Important differences in yield responses to simulated drought among four species and across three sites

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Abstract

Summer droughts are predicted to increase in frequency due to climate change. We evaluated drought resistance in intensively managed grassland by using four model species (*Lolium perenne* L., *Cichorium intybus* L., *Trifolium repens* L., *Trifolium pratense* L.). The species represented different functional types, these being defined as a combination of traits related to symbiotic dinitrogen (N_2) fixation and rooting depth. A summer drought period of ten weeks with complete exclusion of precipitation was simulated in a common field experiment at three sites (Tänikon CH, Reckenholz CH, Wexford IE). Aboveground biomass production was impaired in the drought treatment at all three sites, the mean reduction (compared to a control) was 30% at Tänikon, 48% at Reckenholz, and 85% at Wexford. Different plant functional types varied in their drought resistance: N_2 fixing species showed only 8% and 28% biomass reduction at Tänikon and Reckenholz, respectively, compared to 51% and 68% for the non-fixing species. At Wexford, however, only the deep-rooted species *C. intybus* was able to counteract drought to some degree (57% biomass reduction compared to 94% reduction for the other three species). This suggests that the three sites exerted a very different degree of drought stress on plants but that cropping N_2 fixing and deep-rooted species can be an important management option under future climate conditions.

Keywords: drought, biomass production, plant functional types, intensive grassland

Introduction

In Central and Southern Europe, summer drought spells are expected to occur more frequently due to climate change (Lehner *et al.*, 2006) and to impair forage production in grassland (Gilgen and Buchmann, 2009). Intensively managed grassland with high yielding forage species can be susceptible to drought and farmers might experience considerable loss of income (Finger *et al.*, 2013). Therefore, the current forage production of intensively managed grassland should be adapted to future climate conditions, which could be achieved by cropping forage species with functional traits that improve drought resistance. Here, we present results from a multi-site drought stress experiment that aimed at studying four plant species from different functional types, these being defined as the factorial combination of traits associated with the method of nitrogen acquisition (N_2 fixing *vs.* non-fixing species) and the spatial pattern of root growth (deep- *vs.* shallow-rooted species). We hypothesized that N_2 fixing and deep-rooted species would have an improved drought resistance compared to non-fixing and shallow-rooted species. We also tested whether drought resistance of the four plant functional types would differ among sites.

Materials and methods

A common field experiment was set up at Tänikon and Reckenholz (northern Switzerland) and Wexford (south-east Ireland). At each site, monoculture plots (3 m × 5 m) of four plant species were established. The species represented the following functional types: a non-fixing, shallow-rooted species (*Lolium perenne* L.), a non-fixing, deep-rooted species (*Cichorium intybus* L.), an N_2 fixing, shallow-rooted species (*Trifolium repens* L.) and an N_2 fixing, deep-rooted species (*Trifolium pratense* L.). A drought treatment was set up by simulating a summer drought period of ten weeks using rainout shelters (3 m × 5.5 m) that led to complete rain exclusion. The control treatment consisted of the actual climatic conditions and each combination of species and treatment was replicated three times per site. Aboveground biomass of the central strip (1.5 m × 5 m) of each plot was harvested six times per year (five at Wexford) at a cutting height of 7 cm (5 cm at Wexford) using a plot harvester. There were two re-growth periods during the drought treatment, and results from the second re-growth period are presented here. Differences in dry matter yield between control and drought treatment as well as among species were tested by analysis of variance (ANOVA).

Results and discussion

The simulated drought reduced aboveground biomass production significantly at all sites ($P <$ 0.001 each, Table 1).

Table 1: Mean (± s.e.) aboveground biomass production (kg DM ha^{-1} $harvest^{-1}$) of each of four forage plant species in second harvest period during simulated drought and the % reduction under drought *vs.* control conditions. Biomass production among species and between drought *vs.* control conditions were tested by ANOVA (ln-transformed). Three replicates per treatment.

