Spring water use efficiency of six dryland pastures in Canterbury

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Abstract

The spring water use efficiency (WUE) of six pasture combinations was calculated from the 'MaxClover' grazing experiment at Lincoln University. Pastures have been established for six years and are grazed by best management practices for each combination. Measurements were from individual plots of four replicates of cocksfoot (CF)/subterranean clover (Sub); CF/balansa clover (Bal); CF/white clover (Wc); CF/Caucasian clover (Cc); perennial ryegrass (RG)/Wc or lucerne pastures. Actual water use was measured by time domain reflectometry (0-0.2 m) and a neutron probe (0.2-2.3 m). Dry matter yield, botanical composition and herbage quality were measured at the end of seven regrowth cycles between 1 July 2008 and 30 June 2009 (33-85 d duration). The results highlight differences in spring WUE amongst species and these were related to legume contribution and grass nitrogen (N) yield. Lucerne had the highest spring WUE at 30 kg DM ha^{-1} mm^{-1} of actual water use. This was produced at a rate of 5.7 kg DM ha^{-1} °Cd^{-1}. For grass based pastures CF/Sub clover produced 18 kg DM ha^{-1} mm^{-1} at a rate of 5.9 kg DM ha^{-1} °Cd^{-1} compared with 14 kg DM ha^{-1} mm^{-1} for the other pastures at rates of 3.2 to 4.1 kg DM ha^{-1} °Cd^{-1}. These results highlight the importance of the spring period for dryland pasture production when soil temperatures are rising and moisture levels are high. The spring pasture WUE of dryland pastures was higher than in summer and autumn and therefore it is important that farmers maximise pasture production through combinations of pasture species that maximise spring legume content.

Additional keywords*: Dactylis glomerata, Lolium perenne, Medicago sativa, Trifolium ambiguum, T. michelianum* var. balansae*, T. repens, T. subterraneum*

Introduction

In eastern districts of New Zealand moisture stress of dryland pastures is common over summer (Salinger, 2003). At Lincoln, Canterbury, monthly potential evapotranspiration generally exceeds rainfall from September to April. This produces a long term (1975-2007) average potential soil moisture deficit of approximately 430 mm yr^{-1} in April. Stress is relieved by autumn rain which re-establishes the sward before cool winter temperatures restrict pasture growth (Mills *et al.*, 2008a). On an annual basis the majority of pasture production in these regions occurs in the spring when soil moisture is at, or near, field capacity and soil temperatures begin to rise. The efficiency with which pastures utilise this available soil water in spring is therefore an important contributor to annual pasture yields. Agronomically, water use efficiency (WUE) can be defined as the ratio of the total dry matter (DM) produced to the total water used for growth (Moot *et al.*, 2008), or as DM accumulation against potential or measured evapotranspiration (ET). This can be done on a seasonal or annual scale and is important for understanding how to manage dryland pastures. Enhancements in agricultural WUE depend on productivity gains at the field level, and are quantified by consistent increases in outputs per unit of input. For dryland farmers this can be equated to greater pasture and animal production per unit of water input.

For irrigated dairy pastures Martin *et al*. (2006) reported a mean WUE of 20 kg DM ha^{-1} mm^{-1} of potential evapotranspiration (PET). In dryland pastures, where actual evapotranspiration (Martin, 1990) or water use, was measured, Moot *et al*. (2008) reported a range of values from 7 kg DM ha^{-1} mm^{-1}, for a severely N deficient (*Dactylis glomerata* L.) dominant sward, to 40 kg DM ha^{-1}mm^{-1} of water for lucerne (*Medicago sativa* L.).

In most cases they suggested that pastures which contained high legume content or had received applied N had higher water use efficiency than those with low N. Thus, at the pasture level, differences in water use efficiency were related to the N content of the pasture grown. A difficulty with their comparisons of pasture water use efficiency was that a range of experiments were interpreted from across different soil types. In the present study the spring water use efficiency of six dryland pastures are compared from within the 'MaxClover' grazing experiment. Four of these pastures have cocksfoot as the dominant grass because it is a persistent species commonly used in dryland pastures. However pastures are often N deficient (Peri *et al*., 2002), because of its competitive ability in water extraction that restricts the growth of companion legumes (Evans, 1978; Lee and Cho, 1985). Therefore the 'MaxClover' experiment was designed to identify legume species that may persist in cocksfoot swards to enhance overall pasture productivity (Mills *et al*., 2008a).

The present study compares WUE of cocksfoot (CF) pastures grown with

(1) subterranean (Sub) (*Trifolium subterraneum* L.), or
(2) balansa (Bal) (*T. michelianum* Savi var. balansae Boiss.) annual clovers, or
(3) white (Wc) (*T. repens* L.), or
(4) Caucasian (Cc) (*Trifolium ambiguum* M. Bieb.) perennial clovers with a
(5) perennial ryegrass (*Lolium perenne* L.)/white clover (RG/Wc) control and
(6) a lucerne (Luc) monoculture.

