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Long-term development of fodder quantity and quality of non-intensively managed grasslands in south-western Luxembourg

Langfristige Entwicklung der Futtermenge und -qualität extensiv genutzter Grünlandbestände im Südwesten Luxemburgs

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Abstract

Species-rich non-intensively managed grasslands are among the most threatened ecosystems of Central Europe. Therefore, they are the focus of various conservation efforts at the regional, national and international level. In this context, contractual nature conservation schemes are widely implemented to ensure conservation of these grasslands through adequate agricultural management. These contracts preclude the use of fertilizer and allow only one to two cuts per year, starting not before June. In this study, we analysed data from 468 samples of the first and second cut, from 145 non-intensively managed grassland locations of different vegetation types from grasslands in south-western Luxembourg. The data cover the period 2001 to 2018. With this data set we assessed the long-term impact of low-input grassland management on parameters of fodder quality and quantity, and whether the patterns differ between vegetation types. Based on these findings we evaluated the potential to integrate the harvested fodder into livestock farming. Not surprisingly, the results revealed a decrease in yield over the study period. During the same period, levels of energy and protein increased from 2001 to 2018, while crude fibre content decreased. These changes occurred irrespective of vegetation type. In general, quality parameters indicated that the harvested fodder does not meet highest requirements, i.e. it could be fed to livestock during periods of low energy demand, but is unlikely to be suitable for livestock demanding high quality fodder, e.g. during gestation or lactation. We discuss the implications of these findings for the advancement of the contractual nature conservation schemes. An adjustment of the compensation payments that remunerate for the observed decline in yield could help to motivate farmers to continue non-intensive farming on species-rich meadows.

Keywords: contractual nature conservation, extensive grassland management, grassland conservation, mesophilic and wet grasslands, species-rich meadows

Erweiterte deutsche Zusammenfassung am Ende des Artikels

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1. Introduction

Natural and semi-natural grasslands are among the most prominent, largest and species-rich terrestrial ecosystems in the world (SUTTIE et al. 2005, WILSON et al. 2012, HABEL et al. 2013). The species-rich grasslands in Central Europe evolved in response to continuous human activities over millennia (BRIEMLE & ELLENBERG 1994, PÄRTEL et al. 2005, HEJCMAN et al. 2013) under the prevailing climatic and soil conditions (VANDVIK & BIRKS 2002). Intensified management, abandonment, and conversion of grasslands into arable fields are the main reasons for dramatic losses in plant diversity, as well as in associated animal species (BLACKSTOCK et al. 1999). Therefore, a wide variety of different plant communities found in open landscapes are Red Listed and/or protected by the European Union Habitats Directive (92/43/ECC) and actions to halt and revert this process have been implemented on national and international levels (SCHNEIDER 2011, 2019).

The same steep decrease in species-rich grasslands was observed in Luxembourg and therefore the urgent need to implement long-term conservation schemes became obvious (SCHNEIDER 2011, 2019). Still, despite intense efforts of Luxembourg to protect and restore grasslands of high nature conservation value on national and regional levels (MÉMORIAL 2018), the loss of species-rich grassland in Luxembourg continues (EEA 2019). Among the most prominent and promising efforts to ensure a sustainable conservation of these grassland habitats is their incorporation in contractual nature conservation (MÉMORIAL 2002, 2012, 2017), where farmers receive compensation payments when they adhere to certain management restrictions, e.g. no fertilizers, specified cutting dates. While studies show that these restrictions are effective in halting diversity loss in grasslands managed accordingly (PIQUERAY et al. 2016, WOLFF et al. 2020), less information is available about the consequences for fodder quality. The latter has immediate relevance when farmers incorporate the biomass of species-rich grassland into their farming systems (TALLOWIN & JEFFERSON 1999). In general, the cutting dates imposed by contractual nature conservation tend to lie outside those periods where highest fodder quality, e.g. high content of crude protein but low contents of crude fibre, can be expected (TALLOWIN & JEFFERSON 1999, ISSELSTEIN et al. 2005). In addition, the ban on fertilizer may not only lead to a reduction of fodder quantity, but also of fodder quality (TALLOWIN & JEFFERSON 1999). Even though the relationship between management and fodder quality and quantity is well established in grass-dominated, species-poor grasslands (ISSELSTEIN et al. 2005), it seems this knowledge cannot simply be translated to species-rich grasslands with a higher proportion of forbs, as these, for example, seem to show greater resilience to losses in fodder quality (TALLOWIN & JEFFERSON 1999, ISSELSTEIN et al. 2005). While some studies assessed fodder quantity and quality at one point in time, only a few studies have assessed the long-term effects of management restrictions imposed within agro-economical management schemes (DIERSCHKE & BRIEMLE 2002).

In Luxembourg, the nature conservation contracts aimed at non-intensive grassland management totalled 20 ha in the south-west of Luxembourg in 1993. About 10 years later, 1000 ha were under contract. Currently, about 5200 ha are contractually secured in Luxembourg. Fodder quantity, quality and the value of compensation payments offered are the linchpins for farmers to take part in contractual nature conservation for grasslands. Although the compensation payments offered within the framework of contractual nature conservation schemes aim at compensating losses in fodder quantity and quality that accompany contractual management restrictions, it is against the self-conception of most farmers to invest resources to produce biomass without being able to incorporate it into their farming system.

Until the 1960/70s, species-rich grasslands were commonly incorporated into farming systems, however, progress in agricultural production (mainly increased fertilizer input or higher cutting frequency) made farmers reluctant to continue this traditional management (HEJCMAN et al. 2013). Modern management schemes increased the efficiency of grassland management many-fold, i.e. fodder of high energy content, high crude protein and low crude fibre in high quantities is by far easier to harvest from species-poor grasslands (TALLOWIN & JEFFERSON 1999, ISSELSTEIN et al. 2005). Consequently, studies that assess the possibilities and limits of integrating fodder of species-rich non-intensively managed grasslands into farming systems are rare (TALLOWIN & JEFFERSON 1999, BULLOCK et al. 2001, FRANKE 2003, DONATH et al. 2004, HOFMANN & ISSELSTEIN 2005, SÜSS et al. 2007, KLEINEBECKER et al. 2011). It is obvious that in managed grassland systems, productivity – both with respect to quality and quantity – is inversely related to species diversity (PLANTUREUX et al. 2005, COP et al. 2009). Therefore, there is no immediate economic interest – apart from subsidies – for farmers to manage grassland systems in compliance with nature conservation interests. Perhaps, if fodder quantity and quality would at least not deteriorate past a certain cut-off point in relation to increasing species richness, this would help reconcile the interests of nature conservationists and farmers.

Therefore, we analysed fodder quality and quantity data from species-rich grasslands (mainly hay meadows) of different plant communities collected over a period of 18 years by the Intercommunal Syndicate for Nature Conservation (SICONA). Since 2001, samples have been taken annually from different, and in some cases the same, areas to document the development. Unlike others, our study covers only grasslands that were already classified as species-rich and of high nature conservation value at the start of the survey.

Specifically, we were interested in answering the following questions: (1) What was the effect of long-term non-intensive management on fodder quantity and quality? (2) Did the observed patterns differ between grassland types? (3) What is the overall potential to integrate fodder from non-intensively managed species-rich grassland into livestock farming?

2. Methods

2.1 Grasslands under study

The study sites were located in the south-west of Luxembourg (Fig. 1). This region is a well-known hot spot for species-rich grassland (SCHNEIDER 2019). Heavy Lias (Medium Lias) soils with high clay contents dominate in the area (AEF 1995, SERVICE DE PÉDOLOGIQUE 1999). In the central Gutland, west of the Alzette valley, Luxembourg Sandstone, and further north (near Mersch), Keuper formations appear (SERVICE GÉOLOGIQUE 1992, AEF 1995). Climatically, the region is under a strong Atlantic influence with mild winters and relatively cool summers. The mean annual precipitation lies between 850 and 950 mm, and mean annual temperature is 9 °C (AEF 1995, PFISTER et al. 2005). These specific site conditions and the early initiation of contractual nature conservation more than 25 years ago result in exceptionally species-rich grasslands (SCHNEIDER 2019).

Grasslands included in the present study were classified to four vegetation types according to the biotope register of Luxembourg (MDDI 2017): lowland hay meadows (FFH 6510), *Calthion palustris* hay meadows, *Molinia* meadows (FFH 6410) and mesophilic to wet hay meadows (Fig. 2 a–d). The latter comprises all grasslands that could not be unambiguously grouped to one of the other three vegetation types, e.g. for example mostly mesophilic meadows with moist depressions where humidity indicators dominate the vegetation. Lowland hay meadows are today restricted to only 2900 hectares in Luxembourg (MDDI 2017); they include the *Arrhenatheretum elatioris* Braun 1915 in different

