Variable-rate application of fertiliser – a tool for improving farm systems and environmental performance?

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Abstract
Nitrogenous fertilisers – especially urea – are key inputs into many farming systems. In New Zealand, increasing restrictions on nitrogen application on pastures means there is an urgent need to ensure that it is used effectively. One technology that has been developed that may contribute to this challenge is variable-rate application (VRA) of fertiliser. This trial used VRA technology to apply N fertiliser as a function of the pasture mass present at the time of application. The effect of VRA of N fertiliser on pasture production on five farms over one season was examined, and the impact of those changes on farm system metrics, including environmental performance, was estimated. Averaged over all five farms, there was no statistically significant difference between VRA and blanket-rate application of fertiliser on pasture production. However, one farm did show a significant difference. Although the absolute difference was small, this suggested that VRA could be a useful tool in addressing the challenge of driving better farm performance with reduced environmental impact.

Keywords: Nitrogen Fertiliser, Pasture, Environment, Overseer

Introduction
Nitrogenous fertilisers – especially urea – are key inputs into many farming systems. Non-limiting nitrogen effectively drives pasture growth, and is an important component of the farm's nutrient footprint (Monaghan *et al.,* 2005; Rawnsley *et al.,* 2014). Excessive nitrogen fertiliser application can lead to leaching through the soil, with both direct and indirect losses (through more urine deposition resulting from the increased protein supply). It has been implicated in declining water quality (Julian *et al.,* 2017). With increasing restrictions on nitrogen fertiliser application, there is an urgent need to ensure that nitrogen is used effectively (Hedley, 2015; Beukes *et al.,* 2017). One technology that has been developed to contribute to this challenge is variable-rate application (VRA) of fertiliser. Internationally, this technology has been developed for use in many crops *e.g*., wheat (Robertson *et al.,* 2012), rice (Bakar *et al.,* 2021) and maize (Lan *et al.,* 2008, Sharma and Irmak 2020), but rarely in pastures (Hills *et al.,* 2014; Corrêdo *et al.,* 2019). In New Zealand, it has been developed for application of fertilisers to hill country pastures from aircraft (Morton *et al.,* 2016, White *et al.,* 2017; Grafton *et al.,* 2021) and is now being developed for ground spreading of urea on dairy farms (Wigley *et al.,* 2017).

There are several forms of implementing rule-based variable rate applications. This can be informed by soil testing, yield maps, use of reflectance indices *via* optical sensors, pasture growth rates, pasture mass or farmer-consultant knowledge.

In the present study, fertiliser was applied as a function of the pasture mass present at the time of application. The ground spreader used an active optical sensor that was calibrated to estimate pasture quantity and adjusted the fertiliser application rate in real time (see Vogeler and Chicota 2017 for an example of the calibration process). This trial studied the effect of VRA on pasture production on five farms over one season and estimated the impact of those changes on farm system metrics, including environmental performance.

Materials and Methods
This trial compared 'Blanket Rate ('typical' rates of N fertiliser, spread uniformly across the paddock) application of fertiliser using one or both of two different Variable Rate Application methods:

- VRA-N1: N fertiliser application with sensor in real-time ranging from 40 – 120 kg/ha application rate
- VRA-N2: N fertiliser application with sensor in real-time ranging from 0 – 220 kg/ha application rate

These VRA methods used different, proprietary calibrations to determine fertiliser application rate at a given pasture mass. Five irrigated dairy farms in Canterbury were chosen, with different VRA methods and numbers of replicate paddocks

1) Site 1 – Blanket Rate, VRA-N1 and VRA-N2 (2 replicates)
2) Site 2 – Blanket Rate, VRA-N2 (3 replicates)
3) Site 3 – Blanket Rate, VRA-N2 (4 replicates)
4) Site 4 – Blanket Rate, VRA-N2 (3 replicates)
5) Site 5 – Blanket Rate, VRA-N2 (3 replicates)

The data collection from each farm was coordinated

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																				Fert	GRZ																				Fert	GRZ
Grazing cycle#	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Day#	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
CDAX			•					•					•					•						•					•					•					•			

with the grazing cycle, and was ideally scheduled as above.

Data collection cycles could not always conform to this ideal, however, due to routine farm management and other events.

Pasture growth

To be able to estimate pasture growth and height was estimated at least twice during each grazing cycle, using a C-Dax tow-behind device (C-Dax Ltd, Palmerston North, NZ). At a minimum, the sampling occurred at 0-1 day after grazing and again 1-2 days before the next grazing. C-Dax Pasture Meter was operated in straight lines in parallel to the length of the paddock at speeds between 15 to 20 km/h covering the entire paddock. Transect widths for C-Dax measurements were defined based on the spreader width that the farm was using (*e.g.*, 9 m or 18 m). Pasture height data were used to generate interpolated maps of pasture mass, and difference between measurements at successive samplings was used to estimate growth between those dates. This figure was then scaled as necessary to account for any sub-optimal timing of C-Dax measurement events and the pasture growth rate for each whole grazing cycle was then estimated.

Fertiliser application and efficiency

Data were received from the fertiliser spreader shortly after each application. The data were processed to generate interpolated maps of rate within each paddock at each application. Fertiliser efficiency was then calculated for each grazing cycle (kg dry matter grown/kg N applied) and aggregated over the growing season. Note that the 'fertiliser efficiency' calculated in this report differs from the conventional method of calculating this metric. It usually relates to the extra pasture grown from applied fertiliser compared to a nil control, not the whole amount of pasture. In this trial, it focused on differences between paddocks, fertiliser application methods and farms, so the novel method of calculation is justified. Care should be exercised, however, in comparing fertiliser efficiencies calculated in this study with those derived elsewhere.

