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Original Research

An inventory of grassland use on horse farms

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ABSTRACT

Horses can contribute to the maintenance of grassland. To determine the potential contribution of grassland to horse nutrition, we investigated the seasonal variation of herbage on offer and its nutritional quality in an inventory on six practical horse farms in Central Germany during 2019. On all horse-grazed pastures compressed sward height (CSH) was measured monthly and converted into aboveground herbage (AGH) to allocated short and tall grass sward areas (area-specific) via calibration cuts. In addition, four focus pastures were selected for monthly obtained area-specific herbage quality samples. The farm-specific management was monitored using questionnaires and grazing diaries to determine underlying factors influencing herbage biomass and quality. The proportion of short grass sward areas increased during the grazing season ($p=0.0010$), which was related to high stocking intensity in terms of livestock unit grazing days (LUGD, $p < .0001$). On most farms, LUGD were constant throughout the growing season and not adjusted to changing grass growth. Herbage crude protein (CP, $p=0.0038$), metabolizable energy (ME, $p < .0001$) concentrations and acid detergent fibre in the organic matter (ADF, $p < .0001$) differed among the grass sward areas. The results suggest that sufficient ME (4.2 ± 0.32 – 8.4 ± 0.15 MJ ME kg^{-1} DM) for maintenance and pre-caecal digestible CP (pcdCP) (37.0 ± 3.86 – 77.4 ± 4.44 g kg^{-1} DM) could be provided during the grazing season. The study highlights the need to incentivise grassland management for herbage provision among horse owners to exploit the potential of grassland during the grazing season.

1. Introduction

The long-term sustainable management of grassland is of great importance for maintaining grassland biodiversity and supporting a range of ecosystem services [1]. Horses are well suited for extensive grassland and for horse keepers there are few incentives to intensify pasture management [2]. In Germany, most horses are kept by private persons [3], typically with herd sizes of up to seven horses [4] which provides a suitable means for utilizing small and scattered areas of grassland in regions where arable farming predominates. Such grasslands are otherwise threatened with abandonment. Horse keeping is a diverse activity ranging from professional breeding and sport horse enterprises to private horse keeping for recreational interest [5]. Grazing management for improved grass intake is rather uncommon because of the facilitated feeding of horses using conserved forage [5,6] and concentrates [7].

There is limited information on the seasonal variation of herbage nutritional quality of grazed horse pastures against the background of practical on-farm grassland management. However, there are studies that analyzed the nutritional composition over the growing season and found large variability as related to protein, energy and fibre concentrations [8–14]. Some studies have also analyzed equine grazing systems under practical conditions [15] or linked the nutritional composition to the management system [16–18]. However, the relationship between grassland forage provision over time and grazing management on horse farms has received little attention. Furthermore, there is no general information available on the nutritional quality of grazed grassland herbage on horse farms, which is especially important for ensuring that daily requirements for energy and nutrient intake are met [19]. Links between management and grassland performance are therefore an important factor in the development of sustainable horse livestock systems.

In general, pastures grazed by horses are less homogeneous than pastures grazed by cattle or sheep [20–22] making assessments of herbage quality challenging. Horses create and maintain a matrix in the grass sward consisting of short and frequently grazed areas, sometimes

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overgrazed, and undergrazed tall and rejected herbage in the latrine areas [23,24]. The management diversity ranging from exclusively grazed to grazed and mown or only mown pastures at varying intensities will affect the development of these short and tall grass sward areas and, hence, the contrast of within-field variation of herbage nutritional quality [25,26].

Therefore, we conducted a multisite study on six practical horse farms located in Central Germany to study management systems and herbage quality on grassland grazed by horses. The region has a landscape dominated by arable farming and it is characterized by areas of scattered grassland. Due to the abandonment of small livestock farms and the shift towards fewer but larger farm sizes, the grassland that remains available is predominantly now used by horses, a situation which is not unique to Germany [3,27]. An important research aim was to determine the extent to which grassland in these situations can contribute to the nutrition of horses. We specifically asked i) what is the current grassland management on the farms in the study? ii) how is this management linked to herbage quality and grazing herbage on offer? and iii) is the quality of the feed sufficient to meet the horses' nutritional requirements?

2. Materials and methods

2.1. Ethical approval

No animal interventions were conducted and a specific ethical clearance was not necessary after consultancy with the Animal Welfare Officer.

2.2. Study region, setup and data collection on horse farms

The study was conducted between May and October 2019 on six horse farms in central Germany. All the farms were within 11.6 km of the city of Göttingen (51° 32′ 0.866″ N 9° 55′ 53.292″ E) at elevations of 160 – 295 m above sea-level. Weather data as well as the long-term monthly mean temperatures and precipitation sums (1991-2020) were retrieved from the station of the German Weather Service in Göttingen [28].Monthly mean temperature values during the study period were mostly warmer than the long-term average, except during May and September. Rainfall in May was above average (Table 1).

Management information was obtained from a structured farm questionnaire (Appendix A: Supplementary material). In the description that follows, the six farms are referred to as A-F. Among the farmers all except C were full-time farmers. There were different forms of horse keeping and also some mixed forms like livery stables (A, B, C, E, F), breeding farms (C, D), western riding academies (e.g. reining, pleasure) (B, E) and English riding academies (e.g. dressage, jumping) (E, F) (Table 2). Farms A, C and F used most of the available grassland for grazing, while the others used <30% for grazing with the number of pastures ranging between 6 and 13 per farm. The largest number of livestock units (LU, 1 LU = 500 kg live weight) was found on farms B and D, and these also had the largest total available grassland area (Table 2).

Actual live weights of individual horses were not available. Therefore, LU values were determined by the farmers according to horse classes, based on the instructions they were given. Ponies and foals were assigned to a live weight of <350 kg or a LU of 0.5. Horses with a live weight from 350 – 500 kg (e.g. Icelandic horses) were set to 0.75 LU and horses >500 kg live weight (e.g. German Warmblood) equalled to 1.0 LU.

Table 1
The average monthly temperature (°C) and precipitation sum (mm) from May to October 2019 for the station of the German Weather Service in Göttingen. The long-term monthly mean temperatures and precipitation sums from 1991-2020 are shown in parentheses [28].

Month	Temperature°C	Precipitation mm
May	11.1 (12.9)	90 (63.3)
June	19 (15.9)	65 (65.3)
July	18.1 (17.9)	44 (72.2)
August	19.1 (17.9)	31 (63.4)
September	13.7 (13.9)	48 (48.4)
October	11.6 (9.6)	45 (48.3)

Table 2
For the six farms (A-F) the total grassland areas, proportion of grazed grassland (%), number of grazed pastures, type of horse keeping and livestock units (LU) are shown.