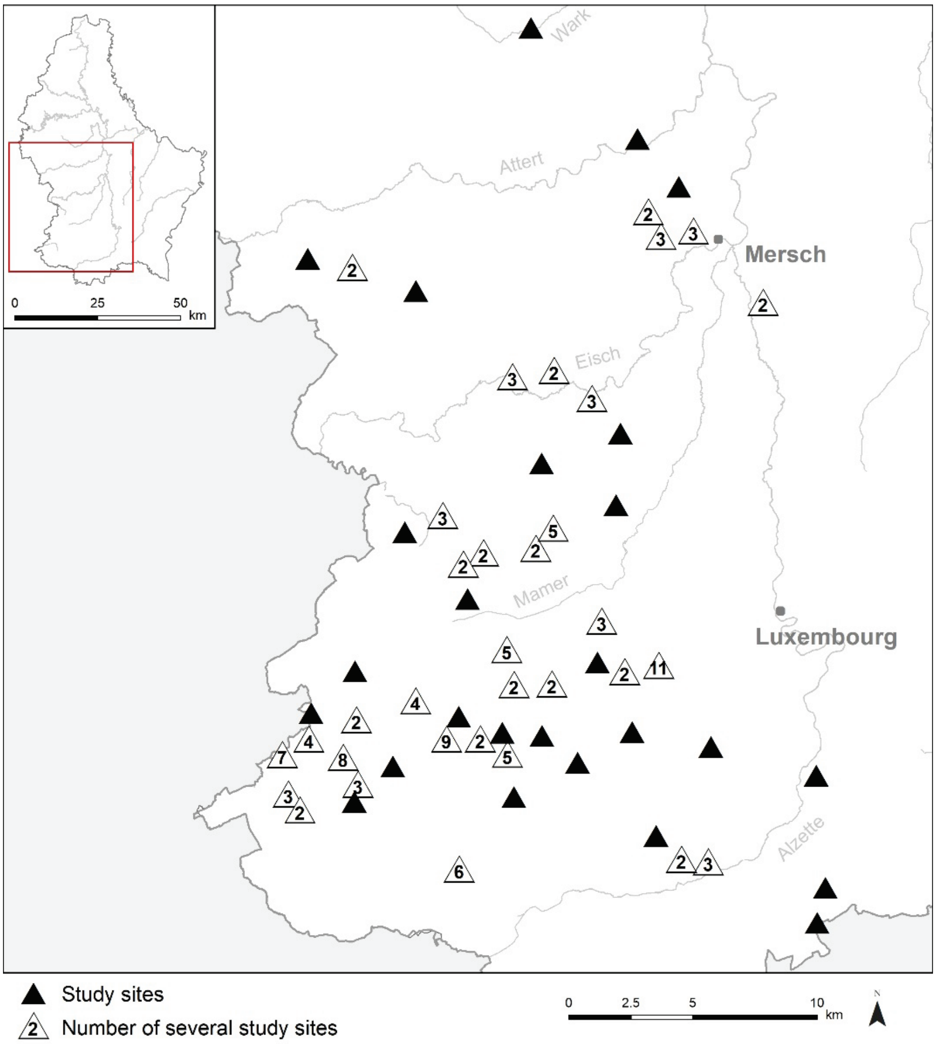


Fig. 1. Location of the study sites. Source map: Topographic map, BD-L-TC, Administration du Cadastre et de la Topographie Luxembourg.

Abb. 1. Lage der Untersuchungsflächen. Quelle Kartengrund: Topographische Karte, BD-L-TC, Administration du Cadastre et de la Topographie Luxembourg.

formations (cf. SCHNEIDER 2011). *Calthion* meadows (different plant communities of the C*althion palustris* Tüxen 1937, e.g. *Bromo-Senecionetum aquatici* Lenski 1953) are even rarer, with only about 375 hectares left nationwide; in addition, there are about 620 hectares, which are classified as sedge marshes, wet fallows and fens (SCHNEIDER 2011, 2019, MDDI 2017). *Molinia* meadows as *Molinion*-alliance (*Molinion caerulea* W. Koch 1926) are the rarest species community included in the present study, only occurring on around 8 hectares (SCHNEIDER 2011, 2019, MDDI 2017). This means that these plant communities can be found in only just below 6% of the total grassland area of Luxembourg. Most of these formerly widespread species-rich grasslands were lost to intensified management or abandonment (MDDI 2017, SCHNEIDER 2019).

Fig. 2. The study sites contained mainly **a)** lowland hay meadows, **b)** *Calthion palustris* hay meadows, **c)** *Molinia* meadows, as well as **d)** a combination category with mesophilic to wet hay meadows (Photos: S. Schneider, 2008).

Abb. 2. Die Untersuchungsflächen umfassten vor allem **a)** Magere Flachlandwiesen, **b)** Sumpfdotterblumenwiesen, **c)** Pfeifengraswiesen sowie **d)** eine Kategorie mit mesophilen bis feuchten Grünlandflächen (Fotos: S. Schneider, 2008).

2.2 Biomass sampling and analysis

Starting in 2001, at each grassland under study, a representative area of 100 m^2 was chosen for biomass sampling. Within these 100 m^2, a frame (wood, metal) of 1 × 1 m was placed five times (subsamples in the centre and at each corner) and all biomass within these five square meters was cut with scissors about 5–7 cm above ground. The biomass of these five subsamples was merged into one sample, packed in a plastic bag, cooled and immediately sent to the laboratory of the agricultural administration (Administration des services techniques de l'agriculture). Sampling of the first cut usually took place a few days before June 15th, which is the earliest mowing date in the nature conservation contracts, and sampling of the second cut took place between early August and late September. The samples of the first and second cut were taken at the same location within a grassland. The current study includes data from 2001 until 2018. Due to logistical constraints, no sampling took place in 2004, 2011 and 2016. During the study period, the majority (107) of the grassland locations was sampled once (i.e. first and second cut), while 38 locations were sampled repeatedly, varying from twice (30 locations) up to twelve times. Therefore, this study comprises 468 samples from 145 non-intensively managed grassland locations (Fig. 1).

Biomass samples were analysed by near-infrared spectroscopy (NIRS; VDLUFA 2004, Shenk et al. 1989). The following parameters were assessed or derived: dry matter (dm, dt/ha), crude protein (% dm), digestible crude protein (g/kg dm), true protein digested in the small intestine (DVE, g/kg dm; Dutch system comparable to the German usable crude protein nXP; Bruijnen 2009), crude fibre (% dm), crude ash (% dm), VEM/kg dm ("voeder eenheden melk" / fodder units milk; Dutch system comparable to the German net energy content for lactation; NEL MJ/kg TS; Bruijnen 2009), VEVI/kg dm ("voeder eenheden vleesvee intensief" / feed units meat livestock intense) as well as nitrogen (% dm), phosphorus (g/kg dm), potassium (g/kg dm), calcium (g/kg dm), magnesium (g/kg dm), sodium (g/kg dm). Furthermore, energy yield per ha and year (kVEM/ha) was calculated based on dry matter yield and energy content (VEM/kg dm).

2.3 Data analysis

To account for differences in sampling intensity between years and short-term variability, data sampling periods were established, i.e. data from 2001 to 2003, 2004 to 2007, 2008 to 2011, 2012 to 2014 and 2015 to 2018 was combined for the data analysis. Since no data was available for 2004, 2011 and 2016, all sampling periods include data from three different years. Data across vegetation types was analysed employing a two-factorial ANOVA to assess the influence of the main vegetation type ($k = 4$) and sampling period ($k = 5$), and their effect on the response variables. In case of significant ANOVA results indicating the existence of relevant general patterns, pairwise differences between sampling periods were assessed by Tukey-test (QUINN & KEOUGH 2002). Prior to the analysis, residuals were visually checked for normal distribution and homogeneity of variances (QUINN & KEOUGH 2002). To assess differences in the response variables between the sampling periods within vegetation types, we calculated 95% confidence intervals of the means; when these do not overlap this indicates a significant difference (QUINN & KEOUGH 2002). Data analysis was conducted using SPSS Statistics 24.0 (IBM CORP. RELEASED 2016).

3. Results

Across vegetation types, total yield declined by about one third from the first to the fifth sampling period (Fig. 3). Decline did not take place continuously, but was greatest from the 2nd to the 3rd sampling period. Decline in yield varied considerably between vegetation types, e.g. from 19% in *Molinia* meadows, to 39% in *Calthion* hay meadows. This strong decline in total yield, as well as in yield between the 1st and 2nd cutting date, led to a high significance of the sampling period, which alone explained between 16% and 23% of variance (Tab. 1). In contrast, vegetation type was only marginally significant in the case of the 2nd cut yield (PES = 2%). This and the, in general, non-significant interaction between vegetation type and sampling period, indicate congruent changes in yield patterns of the grasslands over time (Fig. 3).

Table 1. ANOVA results for the effects of vegetation type, period, and their interactions on total yield, as well as yield of the 1st and 2nd cut, respectively; df = degrees of freedom, MSQ = mean sum of squares, p = error probability, PES = partial eta squared in percent.

Tabelle 1. ANOVA-Ergebnisse für die Auswirkungen von Vegetationstyp, Periode und deren Wechselwirkungen auf den Gesamtertrag sowie auf den Ertrag des 1. und 2. Schnittes; df = Freiheitsgrade, MSQ = mittlere Summe der Quadrate, p = Fehlerwahrscheinlichkeit, PES = partielles eta-Quadrat in Prozent.

	Total biomass				1st cut				2nd cut			
Source	df	MSQ	*p*	PES	df	MSQ	*p*	PES	df	MSQ	*p*	PES
Intercept	1	205352	< 0.001	90	1	103247	< 0.001	87	1	17567	< 0.001	76
Vegetation type [VT]	3	124	0.32	2	3	186	0.050	4	3	36	0.243	2
Period [P]	4	1648	< 0.001	23	4	749	< 0.001	17	4	268	< 0.001	16
P * VT	12	117	0.35	6	12	78	0.348	6	12	21	0.640	4
Error	214	105			213	70			214	25		

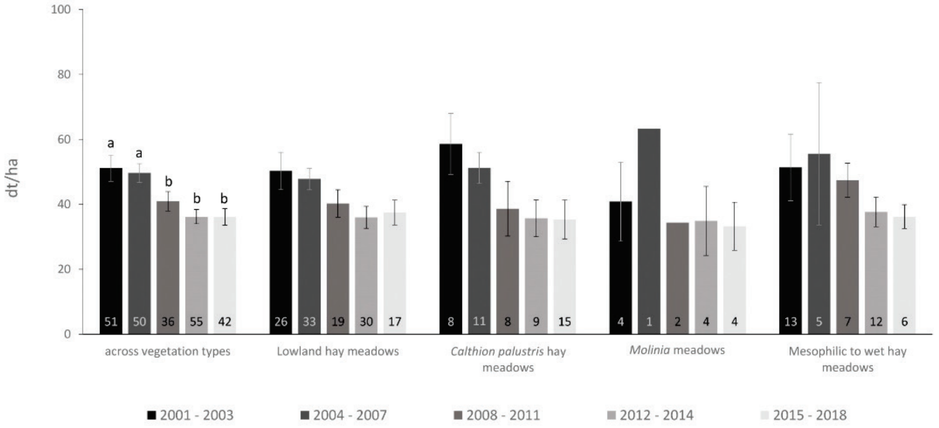


Fig. 3. Total biomass yield across vegetation types and separately for the four vegetation types (mean ± 95% confidence interval). In the case of the data across vegetation types, different letters indicate significant differences between periods assessed by a post-hoc Tukey-test.

