Total annual and seasonal DM production of improved and unimproved resident pastures at three farms in Canterbury

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Abstract

Yield differences between resident and improved pastures were quantified over a 3-4 yr period on three rainfed farms located in North Canterbury (Stockgrove, north of Amberley), Banks Peninsula (Willesden Farm) and the Mid-Canterbury foothills (Inverary Station). Improved pastures produced two- to three-times more feed annually than unimproved resident pastures at each property. At Stockgrove, improved chicory/white clover-based pastures produced 14.1±0.66 t DM/ha/yr compared with 4.36±0.41 t DM/ha/yr from unimproved pastures. Spring accounted for 85% (improved) and 72% (unimproved) of total annual DM production. At Willesden, lucerne monocultures produced 11.5±0.97 t DM/ha/yr, which was more than the 4.44±0.45 t DM/ha/yr produced from resident pastures. Improved pastures at Inverary yielded 7.31±0.59 t DM/ha in summer/autumn of 2018/19, which was more than double the 3.34±0.43 t DM/ha from unimproved pastures. In 2019/2020, improved pastures produced 11.7±1.45 t DM/ha compared with 4.45±0.73 t DM/ha. In the third growth season (2020/2021) improved pastures produced 14.1±1.76 t DM/ha compared with 6.67±1.38 t DM/ha from unimproved pastures. In Year 4 (2021/22) the 12.6±1.29 t DM/ha from improved pastures was 56% more than the 8.07±0.85 t DM/ha from the unimproved pastures. Substantial increases in annual and seasonal feed supply patterns can be achieved through hill country pasture improvement.

Keywords: *Agrostis capillaris*, *Anthoxanthum odoratum,* C*ichorium intybus*, *Holcus lanatus*, *Medicago sativa*

Introduction

Hill country pastures are frequently deficient in nitrogen and thus highly responsive to the application of inorganic nitrogen (N) fertiliser (Gillingham et al., 1998; Lambert et al., 2003; Fasi et al., 2008; Lambert et al., 2012). However, routine application of N is often impractical and environmentally questionable in many areas. Hill country farmers have traditionally applied superphosphate to encourage nitrogen fixation from the legume component of the sward. In wetter regions, white clover (*Trifolium repens*) has been oversown, while subterranean clover (sub clover; *T. subterraneum*), which offers earlier spring growth, is used in drier eastern regions. Despite this, the legume content of hill country pastures is frequently low and, at times, the economics of applying fertiliser and lime to maintain the legume is uncertain (Morton et al., 2022). The introduction of legumes to grass dominant swards is also difficult, particularly through oversowing (Tozer and Douglas 2016). Where they do establish, preferential grazing by animals (Clark and Harris 1985) reduces the legumes competitive ability against resident grasses. Thus, hill country swards become grass dominant unless strict grazing management protocols, aimed at increasing the legume content, are observed (Grigg et al. 2008; Olykan et al. 2019a). The dominance of browntop (*Agrostis capillaris*) in many hill country regions suggests grazing has resulted in plants that are short of carbon (Moot et al., 2021), and its ability to compete for phosphorous (Jackman and Mouat 1973) further compromises legume survival. Resident pasture is often dominated by such low quality species, that produce a flush of spring production that does not meet the needs of lactating animals, and may take the summer and autumn to be brought under control (Chapman et al., 2021). Low quality feed also leads to low animal growth rates and thus, increases their total maintenance requirement and total methane production before slaughter (de Klein et al., 2008).

Current legislation has restricted the use of more than 190 kg N/ha (Ministry for the Environment 2022) and targeted agriculture to reduce its greenhouse gas emissions to enable New Zealand to meet international treaty obligations. The red meat sector has reduced emissions in total by over 30% since 1990 and, per unit, its emissions intensity declined by 30% over the same period (Moot and Davison 2021). This has largely been achieved by the reduction in sheep numbers, improved lambing percentages and increased carcass weights of lambs sold. This has resulted from heavier ewes weaning more meat per kilo of ewe live-weight. The realisation of these changes means the New Zealand red meat industry is producing 5-10% less meat than 30 years ago with fewer than 50% of the ewes. Much of this gain has come from intensification of sheep and beef farms including greater use of specialist legume and

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herb-based pastures. However, the challenge remains to reduce total emissions and emissions intensity further in the coming decade. One strategy to do this is "satellite farming", whereby small areas of cultivatable land within larger hill blocks are developed to support the lower producing steeper country surrounding it. This approach can increase on-farm finishing on hill country and has been used successfully in summer dry regions using lucerne (Avery et al., 2008; Moot et al., 2019). It offers the same opportunity in more "summer safe" regions with herbs and red clover (Chapman et al., 2021). An impediment to greater adoption of these satellite blocks within hill country areas are the legitimate farmer questions of "how much production will I get, and when, from an improved species and how long will it persist in my environment?" The Hill Country Futures Research (https://www.hillcountryfutures.co.nz/) programme aimed to answer this question through on-farm measurement of pasture growth rates from resident and improved pastures. Surprisingly, with the exception of the series of papers summarised by Barker et al. (1993), there was little comparative data available in the literature. This may have been because researchers often compare several improved species in a designed experiment but do not include a resident species control. This paper aims to quantify annual and seasonal yield differences between improved and unimproved pastures at two summer dry and one "summer safe" farm in Canterbury. The expectation is that, over time, similar data from across the country can be generated on-farm to inform local decision making of species choice and utilisation to meet the dual goals of enhanced productivity with a reduced carbon footprint.

Materials and Methods

In autumn 2019 (2018/19; Year 1), pasture exclosure cages (~0.75 m^2) were placed on representative adjacent areas of improved and unimproved pastures on hill country properties in North Canterbury (Stockgrove) and Banks Peninsula (Willesden Farm). The paired cages were placed at two different altitudes at each farm. Paired sites were monitored for three growth seasons (1 July-30 June). Sites at Inverary Station (Mid-Canterbury) were not paired due to an on-going pasture development programme but a total of 52 sites in a range of improved and unimproved pastures were monitored for different durations from summer 2018.

Site co-ordinates and altitudes for the sites were sourced from Google Earth Pro, which uses the WGS 1984 Web Mercator projection. Co-ordinates for NIWA's virtual climate station network (https://niwa.co.nz/climate/our-services/virtual-climate-stations) are based on the NZGD 1949 projection and altitudes are derived from the associated shapefile of 'smoothed' elevations.

Stockgrove, North Canterbury

Stockgrove is a 300 ha sheep breeding property in the North Canterbury foothills just north of Amberley. The farm includes areas of flats, rolling downs and steeper hill country and a maximum altitude of 163 m a.s.l. Pastures range from high quality finishing mixes to conventional perennial ryegrass (*Lolium perenne*)/white clover with lower quality browntop pastures on the higher country. Typically, the property runs ~2000 ewes, 500 hoggets and 500 trading lambs.

Paired cages were placed on dryland sites at 67 m a.s.l. (-43° 5'33.77"S, 172°45'7.00"E) and 120 m a.s.l. (-43°6'47.21"S, 172°45'27.03"E). The improved pastures were direct drilled into paddocks on 22/10/2018 following a rape (*Brassica napus* ssp. *biennis*) crop which was sprayed out with Roundup (a.i. glyphosate) and Granstar (a.i. tribenuron-methyl) at recommended rates. The improved pasture mix was 5 kg/ha chicory (C*ichorium intybus*) with 4 kg/ha white clover drilled with 100 kg/ha of di-ammonium phosphate (DAP; 17.6 N:20.0 P:0 S:1 K). Improved pastures also contained some plantain (*Plantago lanceolata*) and unsown improved grasses (perennial ryegrass and cocksfoot (orchardgrass; *Dactylis glomerata*)). The low altitude improved pasture outside the exclosure cages began to deteriorate in Year 3 and the grazing area was overdrilled with Italian ryegrass (*Lolium multiflorum*) to extend stand life. Subsequently, in spring of Year 4 (2021/22) the low altitude improved pasture was renewed with the same pasture mix sown in 2018. The pasture was drilled on 03/11/2021 and the first harvest was on 03/01/2022. The adjacent unimproved pastures were mainly sweet vernal (*Anthoxanthum odoratum*) and browntop with some perennial ryegrass and white clover.

