Can additives or controlled release coating improve the nitrogen use efficiency of urea fertiliser?

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Abstract

A plot trial was undertaken to determine whether tactical use of nitrogen (N) fertiliser, applied with or without coating or additive, improved herbage yield and N use efficiency. A randomised complete block design was used to compare no fertiliser (CON), frequent low rates of urea (FL), infrequent moderate rates of urea (IM), IM with controlled release (IM+CR), IM with Progibb (IM+PG), IM with AgriSea (IM+AS), or IM with N-Boost (IM+NB) on irrigated, grazed perennial ryegrass and white clover dairy pastures in Canterbury. The total annual N applied in all fertilised treatments was 190 kg N/ha. The use of fertiliser increased annual herbage yield (16.9 vs 14.5±0.44 t DM/ha/y; $P<0.05$). Combining urea with a coating or additive altered the distribution of pasture growth but did not affect net annual production or herbage quality. Due to the lack of response and greater application costs with liquid versus granule products, these results highlight the need to consider expected responses to different fertiliser regimes when adopting practices to achieve economic benefits and N efficiency.

Keywords: *Lolium perenne,* gibberellic acid, plant hormones, seaweed, *Trifolium repens*

Introduction

Nitrogen (N) fertiliser is an important tool for managing feed supply, particularly in intensive production systems such as pastoral dairying. With increasing regulations on N fertiliser use, there is growing interest in improving the efficiency of N fertiliser applications to obtain enhanced herbage yield responses. A recent review by Gray (2023) summarised a wide range of N responses across New Zealand from studies comparing spring and autumn fertiliser applications. Previous research has demonstrated that fertiliser N use efficiency (NUE; kg DM herbage/kg N applied) declines as the rate of N increases, particularly above rates of 50 kg N/application. At higher rates, farmers require fewer applications, reducing costs associated with application. Equally, due to seasonal variation in N responses (Sun et al. 2008, Gray 2023), best practice should seek to maximise NUE to avoid nitrate leaching, nitrification or volatilisation. Fertiliser coatings have already been used to improve N efficiency by reducing volatilisation in products such as Agrotain™ (Blennerhassett et al. 2006). Similarly, a controlled release coating may slow the mineralisation of urea N so that N release rates can be matched to a rate corresponding with the plant N demand to improve N efficiency (Edmeades 2015). Additionally, controlled release fertilisers may offer an opportunity to reduce costs through larger and less frequent applications.

Other products, such as additives, can be used in conjunction with N fertiliser to target an improvement in the response of pasture to fertiliser. In this instance the action of a plant growth additive is regarded as a substance that can promote plant growth without nutrients by stimulating existing biological processes. The mode of action of these additives includes plant growth regulators (hormones), such as gibberellic acid or cytokinin, or compounds that stimulate a hormone-like response (e.g., adenine or microbial or fungal bioactives). There are several commercially available additives whose manufacturers report improvements in the plant use of nutrients; however, reviews of the scientific literature indicate considerable variability in the response to these products (Jenkins et al. 2018, Zaman et al. 2014, Edmeades and McBride 2012). Most of the information on fertilisers and additives follow a single or dual regrowth, rarely following the longer term or seasonal effects. Further, most additives require liquid/foliar applications, which typically doubles the cost of application compared with granular products and requires consideration when determining the economic benefit of these products.

In theory, there are two potential benefits of increased NUE which are to provide economic benefits while simultaneously reducing losses to the environment (Edmeades 2015). Therefore, interest by farmers on the use of these products has increased because if NUE is increased then farmers are able to produce more herbage DM with the same N applied. The main objective of this study was to compare the long-term effect of tactical use of urea fertiliser with and without additives and coating on herbage yield and composition.

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Materials and Methods

The experiment was carried out under irrigation at the Lincoln University Research Dairy Farm (-43.639, 172.457) in Canterbury, New Zealand between 10 April 2021 and 28 April 2022. The soil type consisted of a Paparua sandy loam of moderate fertility (pH 6.2; Olsen P 15; K 1.05 me/100g; Ca 9.3 me/100g; Mg 1.5 me/100g; Na 0.36 me/100g; CEC 16 me/100g and total mineral N of 20 mg/kg at a depth of 75 mm on 4 May 2021). The pasture consisted of established tetraploid perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*), which was sown in an area which had previously been under long term effluent fertigation.