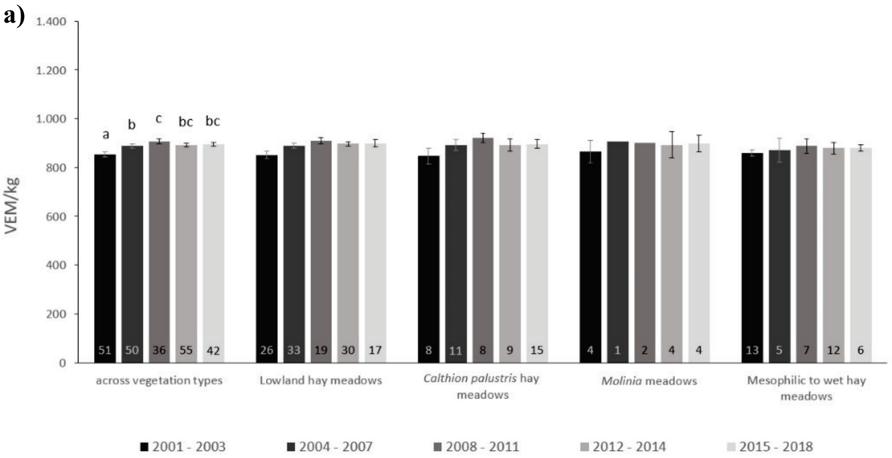
Abb. 3. Gesamter Biomasseertrag über alle Vegetationstypen und getrennt für die vier Vegetationstypen (mittleres ± 95 % Konfidenzintervall). Bei den Daten über alle Vegetationstypen weisen verschiedene Buchstaben auf signifikante Unterschiede zwischen den Zeiträumen hin, die mit dem Tukey-Post-hoc-Test bewertet wurden.

Development of the energy content (VEM) of the biomass harvested at the first and second cut showed a diametrical pattern to total yield (Fig. 4a, b). In both across, as well as within the vegetation types, statistical analysis (cf. Supplement E1) of energy content showed an increase over the years that did not significantly differ between vegetation types. Albeit notable, this increase was relatively small, increasing by about 4% at the first cut and by about 8% at the second cut. While energy content of the first and second cut was significantly influenced by sampling period, only energy content of the second cut differed between vegetation types (Supplement E1). VEVI, the energy parameter, which provides information about the adequacy of the fodder for meat production, showed differences between sampling periods and vegetation types analogous to VEM (Supplement E1).

Despite this increase in energy content, energy yield per ha was halved from the first to the fifth sampling period (Fig. 5). This pattern was mainly explained by sampling period, and only for the first cut was a significant vegetation type effect revealed (Tab. 2). In general, decline in energy yield per ha differed considerably between vegetation types. While in mesophilic to wet meadows energy yield per ha dropped by about one third, *Molinia* meadows showed a drop of 60% in energy yield per ha.

Across vegetation types, the parameters of protein content, i.e. crude protein (Fig. 6), digestible crude protein and DVE (Supplement E1), were always higher in the second compared to the contents in the first cut. Still, protein parameters in biomass of first and second cut showed a common pattern of significant increase from first to third and first to fourth sampling period, respectively, but no significant interaction between vegetation type × sampling period. Only in the case of DVE of the 1st cut did the analysis reveal a significant effect of vegetation type ($p = 0.01$). These general trends of sampling period were also found

a)



b)

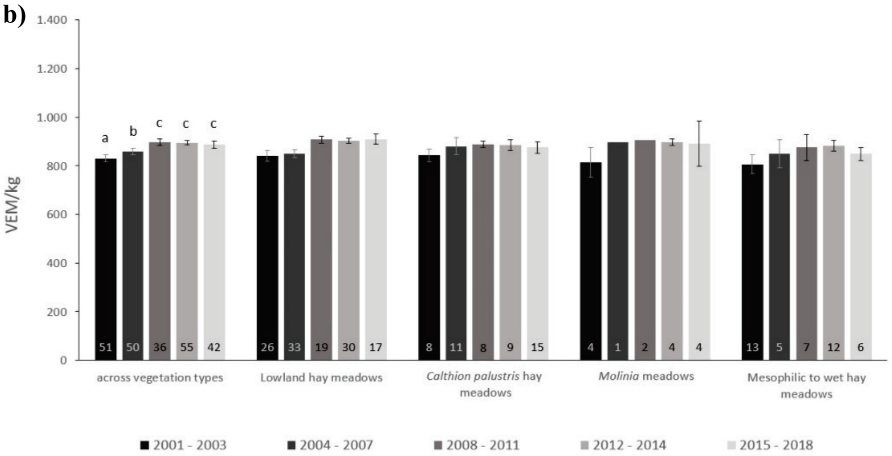


Fig. 4. Energy content of biomass at the **a)** first and **b)** second cut (mean ± 95% confidence interval). In the case of the data across vegetation types, different letters indicate significant differences between periods assessed by a post-hoc Tukey-test.

Abb. 4. Energiegehalt der Biomasse des **a)** ersten und **b)** zweiten Schnittes (mittleres ± 95 % Konfidenzintervall). Im Falle der Daten über alle Vegetationstypen weisen verschiedene Buchstaben auf signifikante Unterschiede zwischen den Zeiträumen hin, die mit dem Tukey-Post-hoc-Test bewertet wurden.

within vegetation types (Fig. 6, Supplement E1). Since protein content is derived from the nitrogen content of the biomass, the above patterns are also true for nitrogen content in the first and second cut.

In contrast to the protein parameters, crude fibre content was higher in the first cut than in the second cut, where it dropped from 30% to about 25% (Supplement E1). While in the first cut vegetation type had a significant effect, the vegetation type × sampling period was, again, not significant. Although levels of crude fibre were significantly lowest in the third sampling period, differences in absolute numbers were rather small and values were not

Table 2. ANOVA results for the effects of vegetation type, period, and their interactions on total energy yield, as well as energy yield of the 1st and 2nd cut, respectively; df = degrees of freedom, MSQ = mean sum of squares, *p* = error probability, PES = partial eta squared in percent.

Tabelle 2. ANOVA-Ergebnisse für die Auswirkungen von Vegetationstyp, Periode und deren Wechselwirkungen auf den Gesamtenergieertrag sowie den Energieertrag des 1. und 2. Schnittes; df = Freiheitsgrade, MSQ = mittlere Summe der Quadrate, *p* = Fehlerwahrscheinlichkeit, PES = partielles eta-Quadrat in Prozent.

	Total kVEM/ha				1st cut				2nd cut			
Source	df	MSQ	*p*	PES	df	MSQ	*p*	PES	df	MSQ	*p*	PES
Intercept	1	142 *10^{7}	< 0.001	89	1	702*10^{6}	< 0.001	84	1	126*10^{6}	< 0.001	74
Vegetation type [VT]	3	220*10^{4}	0.054	3	3	279*10^{4}	0.004	6	3	131*10^{3}	0.593	1
Period [P]	4	247*10^{5}	< 0.001	35	4	115*10^{5}	< 0.001	26	4	268*10^{4}	< 0.001	20
P * VT	12	103*10^{4}	0.27	6	12	684159	0.34	6	12	117424	0.87	3
Error	214	852299			213	605932			214	206890		

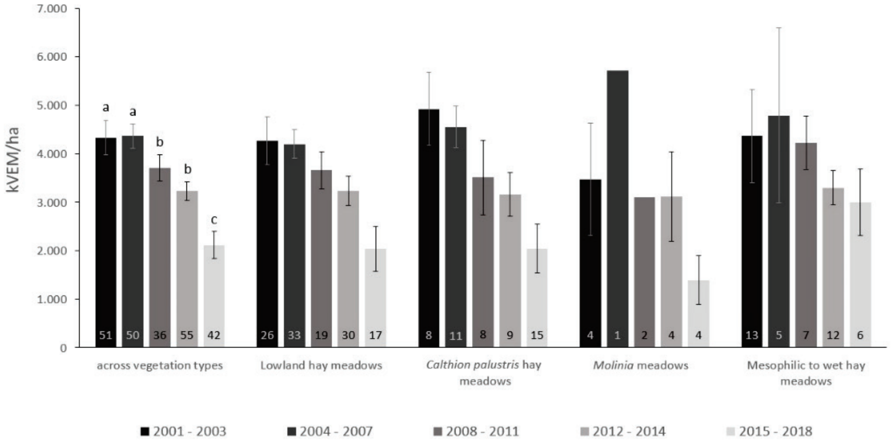


Fig. 5. Total energy yield per ha (mean ± 95% confidence interval). In the case of the data across vegetation types, different letters indicate significant differences between periods assessed by a post-hoc Tukey-test.

Abb. 5. Gesamtenergieertrag pro ha (mittleres ± 95 % Konfidenzintervall). Im Falle der Daten über alle Vegetationstypen weisen verschiedene Buchstaben auf signifikante Unterschiede zwischen den Zeiträumen hin, die mit dem Post-hoc-Tukey-Test bewertet wurden.

significantly different between the first and last sampling period (Fig. 7). Crude ash content showed a significant decrease from the first to the third sampling period in the first and second cut (Supplement E1).

Phosphorus is not only of relevance for cattle nutrition, but, when present in low concentrations, an indicator for potentially species-rich grasslands. Generally, in the last sampling period, phosphorus content of the first cut was about one sixth lower than in the biomass of the second cut (2.24 ± 0.09 vs. 2.90 ± 0.14). Differences between vegetation types were rather small but significant. Although phosphorus content of the biomass across vegetation

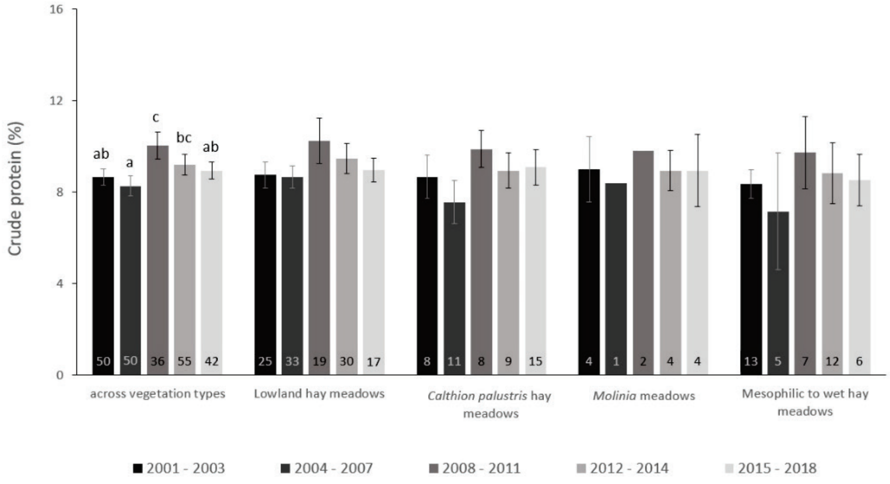


Fig. 6. Content of crude protein in biomass of the first cut in percentage (mean ± 95% confidence interval). In the case of the data across vegetation types, different letters indicate significant differences between periods assessed by a post-hoc Tukey-test.

