Variation of legume contents and symbiotic nitrogen fixation under intensive grazing

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Kurzfassung

Leguminosen sind eine wertvolle Komponente in Weidesystemen: sie fixieren in Symbiose mit Rhizobien Stickstoff, haben einen ausgezeichneten Nährwert und fördern die Futteraufnahme. Wir haben in 13-jährigen Untersuchungen die Wirkung der Nutzungsgeschichte, Boden- und Witterungsverhältnisse auf den Kleeanteil in Weiden aus Neuansaaten (neue Weiden) sowie vorgängig jahrzehntelang als Weiden genutztem Grasland (alte Weiden) untersucht.

Der Untersuchungszeitraum umfasste nasse Jahre und den Jahrhundertsommer 2003, jeweils sechs alte und neue Weidekoppeln und Böden mit sehr unterschiedlicher Nutzwasserkapazität. Die Ertragsanteile der verschiedenen Arten wurden in vier Dauerquadraten auf jeder Koppel jährlich dreimal erfasst (1355 Aufnahmen). Auf alten und neuen Weiden stellten sich, nach Beginn intensiver Weidenutzung, mit einer Halbwertszeit von unter 2 Jahren quasi-stabile Ertragsanteile von Klee (primär Weißklee) ein. Im quasi-stationären Zustand waren die Ertragsanteile von Klee (im Mittel: 4%) und die biologische Stickstofffixierung (im Mittel: 6 kg N ha^{-1} a^{-1}) niedrig. Die Jahrhunderttrockenheit von 2003 führte auf allen Flächen zu einem nahezu vollständigen Zusammenbruch des Kleeanteils (Masseanteil <1%). Dem Zusammenbruch folgte eine rasche, über den Trend hinausgehende Erholung und anschließend eine Rückkehr zum langjährigen Tend.

Langfristig hatten weder die Witterungsbedingungen noch die Bodenverhältnisse (Nutzwasserkapazität und Nährstoffversorgung) und Beweidungsintensität eindeutige Auswirkungen auf den Kleeanteil der Weideflächen.

Introduction

Legumes are important for pastoral systems because of their ability to fix N_2 and because of their high nutritional value. However, unpredictability of legume content and low legume contents cause reluctance to rely on legumes as the predominant source of N particularly in view of the fact that the relation between legume contents and pasture productivity is still not fully understood (Cosgrove *et al.* 1996, Ledgard *et al.* 2001, Schwinning and Parsons 1996). We examined the influence of management (sowing and grazing intensity), weather (including a centennial drought, Ciais *et al.* 2005) and a wide range of soils (varying in water and nutrient availability) in a long-term experiment.

Materials and methods

We conducted a 13 year-long study (including the centennial drought year 2003 and wet years) on 12 pastures exhibiting a large range in plant available water (PAW) capacity and other soil properties (Table 1). Half of the pastures were situated on old permanent grassland and half were sown at the beginning of the experiment. Sowing mixtures contained *Trifolium repens* and *T. pratense*, which contributed 9 and 2% of the number of seeds. All pastures were grazed continuously during the vegetation period without additional feeding. Grazing pressure was adjusted to four levels (for details on pasture properties and management see Schnyder *et al.* 2006).

On each pasture four permanent monitoring plots (1 m²) were installed (marked by buried magnets). Each quadrat was subdivided into 100 tiles (10 x 10 cm²). Species' relative contribution to aboveground biomass, plant height, soil cover and other parameters were visually recorded on each tile, which allowed quantifying species contribution down to 0.01% on a plots. Total biomass was estimated by trained and regularly 'calibrated' persons. Measurements were taken three times every year (early, mid and late growing season), yielding a total of 1355 samples.

Table 1: Range of soil and stocking properties among the 13 experimental pastures (values denote spatio-temporal averages over the 12-yr experimental period of individual paddocks)

Parameter	Unit	Min	Mean	Max
P level in soil [A)]	mg (100 g)$^{-1}$	11	20	50
K level in soil [A)]	mg (100 g)$^{-1}$	13	27	54
N pool in soil 0-10 cm	kg ha^{-1}	4409	6214	9655
PAW capacity	mm	56	96	186
Paddock size	ha	3.6	5.5	8.3
Mean stocking rate	LU ha^{-1} a^{-1}	0.8	1.4	2.0
Target sward height	cm	4.0	6.2	9.0

[A)] Oxide (P_2O_5 or K_2O in CAL extract)

Symbiotic N fixation was estimated using an empirical model (Høgh-Jensen *et al.* 2004). For details of parametrization see Auerswald *et al.* (2010). Actual PAW was modelled according to Schnyder *et al.* (2010) from weather data of a nearby (3 km) meteorological station.

Total variance in legume content was split into four components, which again were grouped in two components:

$$s^2_{\text{total}} = \underbrace{s^2_{\text{Inter-annual}} + s^2_{\text{Intra-annual}}}_{s^2_{\text{time}}} + \underbrace{s^2_{\text{Inter-pasture}} + s^2_{\text{Intra-pasture}}}_{s^2_{\text{space}}}$$

Variance decomposition was done separately for old and new grassland. Four periods were distinguished in order to find out whether the relative importance of the different sources of variation changed over time: T1 = 2000 – 2003, T2 = 2004 – 2006, T3 = 2007 – 2009 and T4 = 2010 – 2012.