Farm system modelling

Using Overseer files and other supplied farm data (including actual milk production), Farmax Dairy Pro (Science Edition 8.0.1.33) models were developed assuming Blanket Rate fertiliser applications. This 'base' farm was then contrasted with a 'VRA' farm, to determine if fertiliser application methods generated statistically significant differences in pasture growth. The models were then used to explore the farm-scale impacts of fertilisation strategy on key farm metrics, including production, profitability and N-leaching (through OVERSEER© version 2.9.0.2).

Statistical analysis

Where data were available, pasture growth was estimated for each grazing cycle on each farm and paddock. Analysis of variance (using Genstat 21) was performed on paddock summaries (Tables 1a-e), fitting farm, treatment and their interaction. Within each farm, two-tailed t-tests for treatment comparisons were done on paddock summaries.

Results

Grazing cycle data

Over the season, there were several occasions where pasture growth for a grazing cycle for a paddock could not be determined. Reasons for this included missing C-Dax data, omitted fertiliser applications and missing spreader GPS or rate data. Over the season, there were between two and eight grazing cycles with complete data for each paddock (Figure 1). It should be noted that, while the 'growing season' covers the period between late October and mid-late March, not all paddocks were grazed over the same 'season' exactly. These issues were most evident at Site 4.

Pasture production

Where data were available, pasture growth was estimated for each grazing cycle (Figure 1). In general, the pasture growth rates were broadly in line with those expected in this region at this time of the year for irrigated dairy farms. There was substantial variability between farms, however (ANOVA; $P<0.001$). It was also observed that the temporal variability within paddocks did not conform to any obvious seasonal pattern (Figure 1).

Total seasonal pasture production was calculated as the average over the number of days actually recorded for each paddock (Figure 2) and normalised to 130 days. T-tests were then used to assess the statistical significance of any differences.

There was a statistically significant difference in pasture growth rates between farms ($P<0.001$) but no differences between fertiliser application methods overall (average pasture growth rate: Blanket Rate=46.9, VRA-N=51.3 kg DM/ha/day; $P=0.22$) or for any individual farm (Tables 1a-e), except for Site 1.

At Site 1, there was an increase in pasture growth rate from Blanket Rate to both VRA methods (around 1100 kg DM/ha extra pasture grown over the season). There was no difference between VRA methods so VRA-N1 and VRA-N2 results were pooled (see Table 1a).

Fertiliser efficiency

Fertiliser efficiencies calculated for individual paddocks were highly variable (17-56 kg DM/kg N applied; Tables 1a-e). Some values were higher than what might be considered 'typical' for in-paddock responses (~30kg DM/kgN applied) – this was due to

Table 1a Site 1: Pasture Growth and Fertiliser Treatment effects. To enable a consistent comparison between paddocks/ treatments, 'Standardised Pasture Growth' was calculated, based on the Average Pasture Growth Rate and scaled to a 'season' of 130 days. This was done to more readily allow comparisons of Pasture Growth to be made between-paddock and between-farm.

Treatment	Pdk#	Average Pasture Growth Rate (kgDM/ha/day)	Sum of N applied (kg/ha)	Sum of Days	Accumulated Pasture Growth (kgDM/ha)	Standardised Pasture Growth (130 Days) (kgDM/ha)	Fertiliser efficiency (kgDM/kgN)
Blanket	13	74	184	140	10233	9502	56
	18	75	238	149	10935	9540	46
VRA-N2	14	81	255	156	12576	10480	49
	16	88	235	133	11364	11108	48
VRA-N1	15	86	216	136	11517	11009	53
	17	85	234	139	11519	10773	49
Means							
Blanket		74	211	145	10584	9521	51
VRA-N2		84	245	145	11970	10794	49
VRA-N1		85	225	138	11518	10891	51
p-value VRA-N2 vs. Blanket		0.10	0.36	1.00	0.19	0.06	0.73
p-value VRA-N1 vs. Blanket		0.01	0.69	0.28	0.12	0.01	0.91
Mean							
VRA		85	235	141	11744	10842	50
sed		2	21	8	471	210	3
P value VRA vs. Blanket		0.01	0.31	0.69	0.07	0.003	0.86

Table 1b Site 2: Pasture Growth and Fertiliser Treatment effects. To enable a consistent comparison between paddocks/ treatments, 'Standardised Pasture Growth' was calculated, based on the Average Pasture Growth Rate and scaled to a 'season' of 130 days. This was done to more readily allow comparisons of Pasture Growth to be made between-paddock and between-farm.

Treatment	Pdk#	Average Pasture Growth Rate (kgDM/ha/day)	Sum of N applied (kg/ha)	Sum of Days	Accumulated Pasture Growth (kgDM/ha)	Standardised Pasture Growth (130 Days) (kgDM/ha)	Fertiliser efficiency (kgDM/kgN)
Blanket	2	30	157	121	3729	4006	24
	9	40	188	165	6460	5090	34
	11	40	165	138	5404	5091	33
VRA-N2	3	46	228	153	6918	5878	30
	10	35	135	114	4181	4768	31
	12	38	170	138	5131	4834	30
Means							
Blanket		37	170	141	5198	4729	30
VRA-N2		40	177	135	5410	5160	31
sed		5	29	17	1130	510	3
p-value		0.56	0.81	0.73	0.86	0.45	0.94

the way that this whole-season metric was calculated. Since the relativities of these numbers that were the focus of this trial, and not the absolute values, this was not considered a critical issue.