Abb. 6. Rohfasergehalt in der Biomasse des ersten Schnittes in Prozent (Mittelwert ± 95 % Konfidenzintervall). Im Falle der Daten über alle Vegetationstypen weisen verschiedene Buchstaben auf signifikante Unterschiede zwischen den Perioden hin, die mit dem Tukey-Post-hoc-Test bewertet wurden.

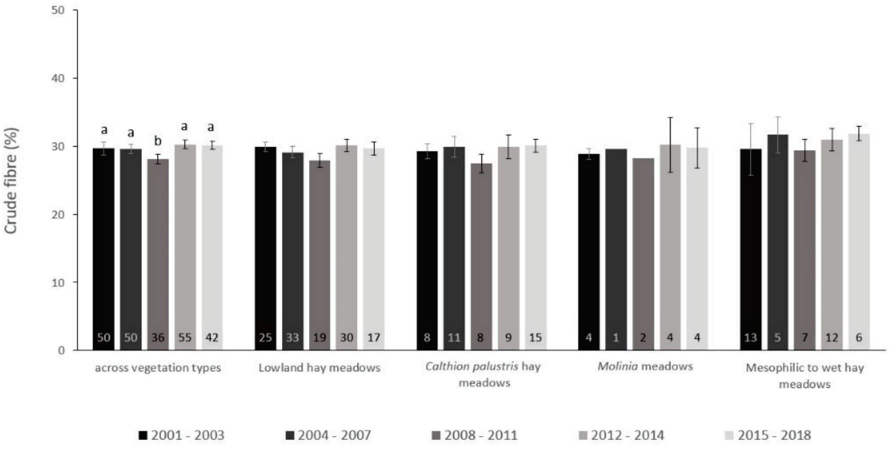


Fig. 7. Content of crude fibre in biomass of the first cut in percentage (mean ± 95% confidence interval). In the case of the data across vegetation types, different letters indicate significant differences between periods assessed by a post-hoc Tukey-test.

Abb. 7. Rohfasergehalt in der Biomasse des ersten Schnittes in Prozent (Mittelwert ± 95 % Konfidenzintervall). Im Falle der Daten über alle Vegetationstypen weisen verschiedene Buchstaben auf signifikante Unterschiede zwischen den Zeiträumen hin, die mit dem Tukey-Post-hoc-Test bewertet wurden.

types showed some significant differences between years, these variations in time were rather small and indicated no clear temporal trend (Supplement E1). Again, a non-significant vegetation type × sampling period interaction indicated that all vegetation types showed the same response pattern over time.

Variation over time of minerals relevant for cattle nutrition, i.e. calcium, magnesium, potassium and sodium were relatively small both across, as well as within, vegetation types. Only in potassium content of the first cut, and magnesium and calcium content in the second cut, do significant differences indicate a decrease in the content of these minerals from the first to fourth sampling period (Supplement E1). Although in almost all cases contents differed between vegetation types (except for K in the first cut), and trends over time were quite similar (i.e. the significant interaction in the case of Na [1st and 2nd cut], Mg [2nd cut] and K [1st cut]), analysis always indicated a quantitative and not a qualitative interaction.

4. Discussion

In general, the biomass yield of all meadows studied lies between that found by other authors for non-intensively managed grassland, and about 50% to 80% below the yield of intensively-managed grassland (SCHMID & JEANGROS 1990, PEETERS & JANSSENS 1998, TALLOWIN & JEFFERSON 1999, ISSELSTEIN et al. 2005). Yield and energy content were the two response parameters that showed the most obvious changes over time. While yield decreased until the third sampling period, energy content increased during the same period. Energy yield (VEM/ha) still declined because the increase in energy in the biomass was too small to compensate for the decline in biomass yield. The continuous decline of biomass yield under non-intensive grassland management without fertilizer input is not surprising (TALLOWIN 1999, WALTER et al. 2012). This decline was much lower than in studies focussing on changes in these parameters when intensively-managed high-input grassland was transformed into non-intensively low-input grassland (ISSELSTEIN et al. 2005). In contrast to such studies, all grasslands included in our study were already species-rich grasslands of high nature conservation value when first sampled. Only grasslands that meet certain thresholds of floristic quality parameters are accepted into the contractual nature conservation programme. Even so, in these high-quality grasslands yield still tended to decline until the third sampling period. There might be two reasons for this pattern to occur. Firstly, some of these grasslands might have received sporadic and low input of organic fertilizer (mainly solid manure) before the conclusion of the nature conservation contracts precluded any kind of fertilization. Secondly, any fertilization of these grasslands might have already stopped quite some time before they were included in the contractual nature conservation programme. In these cases, we might just have observed the continuation of productivity decline after the cessation of fertilization, which is a process lasting for at least 15 years (BRIEMLE 1987). Still, our data suggests that this decline in yield linked to decreasing nutrient availability does slow down or even halts when total yield reached a certain threshold around 35 dt/ha (Fig. 3). This suggests that in our study grasslands mineralisation and removal of nutrients are in balance. Parallel to our finding of decreasing yield under reduced nutrient availability, WOLFF et al. (2020) found in the same study area that under continuous non-intensively grassland management overall species composition was conserved and value-adding grassland species even increased both in number and abundance. This pattern of increasing species-richness when nutrient availability declines is well established (JANSSENS et al. 1998, HEINSOO et al. 2020).

We found only small differences in yield change over the years between vegetation types. Interestingly, despite some differences in the size and pattern of decline in total biomass from the first to the third sampling period, total biomass of all vegetation types declined no further than around 35 dt/ha (Fig. 3). This highlights the generality of the observed pattern in yield decline, independent of vegetation type and associated site conditions (TALLOWIN & JEFFERSON 1999). It is interesting to note that the decrease in yield was accompanied by an increase in protein and energy content on the one hand and a reduction of crude fibre on the other. It is well established that a decrease in nutrient availability favours forbs over grasses (MARRS 1993). Under the precondition of the relatively late cut, an increasing abundance of forbs is responsible for the increase in protein and energy parameters over time. While grasses already show signs of quality decrease (i.e. an increase of crude fibre and decrease of crude protein) early in the vegetation period when the growth of the inflorescence sets in, in the biomass of herbs, senescence starts later and occurs at a slower rate (LEHMANN et al. 1985, OPITZ V. BOBERFELD & THEOBALD 2003). This general pattern is even pronounced under nature conservation contracts that preclude a first harvest before the beginning of June. In addition, vegetation of unfertilized grasslands has to rely solely on those nutrients made available through mineralization, which depends on soil moisture and soil temperature (LEUSCHNER & ELLENBERG 2017). Thus, biomass growth in an unfertilized grassland starts later than in a fertilized grassland. This later start of biomass growth also postpones the onset of biomass senescence, both of grasses and forbs, and tends to increase fodder quality at later cutting dates. Nutrition tables from the Luxembourg Ministry of Agriculture, the German Agricultural Society and the Bavarian State Research Centre for Agriculture for different livestock (DLG 1997, 1998, LFL 2020, MA 2020) suggest that the fodder, which is mostly harvested as hay, can be useful in basic rations. This is in accordance with several authors' findings (TALLOWIN & JEFFERSON 1999, FRANKE 2003, DONATH et al. 2004), who confirmed that biomass with a similar date of harvest tended not to reach the energy levels of high quality forages (NEL > 6 MJ kg^{-1} dm^{-1}, which is equivalent to VEM of about 830 kg^{-1} dm^{-1}), however it should be sufficient to cover the basic requirements of cattle. Since we sampled biomass from species-rich grasslands of high nature conservation value, phosphorus levels were relatively low (TALLOWIN & JEFFERSON 1999). While sodium concentrations were below minimum thresholds for cattle (JARRIGE & MARTIN-ROSSET 1981, LFL 2020), other minerals met the minimum requirements of basic rations.

It is a common phenomenon that fodder from high nature conservation grassland will often meet only the basic requirements of cattle, but rarely those during periods of higher energy demands, e.g. gestation, lactation, growing or hard work. During these periods, fodder of species-rich grasslands can at most only make up a small portion of the total fodder ration (ARNAUD 2019). Still, even continuous feeding of small amounts will add up to a surprisingly high amount of fodder that can be integrated into the farming system. Even in intensive cattle farming, hay from species-rich meadows can be useful as a raw fibre component of the total ration. Therefore, local farmers feed 1 kg hay per cow per day from the type of species-rich meadows under study, which adds up to 365 kg hay per cow per year (SCHUMACHER 2016, pers. comm. Biver 2018). Thus, a herd of 83 cows, which is the average size of a dairy herd in Luxembourg, could consume a total of about 8 ha of species-rich low-input grassland (cf. Fig. 2). Since the portion of this low-energy fodder can be higher during periods of lower energy demands, e.g. in the case of dry cows, young stock or suckling cows, the area integrated into a cattle farm can be even higher (SCHUMACHER 2016, ARNAUD 2019).

5. Conclusion

Our results highlight that for non-intensive grassland management the aims of farmers and nature conservationists can be aligned (Tallowin & Jefferson 1999, Franke 2003). It is obvious that the quantity and quality of the fodder harvested from such species-rich grasslands do not meet the highest standards of intensive grassland management, but still the biomass can be well-integrated, even into local cattle farming. Thus, this study supports the findings that a higher nature conservation value does not preclude agricultural management (Franke 2003, Donath et al. 2004). This notion is supported by the finding that despite a decreasing quantity, the quality of the biomass tends to increase and not to decrease with increasing nature conservation value (Franke 2003, Donath et al. 2004).

In addition to feeding cattle, fodder from such meadows is predesignated to be fed to horses whose health and well-being precludes high-energy fodder, and which are able to compensate for lower forage quality by a higher daily intake (Duncan et al. 1990, Menard et al. 2002). Thus, the production of hay for horses could enable farmers to diversify their sources of income (Donath et al. 2015). Schumacher (2007) suggests the production of hay for small pets, e.g. rabbits, hamster and guinea pigs, as a further option to make use of the biomass from species-rich low-input grasslands. In the strategy for the conservation of the species-rich grassland in Luxembourg, this approach is proposed and could even be financially supported. Additional approaches and concrete recommendations for actions to preserve species-rich grassland are also elaborated in this strategy (MECDD 2020).

