On-farm comparison of pasture production in relation to rainfall in Central Otago

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Abstract
Dry matter (DM) yields of unimproved resident browntop-dominant pasture on three Central Otago dryland farms was <1.5 t /ha/year from 2008-2010. An intensive pasture renewal programme over >18 000 ha applied lime to increase soil pH to ≥5.8 and reduce aluminium to <1.5 mg/kg. The resident vegetation was sprayed in autumn before spring drilling of perennial ryegrass/white clover pastures or lucerne monocultures. After renovation, ryegrass pastures yielded 3.1-5.3 t DM/ha and lucerne produced 4.2-8.4 t DM/ha. Yields of improved pastures were affected by the soil moisture stored during autumn and winter and spring rainfall. Together these gave a water use efficiency of ~16.0 kg DM/ha/mm for lucerne compared with 3.5 kg DM/ha/mm for browntop dominant pasture. Quantifying and explaining yield improvements on-farm in relation to rainfall and soil moisture deficits provide a transferable basis for interpretation of results at other sites.
Keywords: browntop, *Agrostis capillaries*, cocksfoot, *Dactylis glomerata,* tall fescue, *Festuca arundinacea*, lucerne, *Medicago sativa*, perennial ryegrass, *Lolium perenne*, white clover, *Trifolium repens*

Introduction
In the driest areas of New Zealand, such as Central Otago, yields from resident grass dominant pastures are typically low (Radcliffe & Baars 1987). Dryland farmers in these regions must adopt species and systems that will convert the limited amount of annual rainfall into high quality forage. Perennial ryegrass (*Lolium perenne*) is typically the most commonly sown grass species, but lack of dry matter (DM) production and persistence have recently seen its suitability for dryland areas questioned (Avery *et al.* 2008; Brown *et al.* 2006). These authors showed that lucerne (*Medicago sativa)* has an advantage in dryland environments, because it can produce high quality forage and responds rapidly to summer rainfall.

Moot *et al.* (2008) provided the physiological basis for the yield advantages reported for lucerne. Seasonal differences highlighted the importance of spring for DM production and water use efficiency (WUE) on dryland farms. Specifically, lucerne had a spring WUE of 24 kg DM/ha/mm and produced 6.1 t DM/ha from 250 mm of stored soil water and rainfall. This compared with 2.8 t DM/ha of perennial ryegrass/white clover pasture at 11 kg DM/ha/mm. Data that were easily collected on-farm are used in this paper to compare pasture production and water use efficiency from a commercial situation.

Since 2007, Greenfield Agribusiness have been developing dryland properties in the Central Otago and Strath Taieri regions. Traditionally, cold winters and low annual rainfall have meant these regions have been used for fine wool and store lamb production. In these extensive systems, pasture renovation and capital fertiliser applications are limited by financial constraints and unpredictable returns. For development in these regions, quantification of the benefits gained through the correction of soil nutrient status and the introduction of suitably adapted pasture species is required. In many cases perennial ryegrass/white clover pastures have been tried but failed to persist while lucerne has been grown to be conserved. Here we quantify yields of improved and resident pastures measured on three different properties and interpret these in relation to annual and seasonal rainfall.

Methods
Site description
A pasture improvement programme, has been undertaken across 25 000 ha of dryland farmland in the South Island of New Zealand, with 18 000 ha in the Maniototo and Strath Taieri areas of Otago. The three properties in this region that were used in this study are described in Table 1. Long-term air temperature and rainfall for their locations are presented in Table 2.

Initially resident pastures on all the properties were dominated (60-90%) by browntop (*Agrostis capillaris*), with lesser contributors from hieracium (*Hieracium pilosella*), sweet vernal (*Anthoxanthum odoratum*), perennial ryegrass (*Lolium perenne*). Minor species (<5%) included annual weed grass species (*Bromus spp.*), white (*Trifolium repens*) and suckling (*Trifolium dubium*) clovers, sorrel (*Rumex acetosella*), yarrow (*Achillea millefolium*) and Californian thistle (*Cirsium arvense*). Data for this study came from flat-to-rolling

Table 1 Site description for three Otago farms used in this study.

