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Feed quality of modern varieties of *Festuca arundinacea* and *Phleum pratense* as an alternative to *Lolium perenne* in intensively managed grassland with different defoliation schemes

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Abstract

Grassland production based on cutting-only and an increasing frequency of prolonged periods of drought due to climate change could lead to decreased productivity in *Lolium perenne*. In field experiments, we tested whether *Festuca arundinacea* and *Phleum pratense* could be suitable alternatives to *L. perenne* on intensively managed grassland on clay, peat and sandy soil. The three grasses were sown in mixture with *Poa pratensis* and *Trifolium repens* and subjected to different frequencies of defoliation representing a cutting-only system, simulated grazing system and a mixed system. We found that in systems with at least six defoliations, *F. arundinacea* represented an acceptable compromise between feed quality (6.4 MJ net energy/kg dry matter (DM), 19.3% crude protein, CP), persistence (mass proportion >90%), and DM yield (12.7 Mg/ha). However, for dairy production based on intensive cutting-only systems, the quality of *F. arundinacea* was insufficient (5.9 MJ net energy/kg DM, 15.6% CP). Mixtures with *P. pratense* as the main sown species did not differ significantly in production of net energy and CP from *L. perenne* in cutting-only systems on sandy soil. On peat land, all sown mixtures were invaded by *Holcus lanatus*. We found that under frequent defoliation conditions, *H. lanatus*-rich swards had comparatively good DM yields (9.2 Mg/ha) and a feed quality that would be sufficient for dairy cow nutrition (net energy, 6.2–6.4 MJ/kg DM; 18.8–20.4% CP). We conclude that there is potential to adapt the choice of grasses and mixtures in different production systems to meet the challenges of climate change.

Introduction

Lolium perenne (*LoPe*) is the most important species on intensively managed grasslands in Central Europe, especially when precipitation is high (Norris, 1982); and is well adapted to clay soils and frequent defoliations such as those on intensively grazed pasture and lawn (Watson and More, 1962; Frame, 1992; Turner *et al*., 2012). However, in some areas in Central Europe conditions for optimal growth of *LoPe* are likely to become less favourable as climate change might lead to more frequent periods of prolonged drought (IPCC, 2022). There is also a growing trend towards all-year housing of dairy cows relying on systems with cutting-only grassland for silage which usually implies fewer defoliations. Consequently, species better adapted to fewer defoliations might invade the sward and suppress and displace even a highly competitive grass like *LoPe* (Turner *et al*., 2012). Fewer defoliations usually also have a negative effect on feed quality due to longer growing periods resulting in greater plant maturity. Motazedian and Sharrow (1990) found that the content of crude protein (CP) of a grass-clover sward decreased by approximately 0.2% for each additional day between defoliations compared to a minimum defoliation interval of seven days.

Against this background there seems to be a need for alternative species to *LoPe*. *Festuca arundinacea* (*FeAr*), for example, is better adapted to dry conditions (Suter *et al*., 2009; Cougnon *et al*., 2014). *Phleum pratense* (*PhPr*) has a higher content of CP than *LoPe* (Frame, 1991) and is better adapted to cutting-only systems with fewer defoliations (Suter *et al*., 2009). However, these alternative species also have some disadvantages: *PhPr* often has lower yields than *LoPe* (Frame, 1991); *FeAr* has harder leaves, contains silicates, has a lower digestibility than *LoPe* (Cougnon *et al*., 2014), and can affect animal health when infected with endophytes (Stuedemann and Hoveland, 1988). New varieties of *FeAr*, however, are much better accepted by livestock also under grazing (Suter *et al*., 2009) as they have softer leaf tissue, less silicate and are free of endophytes.

In response to the need for alternatives to *L. perenne*, we set up a field experiment with modern varieties of *FeAr* and *PhPr* and used *LoPe* as a reference. These three grass species were sown as the main species in mixtures with smaller amounts of *Poa pratensis* (*PoPr*) and *Trifolium repens* (*TrRp*) on three sites with different soils – a clay, a peat and a sandy soil. The established swards were then subjected to three management schemes that differed in frequency of defoliation: 'cutting-only' (four cuts), 'simulated grazing' (seven cuts) and a 'mixed system' (six cuts).

In the first part of the study, Becker *et al.* (2020) reported on yields and persistence of the main species in the sward over time. We are now presenting results on the feed quality of the three mixtures as affected by the frequency of defoliation, soil type and the interaction of both factors.

To answer the question whether *F. arundinacea* and *P. pratense* might serve as alternatives to *L. perenne*, we followed the hypotheses (i) the feed quality (content of net energy and CP in harvested biomass) of mixtures with *F. arundinacea* and *P. pratense* as the main species is not lower than that of *L. perenne* under varying climatic, soil and management conditions (frequency of defoliation) and (ii) the feed quality of *F. arundinacea* and *P. pratense* is sufficient for the nutrition of dairy cows.

Material and methods

Experimental site and set-up

The experiment was established in early autumn 2013 on three sites – a sandy, a clay and a peat soil – in Northwest Germany within a 30 km radius of the town of Oldenburg (53° 9' N and 8° 5' E; 5 m a.s.l.). Main experimental years covering the full vegetation period were 2014, 2015 and 2016. The pH was 5.2, 4.1 and 5.7 for the sandy, peat and clay soil, respectively. Plant available concentrations of the macronutrients P, K (CAL, calcium-acetate-lactate extraction) and Mg ($CaCl_2$ extraction) in the topsoil (0–10 cm) for the year 2014 were in a range of 40–80 mg/kg for P, 60–130 mg/kg for K and Mg 60–420 mg/kg for Mg, and can in all cases be regarded as sufficient for grass production (Landwirtschaftskammer Niedersachsen, 2011). Climatic conditions are similar for all sites and are characterized by a maritime climate with moderate temperatures in summer and mild and rainy winters. Rainfall in 2014 was comparatively high in May, July and August and moderate in June; in 2015, spring and early summer were characterized by dry conditions that ended only with significant rainfall in July; in 2016 rainfall in spring was rather limited but high in June (Table 1).

