

Cocksfoot pasture production in relation to environmental variables

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Abstract

The effects of temperature, water and nitrogen on pasture production of an 8 year old 'Wana' cocksfoot pasture were quantified at Lincoln University, Canterbury. The maximum dry matter (DM) yield was 22.0 t/ha/yr when neither water nor N were limiting. Crude protein yield of +N pastures was 3.2-4.2 t/ha/yr compared with 1.0 t/ha in -N pastures. Metabolisable energy averaged 178×10^3 MJ ME/ha/yr for the +N pastures compared with 69×10^3 MJ ME/ha/yr for -N pastures. Seasonal differences in pasture production were explained in relation to thermal time with 7.0 kg DM/°Cd for N fertilised pastures and 3.3 kg DM/°Cd when no N was applied. During periods of water stress, the relative yield decreased at a rate of 1.4%/mm when the soils critical limiting deficit of 78 mm was exceeded.

Keywords: *Dactylis glomerata*, irrigation, nitrogen, thermal time.

Introduction

Cocksfoot (*Dactylis glomerata*) is the second most commonly sown pasture grass in New Zealand. It is recommended for low to moderate fertility, summer dry regions (Rumball 1982; Baker *et al.* 1985) and its ability to produce, survive and persist when subjected to drought (Stevens *et al.* 1992) makes it an important component in most dryland pastures. Annual DM yields of cocksfoot in Canterbury range from ~7 to >28 t DM/ha (Stevens *et al.* 1992; Peri *et al.* 2002a). The lower value represents a typical yield under grazed dryland conditions and the upper extreme was the environmental maximum when neither water nor nitrogen limited pasture growth.

In this study, the aim was to quantify the relationship between pasture growth and the main environmental variables of temperature, nitrogen and moisture. Once established, the potential impact of limitations in any one factor can be assessed for different environments and mitigation strategies to overcome production losses developed. Of these factors, temperature induces a seasonal effect that cannot be manipulated through management. However, the impact can be quantified in relation to thermal time and responses predicted. The aggressive growth habit of cocksfoot, compared with legumes such as white clover (*Trifolium repens*), leads to a decrease in the clover component (Lee and Cho 1985; Moloney 1991). This causes nitrogen deficient

pastures with restricted leaf photosynthesis (Peri *et al.* 2002b) and decreased pasture grazing preference (Edwards *et al.* 1993).

Materials and Methods

The experiment was conducted at Lincoln University, Canterbury on a Templeton silt loam soil overlying alluvial gravels (Cox 1978). The site was sown in March 1995 with 'Grasslands Wana' cocksfoot and white, red (*T. pratense*) or subterranean (*T. subterraneum*) clovers but by the beginning of this experiment in September 2003 clover was <2% of total dry matter (DM). Prior to the experiment, lime was applied at 5.0 t/ha and superphosphate at 400 kg/ha. Following annual soil test results, potassium sulphate was applied at 100 kg/ha in October 2004.

The split plot experiment with three replicates used Irrigation (I) or Dryland (D) main plots (12.0 x 12.6 m) and nitrogen (N) (+N or -N) as subplots (6.0 x 6.3 m) for 2 years from September 2003. In 2003/04, 800 kg N/ha was applied as urea (46% N) in eight applications of 100 kg N/ha at the beginning of active regrowth periods. Applications were made in conjunction with rainfall or irrigation to ensure maximum efficiency. In 2004/05, the N rate was 1 600 kg N/ha/y in 11 split applications.

Regrowth periods were 25-35 days during active growth and up to a maximum of 52 days over winter. Dry matter was measured from a 0.2 m² quadrat and plots were mown (cut and carry) to a residual of 30 mm at the end of each rotation. Botanical composition was measured at each harvest before samples were dried at 50-60°C. Green cocksfoot material, including reproductive tillers when present, was analysed for metabolisable energy (ME) and N content (%). The yields and N% of the I+N pastures were used as an indicator of the non limited potential of the pasture.