Description	Hills Creek Station (HC)	Huntleigh Station (HU)	Styx Station (SX)
Location	10.8 km north of Oturehua	14.6 km SE of Middlemarch	11.4 km west of Paerau
Area (ha)	3927	6402	7533
Altitude range (m)	440-860	140-620	560-890
Soil Types (Soil Bureau Bulletin No. 27)	Yellow-Grey Yellow Brown	Yellow-Grey Yellow-Brown	Yellow-Grey Yellow-Brown Gley Recent Recent

Table 2 January, July and annual temperature means (°C) and rainfall (mm) from selected NIWA climate stations near the monitored farms for the period 2000-2010.

	January				July				Annual	
	Temperature				Temperature				Temprature	
NIWA Station*	max	Mean	min	Rain	max	Mean	min	Rain	Mean	Rain
Lauder	20.7	13.7	6.8	94.6	5.1	0.5	-4.1	10.0	10.0	384
Middlemarch	19.9	13.2	6.6	58.2	9.0	2.9	-3.2	36.4	10.2	364
Ranfurly	19.6	12.7	5.9	64.2	6.4	1.0	-4.3	29.0	9.0	432

*Altitudes and distance to monitored farms are: Lauder 375 m and 22 km SW of Hills Creek; Middlemarch 213 m, 13 km NW of Huntleigh and 26 km ESE of Styx; Ranfurly 450 m, 52 km NNW of Huntleigh, 39 km NNE of Styx and 24 km SE of Hills Creek.

Table 3 Typical 15 cm soil test results for pre (2008) and post (2010) fertiliser applications from three Central Otago farms.

	Month	pH	Olsen P (ug/ml)	Calcium (QTU)	Magnesium (QTU)	Potassium (QTU)	Sulphur (ug/g)	Aluminium (mg/kg)
Hills Creek Pre-	Mar	5.2	10	6	21	5	14	2.6
Post-	Mar	5.8	19	7	23	9	31	0.9
Huntley Pre-	Apr	5.2	10	5	17	5	1	6.3
Post-	Mar	6.0	18	10	17	4	25	1.5
Styx - Pre	Mar	5.2	13	3	31	13	3	5.7
Post-	Mar	6.1	29	10	19	13	23	1.1

paddocks that were developed by tractor. Soil tests were conducted in 2008, before pasture renewal, and were repeated in 2010 (Table 3).

At least 250 kg/ha of superphosphate as capital fertiliser and 3-5 t lime/ha were broadcast onto resident vegetation. Existing pastures were sprayed in autumn (April/May), particularly to control browntop with glyphosate at 6 L/ha of 360 g a.i./L, and 40 g a.i./ha tribenuron methyl (Granstar), with caution in relation to the lime applied in the previous 2 months (this can increase the residual effect of the chemical), and 150 ml/ha of an organosilicone penetrant. The paddocks were fallowed over winter, before a second spray with the equivalent of 4 L/ha of 360 g a.i./ha of glyphosate, 192 ml a.i./ha of chlorpyrifos insecticide for control of springtails (*Collembola spp*.), and 150 ml/ha of the organosilicone penetrant in the early spring (September/October). If required, tribenuron methyl was added to control yarrow, fathen, shepherd's purse or Californian thistle. Paddocks were then left for 3-14 days before seed was direct-drilled with a triple-disc drill with 100 kg/ha of serpentine super. 'Grasslands Kaituna' lucerne (*Medicago sativa*) was sown at 10 kg/ha of superstrike-treated seed. Perennial ryegrass (*Lolium perenne*) with the AR37 endophyte was direct-drilled into 10% of the farms at 25 kg/ha with 2 kg/ha of 'Tekapo' cocksfoot and 3 kg/ha of 'Tahora' white clover. The perennial ryegrass/white clover mixture was sown in November 2008 at Hills Creek and The Styx and in November 2009 at Huntleigh.

