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Optionen der Grünlandbewirtschaftung im Klimawandel: Bewertung der Weidewirtschaft und Prüfung von Weidelgras, Rohrschwingel und Lieschgras.

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In dem auf Deutsch verfassten Teil dieser Arbeit wird bei der Bezeichnung von Personen zwischen der weiblichen und männlichen Form abgewechselt.

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Allt är mycket osäkert, och det är just det som lugnar mig.
– All things are so very uncertain, and thats exactly what makes me feel reassured.

Tove Jansson, Trollvinter (1957).

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Abkürzungen

FeAr	*Festuca arundinacea*
LoPe	*Lolium perenne*
PhPr	*Phleum pratense*
PoPr	*Poa pratensis*
HoLa	*Holcus lanatus*

1 Ziele und Aufbau der Arbeit

Die wichtigsten Eigenschaften von Grünland – die Artenzusammensetzung, der Ertrag und die Futterqualität – werden im Wesentlichen durch die Art der Nutzung, das Klima und den Boden bestimmt. Eine hohe Biodiversität, die Wasserspeicherkapazität und die Speicherung von Kohlenstoff sind bedeutende Öksoystemdienstleistungen von Grünland. Futterqualität und Ertrag bestimmen wiederum die Milchleistung und Qualität und sind entscheidend für den wirtschaftlichen Erfolg der Betriebe. Über die Nutzungsintensität und die Wahl der angebauten Grasarten können Landwirtinnen und Landwirte Einfluss auf die Eigenschaften des Grünlands nehmen. Dabei müssen die klimatischen und die pedologischen Gegebenheiten berücksichtigt werden.

In den letzten Jahrzehnten haben viele Betriebe die Weidehaltung aufgegeben, Milchkühe, weibliche Nachzucht und Mastbullen werden ganzjährig im Stall gehalten. Die Bewirtschaftung einer Weide unterscheidet sich stark von der Bewirtschaftung einer reinen Schnittfläche, die Aufgabe der Weidehaltung führt zu starken Veränderungen der Grasnarbe. Weil sie seltener entblättert wird und der Tritt der Tiere sowie die Kot- und Harnflecken auf der Fläche fehlen, geht der Anteil von Weidelgras (*Lolium perenne*) in der Narbe zurück. Dieses geht wiederum mit einer Verringerung der Futterqualität und der Erträge einher und wird durch Nachsaaten und Neuansaaten ausgeglichen.

Da inzwischen auch in Norddeutschland erste Auswirkungen des Klimawandels spürbar werden, kommt dieses Verfahren an seine Grenzen. Die durch den Klimawandel häufigeren Dürreperioden setzen insbesondere dem Weidelgras zu, was noch häufigere Neuansaaten und Nachsaaten erforderlich macht. Nachsaaten gehen allerdings immer mit dem Verlust von Kohlenstoff und Auswaschungen von Stickstoff einher und sind mit hohen Kosten und einem hohen adminstrativen Aufwand verbunden.

Um die hohen Kosten für Neu- und Nachsaaten zu vermeiden und negative Auswirkungen auf die Umwelt zu verhindern, brauchen landwirtschaftliche Betriebe Alternativen zum Anbau Weidelgras. In dieser Arbeit wurde deshalb untersucht, welche Erträge und Qualitäten mit den Grasarten Lieschgras (*Phleum pratense*) und Rohrschwingel (*Festuca arundinacea*) im Vergleich zu Weidelgras in verschiedenen Bewirtschaftungssystemen auf Sand-, Marsch- und Moorboden erreicht werden können und wie ausdauernd sie dort sind. Lieschgras hat eine hohe Futterqualität, wird allerdings in Weidesystemen schnell verdrängt, ist aber in Schnittsystemen beständig. Rohrschwingel war bis vor einigen Jahren aufgrund rauer Blätter und einer geringen Futterqualität ein unerwünschtes Gras. Es ist allerdings gut an Trockenheit angepasst. Neue Züchtungen versprechen eine höhere Futterqualität und weichere Blätter. Rohrschwingel kann auch während Trockenphasen und dabei auch auf Sandböden mit geringer Wasserhaltekapazität hohe Erträge mit einer guten Qualität erbringen. Deutsches Weidelgras ist züchterisch stark bearbeitet und bringt vor allem in Weidesystemen auf guten Standorten dauerhaft gute Erträge mit sehr hoher Qualität.

Neben den nötigen Anpassungen an den Klimawandel müssen Betriebe höhere gesellschaftliche Anforderungen an das Tierwohl beachten und sich auf schwankende Preise einstellen. Nachdem ein Großteil der Betriebe lange Zeit auf Wachstum gesetzt hat, erwies sich diese Strategie oft als unrentabel. Durch die teilweise über lange Zeiträume hinweg niedrigen Milchpreise und gleichzeitig hohen Preise für Futter- und Betriebsmittel sind viele Betriebe in Existenznot geraten. Betriebsleiter suchen nach Alternativen, um die Kosten zu senken oder weitere Einnahmequellen zu generieren. In dem Zuge wurde von vielen Landwirtinnen und Experten auch die bessere Nutzung des betriebseigenen Futters durch eine Steigerung der Weidehaltung in Erwägung gezogen.

Bisher gibt es nur wenige Studien über die Bedeutung der Weidehaltung auf den verbliebenen Weidebetrieben und über den Anteil von Grassilage und Heu an der Fütterung von Milchkühen in den verschiedenen Systemen. Landwirte, die ihre Weidenutzung steigern wollen, benötigen insbesondere am Anfang eine entsprechende Beratung und Informationsmaterial, um Fehler zu vermeiden und die richtigen Methoden anzuwenden. Betriebe, die die intensive Weidehaltung nie aufgegeben haben, könnten durch entsprechende Beratung die Potenziale ihrer Flächen besser ausschöpfen als bisher.

Forschung und Beratung benötigen mehr Informationen über Betriebsstrukturen und über die Motivationen der Betriebsleiterinnen, um Techniken und Methoden zu entwickeln, die die Weidehaltung vereinfachen. Um diese Lücke zu schließen, wurde im Rahmen dieser Arbeit eine Befragung auf Milchviehbetrieben mit Weidehaltung und Stallhaltung durchgeführt. Einerseits wurden die Betriebsstrukturen der Betriebstypen festgestellt, andererseits wurde erhoben, wie die Vor- und Nachteile von Weidehaltung und Stallhaltung durch Landwirte bewertet werden.

2 Einführung in die Thematik

2.1 Hintergründe zur Weidewirtschaft auf Grünland

Grünland befindet sich vor allem auf Standorten, auf denen eine Ackernutzung nicht möglich oder nicht rentabel ist. Im humiden Klima Mitteleuropas betrifft dies insbesondere Marsch -und Moorböden, wo die hohen Niederschläge den Anbau von Feldfrüchten erschweren. Im Mittelgebirge und Hochgebirge sind viele Flächen aufgrund einer starken Hanglage nicht für den Ackerbau geeignet. Sandböden werden aufgrund einer geringen Fruchtbarkeit und unter kontinentalen Bedingungen bei zu geringen Niederschlägen als Grünland genutzt.

Von den 16,7 Millionen Hektar landwirtschaftlicher Nutzfläche in Deutschland (Statistisches Bundesamt, 2019a) waren im Jahr 2017 4,7 Millionen Hektar und damit 28% Dauergrünland (Statistisches Bundesamt, 2019b). Mit dem Begriff Dauergrünland werden Flächen bezeichnet, die zum Anbau von Gräsern und Grünfutterpflanzen genutzt werden und für wenigstens fünf Jahre nicht Bestandteil der Fruchtfolge des landwirtschaftlichen Betriebs sind (Verordnung (EG) Nr. 796/2004). Seit dem Ende des Zweiten Weltkriegs sind die Milch erzeugenden Betriebe kontinuierlich gewachsen und haben sich stark spezialisiert. Parallel zu den wachsenden Betrieben sind viele Betriebe aufgegeben worden und noch immer sinkt der Anteil aktiver Betriebe (Eurostat 2009; Eurostat, 2018). Die Hauptgründe für die Betriebsaufgaben sind einerseits fehlende Hofnachfolger, andererseits die schwierige wirtschaftliche Situation, aufgrund derer viele Betriebe häufig nicht Kosten deckend arbeiten können. Zwischen 2005 und 2015 wurden nur in fünf Jahren Gewinne erzielt, in anderen Jahren reichten die Einnahmen der Milcherzeugerinnen nur zur Deckung der variablen Kosten (Wüstermann und Caglar, 2016). Häufig verzichten potenzielle Hofnachfolger wegen der schlechten wirtschaftlichen Situation auf eine Weiterführung des Betriebes (Groier, 2004).

Nach dem Zweiten Weltkrieg bestand das politische Ziel viele Jahrzehnte lang darin, die Ernährung sicher zu stellen und die Produktion zu steigern. Um innerhalb der EG einen über dem Weltmarktniveau liegenden Milchpreis zu halten, andererseits Lagerbestände abzubauen und die Haushalte zu entlasten, wurde 1984 die Milchquoten-Regelung eingeführt (Verordnung (EWG) Nr. 857/84). Doch auch in den 31 Jahren der Milchquotenregelung schwankten die Erzeugerpreise für Rohmilch um bis zu 20 Cent pro Kilogramm und die Anzahl der Milcherzeuger sank in Deutschland um 80% auf circa 75.000 (BMEL, 2019a). Landwirte versuchten, durch eine Steigerung der Produktion ihre Betriebe zu erhalten, für viele galt das Motto „*wachsen oder weichen*“ (Langthaler et al. 2012). Durch diese sogenannte „Wachstumsstrategie“ (Wüstermann und Caglar, 2016) haben sie zu einer Steigerung des Angebots und dem damit verbundenen Preisverfall beigetragen. Außerdem hat sich die Art der Milchproduktion stark verändert. Die Herden wurden größer und aus der Zucht kamen Kühe, die zu Leistungen von bis zu 12.000 kg Milch je Kuh und Jahr fähig waren (Jerabeck, 1999; Nier et al., 2013). Um die Tiere bei diesen Leistungen bedarfsgerecht zu füttern, reichen Gras und Grassilage nicht aus, die Rationen werden mit Mais und Kraftfutter ergänzt. Bei Milchleistungen von 30 kg wird eine tägliche Gabe von acht kg Trockenmasse Kraftfutter empfohlen (Spiekers und Potthast, 2004).

Die gesteigerten Bedürfnisse der Milchkühe an die Fütterung hatten auch Auswirkungen auf das Grünland. Durch den Einsatz von Drainagen, Neu- und Nachsaaten, häufigere Schnitte und eine höhere Düngung wurde die Produktivität des Grünlands gesteigert. Ein Teil des Grünlands wurde für den Anbau von Silomais und von Energiemais für die Erzeugung von Biogas umgebrochen

(Schramek et al., 2012). Von über 5,2 Millionen Hektar Grünland Anfang der 1990er Jahre ging die Gründlandfläche in Deutschland bis zum Jahr 2014 auf 4,6 Millionen Hektar zurück. Der Anteil von als Weide genutztem Grünland nahm von 1,2 Million Hektar im Jahr 1991 auf 0,6 Millionen Hektar im Jahr 2009 ab (Statistisches Bundesamt, 2019c). Erst in der Folge des Grünlandumbruchverbots stieg die Grünlandfläche bis 2016 wieder leicht auf 4,7 Millionen Hektar an (BMEL, 2001; BMEL, 2017)

2.2 Geringe Flexibilität und Risikoaversion

Alle Marktteilnehmerinnen müssen mit Unsicherheiten umgehen und darauf reagieren. Landwirtschaftliche und insbesondere Milch erzeugende Betriebe unterliegen dabei einer großen Zahl von Unsicherheiten, können aber nur eingeschränkt auf Veränderungen reagieren (BMEL, 2019b).

Ein wesentlicher Grund für die geringe Flexibilität von Milchviehbetrieben ist die kurze Lagerbarkeit von Milch. Die Betriebsleiterinnen sind davon abhängig, dass sie mehrmals in der Woche abgeholt und von der Molkerei sofort weiter verarbeitet wird. Verstärkt wird diese Abhängigkeit durch die Marktkonzentration des Lebensmitteleinzellhandels – vielen Erzeugern stehen nur wenige Molkereien (Milchindustrieverband, 2019) und diesen wiederum nur wenige Lebensmitteleinzellhändler gegenüber (Nielsen Trade Dimensions, 2018). Außerdem sind die Investitionskosten für die Milchproduktion hoch, Ställe werden über Jahrzehnte abgeschrieben, eine kurzfristige Aufgabe oder Drosselung der Milchproduktion kommt darum für die meisten Betriebe nicht in Frage. Durch die langen Aufzuchtzeiten von zwei Jahren für eine Milchkuh wird eine kurzfristige Anpassung der Produktion an den Markt zusätzlich erschwert.

Wie alle anderen Branchen unterliegt auch die Landwirtschaft der Unsicherheit der Märkte und den schwankenden Preisen von Inputs und Outputs. Im Vergleich zu den meisten anderen Branchen ist Landwirtschaft darüber hinaus sehr viel stärker dem Einfluss von Wetter und Klima auf die erzeugten Tiere und Pflanzen ausgesetzt. Darüber hinaus sind auch die sich häufig wandelnden Anforderungen und Gesetze aus der Politik ein großer Faktor der Unsicherheit für Landwirte (Möllmann et al., 2018). Einerseits müssen wie in allen Bereichen auch in der Landwirtschaft die geltenden Gesetze beachtet werden. Des Weiteren sind die meisten landwirtschaftlichen Betriebe auf die staatlichen Subventionen angewiesen (BAL und EMB, 2018) und müssen sich an die mit den Subventionen verknüpften Bedingungen halten. Viele Betriebsleiter in der Landwirtschaft empfinden dies als große Belastung (Schaper et al. 2008).