Currently, farmers receive 420 €/ha a year as compensation under the contractual nature conservation scheme for non-intensively managed grassland in Luxembourg. Within this programme, farmers are allowed to harvest once or twice a year, but are not allowed to fertilize the grassland. For biotopes, as defined in the nature protection act, an additional top-up is paid: for biotopes of the highest (A) and second highest (B) category according to the EU FFH directive, farmers receive an additional premium of 100 €/ha and 50 €/ha, respectively Mémorial (2017). Acceptance of these compensation payments depends on the marginal conditions of grassland management, such as productivity or marketing opportunities. With decreasing quality and quantity of the harvested biomass, compensation payments need to be increased to keep such nature conservation schemes attractive for farmers (Hofmann et al. 2010). Thus, the decrease in yield observed in this study over a period of 18 years calls for an increase of the compensation payments. Based on this observed decline in yield of about one third during the last 18 years, we recommend an equivalent increase of at least 30%, both for the basic payment and for the top-up premiums. This is in view of the fact that the land currently under contract represents the last remnants of non-intensively managed grassland types in Luxembourg, and because significantly higher premiums are paid for other contractual nature conservation programmes with significantly fewer management restrictions such as pasture management. However, the specific species composition and diversity of the grassland types analysed in the present study depend on a meadow rather than pasture management (Briemle & Ellenberg 1994). Therefore, this increase in premiums for meadow management is not only a justified, but also a much-needed investment for maintaining grassland diversity and its associated cultural heritage. In addition, this would be an adequate reward for those farmers whose low-input management created, and who are willing to preserve, these species-rich grasslands, which have to preserved at all costs.

Erweiterte deutsche Zusammenfassung

Einleitung – Trotz vieler Bemühungen, artenreiches Grünland mit hohem Naturschutzwert zu schützen und erhalten, hält der Verlust an artenreichem Grünland weiter an. Zu den vielversprechendsten Bemühungen gehört ihre Einbeziehung in den Vertragsnaturschutz. Futtermenge, Qualität und Höhe der angebotenen Ausgleichszahlungen sind die Dreh- und Angelpunkte für die Landwirte, sich am Vertragsnaturschutz zu beteiligen. Würden Futterquantität und/oder -qualität mit zunehmendem Artenreichtum relativ stabil bleiben, würde dies helfen, die Interessen von Naturschützern und Landwirten in Einklang zu bringen. Deshalb analysierten wir Futterqualitäts- und -ertragsdaten von artenreichen Grünlandflächen verschiedener Pflanzengesellschaften, die über einen Zeitraum von 18 Jahren erhoben wurden. Konkret waren wir an der Beantwortung der folgenden Fragen interessiert: (1) Welchen Einfluss hatte das langfristige extensive Management auf Futtermenge und -qualität? (2) Unterschieden sich die beobachteten Muster zwischen den Graslandtypen? (3) Welches Gesamtpotenzial besteht bei der Verwendung von Futter aus extensiv bewirtschaftetem artenreichem Grünland in der Tierhaltung?

Methoden – Die Untersuchungsflächen lagen im Südwesten von Luxemburg (Abb. 1). Die untersuchten Wiesen gehören zu den Mageren Flachlandwiesen (FFH 6510), den Sumpfdotterblumenwiesen, den Pfeifengraswiesen (FFH 6410) und den mesophilen bis feuchten Magerwiesen. Diese Magerwiesen sind in Luxemburg selten geworden, und es gilt sie durch eine geeignete Nutzung zu erhalten. Ab 2001 wurde auf jeder untersuchten Grünlandparzelle eine Fläche von 100 m^2 für die Biomasseprobenahme ausgewählt. Die Beprobung des ersten Schnittes erfolgte in der Regel einige Tage vor dem 15. Juni, dem frühesten Mähtermin im Vertragsnaturschutz, und die Beprobung des zweiten Schnittes fand zwischen Anfang August und Ende September statt. Insgesamt konnten 468 Proben von 145 Untersuchungsstandorten analysiert werden.

Es wurde eine Reihe von Futtermittelparametern ausgewertet, u. a. Trockensubstanz, Rohprotein, verdauliches Rohprotein, VEM (Futtereinheiten Milch), VEVI (Futtereinheiten Fleischvieh intensiv) sowie einige wichtige Nährelemente. Um den Unterschieden in der Stichprobenintensität zwischen den Jahren und der kurzfristigen Variabilität zwischen den Jahren Rechnung zu tragen, wurden Stichprobenzeiträume festgelegt. Die Daten für alle Vegetationstypen wurden mit Hilfe einer zweifaktoriellen ANOVA analysiert, um den Einfluss der Hauptfaktoren Vegetationstyp ($k = 4$) und Beprobungsperiode ($k = 5$) sowie deren Interaktionseffekt auf die Antwortvariablen zu bewerten. Bei signifikanten ANOVA-Ergebnissen, die auf das Vorhandensein relevanter allgemeiner Muster hindeuteten, wurden die paarweisen Unterschiede zwischen den Stichprobenperioden mittels Tukey-Test bewertet.

Ergebnisse – Über alle Vegetationstypen hinweg ging der Gesamtertrag von der ersten bis zur fünften Probenahmeperiode um etwa ein Drittel zurück (Abb. 3). Der Rückgang erfolgte nicht kontinuierlich, sondern war von der 2. bis zur 3. Beprobungsperiode am stärksten. Der Ertragsrückgang war je nach Vegetationstyp sehr unterschiedlich. Die Entwicklung des Energiegehalts (VEM) zeigte ein diametrales Muster zum Gesamtertrag (Abb. 4 a, b). Sowohl über alle als auch innerhalb der Vegetationstypen zeigten unsere Untersuchungen einen geringen Anstieg des Energiegehalts über die Zeit, der sich in der Größe zwischen den Vegetationstypen nicht signifikant unterschied. VEVI zeigte analoge Unterschiede zwischen Probenahmezeiträumen und Vegetationstypen wie VEM (Anhang E1).

Trotz dieses Anstiegs des Energiegehalts halbierte sich der Energieertrag pro ha von der ersten bis zur fünften Beprobungsperiode (Abb. 5). Im Allgemeinen unterschied sich der Rückgang des Energieertrags je nach Vegetationstyp erheblich.

Über die Vegetationstypen hinweg waren die Parameter des Proteingehalts (Abb. 6, Anhang E1) im zweiten Schnitt immer höher als die Gehalte im ersten Schnitt. Dennoch zeigten die Proteinparameter in der Biomasse der ersten und zweiten Ernte ein gemeinsames Muster mit einem signifikanten Anstieg vom ersten bis zum dritten bzw. ersten bis zum vierten Stichprobenzeitraum, aber keine signifikante Wechselwirkung zwischen Vegetationstyp × Stichprobenzeitraum. Im Gegensatz zu den Proteinparametern waren die Rohfasergehalte im ersten Schnitt höher als im zweiten Schnitt (Anhang E1). Während im ersten Schnitt der Vegetationstyp eine signifikante Wirkung hatte, war der Vegetationstyp × Probenahmezeitraum wiederum nicht signifikant. Obwohl die Rohfasergehalte in der dritten Probenahmeperiode signifikant am niedrigsten waren, waren die Unterschiede in absoluten Zahlen eher gering und die Werte zwischen der ersten und der letzten Probenahmeperiode nicht signifikant unterschiedlich (Abb. 7).

Im Allgemeinen war der Phosphorgehalt des ersten Schnittes in der letzten Beprobungsperiode etwa ein Sechstel niedriger als in der Biomasse des zweiten Schnittes. Auch hier deutete eine nicht signifikante Wechselwirkung zwischen Vegetationstyp × Probenahmezeitraum darauf hin, dass alle Vegetationstypen im Laufe der Zeit das gleiche Reaktionsmuster zeigten.

Die zeitlichen Schwankungen der Gehalte an anderen für die Rinderernährung relevanten Mineralien, d. h. Calcium, Magnesium, Kalium und Natrium, waren sowohl zwischen als auch innerhalb der Vegetationstypen relativ gering (Anhang E1).

Diskussion – Im Allgemeinen liegt der Biomasseertrag aller Wiesen innerhalb der von anderen Autoren für extensiv bewirtschaftetes Grünland gefundenen Werte und etwa 50 % bis 80 % unter dem Ertrag von intensiv bewirtschaftetem Grünland (SCHMID & JEANGROS 1990, PEETERS & JANSSENS 1998, TALLOWIN & JEFFERSON 1999, ISSELSTEIN et al. 2005).

Es zeigte sich, dass der Ertragsrückgang unabhängig vom Vegetationstyp und den damit verbundenen Standortbedingungen ist (TALLOWIN & JEFFERSON 1999). Interessant ist, dass der Ertragsrückgang einerseits mit einem Anstieg des Protein- und Energiegehalts und andererseits mit einer Verringerung der Rohfaser einherging. Es ist gut belegt, dass die Abnahme der Nährstoffverfügbarkeit Kräuter gegenüber Gräser begünstigt (MARRS 1993). Unter der Voraussetzung des relativ späten Schnittes ist ein zunehmender Anteil an typischen Wiesenkräutern für den Anstieg der Protein- und Energieparameter im Laufe der Zeit verantwortlich. Während Gräser bereits zu Beginn der Vegetationsperiode Anzeichen einer Qualitätsminderung (d. h. Zunahme der Rohfaser und Abnahme des Rohproteins) zeigen, setzt bei der Biomasse der Kräuter die Seneszenz später ein und verläuft langsamer (LEHMANN et al. 1985, OPITZ v. BOBERFELD & THEOBALD, 2003). Der spätere Beginn des Biomassewachstums in extensiv genutzten Wiesen verzögert auch das Einsetzen der Seneszenz der Biomasse, sowohl von Gräsern als auch von Kräutern, und erhöht tendenziell die Futterqualität zu späteren Schnittzeitpunkten.

Nährwerttabellen deuten darauf hin, dass das als Heu geerntete Futter gut in Grundrationen eingesetzt werden kann. Dies steht im Einklang mit den Ergebnissen mehrerer Autoren (TALLOWIN & JEFFERSON 1999, FRANKE 2003, DONATH et al. 2005), die bestätigten, dass Biomasse mit einem ähnlichen Erntezeitpunkt tendenziell nicht das energetische Niveau von hochwertigem Futtermitteln erreicht; dennoch sollte sie ausreichen, um den Grundbedarf von Rindern zu decken.

