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Fenwick R Haldenby
Department of Pastoral Agriculture, Faculty of Agriculture and Life Sciences, Lincoln University, Lincoln, Canterbury, New Zealand

Anastasia P Lyttelford
Pastoral Systems Research Group, School of Agriculture and Environment, Massey University, Palmerston North, Manawatu-Whanganui, New Zealand

Cormac J Whitaker-Mossburn
Forage and Soil Science Programme, AgResearch Grasslands, Palmerston North, Manawatu-Whanganui, New Zealand

Corresponding Author:
Fenwick R Haldenby
Department of Pastoral Agriculture, Faculty of Agriculture and Life Sciences, Lincoln University, Lincoln, Canterbury, New Zealand

Effect of pasture renewal and nitrogen fertilization on dry matter yield and feed quality of perennial ryegrass-white clover swards under temperate dairy systems

Fenwick R Haldenby, Anastasia P Lyttelford and Cormac J Whitaker-Mossburn

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Abstract
A two-year field experiment was conducted at the Lincoln University Pastoral Research Farm, Canterbury, New Zealand, during 2023-2025 to evaluate the combined effect of pasture renewal and nitrogen fertilization on Dry Matter (DM) yield and feed quality of perennial ryegrass-white clover swards. A split-plot design with two pasture conditions (renewed and unrenewed) as main plots and five nitrogen levels (0, 50, 100, 150 and 200 kg N ha^{-1} yr^{-1}) as subplots, replicated thrice, was followed. Renewed swards consistently outperformed unrenewed swards, yielding 10.2 to 16.9 t DM ha^{-1} against 7.8 to 12.7 t ha^{-1} in unrenewed plots. Crude protein in renewed plots was 2.5 to 2.8 percentage points higher, while metabolisable energy was elevated by 1.0 to 1.2 MJ kg^{-1} DM. White clover content declined from 28.4% at 0 kg N to 11.6% at 200 kg N ha^{-1} in renewed swards. Apparent nitrogen use efficiency fell from 48 to 34 kg DM kg^{-1} N in renewed swards as nitrogen rose from 50 to 200 kg N ha^{-1}. The findings indicate that pasture renewal combined with moderate nitrogen application of 100 to 150 kg N ha^{-1} yr^{-1} offers the optimum balance between productivity, forage quality and legume persistence under temperate New Zealand dairy systems.

Keywords: Perennial ryegrass, white clover, pasture renewal, nitrogen fertilization, dry matter yield, feed quality, nitrogen use efficiency

1. Introduction

Perennial ryegrass (Lolium perenne L.) and white clover (Trifolium repens L.) swards form the cornerstone of pasture-based dairy production across temperate regions, supplying the bulk of metabolisable energy and crude protein required for grazing livestock [1, 6]. In New Zealand, where over 90% of dairy farms operate on grazed pasture, the productivity and nutritive value of ryegrass-clover mixtures directly determine farm profitability and the environmental footprint of milk production [2, 5]. Recent surveys have documented a marked decline in pasture persistence within five to seven years of establishment, attributed to cultivar deterioration, weed ingress and inadequate replenishment of nitrogen reserves through symbiotic fixation [7, 10].

Pasture renewal has emerged as a strategic intervention to restore DM production and reverse the gradual loss of legume content in ageing swards [7, 9]. Renewed pastures typically demonstrate higher tiller density and improved seasonal growth distribution [11, 13]. Nitrogen fertilization remains the most widely used lever for increasing pasture growth, particularly during periods of low clover activity [3, 8]. However, excessive or poorly timed inputs may suppress white clover, elevate nitrate leaching losses and compromise the protein-to-energy ratio of herbage [4, 12, 14].

Although individual effects have been reported [3, 7, 11], integrated assessments of their combined influence on DM accumulation, botanical composition and feed quality under New Zealand dairy conditions remain limited [9, 15]. The present investigation was undertaken to (i) quantify the effect of pasture renewal on annual and seasonal DM yield, (ii) evaluate the response of renewed and unrenewed pastures to graded nitrogen levels, (iii) assess the consequent changes in feed quality, and (iv) determine the apparent nitrogen use efficiency under each treatment combination.

