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Performance of Modern Varieties of *Festuca arundinacea* and *Phleum pratense* as an Alternative to *Lolium perenne* in Intensively Managed Sown Grasslands

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Abstract: In future, grass swards need to be adapted to climate change and interactions of management and site are becoming more important. The persistence of *Lolium perenne* on peatland or during dry periods is limited and alternative forage species are required. We tested the performance of a modern variety of *Festuca arundinacea* and *Phleum pratense* as an alternative to *Lolium perenne* on clay, peat, and sandy soils. Each of these grasses was sown as main species in mixture with *Poa pratensis* and *Trifolium repens* and the mixtures were subjected to different frequencies of defoliation. Differences in yield proportions in the third year were significantly influenced by main species, site and their interaction. Remaining mass proportions of main species after three years were smallest on peat; on all sites *Festuca arundinacea* showed the highest persistence and largest yield, followed by *Lolium perenne*. Mass proportions of *Phleum pratense* were small on peat soils and *Phleum* had been replaced there by *Holcus lanatus*, and by *Lolium perenne* and *Poa pratensis* on the clay and sandy soils. We conclude that the choice of grass species in mixtures is a management tool to control stability and productivity of grass swards under specific site conditions.

Keywords: temperate humid grasslands; forage grasses; persistence; herbage yield; climate change

1. Introduction

In temperate climates, *Lolium perenne* (*LoPe*) is regarded as the most important and valuable grass species in agricultural grassland—it produces large yields and provides feed of a high feeding value. *LoPe* is well adapted to clay soils and a more maritime climate and profits from intensive grazing [1,2]. In cutting-only systems and during phases of drought, the performance of *LoPe* is decreasing and other species might invade the sward and displace *LoPe* [3]. With a trend to all-year-housing of dairy cows, the amount of cutting-only grassland is increasing. Climate change is expected to lead to a higher probability of drought periods in summer, more rainfall in winter and a generally prolonged vegetation period in North-West Europe [4,5]. These developments reduce the competitiveness of *LoPe*, leading to a lower persistence and reduced performance of the grass sward. Sward degradation is further increased through improper grassland management such as wheel traffic, poaching and overgrazing or untimely and/or an inappropriate rates of slurry application and N-fertilization [6,7].

At the same time, due to land scarcity and increasing forage needs, farmers want to make their grasslands more productive. Apart from improved management practices such as better targeted fertilization and oversowing of valuable forage species, sward renewal is a common measure [1]. However, renovating grass swards is often not a sustainable measure as seed mixtures and sown species are not well adapted to varying site conditions. This increases the need for repeated renovation. It is estimated that 5%–10% of the grassland swards are renewed annually in the Netherlands, Belgium, and Germany [7–9]. In Denmark, up to 50% of the grasslands are renewed every year; such grassland is then part of an arable–grass rotation [10]. The frequency with which swards are renewed is dependent on the soil type. On heavy soils, swards may stay productive over decades while on lighter or organic soils swards are ploughed-up within a period of five years.

The strength and speed of botanical change after renovation depends on the choice of species and varieties, management, site conditions, and the interaction of these factors [6,11]. Grassland renovation should thus be well planned and species should be well adapted to the site and soil conditions and the grassland management. Against this background, it seems necessary to find alternative forage grasses to *LoPe*. *Phleum pratense* (*PhPr*) has a very good feed value and a pronounced winter hardiness, but a lower tolerance to frequent defoliation [12]. In mixtures, *PhPr* has shown potential to reduce the risk of yield losses caused by extreme weather conditions and other stresses. *Festuca arundinacea* (*FeAr*) is a highly competitive grass species and shows a good persistence under cutting and drought. In addition, it tolerates temporary water logging [12,13]. New varieties of *FeAr* have softer leave tissue, less silicate and are more palatable to livestock than older varieties [12].

Although *PhPr* and *FeAr* are commonly used in agricultural grasslands in temperate humid climates, robust knowledge based on comparative systematic research on the performance of new varieties under intensive grassland management is rare. In particular, information on interactions of grass species with soil and climatic conditions is missing. We, thus, initiated an experiment with grass swards based on either *PhPr* or *FeAr* and *LoPe* as dominating species in the seed mixtures to test the hypotheses that (1) modern varieties of *PhPr* and *FeAr* have similar or better yields than *LoPe* and that there are interactions of species with soil and management, and (2) that the persistence of these species is equal to or better than that of *LoPe* under the given soil conditions and management.

We set up a three-year experiment with three seed mixtures and different defoliation schemes on three sites, namely clay, sand, and peat soils, representing the most important soil types in Northwestern Germany. Mixtures consisted of the main species *LoPe*, *PhPr*, and *FeAr*, each accompanied by smaller amounts of *Poa pratensis* (*PoPr*) and *Trifolium repens*.