Farm	Total grassland area (ha)	Grazed grassland (%)	Grazed pastures	Horse keeping[a]	LU[b]
A	8	100	11	LS	36.8
B	56	20	13	LS, WR	55.5
C	7	86	9	BF, PS	35.0
D	24	25	12	BF	50.0
E	15	27	6	LS, ERA	27.0
F	9	78	11	LS, ERA	37.3

[a] indicates type of horse farm: livery stable (LS), breeding farm (BF), western riding academy (WR), English riding academy (ERA)
[b] LU indicates numbers of horses per farm in terms of livestock units (1 LU = 500 kg live weight)

All farmers were asked to fill out a grazing diary for the whole six-month grazing period under study. Within the grazing diary, farmers entered daily values of LU stocking on the grazed grassland to enable calculation of LU grazing days (LUGD, a standardized daily number of horse LU in each pasture in terms of animal number) and the time the horses spent at pasture. The time spent at pasture by each individual horse was recorded into one of three categories (<4 h, 8-4 h, >8 h). Despite grazing during September, on farm D the grazing diary was interrupted between 1 September and 26 September. Therefore, for this farm the LUGD data for September was interpolated from the August and October data. In addition to the grazing diary, a pasture-specific management diary was also kept to record information on harvests, rolling, fertilizer application and other tasks performed on all the pastures chosen for the study.

Before the start of the study all pastures were visited with the farmers and only those pastures that were used for horse grazing during the trial year were considered for inclusion in the study. On each of the six farms, four representative focus pastures were chosen for detailed study of the seasonal dynamics of within-pasture herbage growth and herbage quality in tall-grass rejected sward areas and short-grass grazed sward areas. The aim was to relate this information to the grassland management. Each focus pasture per farm is referred to as P01-P04. The management on these focus pastures was either purely grazed swards or a mixture of grazed swards with one or two harvests for hay or haylage (mown pastures).

2.3. Inventory of sward height on horse grassland

The pasture-specific compressed sward height (CSH) served as a proxy for the standing aboveground herbage on offer (AGH, kg ha^{-1}) and was determined on the total horse grassland. Fig. 1 shows the data acquisition process on the horse pastures. A digital rising plate meter (RPM) ('Grasshopper®', TrueNorth Technologies, Shannon, Ireland) was used to measure the CSH monthly on each of the pastures following official (Teagasc, Ireland) guidelines [29]. The RPM has a diameter of 35.5 cm and a disc weight of 482 g (0.49 g m^{-2}) and measures the CSH depending on the resistance of the grass sward against the disc of the device. All records are reported directly to an app and stored on a cloud for subsequent download. Every spatial point of measurement is additionally stored with an internal GNSS receiver. On the pastures from farms A-D, the measurements took place at the beginning of each month. On the other two farms (E, F), measurements took place from the middle of a month onwards. The pastures were recorded by walking in

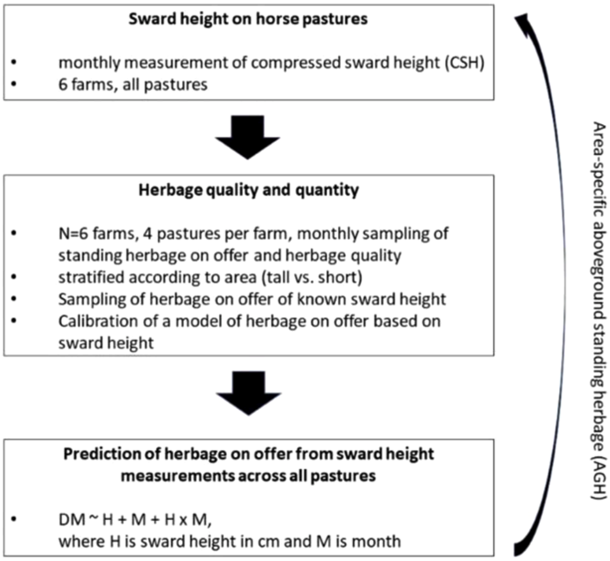

Fig. 1. Data acquisition process on the horse pastures to establish area-specific aboveground standing herbage (AGH, kg ha^{-1}).

longitudinal direction as far as possible. Depending on the size of the pastures one to six longitudinal paths were performed and between 30 and 200 measurement points were taken (Appendix B: Supplementary material). It was not always possible to take measurements on the intended line, for instance if there were obstacles like mobile shelters, drinking troughs, patches of thistles and/or nettles or faeces, or perceived risks of aggressive horse behaviour.

According to a study by Obermayer et al. [30], in which the Grasshopper CSH was compared against the values of a traditional rising plate meter [31], a larger compaction was found which affects the distinction of short and tall grass sward areas [32]. Therefore, areas were considered as short when a CSH $<$7.2 cm was recorded. A tall grass area was considered at a CSH of $\geq$7.2 cm. A similar division was also described by Dumont et al. [33]. The data were used for calculations of the proportion of each area per farm, pasture, and month.

2.4. Using sward height to calculate standing aboveground herbage on offer

On all the focus pastures, a double sampling approach was followed, similar to that of Ebeling et al. [34]. At monthly intervals, four herbage samples were taken on each of the *ex ante* defined focus pastures (4 pastures x 4 samples x 6 months = 96 samples per farm). Samples were taken in the morning the same date the RPM measures were recorded by cutting in the vicinity of previous sampling spots in an area of known CSH by using a steel frame of 0.35×0.35 m. For this, two pairs of pre-defined areas structured according to tall and short grass sward areas were used. The areas inside the metal frame are referred to as quadrats in the description that follows. Quadrat pairs were located close to each other, at 2 - 3 m distance. After CSH recording in each quadrat, the total aboveground standing herbage mass was cut manually close to ground level with battery powered hand shears (GARDENA® GmbH, Ulm, Germany) and packed into perforated bags. These bags were then cooled and transferred to the laboratory for drying to constant weight (at least 48 hours, 60°C). Afterwards the dry matter weight was measured using a precision scale (Sartorius AG, Göttingen, Germany).

The herbage dry matter samples obtained in this way for each CSH measurement were used to calculate the area-specific aboveground standing herbage per pasture (AGH). For this we used a linear regression model where each CSH value without an herbage biomass sample was converted to standing aboveground herbage dry matter (DM g m^{-2}) using the following model:

$$DM \sim H + M + H \times M,$$

where H is compressed sward height (CSH) in cm and M is month (R^2: 0.696, Root Mean Squared Error: 75.5 ± 17.3 g m^{-2}). Several models were tested and the one with the lowest Akaike information criterion (AIC) was chosen for calibration. This model was then used to calculate the DM (g m^{-2}) for each grass sward area per pasture. To assess the area size for each pasture the area proportion was multiplied by the total pasture size (m^2). This was then multiplied by the DM (g m^{-2}) and divided by 1000 to obtain the herbage in the grass sward areas (kg). In the last step the mass of herbage in the area (kg) was divided by the total pasture size (ha) to obtain the area-specific AGH (kg ha^{-1}).