Annual average rainfall was 624 mm, with a mean annual temperature of 11°C as recorded at the Broadfields meteorological station. Daily mean air temperatures were used to calculate thermal time (Tt) accumulation with a base temperature of 3°C and an optimum temperature of 24°C. Total rainfall was 515 mm in year 1 compared with 523 mm in year 2. Similarly, annual potential evapotranspiration (PET) was 1109 mm and 1052 mm in each year. Within this environment, PET usually exceeds rainfall from September to April. The mean annual long term potential

soil moisture deficit is 400 mm compared with 650 mm in year 1 and 625 mm in year 2.

Soil moisture was monitored by Time Domain Reflectometry (TDR) and neutron probe every 7–14 d. Flow meters measured the amount of water applied to irrigated plots with 447 mm of water applied by overhead sprinklers in 2003/04 and 256 mm in 2004/05. Water was consistently extracted from 0.0–0.8 m in all plots so the actual soil moisture deficit was determined to this depth. The critical limiting deficit was the actual soil moisture deficit at which the relative yield of the dryland treatments declined compared with the fully irrigated pasture (Penman 1971).

Results were analysed (GenStat 8.2) using the repeated measure technique. Temperature adjusted growth rates were derived by regression, through the origin, of accumulated DM against accumulated thermal time. The critical limiting soil water deficit, specific to this soil/pasture combination, was determined by broken stick models for dryland data. The annual and seasonal yields of +N and –N treatments differed. Therefore, the relative yield for the two dryland treatments had to be determined separately with 1) I+N used as the potential for the D+N treatment and 2) I-N used as the water non limited maximum for the D-N treatment. The temperature adjusted growth rates (kg DM/°Cd) of dryland pastures were compared with irrigated pastures by ANOVA of slopes against thermal time for pre- and post water stress periods across all treatments.

Results

There was a three way interaction ($P \leq 0.05$) between irrigation, nitrogen and year (I*N*Y) for total annual DM yield (Table 1). Total treatment yields were similar between years for the I+N, I-N and D+N pastures. However, D-N treatments produced more DM in 2003/

04 than in 2004/05. There was an N*Y interaction ($P \leq 0.001$) which resulted from a 30% increase in annual CP yield (t CP/ha) between 2003/04 and 2004/05 from +N pastures but no increase in –N treatments. Annual ME yield was also affected by an N*Y interaction ($P \leq 0.01$) with similar values for the –N pastures in 2003/04 and 2004/05 but a 7% increase for +N pastures between 2003/04 and 2004/05. Over the 2 years, ME of green cocksfoot herbage ranged from 10.2 - 12.4 MJ ME/kg DM.

Mean daily growth rates of I+N pastures increased from a minimum of 10 kg DM/ha/d in winter to >100 kg DM/ha/d in summer in both years (Fig. 1). The I-N pastures also showed the lowest growth rates in winter but maximum growth rates occurred earlier in the growing season and were at least 50% less than those of the I+N pastures. There were I*N interactions observed in summer caused by decreased growth rates in dryland pastures.

To explain the seasonal variations in pasture growth rates the effect of temperature was summarised (Fig. 2) through accumulated thermal time (Moot *et al.* 2000). The temperature adjusted growth rate of the I+N pastures increased ($P \leq 0.001$) at 7.2 kg DM/°Cd above the base temperature. For I-N pastures the rate was 3.2 kg DM/°Cd or 56% lower than that of I+N pastures. For both treatments there was an indication of systematic variation around the regression which suggested an overestimation of DM production in autumn/winter and underestimated production in spring/summer.

The difference between temperature adjusted growth rates of I+N and I-N pastures was quantified by the ratio between actual N% and optimum N content (Lemaire *et al.* 1989). The –N pastures were consistently N deficient, with about 50% of the N content of fertilised treatments, and D+N pastures were N deficient in summer.

Table 1 Total annual dry matter (DM) production, annual % dead material, crude protein (CP) yield (t/ha/yr) and annual metabolisable energy (ME) yield (GJ/ha) of a 'Wana' cocksfoot monoculture grown at Lincoln University, Canterbury, New Zealand in 2003/04 and 2004/05.

Year (Y)	Treatment	Total DM (t/ha)	Annual CP (t/ha)	Annual ME (MJ/ha*10 ³)
2003/04	I+N	22.6	3.7	202
	I-N	10.5	1.2	91
	D+N	15.1	2.7	143
	D-N	7.5	0.6	53
2004/05	I+N	21.2	4.7	204
	I-N	9.1	1.3	86
	D+N	16.4	3.8	161
	D-N	5.0	0.6	45
	Effect	I*N*Y	N*Y	N*Y
	Significance	*	***	**
	LSD ($P \leq 0.05$)	1.8	0.2	10.0

Note: Levels of significance are: 0.05 (*), 0.01 (**), and 0.001 (***).