Environmental - Stockgrove

Weather data were sourced from NIWA's Virtual Climate Station Network (VCSN) Agent No. 20105 (-43.075, 172.775; NZGD1949 projection). The raster elevation value assigned to the location was 60 m a.s.l. The location was 2.8 km NE of the 67 m a.s.l. cage site and 4.5 km NNE of the 120 m a.s.l. cage. Mean air temperature (MAT,°C) was calculated as the arithmetic mean of maximum and minimum daily air temperatures.

The long-term mean (LTM; 2005-2015) rainfall is 576 mm and mean monthly air temperature increases from 7.2°C in July to 17.5°C in January (Figure 1). Long-term potential evapotranspiration (PET) is 989 mm/yr, which is 414 mm, or 72%, higher than average annual rainfall. Over three annual growth seasons rainfall ranged from 551 (2019/20) to 733 mm/yr (2021/22). The lowest monthly rainfall was 0 mm in January 2020 and the highest was 204 mm in February 2022. Rainfall was below average in 16 of the

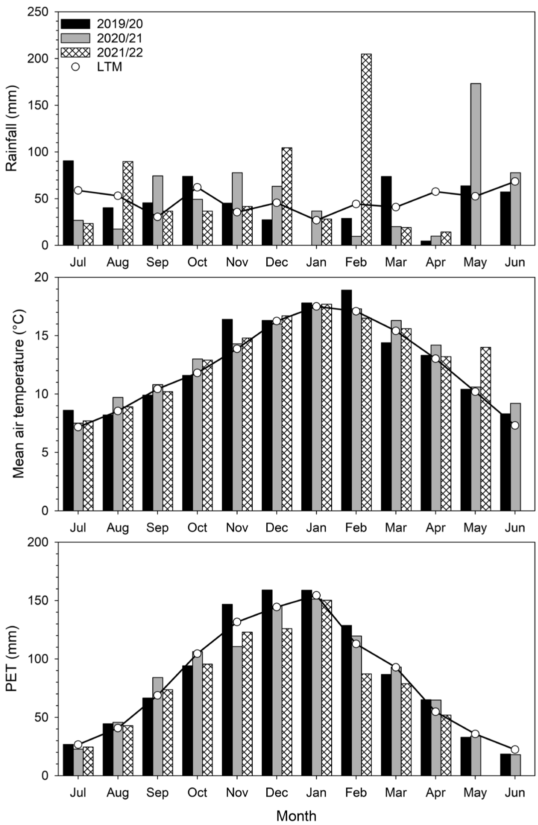

Figure 1 Monthly rainfall (mm, top), mean air temperature (°C, middle) and potential evapotranspiration (PET mm, bottom) in 2019/20, 2020/21 and 2021/22 near Stockgrove, North Canterbury. The line is the long-term mean (2005-2015).

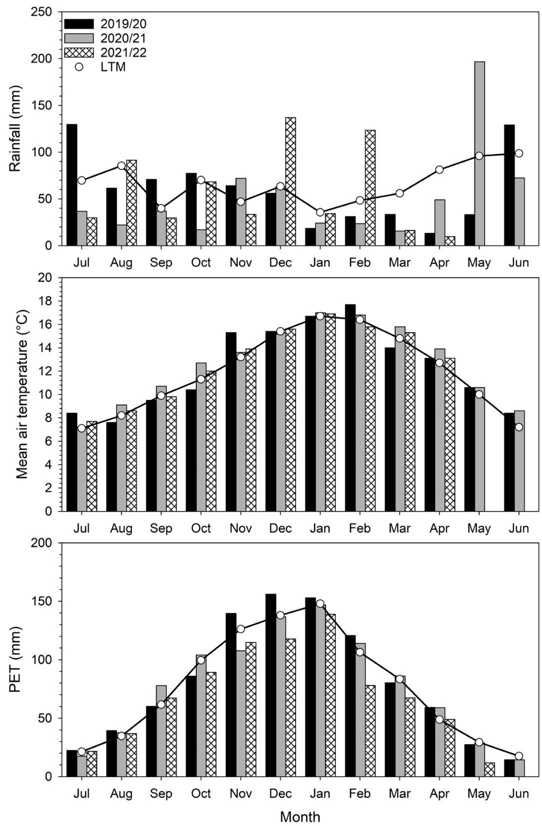

Figure 2 Monthly rainfall (mm, top), mean air temperature (°C, middle) and potential evapotranspiration (PET mm, bottom) in 2019/20, 2020/21 and 2021/22 at Willesden, Banks Peninsula. The line is the long-term mean (2005-2015).

36 months that the sites were monitored. Annual mean air temperature was higher than the LTM of 12.4°C in all years monitored (12.8-13.0°C) with mean monthly temperatures ranging from 7.5 to 18.9°C and following the expected seasonal pattern.

Willesden Farm, Banks Peninsula, Canterbury

Willesden Farm is a 5500 ha sheep and beef property on Banks Peninsula, Canterbury. Approximately 1200 ha, or 22% of the total area, is flat cultivatable land while the remainder is moderate to steep hill country. Topographically, rainfall and altitude are highly variable over short distances. Annual rainfall ranges from 550 to 1100 mm/yr with altitude ranging from sea level (0 m a.s.l.) to >850 m a.s.l.

Paired cages were placed on representative dryland sites at 20 m a.s.l. (-43°46’59.57”S, 172°39’59.76”E) and 175 m a.s.l. (-43°46’32.48”S, 172°40’35.89”E). The improved pasture was a lucerne (alfalfa; *Medicago sativa*) monoculture and the unimproved pastures were dominated by broadleaf weeds including storksbill (*Erodium moschatum*), yarrow (*Achillea millefolium*) and some hedge mustard (*Sisymbrium officinale*), perennial ryegrass and weed grasses including annual barley grass (*Critesion murinum* previously known as *Hordeum murinum*) and perennial sweet vernal.

Environmental – Willesden

Weather data were sourced from NIWA’s Virtual Climate Station Network (VCSN) Agent No. 21128 (-43.775, 172.675; NZGD1949 projection). The raster elevation value assigned to the location was 111 m a.s.l. The location was 1.2 km NNE of the 20 m a.s.l. cage site and 0.2 km NNW of the 175 m a.s.l. cage.

The long-term mean (LTM; 2005-2015) rainfall is 791 mm and mean monthly air temperature increases from 7.1°C in July to 16.7°C in January (Figure 2). Long-term potential evapotranspiration (PET) is 915 mm/yr, which is 124 mm, or 16%, higher than average annual rainfall. Over the three annual growth seasons rainfall ranged from 629 (2020/21) to 718 mm/yr (2019/20). The lowest monthly rainfall was 9.7 mm in

April 2022 and the highest was 197 mm in May 2021. Rainfall was below average in 21 of the 36 months. Annual mean air temperature was higher than the LTM of 11.9°C in all years monitored (12.2-12.6°C) with monthly temperatures ranging from 7.2 (July 2020) to 17.7°C (February 2020) following the expected seasonal pattern.

Inverary Station, Mid-Canterbury

Inverary Station is a 4250 ha sheep and beef property located in the hill country of Mid-Canterbury, near Mt Somers. Inverary has ~3000 ha of steeper hill country with limited grazing and 650 ha of easier hill country which can be improved and is suitable for grazing. The rest of the property is rolling or flat country with cultivatable soils capable of growing large quantities of high-quality feed. There are sunny and shady faces on most hill blocks but the high proportion of low-quality browntop dominant pastures leads to surpluses of poor-quality feed accumulating when it is not needed. This makes it difficult to generate sufficient high-quality pasture when it is critical to meet stock demand. Further information about the development at Inverary Station was reported by Chapman et al. (2021).