Materials and Methods

Full details of the experimental design, establishment and measurements of the 'MaxClover' experiment were reported by Mills *et al.* (2008a). Details related to the present experiment are included. Specifically, the experiment was at Lincoln University, Canterbury with 36 plots (6 pasture treatments x 6 replicates) of 0.05 ha. Four replicates were established in February 2002 and were utilised for a measurement period of 1 July 2008 to 31 March 2009. Meteorological data for rainfall, used in the calculations of actual spring soil water use, and soil temperature, used to calculate thermal time (Moot *et al*., 2000) were recorded at the Broadfields station located 2 km north of the site. Broadfields daily rainfall data is comparable (± 3%) to rainfall data collected closer (approximately 300 m) to the experimental area but has the advantage of having a complete set of other environmental variables including temperature, potential evapotranspiration, solar radiation and wind run.

Environmental conditions

During the experimental period reported annual rainfall was 767 mm which was 23% above the long-term mean (LTM) (Table 1). Specifically rainfall in July 2007 was more than double the long-term mean of 64 mm and in May 2009 rainfall was 171 mm compared with the LTM monthly rainfall of 50 mm. Soil temperature (0.1 m) was 11% higher than the LTM. Monthly mean soil temperatures were 9-19% warmer than the LTM from October to January.

Table 1: Monthly rainfall (mm) and 0.1 m soil temperature (°C) recorded at the Broadfields Meteorological Station located 2 km north of the experimental site. Long-term monthly means (LTM) are for the period 1975-2002.

	Rainfall (mm)		Soil temperature (°C)	
Month	LTM	Actual	LTM	Actual
July	64	145	4.0	5.8
August	62	94	5.4	6.1
September	43	39	8.1	9.8
October	51	22	11.2	12.3
November	52	11	14.0	16.6
December	50	77	16.5	18.0
January	51	46	17.6	20.9
February	41	59	17.1	17.4
March	50	36	14.9	15.1
April	46	53	11.1	12.2
May	50	171	7.4	7.2
June	64	14	4.7	5.4
Annual	624	767	11.0	12.2

Pasture production

Grass based pasture production and botanical composition were measured at 33-85 day intervals from 0.2 m^2 quadrats cut from exclosure cages which were shifted to a new site after each harvest. The herbage, cut to a height of approximately 30 mm, was then sub-sampled and sorted into sown grass; sown legume; other grass, other legume, weeds and dead matter before drying at 65 °C to constant weight. Sown clover and grass samples were ground through a 1 mm sieve and tested by near infrared spectroscopy (NIRS) for N content. The N percentage of the grass and clover herbage and their DM yield were then used to calculate total N yield (kg N ha^{-1}) of the sown species in each plot. Lucerne samples were processed in the same manner but harvests were from 5 x 0.2 m^2 quadrats $plot^{-1}$ immediately prior to grazing.

Soil water measurements

Soil water content was measured by time domain reflectometry (0-0.2 m; Trace Systems 6050X1) and neutron probe (Troxler 4300) at 0.2 m intervals (0.2-2.3 m). Measurements were made at 5-41 d intervals, with the maximum interval occurring in winter. The drained lower limit (DLL) was defined as the lowest volumetric soil water content (Brown, 2004) in each 0.2 m soil layer recorded when soil water content was stable during a known period of water stress in summer. For example, Figure 1a shows little change in soil water content for lucerne in the 0.5-0.7 m soil layer from February to April which coincided with a period of no growth. For this layer the DLL was quantified as 10.1% v/v from a measurement on 4 March 2009. Similar analyses were undertaken for each soil layer in each plot. To define field capacity, or the drained upper limit (DUL), the average of the second and third highest volumetric water contents recorded, when soil moisture profiles were fully recharged, in winter was used. The DUL was calculated from measurements made when soil water content was stable (Robertson *et al*., 1993), prior to the start of root water extraction during active growth, in each of the 12 individual soil layers. The measured volumetric water content in the 2.2-2.3 m soil layer under lucerne grown in plot 19 is shown in Figure 1b. The absolute value of 7.7% indicates a high gravel content which was apparent at 0.5-2.1 m across plots. The consistency of the measured values indicated no water extraction at this lowest depth for lucerne. Slight variations in reading can occur and thus the DUL was taken as the average of the 2nd and 3rd highest volumetric water content measured. The difference between DUL and DLL is a measure of plant available water content in each soil layer. These were summed (0-2.3 m soil depths) for each individual plot.

Analysis of variance indicated the plant available water content was 280 ± 19.8 mm for all pastures and was unaffected by pasture type (Tommukayakul, 2009).

For spring grazed pastures the assumption of a full canopy used in the calculation of potential evapotranspiration was not always fulfilled, particularly under set-stocked conditions. Therefore, actual soil water use was calculated for each individual plot. Actual soil water use was calculated from a total soil water (0-2.3 m) budget which made daily interpolations of soil water content (SWC, Equation 1) and water use (WU, Equation 2). Water use was then accumulated for individual regrowth periods in the spring period.