Die Unsicherheiten bedeuten für Betriebe ein Risiko, durch falsche Entscheidungen in Zukunft nicht mehr wirtschaftlich zu sein und den Betrieb aufgeben zu müssen. Der Begriff „Risiko“ bezeichnet die mit einer Handlung oder Entscheidung einhergehende Möglichkeit eines (wirtschaftlichen) Schadens. Die Wahrscheinlichkeit für das Eintreten dieses Schadens kann gering, hoch oder unbekannt sein (Weber et al. 2018). Aufgrund der Vielzahl von Risiken, denen landwirtschaftliche Betriebe ausgesetzt sind, war es schon immer eine wesentliche Aufgabe der Betriebsleitung, sich mit den Risiken auseinander zu setzten. Die Risiko-Forschung unterscheidet verschiedene Unternehmer-Persönlichkeiten, die im Umgang mit Risiko unterschiedliche Strategien wählen (Miles et al., 1978). Auch für landwirtschaftliche Betriebsleiterinnen können diese Unternehmer-Persönlichkeiten unterschieden werden. Nach Befragungen von landwirtschaftlichen Betriebsleitern wird der Großteil als risikoavers eingestuft (Schaper et al., 2010; Granoszewski und Spiller, 2014). Das heißt, sie gehen nur wenige Risiken ein und informieren sich nur wenig über neue und potenziell riskante Verfahren. Wenn aufgrund der Risikoaversion Veränderungen gemieden werden und keine Anpassung an Marktentwicklungen erfolgt, kann dieses große finanzielle Schwierigkeiten oder die Schließung des Betriebes zur Folge haben (Schaper et al., 2010). Teilweise fehlen den Betrieben auch die Mittel beziehungsweise die Zeit, um sich ausreichend über betriebliche Alternativen zu informieren (Wocken et al., 2008). Gerade wenn sie nur wenige Informationen über ein mögliches Risiko haben, werden Risiken von Landwirtinnen als unwichtig empfunden und dadurch zum Teil unterschätzt (Schaper et. al, 2008).

Die geringe Flexibilität, die hohe Unsicherheit und das häufig risikoaverse Handeln begünstigten das Wachstum der Betriebe (Wüstermann und Caglar, 2016; Wocken et al. 2008) und hatte so auch starke Auswirkungen auf die Bewirtschaftung des Grünlands. Viele Betriebe setzten auf Kühe mit einer hohen Milchleistung und gaben im Zuge der Betriebsvergrößerung die Weidehaltung auf. Die Kühe werden ganzjährig im Stall gehalten und die ehemaligen Weiden werden als Schnittflächen für die Gewinnung von Grassilage genutzt (Van den Pol-van Dasselaar et al., 2015; Van Vuuren und Van Den Pol-van Dasselaar, 2006).

2.3 Risiken der Weidehaltung

Durch die Aufgabe der Weidehaltung konnten die Betriebsleiterinnen die damit einhergehenden Risiken reduzieren. Einerseits sind viele Aspekte der Weidehaltung aktuell schwierig zu kontrollieren, andererseits benötigen Bereiche wie die Tiergesundheit, Fütterung und Fruchtbarkeit aufgrund der für hohe Milchleistungen gezüchteten Kühe heute mehr Kontrolle als vor 25 Jahren (Steinwidder und Starz, 2006). Im Stall kann genauer erhoben werden, welche Futtermengen durch die Tiere aufgenommen wurden, auf der Weide ist dies schwieriger zu bewerten (Hofstetter et al., 2011). Durch den Tritt der Tiere können große Futtermengen zerstört werden und Ertragsrückgänge verursacht werden (Bilotta et al., 2007)

Landwirte verknüpfen Weidehaltung mit einer reduzierten Milchleistung (Kristensen et al. 2010), Tiergesundheit und Fruchtbarkeit sind auf der Weide schwieriger zu überwachen, auf der Weide drohen mehr Infektionen mit Parasiten (Tandler, 2005) und Hitzestress (Kadzere et al., 2002). Aufgrund des großen technischen Fortschritts in der Stallhaltung und der höheren Ansprüche der Milchkühe hat sich Weidehaltung damit zu einer vergleichsweise riskanten Methode entwickelt, obwohl sie selbst sich nicht geändert hat.

Weil die Umstellung von Weidehaltung auf ganzjährige Stallhaltung nur eine Fortsetzung des bekannten Verfahrens aus der Winterperiode ist, bedeutet dieses auch für risikoaverse Betriebe keine Umstellung auf ein neues, potenziell riskantes Verfahren. Der umgekehrte Vorgang, die Wiederaufnahme der Beweidung oder eine Neuausrichtung des Betriebes hin zu Beweidung ist mit deutlich größeren Hemmnissen und Risiken verbunden, nicht zuletzt, weil Kenntnisse über die komplexen Vorgänge bei der Beweidung oftmals nicht mehr vorhanden sind.

2.4 Aktuelle Bedeutung der Weidehaltung

Bei der letzten Landwirtschaftszählung (2010) hatten 42% der Milchkühe in Deutschland Zugang zu einer Weide (BMEL, 2019c). Allerdings ist unklar, in welchem Ausmaß diese Kühe Zugang zur Weide haben und welchen Stellenwert die Weide bei der Fütterung der Milchkühe einnimmt. Ein wichtiges Maß zur Beurteilung der Bedeutung der Weide in der Wiederkäuerfütterung ist der Zugang zur Weide in Stunden und die je Kuh zur Verfügung stehende Weidefläche. Um dem in Deutschland gültigen Weidemilch-Siegel zu entsprechen, müssen je Kuh mindestens 1000 m^2 Weide zur Verfügung stehen, die Kühe müssen an mindestens 120 Tagen im Jahr für sechs Stunden Zugang zu einer Weide haben (Pro Weideland, 2018). In den Niederlanden gelten ähnliche Anforderungen (Stichting Weidegang, 2018). Denn erst wenn je Kuh mehr als 1.000 m^2 Weide zur Verfügung stehen, kann man davon ausgehen, dass das Gras von der Weide zur Ernährung und damit zur Milchproduktion beiträgt. Steht den Tieren weniger Weide zur Verfügung, kann nicht mehr von einer Futteraufnahme auf der Weide ausgegangen werden, die Weide dient dann in erster Linie dem Tierwohl und der Tiergesundheit (Holshof et al., 2016). Neben den Betrieben, die diesen Weidemilchlabeln entsprechen, gibt es auch Betriebe mit Auslaufweiden, die sehr viel weniger Fläche haben und wo die Weide keinen nennenswerten Beitrag zur Ernährung der Kühe leistet. Auch diese Betriebe werden als Weidebetriebe bezeichnet.

Sowohl bei den Weidebetrieben, die dem Weidemilch-Siegel genügen als auch bei den Betrieben mit Auslaufweide besteht ein Großteil des Futters der Kühe neben Grassilage aus Kraftfutter und Maissilage. Der Vorteil von Wiederkäuern aus Futtermitteln, die für die menschliche Ernährung ungeeignet sind wie z.B. Gras, Proteine zu bilden, bleibt somit weitgehend ungenutzt. Das Kraftfutter und die Maissilage werden auf Flächen angebaut, die auch für den Anbau von Lebensmitteln für Menschen geeignet wären (Peyraud und Peeters, 2016).

Im Gegensatz zu den so skizzierten Weidebetrieben mit großem Anteil an Zufütterung stehen Betriebe mit „Vollweidehaltung“. Die Kühe auf diesen Betrieben erhalten kein oder kaum Kraftfutter und Mais und ernähren sich während der Weidesaison fast ausschließlich vom Gras. Solche Betriebe gibt es vor allem in Neuseeland und Irland, vereinzelt auch in der Schweiz, Österreich, den Niederlanden und Deutschland. In Neuseeland weiden diese Kühe das ganze Jahr, in Irland, den Niederlanden und der Schweiz erhalten sie in den Wintermonaten Grassilage, Heulage oder Heu, werden aber in der restlichen Zeit nur mit Weidegras ernährt (Thomet et al., 2004; Frey et al., 2008).

In der Folge von Phasen mit geringen Milchpreisen und gleichzeitig hohen Kosten für Zukaufsfutter gibt es unter Landwirten und Expertinnen Bestrebungen, den Anteil von kostengünstigem betriebseigenen Futter und damit auch den Weideanteil in der Ration von Milchkühen zu erhöhen. Wenn der Anteil von betriebseigenen Grundfutter und der Weideanteil hoch sind, verringert dies die Inputkosten und damit das Risiko finanzieller Engpässe in Phasen mit geringen Auszahlungspreisen für Milch (Kohnen, 2019; Hofstetter et al., 2011). Parallel zu dem zunehmenden Interesse an einer stärkeren Weidenutzung stieg auch der Anteil von Grünlandbetrieben, die ökologisch bewirtschaftet werden (Statistisches Bundesamt, 2019d). Eine Umstellung in Krisenzeiten ist eine häufig gewählte Strategie von risikoaversen Personen. Sie lassen sich auf neue, sogar potenziell riskante Methoden dann ein, wenn es gilt, drohenden umfassenden Schaden oder sogar Vollverlust abzuwenden (Tversky und Kahnemann, 1981).

Das Interesse der Branche an mehr Weidehaltung wird von Politik und Wissenschaft geteilt und unterstützt: 2017 gab es im deutschsprachigen Raum über 20 Weideprojekte (Arbeitsgemeinschaft Grünland und Futterbau, 2016), unter anderem das Projekt Weidemilch in der Schweiz (IG Weidemilch, 2019), das Projekt Weidecoach in Niedersachsen (Grünlandzentrum Niedersachen Bremen, 2019) und ein Projekt zur Nutzung von Ganztags- und Halbtagsweiden in Nordrhein-Westpfahlen (Pries et al., 2015). Da die meisten Verbraucher bei Kühen die Weidehaltung bevorzugen (Weinrich et al., 2014), bieten viele Molkereien Weidemilch und weitere Weidemilch-Produkte an, zum Teil unter dem Weidemilch-Siegel, welches dem Verbraucher die Einhaltung von Standards sichert (Pro Weideland, 2018).

2.5 Weniger Weidehaltung – Folgen

Durch die häufigen Entblätterungen verbunden mit dem Tritt der Tiere und Kot- und Harnflecken wirken weidende Tiere anders auf die Grasnarbe und den Boden ein als ein reine Schnittsysteme mit zwei bis fünf Entblätterungen im Jahr (Bilotta et al., 2007). Durch die Intensivierung der Grünlandnutzung mit einem hohen Einsatz von Dünger, Entwässerung, durch starke Beweidung und durch die Zunahme von reinen Schnittsystem geht die Artenvielfalt auf Grünland zurück (Isselstein et al., 2005).

Auf intensiv bewirtschaftetem Grünland führt die Umstellung von Weidenutzung zu einem Schnittsystem zu einem Rückgang des Weidelgrases, weil dieses Gras am besten an Weidesysteme angepasst ist und vor allem bei häufigen Entblätterungen, wie es bei Beweidung der Fall ist, einen Vorteil hat (Frame, 1992). In einem Schnittsystem geht die Triebdichte von Weidelgras stark zurück und die Lücken werden von anderen Gräsern und Kräutern besetzt (Orr et al., 1988). Die Qualität des Futters (Energie, Protein) nimmt entsprechend ab, so ist in einem Schnittsystem die verdauliche organische Substanz des geernteten Futters in der Regel geringer als in einem Weidesystem (Holmes, 1989). Durch diesen Mechanismus kommt ein System, in dem zugunsten einer hohen Milchleistung und einer besseren Kontrollierbarkeit auf die Weidehaltung verzichtet wird, an seine Grenzen. Die Qualität des Grundfutters ist geringer als auf der Weide, doch die modernen Züchtungen von Holstein-Frisian Milchkühen brauchen eine höhere Energiekonzentration als die früheren Zweinutzungsrassen. Die Rationen der Hochleistungskühe sind durch einen hohen Einsatz von Kraftfutter gekennzeichnet und enthalten viel Maissilage. Maissilage hat im Schnitt einen Energiegehalt von 6,8 MJ NEL und hat damit einen höheren Energiegehalt als die durchschnittliche Grassilage (LfL, 2019).

Durch die ganzjährige Stallhaltung gehen den Betrieben die mit Weidehaltung verbundenen Vorteile wie eine bessere Eutergesundheit (Hanson et al., 2013), eine bessere Klauengesundheit (Armbrecht et al., 2017), eine höhere Fruchtbarkeit (Palmer et al., 2012) und eine generell bessere Tiergesundheit (Washburn et al., 2002) verloren. Bei Untersuchungen des Tierwohls mit dem Tierwohl-Protokoll (Welfare Quality, 2012) erzielten Betriebe, die ihren Kühen Weidegang ermöglichten, bessere Resultate als Betriebe, die ihre Kühe ausschließlich im Stall halten (Burow et al., 2013; Armbrecht et al., 2019)

Verbraucherinnen bewerten in Umfragen reine Stallhaltungssysteme schlechter als Systeme mit Weidehaltung (Weinrich et al., 2014). Sie empfinden ganzjährige Stallhaltung als unnatürlich und kritisieren, die Tiere hätten zu wenig Platz. Generell erwarten Verbraucher, das den Tieren die Möglichkeit gegeben wird, Zeit im Tageslicht und an der frischen Luft zu verbringen. Für eine stärkere gesellschaftliche Akzeptanz der Milchproduktion ist es daher sehr wichtig, den Kühen Zugang zu einer Weide oder wenigstens einen Auslauf anzubieten (Kühl et al., 2019). Der höhere Preis von Weidemilch schreckt Verbraucher allerdings vom Kauf ab (Gassler et al., 2018).

2.6 Auswirkungen des Klimawandels auf das Grünland

Es ist davon auszugehen, dass die Landwirtschaft in den nächsten Jahren und Jahrzehnten starken klimatischen Veränderungen unterworfen sein wird (Easterling et al., 2007). Bereits jetzt treten verstärkt Dürren und Starkregenereignisse auf, die die Bedingungen für die Landwirtschaft erschweren. Etwas abgemildert werden diese negativen Auswirkungen eventuell durch längere Vegetationszeiten.

Für ein gutes Risiko-Management in einem resilienten System ist es wichtig, neben den aktuell bekannten drohenden Risiken und Chancen auch zukünftige Entwicklungen zu berücksichtigen (Urruty et al., 2016). Für die Landwirtschaft ist es daher wichtig, die möglichen Folgen des Klimawandels auszumachen und entsprechende Maßnahmen zu untersuchen und zu optimieren, die besser für die zu erwartenden Veränderungen geeignet sind als bestehenden Methoden und Techniken. In dem Projekt KLIFF (2009 – 2013; Klimafolgenforschung in Niedersachsen) wurde untersucht, welche Folgen lange Trockenheiten bei hohen Temperaturen auf Feldfrüchte, Grünlandbestände und die Tiergesundheit haben (Beese und Aspelmeier, 2014). Es wurde gezeigt, dass die Leistung von Milchkühen bei Hitzestress sinkt, die Produktivität von Grünland generell verringert ist und dass sich Standorteffekte bei Trockenheit stärker auf die Erträge auswirken (Breves et al., 2014; Gauly et al., 2013).

Deutsches Weidelgras ist bislang noch das wichtigste Gras auf intensiv genutztem Grünland im gemäßigten Klima. Allerdings reagiert es mit Ertragsrückgängen und verminderten Anteilen in der Narbe bei längeren Trockenphasen. Fällt lange Zeit kein Niederschlag, können Teile der Narbe absterben oder andere unerwünschte Gräser in die Grasnarbe einwandern und Weidelgras verdrängen (Turner et al., 2012).

