasture biomass samples with a hand shear to a height of 30 mm above ground level to determine the biomass prior to every grazing event. Once per season, three additional rings were cut to determine botanical composition (proportion of kikuyu, ryegrass, other grasses, legumes and weeds). Crude protein (%) was determined from the biomass samples by multiplying the total N obtained from the Kjeldahl method with 6.25. Agronomic N use efficiency (ANUE) was determined as the amount of pasture produced in response to N fertiliser applied to pasture (kg DM kg^{-1} N ha^{-1}) (Equation 1).

$$\text{ANUE (kg DM kg}^{-1}\text{ N } ha^{-1}) = \frac{\text{Pasture production (fertilised)} - \text{pasture production (control)}}{\text{N supply}}$$

[Equation 1]

Results

The effect of N fertiliser rates on pasture characteristics

At both pasture sites, KLS and KRB, pasture production was not influenced by the interaction ($p \geq 0.05$) between season and N fertilisation but was affected by both main effects ($p < 0.05$). In the KLS pasture site, the annual production ranged on average from 21.1 t DM ha^{-1} in the N0 fertilisation treatment to 24.5 t DM ha^{-1} in the N80 fertilisation treatment, while in the KRB site it ranged from 19.4 to 23.5 t DM ha^{-1} in the N0 and N80 treatments, respectively (data not shown). Results generally showed that applying N fertiliser across the range of treatments (N20, N40, N60 or N80) resulted in similar biomass production ($p \geq 0.05$) within a season (KLS data shown in Table 1; see Viljoen et al. 2020 for KBR data). Even applying no N sometimes resulted in biomass production similar ($p \geq 0.05$) to the highest fertilisation rate (N80), as seen in spring 1 and 2, as well as winter and autumn of year 2 on the KLS site (Table 1).

The botanical composition of the pasture differed primarily due to seasonal effects, rather than N fertilisation or an interaction between the two main effects on both sites. The exceptions were the kikuyu grass and the volunteer legume fractions (only volunteer legume data is shown). The response to N fertilisation changed ($p \geq 0.05$) during the seasons. The volunteer legume fraction, consisting mostly of *Trifolium repens*, was negatively correlated with N fertilisation (Table 1). At both sites, the lowest N fertilisation rate resulted in the highest volunteer *T. repens* contribution, typically more than 20%.

Season influenced ($p < 0.05$) how crude protein content responded to N fertilisation at both sites (Table 1). At both sites, high N fertilisation treatments resulted in high crude protein contents and an overall lower crude protein content in summer and spring compared to winter.

The efficiency with which N was used by the pasture was generally low and no differences between fertiliser treatments were observed (Table 1). For all N fertilisation treatments at the KLS site, 16 kg DM ha^{-1} was the highest amount of biomass produced from 1 kg N ha^{-1}, with the average being 5.85 kg DM kg^{-1} N ha^{-1}. The KBR site showed a similar trend, with the average ANUE of 5.41 kg DM kg^{-1} N ha^{-1}.

The effect of N fertiliser rates on soil characteristics

The response of soil mineral N to N fertilisation differed ($p < 0.05$) across seasons at both sites. Throughout the trial period, N0, N20 and N40 showed similar ($p \geq 0.05$) soil mineral N contents. In the KLS site, a build-up ($p < 0.05$) of mineral N was observed during winters and spring of both years in treatments N60 and N80 (Table 1). At the KBR site, soil mineral N also increased ($p < 0.05$) in the N60 and N80 treatments compared to N0, N20 and N40 from winter to summer (data not shown). During autumn 1, all treatments on both sites had a similar (p≥005) total soil mineral N of roughly 20 mg kg^{-1}. During the second year, the KBR site showed results similar to the KLS site, with high winter mineral N contents in N60 and N80, and a decrease in spring.

Table 1: The mean seasonal biomass (t ha^{-1}), legume contribution (%), crude protein (%), agronomic nitrogen use efficiency (ANUE; kg DM kg^{-1} N ha^{-1}) and total soil mineral N (mg kg^{-1}) of the pure kikuyu pasture (KLS) for N fertilisation treatments (N0, N20, N40, N60, and N80) in different seasons. The standard error of the mean is shown in brackets. Means in the same column with no common superscript differed ($p<0.05$). The number following the season denotes the year (1 = 2016/2017; 2 = 2017/2018)