2. Materials and Methods

2.1. Site Conditions and Experimental Design

The experimental design included different sites (sand, clay, and peat), different mixtures based on three main species (*LoPe*, *FeAr*, *PhPr*) subjected to three management regimes (cutting-only, simulated grazing, and a combined regime with a first cutting followed by simulated grazing) over three experimental years. The set-up was the same on all sites and followed a split-plot design with the treatment 'management regime' forming three sub-blocks within the three main blocks (replications) and plots of the treatment 'mixtures' randomly allocated to the sub-blocks.

The main species *LoPe* (cv.Sponsor), *FeAr* (cv. Elodie), and *PhPr* (cv. Barpenta) (25 kg ha^{-1}) were each accompanied by *Trifolium repens* (cv. Rivendel) (3 kg ha^{-1}) and *Poa pratensis* (cv. Lato) (3 kg ha^{-1}). These simple grass mixtures were sown in autumn 2013; the yield and persistence were analysed in the following three years.

We varied the frequency of defoliations as a proxy for the management regimes 'cutting-only' (4 cuttings), 'grazing' (7 cuttings), and 'combined', i.e., a first cutting followed by simulated grazing

(6 cuttings). It is a well-established method to simulate grazing by employing frequent defoliations, the main characteristic of grazing by ruminants, and combine it with N fertilization. The biomass yields and forage quality of plots with simulated grazing and real grazed plots can be seen as comparable [14,15].

The design is an adaption of that of Corrall and Fenlon (1978) [16] where crop growth rates are determined by weekly cuttings of four-week-old regrowths. We harvested four-week-old regrowths every second week and were thus able to determine bi-weekly crop growth rates. Therefore, we established two-sub-plots for every mixture in the grazing and combined regime. The cutting-only regime only consisted of one sub-plot per block.

Cutting for the treatment 'simulated grazing' started between 5–15 April each year; the other treatments were harvested between 15–25 May for the first time. The regrowths of the treatments 'simulated grazing' and 'combined' were then cut every 4 weeks (28-day interval) while the cutting-only plots were harvested every 6 weeks. The plot size was 1.5 × 7.0 m. At each harvest the total plot area was cut for all treatments at a sward height of 4 cm. Grab samples of 500 g from mown swaths were dried at 105 °C for the determination of the dry matter content.

The plant cover of the different species and the percentage of bare soil were visually assessed before each harvest. In July of the third year, we determined the mass proportions of the main species by manually separating grab samples from all treatments in all blocks and on all sites. Border areas of the plots were avoided when collecting grab samples for the determination of the dry matter content and for the determination of mass proportions of species.

2.2. Fertilizer, Soil and Weather Conditions

The experiment was located 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.). The first site ('Sand') is characterised by a sandy soil with a limited water holding capacity, a Plaggic Anthrosol (World Reference Base of Soils, WRB); site 2 ('Peat') is an Ombric Histosol in an area of peatland that is solely used as grassland, and site 3 (Clay) is a Fluvisol in a marshland area close to the River Weser. The pH of the sandy soil was 5.2, that of the Histosol 4.1, and 5.7 for the Fluvisol. Plant available concentrations of the macronutrients P, K (CAL, calcium-acetate-lactate extraction), and Mg ($CaCl_2$ extraction) in the dry soil (0–10 cm) for the year 2014 were in a range of 40–80 mg P kg^{-1}, 60–130 mg K kg^{-1}, and 60–420 mg Mg kg^{-1}, and can in all cases be regarded as sufficient.

The fertilization was carried out according to the farming practice on intensively managed grassland in Northwestern Germany. A nitrogen deficiency was to be avoided. All plots received 320 kg N ha^{-1}, 75 kg P ha^{-1}, and 150 kg K ha^{-1} per year. The nitrogen fertilizer was applied depending on the cutting system in three to six doses of 28–100 kg N ha^{-1} per regrowth. After an initial supply of N (60 kg N ha^{-1}) in March, the remaining N was applied after each cutting. The type of N fertilizer was calcium-ammonium-nitrate (CAN; 27% N), a synthetic fertilizer. Phosphorus and potassium were applied in March in mineral form as triple-phosphate (20.1% P) and potassium chloride (33.2% K), respectively.

Weather conditions are shown in Table 1. They are characterized by a maritime climate with moderate temperatures in summer and mild and rainy winters. Rainfall in 2014 was high in May, July and August, while moderate in June. In 2015, spring and early summer were dry conditions while July was wet. In 2016, rainfall in spring was rather low but it was high in June.

2.3. Statistical Analysis

Herbage yields were analyzed using the lme function of the nlme package [17] in R Studio [18]. 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.

For the analysis of yield persistence (mass proportions of species in the third year), site, mixture, and management were considered as fixed factors in a mixed model approach with replications in blocks and sub-blocks as random factors. A determination of mass proportions of species by separation of grab samples was undertaken only in the last year; consequently, there was no year-effect in this model.

Table 1. Monthly temperature and precipitation in 2014, 2015, 2016, and long-term average. Data from the three sites were averaged as they did not differ significantly from each other.