Equation 1 $$SWC = \sum_{bottom}^{top} \theta \times d$$

Where θ is the volumetric water content (% v/v) and d is depth (mm) of the soil layer measured and *top* is the 0-0.2 m soil layer and *bottom* is the 2.2-2.3 m soil layer.

Equation 2 $WU = P - \Delta SWC - D$

Where P is precipitation or rainfall measured at the Broadfields Meteorological Station, ΔSWC is the change in SWC between successive measurements and D is drainage. Drainage occurs on a daily basis when precipitation causes the SWC to exceed the drained upper limit of the profile. A WU factor was calculated as the ratio between actual evapotranspiration and Penman potential evapotranspiration. This factor was applied to daily PET to estimate daily water use between successive measurements.

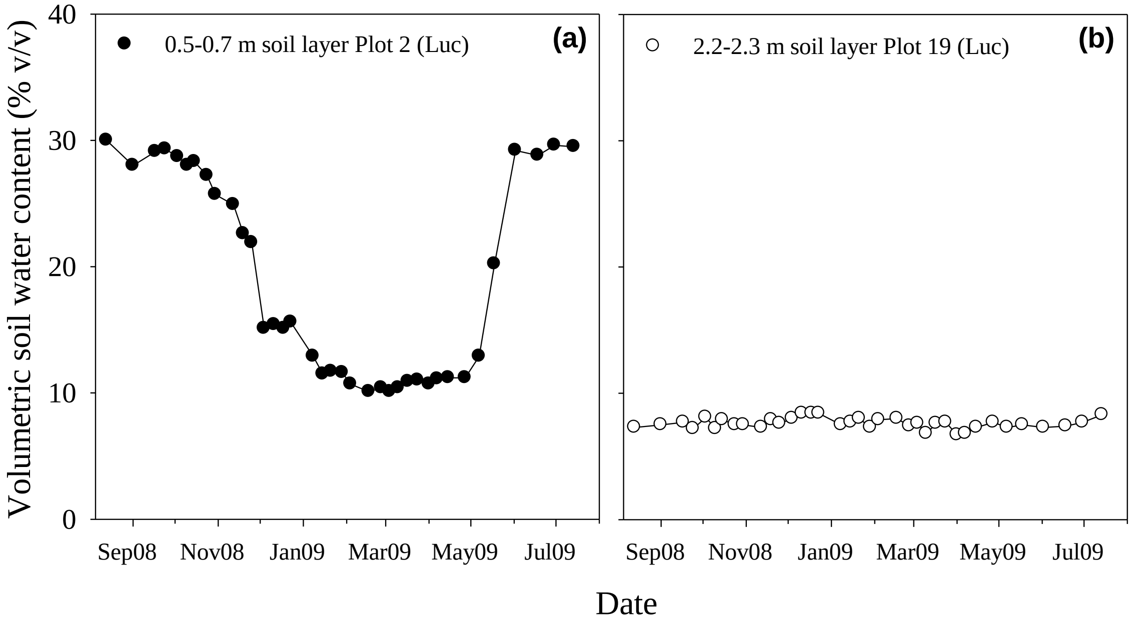

Figure 1: Soil moisture content (a) in the 0.5-0.7 m soil layer in plot 2 (lucerne) and (b) in the 2.2-2.3 m soil layer in plot 19 (lucerne) throughout the 2008-09 growth season at the 'MaxClover' grazing experiment at Lincoln University, Canterbury.

Results and Discussion

The main period of pasture production with the highest pasture growth rates for all species was in the spring (Figure 2). Growth rates for lucerne are shown for reference but were excluded from the analysis of variance as harvests were made at different times from the grass based pastures. During the winter period CF/Sub pastures grew at 21 kg DM ha^{-1} d^{-1} which was almost double ($P<0.001$) the 11 ± 1.4 kg DM ha^{-1} d^{-1} produced by all other grass-based pastures.

In early spring (8 October 2008) a trend ($P<0.10$) suggested that CF/Sub pastures grew faster (57 kg DM ha^{-1} d^{-1}) than CF/Bal, CF/Wc or CF/Cc pastures. As spring progressed the CF/Sub pastures showed superior production ($P<0.01$) and grew at 74 kg DM ha^{-1} d^{-1} (10 November 2008) compared with 43 ± 6.0 kg DM ha^{-1} d^{-1} for all other grass based pastures. Lucerne grew at a rate of approximately 100 kg DM ha^{-1} d^{-1} in November and 75 kg DM ha^{-1} d^{-1} 38 d later in December. Growth, in grass based pastures slowed after the November harvest and they were next harvested 56 d later (5 January 2009) during which period all grass based pastures had grown at 24 ± 6.5 kg DM ha^{-1} d^{-1}. Lucerne, harvested 12 d later, after 38 d of regrowth, had grown at 77 kg DM ha^{-1} d^{-1}.