		Biomass	*Legume contribution*	*Crude protein*	*ANUE*	*Soil mineral N*
Winter 1	N0	4.74 ^{nopq} (0.59)	6.33 ^{ghijk} (2.43)	19.90 ^{lmno} (0.75)		12.17 ^{ef} (2.31)
	N20	5.66 ^{ijkl} (0.12)	13.40 ^{defghij} (4.00)	20.94 ^{hijklmn} (0.57)	15.36 ^{a} (9.65)	17.99 ^{ef} (2.70)
	N40	5.47 ^{jklm} (0.33)	19.52 ^{cdef} (1.88)	22.76 ^{defgh} (0.77)	6.08 ^{abc} (2.73)	15.18 ^{ef} (2.33)
	N60	5.91 ^{hijk} (0.17)	4.29 ^{ijk} (1.64)	24.59 ^{bcd} (0.48)	6.47 ^{abc} (2.73)	22.48 ^{def} (3.34)
	N80	5.99 ^{ghij} (0.63)	17.29 ^{cdefg} (7.83)	27.59 ^{a} (1.11)	5.20 ^{abc} (0.40)	43.36 ^{bcd} (16.49)
Spring 1	N0	6.63 ^{efgh} (0.31)	22.88 ^{bcd} (3.99)	15.93 ^{rst} (0.65)		9.33 ^{f} (1.34)
	N20	7.11 ^{bcde} (0.41)	15.70 ^{defghi} (5.19)	14.77 ^{t} (0.46)	8.03 ^{abc} (11.49)	12.33 ^{ef} (4.81)
	N40	7.33 ^{abcd} (0.26)	10.1 ^{efghijk} (2.17)	16.84 ^{rs} (0.31)	5.83 ^{abc} (2.33)	9.57 ^{f} (1.01)
	N60	7.02 ^{bcde} (0.12)	4.96 ^{ijk} (0.80)	20.27 ^{jklmno} (1.21)	2.15 ^{bc} (2.19)	52.61 ^{bc} (16.76)
	N80	6.92 ^{cdef} (0.34)	8.35 ^{fghijk} (2.15)	22.45 ^{efghi} (1.22)	1.23 ^{bc} (1.64)	86.95 ^{a} (26.85)
Summer 1	N0	6.74 ^{defg} (0.31)	32.45 ^{b} (6.20)	16.09 ^{rst} (0.37)		11.17 ^{ef} (0.25)
	N20	7.54 ^{abc} (0.10)	8.58 ^{fghijk} (4.86)	16.84 ^{qrs} (1.30)	13.42 ^{ab} (5.26)	11.71 ^{ef} (0.62)
	N40	7.20 ^{bcde} (0.50)	7.59 ^{ghijk} (4.10)	18.83 ^{opq} (0.72)	3.86 ^{abc} (3.95)	14.55 ^{ef} (2.36)
	N60	7.73 ^{ab} (0.18)	3.94 ^{jk} (1.67)	21.40 ^{ghijklm} (0.43)	5.53 ^{abc} (1.89)	15.67 ^{ef} (3.14)
	N80	8.01 ^{a} (0.28)	4.33 ^{ijk} (1.78)	22.63 ^{defgh} (1.22)	5.29 ^{abc} (1.29)	14.62 ^{ef} (4.30)
Autumn 1	N0	5.12 ^{lmno} (0.22)	27.72 ^{bc} (6.19)	19.47 ^{mno} (0.82)		18. 19 ^{ef} (1.15)
	N20	5.18 ^{klmno} (0.18)	11.51 ^{defghijk} (5.90)	20.54 ^{ijklmno} (1.27)	1.02 ^{c} (4.29)	19.09 ^{ef} (0.93)
	N40	5.38 ^{jklmn} (0.12)	4.40 ^{ijk} (1.73)	23.05 ^{cdefg} (0.50)	2.18 ^{bc} (1.54)	21.05 ^{ef} (4.11)
	N60	6.27 ^{fghi} (0.21)	4.35 ^{ijk} (3.21)	24.11 ^{cdefg} (0.30)	6.38 ^{abc} (0.74)	18.17 ^{ef} (1.73)
	N80	5.82 ^{ij} (0.23)	3.58 ^{jk} (1.64)	25.03 ^{bc} (0.74)	2.90 ^{bc} (1.88)	30.04 ^{def} (2.93)
Winter 2	N0	1.95 ^{stuv} (0.09)	21.55 ^{cde} (6.43)	21.83 ^{fghijkl} (1.04)		13.08 ^{ef} (1.17)
	N20	2.37 ^{rst} (0.15)	10.24 ^{efghijk} (3.83)	19.48 ^{mnop} (1.36)	10.55 ^{abc} (5.57)	14.50 ^{ef} (1.53)
	N40	2.22 ^{rstu} (0.07)	4.46 ^{ijk} (2.59)	23.48 ^{cdefg} (0.86)	3.38 ^{abc} (1.61)	31.40 ^{cde} (1.46)
	N60	2.68 ^{r} (0.08)	7.60 ^{ghijk} (3.40)	26.21 ^{ab} (0.60)	6.08 ^{abc} (0.94)	58.26 ^{bc} (14.30)
	N80	2.55 ^{rs} (0.07)	6.02 ^{hijk} (1.66)	23.23 ^{cdefg} (2.22)	3.77 ^{abc} (0.52)	51.24 ^{bc} (14.61)
Spring 2	N0	4.26 ^{pq} (0.21)	43.70 ^{a} (6.80)	17.52 ^{pqr} (0.44)		11.49 ^{ef} (1.61)
	N20	4.97 ^{lmno} (0.30)	21.70 ^{bcd} (6.68)	16.29 ^{rst} (0.82)	11.75 ^{abc} (3.92)	11.79 ^{ef} (1.46)
	N40	4.59 ^{opq} (0.11)	13.74 ^{defghij} (7.17)	16.24 ^{rst} (0.61)	2.72 ^{bc} (1.76)	10.28 ^{f} (2.44)
	N60	4.89 ^{mnop} (0.25)	12.99 ^{defghij} (3.14)	19.08 ^{nop} (0.76)	3.48 ^{abc} (2.13)	32.72 ^{cde} (12.38)
	N80	4.59 ^{opq} (0.17)	6.37 ^{hijk} (2.05)	19.09 ^{nop} (1.12)	1.37 ^{bc} (1.32)	25.06 ^{def} (8.09)
Summer 2	N0	4.06 ^{q} (0.20)	21.33 ^{cde} (4.84)	16.49 ^{rst} (0.34)		
	N20	4.98 ^{lmnop} (0.30)	11.86 ^{defghijk} (4.28)	15.08 st (0.61)	10.20 ^{abc} (5.74)	
	N40	4.76 ^{mnop} (0.40)	11.91 ^{defghijk} (6.71)	16.95 ^{qrs} (0.81)	10.99 ^{abc} (11.05)	
	N60	4.80 ^{mnop} (0.38)	6.80 ^{ghijk} (3.06)	20.10 ^{klmno} (0.34)	2.39 ^{bc} (1.94)	
	N80	5.01 ^{lmnop} (0.35)	2.41 ^{jk} (1.18)	21.44 ^{fghijklm} (1.32)	2.68 ^{bc} (1.59)	
Autumn 2	N0	1.41 ^{v} (0.11)	16.74 ^{defgh} (3.60)			
	N20	1.59 ^{uv} (0.06)	12.00 ^{defghijk} (3.77)		8.98 ^{abc} (6.49)	
	N40	1.66 ^{tuv} (0.18)	6.91 ^{ghijk} (5.67)		6.29 ^{abc} (3.96)	
	N60	1.79 ^{tuv} (0.08)	1.53 ^{k} (0.56)		6.30 ^{abc} (1.03)	
	N80	1.83 ^{stuv} (0.08)	9.33 ^{fghijk} (4.43)		5.34 ^{abc} (1.84)	