	2014		**2015**		**2016**		**Average 1980–2009**	
	Temp.	**Prec.**	**Temp.**	**Prec.**	**Temp.**	**Prec.**	**Temp.**	**Prec.**
	[°C]	**[mm]**	**[°C]**	**[mm]**	**[°C]**	**[mm]**	**[°C]**	**[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

3. Results

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

3.1. Persistence of the Species

After sowing, the seeds of all three main grass species germinated well: in a visual assessment in July 2014, main species in their respective mixtures accounted for 86%–95% for *FeAr* and *LoPe*, and for *PhPr* to about 85% on sand and clay and 73% on peat. In the second year, contents of *FeAr* and *LoPe* decreased on the peat soil to about 85% and *PhPr* to 30%. *Holcus lanatus* (*HoLa*) started to invade swards on the peat land already in the first two years (2%–8% in plots with *FeAr* and *LoPe* as main species) and proportions of *HoLa* in *PhPr* mixtures increased from 17%–41% on peat during that period.

The remaining proportions of the main species in the third year were not significantly different among the management treatments cutting-only, grazing, and combined, but mass proportions differed among the soils ($P < 0.001$) and mixtures ($P < 0.001$). After three years, on average 84% of the yield on the sand and clay soil could be attributed to the main species, but only 54% on the peat soil (Table 2).

Table 2. Mass proportions (%) of the sown grass species *FeAr*, *LoPe*, *PhPr* and *PoPr* and of the invading species *Holcus lanatus* on the different soil types. Lsmeans averaged over the three types of managements (grazing, combined, and cutting-only) after three years.

		Sand	**Peat**	**Clay**	**All soils**
	Mixture		%		
Mass proportion of main species (*FeAr*, *LoPe*, *PhPr*) in the respective mixture.	*FeAr*	96	78	98	91 [a]
	LoPe	89	61	91	80 [b]
	PhPr	68	22	67	52 [c]
Mass proportion of *Poa pratensis* in the mixture.	*FeAr*	4	3	2	2 [c]
	LoPe	11	6	8	8 [b]
	PhPr	18	11	30	17 [a]
Mass proportion of *Holcus lanatus* in the mixture.	*FeAr*	0	18 [c]	0	6
	LoPe	0	26 [b]	0	9
	PhPr	0	49 [a]	0	16

Different letters indicate significant differences ($P < 0.05$) among 1. the mean mass proportions of the main species averaged over the soil (row 1, column 6), 2. the mean mass proportions of *Poa pratensis* in the tree mixtures averaged over the soil (row 2, column 6), 3. the mean mass proportions of *Holcus lanatus* in the three mixtures on clay and 4. the mean mass proportions of the main species on the three soil types averaged over the main species. *FeAr*: *Festuca arundinacea*, *LoPe*: *Lolium perenne*, *PhPr*: *Phleum pratense*.

When comparing the main species as averaged over the three management regimes and soils, remaining proportions of *PhPr* were lowest (52%) and those of *FeAr* highest (91%) with proportions for *LoPe* being only slightly less (80%) than those of *FeAr* (Table 2). Proportions of the main species were most reduced on the peat soil ($P < 0.05$) and here especially for *PhPr* with values as low as 22% compared to 78% for *FeAr* and 61% for *LoPe* (Table 2). *PhPr* was generally displaced by *Holcus lanatus* on the peat soil and by the accompanying grass *Poa pratensis* on the sandy and clay soil. Generally, the persistence of the main species correlated with the annual yield in the third year (r = 0.56; $P < 0.001$) and even more so with the yield at the date of grab sampling (r = 0.60; $P < 0.001$). DM yields of *FeAr* were 13810 kg DM ha^{-1}, followed by *LoPe* with 11301 kg DM ha^{-1}, and *PhPr* with 10366 kg DM ha^{-1} (as averaged over all years, management regimes and sites: Table 3). *Trifolium repens* was immediately and strongly replaced by the grass species; mass proportion amounted to less than one percent in all treatments.

The factors management, soil, and year also had significant effects: DM yields were lower in the grazing management than with combined management and cutting-only. Yields were largest on clay followed by sand and peat and significantly higher in 2016 than in 2014 and 2015 (Table 3).

We found significant two-way interactions between all factors (Table 4) and a three-way interaction among year, management and mixture (Table 5). *FeAr* had the largest yields with 14704 kg DM ha^{-1} under cutting-only, 12727 kg DM ha^{-1} under grazing, and 13999 kg DM ha^{-1} in the combined regime; yields were high from the start and even increased over the years (Table 4). Only in 2015 were *FeAr* yields lower in the cutting-only than in grazing and combined (Table 5). Yields of *LoPe* did not differ among management regimes; other than with *FeAr*, there was no increase in yields over the years (Table 4).