After sowing, all lucerne paddocks were left to flower before their first grazing. All ryegrass/white clover pastures were left 6-8 weeks before their first grazing. No mechanical harvesting of forage occurred in the first year on any paddock. After the first winter, the pastures were grazed or mechanically harvested as required. All lucerne paddocks were rotationally grazed for 3-10 days and then spelled for 35-42 days. Each lucerne paddock was left to flower every year at some stage in January or February to build up root reserves (Moot *et al.* 2003). A single spring application of 40 kg N/ha as urea was applied to established ryegrass/white clover pastures, if needed, based on visual assessments. After the second winter, the lucerne paddocks were winter-sprayed (June/July) with paraquat at 500 g a.i./ha and 900 g a.i./ha of atrazine. Soil tests (15 cm depth) occurred each March, and pasture samples for nutrient analysis were taken the following October to determine maintenance fertiliser requirements.

Data collection

Monthly monitoring of dry matter production was from 71 pasture cages (600 x 600 x 300 mm) across the three properties from 1 July 2008 to 30 June 2010. Each month the caged pasture was cut to ground level with a pair of hand shears, weighed fresh on site and a sub sample analysed for dry matter content by ARL laboratories. After each cut the cage was shifted and placed on a pre-cut site, ensuring a fair representation of the area. Fifty-three of these cages were in lucerne, 11 in ryegrass/white clover and 7 on unimproved areas of resident vegetation (Table 4). For this analysis, unimproved areas are represented by parts of improved paddocks that were left undeveloped usually due to their shape or contour which made them difficult to access with large machinery.

Daily rainfall on farm was measured by the farm managers using a plastic rain gauge mounted near the house. For the 2009/2010 season local data from the NIWA CLIFLO database were used. Farm data and synchronous NIWA data were compared and suitable estimates for missing farm data were calculated.

Data analysis

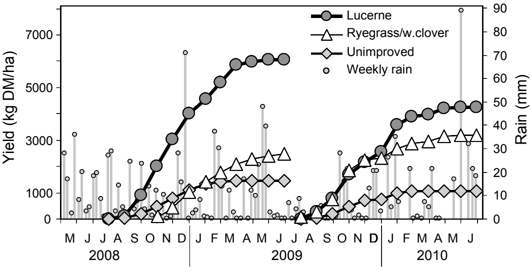
Total dry matter (DM) yield was calculated from monthly harvests. When cuts were taken half way through the month, mean daily growth rates were proportioned to each month. Least squares linear regression was used to examine the relationship between dry matter production and water use, to calculate water use efficiency (WUE).

Results

Annual yield

Over the two growing seasons, total annual DM yields for the unimproved pastures were always less than 1.5 t/ha compared with 3-5 t/ha for improved ryegrass/white clover and between 4.2 and 8.4 t/ha for lucerne (Table 4). The ryegrass/white clover pasture yields at Hills Creek and The Styx in the 2008/2009 (wet) season were compromised because establishment only occurred in November 2008.

Figure 1 Annual accumulated pasture growth and weekly rainfall from July 2008 to June 2010 at Hills Creek farm, Central Otago. Note: The ryegrass/white clover pasture was established during November 2008.



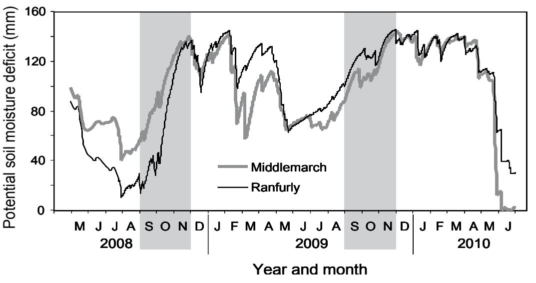
Accumulated pasture yield and rainfall

The pattern of annual yield accumulation differed among pasture types and this is described in detail for Hills Creek (Fig. 1). From 1 September to 31 December 2008, the lucerne produced 4 times that of the unimproved pasture. For all pastures, growth rate slowed in January 2009, before increasing again after ~70 mm of rainfall in February. By the end of March, growth had almost stopped with total production for April-June limited to 20 – 350 kg DM/ha across all pasture types.