Pasture production was monitored from exclosure cages at a total of 52 individual locations across the property from summer 2018 (Appendix 1). Cages were not paired and not all sites were monitored for the full period as pastures underwent renewal as required. For improved pastures 12 cages were monitored for two growth seasons, three for three growth seasons and one for four growth seasons. For the unimproved resident pasture cage sites, three were monitored for two growth seasons, three for three growth seasons and three for four growth seasons. The altitude of the monitored cages ranged from 459 (Lucerne) to 769 m a.s.l. (Swamp) and the maximum distance between cages was -8.4 km. Paddocks were classified as either unimproved or fertilised resident hill country (Unimproved pastures) or cultivated or cross-slot drilled paddocks (Improved pastures). Browntop, sweet vernal and Yorkshire fog (*Holcus lanatus*) mixes dominated unimproved pastures. Improved pastures included lucerne monocultures (sites: Cattle and Stour), pure clover mixes containing red (*T. pratense*), white and Caucasian (*T. ambiguum*) clovers with some Russell lupin (*Lupinus polyphyllus*) and grass/clover mixes mainly based on red and white clovers with cocksfoot, tall fescue (*Schedonorus phoenix*) or timothy (*Phleum pratense*) as the companion grass. Some mixes also included a plantain component.

Environmental – Inverary

Weather data were sourced from NIWA's Virtual Climate Station Network (VCSN) Agent No. 15274 (-43.675, 171.275; NZGD1949 projection) which was the most central grid point in relation to the cage locations on the farm. The raster elevation value assigned to the location was 555 m a.s.l. The location ranged from 0.5 km WSW (closest cage: Nicholls 690 m a.s.l.) to 6.0 km WSW (furthest cage: McAlisters 760 m a.s.l.). There was only minimal growth in June in this environment and the final harvest for each growth season occurred in late May/early June. Over the four growth seasons regrowth periods ranged in duration from 32 to 185 days. Regrowth periods were extended as required during periods of low growth (*e.g.* winter and during the establishment of new improved pastures).

Inverary is classed as having a 'summer safe' environment, meaning it is expected to receive adequate rainfall to support pasture growth through the summer months. The long-term mean (LTM; 2005-2015) rainfall is 910 mm which exceeds annual PET (719 mm). Mean monthly air temperature increases from 3.8°C in July to 14.5°C in January (Figure 3). Over the three full growth seasons annual rainfall ranged from 932 (2019/20) to 1078 mm/yr (2020/21). The lowest monthly rainfall was 9.7 mm in July 2020 and the highest was 353 mm in May 2021. The highest rainfall was associated with severe regional flooding and caused significant damage to farm infrastructure. Rainfall was below average in 14 of the 36 months over the measurement period. Annual mean air temperature followed the expected seasonal pattern and was higher than the LTM of 9.2°C in all years monitored (9.6-10.0°C) with monthly temperatures ranging from 4.4 to 15.2°C.

Measurements

Dry matter (DM) production was quantified from a 0.2 m^2 quadrat cut to a residual height of 2.5 cm 4–5 times a year at Stockgrove and Willesden. Harvests were not made in winter months, which meant DM grown during this period was included in the first spring harvest. At Inverary quadrat cuts were taken from the cages every six weeks from the end of August until the end of May each year from 2019. For Stockgrove and Willesden pasture growth was separated into spring (Jul-Nov), summer (Dec-Feb) and autumn (Mar-Jul). At Inverary the final harvest was made in late-May/early-June as there was minimal growth in June/July. Any herbage produced in this period contributed to the first spring harvest. Seasons were defined to allow DM yield to be based on the season when the majority of DM was produced for the period (*e.g.,* a harvest on 12 December was allocated to the spring period). After harvest, remaining material in the cage area was mown to a residual height of 2.5 cm and trimmings were discarded. The cage was then replaced in the same location. A representative sub sample of the harvested material from each quadrat was sorted into its botanical

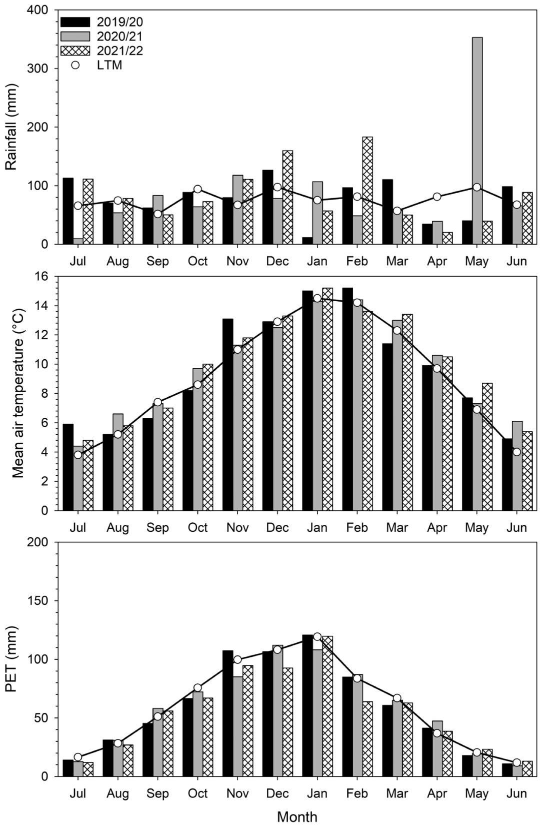

Figure 3 Monthly rainfall (mm, top), mean air temperature (°C, middle) and potential evapotranspiration (PET mm, bottom) in 2019/20, 2020/21 and 2021/22 at Inverary Station, mid-Canterbury. The line is the long-term mean (2005-2015). Note the single rainfall event in May 2021 caused significant on-farm flooding and infrastructure damage.

components and dried in a forced-air oven at 65°C for 48 hours, until constant weight.

Periodically, when sufficient herbage was harvested, nutritive values were analysed from bulk herbage samples for metabolisable energy (ME) and N content (%N).

Statistical analysis

Paired cage samples from Stockgrove and Willesden Farm

One-sided, paired sample t-tests evaluated yield differences between improved and unimproved pastures (H_o: Improved-Unimproved≤0). Growth season provided replication and there were 4-6 paired samples in each test performed. For reporting purposes, the mean of each treatment was calculated along with its associated standard error of the mean (SEM) and coefficient of variation (CV%). The CV% inferred year-to-year variation associated with differences in the main environmental drivers of pasture growth; temperature and rainfall. There was no effect of altitude on pasture production so the duplicate sites provided replication of the species (data not presented).

The low altitude improved pasture at Stockgrove was renewed in spring 2021. Therefore, the low altitude cage data for Year 3 (2021/22) were excluded from the analysis of annual and spring yields, but annual DM production of the renewed pasture is reported for completeness.

Inverary cage data

For simplicity of analysis, pasture sites were classified as either improved or unimproved. Measurements for 2018/19 were a partial year as cages were placed in selected paddocks on 05/12/2018. In each of the four growth seasons data were analysed as a two-sample, two-sided t-test with a group factor (H_o: Improved=Unimproved). Each annual growth season was analysed separately. All means are reported with their standard error (SEM) and sample size (*n*).

The CV% was expected to be high, due to variability in rainfall and, consequently plant water availability, particularly in the summer and autumn periods. For brevity, seasonal production is reported in the Results and associated tables are provided as Supplementary Material (Appendix 2).

Seasonal averages of ME and N% are reported with their respective standard deviations and number of samples (*n*). Data are provided as context for the quality of feed on offer only. Where no values are provided no samples were analysed for quality.