Comparatively, *PhPr* had, on average, the smallest yields. When averaged over the years, *PhPr* yields did not differ significantly among the management regimes; however, yields did increase over the years, with the smallest yield in 2014 (9479 kg DM ha^{-1}) being significantly different from 10638 kg ha^{-1} in 2015 and 10981 kg ha textsuperscript−1 in 2016 (Table 4).

On all three soils, *FeAr* had larger DM yields than *LoPe* and *PhPr*, while yields of *LoPe* were only superior to those of *PhPr* on the clay soil (Table 3). *FeAr* and *PhPr* mixtures had larger yields on the clay and sandy soil than on the peat soil; yields of *LoPe* were larger on clay than on peat soil, but did not differ between sand and clay or sand and peat land. While over the years, yields increased on the sandy and clay soil, they declined on the peat soil. Yields of *LoPe* mixtures stayed at a similar level during the course of the experiment while those of *PhPr* were highest in the third year, and those of *FeAr* increased significantly with each year (Table 4).

The effect of management regime (when averaged over all mixtures) on the yields differed for the three soils (Table 4). On the peat soil, yields did not differ among managements. On the sandy soil, however, differences were pronounced and yields under the cutting-only regime were significantly larger than those under grazing; on the clay soil yields in the combined and cutting-only regime were larger than under grazing.

Main parameters for forage quality as net energy and crude protein concentration differed significantly among mixtures, management, soils and years. Overall net energy concentrations were highest for mixtures with main species of *LoPe* (6.4 MJ kg DM^{-1}) and significantly lower for *FeAr* (6.2 MJ kg DM^{-1}) and *PhPr* (6.1 MJ kg DM^{-1}) mixtures. Crude protein concentrations were highest on peat soils, which could be explained by large proportions of the protein-rich *HoLa*, especially in the *PhPr* mixture plots. This resulted in significantly higher overall crude protein concentrations for *PhPr* of 18.7% compared to 17.7% for *LoPe* and *FeAr*.

3.2. Growth Rates

Growth rates, that is the increase in DM per day for the period before the first defoliation/cutting and between defoliations, under simulated grazing and the combined regime ranged from about 20 to 100 kg DM ha^{-1} d^{-1} and followed a similar pattern with three peaks during the vegetation period: a first peak at the end of May, a second in mid-July, and a third peak in early September (Figure 1).

In May, the growth-rates of the grazing regime were higher than of the other regimes, but were lower later in the year. In the cutting-only regime, *LoPe* and *PhPr* reached their peak growth rates of about 80 and 65 kg DM ha^{-1} d^{-1}, respectively, in July, while *FeAr* showed the highest growth rate of 100 kg DM ha^{-1} d^{-1} in late August to early September. Growth rates of *FeAr* under grazing in the second half of the vegetation period were generally higher than those of the other mixtures. Under cutting-only and the combined regime, growth rates of *FeAr* were higher right from the start, that is after a first cutting in May for the combined regime (Figures 1–3). At the beginning of the season, growth rates of *LoPe* were 5 kg DM ha^{-1} d^{-1} higher than those of *PhPr*, but were similar from July onwards.

Growth rates of *PhPr* declined after spring quite strongly under grazing while they stayed at one level under a combined regime and here even increased later in summer (Figures 2 and 3).

Table 3. Dry matter yields (Lsmeans, in kg DM ha^{-1}) for the main factors mixture, management, soil, and year. * Small letters indicate significant differences between the year and the management within one species. FeAr: *Festuca arundinacea*, LoPe: *Lolium perenne*, PhPr: *Phleum pratense*.

Factor	**Mixture**	***FeAr***	13810 ^{a}	***LoPe***	11301 ^{b}	***PhPr***	10366 ^{c}
	Management	**Grazing**	11209 ^{b}	**Mixed**	12029 ^{a}	**Cutting**	12238 ^{a}
	Soil	**Sand**	12089	**Peat**	10356	**Clay**	13030
	Year	**2014**	11074 ^{b}	**2015**	11774 ^{b}	**2016**	12628 ^{a}

* Different letters for each factor indicate significant differences ($P < 0.05$) among the respective means. *FeAr*: *Festuca arundinacea*, *LoPe*: *Lolium perenne*, *PhPr*: *Phleum pratense*.

Table 4. Dry matter yields (Lsmeans, in kg DM ha^{-1}): all two-way interactions between mixture, management, year and site *.