Figure 1 Daily growth rates of 'Wana' cocksfoot monocultures under I+N (●), I-N (○), D+N (▼) and D-N (▽) treatments. Error bars are maximum SEM for any sampling date for (a) I effects, (b) N effects or (c) I*N interactions.

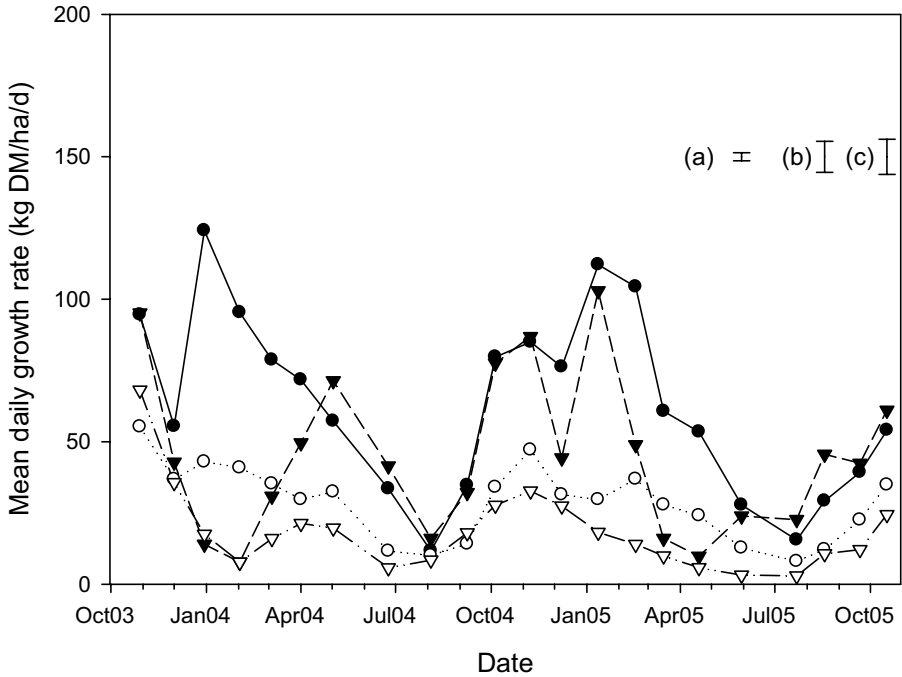


Figure 2 Dry matter (DM) accumulation in 2003/04 (closed symbols) and 2004/05 (open symbols) of I+N (●,○) and I-N (▼,▽) pastures against accumulated thermal time (Tt) with a base temperature of 3°C for a 'Wana' cocksfoot monoculture at Lincoln University, Canterbury New Zealand. Regression of I+N is $y = 7.2 \pm SE 0.1x$ ($R^2 = 0.97$) and I-N is $y = 3.2 \pm SE 0.1x$ ($R^2 = 0.95$) with standard error of the slope is given for each regression. Arrows indicate the range over which the pasture contained reproductive tillers and corresponds to calendar days between 1 December and 15 January.