Overall, the amount of fertiliser applied using Blanket Rate or either VRA method was not statistically different, except for Site 4, where the VRA paddocks received significantly more. However, these paddocks had significantly more days in grazing and the effect on fertiliser efficiency was not statistically different.

While there were statistically significant differences between farms in fertiliser efficiency (P<0.001), there

Table 1c Site 3: Pasture Growth and Fertiliser Treatment effects. To enable a consistent comparison between paddocks/treatments, 'Standardised Pasture Growth' was calculated, based on the Average Pasture Growth Rate and scaled to a 'season' of 130 days. This was done to more readily allow comparisons of Pasture Growth to be made between-paddock and between-farm.

Treatment	Pdk#	Average Pasture Growth Rate (kgDM/ha/day)	Sum of N applied (kg/ha)	Sum of Days	Accumulated Pasture Growth (kgDM/ha)	Standardised Pasture Growth (130 Days) (kgDM/ha)	Fertiliser efficiency (kgDM/kgN)
Blanket	4	66	219	122	8112	8644	37
	6	43	227	131	5550	5507	24
	15	51	152	90	4430	6399	29
	17	64	236	142	9385	8592	40
VRA-N2	5	68	255	138	9252	8716	36
	8	70	177	110	7277	8600	41
	16	49	169	101	4905	6313	29
	19	57	233	132	7671	7555	33
Means							
Blanket		56	208	121	6869	7285	33
VRA-N2		61	209	120	7276	7796	35
sed		7	28	14	1451	968	4
p-value		0.52	1.00	0.95	0.79	0.62	0.63

Table 1d Site 4: Pasture Growth and Fertiliser Treatment effects. To enable a consistent comparison between paddocks/treatments, 'Standardised Pasture Growth' was calculated, based on the Average Pasture Growth Rate and scaled to a 'season' of 130 days. This was done to more readily allow comparisons of Pasture Growth to be made between-paddock and between-farm.

Treatment	Pdk#	Average Pasture Growth Rate (kgDM/ha/day)	Sum of N applied (kg/ha)	Sum of Days	Accumulated Pasture Growth (kgDM/ha)	Standardised Pasture Growth (130 Days) (kgDM/ha)	Fertiliser efficiency (kgDM/kgN)
Blanket	4	42	51	44	1871	5529	37
	14	22	81	63	1471	3036	18
	19	23	82	67	1575	3055	19
VRA-N2	5	41	98	86	3934	5946	40
	15	35	119	81	2833	4547	24
	18	21	109	89	1893	2765	17
Means							
Blanket		29	71	58	1639	3873	25
VRA-N2		33	109	85	2887	4420	27
sed		9	12	7	602	1238	9
p-value		0.72	0.04	0.02	0.11	0.68	0.81

were no differences between fertiliser application treatments over all farms (average: Blanket Rate 35.0, VRA-N 34.0; P=0.75), or for any individual farm (Table 1a-e).

Farm-scale impacts of fertiliser treatments

To understand the whole farm impact of the use of the VRA fertiliser application method, Site 1 was modelled in both Farmax Dairy Pro and OVERSEER© . Site 1 was chosen as it was the only farm to demonstrate a statistically significant difference in Pasture Growth between Blanket Rate and either VRA fertiliser application methods (Table 1a). The results from the Blanket Rate fertiliser application method were used to create the 'Base' farm for modelling purposes. With no statistically significant difference in pasture growth between VRA-N1 and VRA-N2, these results were averaged to create the 'VRA' scenario.

The Base farm model was developed from the farm's 2020 Year End nutrient budget. The actual farm system was quite complicated, with some elements considered irrelevant in this study. The cropping programme and the beef and sheep operation had been included in the 2020 nutrient budget, but these were removed to allow modelling the farm as a simpler dairy farm in Farmax Dairy Pro.

The main changes made to the model to reflect the impact of fertiliser application methods were in pasture growth and nitrogen response. The Blanket Rate application was modelled through Farmax with pasture adjusted to ensure that the variability between zones in Overseer was represented in the Farmax file ('Base'). The N-boosted pasture feature in Farmax was used to show the overall changes to each block and how much extra pasture would be grown in the VRA scenario compared to the uniform application approach.

The extra pasture could be utilised in a variety of ways, including:

1) feeding more per head with the existing herd
2) increasing herd size to consume the extra grass
3) selling the extra pasture grown as silage
4) buy in less grass silage and lucerne baleage

For this modelling approach, option 3 was chosen. This resulted in a simpler model overall, with less interpretation required for farmer decision/management changes and had less direct impact on nitrogen balance. Overall, the financial differences between the Blanket Rate and VRA fertiliser approaches were:

- An extra $1,315 in expenses from making silage, and an extra $10,802 in nitrogen cost.
- Silage made with the extra grass grown under VRA generated $1,974 in revenue

This equated to loss of $10,394 profit before tax from the application of this technology (= a loss of $25/ha expected profits). This did not account for any gains achieved by increased feed utilisation and extra milk production from using this technology, nor for any extra costs incurred from using VRA. As modelled in Overseer, the difference in environmental performance between Blanket Rate application and VRA in the tested scenario was negligible (total N loss of 14,783kg *vs*. 14,816 kg, respectively)

Table 1e Site 5: Pasture Growth and Fertiliser Treatment effects. To enable a consistent comparison between paddocks/treatments, 'Standardised Pasture Growth' was calculated, based on the Average Pasture Growth Rate and scaled to a 'season' of 130 days. This was done to more readily allow comparisons of Pasture Growth to be made between-paddock and between-farm.