		Mixture			**Soil**			**Management**		
		FeAr	***LoPe***	***PhPr***	**Sand**	**Peat**	**Clay**	**Grazing**	**Combined**	**Cutting**
Year	2014	12203 ^{c}	11542 ^{cd}	9479 ^{d}	10666 ^{ghj}	11287 ^{cdefgh}	11269 ^{efhj}	10480 ^{e}	10570 ^{e}	12173 ^{bcd}
	2015	13826 ^{b}	10858 ^{d}	10638 ^{d}	12183 ^{bdfi}	9950 ^{ij}	13188 ^{cdg}	11943 ^{cd}	12987 ^{b}	10391 ^{e}
	2016	15401 ^{a}	11503 ^{cd}	10981 ^{e}	13419 ^{ace}	9831 ^{ij}	14635 ^{ab}	11205 ^{de}	12530 ^{bc}	14150 ^{a}
Management	Grazing	12727 ^{b}	11024 ^{cd}	9878 ^{e}	11107 ^{cd}	10264 ^{d}	12258 ^{bd}			
	Combined	13999 ^{a}	11725 ^{bc}	10364 ^{de}	12116 ^{abcd}	10541 ^{d}	13430 ^{ac}		/	
	Cutting	14704 ^{a}	11154 ^{cd}	10856 ^{cde}	13045 ^{ab}	10264 ^{d}	13405 ^{ac}			
Soil	Sand	14220 ^{ab}	11010 ^{cde}	11038 ^{cde}						
	Peat	11877 ^{bcd}	10011 ^{e}	9181 ^{e}		/			/	
	Clay	15333 ^{a}	12881 ^{bc}	10878 ^{de}						

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

Table 5. Dry matter yields (Lsmeans, in kg DM ha^{-1}) of the mixtures with the main species *Festuca arundinacea* (*FeAr*), *Lolium perenne* (*LoPe*), and *Phleum pratense* (*PhPr*) for different years and management regimes as averaged over the three soils

Species	**Management**	**Year**		
		2014	2015	2016
FeAr	Grazing	11053 ^{e}	14020 ^{bc}	13109 ^{cd}
	Combined	11167 ^{e}	15526 ^{b}	15304 ^{b}
	Cutting	14389 ^{bc}	11932 ^{de}	17791 ^{a}
LoPe	Grazing	11247 ^{ab}	11275 ^{ab}	10549 ^{bc}
	Combined	11620 ^{ab}	12067 ^{ab}	11487 ^{ab}
	Cutting	11759 ^{ab}	9230 ^{c}	12473 ^{a}
PhPr	Grazing	9142 ^{cd}	10535 ^{abcd}	9957 ^{bcd}
	Combined	8923 ^{d}	11368 ^{ab}	10800 ^{abc}
	Cutting	10371^{bcd}	10011 ^{bcd}	12185 ^{a}

Different letters indicate significant differences ($P < 0.05$) among means of year and management regime for each mixture.

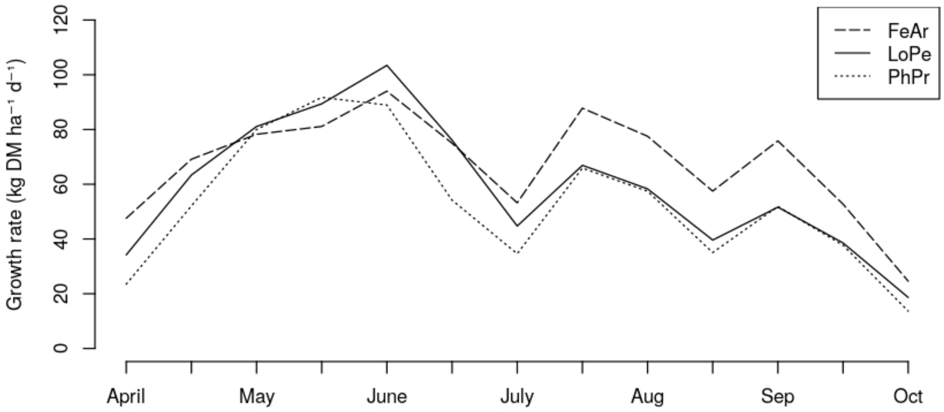

Figure 1. Grazing regime: Growth rates (kg DM ha^{-1} d^{-1}) of *FeAr: Festuca arundinacea, LoPe: Lolium perenne*, *PhPr*: *Phleum pratense*; averaged over years and sites.

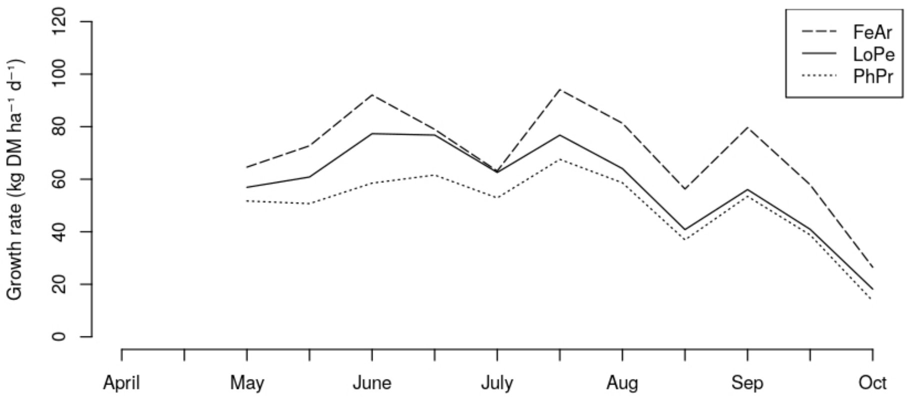

Figure 2. Combined regime: Growth rates (kg DM ha^{-1} d^{-1}) of *FeAr: Festuca arundinacea, LoPe: Lolium perenne*, *PhPr*: *Phleum pratense*; averaged over years and sites.