2.5. Inventory of grassland herbage quality and soil nutrients

After weighing and drying of herbage biomass samples from the focus pastures these were milled in a two-step procedure, first to pass a 4-mm and then a 1-mm screen (Retsch SM 300 & Retsch ZM 300, Retsch GmbH, Haan, Germany). After milling, samples were analysed using near-infrared-reflectance spectroscopy (NIRS) by scanning each sample twice on a Phoenix 5000 (BlueSun Scientific Inc, MD, USA). For the purpose of the present study, concentrations of crude protein (CP), the ash-free acid-detergent fibre in the organic matter (ADF), crude fat (CL) and crude fibre (CF) were analysed. Concentrations were then processed and predicted using the large calibration data set stored on a central server (VDLUFA Qualitätssicherung, NIRS GmbH, Kassel, Germany). The data sets for NIRS of the quality parameters CP, ADF, CL and CF contained 3169, 1088, 949 and 2676 calibration samples, respectively. Standard errors of calibration for CP, ADF, CL and CF were 0.76%, 1.32%, 0.3% and 1.22%, and the corresponding standard errors of cross validation were 0.77%, 1.35%, 0.31% and 1.24%. In total 677 samples were analysed. The nitrogen-free extract (NfE) was calculated as DM - (CA (crude ash) + CP + CL + CF). All variables were expressed in g kg^{-1} DM.

The metabolizable energy (ME MJ kg^{-1} DM) was calculated after Wichert (2011) [35]:

$$\begin{aligned}
ME(MJ\,kg^{-1}DM) &= -3.54 \\
&+0.0129 \times CP(g\,kg^{-1}DM) \\
&+0.0420 \times CL(g\,kg^{-1}DM) \\
&-0.0019 \times CF(g\,kg^{-1}DM) \\
&+0.0185 \times NfE(g\,kg^{-1}DM)
\end{aligned}$$

Additionally in October, topsoil samples (10 cm) were taken on each focus pasture in two obviously tall grass and two short grass sward areas for potassium (K), phosphorus (P) (both calcium-acetate-lactate extraction (CAL-extraction)) and magnesium (Mg) ($CaCl_2$-extraction) analysis. The analysis uses calcium lactate and acetic acid to extract the nutrients in the soil solution using the CAL-extraction method. For the analysis of the K content continuous flow analysis coupled to a flame photometer were used and for the P content UV/VIS spectrophotometer (San System, Skalar, the Netherlands). For the analysis of the Mg content atomic absorption spectrometry (Analyst 400, Perkin Elmer Inc, Waltham, USA) was performed. At each sampling location (each short and tall grass sward area per pasture) a total of fifteen to twenty samples were collected and pooled for analysis. For each focus pasture, consequently, four pooled samples were taken, so that 16 pooled samples were taken on each farm and 96 pooled samples in total over all farms.

2.6. Data analysis

All data were processed with RStudio (R Version 1.4.1717, 2021, The R Foundation for Statistical Computing, Vienna, Austria).

We analysed each parameter using linear mixed effects models (package ‘nlme’) [36] and all models were checked to meet requirements of a normal distribution of residuals and variance homogeneity. The models for proportion of grass sward area and area-specific AGH (kg ha^{-1}) included farm (A-F), month (May-October) and grass sward area (short, tall) as well as their interactions as fixed effects and pasture as random effects. A different variance for each farm was allowed in both models in order to account for varied levels of pastures per farm. The model for LUGD (ha^{-1}) included farm (A-F) and month (May-October) as well as their interactions as fixed effects and pastures as random effects and a different variance for each farm was allowed. The target variables for herbage quality on focus pastures were CP, ADF and ME. The models included farm (A-F), grass sward area (short, tall), month (May-October), as well as their interactions as fixed effects and pastures (n=4 per farm) and quadrat pairs (n=2 per pasture) nested in pastures as random effects. At first significant outliers (1.5-fold interquartile range) were deleted so that 0.96%, 0.38% and 4.41% of the datasets of CP, ADF and ME, respectively were identified and excluded from further analyses. For CP and ME we made a square root transformation and a different variance for each month was allowed in the models for CP, ME and ADF. For each herbage quality model we performed an automatic model selection using the 'MuMIn' package [37]. The models for soil nutrients (K, P, and Mg) included farm (A-F), grass sward area (short, tall), as well as their interactions as fixed effects and pastures (n=4 per farm) and quadrat pairs (n=2 per pasture) nested in pastures as random effects. A logarithmic transformation was modelled for K, P and Mg and a different variance for the individual factor levels of grass sward area and farm was allowed for K, of farm for P, and of farm and pasture for Mg. For all parameters the most parsimonious model was chosen as a final model, as based on the AIC for small samples sizes, and then tested for significance with marginal Wald tests. Comparisons of means were done posthoc for significant influencing variables using Tukey's pairwise comparisons in the 'emmeans' package [38].

3. Results

3.1. Management on horse pastures during the 2019 study period

Organic and mineral fertilisers were applied on farm C, whereas farm D applied only organic fertiliser and F used only mineral fertiliser (Table 3). All farms harrowed their pastures and except for farm A, they also mowed them. Only farm C carried out weed control. Farms A, B and F topped their pastures which is a process of getting rid of the top of a pasture with a large formation of seed head by cutting it off. The main goal of topping is to induce growth and herbage quality. Mean pasture size varied between 0.51 ± 0.65 ha on farm D and 0.86 ± 0.56 ha on B. For farm E no management data were available.

Table 3
Farm-wise mean paddock size, management measures and fertiliser applications and amounts.

Farm	Pasture size (ha ± SD)	Management[a]	Organic/mineral fertiliser[b]	Amount (kg N ha^{-1} year^{-1})
A	0.72 ± 0.30	Mu, H, Pt	-/-	-
B	0.86 ± 0.56	H, R, M, Pt	-/-	-
C	0.68 ± 0.25	H, Wc, M	solid horse manure/ +	70
D	0.51 ± 0.65	H, R, M, Mu	biogas digestate/ -	-
E	0.59 ± 0.59	-	-/-	-
F	0.67 ± 0.49	H, M, Mu, Pt	-/ CAN	63.25

[a] Rolling = R; Harrowing = H; Mulching = Mu; Mowing = M; Pasture topping = Pt; Weed control = Wc; CAN: calcium ammonium nitrate
[b] - shows no fertiliser application and a + that application takes place but the fertiliser is not known

3.2. Tall and short grass sward areas, area-specific AGH per pasture and LUGD

There was an interaction of farm*month*grass sward area for the grass sward area proportion (p=0.0010) and area-specific AGH per pasture (kg ha^{-1}) (p=0.0020) (Table 4). For the LUGD (ha^{-1}) there was an interaction of farm*month (p <.0001) (Table 4).