Es ist ein häufiges Phänomen, dass Futter von Naturschutzgrünland oft nur den Grundbedarf der Rinder deckt, selten aber den Bedarf in Zeiten mit höherem Energiebedarf. In diesen Perioden kann das Futter von artenreichem Grünland nur einen kleinen Teil der Gesamtfutterration ausmachen (ARNAUD 2019). Doch selbst die kontinuierliche Verfütterung kleiner Mengen wird sich zu einer erstaunlich hohen Menge an Futter summieren, die in das landwirtschaftliche System integriert werden kann. Selbst in der intensiven Viehhaltung kann Heu von artenreichen Wiesen gut als Rohfaserkomponente der Gesamtration eingesetzt werden – es eignet sich gut für die Fütterung von trockenstehenden Kühen, Jungvieh oder Mutterkühen (SCHUMACHER 2016, ARNAUD 2019, pers. Mitt. Biver 2018).

Schlussfolgerung – Es ist bekannt, dass die Quantität und Qualität des Futters, das von solch artenreichem Grasland geerntet wird, nicht den höchsten Standards einer intensiven Grünlandbewirtschaftung entspricht; aber dennoch kann die Biomasse auch in die lokale Viehhaltung gut integriert werden. Damit unterstützt diese Studie die Ergebnisse, dass ein höherer Naturschutzwert die landwirtschaftliche Bewirtschaftung nicht ausschließt.

Zusätzlich zur Fütterung von Rindern ist das Futter von solchen Wiesen für die Fütterung von Pferden vorgesehen. Somit könnte die Produktion von Heu für Pferde den Landwirten eine Diversifizierung ihrer Einkommensquellen ermöglichen (DONATH et al. 2015). SCHUMACHER (2007) schlägt die Produktion von Heu für kleine Haustiere, z. B. Kaninchen, Hamster und Meerschweinchen, als eine weitere Option vor, um die Biomasse von artenreichem, ertragsärmeren Grünland zu nutzen.

Der beobachtete Ertragsrückgang über einen Zeitraum von 18 Jahren erfordert eine Erhöhung der Ausgleichszahlungen. Aufgrund des beobachteten Ertragsrückgangs von rund einem Drittel im Zeitraum von 2001–2018 und der Tatsache, dass es sich um die letzten Reste dieser Grünlandtypen handelt, empfehlen wir eine entsprechende Erhöhung der Förderprämie um mindestens 30 %. Dies wäre eine angemessene Entlohnung für diejenigen Landwirte, die mit ihrer extensiven Bewirtschaftung diese artenreichen Grünlandflächen geschaffen haben und die weiterhin bereit sind, diese artenreichen Wiesen und Weiden zu erhalten.

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Author contributions

S. Schneider and T.W. Donath developed and supervised the research project. D. Viain performed the analysis. All authors discussed the results and contributed to the final manuscript.

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Supplements

Additional supporting information may be found in the online version of this article.

Zusätzliche unterstützende Information ist in der Online-Version dieses Artikels zu finden.

Supplement E1. Yield and forage parameters [mean ± S.E.] of non-intensively managed grasslands in south-western Luxembourg.

Anhang E1. Ertrag und Futterparameter [Mittelwert ± S.E.] extensiv genutzter Grünlandbestände im Südwesten Luxemburgs.

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Supplement E1. Yield and forage parameters [mean ± S.E.] of non-intensively managed grasslands in south-western Luxembourg.

Anhang E1. Ertrag und Futterparameter [Mittelwert ± S.E.] extensiv genutzter Grünlandbestände im Südwesten Luxemburgs.

across vegetation types		2001 - 2003					2004 - 2007					2008 - 2011					2012 - 2014					2015 - 2018				
	Cut	*n*	mean		S.E.	Sig.	*n*	mean		S.E.	Sig.	*n*	mean		S.E.	Sig.	*n*	mean		S.E.	Sig.	*n*	mean		S.E.	Sig.
Dry Matter Yield (dt/ha)	1st	51	36.3	±	1.6	a	50	35.3	±	1.2	a	36	26.1	±	1.2	b	55	25.7	±	0.9	b	41	28.1	±	1.1	b
	2nd	51	14.9	±	1.0	a	50	14.3	±	0.7	a	36	14.9	±	0.7	b	55	10.5	±	0.4	b	42	8.7	±	0.7	b
Crude Protein (%)	1st	50	8.6	±	0.2	ab	50	8.3	±	0.2	a	36	10.0	±	0.3	c	55	9.2	±	0.2	bc	42	8.9	±	0.2	ab
	2nd	50	11.4	±	0.3	a	50	13.4	±	0.4	b	36	14.5	±	0.3	bc	55	14.7	±	0.2	c	42	13.7	±	0.3	bc
Digestible Crude Protein (g/kg)	1st	51	46.6	±	1.6	ab	50	42.2	±	2.1	a	36	59.1	±	2.8	c	55	50.9	±	2.2	b	42	48.3	±	1.7	ab
	2nd	51	71.2	±	2.8	a	50	89.1	±	2.8	b	36	97.7	±	3.2	bc	55	100.5	±	2.2	c	42	93.3	±	2.9	bc
DVE (g/kg)	1st	51	63.4	±	0.8	a	50	65.5	±	0.9	ab	36	71.7	±	0.9	c	55	68.1	±	0.8	b	42	67.6	±	0.6	b
	2nd	51	69.7	±	1.4	a	49	80.0	±	1.2	b	36	84.2	±	2.1	bc	55	85.2	±	0.7	c	42	80.4	±	1.1	bc
Crude Fibre (%)	1st	50	29.7	±	0.5	a	50	29.6	±	0.3	a	36	28.1	±	0.3	b	55	30.3	±	0.3	a	42	30.1	±	0.3	a
	2nd	51	25.7	±	0.4	ab	48	24.5	±	0.4	a	36	22.9	±	0.5	c	55	24.4	±	0.3	a	42	26.2	±	0.4	b
Crude Ash (%)	1st	49	8.9	±	0.3	a	50	7.6	±	0.1	b	36	7.5	±	0.1	bc	55	6.8	±	0.1	c	42	6.8	±	0.1	c
	2nd	50	12.5	±	0.3	a	50	10.9	±	0.3	b	36	9.6	±	0.2	c	55	9.1	±	0.1	c	42	9.1	±	0.3	c
VEM/kg dm	1st	51	854.5	±	4.7	a	50	889.2	±	4.4	b	36	907.5	±	4.8	c	55	892.1	±	4.1	bc	42	895.4	±	4.3	bc
	2nd	51	829.9	±	7.5	a	50	858.0	±	6.7	b	36	896.9	±	6.2	c	55	895.1	±	4.1	c	42	886.8	±	6.9	c
VEVI/kg dm	1st	51	869.8	±	5.5	a	50	913.1	±	5.7	bc	36	935.8	±	6.2	c	26	910.2	±	8.2	b	42	914.9	±	5.1	bc
	2nd	51	846.1	±	9.1	a	50	877.5	±	8.3	ab	36	924.9	±	7.8	c	26	917.0	±	6.1	c	42	909.9	±	8.9	bc
kVEM/ha	1st	51	3100.4	±	136.9	a	50	3133.5	±	102.7	a	36	2361.9	±	109.9	b	55	2286.9	±	79.5	b	41	1545.8	±	150.6	c
	2nd	51	1233.5	±	80.4	a	50	1233.5	±	63.4	a	36	1340.2	±	69.2	b	55	940.5	±	37.9	b	42	604.9	±	74.2	c
N (%)	1st	50	1.4	±	0.0	ab	50	1.3	±	0.0	a	36	1.6	±	0.0	c	55	1.5	±	0.0	bc	42	1.4	±	0.0	ab
	2nd	50	1.8	±	0.0	a	50	2.1	±	0.1	b	36	2.3	±	0.1	bc	55	2.3	±	0.0	c	42	2.2	±	0.0	bc
P (g/kg)	1st	51	2.2	±	0.1	ab	45	2.1	±	0.1	a	36	2.2	±	0.1	ab	55	2.4	±	0.0	b	42	2.2	±	0.0	ab
	2nd	45	2.9	±	0.1	a	50	3.1	±	0.1	a	36	3.0	±	0.1	a	55	3.2	±	0.0	a	42	2.9	±	0.1	a
Ca (g/kg)	1st	51	7.1	±	0.3	ab	45	8.1	±	0.4	bc	36	8.6	±	0.3	c	55	6.7	±	0.3	a	42	7.1	±	0.2	ab
	2nd	45	11.1	±	0.4	ab	50	11.1	±	0.5	ab	36	12.5	±	0.5	b	55	10.2	±	0.3	ac	42	9.3	±	0.3	c
K (g/kg)	1st	51	15.7	±	0.4	a	45	15.2	±	0.6	ab	36	15.6	±	0.4	a	55	15.1	±	0.5	ab	42	13.5	±	0.4	b
	2nd	45	15.4	±	0.9	a	50	20.3	±	0.8	c	36	17.3	±	0.5	ab	55	18.7	±	0.5	bc	42	15.6	±	0.9	a
Na (g/kg)	1st	51	1.1	±	0.1	a	45	1.0	±	0.1	a	35	1.6	±	0.2	b	55	0.9	±	0.1	a	42	1.0	±	0.1	a
	2nd	45	1.5	±	0.2	ab	49	1.8	±	0.2	ab	35	1.9	±	0.3	b	55	1.5	±	0.1	ab	40	1.3	±	0.1	a
Mg (g/kg)	1st	51	2.1	±	0.1	a	45	2.2	±	0.1	ab	36	2.4	±	0.1	b	55	2.2	±	0.1	ab	42	2.3	±	0.1	ab
	2nd	45	3.2	±	0.1	a	50	3.2	±	0.1	a	36	3.5	±	0.1	a	55	3.2	±	0.1	a	42	2.8	±	0.1	b