Results

Stockgrove, North Canterbury

Total annual DM accumulation is shown in Figure 4. In 2021/22 the low altitude improved pasture was renewed (November 2021) and is shown separately. Table 1 shows the 14.9±0.96 t DM/ha/yr produced by improved pastures was 10.3±0.99 t DM/ha/yr greater (P<0.001) than the 4.60±0.40 t DM/ha/yr from the unimproved pastures. Despite the four-month delay for pasture renewal, the newly sown low altitude improved pasture produced 9.00 t DM/ha over an 8-month period (Figure 4). For the same year the yield of the established high-altitude pasture was 18.2 t DM/ha, which reflected the above average summer rainfall. In the critical spring lactation period, the improved pastures yielded 8.14±0.61 t DM/ha, which was 5.02±0.46 greater (P<0.001), than the 3.12±0.48 t DM/ha produced by unimproved pastures (Appendix 2: Table 2). This spring period accounted for 55% of total annual production from the improved pastures compared with 68% of total annual production from unimproved pastures. Over summer, improved pastures produced 3.74±0.90

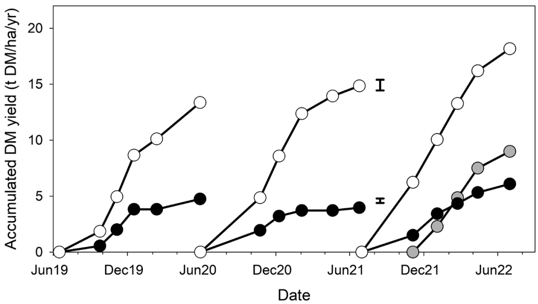

Figure 4 Total accumulated dry matter (DM) production (t DM/ha) of improved (○) and unimproved (●) pastures over three growth seasons at Stockgrove, North Canterbury. The low altitude improved pasture was renewed in November 2021 (●) and is shown separately. Consequently, Year 3 data were excluded from the analysis. Error bars are SEM for analysis of improved (top) and unimproved (bottom) annual DM yields in the first two years (refer Table 1).

t DM/ha compared (P=0.002) with 1.11±0.55 t DM/ha from unimproved pastures. Averaged over three annual growth seasons, this represented ~25% of total annual production. However, year-to-year variation in summer rainfall meant the percentage of total annual DM produced in the summer ranged from 0 (unimproved pastures in 2019/20) to ~53% (unimproved pastures in 2021/22). This was reflected in the high CV%. Dry matter production from improved pastures in autumn (3.41±0.43 t DM/ha) was 2.44±0.32 t DM/ha greater (P<0.001), than that produced by unimproved pastures (0.98±0.34 t DM/ha).

Associated mean daily growth rates (Figure 5) and annual botanical composition (Figure 6) of improved and unimproved pastures at low (67 m a.s.l.) and high (120 m a.s.l.) altitudes are also shown. In spring, metabolisable energy (ME) was 9.9 MJ ME/kg DM from unimproved pastures and 11.3 MJ ME/kg DM from improved pastures. Herbage N% was 2.2 (unimproved)

Table 1 Total annual dry matter (DM). The grey row was production from improved and unimproved paired cage samples at high (120 m a.s.l.) and low (67 m a.s.l.) altitude sites at Stockgrove, North Canterbury and high (175 m a.s.l.) and low (20 m a.s.l.) altitude sites Willesden Farm, Banks Peninsula over three growth seasons. P values for the t-test are reported in brackets in the right-hand column.

Stockgrove

Growth Season	Improved pasture	Yield (t DM/ha/yr)	Unimproved pasture	Yield (t DM/ha/yr)	Difference (t DM/ha/yr)
2019/20	High.Improved	12.7	High.Unimproved	4.82	7.83
2020/21	High.Improved	15.8	High.Unimproved	3.13	12.7
2021/22*	High.Improved	18.2	High.Unimproved	5.54	12.6
2019/20	Low.Improved	14.1	Low.Unimproved	4.68	9.40
2020/21	Low.Improved	13.9	Low.Unimproved	4.81	9.06
2021/22*	Low.Improved (renewed)	(9.0)	Low.Unimproved	(5.15**)	3.85
	Mean	14.9		4.60	10.3
	SEM	0.96		0.40	0.99
	CV%	14.4		19.3	<0.001)

Willesden

Growth Season	Improved pasture	Yield (t DM/ha/yr)	Unimproved pasture	Yield (t DM/ha/yr)	Difference (t DM/ha/yr)
2019/20	High.Improved	15.9	High.Unimproved	4.61	11.2
2020/21	High.Improved	11.9	High.Unimproved	3.15	8.75
2021/22*	High.Improved	17.1	High.Unimproved	8.22	8.84
2019/20	Low.Improved	12.0	Low.Unimproved	6.18	5.85
2020/21	Low.Improved	9.50	Low.Unimproved	3.39	6.11
2021/22*	Low.Improved	19.4	Low.Unimproved	8.81	10.6
	Mean	14.3		5.73	8.57
	SEM	1.53		0.99	0.91
	CV%	26.2		42.3	(P<0.001)

Note: * Grey rows were excluded from the Stockgrove analysis due to pasture renewal of the improved pastures at low altitude in Year 3 but are shown for completeness. ** = a mean was used to determine the low altitude unimproved pasture yield at the first harvest in Year 3.

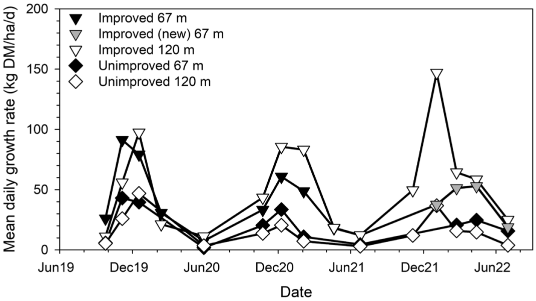

Figure 5 Mean daily growth rate (kg DM/ha/d) of improved and unimproved pastures at high and low altitude sites over three growth seasons at Stockgrove, North Canterbury. Note: Low altitude improved pastures (▼) were renewed on 03/11/2021. Unanalysed individual plot data are shown for completeness.

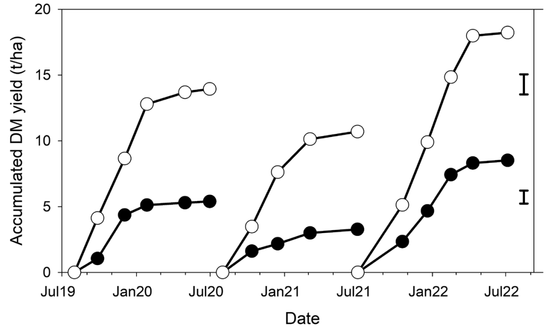

Figure 7 Total accumulated dry matter (DM) production (t DM/ha) of improved (○) and unimproved (●) pastures over three growth seasons at Willesden Farm, Banks Peninsula, Canterbury. Error bars are SEM for mean annual yield of improved (top) and unimproved resident (bottom) pastures over three growth seasons (refer Table 1).