Late summer/autumn (2 March 2009) rains alleviated soil water stress conditions and annual clover seedlings began to germinate. The cocksfoot pastures established with Sub clover grew at 16 kg DM ha^{-1} d^{-1} compared ($P<0.05$) with 9 kg DM ha^{-1} d^{-1} for CF/Cc pastures. By mid-autumn (6 April 2009) the CF/Sub pasture production of 21 kg DM ha^{-1} d^{-1} was double ($P<0.1$) the 10 ± 2.7 kg DM ha^{-1} d^{-1} from perennial clover based pastures. The CF/Bal pasture was intermediate at 13.8 kg DM ha^{-1} d^{-1}. Early autumn production by lucerne was > 30 kg DM ha^{-1} d^{-1} and this decreased to 7 kg DM ha^{-1} d^{-1} when the last lucerne harvest of was taken on 27 May 2009.

For the late autumn/early winter period (30 June 2009) the maximum ($P<0.05$) growth rate of the grass based pastures was 7 kg DM ha^{-1} d^{-1} by the CF/Sub pastures and lowest in RG/Wc pastures (4 kg DM ha^{-1} d^{-1}).

The duration of the spring phase, where moisture was non-limiting, was quantified as the period before a significant reduction in daily growth rates of each pasture occurred. For the grass treatments this reduction was on 10 November 2008 compared with one month later on 9 December 2008 for lucerne. During these periods the growth rate of pastures can be related to thermal time until a lack of soil moisture restricts growth (Mills *et al.*, 2006).

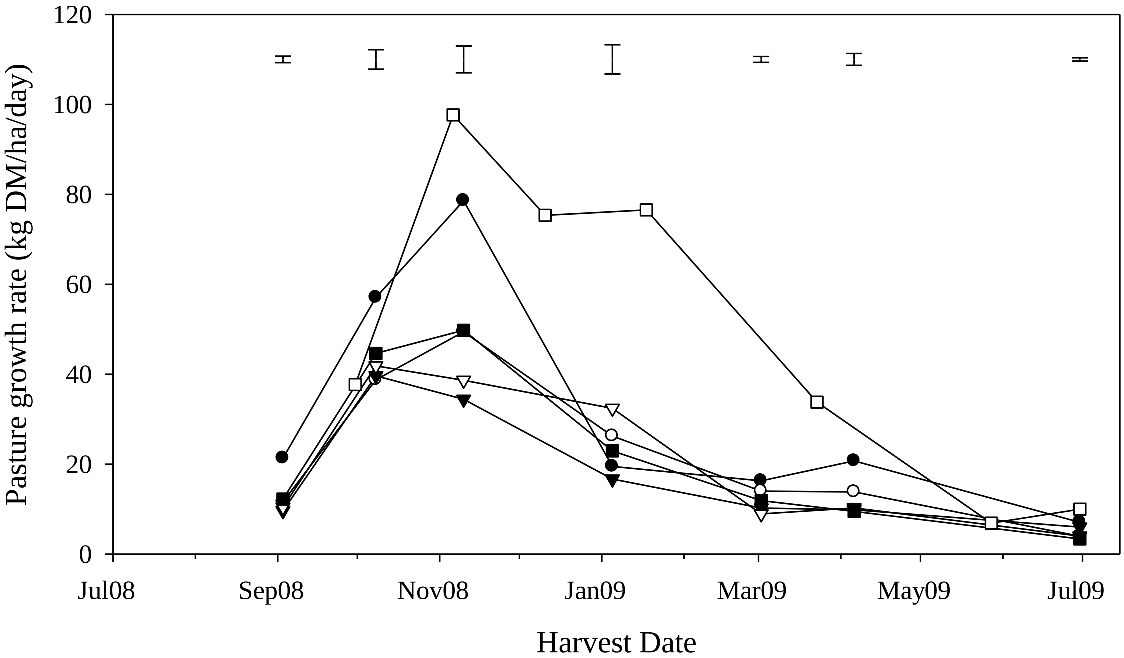

Figure 2: Daily growth rates of CF/Sub (●), CF/Bal (○), CF/Wc (▼), CF/Cc (▽), RG/Wc (■) and Luc (□) pastures at Lincoln University, Canterbury for regrowth cycles between 1 July 2008 and 30 June 2009. Mean daily growth rates of lucerne are shown for reference but were excluded from the analysis as harvests were not made at the same time as those of grass based pastures. Error bars are SEM for grass based pastures.

Figure 3 shows the accumulated pasture DM against accumulated thermal time calculated from 0.1 m soil temperatures with a base temperature of 0 ºC. For the period before water stress compromised growth the relationship was linear for all pasture combinations. In each case the fitted regression equation indicated an x-axis intercept of around 200 ºCd, which translated to 3 August 2008. This value differed from zero and this suggests that pasture accumulation during winter (from 1 July 2008) was not linearly related to temperature. This probably reflects the low pasture covers at this time with the hard autumn grazing removing herbage to below the critical leaf area index. This apparent lag phase was also reported by Fasi *et al*. (2008) for dryland pastures growing in the Lees Valley of Canterbury. This suggests further work is required to identify the mechanism responsible for the lag period, to enable the trigger point to commence linear accumulation with thermal time to enable it to be used in a predictive manner.