	Tänikon CH			Reckenholz CH			Wexford IE		
	Monocultures			Monocultures			Monocultures		
	Control	Drought	%reduction	Control	Drought	%reduction	Control	Drought	%reduction
L. perenne	1355 (±98)	479 (±187)	65	682 (±78)	166 (±47)	75	668 (±146)	96 (±52)	86
C. intybus	1477 (±180)	935 (±78)	37	2062 (±143)	787 (±40)	61	808 (±30)	348 (±183)	57
T. repens	1763 (±34)	1523 (±74)	14	1197 (±129)	789 (±80)	34	1509 (±208)	33 (±19)	98
T. pratense	2841 (±103)	2791 (±150)	2	3232 (±193)	2551 (±259)	21	1013 (±115)	11 (±11)	99
Average			30			48			85

ANOVA

Variable	Df	*F*-value	*P*-value	*F*-value	*P*-value	*F*-value	*P*-value
Species (Sp)	3	29.0	< 0.001	41.7	< 0.001	1.3	0.340
Drought (Dr)	1	18.7	< 0.001	31.1	< 0.001	68.1	< 0.001
Sp x Dr	3	6.3	0.005	8.9	0.006	4.3	0.043

The drought effect was moderate at both Swiss sites but severe at the Irish site. At Tänikon and Reckenholz, drought reduced the average biomass by 30% and 48%, respectively, whereas at Wexford the average reduction was 85%. The four different plant functional types varied in their drought resistance. At the two Swiss sites, aboveground biomass production of the N_2 fixing species *T. repens* and *T. pratense* was clearly less reduced under drought compared to that of the non-fixing species *L. perenne* and *C. intybus* (pooled contrasts: $P = 0.005$ at Tänikon, $P = 0.001$ at Reckenholz). Given the type of nitrogen acquisition (non-fixing or N_2 fixing), the deep-rooted species *C. intybus* and *T. pratense* also tended to be less impaired by drought than the shallow-rooted species *L. perenne* and *T. repens* ($P = 0.061$ at Reckenholz, $P = 0.104$ at Tänikon). However, at Wexford, only *C. intybus*, the species with the deepest roots, was able to counteract drought to some degree (57% biomass reduction) and it performed significantly better than the other three species ($P = 0.020$; contrast of *C. intybus vs.* the other three), which collapsed almost completely due to drought (94% biomass reduction on average).

It might be hypothesized that these differences in pattern of species' responses are related to the big differences in drought severity among sites. Under moderate drought, as at the Swiss sites, the N_2-fixing species have some growth advantage because they have access to N despite restricted uptake from dry soil due to symbiotic N_2 fixation. In contrast, the non-fixing species might suffer from reduced availability of mineral N under drought conditions. Such explanation would match results from previous studies investigating the drought response of plant functional types in temperate grassland (Lüscher *et al.*, 2005; Gilgen and Buchmann, 2009). Under severe drought stress, as at the Irish site, N_2 fixation is strongly impaired (Serraj *et al.*, 1999) and deep-rooted species might better resist the stress (Ho *et al.*, 2005, Gilgen *et al.*, 2010) if they can take up water from deeper soil layers. However, more detailed analyses are needed that will i) allow a more refined assessment of induced drought stress across different sites with varying soils and climatic conditions (Vicca *et al.*, 2012), ii) investigate the effect of drought severity on species' responses, and recovery rates, iii) reveal the effect of drought stress on symbiotic N_2 fixation, and iv) disentangle pure water limitation from a co-limitation of water and nutrients. Doing so should help identify traits for improved drought resistance and thereby selection of species for forage production under future climate conditions.

Conclusion

Our study showed varying species' responses related to differences in drought severity. At least under moderate drought, N_2 fixing as well as deep-rooted species showed mitigation of drought stress in intensively managed grassland. Cultivating mixtures including species from different plant functional types might therefore be a promising strategy to ensure future forage production under varying degree of drought severity.

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