Results and discussion

Shortly after seeding, relative legume content on newly sown pastures was about three times higher than on old pastures (Fig. 1, panel A) and exceeded the relative number of seeds by more than a factor of four. On both types of pastures, legume content quickly decreased over time while the swards adapted to the new and constant grazing regimen. Decreases followed exponential functions with half-lives of legume contents of 0.7 and 1.3 yr. After about ten years, both types of pastures approached the same and very low legume content (about 4% of above-ground biomass), for which a rate of N fixation of on average 6 kg ha^{-1} yr^{-1} was predicted.

Legumes were dominated by the two sown species on the new grassland, but *T. pratense* quickly disappeared and *T. repens* remained. On the whole, *T. repens* was the only legume species on old grassland. During the last years, spontaneous species (*Lotus corniculatus, Medicago lupulina, Trifolium dubium*) established in the sown grassland but their overall contribution to total community biomass remained low (<0.5% when combined).

The year 2003 was an extreme drough year during which quarterly mean PAW dropped to 10 mm even on soils with high water holding capacity (Fig. 1, panel B). During this extreme drought year (4th year after establishment of the experiment), legume contents decreased dramatically but the lowest contents were found early in the growing season of the following year (Fig. 1, panels C and D) although rainfall was already normal in late summer in 2003 and actual PAW returned to normal in the last quarter of 2003 and in 2004. The drought crash was most pronounced on the new pastures, which had a lower plant PAW capacity than old pasture (on average 70 mm vs 140 mm) and consequently a lower mean actual PAW during the growing season in 2003 (8 mm vs 15 mm).

In mid-summer 2004, legume content started to recover and reached its maximum early in the growing season 2006 on both pasture types. During late 2005 and early 2006 legume content even exceeded the values predicted from the long term trend, compensating the low values during 2003 and 2004 (Fig. 1, panels C and D). Thereafter, the legume contents returned to the long-term trend.