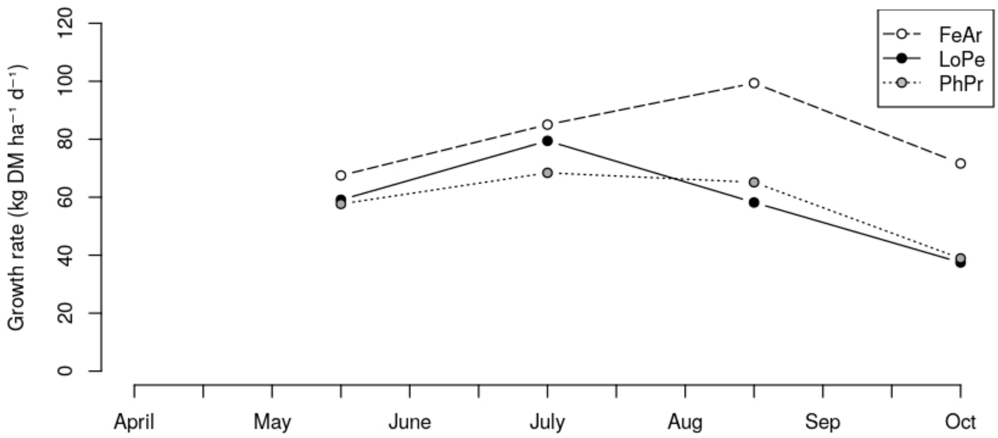

Figure 3. Cutting-only regime: Growth rates (kg DM ha^{-1} d^{-1}) of *FeAr*: *Festuca arundinacea*, *LoPe: Lolium perenne* and *PhPr*: *Phleum pratense*; average over years and sites.

4. Discussion

The aim of the present research was to identify the forage potential of *FeAr* and *PhPr* as alternative grass crops to *LoPe*. It was hypothesized that these alternative species can compete with *LoPe* in terms of persistence and herbage yield but that their relative performance is dependent on the soil and the defoliation conditions. *LoPe* is the agriculturally most important and competitive grass species in temperate Europe and is particularly well suited for heavy soils in coastal areas and lowlands [19].

Also, in our experiments, yields of *LoPe* mixtures were larger on the clay soil than on peat and sand. We found that *FeAr* was superior to *LoPe* while *PhPr* was inferior, both with regard to the herbage production as well as the persistence. However, there were also interactions among factors confirming our hypothesis. It is, therefore, necessary to take into account the different site and management conditions encountered in the farming practice when seeking a differentiated assessment of the potential of these alternative species. It needs to be considered that in our experimental set-up, *LoPe* did not have to compete directly with *FeAr* but with *PoPr*, *Poa trivialis*, and with *HoLa* on the peat land. In the following, we will discuss the roles of *FeAr* and *PhPr* as alternatives to *LoPe,* and of *PoPr* as an accompanying grass, and of *HoLa* as an invading grass on peat land.

4.1. Festuca Arundinacea—High Yields and Good Persistence

On all three soils and in all three management regimes (cutting-only, grazing, and combined) *FeAr* mixtures showed the largest yields and had the greatest persistence; yields of *FeAr* did even increase during the three years of the experiment. The good performance of the *FeAr* mixtures is largely due to the relatively high yields in late summer and autumn—during these periods, *FeAr* had higher growth rates than *LoPe* and *PhPr* (Figures 1–3). In late summer and early autumn, periods of drought are not uncommon. Because of a deeper rooting depth [20], the growth of *FeAr* is less affected by water stress and it recovers faster upon re-watering than *LoPe* [3,21,22].

In the cutting-only treatment (swards are cut every six weeks), the harvests were sometimes later than in the farming practice, where earlier cuttings are common to achieve a high forage quality. As later cutting often implies higher herbage yields, this fact might explain the high yields of *FeAr* in the cutting-only regime. Our results correspond well with those of Da Pontes [23], who found that *FeAr* was highly productive at a low cutting frequency. On peat land, plots with *LoPe* mixtures were more infected with Tipula larvae than *FeAr* plots and this added to the advantage of *FeAr* in our experiments.