The experimental design was a randomised complete block design with four blocks and 7 treatments. With the exception of the control, which received no urea fertiliser, all treatments received 190 kg N/ha/y with variation in either the rate of application, use of additive or coating. The treatments included: control at 0 kg N/ha/y (CON); frequent low rates consisting of 9 urea fertiliser (granular) applications (13/4, 17/9, 3/11, 30/11, 24/12, 21/1, 17/2, 5/3, 1/4) at 21 kg N/ha (FL), infrequent moderate rates consisting of 5 applications (13/4, 17/9, 30/11, 21/1, 5/3) at 38 kg N/ha (IM); IM as a coated controlled release (IM-CR; Rustica Time Release™ CR-N44, Viable Agriculture Ltd, Ashburton, NZ); IM and 20 g/ha of additive Progibb SG™ (Nufarm, Auckland, NZ) applied with urea in April 2021, September 2021, March 2022 (IM+PG); IM plus 5 L/ha of additive Pasture Nutrition (Agrisea Ltd, Paeroa, NZ; IM+AS); IM plus 3 L/ha of additive N-Boost (Donaghys Ltd, Christchurch, NZ; IM+NB).

On 10 April 2021, a 365 m^2 area of pasture was mown to a stubble height of 4 cm and subdivided into 28 plots of 6 × 2.1 m each. A narrow band spray of glyphosate was used to define the boundary of each plot. On 14 April, the treatments were applied to all plots according to label instructions, except for the first two applications of N-Boost where the solid urea was applied separately to the foliar application of the product instead of dissolving the urea with the N-Boost mix. The last three applications of N-Boost followed the label. All liquid applications (IM+PG, IM+AS, IM+NB) were mixed with water and applied at 200 L/ha. The liquid applications were applied with a pressurised sprayer and solid fertilisers were applied by hand.

Plots were harvested on 10 occasions throughout the study. During peak growing season between October 2021 and April 2022, plots were harvested approximately every 25 days except for October 2021 where sampling was delayed to 49 days due to COVID related access procedures. After each harvest, the experimental area was grazed by dairy cows and post graze topping occurred on one occasion in March 2022 following poor utilisation during wet weather grazing.

Measurements

Yield measurements were conducted using a push mower (Masport Ltd, Auckland, NZ) to harvest the same 6 × 0.4 m mowing strip in each plot. The fresh catcher weight was recorded in the field using portable electric scales and a fresh subsample of herbage was placed in labelled paper bags in a chilly bin. Once all the plots were mown, the fresh sub-sample was weighed and then oven dried at 60°C until it reached a constant dry weight to determine dry matter percent (DM%). Herbage yield was determined using the fresh catcher weight, the DM% and the mown area (2.4 m^2). The dried sub-sample was ground to pass through a 2 mm sieve and composition (crude protein and metabolisable energy [ME]) determined by near infrared spectrophotometry (NIRS; FOSS, Hillerød, Denmark).

A second sample of herbage was harvested to ground level from 6 random locations in the unmown area. The sample was mixed and sub-sampled using the quartering method and sorted into sown and unsown species, seed head and dead material. The sorted components were oven dried to a constant weight and recorded for botanical composition. The yield of each botanical component was calculated using the mower yields and botanical percentage to estimate the annual yield-adjusted proportion.

Statistical analysis

Herbage yield data at each harvest was analysed for variance using the general linear model procedure of Genstat (22nd Edition, VSN International Ltd). Fertiliser treatment was the fixed term in the model. Cumulative yields of nitrogen and clover were calculated by multiplying the concentrations in herbage at each harvest by the yield. The following contrasts were carried out using the contrast procedure of Genstat:

1. Effect of frequency/rate (FL vs IM)
2. Effect of additive (IM vs IM+NB & IM+AS)
3. Effect of hormone (IM vs IM+PG)
4. Effect of controlled release (IM vs IM+CR)

Weighted average botanical percentage were calculated for each harvest date and compared using a general linear model in Genstat using randomised complete block design.