The experimental set-up was the same on all sites and followed a split-plot design with the treatment 'management' forming three sub-blocks within the three main blocks (replications) and plots of the treatment 'mixtures' randomly allocated to the sub-blocks. The modern varieties of the main species *LoPe*, *FeAr* and *PhPr* were each accompanied by *T. repens* and *PoPr* and were sown by a self-propelled plot seeder (Wintersteiger Seedmech, Hege 76) in autumn 2013 (Table 2). The mixtures were subjected to three different defoliation frequencies: a cutting-only system (four cuts), a simulated grazing system (seven cuts) and a mixed system (six cuts; one cut as in cutting-only followed by simulated grazing) over three experimental years. The design is an adaption of that of Corrall and Fenlon (1978) where crop growth rates are determined by weekly cuttings of four week old regrowths. In our study, we harvested four week old regrowths of alternate subplots every second week and were thus able to determine bi-weekly crop growth rates. There were two sub-plots for every mixture in the simulated grazing and mixed system which were each harvested every four weeks (thus a double set of plots); harvesting of the second set of the respective sub-plots started two weeks later than that of the first set allowing for calculation of growth curves based on two-week intervals (Becker *et al.*, 2020). The cutting-only plots only consisted of one sub-plot per block. First cutting for the simulated grazing took place from 5–15 April each year whereas the mixed system and the cutting-only system were harvested from 15–25 May for the first time. Other than the four week regime (28-day interval) for the simulated

Table 1. Average monthly temperature (Temp.) and monthly total precipitation (Prec.) in 2014, 2015 and 2016 and long-term average

	2014		2015		2016		Average 1980–2009	
	Temp. [°C]	Prec. [mm]	Temp. [°C]	Prec. [mm]	Temp. [°C]	Prec. [mm]	Temp. [°C]	Prec. [mm]
January	2	26	3	99	2	58	2	64
February	6	32	2	40	3	75	2	47
March	7	32	6	64	4	32	5	61
April	11	46	8	31	8	28	9	39
May	13	105	11	38	14	41	13	52
June	16	43	15	28	17	102	15	79
July	20	69	18	159	18	74	18	85
August	16	61	19	75	17	36	17	72
September	16	18	13	66	17	38	14	69
October	10	31	9	32	9	10	10	63
November	7	18	9	119	4	27	5	62
December	4	77	9	26	4	16	2	68
Year (ø; sum)	11	558	10	777	10	537	9	760

Averaged over two weather stations on the clay site and the sandy soil site; the peat-site is located between the two other sites within a distance of 15 km.

Table 2. Factorial design of the experiments and information on sowing and management

Treatments		Notes
Mixture (Main species)	*LoPe** cv.Sponsor	Sown mixture = 25 kg/ha main species + 3 kg/ha *Poa pratensis* (cv. Lato) + 3 kg *Trifolium repens* (cv. Rivendel)
	FeAr cv. Elodie	
	PhPr cv. Barpenta	
Management	Simulated grazing	Simulated grazing with seven cuts; mixed system with six cuts and cutting-only system with four cuts per year
	Mixed system	
	Cutting-only system	
Site	Sandy soil	Experiment repeated on three different sites; three years; three blocks; split-plot design
	Clay soil	
	Peat soil	

*LoPe: *Lolium perenne*, FeAr: *Festuca arundinacea*, PhPr: *Phleum pratense*.

grazing and mixed systems, the cutting-only plots were harvest every six weeks after the first cut. As we are not showing growth-rates here, the double set of data for the management schemes grazing and the mixed system were averaged to give one value for yield, energy content and CP for each defoliation date. That gives us robust values and also ensures that grazing, mixed and cutting-only now have one data set for each defoliation date for statistical analysis.

The supply of the main nutrients with fertilizer was according to that of intensively managed grassland. A nitrogen deficiency was to be avoided. All plots received 320 kg synthetic N/ha, 75 kg P/ha and 150 kg K/ha per year. The nitrogen fertilizer was applied depending on the cutting system in three to six doses of 28–100 kg N/ha per regrowth (cutting only, 100:80:80:60 kg N/ha; grazing, 100:41:41:41:41:28:28 kg N/ha; mixed system, 100:50:50:50:35:35 kg N /ha). After an initial supply of 100 kg N/ha in March/April of each year, the remaining N was applied for each defoliation frequency (four to seven cuts) after each cut in respective doses. The type of N fertilizer was calcium-ammonium-nitrate (CAN; 27% N). Phosphorus and potassium were applied in March in mineral form as triple-phosphate (20.1% P) and potassium chloride (33.2% K), respectively.

A more detailed description of the experiment can be found in Becker *et al.* (2020).

Samples and analyses

Plot size was 1.5 × 7.0 m and plots were harvested in total with a remaining stubble height of 4 cm. Grab samples of 500 g were taken by hand from the mown swaths and dried for 48 h at 60° C. Dried material was ground to 1 mm and analysed by near infrared reflectance spectroscopy (NIRS) for total N, and for energy content and CP as indicators of feed quality. A grass and forage calibration (Tillmann, 2010) was used to process spectra files which contained 3169 calibration samples for CP with a standard error of calibration (SEC) of 7.6, a standard error of cross validation (SECV) of 7.7 and a standard error of prediction (SEP) of 8.0 g/kg DM. In parallel to this we determined the dry matter (DM) content at 105°C. The net energy content (MJ/kg DM) was calculated in accordance with the guidelines of the German Society of Nutrition Physiology (GfE, 2009). Data on energy content and CP is based on analyses of samples from all treatments, replications and harvest cuts. Annual averages of energy content and CP are weighted averages. When calculating the weighted averages for energy content and CP from data of each cut, the proportions of the DM yield of each cut of the accumulated annual DM yield is considered.

Before each harvest, the plant cover of the different species and the proportion of bare soil were assessed visually. In the third year, July 2016, we determined the mass proportions of the main occurring species by separation of grab samples from every plot.

Statistics

For statistical analysis of the parameters net energy content, CP content, and of their total yields, we used the lme function of the nlme package (Pinheiro *et al.*, 2017) in R Studio (R software environment version 3.6.3, 2020). Year, site, mixture and management and their interactions were considered as fixed factors in a mixed model approach; replications in blocks and sub-blocks were taken as random factors. Least square means were calculated using the 'emmeans' package (Lenth *et al.*, 2019). Comparison of means is done at $\alpha = 0.05$.

Results

In the following, the species name is synonymous with the sown mixture in which it is the main species; if the reference is to the species alone, this is indicated.