A feature of the thermal time approach was the consistency of response within a species. For the grass based pastures the CF/Sub pasture had the highest spring growth rate (P<0.001) at 5.9 kg DM ºCd^{-1} which was similar to the 5.7 kg DM ºCd^{-1} found for lucerne, but higher than those found for all other grass combinations (3.2 to 4.1 kg DM ºCd^{-1}).

For the grass based pastures the higher rate for the CF/Sub pasture led to a spring DM yield of 6,100 ± 270 kg DM ha^{-1} which was 50-90% greater (P<0.001) than the other grass based pastures (Figure 3). Surprisingly, the lucerne grew at a rate comparable to the CF/Sub pastures throughout the early spring growth period despite its reputation for slow early spring growth. Of note was the extended linear duration of the lucerne pastures for 400 ºCd later than grass based pastures. This led to a spring yield from this linear phase of 8,730 kg DM ha^{-1} or > 44% more (P<0.001) than the next highest yielding pasture (CF/Sub). This additional yield of high quality feed (Brown and Moot, 2004) would support higher live-weight gain and consequently yield more meat per hectare (Mills *et al*., 2008b) than traditional pasture combinations. Equally, the higher yield from the CF/Sub pastures supports the recommendation for this combination to be used in dryland pastures to compliment lucerne productivity (Brown and Moot, 2004; Mills *et al*., 2008a).

A feature of soils used for dryland pastures in Canterbury is their variability in depth to gravel which consequently affects soil water holding capacity. This is apparent in Figure 4 where the calculation of plant available water for a CF/Sub pasture in plot 5 of replicate 1 was 223 mm (gravels at approximately 1.0 m) compared with 340 mm for the nearby lucerne in plot 2 of replicate 1 (gravels at approximately 1.5 m). Also when analysing water over the winter-spring period in temperate regions some drainage may occur which is difficult to account for. Figure 4 also shows the water holding capacity of these soils changed markedly with depth. In the top 0.2 m the top soil had a drained upper limit of over 30% and lower limits around 8%, which are consistent with these silt loam soils (McLaren and Cameron, 1996). Below depths of approximately 1.0 m the drained upper limit was between 10 and 15% indicating the presence of stones and a lot less silt with a consequence of lower plant available water in each layer. This variability is common amongst such soils and is one of the reasons the actual water use was measured and quantified for individual plots. The analysis requires assessment of how much water is available and also how much the plant roots can access at lower depths.