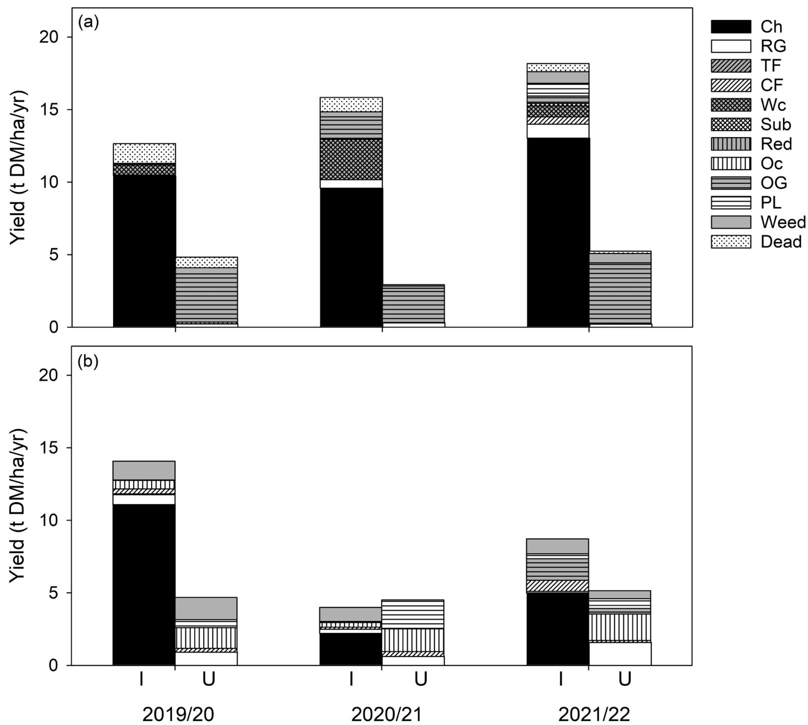

Figure 6

Annual botanical composition of improved (I) and unimproved (U) pastures at (a) high (120 m a.s.l.) and (b) low altitude (67 m a.s.l.) over three growth seasons at Stockgrove, North Canterbury. Components are: Ch=chicory, RG=perennial ryegrass, TF=tall fescue, Wc=white clover, Sub=subterranean clover, Red=red clover, Oc=other clover, OG=other grass and PL=plantain. Data are unanalysed and shown for completeness. Note: Improved low altitude pastures were renewed on 03/11/2021 and yields represent production over an 8-month period.

and 2.4% (improved) (n=1; 2021/22). In summer (2020/21 and 2021/22) the unimproved pastures had a mean ME of 9.3±0.81 and N% of 2.2±0.65 (n=6). Improved pastures had 10.4±0.63 MJ ME/kg DM and 2.4±0.24% N (n=7). In autumn 2021/22 the ME of unimproved pastures was 10.5±0.06 with 2.8±0.01% N (n=2; data not shown).

Willesden Farm - Banks Peninsula

The t-test indicated mean annual accumulated DM (Figure 7) produced by the dryland lucerne monocultures over three annual growth seasons (14.3±1.53 t DM/ha/yr) was 8.56±0.91 t DM/ha more ($P<0.001$) than the 5.73±0.99 t DM/ha/yr produced from unimproved dryland pastures (Table 1).

The mean daily growth rates (Figure 8) and annual botanical composition (Figure 9) of improved and unimproved pastures at low (20 m a.s.l.) and high (175 m a.s.l.) altitudes are presented as single plot data.

In spring (Appendix 2: Table 3), lucerne produced 8.72±0.51 t DM/ha, which was 4.99±0.51 t DM/ha greater ($P<0.001$) than the unimproved pastures over the same period (3.74±0.53 t DM/ha). In summer, lucerne yielded 3.86±0.58 t DM/ha, which was 2.42±0.47 t

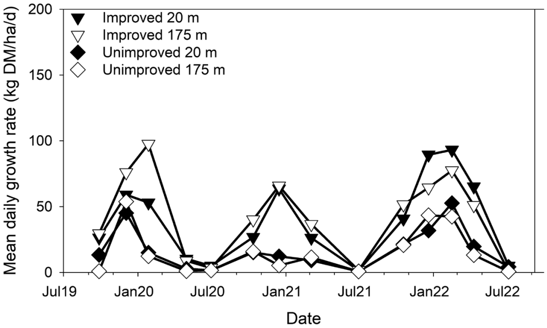

Figure 8 Mean daily growth rate (kg DM/ha/d) of improved and unimproved pastures at high and low altitude sites over three growth seasons at Willesden Farm, Banks Peninsula, Canterbury. Data were unreplicated.

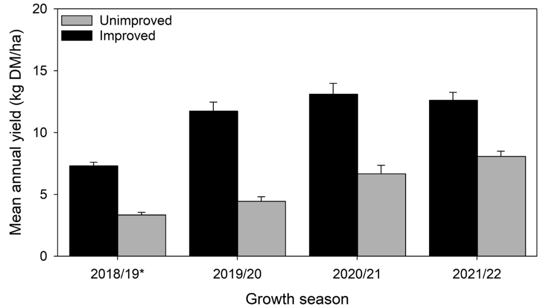

Figure 10 Total accumulated dry matter (DM) production (t DM/ha) of improved and unimproved pastures over four growth seasons at Inverary Station, Mid-Canterbury. Note: * data for 2018/19 is a partial growth season (05/12/2018-28/05/2019). The error bar is the standard error of the mean specific to each treatment in each growth season.

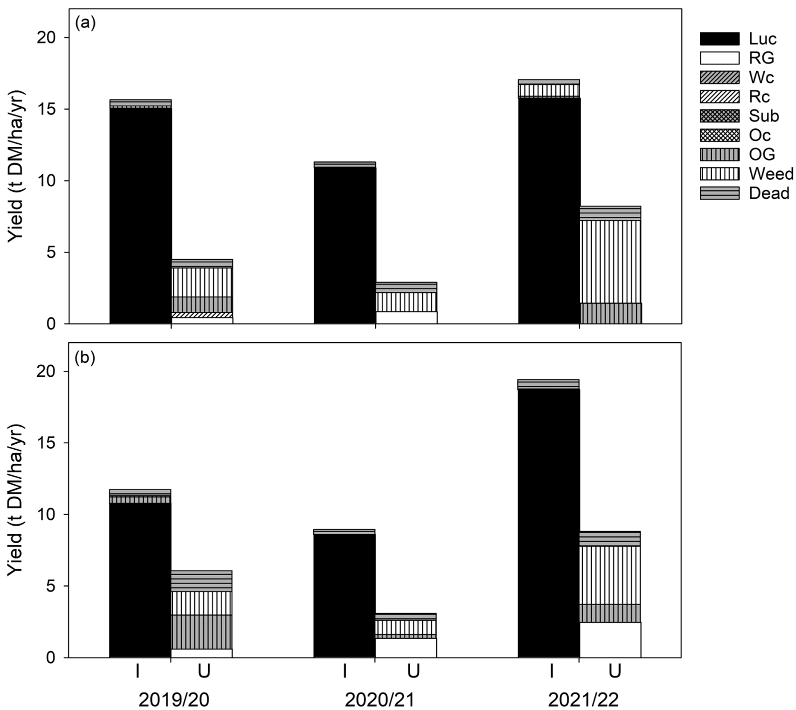

Figure 9

Annual botanical composition of improved (I) and unimproved (U) pastures at (a) high (175 m a.s.l.) and (b) low altitude (20 m a.s.l.) over three growth seasons at Willesden Farm, Banks Peninsula, Canterbury. Components are: Luc=lucerne, RG=perennial ryegrass, Wc=white clover, Rc=red clover, Sub=subterranean clover, Oc=other clover and OG=other grass, Weed and Dead. Data were unreplicated.

DM/ha more (P=0.002) than the 1.44±0.42 t DM/ha produced by unimproved pastures. As expected, autumn yields were low and highly variable (CV% of 80.8 and 86.5%). However, the 1.70±0.56 t DM/ha from lucerne still exceeded (P=0.014) the 1.16±0.38 t DM/ha from the unimproved grass-based pastures.

In spring 2021/22 unimproved pastures had 11.1 MJ ME/kg DM and 2.0% N (*n*=1) and lucerne was 10.3±0.23 MJ ME/kg DM and 3.3±0.12% N (*n*=2). In summer 2021/22, which was the wettest summer, there was 10.4±0.34 MJ ME/kg DM and 2.8±0.32% N in herbage from unimproved resident pastures (*n*=3) compared with 10.0±0.48 MJ ME/kg DM and 2.8±0.39% N in lucerne herbage averaged over two growth seasons (2020/21 and 2021/22; *n*=4). In 2019/20 and 2021/22 autumn ME averaged 10.6±0.60 MJ ME/kg DM with 3.8±0.70% N (*n*=4) for lucerne compared with 11.4±0.33 MJ ME/kg DM and 3.3±0.27% N from resident pastures (*n*=3; data not presented).