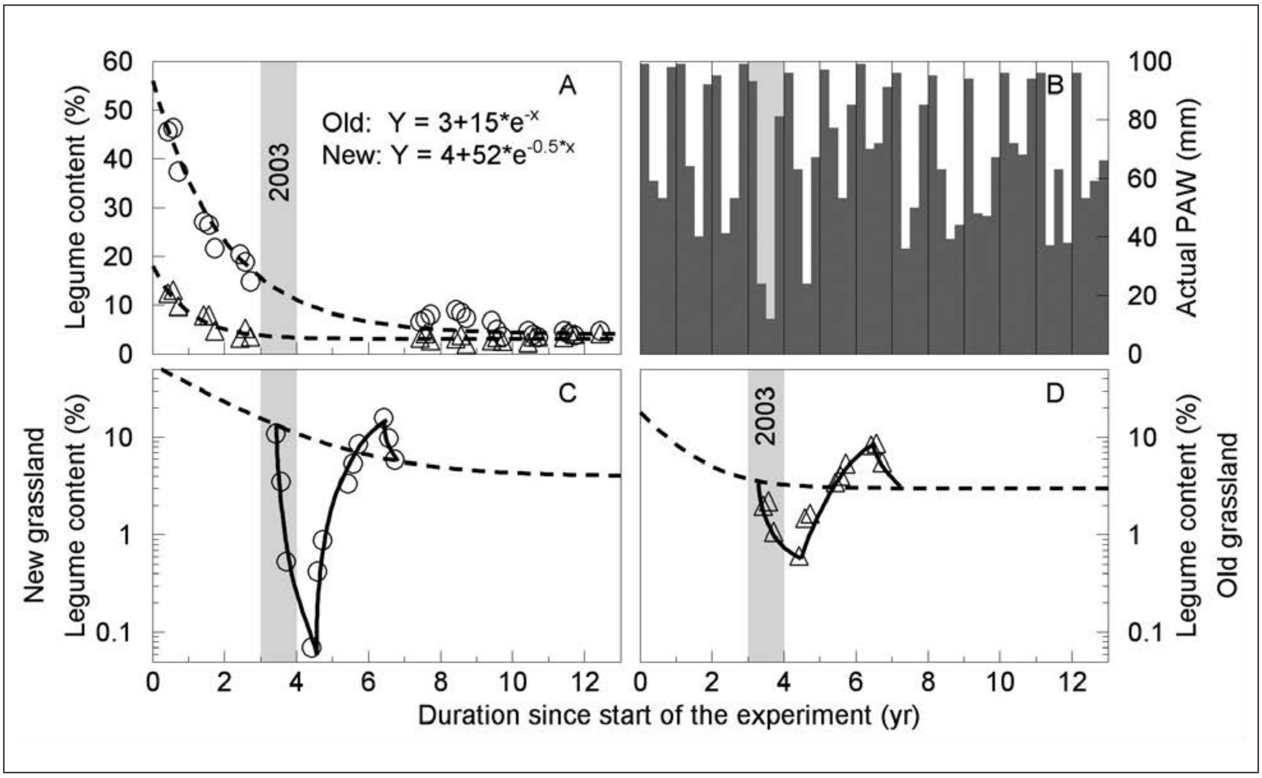

Fig. 1. Mean legume contents averaged for sampling dates on new (O) and old pastures (Δ).
A) Long term trends on old and new grassland without the drought crash.
B) Quarterly mean actual plant available water (PAW) for a soil with high PAW capacity (100 mm).
C) Legume contents in new grassland during the centennial drought (2003, grey shaded) and the recovery years (2004 – 2006) on a logarithmic y axis.
D) Legume contents in old grassland during the centennial drought (2003, grey shaded) and the recovery years (2004 – 2006) on a logarithmic y axis.
Dashed lines in panels A, C and D give the long-term exponential trends. Markers are means of all quadrats within six pastures.

The variance of legume contents between plots strongly decreased over time as a consequence of approaching a very low equilibrium value (Fig. 2, both left panels). This was true for the spatial variation (between plots) and temporal variation (between measuring events). Also it was true for old and new pastures although the decrease was less pronounced on old grassland, which had started at lower legume contents that allowed for less initial variation.

The inter-annual variation contributed most to total variance during the first years, when legume contents declined quickly; later inter-annual variance added only little to total variance, indicating that weather conditions – including the centennial drought in 2003 – had a minor impact on variation of legume contents (Fig. 2, both right panels). The intra-annual (seasonal) variation was very low (< 10%) at all times on both new and old pastures. While the relative contribution of temporal variation declined strongly over time, the relative contribution of spatial variation increased strongly (> 90% during the last term). The within-pasture variation showed no clear pattern over time, while the variation between pastures contributed most to the total variation during the last phase of the experiment. Still, total variance and thus also variance between pastures was extremely small during the last phase (SD 2%) indicating that differences in grazing pressure (compressed target height maintained during the grazing season varied from 4 cm to 7 cm), in PAW capacity, soil nutrient supply (ranging from low to very high for P and K according to the German recommendations) and soil N pool (ranging from 4400 kg ha^{-1} to 9700 kg ha^{-1} in the top 10 cm of the soil) had only a minor influence on legume content.

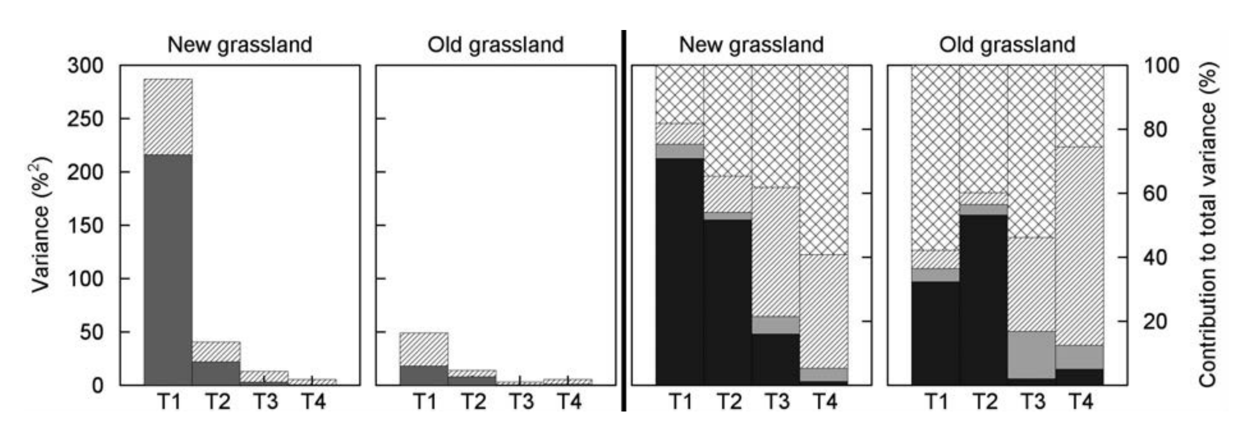

Fig. 2. Variation in legume content over time and space. The experimental period was divided in four periods (T1 = 2000-2003, T2 = 2004-2006, T3 = 2007-2009 and T4 = 2010-2012). The left pair of panels displays the contribution of space (hatched) and time (grey) to total variance on new and old grassland while the right pair displays the relative contribution of inter-annual (dark grey), intra-annual (light grey), within-pasture (hatched) and between-pasture (cross hatched) variation to total variance.

Conclusions

Legume contents adapted quickly to permanent grazing independently of the initial values (half-lives < 2 yr). On the long-term, neither weather (even including a centennial drought) nor soil properties (PAW capacity, nutrient levels), or grazing intensity had a distinct influence on legume content. In all cases, near-equilibrium legume contents and N fixation rates became low under conditions of low N losses and continuous N recycling under permanent grazing even without additional N input from fertilizers or concentrate feeding.

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