Neben den häufigeren Trockenphasen wird der Anbau von Weidelgras außerdem durch einen Rückgang der Weidehaltung erschwert. Die Kühe werden ganzjährig im Stall gehalten und ein Großteil des Grünlandes besteht aus reinen Schnittflächen zur Erzeugung von Grassilage und Heu. Auf reinen Schnittflächen mit weniger Entblätterungen als auf einer Weide wird Weidelgras durch andere Gräser verdrängt. Bisher war es eine gängige Methode, lückenhafte Grasnarben und Narben mit einem hohen Anteil unerwünschter Gräser beziehungsweise zurückgehenden Anteilen von Weidelgras umzubrechen. Bei geringen Problemen werden Übersaaten und Nachsaaten im Bestand genutzt, aufwändiger ist eine Neuanlage mit Umbruch (chemisch, mechanisch) und Neuansaat. Wenn sich Dürren, die eine Neuanlage nötig machen in Zukunft häufen, wird das Verfahren für die Betriebe unrentabel (Schils et al., 2002). Hinzu kommen gesetzliche Vorgaben, die für jeden Umbruch eine Genehmigung erforderlich machen (BMEL, 2018). Zu den negativen Folgen von Grünlandumbrüchen gehören Auswaschungen von Nährstoffen (Stickstoff) und Emissionen von Treibhausgasen (Reheul et al., 2017; Kayser et al., 2018; Vellinga et al., 2004). Mittelfristig sollten Landwirte Grasnarben etablieren, die keine Neuansaaten erforderlich machen. Dazu müssen Arten gewählt werden, die an den jeweiligen Standort und die dort angewandte Bewirtschaftungsform angepasst sind.

Der Umbruch für eine Neuansaat und insbesondere Umbrüche für Ansaaten mit neuen Grasarten sind für Betriebe mit Risiken verbunden. Es besteht die Gefahr eines schlechten Auflaufens der Saat, geringer Erträge oder einer schlechten Qualität. Selbst wenn sich direkt nach der Neuansaat eine gute Narbe mit den erwünschten Gräsern entwickelt hat, besteht die Gefahr, dass diese nach einigen Jahren durch andere Gräser und Kräuter verdrängt werden.

Bei einer Neuansaat gibt es viele einzelne Aspekte, wie die Wahl der Grasart, die Bestimmung des Ausaattermins, der Saatstärke und die Wahl der eingesetzten Maschinen, die vorher festgelegt werden können. Obwohl es daneben noch weitere Faktoren gibt, die den Erfolg der Neuansaat beeinflussen, geht eine Neuansaat mit dem Eindruck einer hohen Kontrollierbarkeit (perceived controll) und in der Folge oft mit einer zu optimistischen Einschätzung der Lage einher (Slovic et al., 1980). Im Vergleich zu anderen Veränderungen können Neuansaaten und auch der Einsatz neuer Grasarten langsam umgesetzt werden, weil nur ein Teil der Flächen neu angesät wird, auf denen der Erfolg anschließend gezielt beurteilt werden kann.

2.7 Rohrschwingel und Lieschgras als alternative Grasarten zu Weidelgras

Eine mögliche Alternative zu Weidelgras vor allem für reine Schnittflächen ist Lieschgras. Es hat eine sehr gute Futterqualität und eine hohe Schmackhaftigkeit, ist allerdings für Weiden weniger geeignet, da es durch zu häufige Entblätterungen aus der Narbe verdrängt wird (Suter et al. 2009; Frame, 1992). Die zu erwartenden Erträge sind etwas geringer als von Weidelgras (Frame, 1991; Swift, 1977).

Eine andere mögliche Alternative zu Weidelgras ist Rohrschwingel. Lange Zeit galt es als unerwünschtes Gras, da es von Tieren aufgrund harter Blätter und hoher Gehalte von Kieselsäure ungern gefressen wurde und eine geringe Futterqualität hat (Cougnon et al., 2014; Kaiser et al., 2018; Turner et al., 2012). Ein weiteres Problem bei Wildformen und älteren Züchtungen ist deren Infektion mit Endophyten. Diese können bei weidenden Tieren zu Leistungseinbußen führen (Strahan et al., 1987; Pedersen et al., 1990). Vorteile von Rohrschwingel liegen in einer hohen Trockenheitstoleranz, auch bedingt durch vergleichsweise große Wurzeltiefe und hohen Erträgen. (Suter et al. 2009; Cougnon et al., 2014; Moore, 1966). Daher wurde Rohrschwingel in den letzten Jahren züchterisch bearbeitet, um die negativen Eigenschaften zu mindern. Die Pflanzenzüchtung hat Sorten entwickelt, die eine höhere Futterqualität und weichere Blätter haben, weniger Kieselsäure enthalten (Mosimann et al., 2010; Suter et al. 2009) und frei von Endophyten sind (Isleib, 2015).

3 Publikationen

Diese kumulative Dissertation beinhaltet vier wissenschaftliche Kapitel, die sich mit der übergeordneten Frage befassen, welche aktuellen Optionen es für eine nachhaltige und wirtschaftliche Bewirtschaftung von Grünland gibt. Ein besonderer Fokus liegt hierbei auf den vielfältigen Funktionen und den Effekten von Weidehaltung, zum einem auf der betrieblichen Ebene, zum anderen auf der Ebene der Pflanzenproduktion.

Die ersten beiden Artikel behandeln die Betriebsstrukturen von Milchviehbetrieben mit Weidehaltung und Stallhaltung und die Bewertung der Vor- und Nachteile der Weidehaltung durch die Betriebsleitenden. In Kapitel I wird die für Kapitel II entwickelte Methodik zur Überprüfung der Validität von Daten aus einer Befragung von Milchviehbetrieben vorgestellt.

In Kapitel III und IV wird vorgestellt, welche Erträge und Qualitäten mit den Grasarten Lieschgras (*Phleum pratense*) und Rohrschwingel (*Festuca arundinacea*) im Vergleich zu Weidelgras (*Lolium perenne*) in verschiedenen Bewirtschaftungssystemen auf Sand-, Marsch- und Moorboden erreicht werden können und wie ausdauernd sie dort sind.

Kapitel I

Becker, T., Blume, L., Kayser, M., Isselstein, J. (2015)
Development of a validity test for survey data on milk-from-grass from German dairy farms.
Grassland Science in Europe 20, 84–86

Kapitel II

Becker, T., Kayser, M., Tonn, B., Isselstein, J. (2018).
How German dairy farmers perceive advantages and disadvantages of grazing and how it relates to their milk production systems.
Livestock Science 214, 112–119.

Kapitel III

Becker, T., Isselstein, J., Jürschik, R., Benke, M., Kayser, M. (2020)
Performance of modern varieties of *Festuca arundinacea* and *Phleum pratense* as an alternative to *Lolium perenne* in intensively managed sown grasslands.
Agronomy 10, 540.

Kapitel IV

Becker., T., Isselstein, J., Kayser, M. (2020)
Feed quality of modern varieties of *Festuca arundinacea* and *Phleum pratense* as an alternative to *Lolium perenne* in intensively managed grasslands.

4 Kapitel I: Development of a validity test for survey data on milk from grass from German dairy farms.

Abstract

Questionnaires are a frequently used instrument to analyze the productivity of farms. As surveys might include wrong or incorrect data, there is a need for validity testing. A validity test aims at generating an adjusted, reliable data set with fewer outliers. Large data sets require an automated approach. We conducted a survey on 47 German dairy farms to evaluate the role of grassland in milk production. The farms are located all over Germany with a focus on Lower Saxony and Hesse. In a first step, we developed a generally applicable validity test for assessing the milk yield directly related to grassland. Several simple, directly measurable parameters were defined which correlate with important parameters with a high error rate. These relations were put into a formula and applied to the data set. We found that out of the 47 data sets three had to be excluded from further analysis because of large deviations from the defined confidence limits. The experience with the validity test did not only result in a more reliable data set but helped to optimize the questionnaire for future surveys. The farms in this survey produced 4,916 l grassland-milk ha^{-1}.

Keywords: survey, validity test, grassland-milk, dairy

Introduction

For evaluating the productivity of farms, questionnaires are a frequently used instrument. However, with surveys there is always a high risk for misunderstandings and miscalculations involved. The validity and plausibility of the data for the most important parameters should be tested before a final analysis takes place. Ideally, this is done in a systematic way based on confidence limits and following a protocol. For extensive surveys, faulty data-sets are then excluded while for small surveys it can make sense to check doubtful data and eventually correct obvious mistakes by hand.

In order to determine the amount of milk based on grass (grassland-milk), 47 German dairy farmers were interviewed. We developed a protocol to test the validity and plausibility of answers to important parameters and applied it to the survey data. We hypothesize that this will improve data quality and the reliability of the following analysis.

Material and Methods

In 2012 and 2013, 47 dairy farmers in Germany were interviewed by students from the Faculty of Agricultural Sciences of the Georg-August University Göttingen. Since it is not possible to ask directly for the amount of grassland-milk produced on the farm, this parameter has to be calculated from the following basic parameters which were provided by the farmers from farm records: amount of concentrates and maize in the ration, number of cows, milk yield per cow and amount of grassland used for milk production. Some of these basic parameters were also used for the validity test. In a first step the data for these basic parameters have to fall within defined confidence limits and are then combined in a formula to calculate parameters that cannot directly be measured e.g. the amount of grass (grass + grass-silage + hay) in the feed ration (Table 1). The results obtained from these formulas (final parameters) have to match previously defined confidence limits as well. Some additional parameters, which were not asked in the survey, were taken from the literature (Table 2). The overview of the protocol of the study is given in Table 3.

Table 1. Basic formulas for determining the final parameters and the amount of grassland-milk ha^{-1}.

Calculation of the amount of grass in the daily ration of one cow

Maintenance requirement per cow per day (MJ NEL[c]) + energy requirement for lactation per cow per day (MJ NEL) = Energy requirement per cow per day (MJ NEL)

Energy requirement per cow per day (MJ NEL) – energy from maize per cow per day (MJ NEL) – energy from concentrates per cow per day (MJ NEL) = Energy from grass (grass + grass-silage + hay) per cow per day (MJ NEL)

Energy from grass per cow per day (MJ NEL) / energy content of silage (MJ NEL kg^{-1} DM) = Amount of grass in feed ration (kg DM per cow per day)

Calculation of the milk from grass per cow per year

Milk yield per cow per day (l) / energy requirement per cow per day (MJ NEL) * energy from concentrates (MJ NEL) = Milk from concentrates per cow per day (l)

Milk yield per cow per day (l) / energy requirement per cow per day (MJ NEL) * energy from maize (MJ NEL) =Milk from maize per cow per day (l)

Milk yield per cow per day (l) – milk from maize per cow per day (l) – milk from concentrates per cow per day (l) * 305[a] = Milk from grass per cow per year (l)

Calculation of the milk from grass per ha grassland per year

Milk (l) from grass per cow per year * cows per farm = Milk from grass per farm per year (l)
Milk (l) from grass per farm per year / ha grassland per farm = Milk from grass per ha grassland per year (l)

Calculation of the yield of grass per ha grassland per year

Amount of grass in feed ration (kg per cow per day) * cows per farm * 305[a] days of lactation = Need for grass (for milk production) per farm per year (kg DM)

Need for grass (for milk production) per farm per year (kg DM) / ha grassland per farm =Yield of grass (for milk production) per ha per year (kg DM)

Yield of grass (for milk production) per ha per year (kg DM) / 60 %[b] = Total yield of grass per ha per year (kg DM)

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[a] lactation duration

[b] amount of grass yield ha^{-1}, that is used for milk production

[c] net energy for lactation

Results and Discussion

In our survey of 47 dairy farms, the data sets from four farms did not match the basic parameters. Three of these had also not matched the final parameters. Besides these three, there were nine other data-sets which did not match the final parameters. In small surveys it often makes sense to have a closer look at the faulty data sets to find out why they failed the test.

When we did that, mistakes in ten data-sets could be corrected, and they passed the test in a second run. Most errors were caused by a confusion of dry matter and fresh matter of feed or by miscalculating the grassland area. Three data-sets, that are three farms, did not pass the test even after an intensive search for mistakes and the correction. As it was not possible to contact the farmers for clarification, these data-sets had to be excluded from further analysis. Data from the remaining farms were then used for calculating the amount of grassland-milk. The validity testing did not lead to drastic changes of the means but resulted in much lower standard deviations. Before the test, standard deviations of grassland-milk ha^{-1}, grassland-milk per cow, grass intake per cow per day and of yield of grass ha^{-1} were in the range of the mean, but were reduced to 50% of the means after applying the test (Table 4).

Table 2. Basic parameters and final parameters which are needed for the validity test.

Basic parameters	**Confidence limits**	**Source**[a]
Amount of concentrates in the ration per cow per day	0–13 kg DM	KTBL, 2009
Amount of maize in the ration per cow per day	0–13 kg DM	KTBL, 2009
Milk-yield per cow per year	0–12,000 l	KTBL, 2009
Energy content of roughage	4–7 MJ NEL[c] kg^{-1} DM	KTBL, 2009
Final parameters for validity test	**Confidence limits**	
Calculated amount of grass (grass + grass-silage + hay) in feed ration per cow per day	0–19 kg DM	KTBL, 2009
Calculated dry matter intake per cow per day	15–24 kg	KTBL, 2009
Basic-parameters taken from literature	**Values**	
Live weight of a dairy cow	650 kg	KTBL, 2009
Lactation duration	305 days	Loeffler, 2002
Maintenance requirement per cow	37.7 MJ NEL day^{-1}	KTBL, 2009
Power requirement per liter milk	3.28 MJ NEL	KTBL, 2009
Energy density of maize	6.7 MJ NEL kg^{-1} DM	KTBL, 2009
Energy density of concentrates	7.6 MJ NEL kg^{-1} DM	KTBL, 2009
Amount of grass yield ha^{-1}, that is used for milk production	60 %	[b]

[c] Confidence limits based on the source

[b] assumption based on common agricultural knowledge of farming practice.

[c] net energy for lactation

Table 3. Protocol for executing the validity test.