Treatment	Pdk#	Average Pasture Growth Rate (kgDM/ha/day)	Sum of N applied (kg/ha)	Sum of Days	Accumulated Pasture Growth (kgDM/ha)	Standardised Pasture Growth (130 Days) (kgDM/ha)	Fertiliser efficiency (kgDM/kgN)
Blanket	2	28	123	122	3627	3865	30
	4	52	102	110	5720	6760	56
	5	25	112	133	2976	2909	27
VRA-N2	3	25	134	97	2523	3381	19
	6	36	118	102	3619	4612	31
	7	44	126	118	4132	4553	33
Means							
Blanket		35	112	122	4108	4512	37
VRA-N2		35	126	106	3425	4182	27
sed		10	8	9	954	1225	10
p-value		0.98	0.15	0.16	0.51	0.80	0.39

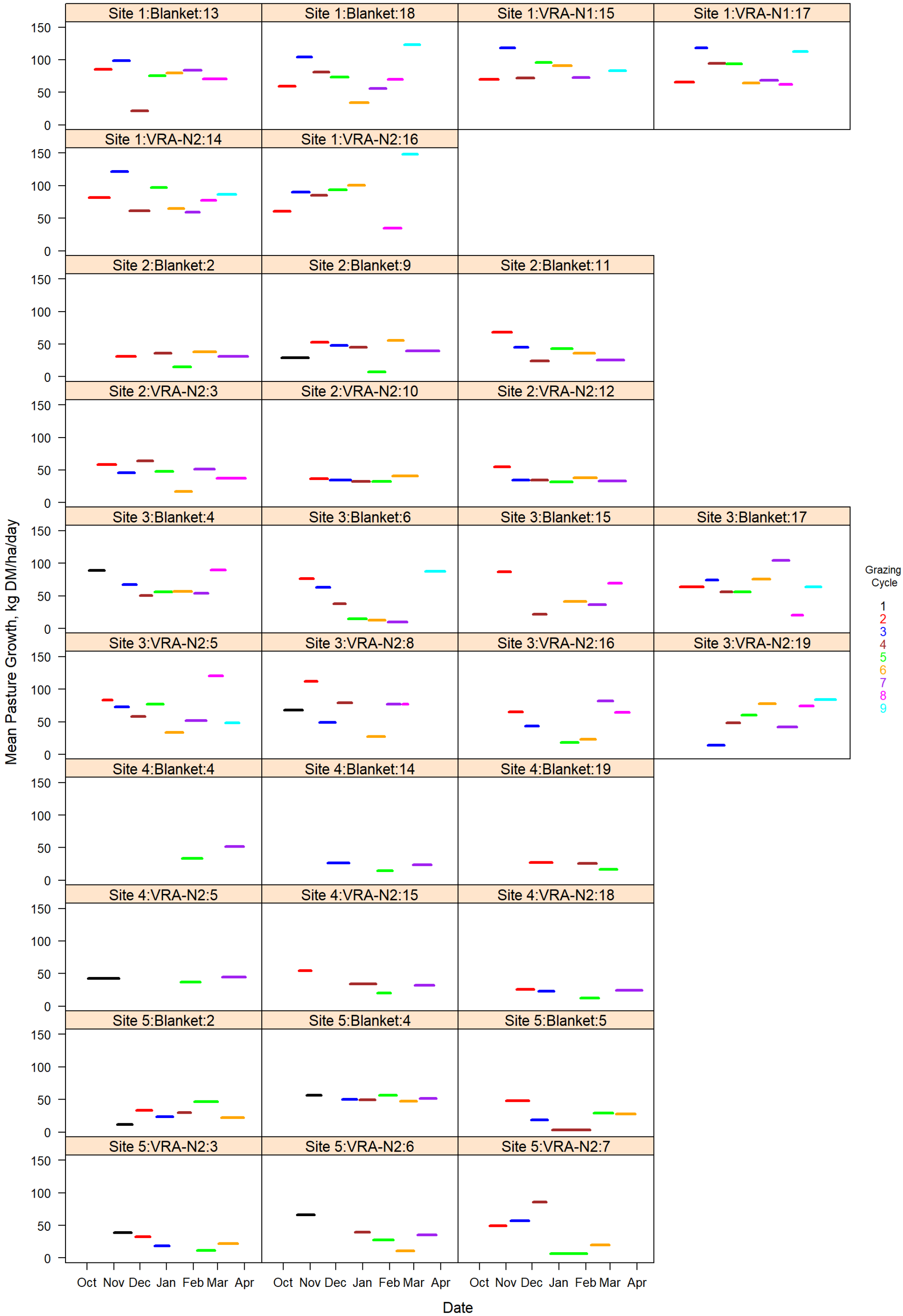


Figure 1 Estimated pasture growth rates for each farm (=Site), with fertiliser application method (Blanket Rate, VRA-N1, VRA-N2) and paddock number; for all grazing cycles for which data was available.

