Chicory (*Cichorium intybus* L.) can beat the heat during summer drought in southeast Australian dairying regions

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Abstract

Perennial ryegrass (*Lolium perenne* L.) is the major sown pasture species in southeast Australian dairying regions. Ryegrass is not only intolerant of soil moisture deficits, but heat waves, which increasingly present a challenge to summer home-grown feed production. To address this challenge, a screening experiment was undertaken to identify temperate perennial forage species, better adapted to combined heat wave stress and soil moisture deficits. Responses of ten perennial forages to optimal and heat wave temperature regimes (day/night ambient temperatures of 23/15˚C and 38/26˚C) were evaluated under greenhouse conditions. The effect of moisture availability (optimal watering or no water) and the recovery capacity of plants grown in optimal conditions (day/night ambient temperature regime of 23/16˚C; optimal watering) for 18 d after stress periods ceased, were also examined. Chicory (*Cichorium intybus* L., cv. Grasslands Puna) had a superior tolerance to heat stress and moisture deficit compared with ryegrass cv. Samson. Chicory not only maintained live above-ground tissue after exposure to the combined stress for 18 d, but increased in yield by 46% during the recovery period. In contrast at 12 d, live tissue was not detectable in the ryegrass, with yield measurements indicating plants unable to recover. Results suggest that under dryland conditions, chicory may enable a greater level of home-grown feed production to resume following an extended heat wave, than possible with ryegrass.

Key words

Heatwave, high temperature, water stress, climate change, grazing, dry matter

Introduction

Dairying in temperate southeast (SE) Australia has remained economically viable, despite declining terms of trade. This is due to the competitive advantage of favourable climatic conditions for growing low-cost home-grown feed (Chapman et al, 2011). Heat waves increasingly challenge this advantage, and often coincide with summer soil moisture deficits. Two of the regions' most severe heat waves in the last century have occurred since 2009 (BOM, 2014). During the January 2009 heat wave, daily ambient temperatures (Ta) exceeded 35-40˚C on three or more consecutive days, at locations typical of the key Victorian dairying districts (East Sale, Kerang, and Warrnambool). Heat waves are forecast to increase in frequency, duration, and intensity during the 21st century (Parker et al, 2014). In Tasmania the frequency of heat waves is projected to increase in the Midlands and Derwent Valley (White et al, 2010); two regions currently experiencing expansion in dairying.

Southeast Australian dairy farming systems are particularly vulnerable, due to 60-70% of the dairy cow's diet being derived from perennial ryegrass (*Lolium perenne* L.) (Chapman et al, 2008). Without moisture, stress shoot growth inhibition of ryegrass occurs at an Ta of 35˚C (Mitchell, 1956), with detrimental high temperatures effects exacerbated by soil moisture deficits (Jiang & Huang, 2001). Summer-active perennial forage species capable of withstanding not only heat wave conditions, but soil moisture deficits are consequently needed. However, there is a paucity of information regarding the heat tolerance of perennial forages. To address this need, the tolerance of a range of species to heat wave conditions with and without irrigation was assessed. Tolerance was defined as a species' ability to support high growth rates during or shortly after the cessation of stress. Only temperate grazeable perennial species were considered in this study, due to their less frequent re-establishment requirements relative to annuals, and suitability to grazing systems.

Methods

Ten species were evaluated, but for the purposes of this paper only key ryegrass cv. Samson and chicory (*Cichorium intybus* L., cv. Grasslands Puna) results are presented. This study was undertaken in two independent chambers, within a greenhouse facility. Plants were established for 255 d, during which defoliations were undertaken at regular intervals. Treatments were imposed in a randomised split-plot design, with the combination of block and temperature regime the main-plot, stress durations assigned to subplots, and the combinations of species, moisture availability and recovery time randomly distributed within subplots. Temperature regimes (14/10 h day/night) consisted of an optimal and heat wave (day/night Ta of 23/15˚C or 38/26˚C) treatment; with temperature regimes maintained for 6, 12, or 18 d stress durations. Each chamber contained only one main-plot at any time; to minimise pseudoreplication main-plots were rotated between chambers at 3 d intervals, so that each main-plot by stress duration spent equal time in both chambers. Moisture levels were optimal watering (daily to through drainage) or no water. The combination of an optimal temperature regime and irrigation is here on referred to as the control treatment. At the conclusion of a stress period, plants were harvested or returned to an optimal temperature (day/night Ta, 23/16˚C) and watering regime for 18 d. At the end of each stress duration by recovery period treatment, herbage above 50 mm was harvested, dried for at least 48 h at 60˚C, and weighed. Maximal photochemical efficiency of photosystem II (PSII; F_v/F_m) was measured on dark adapted plants at the end of each stress period, using an OS-30p Chlorophyll Fluorometer (Opti-Sciences, Hudson, NH, USA).