Yield and persistence

The DM yields of the three mixtures differed significantly ($P < 0.05$) and yields were also significantly influenced by management and year. The soil type had no significant effect on the DM yield (see also Becker *et al.*, 2020). DM yields of mixtures were on average over three years largest for *FeAr* with 13 810 kg/ha, followed by *LoPe* with 11 301 kg/ha and smallest for *PhPr* with 10 366 kg/ha ($P < 0.05$). DM yields were on average lower in the simulated grazing system (11 209 kg/ha) than in the mixed system and the cutting-only system (12 029 and 12 238 kg/ha, respectively; $P < 0.05$), Yields were on average significantly higher in 2016 (12 628 kg/ha) than in 2014 and 2015 (11 074 and 11 774 kg/ha, respectively; $P < 0.05$).

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After three years, persistence of the main species differed significantly ($P < 0.05$) among the three mixtures: in the last year, yield proportions of the main species amounted to 91% for *FeAr*, 80% for *LoPe* and 52% for *PhPr*. On the sand and clay site the main species accounted on average for 84% of the total yield. On the peat soil the main species accounted for only 54% of the total yield, which is significantly less ($P < 0.05$) than on the sand and clay site. On peat, all three main species were displaced mainly by *Holcus lanatus* (*HoLa*). The highest proportion of *HoLa* (49%, $P < 0.05$) occurred in the mixtures with *PhPr* as the main species. On sand and clay, *PhPr* was partly displaced by *PoPr* (sown with 3 kg/ha in all mixtures) which accounted for 30% yield proportion on the clay and 18% on the sand site. The development of yield and persistence of the main species during the experiment are presented in more detail in Becker *et al.* (2020).

Content of net energy and crude protein

The three grass mixtures differed significantly in their net energy content ($P < 0.001$) and CP content ($P < 0.001$). The factors year, management and soil type had significant effects on the content of net energy (year: $P < 0.001$; management: $P < 0.001$; soil: $P = 0.0042$) and CP content (year: $P < 0.001$; management: $P < 0.001$; soil: $P = 0.0003$). We found significant interactions of the factor mixture with year ($P < 0.001$) and soil type ($P < 0.001$) but not with the factor management for the net energy content, and significant interactions of the factor mixture with management ($P = 0.0071$), year ($P < 0.001$), and soil type ($P < 0.001$) for the CP content (Table 3–5).

Table 3. Lsmeans of the content of net energy, the total yield of net energy per ha, lsmeans of the crude protein content (CP) and total yield of CP in dry matter for the factors mixture, management and site and year*

	Net energy content (MJ/kg DM)	Net energy yield (GJ/ha)	CP (%)	CP yield (kg/ha)
FeAr	6.2[b]	86.7[a]	17.6[b]	2,446[a]
LoPe	6.4[a]	73.4[b]	17.7[b]	2,006[b]
PhPr	6.1[c]	63.7[c]	18.7[a]	1,944[b]
Grazing	6.5[a]	72.7[b]	19.4[a]	2,158[a]
Mixed system	6.2[b]	74.1[ab]	18.4[b]	2,176[a]
Cutting-only system	6.0[c]	77.1[a]	16.2[c]	2,062[b]
Sand	6.2[a]	76.8[a]	17.2[b]	2,112[ns]
Peat	6.3[a]	66.2[b]	19.4[a]	2,046[ns]
Clay	6.2[b]	80.8[a]	17.3[b]	2,238[ns]
2014	6.1[c]	67.6[c]	17.6[b]	1,934[c]
2015	6.4[a]	80.5[a]	18.2[a]	2,271[a]
2016	6.2[b]	75.6[b]	18.2[a]	2,192[b]

*Different letters indicate significant differences ($P < 0.05$) in the respective columns for the main species, the managements, the soil types and the years. Grazing: Simulated grazing. *FeAr: Festuca arundinacea, LoPe: Lolium perenne, PhPr: Phleum pratense.*

Content of net energy was significantly higher for mixtures of *LoPe* (6.4 MJ/kg DM) than for those of *FeAr* (6.2 MJ/kg DM) and *PhPr* (6.1 MJ/kg DM). Mixtures with *PhPr* had the significantly highest content of CP (18.7%); the content of CP for *LoPe* (17.7%) and *FeAr* (17.6%) did not differ significantly.

Under conditions of simulated grazing, content of net energy (6.5 MJ/kg DM) and CP (19.4%) were significantly higher than in the mixed system (6.2 MJ/kg DM, 18.4% CP), while in the cutting-only system, net energy and CP content were significantly lowest (6.0 MJ/kg DM and 16.2% CP; Table 3).

LoPe mixtures in the simulated grazing system had on average the significantly highest net energy content (6.7 MJ/kg DM) while *PhPr* mixtures in the cutting-only system had the lowest net energy content (5.8 MJ/kg DM). Mixtures with *PhPr* under simulated grazing management had the highest content of CP (20.1%) while the lowest content of CP was found for *FeAr* (15.6%) and *LoPe* (16.2%) in the cutting-only system.

The energy content of the three sown grass mixtures did not differ among the three soils, but the content of CP was usually higher on peat soil (Table 4 and 5). Averaged over the three mixtures and the three management regimes, CP on peat soil (19.5%) was significantly higher than on sand (17.2%) and clay (17.3%) – the highest content of CP was found for *PhPr* on peat soil (20.4%; Table 5).

The content of net energy and CP when averaged over soils and managements was different in the three experimental years for the three mixtures (Table 4 and 5). In 2014, the content of net energy (6.1 MJ/kg DM) and CP (17.6%) was lowest while the highest net energy content was found in 2015 (6.4 MJ/kg DM). In 2016 the net energy content (6.2 MJ/kg DM) was significantly higher than in 2014 and significantly lower than in 2015. The net energy content was highest for *LoPe* in 2015 and 2016 (6.7 and 6.4 MJ/kg DM, respectively), but did not differ from that of *FeAr* in 2014 (6.2 MJ/kg DM; Table 5).

During the three experimental years, the content of CP increased on the peat soil which corresponds with the increasing proportion of the protein-rich *HoLa* in the plots.

Total yield of net energy and crude protein

All main factors (year, management, mixtures, soils) had a significant effect on the total yield of net energy per ha (GJ/ha). The interactions of the factor mixture with year, soil and management for total yield of net energy (GJ/ha) were significant at $P < 0{,}001$, $P < 0.001$ and $P = 0.0073$, respectively. Total yields of net energy of mixtures of *FeAr* were higher (86.7 GJ/ha; $P < 0.05$) than those of *LoPe* (73.4 GJ/ha) and *PhPr* (63.7 GJ/ha) when averaged over years, management systems and soils. In the cutting-only system (77.1 GJ/ha) the total yield of net energy was significantly higher than in the simulated grazing system (72.7 GJ/ha) while energy yields in the mixed system (74.1 GJ/ha) ranged in-between cutting-only and grazing (Table 3). Yields of total net energy, when averaged over years and mixtures, were significantly smaller on peat soil (66.2 GJ/ha) than on clay (80.8 GJ/ha) and on sand (76.8 GJ/ha; Table 3).