Figure 2ai-iii

Site 1.
Pasture Growth,
Fertiliser Application and
Fertiliser Efficiency

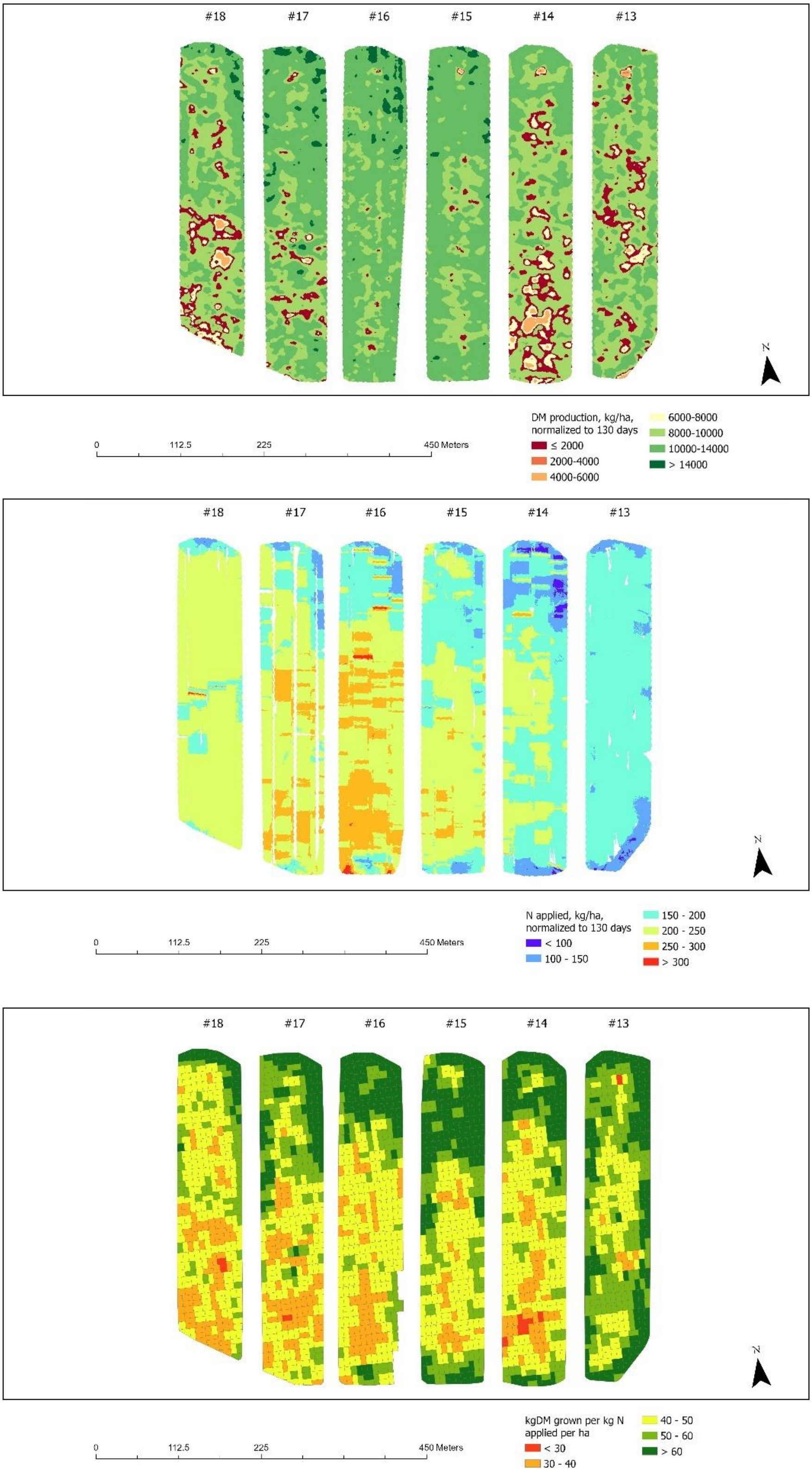


Figure 2bi-iii

Site 2.
Pasture Growth,