Lowland hay meadows		2001 - 2003				2004 - 2007				2008 - 2011				2012 - 2014				2015 - 2018			
	Cut	*n*	mean		S.E.	*n*	mean		S.E.	*n*	mean		S.E.	*n*	mean		S.E.	*n*	mean		S.E.
Dry Matter Yield (dt/ha)	1st	26	36.0	±	2.0	33	33.4	±	1.0	19	25.3	±	1.4	30	25.4	±	1.4	17	29.4	±	2.0
	2nd	26	14.3	±	1.3	33	14.4	±	0.9	19	14.9	±	1.0	30	10.6	±	0.6	17	8.1	±	1.2
Crude Protein (%)	1st	25	8.7	±	0.3	33	8.7	±	0.2	19	10.2	±	0.5	30	9.5	±	0.3	17	8.9	±	0.2
	2nd	25	11.8	±	0.5	33	13.3	±	0.5	19	14.2	±	0.4	30	14.9	±	0.3	17	14.4	±	0.4
Digestible Crude Protein (g/kg)	1st	26	47.8	±	2.6	33	46.1	±	2.3	19	61.1	±	4.6	30	53.3	±	3.1	17	48.5	±	2.4
	2nd	26	74.0	±	4.5	33	89.8	±	3.2	19	93.5	±	4.2	30	103.3	±	2.8	17	99.6	±	4.0
DVE (g/kg)	1st	26	63.7	±	1.4	33	66.7	±	1.0	19	72.3	±	1.5	30	69.2	±	1.0	17	68.3	±	1.1
	2nd	26	71.7	±	2.0	32	79.1	±	1.3	19	83.0	±	3.6	30	86.3	±	0.9	17	84.1	±	1.3
Crude Fibre (%)	1st	25	29.9	±	0.3	33	29.1	±	0.4	19	27.9	±	0.5	30	30.1	±	0.4	17	29.7	±	0.4
	2nd	26	25.4	±	0.5	32	25.2	±	0.4	19	22.3	±	0.9	30	24.3	±	0.4	17	25.0	±	0.6
Crude Ash (%)	1st	25	9.0	±	0.5	33	7.9	±	0.2	19	7.6	±	0.2	30	6.6	±	0.2	17	6.8	±	0.3
	2nd	25	12.1	±	0.4	33	11.0	±	0.3	19	9.1	±	0.2	30	8.8	±	0.2	17	8.6	±	0.2
VEM/kg dm	1st	26	852.4	±	7.4	33	889.9	±	5.1	19	909.1	±	6.2	30	897.1	±	4.9	17	899.1	±	7.3
	2nd	26	840.0	±	10.6	33	850.7	±	7.9	19	907.4	±	7.5	30	903.0	±	5.4	17	909.9	±	9.4
VEVI/kg dm	1st	26	867.5	±	8.7	33	914.4	±	6.7	19	937.9	±	8.0	15	915.5	±	10.6	17	923.1	±	9.2
	2nd	26	858.1	±	13.0	33	868.1	±	9.8	19	938.1	±	9.7	15	917.0	±	9.5	17	936.8	±	12.2
kVEM/ha	1st	26	3069.8	±	176.0	33	2971.9	±	93.3	19	2298.7	±	129.9	30	2275.5	±	122.9	17	1413.4	±	233.1
	2nd	26	1200.0	±	112.9	33	1227.2	±	72.6	19	1356.1	±	89.2	30	957.2	±	55.8	17	620.0	±	146.9
N (%)	1st	25	1.4	±	0.0	33	1.4	±	0.0	19	1.6	±	0.1	30	1.5	±	0.1	17	1.4	±	0.0
	2nd	25	1.9	±	0.1	33	2.1	±	0.1	19	2.3	±	0.1	30	2.4	±	0.0	17	2.3	±	0.1
P (g/kg)	1st	26	2.2	±	0.1	28	2.1	±	0.1	19	2.1	±	0.1	30	2.4	±	0.0	17	2.2	±	0.1
	2nd	23	2.8	±	0.1	33	3.0	±	0.1	19	2.8	±	0.1	30	3.2	±	0.0	17	3.0	±	0.1
Ca (g/kg)	1st	26	7.7	±	0.4	28	8.8	±	0.5	19	8.7	±	0.5	30	7.0	±	0.4	17	7.6	±	0.3
	2nd	23	11.4	±	0.6	33	11.9	±	0.6	19	12.8	±	0.6	30	10.6	±	0.3	17	10.4	±	0.4
K (g/kg)	1st	26	15.9	±	0.6	28	17.1	±	0.7	19	15.6	±	0.6	30	14.7	±	0.6	17	12.6	±	0.7
	2nd	23	15.7	±	1.4	33	21.8	±	1.0	19	17.6	±	0.8	30	18.7	±	0.6	17	15.6	±	1.2
Na (g/kg)	1st	26	1.1	±	0.1	28	0.8	±	0.1	19	1.0	±	0.2	30	0.9	±	0.1	17	0.8	±	0.1
	2nd	23	1.3	±	0.2	33	1.0	±	0.2	19	1.4	±	0.3	30	1.4	±	0.1	16	1.3	±	0.1
Mg (g/kg)	1st	26	2.1	±	0.1	28	2.1	±	0.1	19	2.4	±	0.1	30	2.3	±	0.1	17	2.4	±	0.1
	2nd	23	3.1	±	0.1	33	3.2	±	0.1	19	3.5	±	0.2	30	3.3	±	0.1	17	2.9	±	0.1

***Calthion palustris* hay meadows**		2001 - 2003				2004 - 2007				2008 - 2011				2012 - 2014				2015 - 2018			
	Cut	*n*	mean		S.E.	*n*	mean		S.E.	*n*	mean		S.E.	*n*	mean		S.E.	*n*	mean		S.E.
Dry Matter Yield (dt/ha)	1st	8	40.7	±	3.2	11	36.6	±	1.8	8	23.6	±	2.8	9	25.4	±	2.0	14	26.2	±	2.0
	2nd	8	18.0	±	3.5	11	14.7	±	1.8	8	15.1	±	2.2	9	10.2	±	1.1	15	10.9	±	1.1
Crude Protein (%)	1st	8	8.7	±	0.4	11	7.6	±	0.4	8	9.9	±	0.3	9	8.9	±	0.3	15	9.1	±	0.4
	2nd	8	11.8	±	0.6	11	13.5	±	0.7	8	15.3	±	0.6	9	13.8	±	0.4	15	13.6	±	0.6
Digestible Crude Protein (g/kg)	1st	8	47.0	±	3.6	11	35.3	±	4.0	8	57.5	±	3.2	9	48.4	±	3.3	15	49.8	±	3.5
	2nd	8	74.8	±	6.1	11	87.4	±	6.4	8	106.6	±	5.4	9	92.6	±	3.8	15	92.2	±	5.4
DVE (g/kg)	1st	8	63.0	±	2.3	11	64.0	±	1.6	8	72.8	±	1.5	9	67.5	±	1.8	15	67.6	±	0.9
	2nd	8	72.3	±	2.0	11	82.6	±	3.1	8	86.6	±	1.1	9	82.5	±	1.8	15	78.8	±	2.0
Crude Fibre (%)	1st	8	29.3	±	0.5	11	29.9	±	0.7	8	27.5	±	0.6	9	29.9	±	0.8	15	30.1	±	0.4
	2nd	8	24.8	±	0.7	10	22.9	±	0.9	8	23.2	±	0.4	9	24.5	±	0.9	15	26.3	±	0.8
Crude Ash (%)	1st	8	9.9	±	0.8	11	7.2	±	0.2	8	7.2	±	0.2	9	7.1	±	0.3	15	7.1	±	0.2
	2nd	8	12.3	±	0.3	11	10.3	±	0.5	8	10.3	±	0.6	9	9.5	±	0.4	15	9.7	±	0.6
VEM/kg dm	1st	8	847.6	±	13.6	11	893.5	±	9.9	8	922.0	±	8.4	9	892.4	±	10.3	15	896.0	±	8.2
	2nd	8	842.8	±	11.1	11	879.6	±	15.7	8	889.0	±	5.7	9	885.2	±	9.9	15	874.9	±	10.7
VEVI/kg dm	1st	8	863.8	±	15.8	11	918.1	±	12.9	8	954.3	±	10.8	5	931.2	±	19.2	15	910.7	±	8.3
	2nd	8	862.4	±	14.1	11	905.0	±	19.6	8	915.1	±	6.3	5	919.6	±	8.6	15	895.5	±	13.5
kVEM/ha	1st	8	3422.7	±	235.3	11	3262.2	±	160.6	8	2168.5	±	247.9	9	2261.1	±	163.9	14	1474.1	±	242.8
	2nd	8	1497.2	±	280.6	11	1293.2	±	157.6	8	1344.2	±	196.3	9	903.4	±	95.4	15	668.3	±	96.3
N (%)	1st	8	1.4	±	0.1	11	1.2	±	0.1	8	1.6	±	0.1	9	1.4	±	0.1	15	1.5	±	0.1
	2nd	8	1.9	±	0.1	11	2.2	±	0.1	8	2.5	±	0.1	9	2.2	±	0.1	15	2.2	±	0.1
P (g/kg)	1st	8	2.3	±	0.1	11	2.0	±	0.1	8	2.2	±	0.2	9	2.4	±	0.1	15	2.2	±	0.1
	2nd	7	3.0	±	0.2	11	3.2	±	0.2	8	3.2	±	0.2	9	3.1	±	0.1	15	2.9	±	0.1
Ca (g/kg)	1st	8	7.4	±	0.6	11	7.2	±	0.6	8	8.6	±	0.6	9	7.0	±	0.7	15	7.3	±	0.3
	2nd	7	11.9	±	1.0	11	10.3	±	0.9	8	12.0	±	1.0	9	10.1	±	0.7	15	8.8	±	0.5
K (g/kg)	1st	8	16.5	±	0.8	11	12.3	±	0.6	8	15.0	±	0.5	9	16.0	±	1.3	15	14.2	±	0.6
	2nd	7	13.2	±	1.3	11	16.9	±	1.0	8	16.8	±	1.0	9	19.8	±	1.6	15	15.9	±	1.6
Na (g/kg)	1st	8	1.4	±	0.1	11	1.7	±	0.2	8	2.4	±	0.6	9	1.0	±	0.2	15	1.1	±	0.1
	2nd	7	3.2	±	0.8	11	3.3	±	0.2	8	3.2	±	0.7	9	1.8	±	0.1	15	1.4	±	0.1
Mg (g/kg)	1st	8	2.3	±	0.1	11	2.2	±	0.2	8	2.6	±	0.1	9	2.2	±	0.2	15	2.4	±	0.1
	2nd	7	3.9	±	0.1	11	3.5	±	0.2	8	3.6	±	0.2	9	3.1	±	0.2	15	2.7	±	0.1