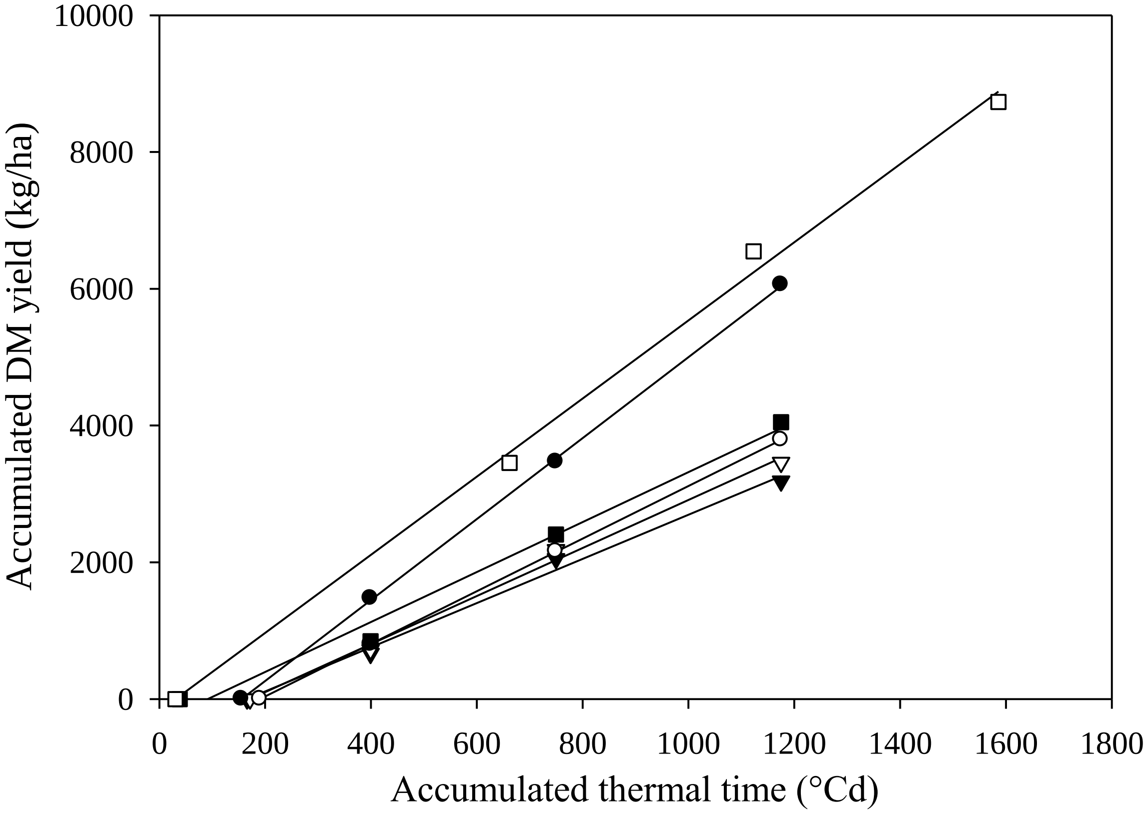

Figure 3: Dry matter (DM) accumulation from 1 July 2008 to 10 November 2008 for CF/Sub (●), CF/Bal (○), CF/Wc (▼), CF/Cc (▽), RG/Wc (■) and from 1 July 2008 to 10 December 2008 for Luc (□) pastures at Lincoln University, Canterbury against accumulated thermal time (Tt) calculated using 0.1 m soil temperature with a base temperature of 0 °C. The regression equation of:
CF/Sub was y = 5.9 (± 0.11)x-922 (± 95.5) (R^2 = 0.99),
CF/Bal was y = 3.9 (± 0.01)x-733 (± 8.6) (R^2 = 0.99),
CF/Wc was y = 3.2 (± 0.37)x-536 (± 307.0) (R^2 = 0.98),
CF/Cc was y = 3.5 (± 0.34)x-602 (± 282.0) (R^2 = 0.98),
RG/Wc was y = 4.1 (± 0.17)x-759 (± 142.0) (R^2 = 0.99) and
Luc was y = 5.7 (± 0.57)x-175 (± 679.0) (R^2 = 0.98).
Standard errors of the slope and intercept are reported in the regression equations.

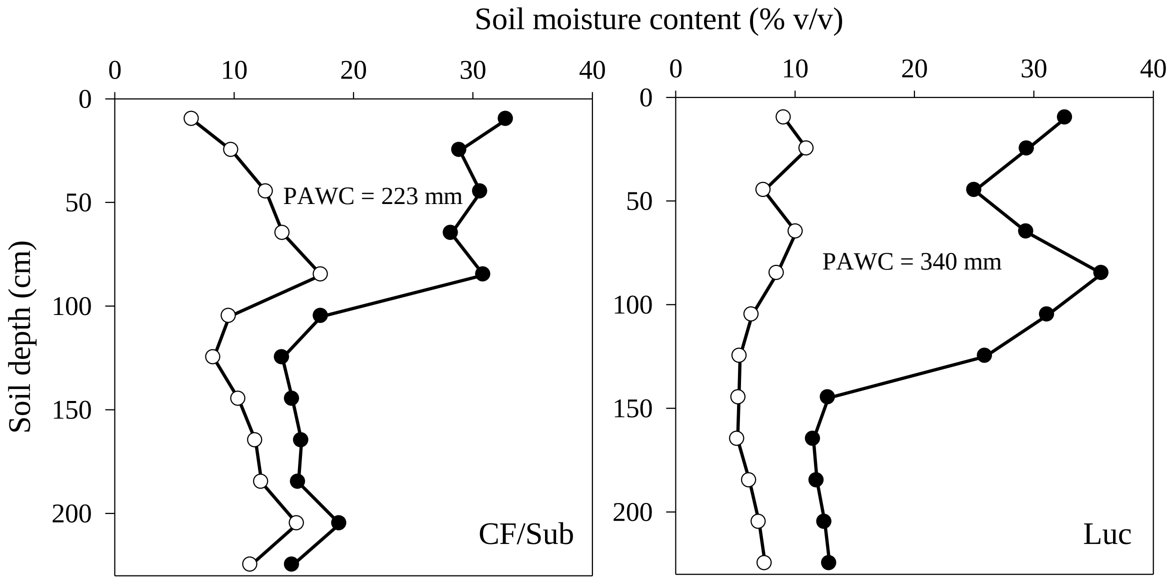

Figure 4: Water storage capacity (% v/v) for each 0.2 m soil layer from 0-2.3 m depth under a CF/Sub (plot 5) and a lucerne (plot 2) pasture grown on a variable depth Templeton silt loam soil at Lincoln University, Canterbury. Where DUL (●) is the drained upper limit and LL (○) is the lower limit to field based extraction measured from 1 July 2008 to 18 June 2009.

The higher yield of the lucerne and CF/Sub pastures (Figure 5) probably resulted from their having access to more moisture in the profile or utilising that moisture more efficiently. Specifically, lucerne produced 8,730 kg DM ha^{-1} using 310 mm of water in spring. A trend ($P<0.1$) indicated lucerne used about 60 mm more water than grass based pastures.

In contrast, the CF/Sub pastures used the same amount of water as the other grass based pastures (approximately 280 mm) but produced a yield that was 50-90% higher than other pastures. Thus, the CF/Sub used a similar amount of water in to produce more DM indicating a more efficient use of the available water to produce yield. For the lucerne pastures higher yields were produced through a combination of access to more water and greater efficiency of that water to produce DM.