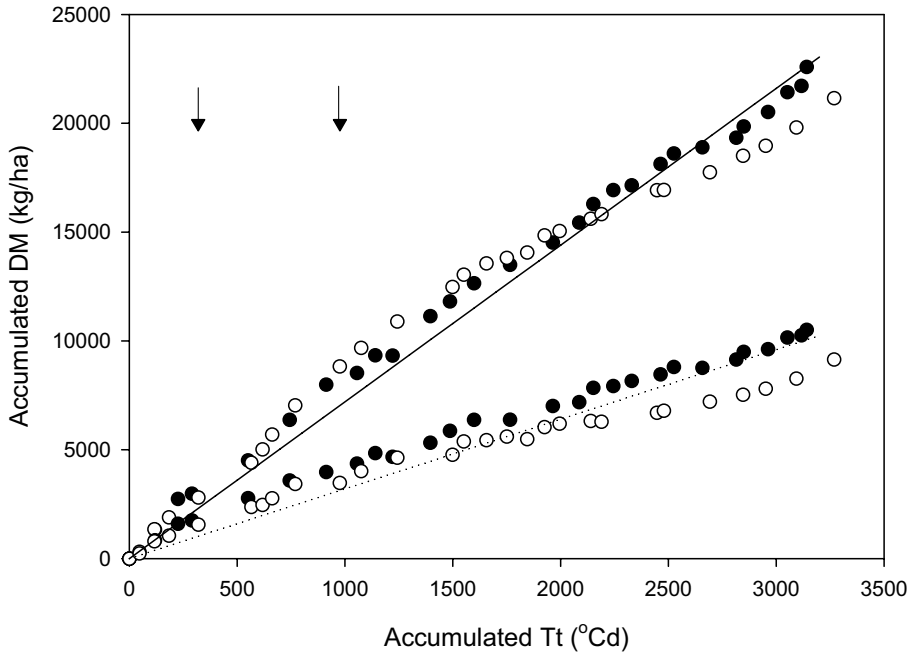
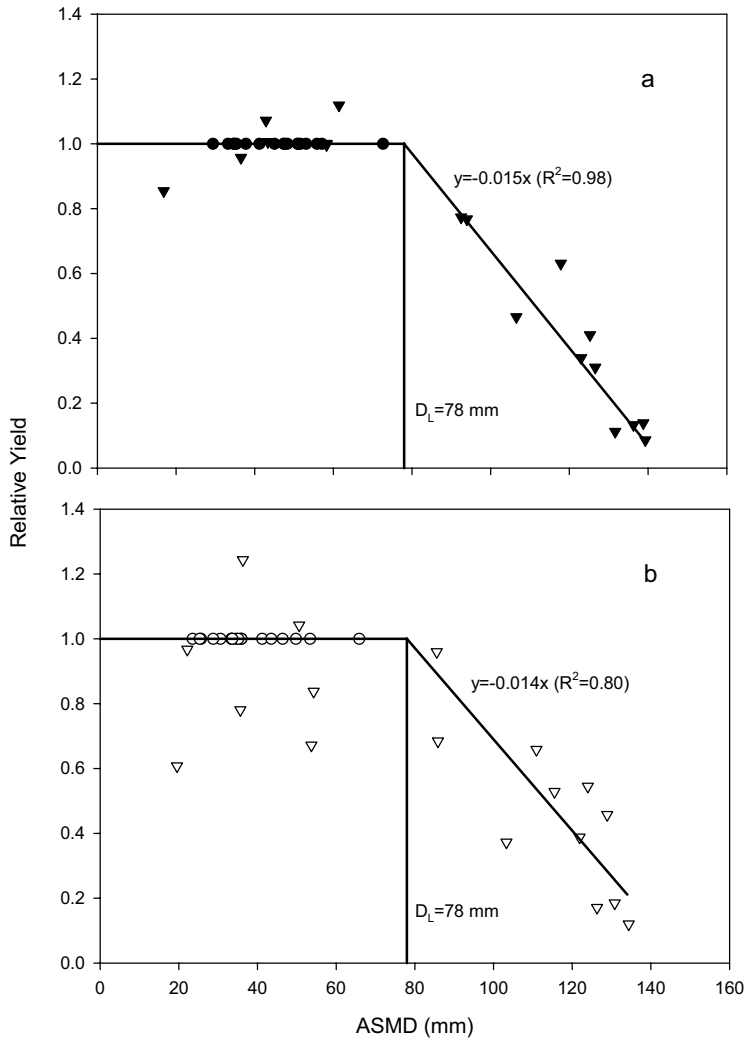


Figure 3 Decrease in relative yield of (a) D+N (▼) relative to I+N (●) and (b) D-N (▽) relative to I-N (○) for 'Wana' cocksfoot pasture at Lincoln University, Canterbury, New Zealand during periods when the actual soil moisture deficit was increasing.



The actual soil moisture deficit (0-0.8 m) reached a maximum of ~140 mm in 2003/04 and ~130 mm in 2004/05. The critical limiting deficit was averaged across treatments to 78 mm with the rate of reduction in relative yield constant at 1.45%/mm. Thus, despite a 2 month difference in the timing of maximum actual soil moisture deficit between years, the critical limiting deficit was comparable and the response of DM production when this was exceeded was similar.