While total net energy yields increased by about 5 GJ/ha for *LoPe* mixtures from the first to the second year, the increase was as high as 21 GJ/ha for *FeAr* and 12.4 GJ/ha for *PhPr* mixtures (Table 4). Total net energy yields for *LoPe* and *FeAr* were largest on clay while the effect of the factor soil on *PhPr* mixtures was negligible.

FeAr mixtures had the highest total yields of net energy in the cutting-only system which was 11 GJ/ha more than in the simulated grazing system, a difference that is statistically significant (Table 4). For *LoPe* and *PhPr* mixtures the total yield of net

Table 4. Lsmeans of the content of net energy and of the total yield of net energy. Two way interactions of the species with the factors management, soil and year*

		Net energy content (MJ/kg DM)			Net energy yield (GJ/ha)		
		FeAr	*LoPe*	*PhPr*	*FeAr*	*LoPe*	*PhPr*
Year	2014	6.2^{c}	6.2^{c}	6.0^{e}	74^{bc}	72^{bc}	57^{e}
	2015	6.2^{c}	6.7^{a}	6.2^{c}	95^{a}	77^{b}	69^{cd}
	2016	6.1^{d}	6.4^{b}	6.1^{d}	91^{a}	71^{cd}	65^{d}
Soil	Sand	6.2^{b}	6.5^{a}	6.0^{cd}	90^{ab}	73^{cdef}	68^{cdef}
	Peat	6.2^{b}	6.4^{a}	6.2^{bc}	76^{bcd}	65^{e}	58^{f}
	Clay	6.1^{bc}	6.4^{a}	6.0^{cd}	94^{a}	83^{bc}	65^{def}
Management	Grazing	6.4^{ns}	6.7^{ns}	6.3^{ns}	82^{b}	73^{c}	62 ^{d}
	Mixed system	6.1^{ns}	6.4^{ns}	6.0^{ns}	85^{ab}	75^{c}	62 ^{d}
	Cutting-only	5.9^{ns}	6.2^{ns}	5.8^{ns}	93^{a}	72^{c}	66 ^{cd}

*Different letters indicate significant differences ($P < 0.05$) within each two-way interaction. Grazing: Simulated grazing. *FeAr: Festuca arundinacea, LoPe: Lolium perenne, PhPr: Phleum pratense.*

energy did not differ significantly among the three management systems. For all mixtures, total net energy yields were highest in 2015; however, for *FeAr* and *PhPr* total net energy yields did not differ significantly between 2015 and 2016.

The total yields of CP per ha were significantly influenced by the factors mixture, management and year; but total yields of CP did not differ among the soil types (Table 3). The interactions of the factor mixtures with year and soil type were significant at $P <$ 0.0001 and $P = 0.0093$, respectively, while the interaction of the factors mixture and management regime was not significant. When averaged over management, soil type and year, total yields of CP were largest for mixtures of *FeAr* (2446 kg/ha); while values for *LoPe* (2006 kg/ha) and *PhPr* (1944 kg/ha) did not differ significantly from each other (Table 3). In addition, total yields of CP of the respective mixtures did not differ significantly among the soil types (Table 5). *FeAr* and *PhPr* had significantly larger yields of CP in 2015 and 2016 than in 2014 (Table 5). Total yields of CP were significantly higher in the simulated grazing system (2158 kg/ha) and in the mixed system (2176 kg/ha) than in the cutting-only system (2062 kg/ha). The total yields of CP also differed among the years.

Discussion

The effects of the tested factors and interactions on DM yields are discussed in detail in Becker *et al.* (2020). Total yields of net energy and CP are calculated from DM yields and the respective content of net energy and CP. This means also that a very high DM yield combined with a lower content of net energy or CP can still lead to high total yields of net energy and CP. For example, a low net energy and CP content in the cutting-only system was balanced by high DM yields; a low content of net energy and CP but large DM yields in *FeAr* mixtures resulted in high total yields of net energy and protein. It should also be considered that the N input with fertilization of 320 kg N/ha for all three management and mixtures was relatively high ensuring potentially good yields and contributing to the CP contents.

Effects of competition of species on net energy content and crude protein

The feed quality of the mixtures in our experiment was determined for every cut. Sward composition changed during the

Table 5. Lsmeans of crude protein content (CP) and of the total yield of CP. Two-way interactions of the species with the factors management, soil and year*

		Content of CP (%)			Total yield of CP (kg DM/ha)		
		FeAr	*LoPe*	*PhPr*	*FeAr*	*LoPe*	*PhPr*
Year	2014	17.7^{cde}	16.8^{f}	18.3^{abc}	2,131^{b}	1,943^{c}	1,728^{d}
	2015	17.6^{de}	18.1^{bcde}	18.8^{ab}	2,628^{a}	2,084^{bc}	2,100^{bc}
	2016	17.5^{e}	18.2^{bcd}	19.0^{a}	2,580^{a}	1,991^{bc}	2,005^{bc}
Soil	Sand	16.9^{de}	17.2^{de}	17.4^{cde}	2,446^{abcgf}	1,929^{dehi}	1,962^{dehi}
	Peat	18.8^{bc}	19.3^{b}	20.4^{a}	2,293^{abcde}	1,933^{fghi}	1,911^{fghi}
	Clay	17.1^{e}	16.7^{e}	18.2^{bcd}	2,599 ^{a}	2,156^{bdfh}	1,960^{cegi}
Management	Grazing	19.3^{b}	18.8^{bc}	20.1^{a}	2,472^{ns}	2,032^{ns}	1,970^{ns}
	Mixed system	17.9^{d}	18.1^{cd}	19.2^{b}	2,490^{ns}	2,050^{ns}	1,988^{ns}
	Cutting-only	15.6^{f}	16.2^{ef}	16.8^{e}	2,376^{ns}	1,936^{ns}	1,874^{ns}

*Different letters indicate significant differences ($P < 0.05$) within each two-way interaction. Grazing: Simulated grazing. *FeAr: Festuca arundinacea, LoPe: Lolium perenne, PhPr: Phleum pratense.*