Extensive surveys	**Small surveys**
Defining basic parameters and final parameters. Determining confidence limits for the parameters	Defining basic parameters and final parameters. Determining confidence limits for the parameters
Checking the basic parameters.	Checking the basic parameters.
Data-sets with one or several basic parameters that do not match the confidence limits are excluded.	Data-sets with one or several basic parameters that do not match the confidence limits are marked.
Applying the formulas for calculating the values of the final parameters.	Applying the formulas for calculating the values of the final parameters.
Data-sets with one or several final parameters that do not match the confidence limits are excluded.	Data-sets, with one or several final parameters that do not match the confidence limits are marked.
-	Search for mistakes in marked data-sets. Eventually correction of the mistakes.
-	Exclusion of data-sets which do not pass the validity tests after correction.
Final analysis of the data from the remaining data-sets.	Final analysis of the data from the remaining data-sets.

Table 4. The effect of applying a validity test on some parameters for evaluating the importance of grassland for milk production.

	Before validity-testing (n=47)		**After validity-testing (n=44)**	
	Mean	**SD**	**Mean**	**SD**
Grassland used for milk production (ha)	64	47	54	36
Milking cows	95	70	98	71
ha grassland per cow	0.7	0.4	0.6	0.3
Milk yield per cow per year (l)	9104	1410	9117	1225
Grassland-milk ha^{-1} (kg)	4206	4442	4916[a]	2053[a]
Grassland-milk per cow per year	2572	2137	2294	1393
Calculated yield of grassland (t ha^{-1} per year)[b]	4.7	5.1	5.7	2.3
Calculated grass-intake (kg per cow per day)[b]	6.0	5.7	7.1	3.8

[a]weighted mean

[b]parameter of validity test.

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5 Kapitel II: How German dairy farmers perceive advantages and disadvantages of grazing and how it relates to their milk production systems

Abstract

Dairy farming in Europe and in Germany in particular, is characterized by a growing trend towards all-year-housing. Along with that the proportion of grass products as sources of energy for dairy cows is decreasing. On the other hand, society and politics strongly advocate grazing resulting in the introduction of pasture-milk programs. Little is known of the dairy farmers' perception of grazing and it is not clear what role their attitude towards grazing plays in their decision-making and how this is related to farm structure. To investigate these questions, we conducted a survey with face-to-face interviews on three types of German dairy farms: i.) grazing farms (n = 17), ii) exercise-pasture farms (n = 19), and iii) all-year-housing farms (n = 18). On grazing farms, pasture contributes significantly to the ration of the cows (0.2 ha grassland with 0.1 ha as pasture per cow and year; at least 6 hours of grazing on 120 days per year). Exercise-pasture farms offer their cows a much more restricted access to rather small pastures. All-year-housing farms have no grazing for dairy at all but feed their cows grass silage and hay.

Farmers from grazing farms expressed a high agreement with the positive aspects of grazing (low fodder costs, low labor input, benefits for animal health and fertility), while the all-year-housing farmers were more aware of the challenges and disadvantages of grazing and expressed a high agreement with its potential negative aspects (reduced milk yield, unsuitability for large herds, insufficient access of the herd to the pastures). The exercise-pasture farmers appreciated the advantages of better fertility and better animal health and saw fewer disadvantages of grazing than the all-year-housing farmers. Utilization of grass products also differed among the three groups: grass and grass silage made up 47% of the ration on grazing farms while on exercise-pasture farms and on all-year-housing farms, grass products amounted to only 28% and 23% of the ration, respectively. The grazing farms had fewer cows (n = 69) and smaller milk yields (8,270 kg milk per cow/year) than the exercise-pasture farms (n = 109; 9,524 kg milk per cow/year) and all-year-housing farms (n = 138; 9,404 kg milk per cow/year).

We also discuss the influence of the human tendency to avoid cognitive dissonance on farmers' responses. We conclude that in developing concepts to promote grazing, the differing attitudes and perceptions of dairy farmers and the interaction with differing farm structures need to be considered.

Keywords: Dairy farmer, Pasture, Perception of grazing, Farm survey, Cognitive dissonance

Introduction

Grazing dairy used to be the common practice in Germany until the 1990s. Since then, dairy farmers in North-Western Europe have increasingly been converting to all-year-housing systems (van den Pol-van Dasselaar et al., 2015; van Vuuren and van Den Pol-van Dasselaar, 2006). Approximately 58% of dairy cows in Germany are kept in all-year-housing systems (Gurrath, 2011), mostly free walk systems (Statistisches Bundesamt 2011). The remaining 42% of dairy cows have access to pasture, but the importance of the pasture for providing energy differs substantially among farms. On some farms, pasture is an important source of energy and roughage in the grazing season, whereas on other farms pasture caters mainly for animal health and animal welfare and contributes almost nothing to the diet of the cows. Between these two extremes there exists a range of varying intermediate stages. Only a few farms rely for the most part on grazing for the diets of their dairy cows (van Vuuren and van Den Pol-van Dasselaar, 2006; Holshof et al., 2016; Washburn and Mullen, 2014). Along with the decline of grazing, the importance of grass, grass silage and hay as the main sources of energy for dairy cows is generally decreasing (Peyraud and Peeters, 2016).

This situation might lead to a loss of trust by consumers in dairy products and in dairy farming as is already the case in poultry and pig farming (Weinrich et al., 2014). Despite the trend towards all-year-housing, society and politics hold a positive view of grazing and are in fact promoting this practice. In a number of countries grazing-milk programs have been established to encourage farmers to allow their cows to graze. A recent initiative in Germany to promote milk from grazing under a 'Pasture Milk' label is based on the 'German Pasture Charta'. According to this agreement, requirements for pasture milk include 0.2 ha grassland with 0.1 ha as pasture per cow and year; and cows need to have access to pasture for at least six hours on 120 days per year (Pro Weideland, 2017).

The advantages and disadvantages of grazing are frequently discussed among farmers and by public authorities (Pries, 2004) and are a topic for journals for the practicing farmer (Diersing-Espenhorst, 2016). A survey among Danish farmers found that all-year-housing farmers more often had an unfavorable image of grazing than farmers who used grazing for their dairy. The main concern of the farmers with all-year-housing was that grazing would reduce the performance of the herd (Kristensen et al., 2010). Increasing herd sizes is another concern and grazing of large grazing herds is challenging and can cause damage to the sward and paths, particularly in areas with heavy soils and high rainfall.

Advantages of grazing include better animal health (Washburn et al., 2002), in particular less incidences of mastitis (Hanson et al., 2013), less claw diseases (Armbrecht et al., 2018), and fewer problems with fertility (Palmer et al., 2012); generally, animal welfare is improved which was confirmed by Burow et al. (2013) who applied the welfare quality protocol (Welfare Quality, 2012). In addition, grazing farms have lower labor costs (Dartt et al., 1999; White et al., 2002) and lower feed costs (White et al., 2002; Tozer et al., 2003; Fontaneli et al., 2005).

In order to estimate the potential of the different farm types to increase or begin with grazing, it is important to know how much grassland the farms provide for their cows and how significant the grassland is to the farms.

Given that north-western Germany is one of the most important dairy regions in Germany (Bundesanstalt für Landwirtschaft und Ernährung (BLE), 2018), we set up an on-farm survey with a focus on this region with the aim of investigating German dairy farmers' perception of the main advantages and disadvantages of grazing.

We used the average milk yield, the herd size, grassland management, and the ration for the cows to assess the significance of grassland and grazing for the farm. We hypothesize that grazing farmers have a higher agreement with positive statements about grazing and that all-year-housing farmers agree more with negative statements.

Materials and methods

Farms

We visited 60 dairy farmers on their farms for face-to-face interviews. The farmers were all full-time farmers, but milk production was not necessarily the only source of farm income. On all the farms milk production was based on high-yielding dairy cows, whose rations were supplemented with concentrates. The grassland was managed intensively with at least three defoliations per vegetation period. We conducted interviews on three types of dairy farms that differed in terms of the role of grazing in providing feed for milk production. Before the visits, farms were approximately categorized according to the duration of grazing per day. After the farm visits, information from the questionnaires about grazing time and the actual amount of pasture available per cow was used to adjust the categorization. (Table 2).

The first group consists of grazing farms (n = 17) on which grazing contributed substantially to the diet. These farms matched the requirements of the German Pasture Charta (Pro Weideland, 2017): at least 0.2 ha grassland with 0.1 ha as pasture per cow and year; cows had access to pasture for at least six hours on 120 days per year. This is rather low but is intended also as an incentive to interest more farmers in grazing. Grazing cows with 8500 l milk per year and a dry matter intake of 20 kg would then take up more than 10% of the ration from grass on pasture (Holshof et al., 2016; Kuratorium für Technik und Bauwesen in der Landwirtschaft (KTBL), 2009). The second group is referred to as exercise-pasture farms (n = 19; Salomon et al. 2010) where cows had access to pasture for less than 6 hours per day and where the contribution of grazing to the total energy supply of the cows was negligible: less than 0.1 ha of pasture per cow. The third group consists of all-year-housing farms (n = 18) where cows did not graze and had no access to pasture at all. In the context of our survey grassland refers to all grassland, grazed and cut, that is used for the production of fresh grass and forage for the dairy herd. This includes dry cows and the heifers needed for replacement as well. Marginal land and set-aside land was not taken into account. ‘Pasture per cow’ refers to grassland which is only grazed by dairy cows. On some farms part of the total pasture is at times cut once or twice before it is solely used for grazing. The farms were mostly situated in the north-western part of Germany – one of the most important regions for dairy in Germany – (Bundesanstalt für Landwirtschaft und Ernährung (BLE), 2018) and were randomly spread over the area.

The survey

The face-to-face interviews with farmers followed a strictly structured questionnaire. In the first part, data on farm structure and dairy production system were requested for. This comprised questions on the farm size, the number of cows, the annual milk-yield, and the ration of the cows including the amount of maize silage and concentrates per cow. In the second part on the farmers’ perception of grazing, farmers were presented with positive and negative statements about grazing. The positive statements about grazing were concerned with lower fodder costs, lower labor input, benefits for animal health and fertility in grazing systems. Negative statements involved lack of knowledge about grazing, inaccessible pastures, potentially reduced milk yield and risks of an insufficient supply with energy, supplemental feeds and water. Furthermore, the farmers were confronted with statements about the difficulties to monitor cow health and fertility in grazing cows and the challenge to combine grazing with large herds (Table 1). They were asked whether these aspects would motivate them to continue and increase grazing or whether they would discourage them from using grazing. Answers were rated on a balanced 5-point Likert scale (Likert, 1932) with both sides of a neutral option (3) ranging from 1 (no agreement) to 5 (full agreement) (c.f. Figs. 1, 2 and 3).

Before data analysis the validity of the information given in the answer sheets on the most important parameters was tested. Basic parameters were the milk yield per cow, the intake of concentrates and maize per cow per day and the energy content of roughage. These basic parameters had to fall within defined confidence limits and were then combined in a formula to calculate final parameters that had to match previously defined confidence limits as well, e.g. the amount of grass (grass + grass-silage + hay) in the feed ration and the dry matter intake per cow per day. For example: limits for concentrates and maize in a daily ration were set at 0 and 13 kg DM; for energy content of the forage and dry matter intake the possible range was defined at 4–7 MJ net energy kg^{-1} DM and 15–24 kg respectively. Detailed information about all parameters of the calculation can be found in a paper about the validity testing of the data (Becker et al., 2015).

Six farms had reported figures for milk yield and intake of concentrates and maize that fell outside the defined confidence limits and were subsequently removed from the survey. Finally, we used data from 19 all-year-housing farms, 18 exercise-pasture farms, and 17 grazing farms for analysis.

As an important explanatory variable the amount of energy from grass supplied to the dairy cows was deduced from the feed ration and milk performance data. Therefore, the amount and energy content of concentrates and maize in the ration, the energy content of grass-silage and the average milk-yield and weight of the cows were used. The energy-content of grass-silage and concentrates was taken from farm records. For maize-silage we used values from tables (6.7 MJ net energy kg^{-1} DM) as published in official documents that form the basis of agricultural advisory services in Germany and assumed the same maize silage quality for the three groups. For the maintenance energy requirements, we calculated with 37.7 MJ net energy per cow, and for the production of 1 l milk (3.4% protein, 3.8% fat) we calculated with 3.28 MJ net energy (Kuratorium für Technik und Bauwesen in der Landwirtschaft (KTBL), 2009). With this data we calculated the net energy provided by grass, grass silage and hay as follows (c.f. Becker et al., 2015; Allen et al., 2011):

Net energy from grass (grass+grass-silage+hay) per cow/day (MJ) = net energy requirement (for maintenance and performance) per cow/day (MJ) – net energy from maize per cow/day (MJ) – net energy from concentrates per cow/day (MJ).

The formula applies for a lactation period of 305 days and takes the energy needed for an unborn calf into account; following standard conditions on German dairy farms, we assume that a cow has one calf per year and is not milked the last two months before giving birth (Kuratorium für Technik und Bauwesen in der Landwirtschaft, 2009; Wurm, 2010). All farms in our survey had Holstein Frisian dairy cows and thus had the same genetic basis. Live-weight varies among individual cows, but differences among herds are small. The average weight of a cow can be assumed as 650 kg (Kuratorium für Technik und Bauwesen in der Landwirtschaft, 2009).

Statistical analysis

All statistical tests were performed with the software package R, version 3.2.3. As most of the data was on an ordinal scale, we used a Kruskall–Wallis one-way analysis of variance by ranks to analyze the effect of farm type on farm structure (farm size, number of cows, milk yield per cow, total grassland, and pasture per cow), on the ration (energy from different sources), and on the farmers' perception of advantages and disadvantages of grazing. For comparing differences between the three farm groups (all-year-housing, exercise-pasture, and grazing), we used means. This is possible as the survey participants perceived the different response possibilities as equidistant and because all rating scales were clearly demarcated at the endpoints, which indicates a quasi-interval scale of the survey data with equal scale sections (Bühner, 2006).

Table 1. Questions of the questionnaire with the positive and negative statements about grazing

Are the following statements a reason for you to not use or not increase grazing or for reducing grazing on your farm?

1. Grazing is not manageable with large HERDS.
2. Grazing can cause damage to the SOIL structure.
3. ACCESS to grassland is difficult/the grassland is not close to our farm.
4.My KNOW-HOW of grazing management is too small.
5. Grazing is connected with difficulties in heat detection and MONITOR cow health.
6. Grazing is connected with a reduced MILK-YIELD due to higher energy requirements for maintenance or reduced feed intake under extreme weather conditions.
7. Grazing is connected with difficulties to SUPPLY cows with water, minerals and supplemental feeds.
8. Grazing is connected with an inconsistent FEED supply which is not consistently high enough on pasture

Do the following statements motivate you to continue or increase grazing?

1. Grazing is related to low fodder COSTS.
2. Grazing is related to low LABOR input.
3. Grazing is related to better animal HEALTH
4. Grazing is related to higher FERTILITY.

