

Supplementary Materials

Grazing strategies for resilience of ryegrass (*Lolium perenne*) dominant pastures in hill country

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Supplementary files

Supplementary Table S1. Fertiliser application details during the experimental period (application rate, month applied and fertiliser constituents) for Kaimai and Otorohaea.

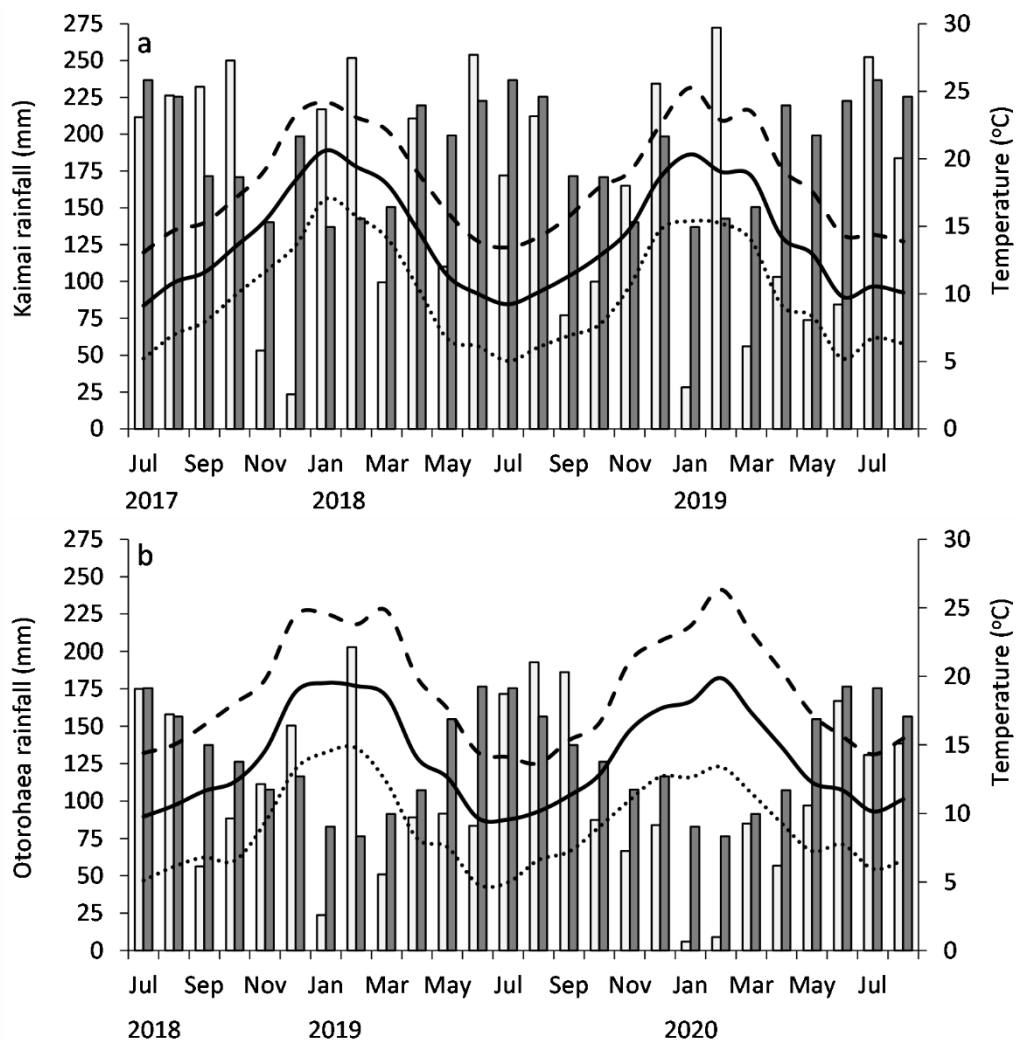
Site	Application rate and month	Fertiliser details
Kaimai	375 kg ha ⁻¹ in April 2018	Fertiliser mix: 52% Serpentine Super, 14% Muriate of Potash, 20% Di Ammonium Phosphate, 9% SustaiN, 4% Agricultural Bulk Salt, 35 kg NutriMax Boron 15%, 90 kg NutriMax Cobalt 10% and 35 kg NutriMax Selenium 1% (7.8% N, 7.6% P, 7.0% K, 4.6% S, 2.6% Mg and 8.7% Ca)
	475 kg ha ⁻¹ in April 2019	Fertiliser mix: 52% Serpentine Super, 16% Muriate of Potash, 14% Di Ammonium Phosphate, 14% SustaiN, 4% Agricultural Bulk Salt, 30 kg NutriMax Boron 15%, 20 kg NutriMax Cobalt 10% and 20 kg NutriMax Selenium 1% (8.5% N, 6.3% P, 8.0% K, 4.6% S, 2.7% Mg and 8.8% Ca)
Otorohaea	100 kg ha ⁻¹ in June 2019	N-rich Urea (46% N)
	85 kg ha ⁻¹ in April 2020	SustaiN Ammo 36N (35.3% N, 0.4% P and 8.8% S)