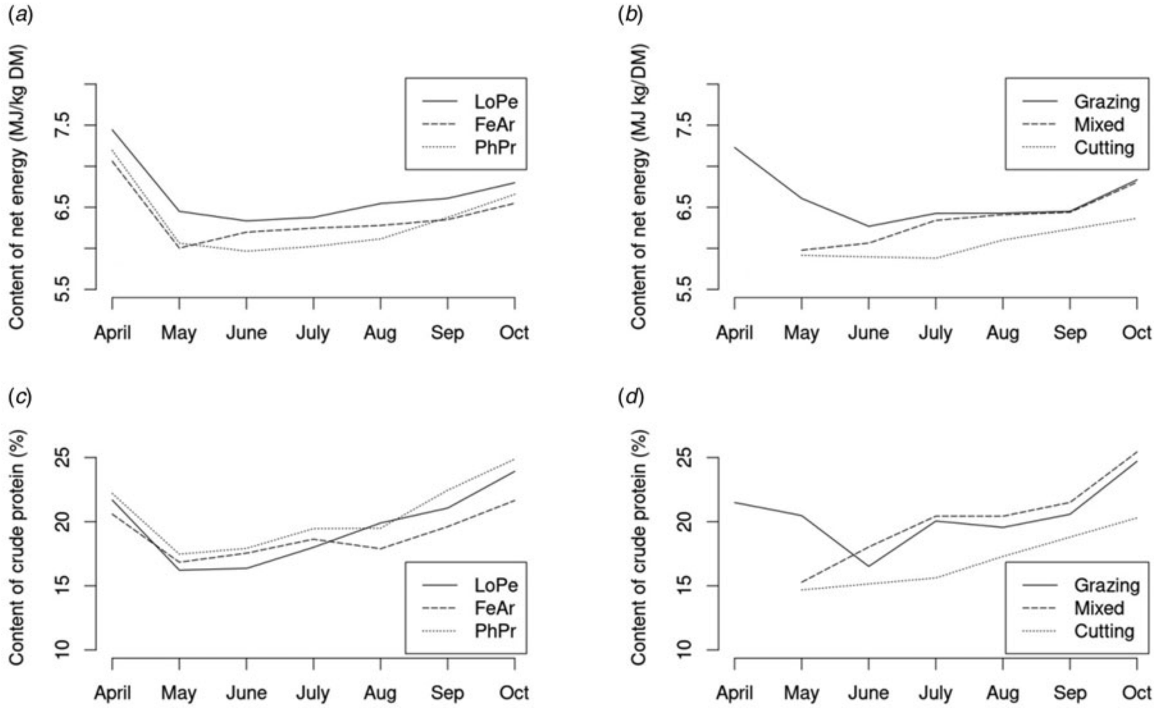

Figure 1. Changes of the content of net energy and crude protein content (CP) during the growing season. Left side, A, B: *FeAr*: *Festuca arundinacea*, *LoPe*: *Lolium perenne* and *PhPr*: *Phleum pratense*; averaged over years, sites and management. Right side, C, D: simulated grazing system (seven cuts), mixed system (six cuts) and cutting-only system (four cuts); averaged over years, sites and mixtures.

course of the experimental years and this change needs to be considered when values of feed quality are interpreted (also see Becker *et al*., 2020). The minor mixture partner *T. repens* is not discussed as the proportions in the sward were negligible. On peat soil all three mixtures were strongly affected by the invasion of *H. lanatus* (*HoLa*), with the sown mixture of *PhPr* being most affected. The proportion of *HoLa* in the third year on peat was 49% for *PhPr* and 26% for *LoPe. Holcus lanatus* is regarded as having a low palatability and is usually avoided by grazing animals. This can be explained by the hairy texture of *HoLa* and a high proportion of inflorescences and dead leaves (Cameron, 1979). However, an improved grazing management can be an effective means to overcome the negative characteristics of *HoLa*. Swards with higher proportions of this grass should ideally be defoliated at least six times per year starting with an early first defoliation in April.

The *PhPr* mixtures on sand and clay were influenced by increasing proportions of *PoPr* (18% on the sandy site and 30% on clay in the third year). Because of the change in species composition over time, the results of the simple mixtures in our experiments might not be fully comparable to the results obtained in experiments with single species. Though the amount of *LoPe* in the mixtures was more reduced than in *FeAr* (persistence in the third year was 90%), the average net energy content of the *LoPe* mixtures (6.4 MJ/kg DM) was always higher than in *FeAr* mixtures (6.2 MJ/kg DM; Figure 1a). This is most likely caused by the higher content of net energy in the leaves of *LoPe*; but also suggests that invading *HoLa* did not affect energy contents negatively. Watkin and Robinson (1974) found that the performance of sheep fed with *HoLa* was only slightly less than that with *LoPe*. These findings are similar to those of other studies. Cougnon *et al*. (2014) compared pure swards of *LoPe* and *FeAr* and found an in-vitro digestibility of 79% for *LoPe* and only 71% for *FeAr;* this corresponds to a content of metabolizable energy (ME) of 12.6 MJ/kg DM for *LoPe* and 11.4 MJ/kg DM for *FeAr* (calculated following a formula suggested by Givens *et al*. (1989)). In the same experiment, mixtures of *LoPe* and *FeAr* had a feed quality which fell intermediate between that of single species swards. Davies and Morgan (1982) compared *FeAr, LoPe* and *PhPr* and found the highest in-vitro digestibility of 70% for *LoPe* (11.2 MJ ME/kg DM) but only 62% in-vitro digestibility and 9.9 MJ ME/kg DM for *FeAr*. Lee *et al*. (2018) in a three-year field trial found that *LoPe* had a significantly higher content of metabolizable energy (ME) (12.1 MJ/kg DM) than *FeAr* (11.8 MJ/kg DM). Kalzendorf and Hinrichsen (2017) found for pure swards of *LoPe* in the first, second and third cut a content of net energy of always more than 6.3 MJ/kg DM while the net energy content of *FeAr* at each cut was below 6.0 MJ/kg DM. In our experiments, the net energy content was always lowest for *PhPr* mixtures (Fig. 1a). This is different from the results of Davies and Morgan (1982) with pure swards of *PhPr* that had an in-vitro digestibility of 66.3% (10.6 MJ ME/kg DM), which is similar to *LoPe* and higher than that of *FeAr*. The relatively low energy content of *PhPr* on sand and clay in our experiments is most likely caused by the high proportions of the sown *PoPr* in the sward. On peat, the invading species *HoLa* could have had, at least indirectly by preventing higher proportions of *PoPr*, a positive effect on the feed quality of *PhPr* swards and contributed to an increased DM digestibility (Frame, 1991). Watt (1987) reported an organic matter digestibility for two commercial varieties of *HoLa* of 73.1% and 74.3% at a low and high N fertilization, respectively; digestibility was at the same level as that for *LoPe*.