Over the grazing season and on all farms except farm E tall grass sward area proportions declined immediately and progressively after May (p<.0071). Farm A was the only exception, showing a more or less stable proportion of tall grass sward areas until July (May: 0.62 ± 0.10, June: 0.65 ± 0.10, July: 0.71 ± 0.09), after which the proportion declined (p<.0001) (Fig. 2). Short grass sward areas increased in inverse proportion to the tall grass sward areas over the grazing season (p≤0.0463).

Despite the smaller values of AGH in short grass sward areas compared with tall grass sward areas (Fig. 3), the AGH per pasture (kg ha^{-1}) available in short grass sward areas increased during the grazing season (p≤0.0226). This was caused by the progressive increase in proportion of short grass sward areas within each pasture (p≤0.0463) (Fig. 2). The AGH per pasture in short and tall grass sward areas was equal in July on farms B (short: 846 ± 233 kg ha^{-1}, tall: 648 ± 254 kg ha^{-1}), D (short: 815 ± 202 kg ha^{-1}, tall: 835 ± 211 kg ha^{-1}) and F (short: 864 ± 184 kg ha^{-1}, tall: 1,253 ± 193 kg ha^{-1}) whereas it was equal in August for farms C (short: 756 ± 291 kg ha^{-1}, tall: 1,242 ± 330 kg ha^{-1}) and E (short: 1,119 ± 310 kg ha^{-1}, tall: 1084 ± 340 kg ha^{-1}), and for farm A (short: 1,175 ± 241 kg ha^{-1}, tall: 1,083 ± 254 kg ha^{-1}) in September (Fig. 3).

The values for LUGD remained relatively stable throughout the grazing season on farms A, B, C and F, with only farm C showing a decrease in October (p≤0.043, 2.6 ± 55.7 LUGD ha^{-1}) (Fig. 4). On the other hand, farm E showed an increase in LUGD during the grazing season with the largest values in October (p≤0.0005, 683. 6 ± 97.8 LUGD ha^{-1}). Farm D showed a stocking pattern similar to grassland growth with an increase till June (p≤0.0223, 568.3 ± 77.6 LUGD ha^{-1}), which was followed by a progressive decline in the stocking on pastures (p≤.0001) (Fig. 4).

3.3. Herbage quality and soil nutrients on focus pastures

All herbage quality parameters were affected by the main effect of grass sward area (CP: p=0.0038; ADF: p <.0001; ME: p <.0001) and the

Table 4
Output of marginal wald tests on the grass sward area proportion, area-specific aboveground herbage per pasture (AGH, kg ha^{-1}) and livestock unit grazing days (LUDG ha^{-1}). Given are degrees of freedom, F- and p-values.

	denDF	F-value	p-value
grass sward area proportion			
farm	573	0.8	0.5795
month	573	9.8	<.0001
grass sward area	573	2.6	0.1058
farm*month	573	1.3	0.1615
farm*grass sward area	573	1.1	0.3829
month* grass sward area	573	19.8	<.0001
farm*month* grass sward area	573	2.2	0.0010
area-specific AGH (kg ha^{-1})			
farm	573	0.1	0.9925
month	573	6.2	<.0001
grass sward area	573	11.7	0.0007
farm*month	573	0.4	0.9986
farm* grass sward area	573	2.4	0.0380
month* grass sward area	573	18.3	<.0001
farm*month* grass sward area	573	2.1	0.0020
LUGD ha^{-1}			
farm	324	3.0	0.0111
month	324	0.8	0.5250
farm*month	324	3.3	<.0001

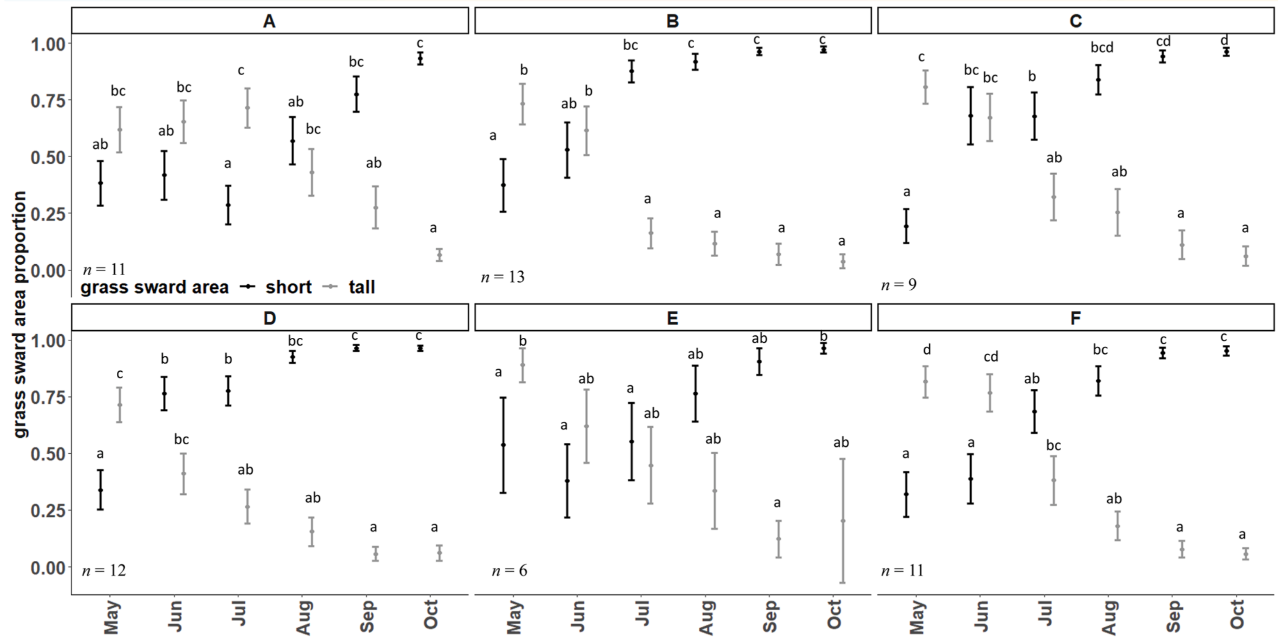

Fig. 2. Proportion of tall and short grass sward areas as presented in an interaction of farm*month*grass sward area (p=0.0010) averaged over all measured horse pastures per farm (*n* indicates number of pastures considered). Shown are estimated means ± standard errors of means. Different letters indicate significant differences between means within farms and grass sward areas (P < 0.05).

