Increased mineral soil N availability contributes to post-drought yield outperformance of *Lolium perenne*

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Abstract

Reoccurring drought events severely restrict forage production. However, intensively managed grasslands have recently been reported to recover quickly after drought stress and to even outperform control yields. Despite several studies showing increased mineral N availability after drought, the contributions of the two N sources: (1) fertilizer-derived N accumulated during drought; and (2) increased availability of soil-derived mineral N, remain unclear. Thus, we examined the effect of a 2-month experimental summer drought and two fertilization levels during drought (non-fertilized and fertilized) on the recovery of *Lolium perenne* swards after rewetting. Even for non-fertilized swards, dry matter yield (DMY) and plant-available N of drought and rewetted (DRW) plots exceeded controls. Fertilization during drought increased the effects of DRW on DMY and on plant available N. Consequently, our study shows that formerly drought stressed swards surpass control yields by profiting from higher N availability, not only deriving N from accumulated fertilizer N but also from increased availability of soil-derived N due to changed soil processes.

Keywords: grassland, drought, yield outperformance, ryegrass, N availability, resilience

Introduction

Drought events during the past years have severely restricted forage production and the frequency of drought events is predicted to keep increasing (Emadodin *et al.*, 2021; Gharun *et al.*, 2020). However, temperate grasslands have recently been reported to show outstanding resilience after experimental drought and rewetting (DRW) and to be even more productive after DRW than non-drought stressed control plots (Hahn *et al.*, 2021; Hofer *et al.*, 2016). Hofer *et al.* (2017) reported higher plant foliar N concentrations after DRW of *L. perenne*, suggesting higher availability of mineral N after rewetting. But their experiment was not able to quantify the contributions of: (1) fertilizer N accumulated during drought; and (2) of the increased availability of N from mineralization of soil organic matter (hereafter soil-derived N). Thus, this study aims to disentangle the contributions of fertilizer derived N and soil-derived N on post-drought yield outperformance of perennial ryegrass (*L. perenne*).

Materials and methods

To test whether yield outperformance after DRW was driven by fertilizer-derived N accumulation during drought and/or by increased availability of soil-derived N, a field experiment was set up in the vicinity of Zurich on an intensively managed ryegrass (*L. perenne*, cv 'Allodia') ley. To simulate summer drought, rain-out shelters were set up for two months on half of the plots. After shelter removal, all plots were re-watered including the controls. Plots were harvested and dry matter yield (DMY) was determined six weeks after shelter removal and rewetting to assess yield resilience. To distinguish fertilizer from soil nutrient effects on DMY, half of the plots were fertilized during drought with 47.5 kg ha^{-1} ammonium nitrate (27% N), and the other half was not fertilized.

For measuring plant available nitrogen in the soil, we used PRS (Plant Root Simulator) ion-exchange membranes (Western AG, Saskatoon, Canada) which mimic soil nutrient sorption by plant roots (Qian and Schoenau, 1994). To avoid confounding effects from potential competition of PRS with plants for nutrient uptake, PRS were installed in plant exclusion cylinders (Huang and Schoenau, 2011). After 4 weeks of incubation they were removed, washed and sent back to Western AG for measuring plant available N concentrations.

Statistical analysis of DMY and plant available soil N were performed using ANOVA with a model considering the interaction of drought treatment (control versus drought) and fertilization (without versus with). All statistical analyses were performed using R (version 4.0.2, 2020).

Results and discussion

Six weeks after rewetting we observed significantly higher DMY in formerly drought stressed plots, compared to control plots, for both plots without and with fertilization (DRW, $P<0.001$, Figure 1). Plots with fertilization showed higher DMY compared to plots without fertilization after DRW (fertilization, $P<0.001$) and fertilization increased the effect of DRW on DMY (drought stress × fertilization, $P<0.01$).