Data was analysed as a split plot design. Quantile-quantile plots of residuals were examined, with transformations required for yield (square root) and F_v/F_m $[(F_v/F_m)/(1-F_v/F_m)]$ data. Yield data from the final establishment defoliation was included as a covariate in the yield analysis. Data were analysed using the PROC MIXED procedure of SAS 9.3, with comparisons of means using appropriately constructed contrasts. Associated P values were adjusted using PROC PLM (Edwards & Berry, 1987). All estimated mean and standard error values presented have been back-transformed. Differences discussed were significant at the $P < 0.05$ level.

Results

Both species recovered from water deprivation, regardless of stress duration (Table 1). Ryegrass was unable to recover from the combined stress of heat wave temperatures and water deprivation, when applied for 12 and 18 d. In contrast chicory recovered from both durations of the combined stress, yielding 57% and 23% of that attained by their control treatment contemporaries (Figure 1; Table 1). During the recovery period the yield of chicory exposed to the combined stress for 12 and 18 d increased by 180% and 46%, respectively.

Figure 1. Perennial ryegrass (*Lolium perenne* L.; Left) and chicory (*Cichorium intybus* L.; Right) after an 18 d recovery period from 18 d of heat wave stress and water deprivation.

Yields of each species at the end of each stress period were unaffected by duration, when exposed to water deprivation and either optimal or heat wave temperatures (Table 1). No yield differences were observed between these treatments, for each species, at each stress duration (Table 1). Ryegrass exposed to heat wave temperatures and water deprivation for 12 and 18 d had lower F_v/F_m levels than their control treatment contemporaries. Under irrigation neither the yield nor F_v/F_m of each species differed between temperature treatments, at the end of each stress period (Table 1).

Table 1. Ryegrass and chicory F_v/F_m and dry matter production when exposed to contrasting temperature regimes (*O* = Optimal, *H* = Heat wave) and moisture availability levels (*Irr* = optimal watering, *Dry* = no water) for different durations, with and without a recovery period (denoted, *R0* and *R18*). Values are back-transformed means ± 1 SE.