The total accumulated water use in spring shows some differences among pasture species (Figure 5). The regression relationships were forced through the origin on the basis that water use and yield are intrinsically linked. Of the grass-based pastures, total accumulated water used by the CF/Wc and CF/Cc pastures in spring was < 246 mm which was less ($P<0.1$) than the 310 mm used by lucerne. The relationship between this actual water use and DM yield gave a water use efficiency of approximately 14 kg DM ha^{-1} mm^{-1} for the CF/Wc, CF/Cc, CF/Bal and RG/Wc pastures. The variation in total accumulated yield among these pastures was proportional to the additional water used. For the CF/Sub plots the total accumulated water use was comparable to the RG/Wc pastures (approximately 280 mm) but the higher yield gave a calculated WUE of 18 kg DM ha^{-1} mm^{-1} of water used. For lucerne the WUE was 30 kg DM ha^{-1} mm^{-1} of water and it also had the highest total accumulated water use of 310 mm. This combination of a higher WUE and greater access to water, due to a deep tap root (Moot *et al*., 2008) explains the higher spring yields for the lucerne.

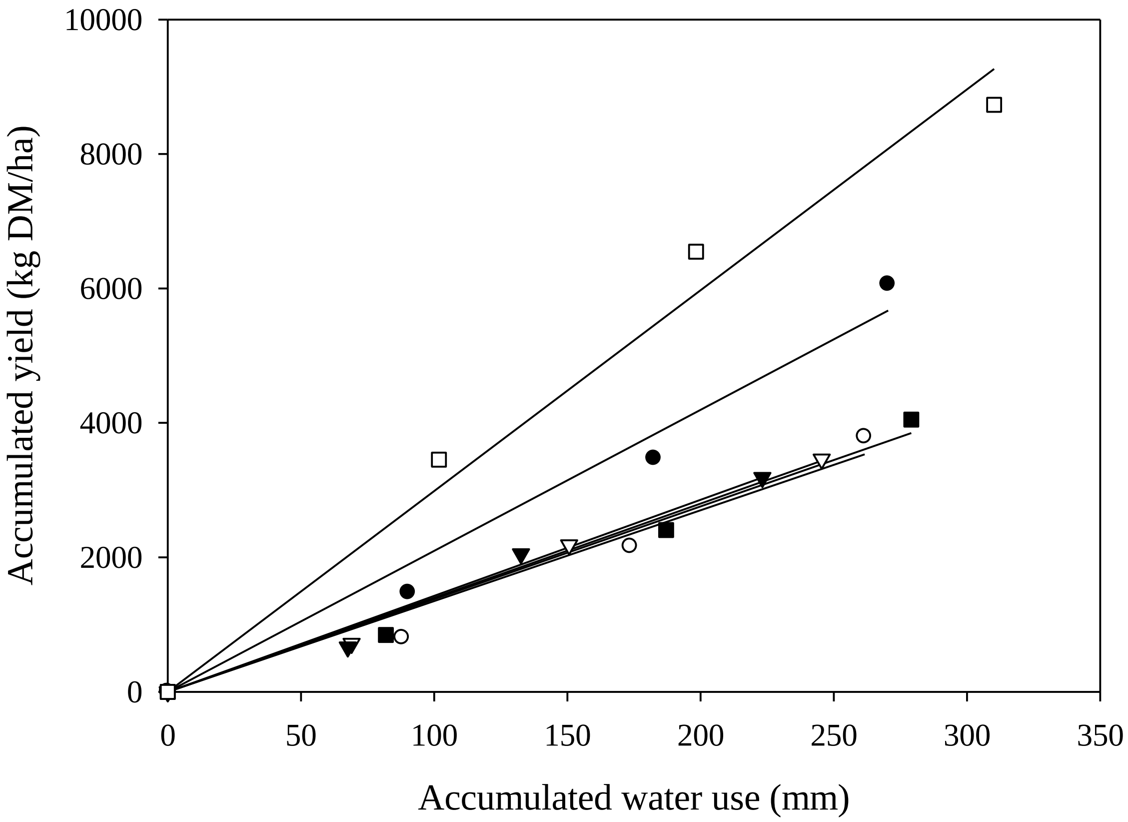

Figure 5: Relationship between accumulated yield (kg DM ha^{-1}) and water use (mm) over spring season for CF/Sub (●), CF/Bal (○), CF/Wc (▼), CF/Cc (▽), RG/Wc (■) and Luc (□) pastures. The regression equation of
CF/Sub was y = 21.0 (± 1.16)x (R^2 = 0.98),
CF/Bal was y = 13.5 (± 0.89)x (R^2 = 0.97),
CF/Wc was y = 14.3 (± 0.73)x (R^2 = 0.98),
CF/Cc was y = 14.0 (± 0.51)x (R^2 = 0.99),
RG/Wc was y = 13.8 (± 0.65)x (R^2 = 0.98) and
Luc was y = 29.9 (± 1.39)x (R^2 = 0.98).
Standard error of the slope is included for the regression equations.