***Molinia* meadows**		2001 - 2003				2004 - 2007				2008 - 2011				2012 - 2014				2015 - 2018			
	Cut	*n*	mean		S.E.	*n*	mean		S.E.	*n*	mean		S.E.	*n*	mean		S.E.	*n*	mean		S.E.
Dry Matter Yield (dt/ha)	1st	4	27.7	±	2.5	1	42.2	±	n/a	2	22.8	±	1.0	4	24.5	±	2.4	4	25.2	±	2.8
	2nd	4	13.1	±	2.1	1	21.1	±	n/a	2	11.6	±	2.0	4	10.4	±	0.9	4	8.1	±	3.0
Crude Protein (%)	1st	4	9.0	±	0.4	1	8.4	±	n/a	2	9.8	±	0.4	4	8.9	±	0.3	4	8.9	±	0.5
	2nd	4	11.7	±	0.5	1	10.5	±	n/a	2	14.6	±	0.8	4	15.5	±	0.7	4	12.9	±	1.0
Digestible Crude Protein (g/kg)	1st	4	49.9	±	4.2	1	42.7	±	n/a	2	56.9	±	4.0	4	48.3	±	2.6	4	48.3	±	4.8
	2nd	4	75.1	±	5.5	1	61.2	±	n/a	2	98.9	±	6.5	4	107.3	±	7.5	4	85.9	±	9.0
DVE (g/kg)	1st	4	65.8	±	2.1	1	68.0	±	n/a	2	70.6	±	1.7	4	67.6	±	2.2	4	68.2	±	1.9
	2nd	4	68.4	±	3.0	1	75.3	±	n/a	2	87.0	±	5.5	4	88.3	±	1.7	4	78.1	±	2.8
Crude Fibre (%)	1st	4	28.9	±	0.2	1	29.6	±	n/a	2	28.3	±	1.9	4	30.2	±	1.3	4	29.8	±	0.9
	2nd	4	25.2	±	0.8	1	22.8	±	n/a	2	22.8	±	1.9	4	22.7	±	1.3	4	27.4	±	1.5
Crude Ash (%)	1st	4	9.1	±	0.7	1	6.2	±	n/a	2	7.8	±	0.2	4	6.8	±	0.2	4	6.7	±	0.2
	2nd	4	14.2	±	1.8	1	10.3	±	n/a	2	9.3	±	0.6	4	9.9	±	0.6	4	8.2	±	0.5
VEM/kg dm	1st	4	865.8	±	14.1	1	908.0	±	n/a	2	901.0	±	26.0	4	893.0	±	16.7	4	898.5	±	10.6
	2nd	4	813.8	±	18.8	1	896.0	±	n/a	2	905.0	±	28.0	4	898.0	±	4.2	4	890.3	±	29.1
VEVI/kg dm	1st	4	885.5	±	16.7	1	935.0	±	n/a	2	928.0	±	35.0	1	866.0	±	0.0	4	922.0	±	14.1
	2nd	4	828.5	±	20.8	1	930.0	±	n/a	2	934.5	±	35.5	1	911.0	±	0.0	4	924.0	±	41.9
kVEM/ha	1st	4	2403.6	±	245.5	1	3829.9	±	n/a	2	2054.9	±	150.8	4	2180.8	±	203.6	4	961.6	±	124.0
	2nd	4	1062.5	±	164.7	1	1887.1	±	n/a	2	1051.6	±	215.3	4	935.7	±	86.9	4	431.4	±	258.8
N (%)	1st	4	1.4	±	0.1	1	1.3	±	n/a	2	1.6	±	0.1	4	1.4	±	0.0	4	1.4	±	0.1
	2nd	4	1.9	±	0.1	1	1.7	±	n/a	2	2.3	±	0.1	4	2.5	±	0.1	4	2.1	±	0.2
P (g/kg)	1st	4	1.8	±	0.1	1	1.8	±	n/a	2	1.9	±	0.5	4	2.3	±	0.0	4	2.2	±	0.1
	2nd	4	2.5	±	0.1	1	2.5	±	n/a	2	2.4	±	0.4	4	2.9	±	0.3	4	2.7	±	0.2
Ca (g/kg)	1st	4	8.1	±	0.5	1	7.6	±	n/a	2	8.1	±	1.3	4	6.8	±	0.6	4	7.5	±	0.7
	2nd	4	10.4	±	0.8	1	11.2	±	n/a	2	13.3	±	1.5	4	12.5	±	0.2	4	9.5	±	0.8
K (g/kg)	1st	4	13.3	±	0.4	1	9.9	±	n/a	2	19.1	±	0.9	4	14.3	±	1.8	4	12.5	±	1.0
	2nd	4	12.2	±	2.5	1	11.6	±	n/a	2	16.0	±	4.1	4	14.9	±	2.0	4	13.4	±	3.3
Na (g/kg)	1st	4	1.4	±	0.2	1	2.1	±	n/a	2	2.0	±	0.7	4	1.1	±	0.1	4	1.0	±	0.1
	2nd	4	1.2	±	0.1	1	4.6	±	n/a	2	1.7	±	0.4	4	1.8	±	0.1	4	1.3	±	0.1
Mg (g/kg)	1st	4	2.7	±	0.2	1	2.7	±	n/a	2	2.5	±	0.5	4	2.3	±	0.2	4	2.4	±	0.1
	2nd	4	4.0	±	0.2	1	4.6	±	n/a	2	4.1	±	0.0	4	3.7	±	0.2	4	2.6	±	0.1

Mesophilic to wet hay meadows		2001 - 2003				2004 - 2007				2008 - 2011				2012 - 2014				2015 - 2018			
	Cut	*n*	mean		S.E.	*n*	mean		S.E.	*n*	mean		S.E.	*n*	mean		S.E.	*n*	mean		S.E.
Dry Matter Yield (dt/ha)	1st	13	36.8	±	4.1	5	43.8	±	9.0	7	31.8	±	3.0	12	27.0	±	1.8	6	30.9	±	1.9
	2nd	13	14.6	±	1.4	5	11.8	±	2.3	7	15.6	±	1.4	12	10.6	±	1.0	6	5.3	±	1.1
Crude Protein (%)	1st	13	8.3	±	0.3	5	7.1	±	0.9	7	9.7	±	0.6	12	8.8	±	0.6	6	8.5	±	0.4
	2nd	13	10.4	±	0.5	5	14.2	±	1.1	7	14.6	±	1.0	12	14.4	±	0.6	6	12.7	±	0.8
Digestible Crude Protein (g/kg)	1st	13	43.2	±	2.8	5	31.4	±	8.8	7	56.1	±	6.2	12	47.4	±	5.9	6	44.2	±	4.2
	2nd	13	62.1	±	4.4	5	94.0	±	10.8	7	98.4	±	9.6	12	97.3	±	5.9	6	83.2	±	8.0
DVE (g/kg)	1st	13	62.4	±	0.9	5	60.6	±	3.6	7	69.0	±	1.8	12	65.8	±	1.7	6	65.1	±	0.8
	2nd	13	64.6	±	3.1	5	81.0	±	3.8	7	83.9	±	4.5	12	83.4	±	1.8	6	75.2	±	2.1
Crude Fibre (%)	1st	13	29.6	±	1.8	5	31.7	±	1.0	7	29.4	±	0.7	12	31.0	±	0.7	6	31.8	±	0.4
	2nd	13	27.0	±	1.0	5	23.8	±	0.7	7	24.0	±	1.1	12	25.1	±	0.6	6	28.3	±	0.8
Crude Ash (%)	1st	12	7.8	±	0.4	5	7.3	±	0.4	7	7.7	±	0.4	12	7.0	±	0.4	6	6.3	±	0.2
	2nd	13	13.1	±	0.8	5	11.6	±	1.5	7	10.3	±	0.7	12	9.3	±	0.3	6	9.3	±	0.2
VEM/kg dm	1st	13	859.4	±	6.1	5	871.6	±	17.3	7	888.4	±	12.2	12	879.1	±	10.5	6	881.0	±	4.8
	2nd	13	806.5	±	17.2	5	850.8	±	20.8	7	875.1	±	22.1	12	881.8	±	9.7	6	848.7	±	10.5
VEVI/kg dm	1st	13	873.4	±	7.3	5	889.2	±	21.5	7	911.0	±	15.7	5	882.2	±	14.4	6	897.2	±	6.7
	2nd	13	817.5	±	20.7	5	869.2	±	23.5	7	897.4	±	27.2	5	915.8	±	13.0	6	860.2	±	14.2
kVEM/ha	1st	13	3177.5	±	366.7	5	3778.0	±	713.9	7	2842.4	±	299.8	12	2370.0	±	152.6	6	2477.8	±	389.7
	2nd	13	1190.7	±	132.3	5	1013.4	±	206.5	7	1374.8	±	145.8	12	928.1	±	77.8	6	519.2	±	146.8
N (%)	1st	13	1.3	±	0.0	5	1.1	±	0.1	7	1.6	±	0.1	12	1.4	±	0.1	6	1.4	±	0.1
	2nd	13	1.7	±	0.1	5	2.3	±	0.2	7	2.3	±	0.2	12	2.3	±	0.1	6	2.0	±	0.1
P (g/kg)	1st	13	2.3	±	0.1	5	2.0	±	0.2	7	2.6	±	0.0	12	2.4	±	0.1	6	2.4	±	0.1
	2nd	11	3.1	±	0.1	5	3.5	±	0.2	7	3.5	±	0.2	12	3.3	±	0.1	6	2.8	±	0.2
Ca (g/kg)	1st	13	5.7	±	0.5	5	6.5	±	0.9	7	8.3	±	0.9	12	5.9	±	0.5	6	4.7	±	0.5
	2nd	11	10.1	±	0.8	5	7.5	±	0.6	7	11.9	±	1.6	12	8.5	±	0.6	6	7.5	±	0.8
K (g/kg)	1st	13	15.8	±	0.9	5	11.7	±	1.7	7	15.5	±	1.3	12	15.5	±	1.2	6	15.2	±	0.9
	2nd	11	17.6	±	1.9	5	20.1	±	3.8	7	17.2	±	1.0	12	19.1	±	1.4	6	16.3	±	3.4
Na (g/kg)	1st	13	0.6	±	0.1	5	1.0	±	0.2	6	2.3	±	0.9	12	0.9	±	0.1	6	0.9	±	0.1
	2nd	11	0.9	±	0.2	4	3.0	±	0.7	6	1.8	±	0.8	12	1.3	±	0.1	5	0.6	±	0.1
Mg (g/kg)	1st	13	1.9	±	0.1	5	2.3	±	0.4	7	2.2	±	0.2	12	2.1	±	0.1	6	1.8	±	0.1
	2nd	11	3.0	±	0.3	5	2.9	±	0.5	7	3.3	±	0.3	12	2.9	±	0.1	6	2.6	±	0.2