During the 2009 winter (1 May to 1 September), only 141 mm of rainfall was received at Hills Creek compared with 243 mm during the same period in 2008. As a consequence the linear period of growth for the spring in 2009 was from 1 September until 31 October, or 2 months shorter than the previous year. During this period, the lucerne and new ryegrass/white clover pastures grew 1 400 – 1 600 kg DM/ha compared with 440 kg DM/ha for the resident browntop-based pastures. Rainfall events in December then increased the rate of dry matter accumulation before growth slowed again in January. There was little response to the rainfall from February onwards, despite 120+ mm of rainfall from 1 May 2010.

The potential soil moisture deficit (PSMD; Fig. 2) decreased as rainfall occurred. During the winter of 2008, the NIWA site at Middlemarch showed the PSMD decreased from 95 to 40 mm. At the start of the spring growing season (shaded area) this deficit increased from 50 to 140 mm, suggesting 90 mm of stored soil moisture had been used for plant growth. The Ranfurly site started the growing season at a PSMD of 15 mm, and ended the spring growth period at 140 mm, indicating plants used 125 mm of water of stored soil moisture for growth. A major difference between winter 2008 and winter 2009 was the lower rainfall in 2009. As a result, the PSMD for both sites were already between 100 and

Figure 2 Potential soil moisture deficits (SMD) from May 2008 to June 2010. Shaded areas indicate the main spring growth period (NIWA, 2010).



120 mm at the start of spring growth. By the end of the spring growth period, the Middlemarch site only accrued an extra 40 mm of stored water and Ranfurly an extra 20 mm from the limited spring/summer rainfall (Fig. 1). For Middlemarch, winter rainfall in 2010 reduced the PSMD to zero which equates to full soil water storage or field capacity (Fig. 2).

Water use efficiency

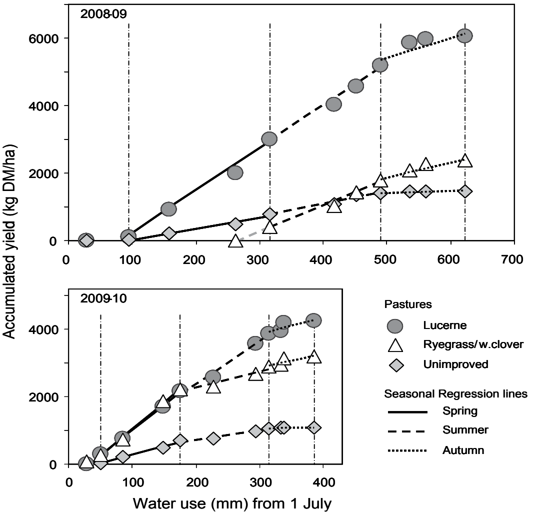
From the data for accumulated dry matter yield (kg DM/ha), rainfall received (Table 4) and PSMD (Fig. 2), the water use efficiency (WUE) was calculated (Table 5). This is presented in detail for the Hills Creek site (Fig. 3). At Hills Creek WUE for lucerne was 12.6 kg DM/ha/mm during spring 2009 and 18.3 kg DM/ha/mm for Huntleigh during spring 2008. WUE for the unimproved pasture ranged from 0 to 3.7 kg DM/ha/mm at the different sites. The lucerne at the Styx had the highest WUE of all the sites with 24.6 kg DM/ha/mm during the summer 2008. The WUE for ryegrass/white clover pastures during the 2009/2010 season ranged from 2.6 to 18.8 kg DM/ha/mm.