DRW resulted in higher plant-available soil N during the first recovery regrowth compared to control soil (DRW, $P<0.01$) in both, plots without and with fertilization during drought (Figure 2). Also, plots with fertilization during drought showed higher plant-available soil N (fertilization, $P<0.1$). The interaction of DRW and fertilization on available soil N was not statistically significant but shows a tendency towards a higher DRW effect in plots with fertilization compared to plots without fertilization.

Greater DRW effects of fertilized plots, compared to non-fertilized, for DMY, and a similar trend in plant-available N, suggest that yield overcompensation in plots with fertilization under drought occurred partially due to fertilizer N that had accumulated during drought stress. Remarkably, DRW resulted in higher yield and plant-available N not only in plots with fertilization during drought, but also in plots that were not fertilized during drought. Measuring plant-available soil N under plant exclusion allowed us to measure DRW effects of soil processes on the amount of soil-derived N without the effects of N uptake by the plants. Therefore, higher DMY and plant-available N after DRW in plots without fertilization during drought indicate that changed processes in the soil such as higher N-mineralization rates due to higher microbial activity (Borken and Matzner, 2009; Gordon *et al.*, 2008) increased the availability of soil derived N and led to the observed yield outperformance of DRW swards.

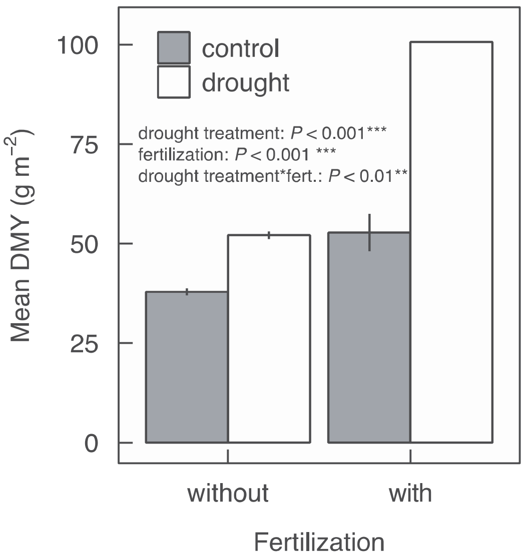

Figure 1. Dry matter yield (DMY) six weeks after release of drought for control and formerly drought-stressed plots with or without fertilization during drought (mean ± standard error, n=4).

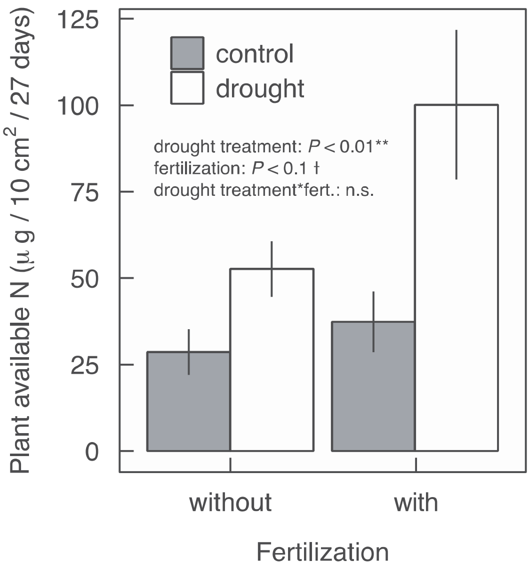

Figure 2. Plant-available N in the soil six weeks after release of drought, for control and formerly drought-stressed plots with or without fertilization during drought (mean ± standard error, n=4).

Conclusions

Formerly drought-stressed *L. perenne* swards were highly resilient and outperformed non-drought stressed controls not only in dry matter yield but also in showing higher plant-available total N in fertilized and non-fertilized swards. Thus, our study shows that the increased availability of total mineral N for plant growth after drought stress and rewetting derive from both the fertilizer N accumulated during drought where fertilizer was applied, and from increased availability of soil-derived mineral N.

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