Results

Climate

Total rainfall for the reported period was 746 mm, which was 24% greater than the historic 10-year average of 602 mm because of large rainfall events in May and December 2021 and February 2022 (Figure 1). An additional 210 mm was applied to the plots as irrigation

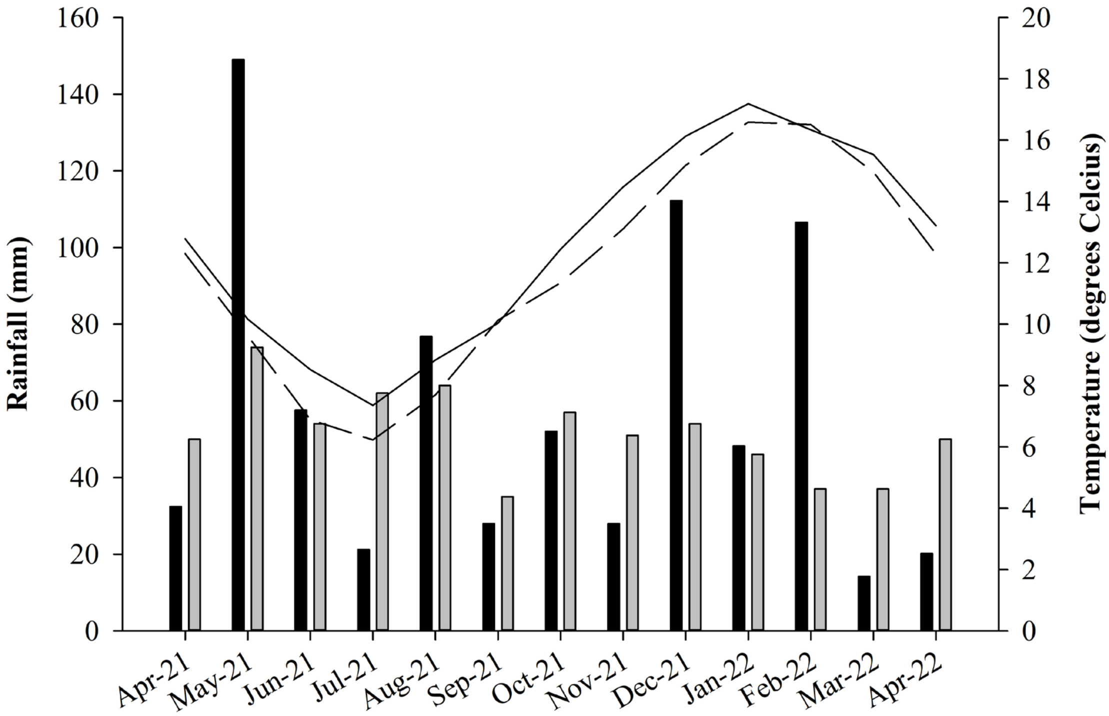


Figure 1 Rainfall and monthly average air temperatures during the experimental period (black bars and solid line) and the historic 10-year average (grey bars and dashed line)

between October and March. Temperatures during the experimental period were similar to historical averages with a total of 3,236 growing degree days (assuming a base temperature of 4°C) between 13 April 2021 and 28 April 2022.

Herbage yield

Compared with the control, fertilising with 190 kg N/ha/y increased annual DM yield, on average, by 2,445 kg DM/ha (P<0.05, Table 1). Among fertilised treatments, the use of additives or controlled release coatings, and the frequency/rate of urea applications had no significant effect on annual herbage yield (Table 1). The average annual yield for treatments receiving 190 kg N/ha/y was 16,917 ± 461 kg DM/ha/y (mean ± SEM) resulting n a similar N response for all treatments of 12.9 ± 2.42 kg DM/kg N (P=0.60) average N response of 12.9 ± 2.42 kg DM/kg N (P=0.60). Nevertheless, contrast analysis between FL and IM treatments revealed a tendency (P<0.10) for reduced N response using frequent low applications of urea (9.4 kg DM/kg N) compared with infrequent moderate (15.5 kg DM/kg N) applications (Table 1 and 2). There were no effects of using controlled release or additives on annual DM yield; however, there was an impact of tactical use of different fertiliser regimes on the pasture growth profile (Table 1). For instance, a late autumn application of controlled release fertiliser did not elicit a N response until late spring and summer. At no single harvest did any of additives used provide a herbage DM yield advantage (numerical or statistical) compared with the IM urea fertiliser control. The inclusion of gibberellic acid in the IM+PG treatment at the first application in autumn provided an 8% yield advantage over the IM treatment at the first harvest date in June, but this difference was not statistically significant (P>0.10). Due to the lack of herbage response to using an additive or coating, the added cost of the product and/or increased cost of liquid application ($12 vs. $24/ha) was less economical than using urea alone (Table 2).

