Belowground Productivity in Patches of Heterogeneous Grass Swards After Nearly Two Decades of Low-Intensity Cattle Grazing

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Abstract

In low-input grassland, patch-grazing leads to tall and short patches that provide different growth conditions for the grass sward. Since belowground biomass and the associated turnover represent the main carbon input to soil in grassland, we investigated within-pasture variation of above- and belowground net primary production in relation to patches over one year of production in a long-term grazing experiment during the year 2022. The analysis of above- and belowground net primary production showed an effect of patch types, partly in interaction with the month, indicating a strong variation due to climatic conditions. In those few cases where differences existed among patches, then tall patches were more productive than short ones. Overall, the experimental year was unusually dry and hot.

Introduction

In grasslands the turnover of carbon related to root production is essential for soil organic carbon storage (Kuzyakov and Domanski 2000). In low-input grazed grassland, patch grazing leads to heterogeneous grass swards (Adler et al. 2001) because cattle prefer short patches for herbage intake (Dumont et al. 2007) and avoid tall patches. Patches represent a heterogeneous vegetation composition of different sward height classes of tall and mature (≥10.5 cm) and shorter mainly vegetative areas (Ludvíková et al. 2015). These patches remain stable over many years (Tonn et al. 2018) and they represent contrasting micro-habitats for grassland growth potentially affecting both above- and belowgroung net primary production (NPP). Short patches can be expected to have fewer resources available to invest in belowground NPP than tall patches as the constant defoliation by herbivores requires continuous regrowth aboveground (Ebeling et al. 2020). Regular regrowth after defoliation on the other hand requires a versatile root system in order to enable sufficient uptake of nutrients (Whitehead 2000) which indicates that soil nutrient availability will affect differences among patches on NPP. Therefore, in short patches a trade-off between above- and belowground biomass allocation is assumed. Information on the spatial variation of belowground biomass production among patches is, to the best of our knowledge, not yet available. The hypothesis of the present study is that belowground NPP varies among patches in interaction with soil nutrient availability. For this, above- and belowground net primary production (ANPP, BNPP) were studied in patches of pastures managed under extensive continuous stocking in a long-term grazing experiment.

Methods

The study was performed during the year 2022 in a 20-year old grazing experiment located in Central Germany (51° 46' 56.3" N 9° 42' 11.6" E), 265-340 m above sea-level. The experimental site was established in 2002 (Isselstein et al. 2007) and has been maintained in its current form since 2005 without interruption. The area has an agro-climate on the boundary between humid and continental temperate. The long-term (1991-2020) growing season (April-October) precipitation sum is 427 ± 36 mm, with an average mean temperature of 13.3 ± 0.7°C (mean ± SD) (German Weather Service Station Moringen-Lutterbeck, 18 km distance). The grassland is of moderate species-richness with a mean of 11.2 ± 4.1 vascular plant species per 0.25 m^2 (Perotti et al. 2018) and it represents the association *Cynosurion cristati* (Runge 1973). The soil type is a Vertic Cambisol.

The setup of the experiment underlying this study represents a one-factorial randomized block design with three replicates comparing three stocking intensity treatments, i.e. moderate, lenient and very lenient stocking, on nine 1-ha paddocks (Tonn et al. 2018). The grazing management is based on continuous stocking. For the present study only the lenient stocking intensity is considered. The stocking intensity is defined by a target compressed sward height of 12 cm on average per year measured bi-weekly at 50 random points using a rising plate meter (Castle 1976, 200 g plate weight, 30 cm diameter). Each paddock was grazed by pregnant, non-lactating Fleckvieh beef cows during the grazing season from April to October. A put-and-take approach was applied to manage the stocking of the experimental paddocks in order to maintain the target compressed sward heights. Cows grazed on a compensation area surrounding the experimental plots after they were removed from the experimental paddocks. Throughout the grazing season, cows had *ad libitum* access to water and salt lick. There were no applications of fertilizers or pesticides, or any mechanical sward maintenance for at least 10 years before the field experiment was established in 2002. No fertilizer or lime was added to the experimental area, although growth of emerging shrubs was controlled mechanically.