Possible answers:

1. I disagree; 2. I do partially disagree; 3. I neither agree nor disagree; 4. I do partially agree; 5. I agree

Results and discussion

Production system: farm structures and milk-yields

All three farm types had on average the same amount of grassland but differed in the number of cows (Table 2). Grazing farms had smaller herds than exercise-pasture farms and all-year-housing farms (Table 2). So the grazing farms had more grassland per cow. These results are in line with studies on farms structures in dairy from Denmark, USA and Great Britain, which confirm that grazing farms generally have smaller numbers of cows and more grassland per cow than farms with all-year- housing (Kristensen et al., 2010; Parsons et al., 2004; March et al., 2014).

Cows from grazing farms in our survey had an average intake of 47% of their energy from grass and grass silage, which is significantly more than the 28 and 23% for the exercise-pasture farms and the all- year-housing farms, respectively. The energy intake from grass, grass silage and hay does not differ significantly between the exercise-pasture farms and the all-year-housing farms. Due to the lower intake from grass, grass silage and hay, all-year-housing farms and exercise-pasture farms had significantly more maize silage in the diet than grazing farms. They also had more concentrates in the ration, though differences were not significant. A higher proportion of maize in the ration of dairy cows is often related to an improved forage intake and higher milk yields (Khan et al., 2014; Kliem et al., 2008; OMara et al. 1998). This was also the case in our survey: average milk yield per cow and year on all-year-housing and exercise-pasture farms was about 1,100 kg more than on grazing farms (Table 2).

Table 2. Some data on farm structure and dairy production for the three groups of farms in the survey (n = 54).

	Farm type					
	Grazing farm		Exercise-pasture farm		All-year-housing farm	
	Mean	SD	Mean	SD	Mean	SD
Farm structure						
Number of farms	17	-	19	-	18	-
Agricultural land (ha)	117	42	230	453	245	313
Grassland (ha)	59	31	61	52	64	56
Number of milking cows	69^{b}	32	109^{ab}	70	138^{a}	115
Grassland per cow (ha)	0.86^{a}	0.37	0.53^{b}	0.19	0.50^{b}	0.23
Pasture per cow (ha)	0.28^{a}	0.15	0.04^{b}	0.02	0.00^{c}	0.00
Milk per cow/year (kg)	$8{,}270^{b}$	1,427	$9{,}524^{a}$	1,030	$9{,}404^{a}$	1,121
Ration						
Proportion of energy from grass, grass silage and hay of the total energy requirement per cow/day (%)	47^{a}	18	28^{b}	11	23^{b}	12
Net energy from grass, grass silage and hay per cow/day (MJ)	61^{a}	22	40^{b}	16	32^{b}	16
Net energy from maize per cow/day (MJ)	24^{b}	22	46^{a}	10	51^{a}	13
Net energy from concentrates per cow/day (MJ)	44	24	56	18	57	17

$^{a-c}$Means within a row with different superscript letters differ significantly ($P < 0.05$).

There are no significant correlations between the opinions of the farmers and the continuous variables herd size, milk yield per cow, total grassland, and total agricultural land. Besides, we found no correlation between the farmers' years of work experience with dairy cows and their attitude towards grazing.

We undertook our survey in the north-west of Germany, one of the most important regions for dairy in Germany. Another important dairy region is the south-west of Germany where the farms are generally smaller, but where, like in the North-West, family farms are predominant. We assume that a survey with a focus on the south-west region in Germany would generate similar results as those we present here. Our results might not be fully representative for the east of Germany, the former German democratic republic, where dairy farms are structured differently (family farms are not predominant) and where farms are generally much larger than in the west. However, this region is not as important for milk production as the north-western and south-western region (Bundesanstalt für Landwirtschaft und Ernährung (BLE), 2018; Eurostat, 2018).

Grazing is complicated: herd size and access to pasture

The first four negative statements on grazing in our survey which related to herd size, access to pasture and know-how are as follows: grazing is not manageable with large herds; grazing might cause damage to the soil structure; access to pasture land is difficult; and farmers' knowledge about the management of grazing is limited (Fig. 1, Table 1).

Based on the farmers' responses to these four statements, we found that farmers with cows in all-year-housing in all cases had a significantly stronger agreement with these statements than grazing farmers (Fig. 1). Grazing farmers were indifferent about the effect of herd size, but disagreed with the negative statements about soil structure, access to pasture and know-how. The responses of exercise-pasture farmers were closer to the opinions of grazing farmers with respect to the impact of large herd size and the role of know-how; but like farmers from all-year-housing farms they tended to partially agree that problems with damage to the soil and access to pasture would discourage them from grazing. In Germany, there is a widely-held belief among dairy consultants that grazing with large herds is generally difficult if not impossible, because it is difficult to manage access for cows to pasture (Sommer and Bockisch, 2002). However, there is no clear definition of what a large herd is. It has been suggested that for a herd to be considered as large, it has to be twice the average herd size of a certain country or a certain region (van den Pol-van Dasselaar et al., 2014). In the case of Germany, where the average herd size is 53 cows, this would correspond to a number of more than 106 cows (Eurostat, 2016). Following this approach, in Germany the herd size of grazing farms (n = 69, s.d. 32, Table 2) in our survey can be regarded as average while those of exercise-pasture farms (n = 109, s.d. 70) and all-year-housing farms (n = 138, s.d. 115) can be considered large. The perception of farmers of what constitutes a large herd might have been different as the size of a large herd was not stipulated in the questionnaire. Grazing farmers might have regarded their own herds as large and, having had the experience that grazing their herds is manageable, they tended to partially disagree with negative statement on herd size.

Various authors found that the lack of well-rounded pasture close to the farm which is a prerequisite for grazing is the main obstacle to grazing with large herds. Often farms with large herds do not have sufficient pasture land available (Peyraud et al., 2010; van Vuuren and van Den Pol-van Dasselaar, 2006), and it has become increasingly difficult to acquire land close to the farm (Hanson et al., 2013; Thomet et al., 2011). Moreover, not all grassland can be used as pasture, e.g. because the cows would have to cross roads or land of other farms or because the pasture is too far away. The exercise-pasture farms and the all-year-housing farms are most likely confronted with both problems. On the one hand, they have relatively little grassland per cow, and on the other hand, they might not be able to use it as pasture for dairy cows. Generally, when herd size increases, the average distance between the pasture and the milking parlour increases, too (van den Pol – van Dasselaar et al., 2008). Kristensen et al. (2010) reported that Danish farmers perceived difficult access to pasture land and the establishment and maintenance of walkways as serious obstacles for grazing management. All-year-housing farmers in this Danish study, who had on average enough grassland to allow their cows to graze, found grazing too difficult to organize because of the distance of the fields from the milking parlor and the need to cross roads. These constraints might have been of concern for the exercise-pasture and all-year-housing farmers in our study as well.

Another potential disadvantage related to grazing is the risk of damage to soil and sward, especially when stocking rates are high (McCalla et al., 1984). Specifically, in entrances and exits heavy trampling can lead to the destruction of the vegetation cover and a compaction of the soil resulting in reduced drainage and waterlogging (Cluzeau et al., 1992). In our survey, grazing farmers did not regard damage to the soil as a serious problem whereas exercise-pasture farmers and all-year-housing farmers were on average indifferent or agreed partially that it was a serious problem. Stocking rates in exercise-pasture farms were much higher than in grazing farms (0.04 ha per cow for exercise-pasture farms compared to an average of 0.28 ha per cow on grazing farms). It is likely that these high stocking rates on exercise-pasture farms have caused damage to sward and soil and this experience would at least partly explain the negative opinion on this aspect. All-year-housing farmers might have had negative experiences in the past with grazing or may not even be familiar with the concept of grazing and would therefore expect damage to sward and soil. We can thus conclude that factors like herd size, potential damage to soil and sward, and access to pasture – individually or in combination – play a role in farmers' decision not to graze. In a study from the USA, grazing farmers in Virginia and Pennsylvania with large herds were found to be less likely to increase their reliance on grazing than farmers with smaller herds – for every 10-cow-increase in herd size it was 3% less likely that a farmer would increase grazing in future (Winsten et al., 2000).

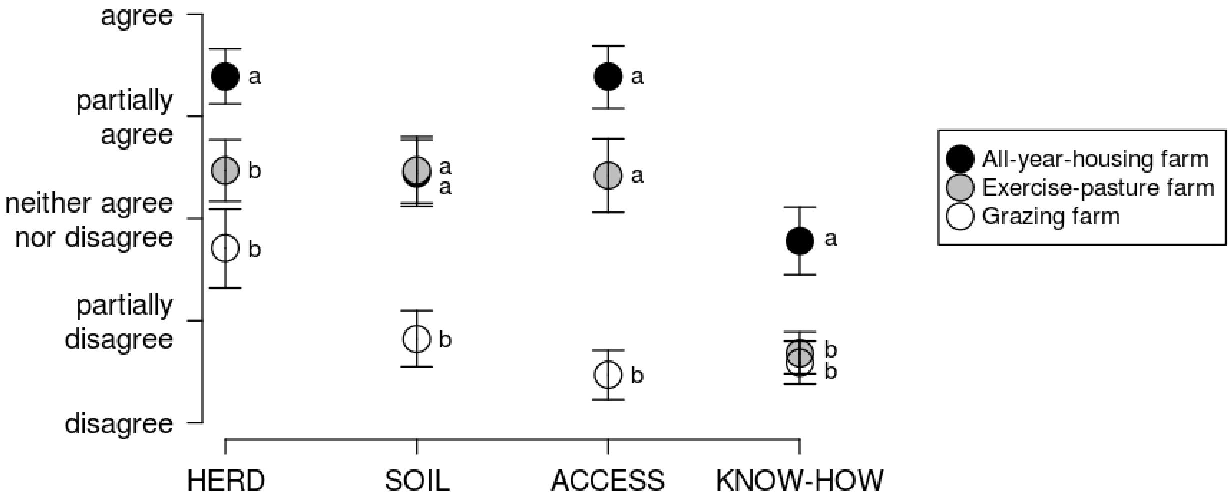

Figure 1. Perception of dairy farmers of disadvantages of grazing I. 'Are the following statements a reason for you to not use or not increase grazing or for reducing grazing on your farm? Grazing is not manageable with large HERDS; grazing can cause damage to the SOIL structure; ACCESS to grassland is difficult/the grassland is not close to our farm; my KNOW-HOW of grazing management is too small.

$^{a\text{-}b}$Values with different superscript letters above one question (HERDS, SOIL, ACCESS, KNOW-HOW) differ (*$P < 0.05$).

Grazing is complicated: milk-yield and supply with water, minerals, and supplemental feeds

The second four negative statements about grazing which relate to a farmers decision not to graze or to reduce grazing are as follows: it is difficult to monitor health and fertility when cows are on pasture; the milk yield is reduced with grazing; it is difficult to supply cows with water, minerals and supplemental feeds; the feed supply from pasture is not consistently high enough.

All-year-housing farmers agreed with the negative statements about monitoring health and fertility, milk yield and feed, and partially agreed with the statement about difficulties to supply water, minerals and supplemental feed on pasture (Fig. 2). Farmers from grazing farms partially disagreed with the negative statements about monitoring and feed and water supply and were indifferent towards statements that milk yields are smaller and that the feed supply on pasture is not consistently high enough. The differences in opinion between all-year-housing farmers and grazing farmers were significant ($P < 0.05$). The differences in opinion between all-year-housing farmers and grazing farmers were significantly different for the four statements discussed here ($P < 0.05$). The responses from exercise-pasture farmers were more or less indifferent. With regard to negative statements about health and fertility monitoring, milk yield and feed supply, their responses tended to be closer to those from grazing farmers and showed significantly less agreement with the all-year-housing farmers (Fig. 2).

Generally, it seems that cows that are fed at least partly by grazing have a smaller milk yield than cows in all-year-housing systems, even when grazing is supplemented (White et al., 2002; Fontaneli et al., 2005). It is only when grazing management is very intensive that milk yields in grazing systems can be comparable to those in all-year-housing (Freeden et al., 2002). There are several explanations for a smaller milk yield related to grazing. During grazing cows might be exposed to heat stress in summer which has been found to reduce the milk yield of highly performing cows (Kadzere et al., 2002). The energy requirements for maintenance are higher for grazing cows than for cows in all-year-housing as they spend more time on feed selection and actual feed uptake and additionally need to walk a certain distance to the milking facilities (Agnew and Yan, 2000). During the grazing season, there is a decline in the amount and quality of fresh grass (Corrall and Fenlon, 1978). Furthermore, it can become more difficult to guarantee high yielding dairy cows on pasture a continuous supply of water, minerals and supplement feeds. Dairy farmers are usually focused on achieving a high milk yield per cow, and this is in conflict with maintaining or increasing grazing (Thomet et al., 2011). The farmers in our survey were not provided with a definition of what could be regarded as a high milk yield and in the interviews, we did not ask for a specific figure which in their opinion represented a high yield. This renders the term ‘high milk yield’ ambiguous. In the north-western regions of Germany – where most of the farms in our survey are situated – farms produce on average between 8,500 and 8,900 kg milk per cow and year (VIT, 2014) and these figures might have served as a benchmark for the farmers interviewed in our survey. The average milk yield for grazing farms in our survey of 8,200 kg per cow and year is lower than these figures, while exercise-pasture farms and all-year-housing farms exceed the benchmark with 9,524 and 9,404 kg per cow and year, respectively (Table 2). Exercise-pasture farmers referred to the time their cows spent outside the stable as ‘grazing’ although their pasture contributes almost nothing to the ration of the cows. In fact, exercise-pasture farmers fed a similar ration to their cows as all-year-housing farmers resulting in a similar milk yield that is significantly higher than that of grazing farms (Table 2). Cows in exercise-pasture farms are provided with consistent feed quality. Cows are easily supplied with water, minerals and supplemental feeds in the barn and are easily monitored as they only spend little time on a comparatively small pasture. Consequently, potential negative effects of grazing are not of much concern for farmers with exercise-pasture farms. However, these affects still discourage them from increasing grazing. On the other hand, farmers from all-year-housing farms most likely had the system of the grazing farms and the related smaller milk yields per cow in mind when they expressed their strong agreement with the negative statements about grazing.

As milk yields per cow on grazing farms are smaller than the average in north-western Germany the indifference of grazing farmers towards negative statements on milk yield and feed quality seems to be inconsistent. A possible explanation for this could be that farmers of grazing farms have a different perception of what a high milk yield is and considered the milk yield of their cows as ‘high’ in their specific circumstances. Compared to other studies with dairy cows on pasture supplemented with concentrates, the milk yield of grazing farms in our study is still relatively high (Fontaneli et al., 2005; Bargo et al., 2002). Farmers from grazing farms partially disagreed with negative statements about the monitoring of cow health and fertility and supply of extra feed on pasture. Cows which do not produce very high milk yields are more robust when faced with inconsistent feed quality and do not need supplemental feed on pasture. Generally, they have fewer problems with fertility than cows with a higher milk yield (Walsh et al., 2011; Lucy, 2001).