Composition

Treatments influenced botanical composition (Figure 2), which was predominantly made up of ryegrass (72 ± 2.4%) with the remaining content consisting of dead material, weeds (dandelion, daisy, couch grass and poa- annua) and white clover (13 ± 1.1%, 10 ± 1.3%, 5 ± 1.5%, respectively). There was no difference in botanical content among the fertilised treatments. However, the CON treatment contained less ryegrass

Table 1 Herbage dry matter yield (kg DM/ha) at each of ten harvest (H) dates, and total annual DM and nitrogen (N) yield (kg/ha/y) for pasture which received no fertiliser (CON) or 190 kg N/ha in either 9 (FL) or 5 applications of urea without additive (IM) or with controlled release coating (IM+CR), Progibb (IM+PG), Agrisea (IM+AS), or N-Boost (IM+NB)

	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	Annual DM yield	Annual N yield
	11-Jun	9-Sep	28-Oct	26-Nov	19-Dec	18-Jan	9-Feb	1-Mar	28-Mar	28-Apr		
Con	699^{b}	1104	2457^{d}	1132^{bc}	1084^{b}	2133^{c}	2359	1300	1468	737	14,472^{b}	497^{d}
FL	878^{b}	1058	3236^{bc}	1532^{a}	1343^{a}	2792^{ab}	2337	1231	1247	613	16,267^{a}	524^{cd}
IM	1350^{a}	1599	3968^{a}	1262^{bc}	1342^{a}	2232^{c}	2301	1289	1379	690	17,413^{a}	574^{a}
IM+CR	702^{b}	1417	2923^{cd}	1369^{ab}	1359^{a}	2830^{a}	2935	1311	1431	746	17,023^{a}	560^{ab}
IM+PG	1454^{a}	1162	3968^{a}	1098^{c}	1307^{a}	2144^{c}	2769	1267	1335	603	17,109^{a}	555^{ab}
IM+AS	1276^{a}	1436	3550^{ab}	1048^{c}	1378^{a}	2269^{c}	2387	1190	1433	695	16,663^{a}	537^{bc}
IM+NB	1291^{a}	1423	3456^{b}	1158^{bc}	1283^{a}	2367^{bc}	2704	1261	1428	654	17,026^{a}	553^{abc}
SEM	74.1	138.8	163.5	86.6	58.6	146.8	271.8	45.2	95.1	35.8	441.9	10.2
P val	<.001	0.09	<.001	0.01	0.04	0.01	0.53	0.53	0.70	0.07	0.003	<.001

Letters in superscripts denote significant differences between treatments at P<0.05

and more weeds and white clover compared with the fertilised treatments (P<0.05). There was considerable variation in the estimated clover yield for each treatment, with more than twice the clover in the CON treatment than fertilised treatments (1,530 vs 690 ± 245 kg DM/ha; P<0.05).

The ME content varied throughout the season (Figure 3), with the lowest value occurring in February 2022 (11.2 MJ ME/kg DM) and highest in September 2021 (12.5 MJ/kg DM). On average, ME was 11.6 ± 0.03 MJ/kg DM with treatments using frequent low applications (FL), or Progibb and Agrisea additives having greater average ME (P<0.05) than either CON or infrequent moderate rates of urea (IM).

There was no effect of treatment on crude protein (CP) content, which averaged 21.2 ± 0.40% of the DM. Over the season, CP content varied from a low of 16% in October to a peak concentration of 26% in early March. Similarly, the average ratio of CP to ME (1.78 ± 0.027) was not affected (P=0.64) by treatment over the measurement period. The accumulated N harvested in herbage ranged from 496 to 574 kg N/ha with the lowest N harvested from CON areas. There was 10% more N harvested from fertilised areas, though treatments differed in the total amount of N harvested (Table 1).