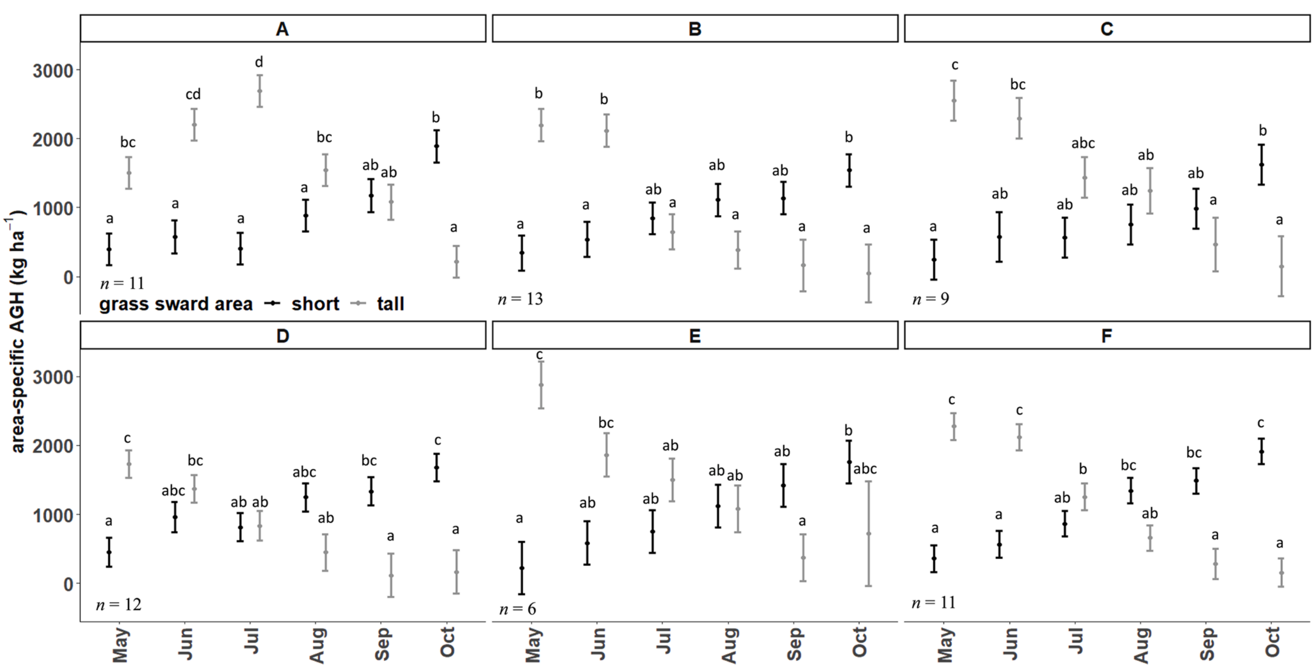

Fig. 3. Area-specific aboveground herbage (AGH) per pasture (kg ha^{-1}) as presented in an interaction of farm*month*grass sward area (p=0.0020) averaged over all measured horse pastures per farm (*n* indicates number of pastures considered). Shown are estimated means ± standard errors of means. Different letters indicate significant differences between means within farms and grass sward areas (P < 0.05).

interaction of farm*month (CP: p <.0001; ADF: p <.0001; ME: p <.0001) (Table 5).

The effect of grass sward area was related to greater concentrations of CP and ME in short grass sward areas than tall ones (CP: p=0.0001; ME: p <.0001) while the opposite was true for ADF (p <.0001)(Table 6).

Concentration of CP was characterized by large variation within the growing season and also between farms (Fig. 5). The lowest CP concentration was 94.7 ± 9.57 g kg^{-1} DM on farm F in September. The greatest CP concentrations were reached on farm C in May (198.1 ± 11.17 g kg^{-1} DM), September (181.7 ± 14.0 g kg^{-1} DM) and October (180.3 ± 14.0 g kg^{-1} DM). On farms A (159.7 ± 10.03 g kg^{-1} DM), B (177.9 ± 10.58 g kg^{-1} DM), C (198.1 ± 11.17 g kg^{-1} DM) and E (165.7 ± 13.06 g kg^{-1} DM) the greatest CP concentration was found in May. On the contrary, on farms D (150.9 ± 12.19 g kg^{-1} DM) and F (155.1 ± 13.02 g kg^{-1} DM) the greatest CP concentration was found in October.

For each farm the ADF concentration increased over the course of the growing season from a fairly low level across farms (p≤.0001) (Fig. 5). Farm A reached the largest overall ADF concentration of 402 ± 16.2 g

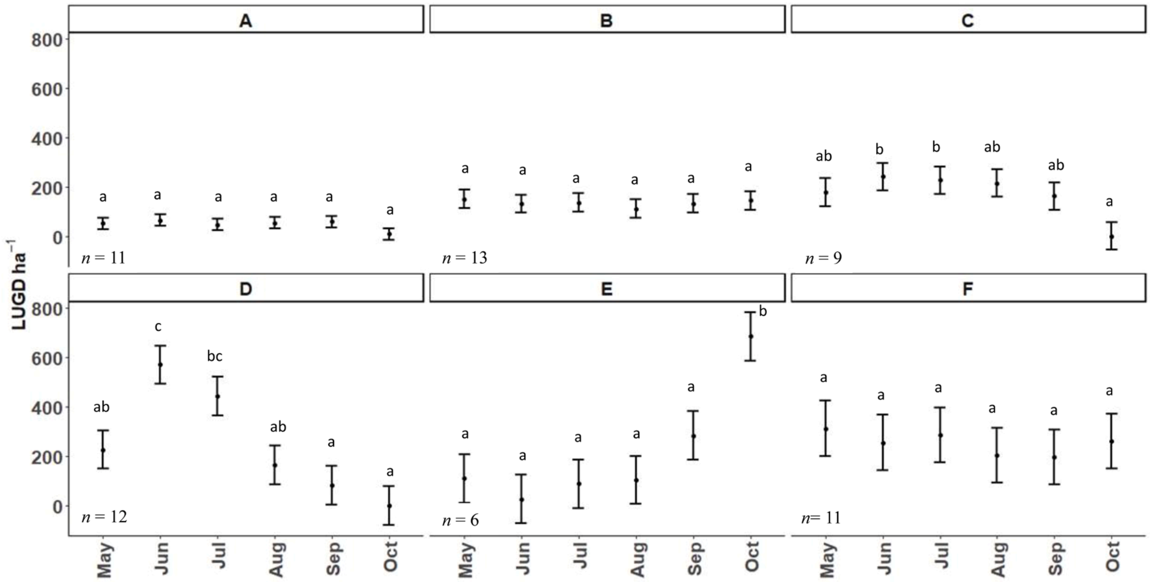

Fig. 4. Livestock unit grazing days (LUGD ha^{-1}) as presented in an interaction of farm*month (p <.0001) averaged over all measured horse pastures per farm (*n* indicates number of pastures considered). Shown are estimated means ± standard errors of means. Different letters indicate significant differences between means within farms (P < 0.05).