Discussion

Pastures in the southern Cape of South Africa could be managed productively with fertiliser application rates lower than the current N guidelines. A rate lower than 200 kg N ha^{-1} year^{-1} is suggested on both the KLS and the KRB (Viljoen et al. 2020) site. A collective approach, looking at both the pasture and soil characteristics, should be followed to determine an N fertilisation rate that would be both financially and environmentally conscious.

Biomass production was minimally affected by N and was more influenced by seasonal changes. Thus, it does not make financial sense to apply high rates when the production does not reflect it. Crude protein was used as a measure of quality of the pasture. Jersey cows used in this study (small breed lactating cows) require a crude protein content of between 15 and 19% (NRC 2001; Frank and Swensson 2002; Radostits et al. 2006). As seen in the current study, applying 60 and 80 kg N ha^{-1} generally resulted in crude protein contents higher than the recommended rate on both sites. High crude protein contents, above what is required by the cows, results in a decreased milk production (NRC 2001) due to an increased N excretion by the cow and thereby lowering the N efficiency of the cow (Olmos Colmenero and Broderick 2006). The heat stability of the milk also decreases, which is undesirable for milk processors (Reid et al. 2015). Legumes have the potential to add N to the system through biological N fixation. As seen in the current study, high N rates result in a lower legume contribution. Producers could benefit from low amounts of N by financial saving and an increase in the nutritional quality of the pasture that accompanies pasture with higher *T. repens* content (Botha et al. 2008).

The build-up of total mineral soil N, which consists of plant available nitrate and ammonium, in the high N treatments (N60 and N80) has the potential to cause environmental losses. Nitrate could leach into the ground water when it is available in excess and cause eutrophication. Nitrogen fertiliser increase the amount of nitrous oxide being released into the atmosphere. This was confirmed in a study by Smit et al. (2020) that showed the increase of nitrous oxide losses as fertiliser increased from N0 to N80 on the same site as the current study.

Concurring with Viljoen et al. (2020), the results suggest that both pasture sites contain enough N to sustain the pasture. The N inputs from animal excreta were estimated to be in the range of 450 kg N ha^{-1} $year^{-1}$ on the same site with the same study design as the current study (Smit et al. 2020). The current guidelines could be adjusted downward to less than 200 kg N ha^{-1} $year^{-1}$ (Viljoen et al. 2020) for kikuyu and kikuyu-ryegrass pastures managed under long term minimum tillage practices, at least for the first two years after receiving approximately 350 kg N ha^{-1} $year^{-1}$. This will ensure both financial savings and reduce environmental risks.

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