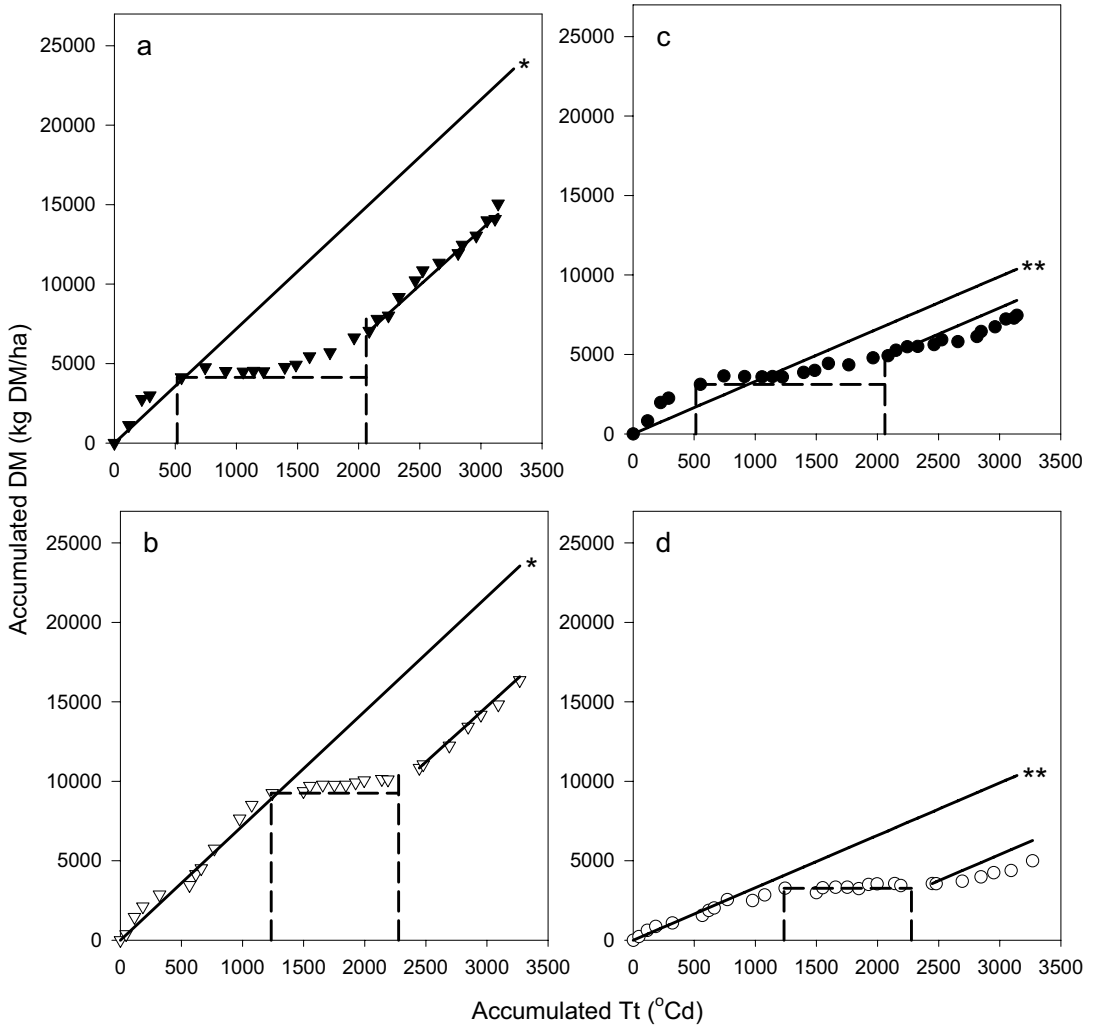
Discussion

The maximum yield attained within this environment was 22.0 t DM/ha (Table 1). When no N was applied (I-N) yields were less than 50% of this potential. Dryland pastures supplied with non limiting N

produced 72% of the yield of the I+N pasture showing the major impact of N availability on cocksfoot production. This confirms previous work which showed N, rather than water, was the factor most limiting cocksfoot production (Peri *et al.* 2002a). When no irrigation or N were applied, yields were only 25% of the environmental potential and similar to previous results (Stevens *et al.* 1992). In addition, N was the main factor influencing pasture quality parameters (Table 1). Reports of low cocksfoot pasture quality and associated poor preference (Edwards *et al.* 1993) may reflect increased proportions of senesced and/or diseased leaf material of low N content relative to total DM.

