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Production and persistence of Mediterranean perennial grasses under contrasting climatic scenarios

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Abstract. In the current context of increasing droughts due to climate change, this study analyzed the effects of a range of severe summer water deficits (-329 to -710 mm) and summer high temperatures (+3 and +6°C than ambient temperatures for 2-3 weeks) on the persistence and production of perennial forage grasses. We compared a Mediterranean cultivar (cv) of cocksfoot (*Dactylis glomerata* L., cv Medly) and of tall fescue (*Festuca arundinacea* Schreb, cv. Centurion), in both a Mediterranean and a temperate site in France. The results show that (1) the annual production was variable but reduced on average by 40% along the range of tested water deficits; (2) the thresholds of significant increased mortality occurred at around 560 mm of water deficit; (3) deeper water uptake can be associated with the greater persistence of tall fescue at high water deficit and (4) an after-effect of summer water deficits resulted in an increase of frost sensitivity especially for cocksfoot. To cope with climate change, breeding programs for Mediterranean cultivars should aim to improve both frost tolerance and drought survival through increased summer dormancy.

Keywords. Climate change – Summer drought – Grassland – Stress survival – Plant mortality.

Production et pérennité de graminées pérennes sous sécheresses et hautes températures estivales

Résumé. *Sécheresse et évènements climatiques extrêmes risquent de survenir plus fréquemment sous l'influence du changement climatique. Nous avons testé une gamme de déficits hydriques estivaux (-329 à -710 mm) et des températures estivales élevées (+3°C and +6°C que la température ambiante pour 2-3 semaines) sur la persistence et la production de graminées fourragères pérennes. Un cultivar méditerranéen de dactyle* (Dactylis glomerata *L., cv Medly) et de fétuque élevée* (Festuca arundinacea *Schreb. cv Centurion) ont été comparés dans un site méditerranéen et un site tempéré en France. Les résultats montrent que (1) sur la gamme de traitements testés, la production annuelle a été variable mais réduite en moyenne de 40%, (2) les seuils de déficits hydriques cumulés associés à une augmentation significative de mortalité sont définis autour de -560 mm; (3) Des prélèvements en eau plus profonds peuvent être associés à la meilleure persistence de la fétuque et ; (4) la sensibilité au gel hivernal, surtout du dactyle, augmente quand les plantes ont été soumises à de forts déficits hydriques l'année précédente. Pour faire face au changement climatique, les programmes de sélection végétale de cultivars méditerranéens doivent améliorer la tolérance au gel et la survie à la sécheresse estivale par une dormance estivale supérieure.*

Mots-clés. *Changement climatique – Sécheresse estivale – Prairies – Survie au stress – Mortalité.*

I – Introduction

Although increasing droughts and extreme events are predicted to occur more often under climate change (I.P.C.C., 2007), their effects are currently poorly described by crop and pasture models (Tubiello *et al*., 2007). A decrease in summer precipitation in southern Europe, accompanied by increased temperatures would inevitably lead to more frequent and more intense droughts (Lehner *et al*., 2006) resulting in widespread mortality events. To cope with the nega-

tive effects of climate change, short-term adaptations may include changes of species or cultivars (Olesen *et al*., 2007). As summer aridity will increase, the interest of genotypes and cultivars originating from the Mediterranean basin, may extend to larger areas. We tested the responses of the two major perennial grass species adapted to drought, i.e. cocksfoot *Dactylis glomerata* L. and tall fescue *Festuca arundinacea* Schreb. at both Mediterranean and temperate sites in France. By manipulating temperatures and water availability to grass sward in the field, we aimed to define for each of the tested Mediterranean cultivars, the climatic thresholds associated with critical plant mortality and reduced resilience of these perennial forage crops.

II – Material and methods

We compared mono-cultures of perennial cultivars (cvs) of forage grasses of cocksfoot (cv. Medly) and tall fescue (cv. Centurion), in both a Mediterranean (Montpellier) and a temperate site (Lusignan) with average May-September water deficits of 289 mm and 424 mm respectively.

The temperate (46°4N, 0°1E) site (Temp-site) and the Mediterranean (43°6N, 3°8E) site (Med-site) had both a cambisoil with a depth of 1m and a comparable soil water reserve.

Over 2 years, 14 treatments combining controlled water supply and night temperature (T = +1°C and C = control low) under 6m^2 rainout shelters (throughout both years) + infra-red heating (+3°C or +6°C relatively to the temperatures of the unheated treatments) for three weeks in summer, induced a range of cumulative water deficits (Table 1). They were computed for the periods during which soil water was depleted (May to September). The main effects of heat stress were ascribed to increased soil water deficit (Poirier *et al*., 2012). Soil moisture was measured regularly with a neutron probe in all un-heated treatments in summer. Each treatment was replicated four times.

Table 1. Cumulative Precipitation-Evapotranspiration (P-ETP) from May to September for the 14 climatic treatments over two sites in France

	Temperate site (8 climatic treatments)								**Mediterranean site (6 climatic treatments)**					
Year	**2009**				**2009**				**2009**				**2010**	
Treat.	T	T + 3°C	C	C + 6°C	T	T + 3°C	C	C + 6°C	T	T + 3°C	C	C + 6°C	T	C
|P-ETP|	329	412	445	488	433	485	536	553	436	484	545	584	624	707

Above-ground biomass was cut when required and oven dried to assess dry biomass. The density of living plants was assessed visually after each cut and after autumn rehydration by assigning a score (0-100%) to the percentage cover by plants in each sward. Autumn survival rates after summer treatments were calculated as the ratio between the density rate of living tillers in the autumn versus the density rate of living tillers in the previous spring. Similarly, survival rates after winter frost were calculated as the ratio between the density rate of living tillers in the spring versus the density rate of living tillers in the previous autumn.

