# Drought-resistant species enhance yield but lower forage quality under drought in mountain grassland

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## Abstract

Summer droughts reduce forage yield and quality in mountain grasslands. This study aimed to determine the most suitable multi-species mixtures that provide satisfactory yield and quality under drought, yet performing well under optimal rainfall conditions. To this end, in 2023 we sowed nine multi-species mixtures differing in dominant species identity (*Dactylis glomerata*, *Alopecurus pratensis*, co-dominance of both) and expected proportion of drought-resistant species (0, 15, 30% DRsp) including *Plantago lanceolata*, *Lotus corniculatus*, *Festuca rubra*, *Agrostis capillaris* in a mountain site (1115 m a.s.l., Switzerland). The experiment followed a split-plot design with the nine mixtures growing under either control or drought conditions with four replicates. Drought was simulated during the year after sowing using rainout shelters excluding all precipitation during 7 weeks in summer. Yield decreased for all mixtures under drought (up to 48%), but the reduction was less severe for the mixtures with drought-resistant species. In both drought and control conditions, yield and acid detergent lignin (ADL) content of the second regrowth increased with increasing DRsp abundance, while crude protein (CP) and neutral detergent fibre (NDF) decreased. Within the same climatic conditions, the annual yield was similar among the different mixtures.

**Keywords:** crude protein, experimental drought, fibres, multi-species mixture, yield

## Introduction

Climate change is expected to reshape ecosystems due to rising temperatures and increasing extreme climatic events, such as drought. In grasslands, summer droughts reduce forage yield (Vitra *et al.*, 2019) and have contrasting effects on forage quality (Deléglise *et al.*, 2015). Mountain grasslands are particularly vulnerable to climate change, with communities expected to be severely affected by drought (Thuiller *et al.*, 2005). However, greater plant diversity can help to increase grassland yield stability, resistance and recovery to drought (Lüscher *et al.*, 2022) because many species provide greater guarantees that some will maintain functioning even if others fail (i.e., insurance hypothesis, Yachi and Loreau, 1999). The aim of the present study was thus to evaluate the effects of adding drought-resistant species to common productive grassland mixtures on yield and forage quality under simulated drought.

## Materials and methods

Grassland mixtures were established on a sandy loam soil at 1115 m a.s.l. in the canton of Bern, Switzerland. In spring 2023, we sowed nine multi-species mixtures differing in dominant species identity (*Dactylis glomerata*, *Alopecurus pratensis* or co-dominance of both) and expected biomass proportion of drought-resistant species (DRsp 0, 15, 30%), including *Agrostis capillaris*, *Festuca rubra*, *Lotus corniculatus* and *Plantago lanceolata*. Five common grassland species, with high forage quality, were added to all mixtures, i.e., *Lolium perenne*, *Phleum pratense*, *Poa pratensis*, *Trifolium pratense* and

*Trifolium repens*. The experiment followed a split-plot design with the nine mixtures growing under either control or drought conditions with four replicates. Drought was simulated with rainout shelters, which excluded all rainfall during seven weeks in summer 2024 (late June to mid-August). The mixtures were harvested three times during the season (before and after the drought simulation and after the post-drought regrowth). At each harvest, we measured dry matter (DM) yield, crude protein (CP), neutral detergent fibres (NDF) and acid detergent lignin (ADL) of each mixture. Biomass was sorted to species to assess the botanical composition of the mixtures. The relative abundance of each species was determined in each plot as the ratio of each single species yield to the total plot yield. The DRsp relative abundance was calculated as the cumulative relative abundance of the four corresponding species. All statistical analyses were carried out with R version 4.3.3 (R Core Team, 2024).

## Results and discussion

The experimental drought excluded 182 mm of precipitation and decreased soil moisture by an average of 41%. Drought and DRsp abundance affected yields differently throughout the harvests. At the 1st harvest, yields of the 15 and 30% DRsp mixtures were 9 and 17% lower, respectively, compared to the absence of DRsp (Table 1). At the 2nd harvest, drought significantly reduced yields for all mixtures but there was a higher decrease without (−48% in 0% DRsp) than in the presence of DRsp (−34% in 15% and 30% DRsp mixtures). After the recovery period (3rd harvest), yields were similar across DRsp mixtures. Total annual yield was not significantly different among DRsp mixtures (10.8 t/ha on average) but was reduced by 16% under drought (9.1 t/ha on average). Dominant species identity and its interaction with drought and DRsp abundance had no effect on the measured variables ($P > 0.05$), except for yields after the post-drought regrowth (harvest 3), where co-dominated mixtures had a higher yield than the others ($P < 0.001$), and for annual yields, where co-dominated mixtures had a higher yield than those dominated by *Alopecurus pratensis* ($P < 0.05$, data not shown).