Table 5
Output of marginal wald tests on the concentrations of crude protein (CP, g kg^{-1} DM), acid-detergent fibre in the organic matter (ADF, g kg^{-1} DM) and metabolizable energy (ME, MJ kg^{-1} DM). Given are degrees of freedom, F- and p-values.

	CP			ADF			ME		
	denDF	F-value	p-value	denDF	F-value	p-value	denDF	F-value	p-value
grass sward area	472	8.4	0.0038	475	28.3	<.0001	454	28.0	<.0001
farm	472	9.7	<.0001	475	1.8	0.1192	454	2.1	0.0701
month	472	7.1	<.0001	475	39.9	<.0001	454	24.1	<.0001
farm*month	472	3.3	<.0001	475	3.6	<.0001	454	3.2	<.0001

Table 6
Estimated means (± se) of crude protein (CP, g kg^{-1} DM), acid-detergent fibre in the organic matter (ADF, g kg^{-1} DM) and metabolizable energy (ME, MJ kg^{-1} DM) for distinct grass sward areas on horse pastures across focus pastures (*n*=4) and farms (*n*=6). CP: p=0.0038; ADF: p <.0001; ME: p <.0001.

Grass sward area	CP	ADF	ME
tall	136 ± 6.11 a	317 ± 4.29 b	6.37 ± 0.06 a
short	145 ± 6.31 b	299 ± 4.27 a	6.75 ± 0.06 b

Lowercase letters indicate significant differences between means within columns (p < 0.05)

kg^{-1} DM in October whereas E had the lowest overall value of 222 ± 9.1 g kg^{-1} DM in May. In July and August there were only small differences in the ADF concentration between the farms. Farms D (p=6833) and F (p=0.9102) showed a decrease in ADF concentration from June to July.

The ME concentration generally followed the ADF concentration; however, in the opposite order and it declined as the growing season progressed (p<.0001) (Fig. 5). Farm B maintained herbage with a relatively stable ME concentration between June and September (p=0.9963). The greatest ME concentration was reached in May on farm D (8.4 ± 0.15 MJ ME kg^{-1} DM) and the lowest was recorded in October on farm E (4.2 ± 0.32 MJ ME kg^{-1} DM).

The soil K content was greater in the tall grass sward areas (p <.0001; 314 ± 29.4 vs 189 ± 15.4 mg kg^{-1} soil) whereas for P (p=0.1694) and Mg (p=0.023) there were no differences between the tall and short grass sward areas (Table 7) (P: 7.1 ± 0.71 vs 5.9 ± 0.59 mg 100 g^{-1} soil; Mg: 23.4 ± 2.01 vs 21.4 ± 2.20 mg 100 g^{-1} soil in tall and short grass sward areas, respectively).

Differences between farms were less clear (K: p=0.0334, P: p<.0001, Mg: p <.0001) with soil on farm B showing greater K content than farm F (p=0.0346) (Table 8). The P content on farm D was greater than on all other farms (p≤0.0046, except farms C & F), while farms A and B (p≤0.0002, except farm F) had the greatest Mg contents.

4. Discussion

Grassland is the dietary basis for healthy horse nutrition [23,39,40] and in Germany between 15 and 20% of the total grassland area is used for horses [3]. In regions where grassland is often fragmented it occurs in small areas. Grazing with large herds is hardly possible in such situations. In these circumstances, horses play an important role in maintaining these grasslands, both as a source of feed for grazing and supporting their wider ecological value. The region of the farms in our study is typical of this situation. The present study was conducted against a background of inadequate information on the capacity of grassland to supply nutrients and energy to horses on farms, despite its relevance with regard to resource use efficiency of the livestock sector [41]. Our aims were therefore to establish an inventory of grassland utilization on horse farms, to determine the extent grassland can contribute to the nutrition of horses under the prevailing conditions through a series of specific questions.

4.1. Management and stocking intensity on practical horse farms

The results of this study show that within this sample of farms there is a huge variability in the management operations on grasslands used by horses. These management operations vary in their intensity and