Fertiliser Application and
Fertiliser Efficiency

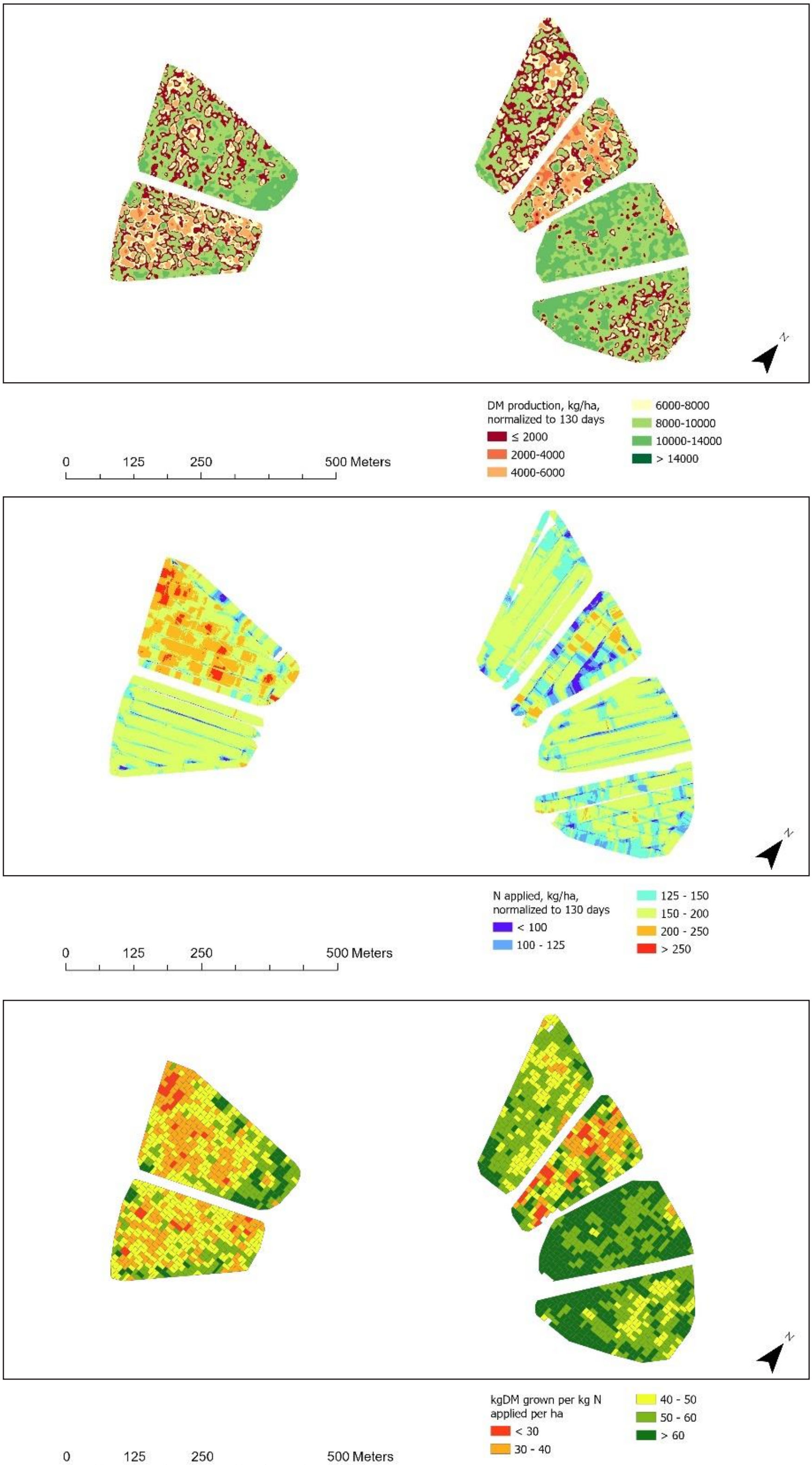
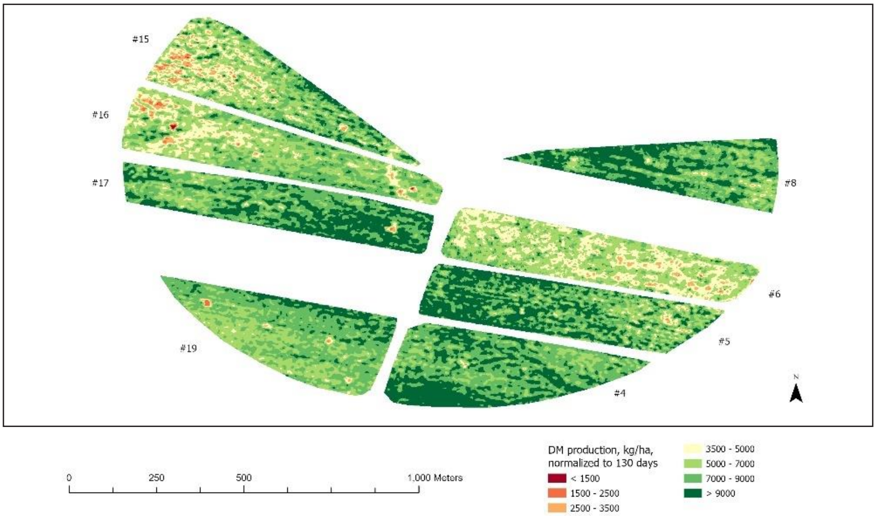
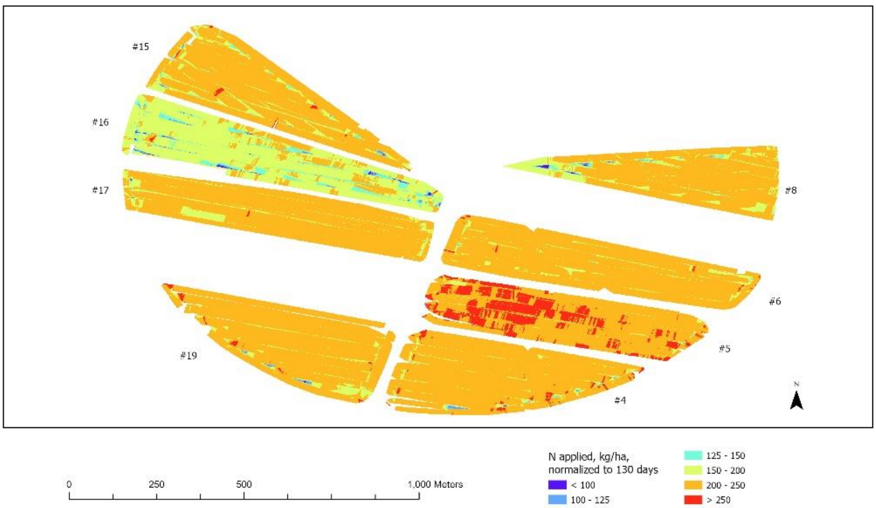


