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 leaf 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 Northwestern 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 characterized 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.

<table>
<thead>
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<tbody>
<tr>
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<td>[˚C]</td>
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<tr>
<td>January</td>
<td>2</td>
<td>26</td>
<td>3</td>
<td>99</td>
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<tr>
<td>February</td>
<td>6</td>
<td>32</td>
<td>2</td>
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<tr>
<td>March</td>
<td>7</td>
<td>32</td>
<td>6</td>
<td>64</td>
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<tr>
<td>April</td>
<td>11</td>
<td>46</td>
<td>8</td>
<td>31</td>
</tr>
<tr>
<td>May</td>
<td>13</td>
<td>105</td>
<td>11</td>
<td>38</td>
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<tr>
<td>June</td>
<td>16</td>
<td>43</td>
<td>15</td>
<td>28</td>
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<tr>
<td>July</td>
<td>20</td>
<td>69</td>
<td>18</td>
<td>159</td>
</tr>
<tr>
<td>August</td>
<td>16</td>
<td>61</td>
<td>19</td>
<td>75</td>
</tr>
<tr>
<td>September</td>
<td>16</td>
<td>18</td>
<td>13</td>
<td>66</td>
</tr>
<tr>
<td>October</td>
<td>10</td>
<td>31</td>
<td>9</td>
<td>32</td>
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<tr>
<td>November</td>
<td>7</td>
<td>18</td>
<td>9</td>
<td>119</td>
</tr>
<tr>
<td>December</td>
<td>4</td>
<td>77</td>
<td>9</td>
<td>26</td>
</tr>
<tr>
<td>Year (ø; sum)</td>
<td>11</td>
<td>558</td>
<td>10</td>
<td>777</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th></th>
<th>Sand</th>
<th>Peat</th>
<th>Clay</th>
<th>All soils</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixture</td>
<td>%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FeAr</td>
<td>96</td>
<td>78</td>
<td>98</td>
<td>91</td>
</tr>
<tr>
<td>LoPe</td>
<td>89</td>
<td>61</td>
<td>91</td>
<td>81</td>
</tr>
<tr>
<td>PhPr</td>
<td>68</td>
<td>22</td>
<td>67</td>
<td>52</td>
</tr>
<tr>
<td>HoLa</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>PoPr</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

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\(^{-1}\) 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 HolLa, 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.

<table>
<thead>
<tr>
<th>Mixture</th>
<th>FeAr</th>
<th>LoPe</th>
<th>PhPr</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grazing</td>
<td>13810</td>
<td>11301</td>
<td>10366</td>
<td>2014</td>
</tr>
<tr>
<td>Mixed</td>
<td>11209</td>
<td>12029</td>
<td></td>
<td>2015</td>
</tr>
<tr>
<td>Cutting</td>
<td>12238</td>
<td></td>
<td></td>
<td>2016</td>
</tr>
</tbody>
</table>

* 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.

<table>
<thead>
<tr>
<th>Mixture</th>
<th>Soil</th>
<th>Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>FeAr</td>
<td>Sand</td>
<td>Grazing</td>
</tr>
<tr>
<td>2014</td>
<td>12203</td>
<td>11542 a</td>
</tr>
<tr>
<td>2015</td>
<td>13826</td>
<td>10858 b</td>
</tr>
<tr>
<td>2016</td>
<td>15401 a</td>
<td>11503 c</td>
</tr>
</tbody>
</table>

* 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.

<table>
<thead>
<tr>
<th>Species</th>
<th>Management</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>FeAr</td>
<td>Grazing</td>
<td>2014</td>
</tr>
<tr>
<td></td>
<td>Combined</td>
<td>2015</td>
</tr>
<tr>
<td></td>
<td>Cutting</td>
<td>2016</td>
</tr>
</tbody>
</table>

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