These differences in spring WUE of the grass-based pastures may be explained by differences in their botanical composition which contributed to differences in the total N yield. Table 2 shows that the sown grass component of these six-year-old pastures ranged from 25% for the RG/Wc pastures to 58% for the CF/Wc. The legume component of the grass pastures ranged from a maximum of 49% in the CF/Sub to < 20% in all other grass plots. The balance was predominantly from dicotyledonous (dicot) weed species and unsown grasses, especially in the ryegrass plots. These results show the continued decline in the ryegrass pastures and the relative superiority of the cocksfoot after seven years (Mills *et al.*, 2008a). Combining the botanical composition results and the herbage N percentage (N %) allowed the total N yield from each pasture to be determined (Table 3).

Table 2: Botanical composition of six dryland pastures at Lincoln University, Canterbury during the spring period of year 7 (2008-09). Legume content (%) in grass based pastures shows the contributions of volunteer (unsown) white clover in brackets for each treatment. For lucerne monocultures the total weed content is reported and this includes contributions from volunteer white clover, grass weeds and dicot weeds. Values may not sum to 100 due to rounding.

				Weeds (%)	
Treatment	Sown grass (%)	Legume (%)	Dead (%)	Grass	Dicots
CF/Sub	30	49 (<1)	3	17	1
CF/Bal	36	17 (17)	2	18	9
CF/Wc	58	14	3	22	3
CF/Cc	40	12 (11)	3	24	10
RG/Wc	25	16	3	43	14
Luc	-	95	<1	0	4

Table 3: Nitrogen content (% N) and corresponding N yields of the sown grass and legume components of the six dryland pastures at Lincoln University, Canterbury in spring. The sown species % N is the weighted N concentration based on botanical composition from the sown grass and legume components.

Treatment	Grass %N	Legume %N	Grass N yield (kg ha^{-1})	Legume N yield (kg ha^{-1})	Sown species N%	Sown species N yield (kg ha^{-1})
CF/Sub	3.8a	4.4	74.2a	45.3b	4.1a	119.5b
CF/Bal	3.3ab	3.0	65.0a	9.3b	3.4abc	74.3cd
CF/Wc	3.5a	4.2	74.2a	16.3b	3.6ab	91.0bc
CF/Cc	3.5a	4.8	58.3a	15.1b	3.7ab	73.4cd
RG/Wc	1.9b	3.6	24.4b	19.1b	2.4c	43.5d
Luc	-	4.0	-	288.3a	4.0ab	288.3a
Grand mean	3.2	4.0	59.3	65.6	3.5	115.0
SEM	0.30	0.68	6.66	13.1	0.34	14.45
Significance	<0.01	NS	<0.01	<0.01	<0.05	<0 .01

Note: Separations were made with Fishers' Protected LSD. Means followed by the same letter are similar at the P<0.05 level. NS = non-significant.

For all of the cocksfoot pastures the N percentage in the sown grass was between 3.3 and 3.8%. These values are consistent with those found by Peri *et al.* (2002) which were required to give at least 80% of the maximum potential photosynthetic capacity in cocksfoot. Once values fell below 2.6% the rate of photosynthesis was severely compromised. This appears to have been the case for the ryegrass which had the lowest herbage N of 1.9% and a consequent N yield of only 24 kg N ha^{-1}. It was therefore unexpected that the total DM yield and water use efficiency of the RG/Wc pasture was similar to that of several of the cocksfoot based pastures. This suggests that the annual weed grasses (predominantly barley grass (*Hordeum murinum* L.) and *Bromus* spp.) that had invaded these pastures were producing DM at a similar rate to the cocksfoot. Without determination of the N percentage of these components it is difficult to know exactly how much N was harvested from this treatment. The total of 44 kg N ha^{-1} calculated from sown species probably underestimates the total N yield.

In contrast, the superior clover content (49%) in the CF/Sub pastures resulted in the highest total N yield of 120 kg ha^{-1} from grass based pastures. These results highlight the importance of N availability to maximise the WUE of dryland pastures. In most cases, spring DM production of dryland pastures is N limited and the highest response of yield to applied N can be expected at this time (Fasi *et al.*, 2008). The main impact of N deficiency is to reduce leaf area. Many species adjust their leaf size to maintain N concentrations above critical levels that affect photosynthesis (Lemaire *et al.*, 2008). This probably explains why the herbage N percentage values are usually conservative within the range of 3-4% found in this study. On its own herbage N concentration does not reflect whether the pasture would respond to applied N.

The benefits of managing dryland pastures to maintain a legume in the system are frequently directly related to the herbage quality of feed on offer (Litherland and Lambert, 2007). Indirectly, the increased water use efficiency means each unit of water use results in a higher DM yield, particularly in spring. The additional benefit of a pure legume can be gauged from the lucerne pastures which yielded 288 kg N ha^{-1} or about 30 kg N t^{-1} DM produced. This is similar to the generalized figure for N fixation of 25 kg N t^{-1} DM produced (Peoples and Baldock, 2001). The higher value possibly represents the added input of soil N from these grazed pastures. Regardless of the source, the availability of N in spring pastures is crucial to maximise the limited water storage capacity of the soil in dryland regions. The resulting increase in water use efficiency leads to higher DM yields through a faster rate of DM accumulation per unit of thermal time before the dry summer.

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