Inverary Station – Mid-Canterbury

In the first (partial) growth season (2018/19) improved pastures yielded 7.31±0.59 t DM/ha (*n*=14; CV% = 30.0) which was more than double (P<0.001) the 3.34±0.43 t DM/ha (*n* = 16; CV% = 51.0) from the unimproved pastures (Figure 10). In 2019/20, the first full growth season, improved pastures produced 11.7±1.45 t DM/ha (n = 12; CV% = 42.9) compared (P<0.001) with 4.45±0.73 t DM/ha (n = 9; CV% = 49.3) from the unimproved resident pastures. In the third growth season (2020/21) improved pastures produced 14.1±1.76 t DM/ha (n = 13; CV% = 44.9) compared (P=0.016) with 6.67±1.38 t DM/ha from unimproved resident pastures (n = 6; CV% = 50.6). Improved pastures produced 12.6±1.29 t DM/ha (n = 14; CV% = 38.3) in 2021/22 which was 56% more (P=0.042) than the 8.07±0.85 t DM/ha (n = 6; CV% = 25.8) from the unimproved (resident) pastures.

Spring yield was not measured in 2018/19. Improved pastures produced 5.66±0.57 (2021/22) to 6.69±0.67 t DM/ha (2020/21) in spring. This was 2.05±0.89 (2021/22) to 4.24±0.61 t DM/ha (2019/20), or 57-218% greater (P=0.036 to P<0.001) DM than resident pastures which yielded 1.90±0.32 (2019/20) to 3.61±0.52 t DM/ha (2021/22) (Appendix 2: Table 4). In summer, improved pastures produced 4.81±0.49 to 6.49±0.63 t DM/ha which was 95 to 191% more than the resident pastures over the same period (1.90±0.32 to 3.20±0.37 t DM/ha). Results were significant in three out of four spring seasons. In spring 2020/21, there was a trend (P=0.062) that indicated the 3.11 t DM/ha was greater for improved than resident pastures but this was associated with high CV's (47.5 – 58.9%). Autumn yields were low. Over four growth seasons autumn DM production from the improved pastures ranged from 1.25±0.20 (2020/21) to 2.20±0.18 t DM/ha. The unimproved pastures produced 0.55±0.30 (2020/21) to 1.26±0.13 t DM/ha (202122). Improved pastures produced greater (P<0.001) yields than resident pastures in 2018/19 and 2019/20. In 2020/21 and 2021/22 trends (P<0.10) showed higher DM production from the improved pastures but production in the autumn period was highly variable and CV% ranged from 27.6% to 132% over the four growth seasons.

The mean daily growth rate, averaged for improved and unimproved resident pastures is shown in Figure 11. Over the entire measurement period there were 23 rotations on improved pastures, with mean daily growth rates ranging from 9.9 to 85.2 kg DM/ha. For unimproved resident pastures 17 rotations were completed over the same period, with mean daily growth rates ranging from 4.6 to 43.1 kg DM/ha/d.

Unimproved pastures averaged 9.8±0.83 MJ ME/kg DM and 2.4±0.49% N in spring (n=19) compared with 11.0±0.69 MJ ME/kg DM and 3.5±0.87% N in improved pastures (n=33) from 2019/20 to 2021/22. In summer unimproved pastures averaged 10.0±0.33 MJ ME/kg DM and 2.3±0.53% N (n=26) compared with 10.5±0.51 MJ ME/kg DM and 3.3±0.82% N from improved pastures (n=24). During the autumn ME averaged 10.8±0.43 MJ/kg DM and N% was 2.6±0.38

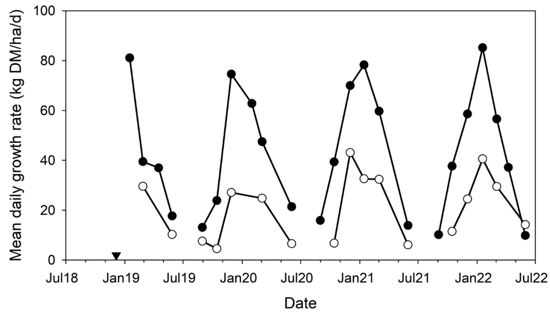

Figure 11 Mean daily growth rate of improved (●) and unimproved (○) resident pastures at Inverary Station, Mid-Canterbury. The arrow is the start date (05/12/2018). Note: due to a lack of harvestable material unimproved pastures often had longer regrowth cycles and fewer harvests occurred.

from the resident pastures (n=15) compared with 11.2±0.50 and 3.4±0.0.71% N from improved pastures averaged over three autumn seasons (n=30).

Discussion

Annually, improved pastures produced more than three times the DM of unimproved resident pastures at Stockgrove, and more than double the production at Willesden (Table 1) and Inverary Station (Figure 10). Yields of unimproved pastures at Stockgrove and Willesden were less than the average reported from long-term monitoring of dryland, superphosphate fertilised, pastures at Winchmore, Canterbury (5.85 t DM/ha/yr; range 4.75-6.70) reported by Rickard and Radcliffe (1976). For the 'summer safe' Inverary Station sites, annual production was below the 10.2 t DM/ha/yr (range 9.15-11.2) reported for irrigated pastures at Winchmore, which probably reflects the higher altitude and thus cooler temperatures at Inverary. However, introduction of pastures containing a high proportion of legume resulted in yields which exceeded those of the irrigated and fertilised pastures at Winchmore. This highlights the ability of legume dominant pastures to overcome the severe N deficiency found on most unimproved resident hill country pastures throughout New Zealand (Ledgard 2001). The introduction of legumes, and herbs with legumes, results in greater N cycling through the plant-animal-soil. The result is greater DM yields, improved feed quality and less use of N fertiliser. Indeed, none of the improved or unimproved pastures received an N application. For the two summer dry properties the increase in dry matter production from lucerne and chicory with clover was consistent with the improved yields reported by Mills et al. (2006) for N fertilised grass monocultures. The 4-6 t DM/ha/yr is consistent with unfertilised dryland cocksfoot yields produced at Lincoln, while the improved pastures were consistent with the dryland plus N pastures that produced ~15 t DM/ha/yr. Similarly, Barker et al. (1993) summarised a series of papers which introduced improved grasses to dry hill country. When fertilised these pastures produced 18-68% more DM than the unfertilised resident pastures, which produced 6.0-10.5 t DM/ha/yr. However, outside the experimental area, resident pasture yields were lower and ranged from 5.0-7.8 t DM/ha/yr, which was comparable with the yields reported here. These results (Figures 4, 7 and 10) show that unimproved hill country pastures can be renovated to double or triple production. The cost benefit analyses should then be based on the establishment costs discounted over the longevity of the pastures and the ability to renew them. The improved pastures were established by direct drilling or aerial oversowing following herbicides at Inverary. This reduces soil moisture and organic matter losses associated with conventional cultivation. In most cases the legume followed a fallow or forage crop phase when control of resident poor quality grasses and weeds occurred. This was considered easier with pure swards of legume than when grasses are included in the mix (Chapman et al., 2021). At this stage the chicory based pastures are renewed every 3-4 years but the lucerne at Willesden is five years old and expected to last at least two more (Moot et al., 2019). At Inverary a sequence of legume monocultures followed by annual grasses has been developed with movement towards red clover and timothy or tall fescue as the permanent pastures (Chapman et al., 2021).