Figure 2ci-iii

Site 3.
Pasture Growth,
Fertiliser Application and
Fertiliser Efficiency





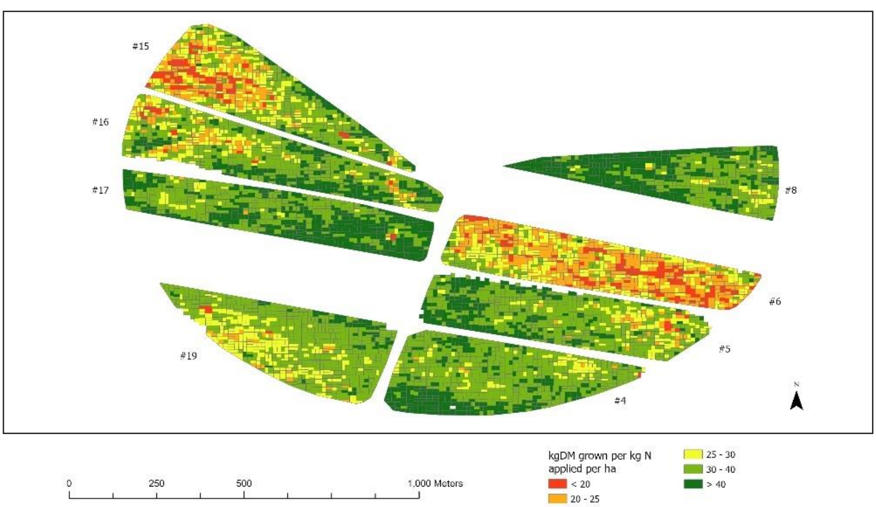


Figure 2di-iii.

Site 4.
Pasture Growth,
Fertiliser Application and
Fertiliser Efficiency

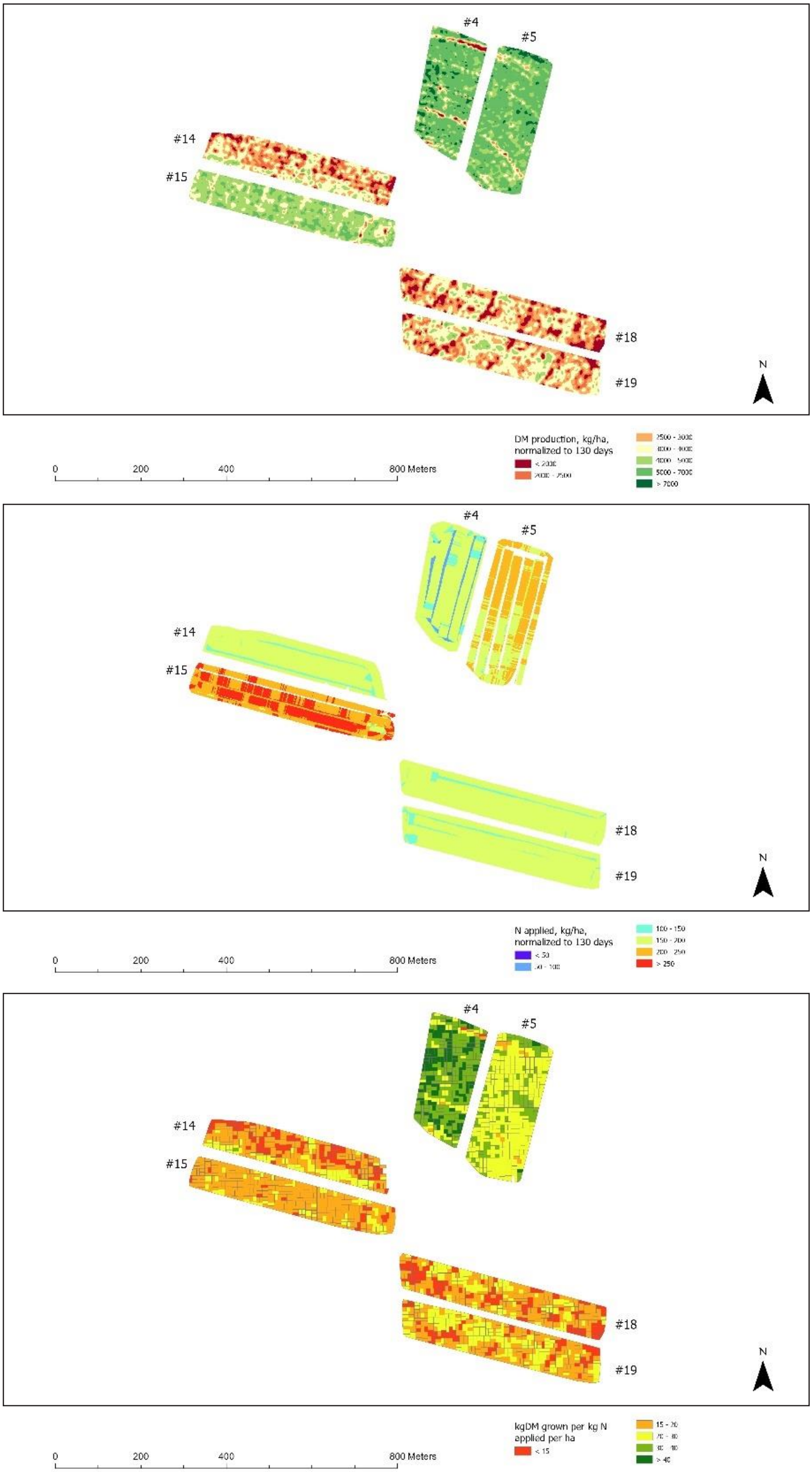
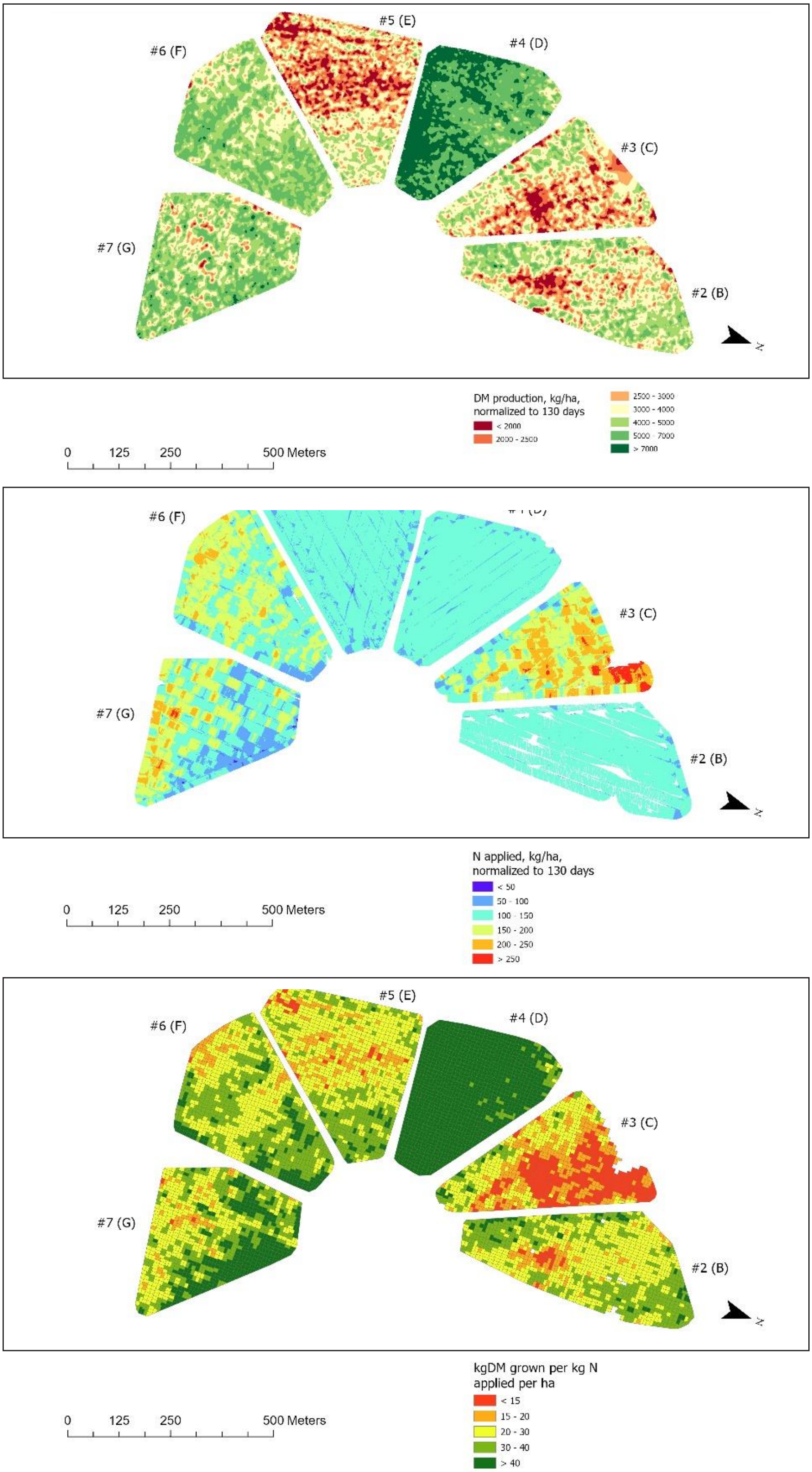