Species	Main-plot	Recovery	Stress Duration		
			Short (6 d)	**Medium (12 d)**	**Long (18 d)**
			F_v/F_m (arb. units)		
Perennial Ryegrass	*OIrr*	*R0*	$0.833 \pm 0.007^{\mathrm{Aa}}$	$0.830 \pm 0.008^{\mathrm{Aa}}$	$0.828 \pm 0.008^{\mathrm{Aa}}$
	ODry	*R0*	$0.831 \pm 0.008^{\mathrm{Aa}}$	$0.806 \pm 0.010^{\mathrm{Aa}}$	$0.048 \pm 0.240^{\mathrm{Bb}}$
	HIrr	*R0*	$0.823 \pm 0.008^{\mathrm{Aa}}$	$0.818 \pm 0.010^{\mathrm{Aa}}$	$0.806 \pm 0.010^{\mathrm{Aa}}$
	HDry	*R0*	$0.805 \pm 0.010^{\mathrm{Aa}}$	$0.017 \pm 0.256^{\mathrm{Bb}}$	$0.025 \pm 0.252^{\mathrm{Bb}}$
Chicory	*OIrr*	*R0*	$0.841 \pm 0.007^{\mathrm{Aa}}$	$0.840 \pm 0.007^{\mathrm{Aab}}$	$0.838 \pm 0.007^{\mathrm{Aab}}$
	ODry	*R0*	$0.842 \pm 0.007^{\mathrm{Aa}}$	$0.849 \pm 0.006^{\mathrm{Aab}}$	$0.851 \pm 0.006^{\mathrm{Aa}}$
	HIrr	*R0*	$0.842 \pm 0.007^{\mathrm{Aa}}$	$0.855 \pm 0.006^{\mathrm{Aa}}$	$0.853 \pm 0.006^{\mathrm{Aa}}$
	HDry	*R0*	$0.842 \pm 0.007^{\mathrm{Aa}}$	$0.819 \pm 0.009^{\mathrm{Ab}}$	$0.801 \pm 0.010^{\mathrm{Ab}}$
				Dry matter (g/pot)	
Perennial Ryegrass	*OIrr*	*R0*	$5.87 \pm 0.04^{\mathrm{Ba}\underline{\mathrm{b}}}$	$10.95 \pm 0.04^{\mathrm{Aa}\underline{\mathrm{b}}}$	$12.38 \pm 0.03^{\mathrm{Aa}\underline{\mathrm{b}}}$
		R18	$15.59 \pm 0.03^{\mathrm{Bab}\underline{\mathrm{a}}}$	$20.73 \pm 0.03^{\mathrm{ABa}\underline{\mathrm{a}}}$	$24.85 \pm 0.03^{\mathrm{Aa}\underline{\mathrm{a}}}$
	ODry	*R0*	$5.17 \pm 0.04^{\mathrm{Aa}\underline{\mathrm{b}}}$	$5.00 \pm 0.04^{\mathrm{Abc}\underline{\mathrm{b}}}$	$5.35 \pm 0.04^{\mathrm{Ab}\underline{\mathrm{b}}}$
		R18	$13.58 \pm 0.03^{\mathrm{Aab}\underline{\mathrm{a}}}$	$13.11 \pm \mathbf{0.03}^{\mathrm{ABb}\underline{\mathrm{a}}}$	$9.31 \pm 0.04^{\mathrm{Bb}\underline{\mathrm{a}}}$
	HIrr	*R0*	$5.10 \pm 0.04^{\mathrm{Ba}\underline{\mathrm{b}}}$	$7.04 \pm 0.04^{\mathrm{ABab}\underline{\mathrm{b}}}$	$9.17 \pm 0.04^{\mathrm{Aa}\underline{\mathrm{b}}}$
		R18	$17.47 \pm 0.03^{\mathrm{Aa}\underline{\mathrm{a}}}$	$17.57 \pm 0.03^{\mathrm{Aab}\underline{\mathrm{a}}}$	$22.36 \pm 0.03^{\mathrm{Aa}\underline{\mathrm{a}}}$
	HDry	*R0*	$4.03 \pm 0.04^{\mathrm{Aa}\underline{\mathrm{b}}}$	$3.29 \pm 0.05^{\mathrm{Ac}\underline{\mathrm{a}}}$	$3.16 \pm 0.05^{\mathrm{Ab}\underline{\mathrm{a}}}$
		R18	$11.92 \pm 0.03^{\mathrm{Ab}\underline{\mathrm{a}}}$	$4.05 \pm 0.04^{\mathrm{Bc}\underline{\mathrm{a}}}$	$3.18 \pm 0.05^{\mathrm{Bc}\underline{\mathrm{a}}}$
Chicory	*OIrr*	*R0*	$4.17 \pm 0.04^{\mathrm{Ba}\underline{\mathrm{b}}}$	$6.47 \pm 0.04^{\mathrm{ABa}\underline{\mathrm{b}}}$	$9.91 \pm 0.04^{\mathrm{Aa}\underline{\mathrm{b}}}$
		R18	$11.54 \pm 0.03^{\mathrm{Bab}\underline{\mathrm{a}}}$	$12.67 \pm 0.03^{\mathrm{Ba}\underline{\mathrm{a}}}$	$18.12 \pm 0.03^{\mathrm{Aa}\underline{\mathrm{a}}}$
	ODry	*R0*	$3.31 \pm 0.05^{\mathrm{Aa}\underline{\mathrm{b}}}$	$3.91 \pm 0.05^{\mathrm{Aab}\underline{\mathrm{b}}}$	$3.91 \pm 0.05^{\mathrm{Ab}\underline{\mathrm{b}}}$
		R18	$8.95 \pm 0.04^{\mathrm{Ab}\underline{\mathrm{a}}}$	$11.12 \pm 0.04^{\mathrm{Aab}\underline{\mathrm{a}}}$	$9.65 \pm 0.04^{\mathrm{Ab}\underline{\mathrm{a}}}$
	HIrr	*R0*	$4.37 \pm 0.06^{\mathrm{Ba}\underline{\mathrm{b}}}$	$6.42 \pm 0.04^{\mathrm{ABa}\underline{\mathrm{b}}}$	$9.10 \pm 0.04^{\mathrm{Aa}\underline{\mathrm{b}}}$
		R18	$15.62 \pm 0.04^{\mathrm{Aa}\underline{\mathrm{a}}}$	$14.56 \pm 0.03^{\mathrm{Aa}\underline{\mathrm{a}}}$	$16.13 \pm 0.03^{\mathrm{Aa}\underline{\mathrm{a}}}$
	HDry	*R0*	$3.18 \pm 0.05^{\mathrm{Aa}\underline{\mathrm{b}}}$	$2.59 \pm 0.05^{\mathrm{Ab}\underline{\mathrm{b}}}$	$2.85 \pm 0.05^{\mathrm{Ab}\underline{\mathrm{b}}}$
		R18	$8.46 \pm 0.04^{\mathrm{Ab}\underline{\mathrm{a}}}$	$7.24 \pm 0.04^{\mathrm{Ab}\underline{\mathrm{a}}}$	$4.15 \pm 0.04^{\mathrm{Bc}\underline{\mathrm{a}}}$