Even in the grazing regime, *FeAr* showed the largest yields in our experiment. This demonstrates the potential of FeAr even for frequent or early season cutting or grazing. For intensive ruminant husbandry, a high roughage quality is required to meet the nutritional demand. As *FeAr* has rough leaves, contains secondary plant products and has a limited digestibility [13], the voluntary feed intake is often restricted [24,25]. Utilizing *FeAr* at young developmental stages can help to overcome these restrictions and produce forage of a quality that can support intensive dairying. In mixed swards, *LoPe* is preferred by cattle [26] and in pasture grass, leavings would be larger in pure swards of *FeAr* than in pure swards of *LoPe* [27]. However, modern varieties of *FeAr,* as were used in our study, have softer leaves and can be an appropriate component in mixtures for grazing [28]. Combining *LoPe* and *FeAr* is also an interesting option and could result in stable forage production during dry periods, especially on lighter soils, and produce a good forage quality. Finding the optimal proportion of these species in a mixture is still a main challenge [13]: if the proportion of *FeAr* in a mixture is too high, it will dominate the sward [28], if is it too low than it might be suppressed by *LoPe* [26], especially when cut very often [29]. Wilman and Gao [30] found that *LoPe* dominated *FeAr* when the seed weight proportion was 1:1. Cougnon et al. [13] tested several mixtures of *FeAr* and *LoPe* and propose a share of 25%–50% *LoPe* and a regular utilization of the sward.

In future, the greatest potential for *FeAr* is probably in situations with climatic and legal restrictions. This applies to areas with coarse soils that will be prone to droughts under conditions of climate change. This also applies to intensive dairy farming on peat soils where the frequency of sward renewal is often high. Grassland renewal with a disturbance of the old sward on peat soil can lead to increased losses of greenhouse gases [31–33] and further restrictions to this practice can be expected. In our experiments, *FeAr*-based mixtures proved to be most competitive and even managed to persist on the peat soil. Other studies also observed a good persistence and yield stability of *FeAr* on peat soil (fens) [12,34,35]. These promising qualities of *FeAr* could help to establish swards where the main sown species lasts much longer and reduces the need for renewal. However, caution needs to be applied when generalising the results as the choice of variety might have an impact on persistence as well.

4.2. Phleum Pratense: Accompanying Species with Problems on Organic Soils

In intensively managed grass swards in the rather mild North-German maritime climate and with high inputs of N fertilizer, *PhPr* has smaller yields than *LoPe* and *FeAr* and is replaced by other species. However, on clay and sand and in a cutting-only regime, mixtures with *PhPr* are generally able to compete with *LoPe*.

Persistence of *PhPr* was generally poor on all sites in our three-year experiment. *PhPr* showed the greatest reductions in the sward and was displaced by not sown *Holcus lanatus* (*HoLa*) on the peat soil and by the accompanying sown grass *Poa pratensis* (*PoPr*) on the sandy and clay soil. On the peat soil, the reduction of *PhPr* was already evident in the first year. These results differ somewhat from findings of Frame [36] who found that *PhPr* swards on a sandy loam still had a proportion of 90% after three years. However, in the experiments of Frame [36], *PhPr* was sown as a single species and pressure from invading species or from newly germinating dormant seeds in the topsoil was probably much less than on the peat soil in our investigation.

Despite the changes in sward composition, herbage yields were much less affected. However, yields of *PhPr* mixtures were always lower compared to the referring *FeAr* mixtures, while this inferiority was less expressed compared to mixtures of LoPe. This corresponds with other studies: from results of an experiment with six cuttings and an N fertilization of 360 kg N ha^{-1} on a sandy loam, Frame [36] concluded that *PhPr* has only a restricted yield capacity compared to *LoPe*. Swift [37] found under similar conditions that the yield of *PhPr* was 10% lower than the yield of *LoPe*.

The number of defoliations from four cuttings in a cutting-only regime to seven cuttings in a simulated grazing regime in our experiments had no influence on either persistence or yield of *PhPr*. This corresponds well with [23], where the yields of *PhPr* cut once a month were similar to bi-monthly cuttings. While *LoPe* was significantly better than *PhPr* in the grazing and combined regime, we found no significant difference between the yields of *LoPe* (11.2 t DM ha^{-1}) and *PhPr* (10.8 t DM ha^{-1}) in the cutting-only regime. Despite the relatively poor persistence and smaller yields, *PhPr* will also in future have some relevance in mixtures along grasses like *FeAr*, *LoPe* or *Dactylus glomerata*. Apart from the smaller yields, *PhPr* is generally regarded as a valuable grass with a high palatability and good feed quality which complies well with cutting-only regimes [38]. *PhPr* is not a strong competitor when sown in mixtures which can facilitate the establishment of slowly developing species like *PoPr* in newly sown swards on sandy and clay soils [39] This would also ensure a certain stability of the sward, which under conditions of drought, cold stress [40] or in cutting-only regimes could be superior to *LoPe* swards and would produce feed of higher quality than *FeAr*.