Figure 2ei-iii

Site 5.
Pasture Growth,
Fertiliser Application and
Fertiliser Efficiency



Discussion

The use of VRA fertiliser technology on dairy farms has been suggested as a useful tool in driving farm financial and environmental performance (Hedley, 2015). Comparing pasture production with fertiliser application in a spatially explicit manner was the most appropriate way to test this principle. The practical difficulties associated with running long-term trials on multiple farms, however, resulted in a dataset that was highly variable, with multiple missing values.

To minimise sources of variability, the trial included soil tests, electromagnetic soil surveys, bucket tests for the irrigator, use of Spreadermark-certified spreaders and similarly configured sensors and sharing a common protocol for managing the trial paddocks. Future research on this topic should consider, where possible, control for other sources of variability, such as differences in soil characteristics (*e.g.*, texture, drainage, compaction and elevation) and plant stresses (*e.g.,* pests, diseases and water availability).

The farm with the most complete dataset (Site 1) showed statistically significant differences between Blanket Rate and VRA fertiliser application methods. The difference was small, however, and impact on the farm system was negligible. This result was similar to data from the previous season (King *et al.,* unpublished), although the difference in pasture production in the 2019/2020 season was large enough to generate a 9% reduction in modelled N leaching from Blanket Rate to VRA method.

In addition, there were benefits from this study beyond the ability to measure the impacts of fertiliser application methods on pasture production. The obvious circular patterns in some of the paddocks that are irrigated by centre-pivot (Sites 4, 5) suggested sub-optimal irrigator performance and compromised pasture production. This needs to rectified as a matter of course, as it would improve the quality of data in any future trial work on this farm and increase the understanding of the situations and underlying factors that need to be controlled for a VRA strategy to show production efficiency or environmental benefits. It also suggested that there may be additional value in analysing the spatial data at sub-paddock scale.

Conclusions/Practical implications/Relevance

The differences in pasture production due to fertiliser application method observed in this study are worthy of further investigation. Although, when averaged over all five farms, the difference was not significant, on one individual farm (Site 1) and for some individual events on multiple farms, paddocks demonstrated positive impacts on pasture production from the VRA fertiliser application method. There is sufficient value in the data presented here to merit further investigation with more tightly controlled data collection methods. The ability of VRA fertiliser application methods to contribute to farm financial and environmental performance cannot be discounted.

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