2. Materials and Methods

The field experiment was conducted during 2023-24 and 2024-25 at the Lincoln University Pastoral Research Farm, Canterbury (43°38'S, 172°28'E, 12 m above mean sea level). The site has a temperate maritime climate with mean annual rainfall of 648 mm and mean annual temperature of 11.6 °C. The soil is a Templeton silt loam (Udic Ustochrept) with pH 6.1, organic carbon 3.2%, available N 142 kg ha^{-1}, available P (Olsen) 21 mg kg^{-1} and available K 168 mg kg^{-1}.

The experiment followed a split-plot design with three replications. Main plots comprised pasture renewal status: renewed (R), resown in autumn 2023 with perennial ryegrass cv. 'Trojan NEA2' at 18 kg ha^{-1} and white clover cv. 'Tribute' at 4 kg ha^{-1} [1, 11], and unrenewed (U), an existing 8-year-old ryegrass-clover sward. Subplots (6 m × 4 m) received five nitrogen levels (N0, N50, N100, N150 and N200 kg N ha^{-1} yr^{-1}), applied as urea in four equal splits during August, October, January and March [3, 8]. Phosphorus, potassium and sulphur were applied uniformly at maintenance rates. Herbage cuts were taken at approximately 3-week intervals using a Haldrup plot harvester at 5 cm cutting height; subsamples were oven-dried at 65 °C for 48 h. Botanical composition was determined by hand separation of three 0.1 m² quadrats per plot [9]. Crude Protein (CP), Neutral Detergent Fibre (NDF), Acid Detergent Fibre (ADF) and Metabolisable Energy (ME) were estimated by NIRS (FOSS DS2500), calibrated against wet chemistry standards [6]. Apparent NUE was computed as additional DM produced per kg N applied, relative to the N0 control [8, 15]. Data were subjected to ANOVA using SAS 9.4, with means separated by LSD at P = 0.05.

3. Results

3.1 Annual dry matter yield

Annual DM yield was significantly influenced by both pasture renewal and nitrogen fertilization ($p<0.01$), with a significant renewal × nitrogen interaction (Figure 1). Renewed swards produced 30.6 to 33.1% higher DM yield than unrenewed swards across all nitrogen levels, attributable to higher tiller density (4,820 vs 3,140 tillers m^{-2}) [11, 13]. The yield response curve flattened beyond 150 kg N ha^{-1}, with the marginal response declining from 26 to 12 kg DM kg^{-1} N in renewed swards, indicating diminishing returns [3, 8].

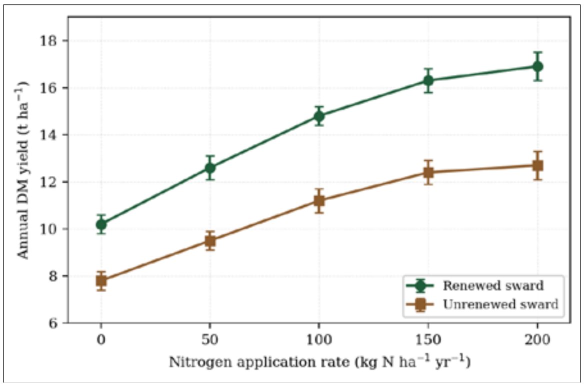

Fig 1: Effect of nitrogen application rate on annual DM yield of renewed and unrenewed swards (bars indicate ± SE)

3.2 Seasonal yield distribution

Seasonal DM yield distribution (Figure 2) showed that renewed swards captured a larger share of growth in spring and autumn, while winter contributions remained modest [2, 11]. At N150, spring DM yield of renewed swards (5.6 t ha^{-1}) was 37% higher than that of unrenewed swards (4.1 t ha^{-1}). The autumn yield advantage of renewed plots (31%) is particularly relevant for autumn-calving herds [5].