Each experimental paddock is characterized by a stable mosaic pattern of tightly defoliated short patches and rejected tall patches and these patches are very stable over years (Tonn et al. 2018). In addition, areas of high and low availability of potassium and phosphorus in the soil are present resulting from a within pasture nutrient transfer (Tonn et al. 2019). Thus, the allocation of ANPP and BNPP in relation to patches (stable over many years) and soil nutrient availability can be tested. For the purpose of the present study a factorial design was implemented consisting of soil nutrient availability (n=2) x patch (n=2) x replicate (n=3). Tall patches refer to areas with a compressed height of ≥10.5 cm and short ones of <10.5 cm. We included an additional factor for stratification in order to account for influences in the botanical composition. For this, we chose areas dominated either by dicotyledonous or monocotyledonous plant species. Thus, in total 24 sampling plots resulted (soil nutrient availability x patch x botany x replicate). The soil nutrient availability represents locally distinct areas of high and low P and K contents which were determined in January 2022 by sampling the topsoil layer (10 cm soil depth) using a soil corer (2 cm diameter) for a composite soil sample around each sampling plot. Analyses of P and K refer to the Calcium-Ammonia-Lactate (CAL) method. The ingrowth core method was used for BNPP measurements (Steingrobe et al. 2001). At each sampling plot three holes were drilled with a spiral hand auger (4 cm diameter, 45° angle) to a soil depth of 30 cm. An amount pre-defined according to soil bulk density (1.4 g cm^{-3}) and previously sieved (1-2 mm) root-free soil was filled into mesh bags (1-mm mesh size, polyamid) (Franz Eckert GmbH, Waldkirch, Germany) and these mesh bags were then inserted into each hole for a ingrowth period of four weeks. After four weeks of root ingrowth, mesh bags were recovered and new mesh bags installed into the same holes. Recovered mesh bags were cooled (4°C) until the next day. All roots inside the three mesh bags per sampling plot were washed in an hydropneumatic elutriation system over a sieve size of 640 µm and separated in floation using hand tweezers. After drying (60°C, 48) the root dry weight accumulated over four weeks of ingrowth was determined. This procedure was performed from early April till early November. Accordingly compressed sward heights (CSH) were measured bi-weekly at each sampling plot and converted into standing herbage on offer (g DM m^{-2}) from linear regression between CSH and herbage mass (R^2=0.55) as determined in manual calibration cutting near the soil surface of known CSH to derive ANPP (Correll et al. 2003). Four manual sampling dates were performed for this during 2022 (May, July, October, November). Each sampling area within paddock was fenced out in order to avoid trampling by the grazing cattle. During stocking on the paddocks, standing herbage in short patch areas was cut manually to 4 cm stubble height using electric hand shears in order to imitate defoliation by grazing. Tall patch areas were never defoliated. Data analysis refers to monthly mean daily rates of ANPP and BNPP between April and November. Statistical analyses were performed in R studio (R Core Team 2022) using repeated-measures linear-mixed effects models ("nlme" package) with the fixed and interaction effects of soil nutrient availability x patch x month. The sampling location nested in paddock, nested in block was used as a random effect. The factor botany was used as a replicate since it did not show any influence on the target variable (not shown). Posthoc comparison of means were followed using Tukey's HSD test ("emmeans" package).

Results and Discussion

The weather conditions during the growing season in 2022 were 40% drier and 9% hotter (Figure 1) than the long-term climatic conditions. Thus, a strong drought coupled with heat occurred during the growing season. In the sampling areas with low and high soil nutrient availability contents of 83 ± 41 and 170 ± 49 mg P kg^{-1} soil were found, respectively (mean ± SD). Corresponding values for K were 170 ± 49 and 338 ± 160 mg kg^{-1} soil, respectively (mean ± SD). In total 161 livestock unit grazing days (1 LU = 500 kg live weight) resulted in 2022. During the years 2005-2020 the same stocking treatment was grazed for 238 livestock unit grazing days (Grinnell et al. 2022). The lower intensity during 2022 reflects the unfavorable growing conditions for the grass sward.

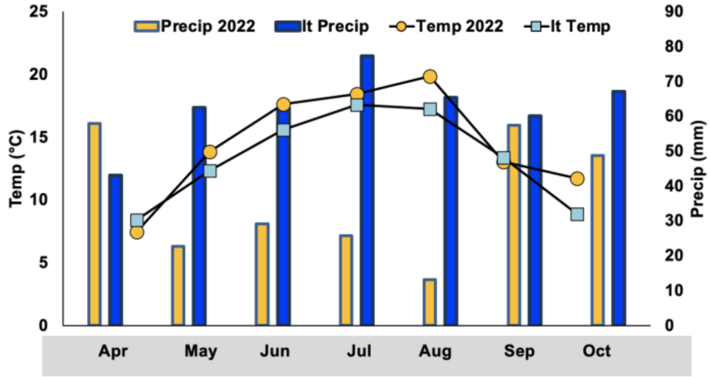

Figure 1. climatic conditions during the experimental year (2022) compared to long-term (lt, 1991-2020) climatic conditions as retrieved from the German Weather Service. Given are monthly mean temperatures and monthly precipitation sum.