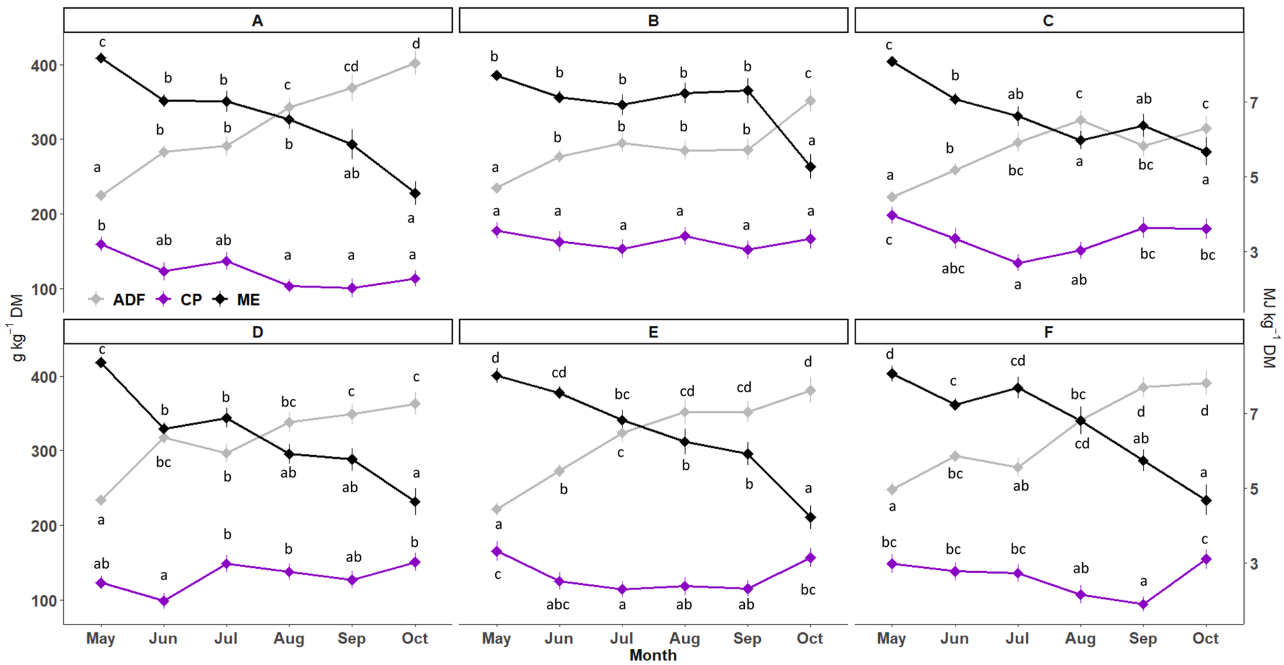

Fig. 5. Concentration of crude protein (CP, g kg^{-1} DM), acid-detergent fibre in the organic matter (ADF, g kg^{-1} DM) and metabolizable energy (ME, MJ kg^{-1} DM) as presented in an interaction of farm*month across focus pastures (n=4) and farms (n=6) (p <.0001). Shown are estimated means ± standard errors of means. Different letters indicate significant differences between means within farms (P < 0.05).

Table 7
Output of marginal wald tests on the contents of potassium (K), phosphorus (P) and magnesium (Mg) in soil. Given are degrees of freedom, F- and p-values.

		K		P		Mg	
	denDF	F-value	p-value	F-value	p-value	F-value	p-value
farm	77	2.6	0.0334	10.8	<.0001	22.1	<.0001
grass sward area	77	25.3	<.0001	1.9	0.1694	5.4	0.023
farm*grass sward area	77	1.6	0.1576	0.6	0.7112	0.1	0.9971

Table 8
Estimated means (± se) of potassium (K), phosphorus (P) and magnesium (Mg) contents (mg kg^{-1} soil) in the 10 cm soil depth across focus pastures (n=4) and farms (n=6). K: p=0.0334, P: p <.0001, Mg: p <.0001.

Farm	K	P	Mg
A	215 ± 28.0 ab	52.4 ± 11.1 ab	338 ± 37.3 b
B	310 ± 33.9 b	46.1 ± 6.4 a	346 ± 54.2 b
C	295 ± 40.5 ab	86.7 ± 13.4 bc	171 ± 15.2 a
D	265 ± 68.6 ab	147.1 ± 25.9 c	149 ± 11.1 a
E	199 ± 25.6 ab	28.3 ± 5.5 a	156 ± 13.7 a
F	203 ± 16.9 a	86.0 ± 12.3 bc	271 ± 58.6 ab

Lowercase letters indicate significant differences between means within columns (P < 0.05)

intervention in terms of defoliation or sward maintenance. It can be concluded that the grassland is clearly less intensively managed compared to cattle pastures [6,20]. This indicates that grasslands used by horses have great potential to support nature conservation objectives, as evidenced by their within-pasture structural heterogeneity in terms of differences in sward height, heterogeneity in herbage on offer and herbage nutritional quality as the results of this and other studies indicate [12,16,18]. The management is also supportive to promote the phytodiversity of grassland [13,14]. Nutrient concentrations and selective grazing are known to influence species composition and heterogeneity of the vegetation and these effects are more evident on horse pastures compared to cattle pastures [24,42] and can therefore contribute to support phytodiversity. Increased phytodiversity and less intrusion on grasslands can also be beneficial for insects [43] and bees [44]. The lower amount of N fertilization found on the horse farms is likely associated with less nitrate pollution of groundwater [45] or nitrous oxide emission [46] adding further environmental value to horse grassland management operations.

One remarkable result was that the LUGD remained constant over the grazing season on almost all farms. Farm D had a pasture management adapted to the grass growth, which seems to aim at providing the horses with the best possible supply of available herbage from grassland. The opposite was true for farm E, which had relatively constant LUGD between May and September, with a sharp increase towards October. Except for farm D, this contradiction points to the fact that the grazing management was not adapted to the seasonal grass growth. Subsequently, damage to the grass sward occurs due to overgrazing, which results in poor regrowth, unfavourable botanical composition and insufficient energy and forage supply [2,42]. The more or less constant stocking further mirrors the low importance of grassland as a source of feed and more to its role as a run and exercise area [23,47]. Another reason for poor grassland management could be that the farms are located in the vicinity of an urban area, and therefore there is less available grassland [47] in conjunction with a low level of professionalization [6]. The three farms with the least available grassland area (farms A, C and F) used most of it for grazing, resulting in less grassland being available for forage conservation, which would then require extra costs for forage purchase.

4.2. Development of short and tall grass sward areas throughout the grazing season

All farms had a greater proportion of tall grass sward areas in May due to the seasonal pattern of grass growth and the start of the grazing season. Continued grazing and mowing of the pastures promoted short grass sward areas from June onwards. A decrease in grass growth towards autumn together with the effect of mulching triggered this pattern further and resulted in lower area-specific AGH in tall grass sward areas. On farm A pastures were topped, a management procedure that aims to increase herbage quality, and this resulted in a more homogeneous grass sward [6]. Thus, the role of short grass sward areas for the provision of herbage was important given the increase in their proportion of the sward area in pastures over the duration of the grazing season. It is also known from previous studies that tall grass sward areas are hardly grazed by horses [24]. However, our study goes beyond the scope of earlier studies as it considers the variability of distinct grass sward areas in detail over the course of the growing season on a total of 62 pastures. These typical grass sward areas develop due to the grazing behaviour of horses, which results in tall grass sward areas developing around dung deposits coexisting with short grass sward areas in varying settings and spatial complexity [20,42].

In terms of herbage requirement, depending on the season, free-living Przewalski horses consumed between 3.3% and, in extreme cases, 5.1 % of their liveweight from pasture [48]. However, horses in our study are unlikely to consume such quantities from grazing due to supplemental feeding and training phases by which grazing time is limited. The DM intake of horses fed in stable trials varied from 1.3 to 2.8% of liveweight [49–51] and according to these values a horse with a liveweight of 500 kg would consequently ingest between 6.5 and 14.0 kg grassland herbage DM d^{-1}. On a monthly basis between 926.9 (farm A) and 3,617 (farm D) kg ha^{-1} of grassland herbage was required. These quantities could be delivered from the grasslands, at least on some farms. In the future, the goal must be to enable the exploitation of growth through adapted pasture management. Adapted horse grazing management with the aim of increasing grass herbage intake needs to take into account that the grazing time is reduced because of riding and other activities [2,23]. With respect to our first question, we consequently demonstrated that the grassland management is highly variable and that optimal and targeted grazing practices are yet to be established. Overall, there is a need to improve the knowledge of grassland management by education on horse farms, with the aim of ensuring that improved herbage provisioning potential will contribute to an immediate improvement of the herbage supply from grassland.