Discussion

This research indicated that tactical use of urea with or without controlled release coating or additive can alter the distribution of feed supply but does little to alter the net annual herbage DM accumulation or quality at the same N application rate. On average, the NUE in this study was regarded as moderate at 12.5 kg DM/kg N (Gray 2023). Gray (2023) recently reviewed N fertiliser use in NZ pastoral systems and reported wide variation in response in terms of both DM (kg DM/ha) and N (kg DM/kg N). In any biological system there is inherent variability and risk of Type I and II statistical errors (Jenkins et al. 2018). For instance, in the current study, we were unable to statistically detect a 7% annual DM response or 60% annual N response difference between FL and IM treatments. Previous research has indicated that altering the rate and frequency of N fertiliser will alter the timing of accumulation, but that net accumulation is typically unaffected (Sun et al. 2008, Penno 1993). Our results confirm the effect of altering rate and frequency on timing of accumulation, but they would also suggest that over the long term, dynamics in species composition may also influence the response to N fertiliser. In the low-rate high-frequency treatment, more clover and weeds accumulated and contributed to numerically lower N response. N efficiency can be improved by selecting pastures that contain a high proportion of N responsive species.

Our results indicated that without N fertiliser, N

Table 2 Dry matter response of pasture which received 190 kg N/ha in either 9 (FL) or 5 applications of urea fertiliser ($899/t) without additive (IM) or with controlled release coating (IM+CR, $1,450/t), Progibb (IM+PG, $160/250g), AgriSea (IM+AS, $6.60/L) or N-Boost (IM+NB, $6.47/L), relative to a no urea fertiliser control.

	Dry matter response (kg DM/ha/y)	Nitrogen response (kg DM/kg N)	Product cost ($/ha/y)	Application cost ($/ha/y)	Cost of response (c/kg DM)
FL	1,795	9.45	372	108	26.74
IM	2,941	15.48	372	60	14.69
IM+CR	2,551	13.43	626	60	26.89
IM+PG	2,637	13.88	398	84	18.28
IM+AS	2,191	11.53	606	120	33.14
IM+NB	2,554	13.44	487	120	23.77

Where product costs were based on prices listed in March 2024 and excluded GST. The annual product costs are the combined cost of the products. Application costs assumed $12/ha for solid and $24/ha for liquid.

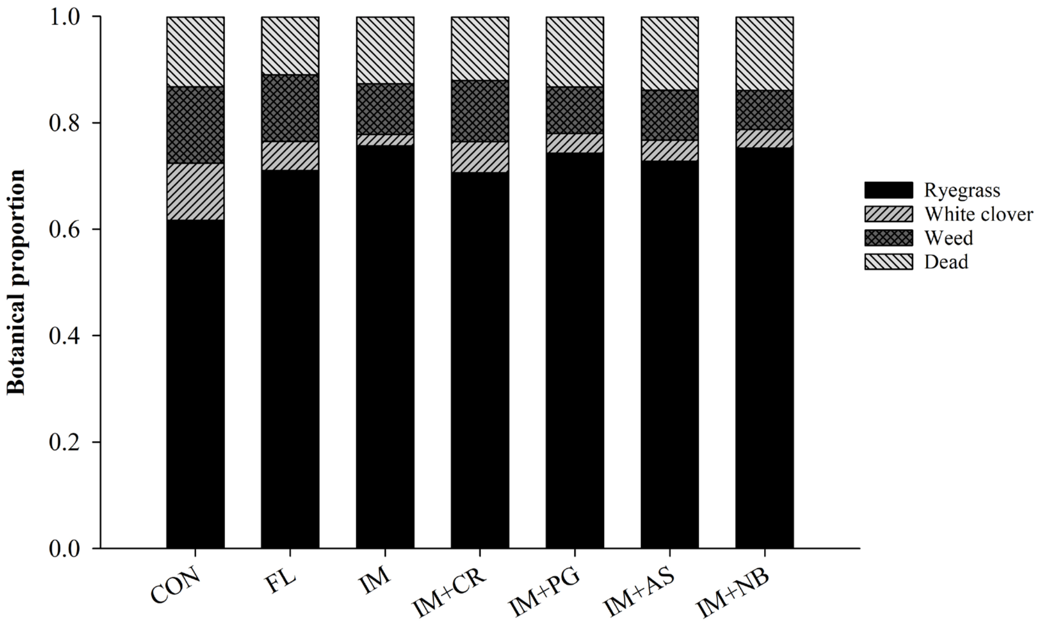
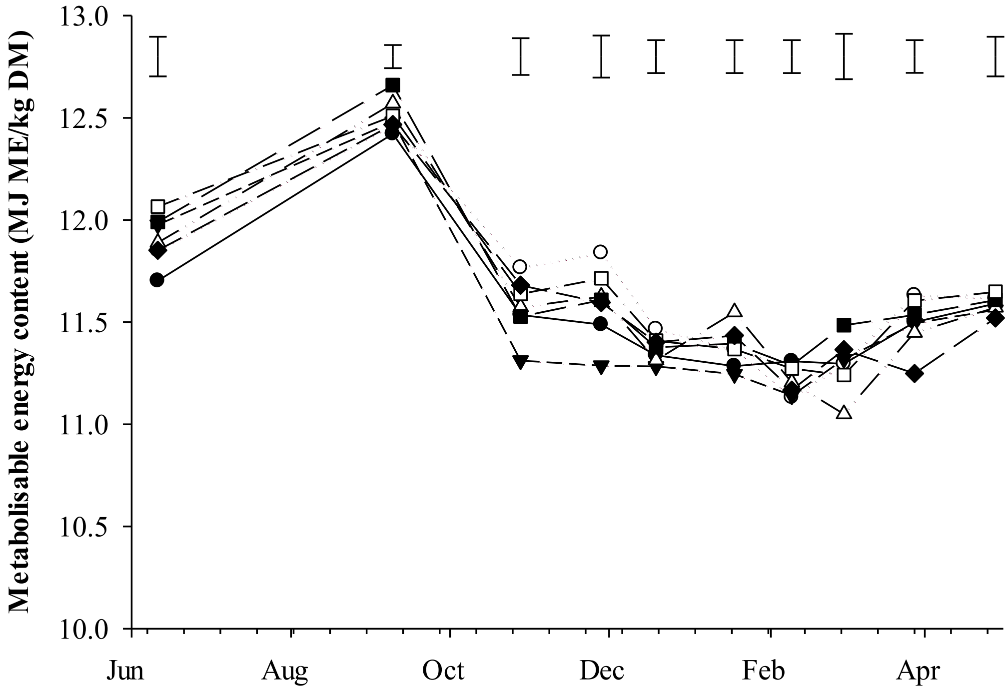