For analysis of variance, climatic treatments and cultivars were considered as fixed effects, whereas replications were considered to be random effects.

III – Results

1. Water use

The minimum soil water content at the end of the summer reached 220 mm on average for both species in Med-site whatever the treatments. Conversely, it reached significantly lower levels for tall fescue (230 mm) than for cocksfoot (249 mm) across all un-heated treatments in Temp-site.

2. Aboveground biomass production

Between 329 mm and 707 mm summer climatic deficit, the annual biomass production was reduced on average by 40% for tall fescue “Centurion”. The production of cocksfoot “Medly” was as variable but less affected by the greatest summer climatic deficits (Fig. 1a).

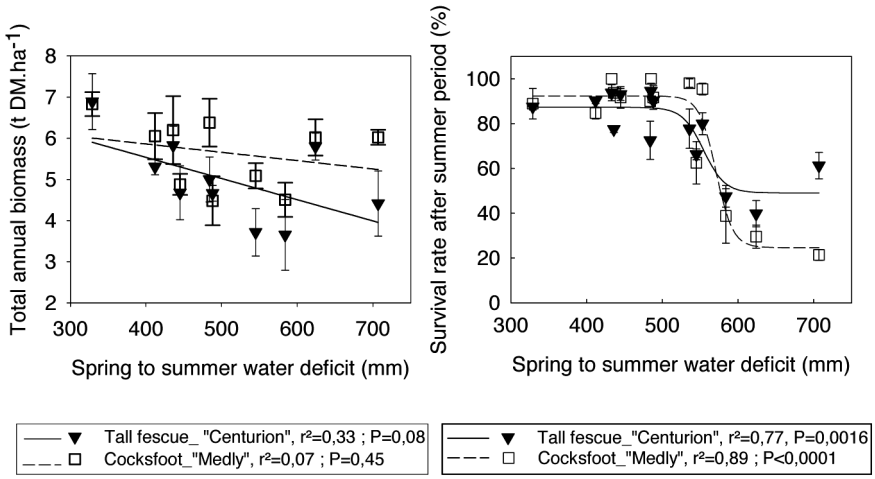


Fig. 1. (a) Total annual biomass (t DM ha^{-1}) and (b) Summer survival rates (%) of tall fescue “Centurion” and cocksfoot “Medly”, under a range of water deficit from April to September (mm).

Summer survival rates were greater than 80% for both species when the maximum climatic water deficit was lower than -550 mm (Fig. 1b). 50% plant survival occurred at a water deficit of -554 mm for tall fescue “Centurion” and -571 mm for cocksfoot “Medly”. At higher deficits, plant survival rates declined drastically especially for cocksfoot “Medly” that reached 20% survival at -700 mm deficit. Tall fescue “Centurion” displayed a lower plant mortality (50%) at high aridity when it could maintain higher hydration in surviving organs (not shown). Following the autumn recovery, both cultivars displayed active tillering in the subsequent seasons and the spring density rates was greater than 60% in all treatments.

3. Frost survival

In the 2009 winter, the number of degrees-days lower than -0.5°C was twice as many at Temp-site (-1882°C) than at Med-site (-914°C). Frost damage induced tiller mortality and was greater when plants (especially “Medly”) had been subjected to high water deficits in the previous year. Spring survival following winter frost was decreased by 25% for fescue “Centurion” and up to 40% for cocksfoot “Medly” in Temp-Site (Fig. 2). At Med-Site, the trends of these effects were similar but less marked and spring tiller survival was unaffected (not shown).

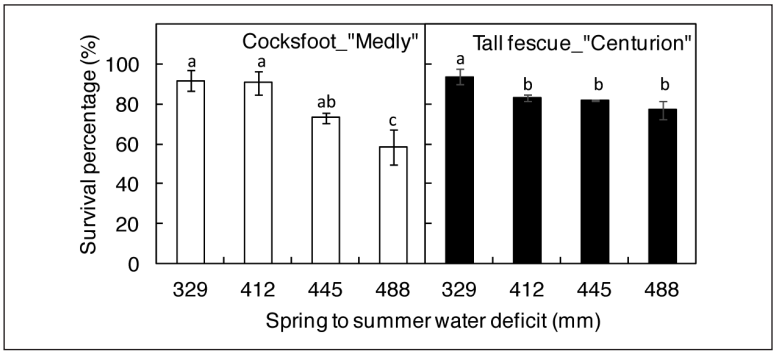


Fig. 2. Plant survival to frost (%) in cocksfoot "Medly" and tall fescue "Centurion" under a range of water deficit from April to September (mm) in the previous year. Significant differences between treatments are indicated by distinct letters a, b, c.

IV – Discussion and conclusions

We analysed the effects of a broad range of climatic treatments and extreme events that even exceed the worst cases projected by IPCC. The adaptation of tall fescue and cocksfoot cultivars had also previously been modelled appropriately as a function of spring-summer drought stress intensities at different sites across the Mediterranean basin (Annicchiarico *et al*., 2011; Pecetti *et al*., 2011). Our results show that a spring to summer- water deficit greater than -560 mm is a critical threshold for the persistence of the most Mediterranean cultivars of cocksfoot and tall fescue. Deeper water uptake and incomplete summer dormancy can be associated with the greater drought survival of tall fescue at -700 mm water deficit. The limited winter hardiness of this material questions the substantial northward expansion of their thermal suitability in Europe (Olesen *et al*., 2007), because the use of Mediterranean forage grass cultivars may well improve crop persistence under summer drought but increase the risk of frost susceptibility to the spells of extremes winter temperatures that can occur in temperate areas. To cope with climate change, breeding programs for Mediterranean cultivars should aim to improve both frost tolerance and drought survival through increased summer dormancy.

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