4.3. Nutritional requirements of horses and how they can be fulfilled from pasture during the grazing season

Herbage of the short grass sward areas of the farms in our study had higher energy and protein concentrations compared to tall grass sward areas. In previous studies on horse pastures, it was found that energy and protein concentrations were larger in short grass sward areas compared to mown pastures and tall grass sward areas [12]. In the short grass sward areas greater CP concentrations were found than in the tall ones due to the frequent defoliation and regrowth of young and leafy herbage which is in accordance with Fleurance et al. [52]. If horses are to be fed exclusively on grass, the short grass sward areas are thus an important source of protein and energy. This is especially true for horses that are also required to perform at a higher level. However, there is also variability within patches in terms of energy and protein concentration, which may be influenced by fertilisation. Especially the CP concentration can be controlled by reduced or no fertilisation [53]. Although the horses prefer to graze in the short grass sward areas, the less energy- and protein-rich tall grass sward areas are also sought out for grazing, so that the intake can be adjusted.

We analysed the CP concentration using standard methods. The general course of the CP concentration on the focus pastures in our study showed a decrease from spring to summer followed by an increase in autumn. The CP concentrations of individual farms reached up to 198.1 g kg^{-1} DM with a minimum value of 94.7 g kg^{-1} DM. In a recent study from Fleurance et al. [54], conducted in France, the average CP concentration on horse pastures was 116 g kg^{-1} DM.

A study from Tuescher et al. [55] found that a proportion of the CP (on average 0.391 of the CP) was represented by pre-caecal digestible CP (pcdCP). Horses have a daily requirement of 3 g pcdCP kg^{-1} live $weight^{-0.75}$ [56]. Based on the CP values determined in our study, we estimated pcdCP concentrations of between 37 and 77.4 g kg^{-1} DM. According to the analyses in our study and under the assumption of 10 kg daily herbage intake the concentration of CP and therefore pcdCP will mostly be excessive to cover requirements from May till October as was also found in other grazing equine studies [57,58].

The outliers for ME were slightly higher due to the fact that it was a calculated concentration and not directly measured. During the grazing season the ME concentration on all farms declined from spring to autumn, which follows a fairly strong pattern. Only farm B showed a relatively stable ME concentration in the herbage until September. The maintenance energy requirement of adult horses is approximately 54.98 MJ ME d^{-1} LU^{-1} [56]. However, most of the horses in our study were under a training protocol with increased energy demand at least for light training, as can be assumed for most of the horse population in Germany [7,59]. On horse farms, the actual feeding level of concentrates is variable and challenging to determine. With respect to our third question, the ME concentrations in the grassland were in general sufficient to cover maintenance requirements until late summer (September) and also sufficient to support the nutritional requirements for light training activities until July, which implies that no concentrate feeding was necessary. The ME concentration in grass usually declines with maturity [60] particularly when grass swards develop inflorescences, a feature likely to be applicable to the pastures in the present study. The feeding regime depends on the purpose for which the horses are kept (e.g. breeding, dressage, riding academies, hobby horses) and also if they are kept in rural or urban areas, because the access to pasture is often restricted in the latter [61]. The most common horse keeping forms in the present study were livery stables and riding academies. Here, horse owners determine the feeding regime, which makes it difficult to assess the type and amount of the feeding components. Often the horses' diets have a high energy concentration, either to allow for intensive training or it may reflect overestimation of the requirement [62].

Due to the large number of pastures, their sizes and that all measurements were taken by the same person it was only possible to perform the measurements throughout the month. However, in each month measurements on the farms took place in the same order so that the monthly interval for each pasture was the same. This may affect differences of herbage nutritional quality among farms. However, as we study the effects of farm management decision over time our approach reflects the individual circumstances.

An important finding of the herbage quality analysis in our study was the significant interaction between farm and month over the growing season. This points to a large extent to variations in management but may also be related to differences in sward age, pedo-climatic conditions or the botanical composition [63–65].

4.4. Management of fertilisation and nutrient shifts

Farm C applied most fertiliser and had greatest CP values, and potentially of pcdCP, which is in line with previous studies [50,53]. This points to the need for optimization potential in fertiliser management [66], to save resources and avoid excesses. According to official fertilisation recommendations for phosphorus, a P content of 31-60 mg kg^{-1} soil is recommended. This level was achieved on most farms although potassium levels were often higher than recommended, indicating potential to save resources in terms of fertiliser input by optimized grassland management. Overall, the extent of within-pasture variability of soil nutrient contents between grass sward areas in the present study was less than in previous studies [34,42] which may have been related to pasture management decisions. For instance, some farms harrowed their pastures to re-distribute faeces in order to balance shifts in soil nutrients related to tall grass sward areas [67].

4.5. Limitations of the study

A limitation of the current study is the lack of assessment of the botanical composition of the grass swards. This could be different between the farms and also within one farm. In general, Schmitz and Isselstein [20] found larger botanical diversity on managed horse farms compared to cattle farms. The botanical composition could have an influence on the regrowth, preferred grazing spots and nutritional quality. Therefore, this needs to be assessed in further studies. The vegetative cover also was not determined, which can be an indicator for overgrazing or damage to the sward through the horses. Furthermore, the present study was conducted over one grazing season making evaluations of interannual variation impossible showing that further studies are required.

5. Conclusion

Our study illustrates a diversity of grassland management practices in horse husbandry. The study has provided evidence for seasonal changes in the ratios of tall and short grass sward areas in horse-grazed pastures and of seasonal changes in herbage nutritional values. Such information has potential to allow horse keepers to adjust supplementary feeding in response to changes in herbage supply and feed value and thereby improve feed resource management and reduce concentrate use. Better training in grassland management could also result in better adaptation of grazing practices to the grassland growth curve and avoidance of soil nutrient oversupply. The associated effects of horse grazing in terms of sward structural variation have potential benefits for grassland biodiversity, grassland conservation management and other ecosystem services.

CRediT authorship contribution statement

C. Siede: Data curation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **M. Komainda:** Conceptualization, Formal analysis, Methodology, Supervision, Writing – review & editing. **B. Tonn:** Conceptualization, Funding acquisition, Writing – review & editing. **S.M.C. Wolter:** Investigation. **A. Schmitz:** Conceptualization. **J. Isselstein:** Conceptualization, Methodology, Resources, Supervision, Writing – review & editing.

Declaration of competing interest

None of the authors has any financial or personal relationships that could inappropriately influence or bias the content of the paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jevs.2024.105011.

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