On all properties there was superior spring production of the improved species over the unimproved. This contradicts the common perception of lucerne, red clover and chicory being slow to grow in spring (Brown et al., 2003). However, most comparisons are made against improved perennial grass species such as cocksfoot, tall fescue and ryegrass rather than the resident grasses such as browntop, sweet vernal and *Notodanthonia*. On all three farms the improved pastures produced more feed than the unimproved in all seasons. Importantly, spring growth rates of these swards were greater than the comparable resident species. This allows higher stocking rates on these pastures and flexibility in grazing management. For example, the lucerne at Willesden is used for hogget lambing with the aim of ensuring hoggets are still able to grow while raising lambs. A feature of the nutritive value results as Willesden was the lower ME from the lucerne than the resident pasture. However, based on seasonal yield (Appendix 2) the total ME available in spring was 89.8 GJ ME/ha from the lucerne, which was more than double the 41.5 GJ ME/ha from the resident pasture. The ME of lucerne reflects the proportion of stem and leaf in the sample (Brown et al., 2005) and higher quality could have been achieved from earlier harvesting.

The improved paddocks were also all more productive in summer, and able to take advantage of the above average rainfall in 2021/22, particularly on the two east coast ‘summer dry’ properties. This allows stock to be maintained and finished on-farm more easily than when using resident pastures alone. However, the lower-than-average rainfall received in 2020/21 meant the summer and autumn were dry with little growth across the farms. Even in these circumstances the lucerne and chicory-based pastures grew twice as much as the resident pastures.

The high pasture growth rates of the improved pastures mean animals can be stocked at higher rates and be expected to grow more meat/ha than on the unimproved pastures. Therefore, as the proportion of improved pastures increases more of the total farm stock units are grazed on the high-quality feed. The intangible benefit is that the destocking of the unimproved areas allows them to recover their canopy of leaf area to increase light interception and water use efficiency. This is because set stocked pastures frequently have a leaf area index below the critical value of 3.5 (Moot et al., 2007). This means light is not fully captured and more of the water is lost from the systems as soil evaporation rather than transpired through a growing plant.

Metabolisable energy content of DM produced in spring (10.3-11.3 MJ ME/kg DM) was generally higher from improved pastures. Assuming a ewe with twin lambs requires 33 MJ ME/day during spring lactation to meet energy requirements (Rattray and Trigg 1979; Kerr 2010) ewes grazing the unimproved resident pastures at Stockgrove and Inverary sites would need to ingest more DM daily than those grazing the improved pastures to meet energy demands. At Willesden, the ewe grazing lucerne would need to ingest 7% more DM than those on unimproved pastures. However, this ignores selective grazing of leaves and soft palatable stems which would be of higher quality (Brown and Moot 2004). At Stockgrove, total spring metabolisable energy available averaged 30.9 GJ ME/ha (unimproved pastures) compared with 92.0 GJ ME/ha (improved chicory-based pastures). At Inverary, the resident unimproved pastures produced 19.0-35.4 GJ ME/ha over three spring periods while the improved pastures had 62.3-67.9 GJ ME/ha. The implication is that the improvements reported here, for both yield and quality of feed on offer, mean improved pastures can support more stock (ewes and/or lambs) and help reduce grazing pressure on the rest of the farm particularly early in the critical spring period.

How improved species are used will differ from farm to farm. However, the shift to improved pastures with legume monocultures or legume dominant pastures is overcoming the fact that nitrogen is the most deficient nutrient in these environments most of the time. Maintaining adequate P and S levels with routine herbage monitoring of molybdenum (Olykan et al., 2019b) will be required to maintain legume growth.

The additional feed supply provided by the improved pastures has added resilience and flexibility to these farms. However, the weather will always provide periods of dry/cold/wet/warm outside the mean. The three years of monitoring has enabled some of the impacts of seasonal variation to be quantified. In all cases the improved pastures continued to produce more feed than the resident pastures and responded with more feed when the period of adverse conditions were over.

Practical implications

These results highlight the opportunity provided by pasture species in areas where cultivation or aerial renovation of pastures is possible. At times maintaining fertiliser and lime inputs on large blocks of low-quality feed is uneconomic. However, it may be possible to identify smaller areas of flatter land to improve through subdivision, fertiliser and monocultures or legume/herb-based pastures. Historically these areas have been improved with grass-based pastures, but the competitiveness of the grass and grazing preference for legumes mean such areas often become grass dominant. Consequently, the sown grasses become nitrogen deficient and productivity declines. Taking a longer-term view of the role of legume dominant pastures in the farm system provides an opportunity to overcome the dominant N deficiency without using inorganic N. At the same time, it provides high quality feed to maximise live-weight gain and therefore reduce the time on farm of lambs, which is one currently available method to reduce total methane emissions and emissions per unit product.

Conclusions

Improved pastures monitored over three years consistently yielded 2-3 times the annual herbage production of resident pastures. The economics of pasture improvement should be based on the expected yield and quality increases and duration of stand persistence. These "satellite" areas of high quality forage have the potential to increase productivity and reduce greenhouse gas emissions from livestock farming.

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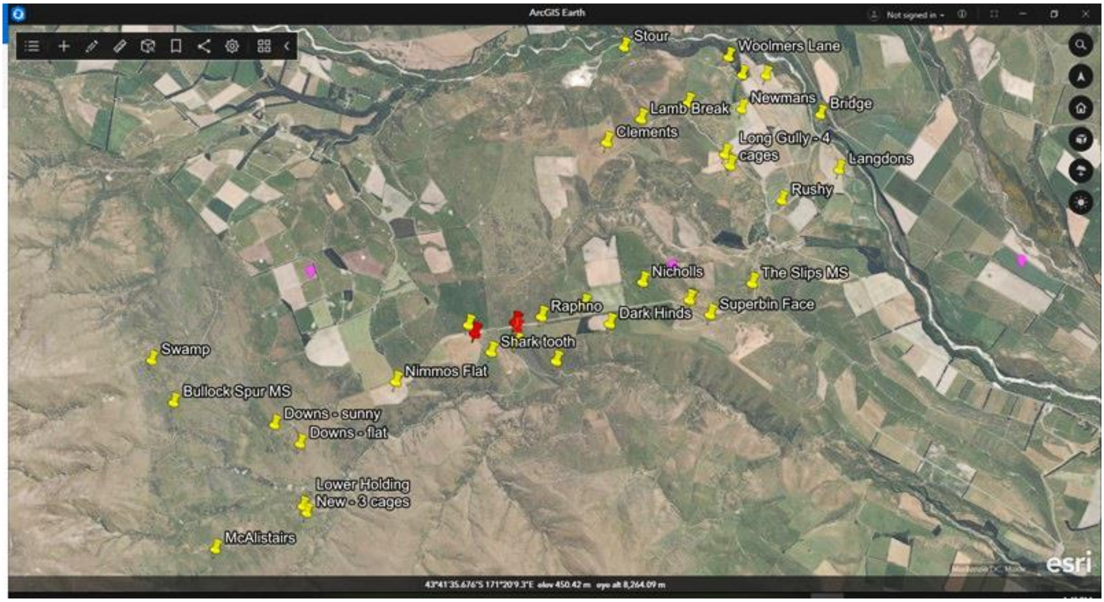
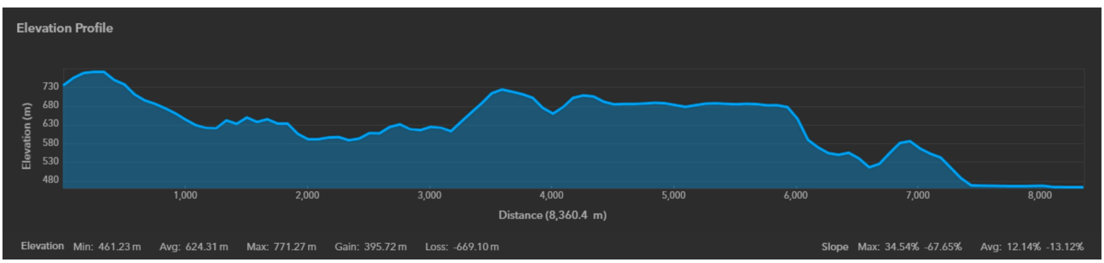
Appendix 1 (top) Cage locations (yellow pins) at Inverary Station, Mid-Canterbury and (bottom) the associated elevation profile between the cages at McAlisters and Bridge sites. Red pins are on-site weather stations and data loggers. Pink points are NIWA VCSN locations (shapefile provided by NIWA). (Maps were created using ArcGIS Earth® software by Esri Inc. and are the intellectual property of Esri and are used herein under license. Copyright © Esri. All rights reserved. version 1.15.0.3446, Build date: 10/04/2022).