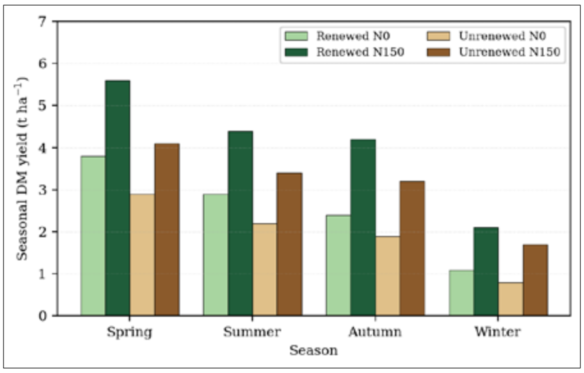

Fig 2: Seasonal DM yield distribution under contrasting renewal and nitrogen treatments

3.3 Feed quality parameters

Crude protein and I were consistently higher in renewed plots across all nitrogen levels (Figure 3). At zero nitrogen, renewed swards recorded CP of 21.4% and ME of 11.6 MJ kg^{-1} DM, versus 18.9% and 10.4 MJ kg^{-1} DM in unrenewed swards [1, 6]. Increasing nitrogen elevated CP modestly (1.4 to 2.2 percentage points at 200 kg N) but had negligible effect on ME [3, 14]. The complete profile, including NDF and ADF, is summarised in Table 1.

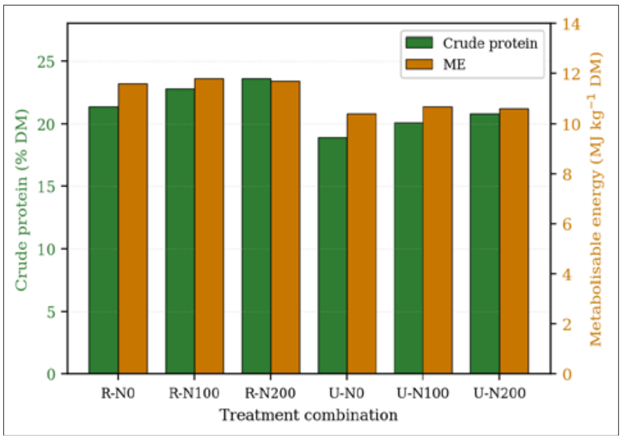

Fig 3: Crude protein and metabolisable energy under selected renewal × nitrogen treatments. R = Renewed; U = Unrenewed

Table 1: Feed quality parameters of herbage under different renewal × nitrogen treatments (mean of two years)

Treatment	CP (%)	NDF (%)	ADF (%)	ME (MJ/kg)	DMD (%)
R-N0	21.4	41.8	22.4	11.6	78.2
R-N100	22.8	43.6	23.7	11.8	78.9
R-N200	23.6	46.3	25.1	11.7	77.6
U-N0	18.9	44.5	24.6	10.4	72.4
U-N100	20.1	46.1	25.8	10.7	73.1
U-N200	20.8	48.4	27.2	10.6	71.9
LSD (0.05)	0.6	1.1	0.8	0.2	1.2

Note: R = Renewed; U = Unrenewed; CP = Crude protein; NDF/ADF = Neutral/Acid detergent fibre; ME = Metabolisable energy; DMD = DM digestibility

3.4 Botanical composition

White clover content declined sharply with increasing nitrogen (Table 2), falling from 28.4% at N0 to 11.6% at N200 in renewed swards, and from 18.6% to 7.2% in unrenewed plots [1, 4]. The shift towards a grass-dominated sward reflects competitive suppression of clover by vigorous ryegrass growth [12, 14]. Weed content stayed below 6% in renewed plots but rose to 11-14% in unrenewed plots, dominated by browntop and yarrow [7, 10].