CP content did not differ between *LoPe* (17.7%) and *FeAr* (17.6%) (Table 3; Figure 1b). Although the content of CP for *LoPe* and *FeAr* vary in the literature, reports agree that generally

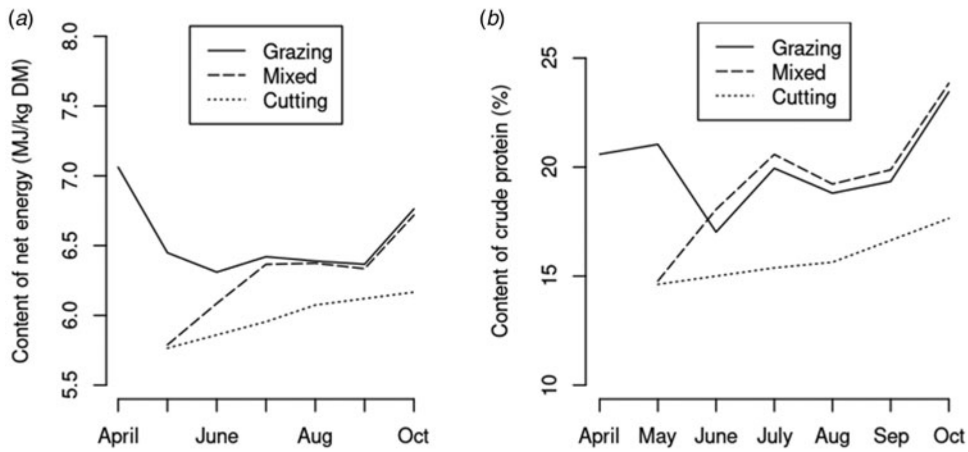

Figure 2. Changes of the content of net energy a) and crude protein content (CP) (b) of *Festuca arundinacea* during the growing season averaged over years and sites in the simulated grazing system (seven cuts), mixed system (six cuts) and the cutting-only system (four cuts).

differences in CP between *LoPe* and *FeAr* are small. Cougnon *et al.* (2014) found a CP content of 12.7% and 12.5% for *LoPe* and *FeAr*, respectively. Lee *et al.* (2018) report somewhat higher values of 23% for *LoPe* and 24% for *FeAr*, while the values found by Davies and Morgan (1982) with 18.4% for *LoPe* and 18.3% for *FeAr* are very similar to the values in our study.

In our study we found the highest CP contents (18.7%) with the main species *PhPr* in mixture with *PoPr* and *T. repens* on the peat site. This is likely the combined effect of a higher level of CP in *PhPr* with a great proportion (49%) of invading and protein-rich *HoLa*. This finding is in line with studies of pure swards where *PhPr* also had the highest content of CP: Davies and Morgan (1982) found 19% CP for *PhPr*; and Frame (1991) reported somewhat higher values of 23% CP for *LoPe* and of 29% for *PhPr*. We found the highest content of CP on the peat site in the swards where *PhPr* (20.4% CP) was sown as the main species. These are also the plots where *HoLa* as an invading species reached a mass proportion of 49% in the third year. It has been reported that the CP content of *HoLa* is higher than that of *LoPe*. Suckling (1960) found a protein content of 18.8% for *LoPe* and 19.5% for *HoLa*. With a fertilization regime similar to our trial, Frame (1991) found for a CP content of 22.7% for *LoPe* and 25.7% for *HoLa*; Harrington *et al.* (2006) found a CP content of 23.2% for *LoPe* and values as high as 29.5% for *HoLa*.

Influence of management on net energy content and crude protein

In our experiments, the lowest content of net energy and CP were found in the cutting-only system (5.8–6.2 MJ/kg DM; 15.6–16.8% CP), while the simulated grazing system had the highest content of net energy (6.3–6.7 MJ/kg DM) and of CP (18.8–20.1%) (Fig. 1c, 1d; Table 4, Table 5).

Generally, frequent defoliations lead to a better feed quality but can also result in smaller DM yields (Frame and Hunt, 1971, Chestnutt *et al.*, 1977; Pontes *et al.*, 2007; Donaghy *et al.*, 2008). With more frequent defoliations, young plants which have a high digestibility and a high content of water-soluble constituents and of CP are utilized (Terry and Tilley, 1964; Minson *et al.*, 1964). This would be an important consideration when thinking of *FeAr* as an alternative to *LoPe*. In the cutting-only system in our experiments only the mixtures based on *LoPe* had a content of net energy higher than 6.0 MJ/kg DM, which is considered necessary for the nutrition of dairy cows (Spiekers, 2004). This is why *LoPe* remains so important not only for grazed pastures but also for grass silage. When cut only four times per year, the net energy of *FeAr* of on average 5.9 MJ/kg DM is below the value required for dairy cows (Fig. 2a). However, in the mixed system with five defoliations (6.1 MJ/kg DM) and in the grazing system with seven defoliations (6.4 MJ/kg DM) the net energy of *FeAr* can be considered high enough for the requirements of dairy cows. In addition, *FeAr* produced by far the largest total yields of net energy (82–93 GJ/ha), not only under grazing and the mixed system but also in the cutting-only system (Table 4). When using *FeAr* for nutrition of dairy cows, at least five defoliations would be recommended to ensure sufficiently high energy content. In our experiments, an early first defoliation in April led to a net energy content of >7 MJ/kg DM for all mixtures (Fig. 1a) with an acceptable CP content of 20%. This could be important for the utilization of *FeAr* in dairy farming (Pontes *et al.*, 2007). We found for the simulated grazing management scheme that, after an early defoliation in April, the net energy content of *FeAr* stayed at >6.3 MJ/kg DM for the whole growing season (Fig. 2a). During summer the number of defoliations could be reduced without a drop in energy content as shown by the mixed system in our experiments where net energy content was >6.3 MJ/kg DM from July onwards (Fig. 2a). The protein content of *FeAr* was lowest for the cutting-only system. The mixed system led to a strong increase of >5% in CP content of *FeAr* from the first defoliation in May to July and stayed as high as in the simulated grazing system for the whole growing season (Fig. 2b).