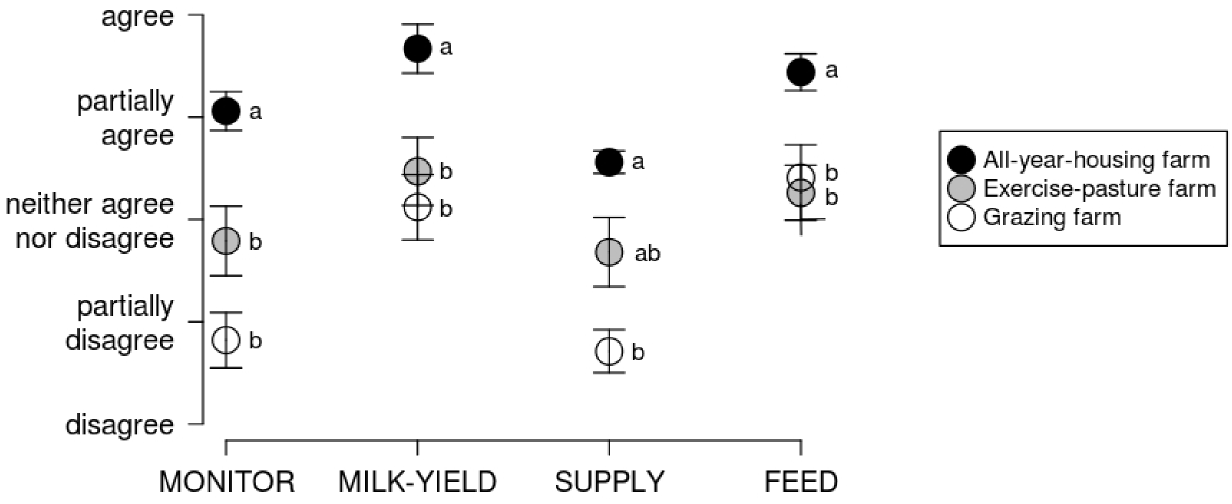

Figure 2. Perception of dairy farmers of disadvantages of grazing II. Question: 'Are the following statements a reason for you to not use or not increase grazing or for reducing grazing on your farm?' Statements: Grazing is connected with: Difficulties in heat detection and MONITOR cow health; a reduced MILK-YIELD due to higher energy requirements for maintenance or reduced feed intake under extreme weather conditions; difficulties to SUPPLY cows water, minerals and supplemental feeds; an inconsistent FEED supply which is not consistently high enough on pasture.
$^{a\text{-}b}$Values with different superscript letters above one question (MONITOR, MILK-YIELD, SUPPLY, FEED) differ ($*P <$ 0.05).

Grazing has advantages: costs and cow health

There are four positive statements related to the question, 'Do the following statements about grazing motivate you to continue or increase grazing': grazing results in lower feeding costs, less input of labor, better animal health, and higher fertility.

Farmers from grazing farms agreed or at least partially agreed with the positive statements on grazing concerning costs, labor, health and fertility, and differed significantly from all-year-housing farmers who were indifferent or disagreed partially (Fig. 3). The attitude of exercise-pasture farmers was less clear: they were similar to all-year-housing farmers in their critical view of the statements that grazing reduces feeding costs and requires less labor input but agreed with grazing farmers that grazing leads to better cow health and fertility (Fig. 3). This is in line with a Danish study where all-year-housing farmers mostly disagreed with the statement that grazing reduces health problems, whereas grazing farmers mostly agreed with it (Kristensen et al., 2010). Generally, lower feeding costs and less labor input can lead to a higher profitability per cow (Kriegl and McNair, 2005) or to higher labor profitability (Meul et al., 2012). The fact that the exercise-pasture farmers tended to partially disagree with the positive statements on costs and labor related to grazing can again be explained by the farm structure. The pastures on exercise-pasture farms are too small to contribute significantly to the ration of the cows and the cows are mainly fed in the stable. For meeting the criteria of the German Pasture Charta, at least 0.1 ha of good pasture per cow and year need to be available. We used values as provided in the study of Holshof et al. (2016) for calculating potential grass intake for the farms in our survey. The grazing farms in our study provided on average 0.28 ha pasture per cow and that corresponds to a potential intake of 8.5 kg DM grass per day. The exercise-pasture farms in our study have on average 0.04 ha pasture per cow, which corresponds to less than 1 kg DM of grass per cow per day. In a simulation of the economic effects of grazing, Van Den Pol-Van Dasselaar et al. (2010) found that the monetary benefits of grazing disappear when a farm has less than 0.1 ha of pasture per cow.

Hence, the exercise-pasture farmers will not profit from the lower feeding costs and the smaller labor input that are associated with grazing. In contrast to labor and fodder costs, the amount of pasture is not that important to achieve positive effects on animal health and fertility (Armbrecht et al., 2018). A study from Finland confirmed that cows profit from being on pasture due to the positive effects on their health even when the time spent outdoors is limited and even on a yard (Sairanen et al., 2006;). These effects are probably what exercise-pasture farmers mainly try to achieve.

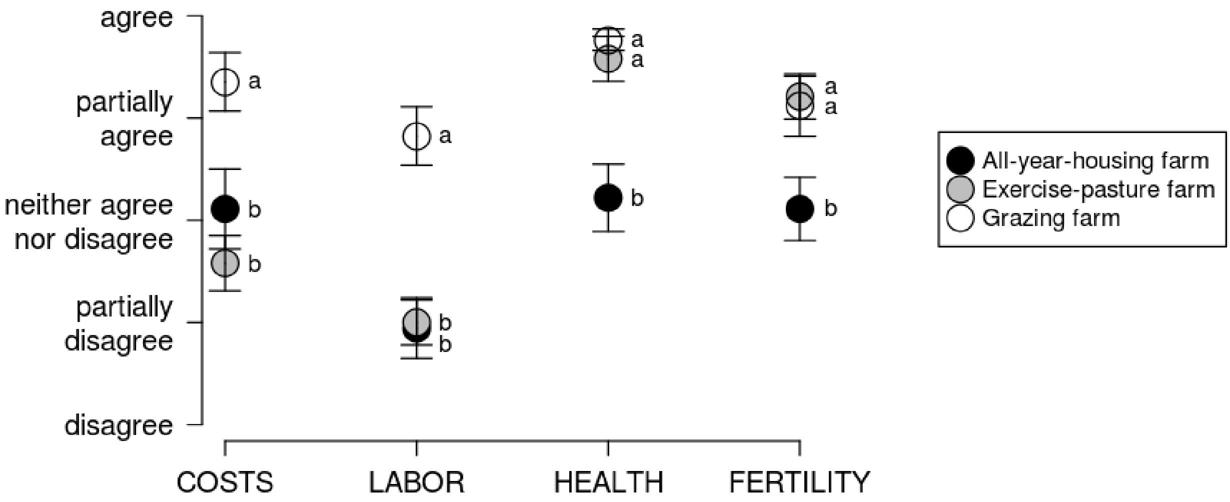

Figure 3. Perception of dairy farmers of advantages of grazing. 'Do the following statements motivate you to continue or increase grazing?' Grazing is related to: low fodder COSTS, low LABOR input, better animal HEALTH, higher FERTILITY.

$^{a\text{-}b}$Values with different superscript letters above one question (COSTS, LABOR, HEALTH and FERTILITY differ (*$P <$ 0.05).

Cognitive dissonance and lack of knowledge

The different views of dairy farmers on grazing might to a great extent be explained in terms of varying herd sizes, milk yields, and rations. It is nevertheless striking that farmers always agreed with statements that were in line with their production system. Here the concept of cognitive dissonance might be considered to elucidate reasons why dairy farmers chose to adhere to a production system or to change it. Cognitive dissonance is the discomfort experienced by someone who holds two or more contradicting beliefs or values at the same time or is confronted with new information which is in conflict with existing beliefs. Ways to reduce cognitive dissonance include change of opinion, of behavior or of perception. After a decision between two alternatives is made, the process of dissonance reduction leads to an increase in the desirability of the chosen alternative and a decrease in the desirability of the rejected alternative (Festinger, 1962). Winsten et al. (2000) found an increasing readiness to continue grazing in the future among farmers who used pasture intensively and concluded that this finding could have been a result of cognitive dissonance. In dairy farming, a change in the production system usually involves high investment costs and a difficult process of adaptation to a new work routine. It is difficult to return to grazing once an all-year-housing system has been established. On the other hand, grazing farmers would have to invest in machinery, buildings and labor if they were to give up grazing. Dairy farmers are somewhat trapped in their chosen system and tend to agree with their system and perceive alternatives negatively – thus avoiding cognitive dissonance. We have seen that the grazing farmers agreed to all the positive statements and the exercise-pasture farmers to two of them, while the all-year-housing farmers disagreed or expressed indifference towards them. It is very likely that the all-year-housing farmers have at some point had problems with animal health and fertility, since this is an issue on most farms. They may have still disagreed or showed indifference to the positive statements about grazing in this respect in order to not disagree with their system and the very high milk yields per cow. The negative attitude of the all-year-housing farmers towards grazing might have been reinforced by their limited know-how of grazing. An analysis of German, Austrian and Swiss farms identified the lack of knowledge of farmers and advisors about managing grazing systems as one of the main reasons for farmers choosing not to let their cows graze or for not increasing grazing (Thomet et al., 2011). While the exercise-pasture farmers and grazing farmers disagreed with the statement that their knowledge about grazing is limited, the all-year-housing farmers were indifferent towards the same statement.

The grazing farmers do not believe that milk yields necessarily needed to be smaller in grazing systems, although this was the case in our survey. As mentioned earlier, possibly the grazing farmers considered their milk yield to be comparably high. In this case it also seems likely that the farmers tried to avoid cognitive dissonance. Moreover, the exercise-pasture farmers' responses might also reflect what they actually do: they tend to partially agree with the statements that grazing is difficult to manage with large herds and that it can reduce the milk-yield, and consequently they offer only some kind of exercise for their cows so that they can benefit from its positive effects on health and fertility.

Conclusion

While consumers have a distinctly positive perception of grazing, the attitude of German dairy farmers towards grazing varies greatly. Farmers who let their cows graze and where grazing contributes to a significant part of the diet, show a high agreement with the positive aspects of grazing, while farmers from all-year-housing farms agree more with the negative aspects of grazing and seem concerned about management and milk yields. Exercise-pasture farmers appreciate the positive effects of time spent on pasture on the fertility and health of their dairy cows and are less concerned with the potential disadvantages of grazing than all-year-housing farmers. The latter is most likely due to the fact that their cows get almost the same ration as cows from all-year-housing farms. Grazing farms are usually smaller and have a lower milk yield which implies some adaption to the potential limitations of grazing management. Farmers' perception of the positive and negative aspects of grazing is influenced by farm structure and the actual experiences and prejudices of dairy farmers and is further reinforced by the human tendency to avoid cognitive dissonance. We found that in conducting a survey with dairy farmers it is important to clearly define terms like 'large herd' or 'high milk yield' as farmers from different dairy systems and backgrounds have different notions about these terms and this complicates the interpretation of their responses. In developing concepts to promote grazing, the differing attitudes and perceptions of dairy farmers and the interactions of these attitudes with farm structures and management need to be considered.

Conflict of interest statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of interests

None.

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6 Kapitel III: Performance of modern varieties of *Festuca arundinacea* and *Phleum pratense* as an alternative to *Lolium perenne* in intensively managed sown grasslands.

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

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 [7,8,9]. 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*.

Materials and Methods

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 systems (cutting-only, simulated grazing, and a mixed system 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 system’ 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 systems ‘cutting-only’ (4 cuttings), ‘simulated grazing’ (7 cuttings), and ‘mixed system’, 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 simulated grazing and mixed system. The cutting-only system 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 a 'mixed system' 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.

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 (CaCl2 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.

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

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.

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, simulated grazing, and the mixed system, 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).

When comparing the main species as averaged over the three management systems 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 13,810 kg DM ha^{-1}, followed by *LoPe* with 11,301 kg DM ha^{-1}, and *PhPr* with 10,366 kg DM ha^{-1} (as averaged over all years, management systems 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 simulated grazing management than with the mixed system and the cutting-only system. Yields were largest on clay followed by sand and peat and significantly higher in 2016 than in 2014 and 2015 (Table 3).

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

		Sand	Peat	Clay	All soils
	Mixture			%	
Mass proportion of main species (*FeAr, LoPe, PhPr*) in the respective mixture.	*FeAr*	98	78	98	92^{a}
	LoPe	92	57	91	82^{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 I. the mean mass proportions of the main species averaged over the soil (row 1, column 6), II. the mean mass proportions of *Poa pratensis* in the tree mixtures averaged over the soil (row 2, column 6), III. the mean mass proportions of *Holcus lanatus* in the three mixtures on peat (row 3, column 4). *FeAr: Festuca arundinacea, LoPe: Lolium perenne, PhPr: Phleum pratense*

Table 3. Dry matter yields (Lsmeans, in kg DM ha^{-1}) for the main factors mixture, management, soil, and year*.

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

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

Comparatively, *PhPr* had, on average, the smallest yields. When averaged over the years, *PhPr* yields did not differ significantly among the management systems; however, yields did increase over the years, with the smallest yield in 2014 (9,479 kg DM ha^{-1}) being significantly different from 10,638 kg ha^{-1} in 2015 and 10,981 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 4). *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

Table 4. Dry matter yields (Lsmeans, in kg DM ha^{-1}): all two-way interactions between mixture, management, year and site*. Different letters indicate significant differences (P<0.05) among means. *FeAr: Festuca arundinacea, LoPe: Lolium perenne, PhPr: Phleum pratense.*

		Mixture			**Soil**			**Management**		
		FeAr	*LoPe*	*PhPr*	Sand	Peat	Clay	Grazing	Mixed	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}			
	Mixed	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}	1001^{e}	918^{e}	/			/		
	Clay	15333^{a}	1288^{bc}	10878^{de}						

Different letters indicate significant differences (P<0.05) among means. Grazing: Simulated grazing. *FeAr: Festuca arundinacea, LoPe: Lolium perenne, PhPr: Phleum pratense.*

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 system (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 system were significantly larger than those under simulated grazing; on the clay soil yields in the mixed system and the cutting-only system were larger than under simulated 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*.