Appendix 2 Supplementary results tables

Table 2 Seasonal total DM production from improved and unimproved paired cage samples at high (120 m a.s.l.) and low (67 m a.s.l.) altitude sites at Stockgrove, North Canterbury over three growth seasons. P values for the paired t-test are reported in brackets in the right-hand column. Data from low altitude pastures in spring 2021/22 was excluded due to renewal of the improved pastures (grey fill).

Spring	Improved pasture	Yield (t DM/ha/yr)	Unimproved pasture	Yield (t DM/ha/yr)	Difference$_{(I-U)}$ (t DM/ha)
2019/20	High.Improved	7.55	High.Unimproved	3.60	3.95
2020/21	High.Improved	8.97	High.Unimproved	2.53	6.44
2021/22	High.Improved	6.23	High.Unimproved	1.51	4.72
2019/20	Low.Improved	9.77	Low.Unimproved	4.05	5.72
2020/21	Low.Improved	8.18	Low.Unimproved	3.90	4.29
2021/22	Low.Improved*		Low.Unimproved		
	Mean	8.14		3.12	5.02
	SEM	0.61		1.08	0.46
	CV%	16.6		34.6	(P<0.001)
Summer					
2019/20	High.Improved	1.20	High.Unimproved	0.00	1.20
2020/21	High.Improved	4.66	High.Unimproved	0.40	4.26
2021/22	High.Improved	7.04	High.Unimproved	2.99	4.05
2019/20	Low.Improved	1.72	Low.Unimproved	0.00	1.72
2020/21	Low.Improved	2.94	Low.Unimproved	0.61	2.33
2021/22	Low.Improved*	4.86	Low.Unimproved	2.68	2.18
	Mean	3.74		1.11	2.62
	SEM	0.90		0.55	0.55
	CV%	58.9		121.9	(P=0.002)
Autumn					
2019/20	High.Improved	3.91	High.Unimproved	1.22	2.68
2020/21	High.Improved	2.20	High.Unimproved	0.20	2.00
2021/22	High.Improved	4.90	High.Unimproved	1.04	3.86
2019/20	Low.Improved	2.59	Low.Unimproved	0.63	1.96
2020/21	Low.Improved	2.75	Low.Unimproved	0.30	2.45
2021/22	Low.Improved*	4.14	Low.Unimproved	2.47	1.67
	Mean	3.41		0.98	2.44
	SEM	0.43		0.34	0.32
	CV%	30.9		85.5	(P<0.001)

Note: (I-U) = improved yield – unimproved yield. Data has been rounded to 3 significant figures for presentation. * Low altitude improved pastures were renewed in spring 2021 and were excluded from the analysis.

Table 3 Seasonal total DM production from improved and unimproved paired cage samples at high (175 m a.s.l.) and low (20 m a.s.l.) altitude sites at Willesden Farm, Banks Peninsula, Canterbury over three growth seasons. P values for the t-test are reported in brackets in the right-hand column.

Spring	Improved pasture	Yield (t DM/ha/yr)	Unimproved pasture	Yield (t DM/ha/yr)	Difference$_{(I-U)}$ (t DM/ha)
2019/20	High.Improved	9.46	High.Unimproved	3.74	5.72
2020/21	High.Improved	8.38	High.Unimproved	1.99	6.39
2021/22	High.Improved	9.73	High.Unimproved	5.00	4.73
2019/20	Low.Improved	7.85	Low.Unimproved	4.99	2.86
2020/21	Low.Improved	6.86	Low.Unimproved	2.36	4.50
2021/22	Low.Improved	10.07	Low.Unimproved	4.34	5.73
	Mean	8.72		3.74	4.99
	SEM	0.51		0.53	0.51
	CV%	14.3		34.9	(P<0.001)
Summer					
2019/20	High.Improved	5.37	High.Unimproved	0.68	4.69
2020/21	High.Improved	2.92	High.Unimproved	0.91	2.01
2021/22	High.Improved	4.49	High.Unimproved	2.46	2.03
2019/20	Low.Improved	2.91	Low.Unimproved	0.83	2.09
2020/21	Low.Improved	2.09	Low.Unimproved	0.73	1.36
2021/22	Low.Improved	5.40	Low.Unimproved	3.05	2.35
	Mean	3.86		1.44	2.42
	SEM	0.58		0.42	0.47
	CV%	36.5		71.8	(P=0.002)
Autumn *					
2019/20	High.Improved	1.03	High.Unimproved	0.19	0.83
2020/21	High.Improved	0.60	High.Unimproved	0.25	0.35
2021/22*	High.Improved	2.84	High.Unimproved	0.76	2.08
2019/20	Low.Improved	1.27	Low.Unimproved	0.36	0.91
2020/21	Low.Improved	0.55	Low.Unimproved	0.30	0.25
2021/22*	Low.Improved	3.94	Low.Unimproved	1.42	2.51
	Mean	1.70		0.55	1.16
	SEM	0.56		0.19	0.38
	CV%	80.8		86.5	(P=0.014)

Note: (I-U) = improved yield – unimproved yield. Data has been rounded to 3 significant figures for presentation.

Table 4 Seasonal DM production (t DM/ha) of improved and unimproved resident dryland pastures at Inverary Station, Mid-Canterbury over four growth seasons from 2018/19 to 2021/22.

		Spring		Summer		Autumn	
		Improved	**Unimproved**	**Improved**	**Unimproved**	**Improved**	**Unimproved**
2018/19*	Yield	(nd)	(nd)	4.81	2.46	2.50	0.94
	SEM			0.49	0.27	0.18	0.16
	(*n*)			14	16	14	15
	CV%			38.1	43.6	27.6	67.1
	$\text{Difference}_{(I\text{-}U)}$			2.35		1.56	
	SED			0.54		0.25	
	P value			<0.001		<0.001	
2019/20	Yield	6.18	1.94	5.54	1.90	1.97	0.61
	SEM	0.50	0.32	0.49	0.32	0.20	0.19
	(*n*)	10	9	10	8	12	9
	CV%	25.6	49.4	28.0	50.8	34.9	93.4
	$\text{Difference}_{(I\text{-}U)}$	4.24		3.64		1.36	
	SED	0.61		0.60		0.28	
	P value	<0.001		<0.001		<0.001	
2020/21	Yield	6.69	3.05	6.17	3.07	1.25	0.55
	SEM	0.68	0.55	1.01	0.59	0.20	0.30
	(*n*)	13	6	13	6	13	6
	CV%	36.4	44.3	58.9	47.5	56.6	132
	$\text{Difference}_{(I\text{-}U)}$	3.63		3.11		0.70	
	SED	1.07		1.56		0.35	
	P value	0.003		0.062		0.064	
2021/22	Yield	5.66	3.61	6.49	3.20	1.87	1.26
	SEM	0.57	0.52	0.63	0.37	0.28	0.13
	(*n*)	12	6	13	6	13	6
	CV%	35.0	35.4	35.2	28.1	54.0	24.5
	$\text{Difference}_{(I\text{-}U)}$	2.05		3.29		0.61	
	SED	0.89		0.98		0.31	
	P value	0.036		0.004		0.066	

Note: *Spring yield was not determined (nd) in 2018/19 as cages were placed on 05/12/2018. SEM is standard error of the mean. SED is standard error or the difference.