To extrapolate results to other environments, the relationship between pasture production and the main

Figure 4 Dry matter production of D+N pastures in (a) 2003/04 and (b) 2004/05 and D-N pastures in (c) 2003/04 and (d) 2004/05. Solid lines shown by * and ** represent temperature adjusted growth rates of I+N ($y = 7.2x$) and I-N ($y = 3.2x$) as shown in Figure 2. Dashed vertical lines represent the period during which the critical limiting deficit (78 mm) was exceeded by dryland pastures. Temperature adjusted growth rates of dryland pastures, excluding the drought period, were 7.0 and 3.3 kg DM/°Cd for D+N and D+N pastures, respectively.



environmental drivers were derived. The seasonal variation in growth rates was accounted for using thermal time, where the I+N pasture had a temperature adjusted growth rate double that of I-N pastures (Fig. 2). Thus, at any given temperature, when moisture was non-limiting, the I+N pastures produced DM at twice the rate of the I-N or control pastures. The difference between temperature adjusted growth rates of I+N and I-N pastures was due to N content. Leaf N concentrations between 4.0-5.9% do not limit photosynthesis whereas it is almost halved when leaf N is between 1.5-4.0% (Peri 2002) as found in the -N pastures.

The effect of water stress for D+N and D-N pastures was examined separately. Beyond the critical limiting deficit of 78 mm, relative yield decreased at a constant rate of 1.45%/mm (Fig. 3). Therefore, at any given actual soil moisture deficit, the extent of yield reductions below potential can be quantified. For example, at an actual soil moisture deficit of 100 mm yield would be 32% below potential. In 2003/04, the D+N pastures were water stressed during the period between 465-2062 °Cd (Fig. 4). This corresponded to the calendar dates of 21/11/2003-30/3/2004. In D-N pastures, water stress compromised DM production between 515 to 2062 °Cd, or from 1/12/2003 to 30/3/2004. In 2004/05,

December 2004 rainfall caused two separate periods of water stress. The first occurred between 320–550°Cd (8/11/2004–1/12/2004) and the second occurred between 1243–2278°Cd (31/1/2005–1/5/2005).

Based on the known periods of water stress, the potential yield loss due to insufficient water was estimated, from temperature adjusted growth rates, to be 11.5 and 9.1 t/ha for D+N pastures compared with 4.9 and 4.0 t/ha for D-N pastures in 2003/04 and 2004/05. Rainfall during the deficit period is available for growth even if it does not appear to increase the actual soil moisture deficit to <78 mm. As a result DM produced within the deficit period was subtracted from the estimated yield loss. This decreased the variation between estimated and actual yields to within 1% for D+N pastures and within 4–12% of measured DM yield for D-N pastures.

Data were then reanalysed by ANOVA to compare temperature adjusted growth rates of all pastures during periods when water was not the main limitation to DM production (Fig. 4). These results showed N deficiency caused ($P \leq 0.001$) the main differences in the temperature adjusted growth rates. The +N pastures produced 7.0 kg DM/°Cd compared with 3.3 kg DM/°Cd for –N pastures. These values show that the rate of DM accumulation prior to reaching the critical limiting deficit, and then after rainfall alleviated water stress, were comparable to those calculated under non limiting moisture conditions for the I+N and I–N pastures (Fig. 2).

If there is no water for growth, regardless of pasture species, no growth will occur. The main objective in a dryland system regularly subjected to summer water stress is to ensure the sown pasture can persist through, and recover after, experiencing drought conditions. This study confirms the importance of cocksfoot in summer dry regions and shows that yield can be improved by increased N fertility. The rates of N applied in this study are not recommended for commercial use. It is important to identify a legume which can survive and persist in a mixture with cocksfoot to alleviate the main yield constraint of N deficiency and the associated reduction in pasture quality (Lee and Cho 1985; Moloney 1991; Edwards *et al.* 1993).

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