Table 5. Dry matter yields (Lsmeans, in kg DM ha^{-1}) of the mixtures with the main species *FeAr, LoPe* and *PhPr* for different years and management systemes as averaged over the threes soils*.

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

*Differen letters indicate significant differences ($P<0.05$) among means of year and management for each mixture.
FeAr: Festuca arundinacea, LoPe: Lolium perenne, PhPr: Phleum pratense.

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 mixed system 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 1−3).

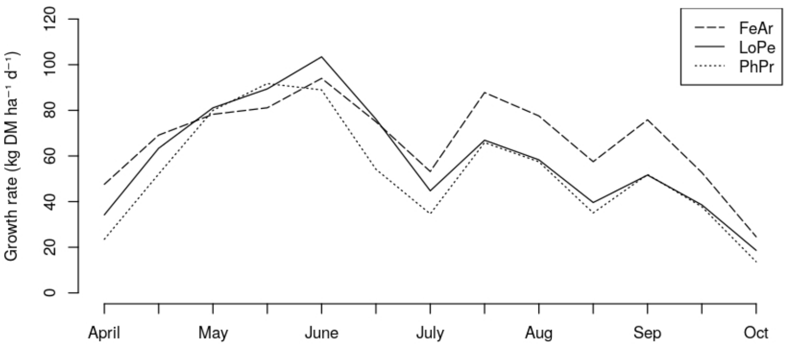

Figure 1. Simulated grazing: Growth rates (kg DM ha^{-1} d^{-1}) of *FeAr: Festuca arundinacea, LoPe: Lolium perenne*, *PhPr*: *Phleum pratense,* averaged of years and sites.

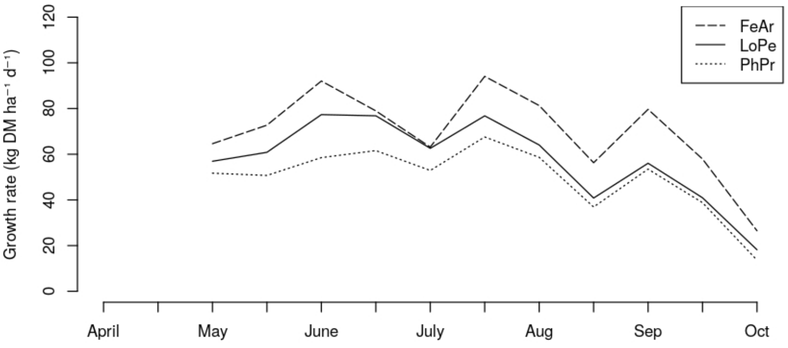

Figure 2. Mixed system: Growth rates (kg DM ha^{-1} d^{-1}) of *FeAr: Festuca arundinacea, LoPe: Lolium perenne*, *PhPr*: *Phleum pratense*, averaged of years and sites.

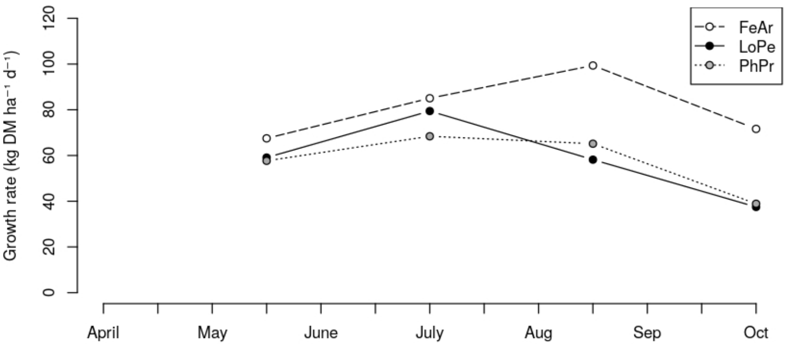

Figure 3. Cutting-only system: Growth rates (kg DM ha^{-1} d^{-1}) of *FeAr: Festuca arundinacea, LoPe: Lolium perenne and PhPr: Phleum pratense*, averaged of years and sites.

In May, the growth-rates of the simulated grazing system were higher than of the other systems but were lower later in the year. In the cutting-only system, *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 simulated grazing in the second half of the vegetation period were generally higher than those of the other mixtures. Under cutting-only and the mixed system, growth rates of *FeAr* were higher right from the start, that is after a first cutting in May for the mixed system (Figure 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.

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.

Festuca arundinacea: high yields and good persistence

On all three soils and in all three managements (cutting-only system, simulated grazing, and mixed system) *FeAr* mixtures showed the largest yields and had the greatest persistence; yields of *FeAr* did even increase during the three years of the experiment (Table 4−5). 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* (Figure 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 system. 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 simulated grazing system, *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 [31,32,33] 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.

Phleum patense: 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 system, 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 system to seven cuttings in a simulated grazing system 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 simulated grazing and mixed system, 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 system. 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 systems [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 systems could be superior to *LoPe* swards and would produce feed of higher quality than *FeAr*.

Poa pratensis: potential of an accompanying grass

In the present investigation, seeds of white clover (*Trifolium repens*) 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} year^{-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.

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 CO2 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.

Conclusion

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.

Author Contributions

Conceptualization: M.K., M.B., J.I.; methodology: T.B., R.J., M.K.; data curation: T.B., R.J.; writing—original draft preparation: T.B., M.K.; writing—review and editing: M.K., J.I.; supervision: M.K., J.I. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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7 Kapitel IV Feed quality of modern varieties of *Festuca arundinacea* and *Phleum pratense* as an alternative to *Lolium perenne* in intensively managed grassland.

Abstract

Under climate change prolonged periods of droughts, which might decrease the performance of *Lolium perenne,* are predicted to occur more often. In field experiments we tested whether *Festuca arundinacea* and *Phleum pratense* could be suitable alternatives to *Lolium perenne* on intensively managed clay, peat, and sandy soil. These grasses were sown in mixture with *Poa pratensis* and *Trifolium repens* and were subjected to different frequencies of defoliation representing a cutting-only system, simulated grazing, and a mixed system.

We found that in systems with at least six defoliations, *Festuca arundinacea* represented an acceptable compromise between feed quality, persistence – even on peat land - and yield. It had higher yields but a lower feed quality than *Lolium perenne*. However, for farms which are based on intensive cutting-only systems and are aiming at high feed qualities and yields, the quality of *Festuca arundinacea* is not sufficient. *Phleum pratense* was increasingly displaced by other species. But in the cutting-only system and in a mixture with *Poa pratensis* on sand and clay, total yields of net energy and crude protein did not differ significantly from *Lolium perenne.* On peat land all mixtures were invaded by *Holcus lanatus* with *Festuca arundinacea* mixtures being the least affected. We found that under conditions of frequent defoliations, *Holcus lanatus*-rich swards had comparatively good yields and a forage quality that would be acceptable even for dairy cows. We conclude that in future it will become more important to adapt the choice of grasses and mixtures for the use in certain production systems to the challenges of climate change.

Introduction

Lolium perenne (LoPe) is the most important species on intensively managed grasslands, especially when precipitation is high (Norris, 1982), and is in particular well adapted to clay soils and frequent defoliations like on grazed pasture (Turner et al., 2012; Watson and More, 1962; Frame, 1992*)*. However, in some areas in Central Europe conditions for optimal growth of *LoPe* are likely to become less favourable as climate change might lead to more frequent periods of prolonged drought (IPCC, 2007). There is also an on-going trend to all-year housing of dairy cows relying on systems with more cut grassland for silage. In turn, species better adapted to fewer defoliations might invade the sward and suppress and displace even a highly competitive grass like *LoPe* (Turner et al., 2012). Fewer defoliations usually also have a negative effect on feed quality while with more defoliations, the contents of crude protein (Frame and Hunt, 1971) and net energy (Motazedian and Sharrow, 1990) in the sward increase.

Against this background there seems to be a need for alternative species to *LoPe*. *Festuca arrundinacea (FeAr),* for example, is better adapted to dry conditions (Suter et al., 2009, Cougnon et al., 2014). *Phleum pratense* (*PhPr)* has a higher content of crude protein than *LoPe* (Frame, 1991) and is better adapted to fewer defoliations like in cutting-only systems (Suter et al., 2009). However, both alternative species also have some weaknesses: often *PhPr* has lower yields than *LoPe* (Frame, 1991); *FeAr* has harder leaves, contains silicates, has a lower digestibility than *LoPe* (Cougnon et al., 2014) and can affect animal heath when infected with endophytes (Stuedemann and Hoveland, 1988). But new varieties of *FeAr* are much better accepted by livestock (Suter et al. 2009) as they have softer leave tissue, less silicate and are free of endophytes (Isleib, 2015).

In order to test for alternatives to *LoPe* we set up a field experiment with modern varieties of *FeAr* and *PhPr* and *LoPe* as a reference. The mixtures were accompanied by smaller amounts of *Poa pratensis (PoPr)* and *Trifolium repens* and were sown on three differing sites - a clay, a peat, and a sandy soil. The established swards were then subjected to three different management schemes as distinguished by frequency of defoliation: 'cutting-only' (4 cuts), 'simulated grazing' (7 cuts), and a'mixed system' (6 cuts).

In a first part of the study (Becker et al., 2020), we found, that *FeAr* was more persistent than *LoPe* and had higher yields, especially on peat and clay. *PhPr* was less persistent and had lower yields than *LoPe;* in combination with increasing proportions of *PoPr* the respective swards showed a good persistence and had yields similar to those of *LoPe*. When grown on peat soil, *LoPe* and *PhPr* were strongly displaced by invading *Holcus lanatus*; under such conditions *LoPe* had lower yields than *FeAr* (Becker et al., 2020). We are now presenting further results from the study on the feed quality of the three mixtures as affected by frequency of defoliation, the soil type and the interaction of both factors. To answer the question whether *Festuca arundinacea* and *Phleum pratense* might serve as alternatives to *Lolium perenne* under unfavorable conditions we asked: i) how does the feed quality of *Festuca arundinacea* and *Phleum pratense* differ from that of *Lolium perenne*?; ii) is the feed quality (content of net energy and crude protein in harvested biomass) of *Festuca arundinacea* and *Phleum pratense* sufficient for the nutrition of dairy cows?; and iii) how are the feed quality and the total yield of net energy and crude protein of the three mixtures influenced by management (frequency of defoliation) and soil type?

Material and methods

The experiment was established in early autumn 2013 on three sites, a sandy, a clay and a peat soil, in Northwest Germany within a 30 km radius of the town of Oldenburg (53° 9' N and 8° 5' E; 5 m a.s.l.). The pH of the sandy soil was 5.2, that of the peat soil 4.1, and was 5.7 for the clay soil. Plant available concentrations of the macronutrients P, K, CAL (calcium-acetate-lactate extraction), and Mg ($CaCl_2$ extraction) in the topsoil (0–10 cm) for the year 2014 were in a range of 40–80 mg 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 (Landwirtschaftskammer Niedersachsen, 2011).

The experimental set-up was the same on all sites and followed a split-plot design with the treatment ‘management’ forming three sub-blocks within the three main blocks (replications) and plots of the treatment ‘mixtures’ randomly allocated to the sub-blocks. The main species *LoPe*, *FeAr,* and *PhPr* were each accompanied by *Trifolium repens* and *PoPr* and were sown by a special sowing machine for experimental plots in autumn 2013. In 2014, 2015 and 2016 the mixtures were subjected to three different defoliation frequencies: a cutting-only system (four cuts), a simulated grazing system (seven cuts), and a mixed system (six cuts). The design is an adaption of that of Corrall and Fenlon (1978). There were two sub-plots for every mixture in the simulated grazing and mixed system which were each harvested every four weeks; harvesting of one of the respective sub-plots started two weeks later allowing for calculation of growth curves based on two weeks intervals (Becker et al., 2020). The cutting-only plots were harvested every six weeks after the first cut. Cutting for the simulated grazing started 5–15 April each year, the mixed system and the cutting-only system were harvested 15–25 May for the first time. Plot size was 1.5 x 7.0 m and harvested in total with a remaining stubble height of 4 cm. Grab samples of 500 g from the mown swaths were dried for 48 h at 60°C.

Table 1: Factorial design of the experiments*

Factor	Steps	Notes
Mixture (main species)	*LoPe* cv.Sponsor *FeAr* cv. Elodie *PhPr* cv. Barpenta	Sown mixture = 25 kg ha^{-1} main species + 3 kg *Poa pratensis* (cv. Lato) + 3 kg *Trifolium repens* (cv. Rivendel)
Management	Simulated grazing Mixed system Cutting-only system	Simulated grazing with 7 cuts; mixed system with 6 cuts, and cutting-only system with 4 cuts per year
Site	Sand / Geest landscape Clay / Marsh land Peat / Moor land	Experiment repeated on three different sites; 3 years; 3 blocks; split-plot design

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

Dried material was ground to 1 mm and analyzed via near infrared reflectance spectroscopy (NIRS) for total N and the quality parameters energy content and crude protein; parallel to that the dry matter content at 105°C was determined. Energy content (MJ net energy kg^{-1} DM) was calculated according to the guidelines of the German Society of Nutrition Physiology (GfE, 2009)

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

The fertilization was in line with that of intensively managed grassland and was targeted at avoiding N-deficiency. All plots received 320 kg N ha^{-1}, 75 kg P ha^{-1}, and 150 kg K ha^{-1} per year;

after an initial supply of N (60 kg N ha^{-1}) in March the remaining N was applied in respective doses after each cut.

Weather conditions were similar for all sites (Table 2) and are characterized by a maritime climate with moderate temperatures in summer and mild and rainy winters. Rainfall in 2014 was comparatively high in May, July, and August while moderate in June; in 2015 spring and early summer were characterized by dry conditions that ended only with significant rainfall in July; also in 2016 rainfall in spring was rather limited but high in June.

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

Table 2. Average monthly temperature (Temp.) and monthly precipitation (Prec.) in 2014, 2015 and 2016, averaged over the stations on the clay site and the sandy soil site and long-term average. The peat-site is located between the two other sides within a distance of 15 km.

	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

Statistics

For statistical analysis (content of net energy and crude protein and total yield of net energy and crude protein) we used the lme function of the nlme package (Pinheiro et al., 2017) in R Studio (RStudio Team, 2016). 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.

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.

Yield and persistence

The dry matter yields of the three mixtures differed and were significantly influenced by management, year and soil type. Dry matter yields of mixtures with the main species *FeAr* were

13,810 kg DM ha^{-1}, followed by *LoPe* with 11,301 kg DM ha^{-1}, and *PhPr* with 10,366 kg DM ha^{-1}. DM yields were lower in the simulated grazing system than in the mixed system and the cutting-only system. Yields were largest on clay soil and significantly higher in 2016 than in 2014 and 2015.