To deepen our understanding of DRsp impact on mixture performances, especially under drought conditions, we further investigated the linkages between the forage yield and nutritive value and the measured DRsp abundance during the 2nd harvest (drought simulation). Across all plots, DRsp abundance ranged from 0 to 80%, which exceeded our maximum expected target of 30%. We found that *Plantago lanceolata* was the main species driving the increasing relative abundance of DRsp, as it was the most abundant drought-resistant species in most mixtures (on average 67% of total DRsp biomass). Under both drought and control conditions, forage yield and ADL increased with increasing DRsp abundance, whereas CP and NDF decreased with increasing DRsp abundance (Table 2).

Table 1. Forage yields of the three harvests and annual production across DRsp abundance treatments in control and drought conditions.

| | | | Expected DRsp abundance | | |
|---|---|---|---|---|---|
| | | | 0% | 15% | 30% |
| Yield (t/ha) (mean ± SE) | Harvest 1 | | 5.7 ± 0.2 a[1] | 5.2 ± 0.1 b | 4.7 ± 0.1 c |
| | Harvest 2 | Control | 3.1 ± 0.1 b | 3.5 ± 0.1 a | 3.6 ± 0.1 a |
| | | Drought | 1.6 ± 0.1 b *** | 2.3 ± 0.1 a *** | 2.4 ± 0.1 a *** |
| | Harvest 3 | Control | 1.8 ± 0.1 | 1.9 ± 0.1 | 1.9 ± 0.1 |
| | | Drought | 2.1 ± 0.1 | 2.2 ± 0.1 | 2.0 ± 0.1 |
| | Total | Control | 11.1 ± 0.3 | 10.7 ± 0.2 | 10.5 ± 0.3 |
| | | Drought | 8.9 ± 0.2 *** | 9.5 ± 0.2 *** | 9.0 ± 0.2 ** |

Data were analysed using linear mixed-effect models with Plot nested into Block as random factor. **, *** indicate $P < 0.01$ and $P < 0.001$, respectively, between control and drought within harvest and DRsp abundance.

[1] Different letters indicate significant differences among theoretical DRsp abundance within harvests (a > b > c, $P < 0.05$).

Table 2. Summary of linear regressions testing the effect of DRsp abundance on forage yield, CP, NDF and ADL under control and drought conditions at the 2nd harvest.

| DRsp abundance | Yield (t/ha) | | CP (g/kg) | | NDF (g/kg) | | ADL (g/kg) | |
|---|---|---|---|---|---|---|---|---|
| | Control | Drought | Control | Drought | Control | Drought | Control | Drought |
| *P* | *** | *** | * | *** | *** | *** | *** | *** |
| $R^2$ | 0.61 | 0.35 | 0.39 | 0.49 | 0.46 | 0.64 | 0.79 | 0.76 |
| Slope | 0.008 | 0.009 | −0.10 | −0.19 | −0.56 | −0.61 | 0.19 | 0.19 |
| Range | 3.2–3.8 | 1.8–2.5 | 121–113 | 109–95 | 447–402 | 438–389 | 35–50 | 35–50 |

Data were analysed using a linear mixed-effect model with Block as random factor. *$P < 0.05$, ***$P < 0.001$. $n = 36$. The range indicates the values of each variable from plots without to plots with 80% DRsp.

Overall, our results highlight positive impacts of DRsp abundance on forage yield but negative impacts on quality, particularly due to the decrease in CP and increase in ADL.

## Conclusions

In this study, we showed that drought reduced forage yield, but this reduction was lower in the presence of DRsp, suggesting that DRsp can reduce the negative impact of drought on mixture yield. However, we simultaneously showed that DRsp could have negative impacts on forage quality (CP and ADL), highlighting the need to find a compromise between forage yield and quality. Finally, as the relative abundance of DRsp was strongly influenced by *Plantago lanceolata*, it seems that this species has a strong potential to limit yield loss under drought, thanks to a deep rooting system and symbiotic interactions with mycorrhiza that enhance nutrients and water uptake (Pol *et al.*, 2021). However, the abundance of this species could also explain the negative effects on forage quality, since the ADL content of *P. lanceolata* is known to be higher than other forage species (Elgersma *et al.*, 2014).


## Acknowledgements

We thank Michael Feller and Joel Brülhart for their support in the project coordination and Hansruedi Kohli, the farmer owning the field, as well as Patrick Ledermann, Margaux Genoud, Mathieu Devaux and Olivier Leost for their help during fieldwork.


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