Table 2: Effect of nitrogen on white clover (WC), ryegrass (RG) and weed proportions in renewed and unrenewed swards

N rate (kg/ha)	R-WC (%)	R-RG (%)	R-Weed (%)	U-WC (%)	U-RG (%)	U-Weed (%)
0	28.4	64.2	5.8	18.6	68.7	13.9
50	24.1	69.8	4.7	15.2	72.4	13.0
100	18.7	75.1	4.2	11.8	76.3	12.6
150	14.2	79.6	3.8	8.9	79.1	12.0
200	11.6	82.4	3.4	7.2	81.0	11.8
LSD (0.05)	1.3	1.9	0.6	1.1	2.0	1.4

3.5 Nitrogen use efficiency

Apparent NUE declined non-linearly with increasing nitrogen rate in both pasture types (Figure 4). Renewed swards consistently exhibited higher NUE, falling from 48 to 34 kg DM kg^{-1} N from N50 to N200, while unrenewed swards declined from 34 to 24 kg DM kg^{-1} N [8, 15]. The NUE advantage of renewed swards reflects their greater capacity to capture and partition applied nitrogen into vegetative growth [13].

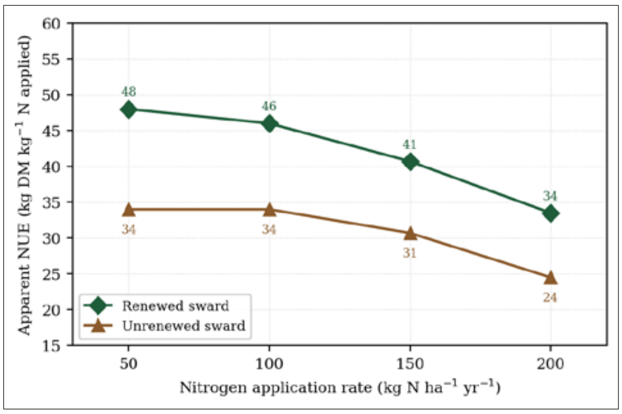

Fig 4: Apparent NUE (kg DM per kg N applied) of renewed and unrenewed swards

4. Discussion

The 30 to 33% yield advantage of renewed swards is consistent with published estimates for New Zealand dairy systems, where renewal benefits typically range from 25 to 40% during the first three post-establishment years [7, 11]. Higher tiller density and superior cultivar vigour of newly sown 'Trojan NEA2' account for most of this gain [13], with secondary contributions from reduced weed competition [9, 10]. The diminishing-returns pattern of nitrogen response mirrors classical curves for temperate ryegrass swards [3, 8] and reflects saturation of plant N uptake, intensified competition for light and water, and partial substitution of biologically fixed N by fertilizer-N [12, 15]. The agronomic optimum of 100 to 150 kg N ha^{-1} yr^{-1} aligns with operational windows currently recommended for Canterbury [2]. The decline of white clover from 28.4% to 11.6% in renewed swards with rising nitrogen is consistent with the competitive disadvantage of legumes under high mineral-N [1, 4], driven by reduced light penetration and downregulation of nodulation [12, 14]. Maintaining clover above 20% [1] was achieved only at nitrogen levels up to 50 kg N ha^{-1} in renewed swards, representing a critical sustainability trade-off [4, 14].

Renewal benefits extend beyond yield to feed quality: higher CP, ME and DMD in renewed plots reflect a younger leaf population and higher clover content [6, 11]. The concurrent rise in NDF and ADF with nitrogen (Table 1) suggests prolonged high inputs encourage stem elongation, partially offsetting the protein gain [3, 6]. The renewed N100 treatment offered the most favourable combination of CP (22.8%), ME (11.8 MJ kg^{-1} DM) and DMD (78.9%), aligning with dairy cow requirements during peak lactation [6]. The lower NUE of unrenewed swards [8, 15] indicates that 14 to 28% more nitrogen would be required to match renewed productivity, suggesting renewal should be regarded as a prerequisite rather than alternative to nitrogen-intensive management [7, 9], integrated with moderate N rates to optimize farm and catchment outcomes [4, 5].

5. Conclusion

Pasture renewal substantially improved DM yield, feed quality and nitrogen use efficiency of perennial ryegrass-white clover swards under temperate dairy conditions in Canterbury, New Zealand. The combination of renewal with moderate nitrogen at 100 to 150 kg N ha^{-1} yr^{-1} offered the best compromise between productivity, herbage quality and white clover persistence. Higher rates yielded diminishing returns while accelerating clover decline. Future work should examine the persistence of these benefits over a longer post-renewal horizon and quantify nitrate leaching and nitrous oxide losses across the same treatment matrix.

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