Figure 2 Annual weighted botanical content of herbage which received no fertiliser (CON) or 190 kg N/ha in either 9 (FL) or 5 applications of urea without additive (IM) or with controlled release coating (IM+CR), Progibb (IM+PG), Agrisea (IM+AS) or N-Boost (IM+NB).

recovery in herbage was nearly 500 kg N/ha. This was relatively high compared with a nearby site in Ashburton, which had a reported N recovery of 322 kg N/ha with similar DM yields (Blennerhassett et al. 2006). The high N recovery in the current site was likely due to previous effluent fertigation and minimal soil disturbance from renovation, which likely lead to an accumulation of soil N. Moderate temperatures and sufficient moisture would have supported mineralisation and uptake of N in all treatments and diminished potential differences between treatments.

Coating fertilisers to control the release of N has been reported to improve NUE (Edmeades 2015). In the current study, use of controlled release fertiliser significantly influenced timing of herbage accumulation with delayed N response to the first autumn application until spring and summer. Overall, the net herbage accumulation was similar to other fertilised plots but the evidence from this and other studies (Edmeades 2015) indicate an opportunity to combine coated and uncoated urea to achieve a more consistent DM response through autumn and late winter. There was



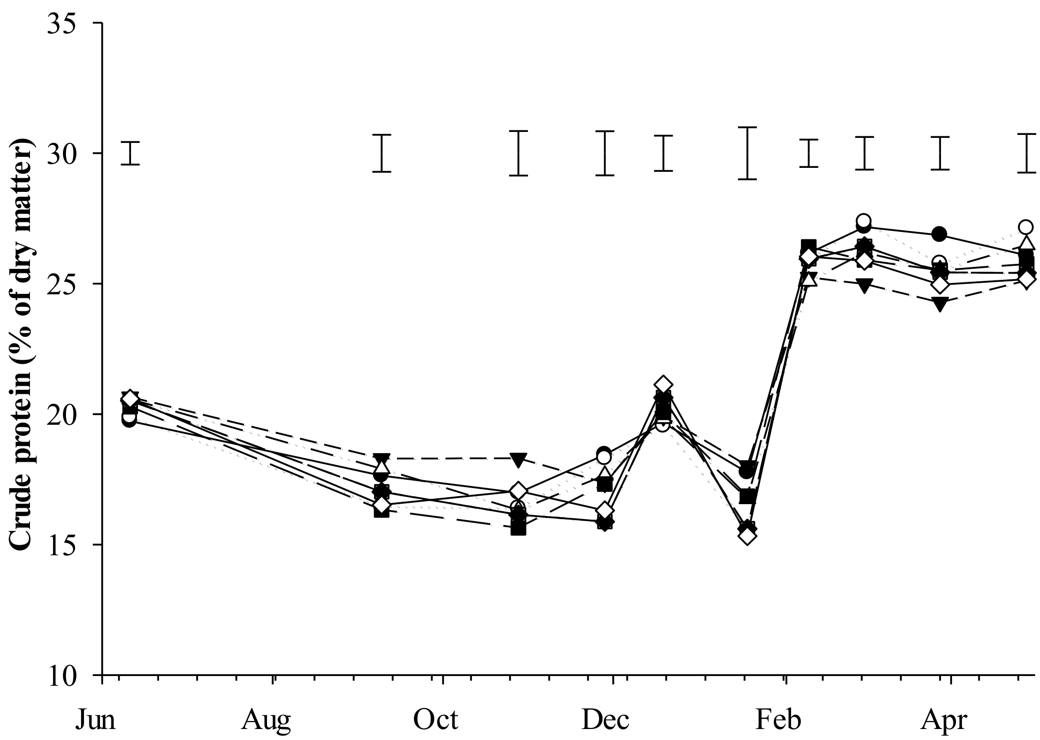


Figure 3 Metabolisable energy (upper) and crude protein (lower) content of mown herbage which received no fertiliser (black circle) or 190 kg N/ha in either 9 (open circles) or 5 applications of urea without additive (closed triangle) or with controlled release coating (open triangle), Progibb (closed square), Agrisea (closed diamond) or N-Boost (open diamond)

no evidence of any penalties in herbage quality, and using controlled release fertilisers tactically may reduce spreading costs. The main disadvantage of the coated fertiliser is the high cost of the product, which made it one of the more expensive fertilisers to use. Nevertheless, in the absence of major improvements in N response, this product may have the potential to be applied in only two or three applications to improve the economic efficiency. Further research in long-term trials would be warranted to confirm this hypothesis.