Supplementary Table S2. Methods used to assess soil quality parameters at the Kaimai and Otorohaea field sites in the deferred and grazed treatments.

Measurement	Method	Reference
Total carbon (C) and nitrogen (N)	Dumas dry combustion on a LECO TruMac CN analyser (LECO Corporation, St. Joseph, Michigan, USA) at 1250°C following oven drying overnight at 60°C	(Blakemore <i>et al.</i> 1987)
Hot water extractable C	3 g of soil was added to 30 ml of water, placed in a 80°C water bath for 16 h before being centrifuged, decanted and filtered, followed by measurement of organic C on a Shimadzu TOC-VCSH analyser (Shimadzu Corporation, Kyoto, Japan),	(Ghani <i>et al.</i> 2003)
Inorganic N	1-hour extraction of 5 g soil with 25 ml of 2 M KCl, followed by analysis of filtered extract for NH ₄ ⁺ and NO ₃ ⁻ on a Lachat QuikChem 8500 Series 2 Flow Injection Analysis System (Lachat Instruments, Loveland, Colorado, USA)	(Keeney and Nelson 1982)
Anaerobically mineralisable N	Measured as for inorganic N after extracting the soil under anaerobic conditions for 7 days at 40°C	(Curtin and Campbell 2007)
Olsen P	Extraction of 2 g of air dry soil in 40 mL of 0.5N NaHCO ₃ solution buffered to pH 8.50 +/- 0.05 at 25°C with end-over-end tumbling for 30 minutes; Centrifuged and filtered extracts analysed for orthophosphate on a Lachat QuikChem 8500 Series 2 Flow Injection Analysis System (Lachat Instruments, Loveland, Colorado, USA)	(Olsen <i>et al.</i> 1954)
Dehydrogenase activity	Measured using iodonitrotetrazolium chloride as the substrate	(Shaw and Burns 2006)
Soil water repellency	Determined in subsample, sieved to < 5 mm and oven dried at 65°C for 48 h, using water drop penetration time test (WDPTT _{pot}), molarity of ethanol droplet test (MED) and the contact angle test (CA).	(WDPTT _{pot} : Doerr 1998; MED and CA: Roy and McGill 2002)
Texture	Sieved <4 mm and air-dried sample was dispersed with ultrasonic vibrator before being separated into sand, silt and clay fractions using pipette method	(Gee and Or 2002)
Soil water retention	Measured at 0, -5, -10, -100, and -1500 kPa using a tension table and vacuum plate to determine total porosity, field capacity, macroporosity (at -10 kPa), air capacity and permanent wilting point	(Hu <i>et al.</i> 2018)

Supplementary Table S3. Topsoil quality parameters (average \pm SEM (standard error of the mean)) in the grazed and deferred treatments at Kaimai in November 2018.

Parameter	Grazed	Deferred
Mineral-nitrogen ($\mu\text{g N g}^{-1}$)	5.1 \pm 1.51	4.5 \pm 1.29
Anaerobically mineralisable nitrogen ($\mu\text{g N g}^{-1}$)	32.1 \pm 3.14	36.5 \pm 5.24
Hot water extractable carbon ($\mu\text{g C g}^{-1}$)	1080 \pm 212	960 \pm 269
Dehydrogenase activity ($\mu\text{g product min}^{-1} \text{g}^{-1}$)	2.1 \pm 0.24	2.1 \pm 0.47
pH (in H ₂ O)	5.1 \pm 0.04	5.3 \pm 0.05
Bulk density (g cm^{-3})	0.69 \pm 0.020	0.69 \pm 0.029



Supplementary Figure S1. Rainfall (monthly (□), 25-year long-term (1990-2014) average monthly (■)), and air temperatures (monthly maximum (- - -), average (—) and minimum (·····)) at a) Kaimai, and b) Otoroha. Climate data for each site were obtained from the New Zealand National Climate Database. The nearest meteorological station is used as a proxy and data are interpolated for each site, according to Tait *et al.* (2006).