Phleum pratense (*PhPr*) as the main species in our mixtures proved to be less persistent and mixtures had lower yields than those of *LoPe* and *FeAr*. The partial replacement of *PhPr* on peat soil by *H. lanatus* and on sand by *P. pratensis* needs to be considered when net energy content and CP for *PhPr* mixtures are assessed.

Influence of precipitation/climatic conditions

The spring and early summer of 2015 were characterized by mainly dry conditions (precipitation in that period was 30% less than the long-term average; Table 1). DM yields of *LoPe* mixtures were lowest in 2015 (10 858 kg/ha) but the difference to the DM yields in 2014 and 2016 was not significant. DM yields for *FeAr* mixtures were significantly larger in 2015 (13 826 kg/ha) than in 2014 (12 203 kg/ha), but smaller than in 2016 (15 401 kg/ha).

While periods of drought can have a negative effect on DM yields of productive grassland with high proportions of *LoPe* (Norris, 1982; Cougnon *et al*., 2014), the effect on feed quality can generally be positive provided that the drought does not last too long. (Dumont *et al*., 2014). Accordingly, we found a higher net energy content for *LoPe* (6.7 MJ/kg DM) and *PhPr* (6.2 MJ/kg DM) in 2015. This is in accordance with other trials which also found a better feed quality under moderate water stress (Sheaffer *et al*., 1992, Hoffstätter-Müncheberg *et al*., 2013, Küchenmeister *et al*., 2013), as the stems, which are higher in crude fibre content, will grow more slowly (Buxton, 1996). However, *FeAr* responded differently with a decreasing quality under moderate water stress. In spring, *FeAr* shows a faster and earlier reproductive growth and this might have been accelerated by high temperatures that often come along with drier spells.

During late summer and autumn, when the precipitation was on average lower than in spring and early summer, *FeAr* still showed high growth rates, while the growth rates of *LoPe* and *PhPr* declined (Becker *et al*., 2020). However, on sites with a high water holding capacity like clay and under conditions of high precipitation or irrigation, *LoPe* will continue to be the most important species in grassland for dairy farming. *LoPe* has a high turnover of tillers throughout the year and thus the amount of young plant parts with a high feed quality is higher than in other species (Duchini *et al*., 2018). Currently, in practice, *F. arundinacea* would only be used when the risk of using *L. perenne* proves to be too high, especially under more frequent drought periods. These are the conditions under which *F. arundinacea* needs to be tested and evaluated and not under the optimal conditions for *L. perenne*.

Conclusions

We found that in grassland systems with at least six defoliations and/or an early utilization, *F. arundinacea* represented an acceptable compromise between feed quality, persistence and DM yield. However, for dairy production based on intensive cutting-only systems the net energy content and CP concentration of *F. arundinacea* were not sufficient.

On peat land, where the pressure of invading *H. lanatus* is high, the introduction of more competitive species like *F. arundinacea* might be an alternative. However, we found that under conditions of frequent defoliations, *H. lanatus*-rich swards had comparatively good yields and a forage quality that would be acceptable for dairy cows. In fact, on peat land allowing for a certain amount of *H. lanatus* in combination with the use of competitive species might be an alternative to frequent sward renovations.

We conclude that there is potential to adapt the choice of grasses and mixtures in different production systems to the challenges of degraded swards on peat land and climate change.

Author's contributions. TB: Investigation, project administration, data analysis, writing – draft & editing. MK: Conceptualization, project administration, supervision, writing – review & editing. JI: Supervision, writing – review and editing.

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Competing interests. None

Ethical standards. Not applicable.

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References

Becker T, Isselstein J, Jürschik R, Benke M and Kayser M (2020) Performance of modern varieties of *Festuca arundinacea* and *Phleum pratense* as an alternative to *Lolium perenne* in intensively managed sown grasslands. *Agronomy* **10**, 1–13.

Buxton DR (1996) Quality-related characteristics of forages as influenced by plant environment and agronomic factors. *Animal Feed Science Technology* **59**, 37–49.

Cameron NE (1979) *A Study of the Acceptability of Holcus spp. to Perendale Sheep* (Master's thesis). Massey University, Auckland, New Zealand.

Chestnutt DMB, Murdoch JC, Harrington FJ and Binnie RC (1977) The effect of cutting frequency and applied nitrogen on production and digestibility of perennial ryegrass. *Grass and Forage Science* **32**, 177–183.

Corrall AJ and Fenlon JS (1978) A comparative method of describing the seasonal distribution of production from grasses. *Journal of Agricultural Science* **91**, 61–67.

Cougnon M, Baert J, Van Waes C and Reheul D (2014) Performance and quality of tall fescue (*Festuca arundinacea Schreb.*) and perennial ryegrass (*Lolium perenne L.*) and mixtures of both species grown with or without white clover (*Trifolium repens L.*) under cutting management. *Grass and Forage Science* **69**, 666–677.

Davies DA and Morgan TEH (1982) Herbage characteristics of perennial ryegrass, cocksfoot, tall fescue and timothy pastures and their relationship with animal performance under upland conditions. *The Journal Agricultural Science* **99**, 153–161.

Donaghy DJ, Turner LR and Adamczewski KA (2008) Effect of defoliation management on water-soluble carbohydrate energy reserves, dry matter yields, and herbage quality of tall fescue. *Agronomy Journal* **100**, 122–127.

Duchini PG, Guzatti GC, Echeverria JR, Américo LF and Sbrissia AF (2018) Is the growth strategy of perennial grasses linked to their persistence pathway? *Grass and Forage Science* **23**, 157–159.

Dumont B, Andueza D, Niderkorn V, Lüscher A, Porqueddu C and Picon-Cochard C (2014) A meta-analysis of climate change effects on forage quality in grasslands: perspectives for mountain and Mediterranean areas. *Options Méditerranéennes. Série A, Séminaires Méditerranéens* **109**, 49–65.

Frame J (1991) Herbage production and quality of a range of secondary grass species at five rates of fertilizer nitrogen application. *Grass and Forage Science* **46**, 139–151.

Frame J (1992) *Improved Grassland Management*. Ipswich: Farming Press Books.