Discussion

Impact of lime on Soil pH

On these Central Otago farms pasture productivity was improved at least four fold by the correction of nutrient deficiencies and the introduction of improved pasture

Figure 3 Pasture yield in relation to water use (rain plus stored soil water) for Hills Creek farm, Central Otago, from July 2008 to May 2010. Vertical broken lines demarcate, from left, the winter (July and August), spring (September, October and November), summer (December, January and February) and autumn (March, April and May) growth periods. Regression lines are shown for each season's data excluding winter. The values of the slopes for the regression lines indicate the water use efficiency (WUE) and are presented in Table 3. Note: The ryegrass/white clover pasture was established during November 2008.



species. The unimproved pastures all yielded less than 1.5 t DM/ha on soils that had a pH of < 5.2. This low pH was addressed by the application of lime to reduce soil aluminium levels to <1.5 mg/kg. There is a strong relationship between soil pH and aluminium levels in many high country soils (Moir & Moot 2010, this volume). The addition of sufficient lime to increase the soil pH to at least 5.8 is required to enable aluminium sensitive species, such as lucerne, to be grown (Edmeades *et al.* 1983). The advantage of creating a soil environment that enables improved pastures to

Table 4 Annual rainfall (mm) recorded at three farms over 2 years and pasture dry matter yield (kg/ha) from three pasture types in the Maniototo region of Central Otago. The number of paddocks monitored (= sample size) are shown in parentheses.

Farm	Date	Rain	Lucerne	Ryegrass white clover	Unimproved
Hills Creek	July 2008-June 2009	596	6050 (18)	2460 [2] (3)	1470 (2)
	July 2009-June 2010	466 [1]	4250 (18)	3180 (3)	1080 (2)
Huntleigh	July 2008-June 2009	507	6440 (19)	-	970 (2)
	July 2009-June 2010	537 [1]	4760 (19)	2940 [2] (4)	400 (2)
Styx	July 2008-June 2009	499	8340 (16)	5070 (4)	130 (3)
	July 2009-June 2010	415 [1]	8480 (16)	5330 (4)	130 (3)

[1] Rain for the respective properties in May and June 2010 was 165, 235 and 99 mm but no growth response in any pastures was observed from this.

[2] Ryegrass/white clover pastures sown in November of their respective years.

Table 5 Water use efficiency (WUE; kg DM/ha/mm) during spring (September, October, November), summer (December, January, February) and autumn (March, April, May) from 2008 - 2010 for pastures grown on three farms in the Maniototo region of Central Otago. Note: WUE was calculated using rainfall plus the soil water used, the latter estimated using potential soil moisture deficits (SMD) from NIWA meteorological stations at Ranfurly (for Hills Creek and Styx) and Middlemarch (for Huntleigh). Regression goodness of fit is indicated by the coefficient of determination (R^2). Missing data (-) are from when pastures were not yet established.

			Pasture type		
Farm	Season	R^2	Lucerne	Ryegrass/ white clover	Unimproved
Hills Creek	Spring 2008	>0.97	12.6	-	3.3
	Summer 2008-09	>0.96	12.3	7.8	3.7
	Autumn 2009	<0.90	6.0	4.5	0.5
	Spring 2009	>0.99	14.9	16.0	5.0
	Summer 2009-10	>0.93	12.6	4.8	2.7
	Autumn 2010	<0.72	5.1	4.1	0.3
Huntleigh	Spring 2008	>0.95	18.3	-	3.7
	Summer 2008-09	>0.92	8.3	-	1.8
	Autumn 2009	<0.88	8.6	-	0.3
	Spring 2009	>0.90	17.3	-	2.5
	Summer 2009-10	<0.90	14.0	11.4	0.0
	Autumn 2010	>0.97	2.8	6.5	0.1
Styx	Spring 2008	>0.97	17.4	13.6	-
	Summer 2008-09	>0.93	24.6	8.2	3.6
	Autumn 2009	>0.95	10.0	9.4	0.6
	Spring 2009	>0.90	19.3	18.8	0.3
	Summer 2009-10	>0.90	31.0	8.2	0.5
	Autumn 2010	<0.30	6.0	2.6	0.1

be grown was apparent at all sites. Fig. 1 shows the superiority of lucerne over unimproved and improved pastures in both years. In 2008/2009 (wet) the 596 mm of rainfall produced 6.1 t DM/ha lucerne compared with 2.8 t DM/ha of an establishing perennial ryegrass pasture. In 2009/2010 (dry) the pasture also produced about 3.1 tonnes of biomass which was 3 times that produced by the unimproved pasture. Assuming these pasture responses are typical for the environment would then allow the economic feasibility of pasture renovation and fertiliser inputs to be assessed in these extensive pastoral systems.