4.3. Poa Pratensis–Potential of an Accompanying Grass

In the present investigation, seeds of white clover (*Trifolium repens*, *TrRe*) and *Poa pratensis* (*PoPr*) were added as minor partners to all mixtures. *PoPr* is often used as a secondary grass in mixtures as it contributes to the development of a dense sod, despite the fact that it is usually sown at a small rate [36,38,41]. Unfortunately, the establishment of *PoPr* is very slow [42]. This was also the case in our experiments. In the third year, *PoPr* reached yield proportions in mixture with *LoPe* of almost 10%. In mixtures with *PhPr*, yield proportions were even higher and amounted to 18% on the sandy soils and 30% on the clay soil. However, *PoPr* was strongly suppressed by *FeAr*.

We found that *PoPr* showed the highest performance on clay soil; and here in combination with *PhPr* as the main sown species. This is in accordance with Moore [20], who stated that *PoPr* benefits from high soil fertility. Spedding and Diekmahns [41] found that *PoPr* can produce yields that are similar to those of *LoPe* and *PhPr*. Moreover, Frame [36] states that yields of *PoPr* respond well to fertilizer N as was the case in our experiments with a N level of 320 kg N ha^{-1} yr^{-1}.

PoPr has potential to become a more important species for intensively managed grasslands in future. *PoPr* is less sensitive to drought compared to *LoPe* [2,36,42] and could serve as an alternative grass in situations where *LoPe* is less adapted or *FeAr* is not wanted by the farmer. Compared to *FeAr*, *PoPr* has a higher feed quality [36,43] and is preferred by grazing cattle and sheep [20,42]. In addition, it is well adapted to frequent defoliation [39]. As *PoPr* is a common species in older meadows [20,42], it might spread in the future in cases where sward renovation is no longer allowed because of environmental concerns.

4.4. Holcus Lanatus–Substitute on Peat Soils

Holcus lanatus (HoLa) often dominates grass swards on peat soils [41] and is unpopular among farmers. *HoLa* was not part of any mixture in our experiment but became an important species on the peat soil. In the past, *HoLa* was often associated with poor drainage, low soil fertility, hay cutting, short-season grazing and low fertilizer N [44]. *HoLa* is often considered as a weed [45] and farmers would undertake sward renewal rather often to increase the proportion of *LoPe* in the sward. However, frequent renovation measures on peat land have several disadvantages: they are costly, a sward is difficult to establish, there can be yield depressions, and losses of CO_2 are almost inevitable [6].

All sown mixtures (main species *LoPe, FeAr*, and *PhPr*) were to different degrees displaced by *HoLa* on peat. *HoLa* had been one of the main species in the grassland of the experimental field on peat land and started to invade the plots already in the first year, probably from the seed bank in the soil. *HoLa* is susceptible to damages by strong frost [43,46]. The mild winters of the experimental years 2014–2016, however, would have indirectly promoted invasion of *HoLa* to the swards. Of the main species, *FeAr* was the least reduced on the peat soil. The higher growth rates in the second half of the vegetation period helped *FeAr* to better compete with invading species like *HoLa*.

HoLa has a generally low palatability and is usually avoided by grazing animals. This is due to the hairy texture of *HoLa*, a high proportion of inflorescences and dead leaves and the fact that it is often infected with rust [47]. However, in an experiment with the variety 'Massey Bassin', Watkins and Robinson [48] found that the performance of sheep fed with *HoLa* was only slightly less than that with *LoPe*. Similarly, beef cattle grazing intensively on swards with a high proportion of *HoLa* had the same live-weight gain as animals grazing on swards with a high proportion of *LoPe* [49]. An improved grazing management is an effective means to overcome the negative characteristics of the grass [47].

Considering the grassland farming practice for intensive dairying on peat soils, grassland farmers have to cope to a certain degree with *HoLa,* especially if a regular sward renewal is out of the question. Therefore, *HoLa* is an important part of the swards and contributes to the nutrition of dairy cows and hence for the milk production. Given moderate rates of fertilizer, *HoLa* can be quite productive [1,50] and the crude protein content is even higher than that of *LoPe* [51]. Instead of spending time and money for the renovation, the farmers could accept certain proportions of *HoLa* and try to repress it by competitive grasses and an adapted management.

5. Conclusions

Adaptation to climate change will include an expansion of the range of grass species sown in agricultural grasslands. From our experimental results, it is evident that the choice of grass species in mixtures is a management tool to control stability and productivity of grass swards under specific conditions. In forage systems with more frequent defoliations and especially on clay soils, *Lolium perenne* performed well, confirming its important role in the future. *Festuca arundinacea* showed a high forage potential and might help to reduce the frequency of sward renovations on peat soils and thus reduce the mineralisation of organic carbon in the soil. For extensive management on peat soil, it could also be an option to accept larger proportions of *Holcus lanatus* as yields are often better than assumed.

Even minor or secondary grasses, sown or not sown, can be productive and contribute to sward development and forage productivity in intensive dairy systems. We found that combinations of *Phleum pratense* and *Poa pratensis* have a good feed quality and can have similar yields as *Lolium perenne* on sand and might have advantages under less favorable conditions such as temporary droughts or cutting-only systems.

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