A strong effect of the dry conditions became evident in the main effect of month on ANPP with lowest and even negative values during June and July (Figure 2a) which may be associated with senescence as caused by drought. Rainfall towards the end of the growing season caused an increase in ANPP. The analysis of variance revealed a marginally significant effect of patch types for ANPP (Figure 2a). Comparison of means showed that patches generally did not differ significantly from each other although short patches tended to have a smaller productivity 0.18 ± 0.7 (g DM m^{-2} day^{-1}) compared to tall patches (0.5 ± 0.7 g DM m^{-2} day^{-1}) (LSmeans ± SE) when climatic conditions were drier. A larger productivity of tall patches compared to short ones is in line with Ebeling et al. (2020) a few years earlier on the same experiment. The absent effect of soil nutrient availability on ANPP may be caused by two possible reasons: the lack of water prevented a potentially larger potassium mass flow through the soil surface under higher nutrient availability. It might also be that P and K are generally not limiting plant production in the present study which requires further investigation. We found a significant main effect of soil nutrient level on BNPP in the ANOVA (Figure 2b). However, the comparison of means revealed that the difference between high and low soil nutrient availability was not significant (0.82 ± 0.05 vs. 0.68 ± 0.05 g DM m^{-2} day^{-1}, LSMeans ± SE). The interaction between patch x month was also significant for BNPP (Figure 2b) and tall patches had a larger BNPP than short patches in June. The BNPP declined towards summer and increased again until October with the onset of rainfall.

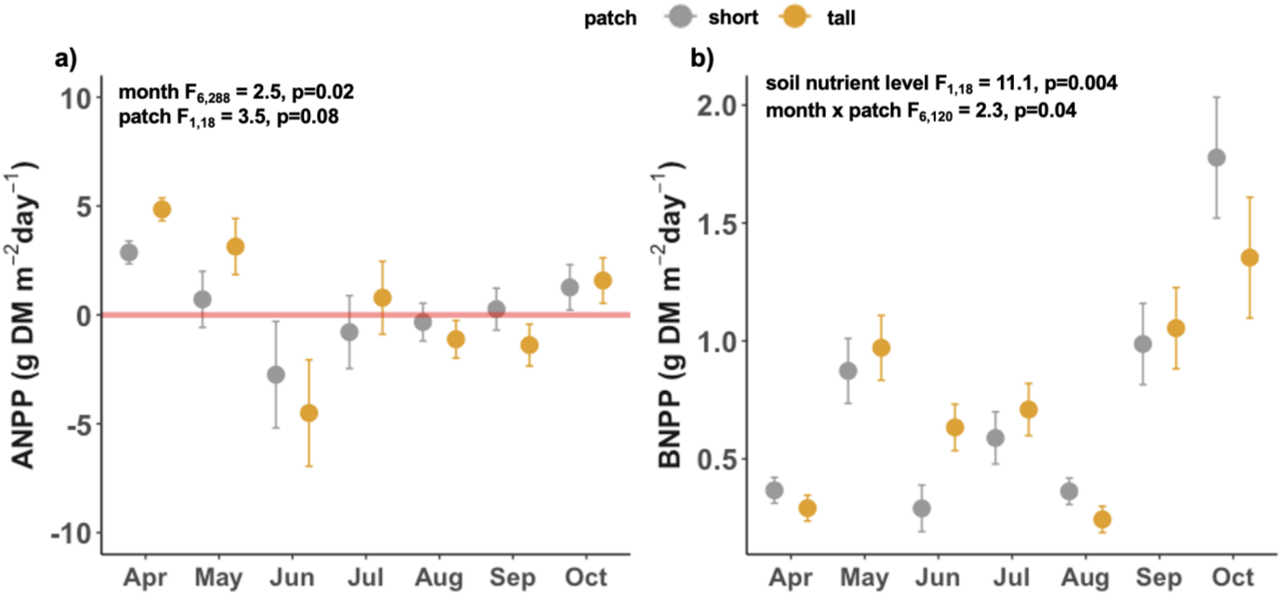

Figure 2. Monthly mean values of daily aboveground (a) and belowground (b) net primary productivity (ANPP, BNPP) as affected by the interaction of patch x month. Shown are estimated model means ± standard errors of means. Given are also the outputs of analyses of variance for each variable. The horizontal red line indicates zero ANPP.

Conclusions

After one year of experimentation on above- and belowground biomass production in patches of low-input grassland, under extremely dry climatic conditions, the hypothesis of patch-specific root production is supported. The interaction with soil nutrient level was not significant. Studies on root turnover, soil organic carbon stocks and comparisons with higher stocking intensity will follow.

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