Frame J and Hunt IV (1971) The effects of cutting and grazing systems on herbage production from grass swards. *Grass and Forage Science* **26**, 163–172.

GfE (2009) New equations for predicting metabolisable energy of compound feeds for cattle. *Proceedings of the Society of Nutrition Physiology* **18**, 143–146.

Givens DI, Everington JM and Adamson AH (1989) The digestibility and metabolisable energy content of grass silage and their prediction from laboratory measurements. *Animal Feed Science and Technology* **24**, 27–43.

Harrington KC, Thatcher A and Kemp PD (2006) Mineral composition and nutritive value of some common pasture weeds. *New Zealand Plant Protection* **59**, 261–265.
Hoffstätter-Müncheberg M, Merten M, Kayser M, Wrage-Mönnig N and Isselstein J (2013) Der Einfluss simulierter Trockenperioden auf den Futterwert von Grünlandprodukten (The influence of simulated dry periods on the feed value of grassland products). *Schriftenreihe der Bayerischen Landesanstalt für Landwirtschaft* **6**, 209–213.
IPCC (2022) Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., doi: 10.1017/9781009325844.
Kalzendorf C and Hinrichsen HC (2017) Ertragsleistungen und Futterqualitäten von Rohrschwingel, Lieschgras und Deutschem Weidelgras – dreijährige Untersuchungen in Nordwestdeutschland (Yield performance and forage qualities of fescue, fescueolium, timothy and ryegrass - three-year studies in north-west Germany). *Mitteilungen der Arbeitsgemeinschaft Grünland und Futterbau* **18**, 195–198.
Küchenmeister K, Küchenmeister F, Kayser M, Wrage-Mönnig N and Isselstein J (2013) Influence of drought stress on nutritive value of perennial forage legumes. *International Journal of Plant Production* **7**, 693–710.
Landwirtschaftskammer Niedersachsen (2011) *Richtwerte für die Düngung in Niedersachsen (Guide values for fertilization in Lower Saxony).* Hannover, Germany: Landwirtschaftskammer Niedersachsen, pp. 1–8.
Lee JM, Clark DA, Clark CEF, Waugh CD, Roach CG, Minneé EMK, Glassey CB, Woodward SL, Woodfield DR and Chapman DF (2018) A comparison of perennial ryegrass- and tall fescue-based swards with or without a cropping component for dairy production: animal production, herbage characteristics and financial performance from a 3-year farmlet trial. *Grass and Forage Science* **73**, 340–354.
Lenth R, Singmann H, Love J, Buerkner P and Herve M (2019) emmeans: Estimated Marginal Means. R package version 1.4.1. Available at https://CRAN.R-project.org/package=emmeans.
Minson DJ, Harris CE, Raymond WF and Milford R (1964) The digestibility and voluntary intake of S22 and H. 1 ryegrass, S170 tall fescue, S48 timothy, S215 meadow fescue and Germinal cocksfoot. *Grass and Forage Science* **19**, 298–305.
Motazedian I and Sharrow SH (1990) Defoliation frequency and intensity effects on pasture forage quality. *Rangeland Ecology & Management/Journal of Range Management Archives* **43**, 198–201.
Norris IB (1982) Soil moisture and growth of contrasting varieties of *Lolium perenne*, *Dactylis* and *Festuca species*. *Grass and Forage Science* **37**, 273–283.
Pinheiro J, Bates D, DebRoy S, Sarkar D, Heisterkamp S, Van Willigen B and Maintainer R (2017) Package 'Nlme.' Linear and nonlinear mixed effects models Version 3.1. Available at https://svn.r-project.org/R-packages/trunk/nlme.
Pontes LS, Carrère P, Andueza D, Louault F and Soussana JF (2007) Seasonal productivity and nutritive value of temperate grasses found in semi-natural pastures in Europe: responses to cutting frequency and N supply. *Grass and Forage Science* **62**, 485–496.
RStudio Team (2020) *RStudio: Integrated Development for R*. Boston, USA: R Studio, Inc.
Sheaffer CC, Peterson PR, Hall MH and Stordahl JB (1992) Drought effects on yield and quality of perennial grasses in the North Central United States. *Journal of Production Agriculture* **5**, 556–561.
Spiekers H (2004) Tierphysiologische Anforderungen an die Silagequalität (Nutritional requirements in silage quality). Landesanstalt für Landwirtschaft, Grub, Germany, 1–8. Available at https://www.lfl.bayern.de/mam/cms07/ite/dateien/030320_tierphysiologische_anforderungen_an_die_silagequalitaet.pdf; 15.11.2022.
Stuedemann JA and Hoveland CS (1988) Fescue endophyte: history and impact on animal agriculture. *Journal of Production Agriculture* **1**, 39–44.
Suckling FET (1960) Productivity of pasture species on Hill Country. *New Zealand Journal of Agricultural Research* **3**, 579–591.
Suter D, Frick R, Hirschi H and Chapuis S (2009) Rohrschwingel- und Timothesorten geprüft (Varieties of tall fescue and timothy tested). *Agrarforschung* **16**, 250–255.
Terry RA and Tilley JMA (1964) The digestibility of the leaves and stems of perennial ryegrass, cocksfoot, timothy, tall fescue, lucerne and sainfoin, as measured by an in vitro procedure. *Grass and Forage Science* **19**, 363–372.
Tillmann P (2010) Anwendung der Nahinfrarotspektroskopie (NIRS) an Grünlandproben. *VDLUFA Schriftenreihe* **66**, 145–150.
Turner LR, Holloway-Phillips MM, Rawnsley RP, Donaghy DJ and Pembleton KG (2012) The morphological and physiological responses of perennial ryegrass (*Lolium perenne L.*), cocksfoot (*Dactylis glomerata* L.) and tall fescue (*Festuca arundinacea Schreb.; syn. Schedonorus phoenix Scop.*) to variable water availability: response of three perennial pasture species to moisture stress. *Grass and Forage Science* **67**, 507–518.
Watkin BR and Robinson GS (1974) Dry matter production of "Massey Basyn" Yorkshire Fog (*Holcus lanatus*). *Proceedings of the New Zealand Grassland Association* **35**, 278–283.
Watson JAS and More JA (1962) *Agriculture. The Science and Practice of British Farming*. Edinburgh, Scotland; London, UK: Oliver and Boyd.
Watt TA (1987) A comparison of two cultivars of *Holcus lanatus* with *Lolium perenne*, under cutting. *Grass and Forage Science* **42**, 43–48.