Values followed by the same letters do not differ ($P < 0.05$); upper-case letters compare species across stress durations within main-plot by recovery period treatments; lower-case letters compare between main-plots (*OIrr* vs. *ODry* vs. *HIrr* vs. *HDry*) within each stress duration for each species by recovery period combination; lower-case underlined letters compare between recovery periods (*R0* vs. *R18*) within stress durations for each species by main-plot combination.

Discussion/Conclusion

Neither species grew after the first 6 d of heat wave temperature and moisture deficit stress. Chicory unlike ryegrass recovered, evidenced by yield increases of 180% and 46% over the recovery period from 12 and 18 d of the combined stress, respectively. After recovery from 12 and 18 d of the combined stress, chicory yielded 57% and 23% of their control treatment contemporaries. Explanation is provided by the high photochemical efficiency of PSII in the youngest fully-emerged chicory leaves during the stress period, indicating that the combined stress had minimal effect on the photosynthetic capacity (Jiang & Huang, 2001). Despite senescence being observed in older leaves, the maintenance of some leaves with undamaged photosynthetic apparatus would support the recovery growth seen in chicory, when returned to optimal conditions. In contrast ryegrass exposed to the combined stress for 12 and 18 d had very low F_v/F_m levels (0.017-0.025), attributed to widespread above-ground tissue senescence. It is suggested that whole-plant death occurred, given the inability of ryegrass to recover.

The combined stress also had a greater effect than either stress in isolation, as temperature had no effect on the yield and F_v/F_m of either species under irrigated conditions. Furthermore, both species recovered from moisture deficit in isolation, regardless of duration. Interestingly, heat wave temperatures had no additional impact on the yield of either species during the stress period, when subject to water deprivation. This is because neither species grew after the first 6 d of water deprivation, regardless of temperature. It is concluded the survival capacity of chicory during extended periods of the combined stress underlies the superior tolerance of this species, enabling the resumption of production on return to optimal conditions, not possible with ryegrass. Chicory could potentially be used to mitigate the detrimental impacts of these stresses on dryland systems. This is particularly important, due to the regular occurrence of soil moisture deficits and increasing frequency of heat waves in SE Australia (Neal et al, 2009; Parker et al, 2014). Despite the low likelihood of comparable heat waves temperatures occurring for ≥ 12 d in SE Australia during the short-term (BOM, 2014), such conditions would be expected to more rapidly effect the survival of ryegrass already experiencing soil moisture deficits. A possible explanation is provided by the high moisture content of the potting media at the commencement of treatments, meaning that moisture deficits developed progressively. Declines in moisture content would have reduced the capacity of plants to mitigate heat stress via transpirational cooling.

The finding that the yield and F_v/F_m of irrigated plants was independent of temperature treatment, suggests that irrigation may be used as a management strategy to alleviate detrimental high temperature effects. However, this finding contrasts with previous studies reporting reductions in ryegrass growth at temperatures above 29.4˚C, and F_v/F_m level after 6 d of comparable heat stress (Mitchell, 1956; Jiang & Huang, 2001). A possible explanation for this discrepancy is the large pot volume used, which may have contained sufficient moisture to support evaporative cooling throughout the day.

In conclusion the key finding of this study was the ability of chicory to recover from combined heat stress and moisture deficit, when applied for 12 and 18 d. These conditions caused ryegrass to senesce. Future research will confirm these findings under field conditions, and elucidate the mechanisms underlying chicory's tolerance to combined heat stress and moisture deficit. Potential irrigation strategies for mitigating heat stress in existing ryegrass pastures will also be investigated.

Acknowledgements

The authors gratefully acknowledge the financial support of the CSIRO and Dairy Australia; advice and seed provided by PGG Wrightson Seeds, Heritage Seeds, Stephen Pasture Seeds, and the TIA Herbage Development Program; and assistance of Mr. Steven Boon, Mr. Jake Eyles, Mr. Gordon Grundy, Mr. David McLaren, Mr. Philip Murphy, and Ms. Susan Walker. Mr. Adam Langworthy's stipend was provided by a Cuthbertson Elite Tasmanian Graduate Research Scholarship.

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