We expected to see improvements in herbage yield and quality based on prior evidence of the benefits of additives (Jenkins et al. 2018). The reason for lack of benefit of the additives used in the present trial was not clear. Several additives, including Agrisea and N-Boost used in the current study, involve the exogenous application of cytokinin (CK) or CK-like compounds. These compounds play an important role in plant development such as tiller bud initiation and leaf senescence. Previous research has shown improved plant growth during drought stress when CK was applied (Chang et al. 2016). The conditions of the present study may not favour the use of additives as the experimental area was not under water or N deficit. Modes of action of additives should be clearly advertised and guidelines provided as to expected response so users can assess the financial risk of adopting more expensive fertiliser options.

Of the exogenous hormones, we had anticipated a response from gibberellic acid, particularly in spring. While we obtained an 8% numerically greater DM yield following the application of gibberellic acid,, the results were not statistically different. There are a number of guidelines for obtaining the best response from gibberellic acid, and in this study the lack of DM response is likely due to falling short of best practice recommendations. For instance, the long delay between application and harvest, in autumn and spring 2021, of nearly 50 days diminished much of the potential gains. Exogenous applications of GA are also known for yield reductions in subsequent regrowth periods (Matthew et al. 2009) and our earlier research (Miller et al. 2022) showed that although gibberellic acid can be useful to alter the timing of herbage accumulation it is unlikely to affect total annual yields.

From an environmental perspective, we also considered the tactical use of N fertiliser and additives as a means for managing high dietary CP content – particularly in autumn, when surplus N in the diet leads to increased urinary N losses (Bryant et al. 2020). The lack of treatment effect on CP content aligns with the lack of treatment effect on yields. Even under irrigation, the results of this study show a strong effect of precipitation on protein content where elevated CP levels are seen in the months following big rain events in December and February, likely due to mineralisation of organic N. This may have implications for farmers wanting to reduce urinary N losses in autumn through dietary management, as control of pasture CP and N intake could be challenging.

Conclusions

With increasing operating expenses and regulatory pressures to reduce nutrient losses, management of N fertiliser to optimise efficiency will require careful consideration of factors driving the probability of a high DM response. Under the conditions of this study, adopting any tactical practice other than infrequent moderate rates of urea application resulted in increased cost with no evidence of a NUE benefit.

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