Yield and rainfall

The total annual production from improved pastures was dependent on the rainfall received once growth stopped in the autumn, due to cool temperatures, and until it started in the following spring. For example, from the 1 May until the 1 September 2008 there was 243 mm of rainfall with little pasture growth. Effectively this winter fallow provided ~100 mm of stored soil moisture (Fig. 2) that assisted spring pasture production from September. Additional in-season rainfall then maintained at least some growth between rainfall events until all of the stored soil moisture had been utilised. For the unimproved browntop dominant pasture, growth essentially stopped in January compared with March for the lucerne (Fig. 1). Similarly, in 2009/2010 (dry) the unimproved pasture growth stopped in January. However, in this season the lack of winter and spring-summer rainfall meant the lucerne and improved pastures also ceased growth at this time. Specifically, from 1 May to 1 September 2009, only 141 mm of rain fell which produced 45-55 mm of available soil moisture on 1st September. A further 136 mm of rain was recorded to the 1 January with negligible summer rainfall. As a consequence the yield advantage for lucerne was only 1.1 t DM/ha over the ryegrass pastures. In autumn 2010, the 120+ mm of rainfall did not result in a pasture growth response, but has reduced the PSMD to 0 mm (Fig. 2) suggesting the soil was fully recharged for spring 2010.

The importance of winter rainfall and subsequently spring growth was quantified by calculating the WUE. An estimate of the amount of soil water used was made from the change in soil moisture deficit at the nearest NIWA station (Fig. 2). For Hills Creek, using Ranfurly data (NIWA) for spring 2008, the soil contributed about 120 mm of water in addition to the spring rainfall. Using these values, the WUE of the lucerne was calculated at 16.0 kg DM/ha/mm, and comparable with other reports (Moot *et al*. 2008). The WUE was 3.7 kg DM/ha/mm for the unimproved pasture. The difference in winter soil water storage is highlighted by the change in soil moisture deficit in 2009. However, it must be remembered that the NIWA data on soil moisture can only approximate the actual soil moisture on any given paddock because of different soil depths, pasture rooting depth, and differences in rainfall and potential evaporation between sites.

On farm calculation of WUE

The calculations made for WUE could be made for any site in the country for which meteorological data are available. These on-farm WUE calculations rely on accurate rainfall data and preferably a close estimate of the contribution of stored soil water by using nearby NIWA climate station data. The process then adds a percentage of winter rainfall to the following growing season rainfall or use of an on farm measurement of soil moisture status. Once pasture growth stops in autumn/winter, transpiration also stops so soil moisture recharge occurs. The NIWA soil moisture deficit (SMD) data allows for potential evapotranspiration over winter when there is still soil evaporation and run-off so not all winter rain becomes stored soil moisture. The level of this recharge is dependent on the water holding capacity of the soil before field capacity is reached and drainage occurs (Moot *et al*. 2008).

Of note was the spring WUE of the new ryegrass/white clover pasture at Hills Creek that was similar to the lucerne in 2009/2010. This probably reflects the higher legume content of these establishing pastures. The importance of maximising spring growth has previously been highlighted by Moot *et al*. (2008). In their studies, the WUE in spring was higher than in any other season and has been attributed to differences in herbage nitrogen content (Tonmukayakul *et al.* 2010).

Conclusion

The development of 18 000 ha in Central Otago has quantified, on a commercial scale, the production advantages to improved species over the resident vegetation and related these to the soil water and its use. Importantly, rectifying soil nutrient requirements coupled with the introduction of N fixing plants more than trebled the production in this low rainfall, cold winter environment.

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