After three years, mixtures differed in the persistence of the main species: in the last year, yield proportion of the main species in the respective plots amounted to 91% for *FeAr*, 80% for *LoPe*, and 52% for *PhPr*. While on sand and clay the main species accounted on average for 84% of the yield, only 54% of the yield on peat soil could be attributed to the main species. On peat the main species were displaced mainly by *Holcus lanatus* (*HoLa*). The highest proportion of *HoLa* (49%) was in the mixtures with *PhPr* as main species. On sand and clay, *PhPr* was partly displaced by the mixture partner *PoPr* which accounted for 30% yield proportion on clay and for 18% on sand (Table 3). The development of yield and persistence are presented in detail in a previous publication (Becker et al. 2020).

Table 3. 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 (simulated grazing, mixed system, and cutting-only system) after three years*.

		Sand	Peat	Clay	All soils
	Mixture		%		
Mass proportion of main species (*Festuca arundinacea, Lolium perenne, Phleum pratense*) in the respective mixture.	*FeAr*	98	78	98	92^{a}
	LoPe	92	57	91	82^{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 I. the mean mass proportions of the main species averaged over the soil (row 1, column 6), II. the mean mass proportions of *Poa pratensis* in the tree mixtures averaged over the soil (row 2, column 6), III. the mean mass proportions of *Holcus lanatus* in the three mixtures on peat (row 3, columns 4). *FeAr: Festuca arundinacea, LoPe: Lolium perenne, PhPr: Phleum pratense, PoPr: Poa pratensis.*

Content of net energy and crude protein

The net energy content and the content of crude protein of the three grass mixtures differed significantly and were influenced by the factors year, management and soil type (Table 4–6). Contents of net energy were significantly higher for mixtures of *LoPe* (6.4 MJ net energy kg^{-1} DM) than those of *FeAr* (6.2 MJ net energy kg^{-1} DM) and *PhPr* (6.1 MJ net energy kg^{-1} DM). Mixtures with *PhPr* had the significantly highest contents of crude protein (19% kg^{-1} DM); the contents of crude protein for *LoPe* (18% kg^{-1} DM) and *FeAr* (18% kg^{-1} DM) did not differ significantly.

Under conditions of simulated grazing, contents of net energy (6.5 MJ net energy kg^{-1} DM) and crude protein (19% kg^{-1} DM) were significantly higher than in the mixed system (6.2 MJ net energy kg^{-1} DM, 18% crude protein kg^{-1} DM), while in the cutting-only system net energy and crude protein contents were significantly lowest (6.0 MJ net energy kg^{-1} DM, 16% crude protein kg^{-1} DM) (Table 4).

The highest content of net energy was found for *LoPe* mixtures in the simulated grazing system, the lowest content for *PhPr* in the cutting-only system. Mixtures with *PhPr* under simulated grazing management had the highest content of crude protein while the lowest content of crude protein were found for *FeAr* and *LoPe* in the cutting-only system.

Table 4 Lsmeans of the content of net energy (MJ kg^{-1} DM), the total yield of net energy per ha (GJ ha^{-1}), lsmeans of the content of crude protein (% kg^{-1} DM) and total yield of crude protein (kg ha^{-1}).

	Net energy content (MJ kg^{-1} DM)	Net energy yield (GJ ha^{-1})	Crude protein content (% kg $^{-1}$ DM)	Crude protein yield (kg ha^{-1})
FeAr	6.2^{b}	86.7^{a}	18^{b}	2,446^{a}
LoPe	6.4^{a}	73.4^{b}	18^{b}	2,006^{b}
PhPr	6.1^{c}	63.7^{c}	19 ^{a}	1,944^{b}
Simulated grazing	6.5^{a}	72.7^{b}	19^{a}	2,158^{a}
Mixed system	6.2^{b}	74.1^{ab}	18^{b}	2176^{a}
Cutting-only system	6.0^{c}	77.1^{a}	16^{c}	2,062^{b}
Sand	6.2^{a}	76.8^{a}	17^{b}	2,112
Peat	6.3^{a}	66.2^{b}	19^{a}	2,046
Clay	6.2^{b}	80.8^{a}	17^{b}	2,238
2014	6.1^{c}	67.6^{c}	18^{b}	1,934^{c}
2015	6.4^{a}	80.5^{a}	18^{a}	2,271^{a}
2016	6.2^{b}	75.6^{b}	18^{a}	2,192 ^{b}

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

The energy contents of the respective mixtures did not differ among the three soils, but the content of crude protein was usually higher on peat soil (Table 5 and 6). Averaged over mixtures and management, crude protein on peat soil (19% kg^{-1} DM) was significantly higher than on sand (17% kg^{-1} DM) and clay (17% kg^{-1} DM) - the highest content of crude protein was found for *PhPr* on peat soil (Table 6).

Table 5: Lsmeans of the content of net energy (MJ kg^{-1} DM) and of the total yield of net energy (GJ ha^{-1}). Two way interactions of the species with the factors management, soil and year*.

		Net energy content (MJ kg^{-1} DM)			Net energy yield (GJ ha^{-1})		
		FeAr	*LoPe*	*PhPr*	*FeAr*	*LoPe*	*PhPr*
Year	2014	6.2^{c}	6.2^{c}	6.0^{e}	74^{bc}	72^{bc}	57^{e}
	2015	6.2^{c}	6.7^{a}	6.2^{c}	95^{a}	77^{b}	69^{cd}
	2016	6.1^{d}	6.4^{b}	6.1^{d}	91^{a}	71^{cd}	65^{d}
Soil	Sand	6.2^{b}	6.5^{a}	6.0^{cd}	90^{ab}	73^{cdef}	68^{cdef}
	Peat	6.2^{b}	6.4^{a}	6.2^{bc}	76^{bcd}	65^{e}	58^{f}
	Clay	6.1^{bc}	6.4^{a}	6.0^{d}	94^{a}	83^{bc}	65^{def}
Management	Grazing	6.4	6.7	6.3	82^{b}	73^{c}	62^{d}
	Mixed system	6.1	6.4	6.0	85^{ab}	75^{c}	62^{d}
	Cutting-only	5.9	6.2	5.8	93^{a}	72^{c}	66^{cd}

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

Table 6: Lsmeans of the content of crude protein (% kg^{-1} DM) and of the total yield of crude protein (kg DM ha^{-}1). Two-way interactions of the species with the factors management, soil and year *.

		Content of crude protein (% kg^{-1} DM)			Total yield of crude protein (kg DM ha^{-1})		
		FeAr	*LoPe*	*PhPr*	*FeAr*	*LoPe*	*PhPr*
Year	2014	18^{cde}	17^{f}	18^{abc}	$2,131^{b}$	$1,943^{c}$	$1,728^{d}$
	2015	18^{de}	18^{bcde}	19^{ab}	$2,628^{a}$	$2,084^{bc}$	$2,100^{bc}$
	2016	17^{e}	18^{bcd}	19^{a}	$2,580^{a}$	$1,991^{bc}$	$2,005^{bc}$
Soil	Sand	17^{de}	17^{de}	17^{cde}	$2,446^{abcgf}$	$1,929^{dehi}$	$1,962^{dehi}$
	Peat	19^{bc}	19^{b}	20^{a}	$2,293^{abcde}$	$1,933^{fghi}$	$1,911^{fghi}$
	Clay	17^{e}	17^{e}	18^{bcd}	$2,599^{a}$	$2,156^{bdfh}$	$1,960^{cegi}$
Management	Grazing	19^{b}	19^{bc}	20^{a}	2,472	2,032	1,970
	Mixed system	18^{d}	18^{cd}	19^{b}	2,490	2,050	1,988
	Cutting-only	16^{f}	16^{ef}	17^{e}	2,376	1,936	1,874

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

Contents of net energy and crude protein were different in the three experimental years (table 5 and table 6). In 2014 contents of net energy (6.1 MJ net energy kg^{-1} DM) and crude protein (18% kg^{-1} DM) were lowest while the highest net energy content occurred in 2015 (6.4 MJ net energy kg^{-1} DM). In 2016 the net energy content (6.2 MJ kg^{-1} DM) was significantly higher than in 2014 and significantly lower than in 2015.

During the three experimental years, the content of crude protein increased on the peat soil which corresponds with the increasing proportion of the protein-rich *HoLa* in the plots (2014: 18% kg^{-1} DM; 2015: 20% kg^{-1} DM; 2016: 20% kg^{-1} DM).

Total yield of net energy and crude protein

All main factors (year, management, mixtures) had a significant effect on the total yield of net energy per ha (Table 4). Total yields of net energy of mixtures with *FeAr* were highest (86.7 GJ ha^{-1}) and were statistically different from those with *LoPe* (73.4 GJ ha^{-1}) and *PhPr* (63.7 GJ ha^{-1}) when averaged over years and management. In the cutting-only system (77.1 GJ ha^{-1}) the total yield of net energy was significantly higher than in the simulated grazing system (72.7 GJ ha^{-1}) while energy yields in the mixed system (74.1 GJ ha^{-1}) ranged in-between (Table 4). Yields of total net energy, when averaged over years and mixtures, were significantly smaller on peat soil (66.2 GJ ha^{-1}) than on clay (80.8 GJ ha^{-1}) and sand (76.8 GJ ha^{-1}) (Table 4). As total yields of net energy and crude protein are calculated from dry matter yields and contents of net energy and crude protein, a very high yield combined with lower contents of net energy or protein can still lead to high total yields of net energy and protein. For example, lower net energy and crude protein contents in the cutting-only system were balanced by the high DM yields; lower contents of net energy and crude protein but large DM yields in *FeAr* mixtures resulted in high total yields of net energy and protein.

While total net energy yields increased by about 5 GJ ha^{-1} for *LoPe* from the first to the second year, the increase was as high as 21 GJ ha^{-1} for *FeAr* and 12.4 GJ ha^{-1} for *PhPr* mixtures (Table 5). Total net energy yields for *LoPe* and *FeAr* were largest on clay while the effect of the factor soil on *PhPr* mixtures was indifferent.

FeAr mixtures had the highest total yields of net energy in the cutting-only system which was 11 GJ ha^{-1} more than in the simulated grazing system, a difference that is statistically significant (Table 5). For *LoPe* and *PhPr* mixtures the total yield of net energy did not differ significantly between the three management systems. For all mixtures, total net energy yields were highest in 2015; however, for *FeAr* and *PhPr* total net energy yields did not differ significantly between 2015 and 2016.

The total yield of crude protein per ha was influenced by the factors mixture, management, and year, but did not differ among the soil types (Table 4). When averaged over management, soil type, and year, total yields of crude protein were largest for mixtures of *FeAr* (2,446 kg ha^{-1}); while values for *LoPe* (2,006 kg ha^{-1}) and *PhPr* (1,944 kg ha^{-1}) did not differ significantly from each other (Table 4). Total yields of crude protein were significantly higher in the simulated grazing system (2,158 kg ha^{-1}) and in the mixed system (2,176 kg ha^{-1}) than in the cutting-only system (2,062 kg ha^{-1}). The total yields of crude protein differed among the years. Yields of crude protein of the respective mixtures did not differ among the soil types (Table 6). *FeAr* and *PhPr* had larger yields of crude protein in 2015 and 2016 than in 2014. The soil type had no effect on total yields of crude protein of the respective mixtures (Table 6).

Discussion

Persistence of main species and feed quality

The feed quality of our mixtures was determined for every cut. It needs to be considered that the sward composition during the three experimental years deviated to some degree from that of the sown mixtures (Table 3; see Becker et al. 2020). This was especially evident on the peat soil; here all three mixtures were strongly affected by the invasion of *Holcus lanatus* (*HoLa*), especially in mixtures of *PhPr*. Other than on peat, on sand and clay the feed quality of *PhPr* mixtures was influenced by increasing proportions of *PoPr*. In terms of feed quality the simple mixtures in our experiment might not be fully comparable to results obtained in experiments with single species. However, the net energy content in *LoPe* mixtures, although containing *PoPr* and *HoLa* which have a lower content of net energy (Frame, 1989), was higher than that of *FeAr* and *PhPr* mixtures. In this respect the results of the presented experiment are comparable to those with single-species swards with *LoPe*, *FeAr* and *PhPr* (Kalzendorf and Hinrichsen, 2017; Davies and Morgan, 1982; Cougnon et al., 2014; Lee et al., 2018).

Protein contents did not differ significantly between *LoPe* and *FeAr* which confirms the findings of Cougnon et al. (2014) and of Lee et al. (2018) We found that the protein contents developed differently in time for *LoPe* and *FeAr* mixtures: in late summer and autumn the protein contents of *LoPe* were higher than those of *FeAr* (Figure 1).

HoLa did invade all swards on the peat site in our experiment (Table 3). It has been reported that the crude protein content of *HoLa* is higher than that of *LoPe* (Suckling, 1960; Frame, 1991; Harrington et al., 2006). This would explain the high contents of crude protein in all mixtures on peat in our experiment (Table 6) as the content of crude protein over the three experimental years seems to be correlated with increasing proportions of *HoLa* in the plots. Jacques (1974) explains high contents of crude protein of *HoLa* with a highly competitive ability in cation exchange capacity in the roots for uptake of nitrogen. Especially *PhPr* mixtures on peat had high contents of crude protein as both, the main species *PhPr* and the invading *HoLa* are rich in protein.

Despite the fact that *HoLa* is unpopular among farmers as it is associated with declining yields and poor forage quality we found acceptable energy contents in our experiments. Plots of mixtures with *PhPr* on peat had high proportions of about 49% *HoLa* in the third year, but still on average 6.2 MJ net energy kg^{-1} DM, which is above the recommended minimum of 6.0 MJ net energy kg^{-1} DM for high-yielding dairy cows (Spiekers, 2004). In our experiments, the main species *FeAr* was the least reduced in the respective mixtures on peat soil which is in line with previous studies (Suter et al. 2009, Jänicke, 2017; Kalzendorf and Hinrichsen, 2017). The relatively good persistence along with high yields and high production of net energy and crude protein and acceptable contents of net energy and crude protein make *FeAr* a promising alternative to *LoPe* on peat soils.

We did not find a direct effect of soil type on feed quality (net energy content and crude protein). But the soil type has an effect on persistence of sown species and thus indirectly on the duration of an intended mixture. This was especially the case with peat soil in our experiments. It seems that the varying persistence of species under different soil and site conditions and how that affects the feed quality is an important aspect when evaluating suitability of grass species. All three main species in our experiment showed a good persistence on sand and clay while peat proved to be difficult for *LoPe* and *PhPr* mixtures. On peat, it could be advantageous to accept certain amounts of the protein-rich *HoLa* and to introduce *FeAr* as a competitive and high-yielding species.

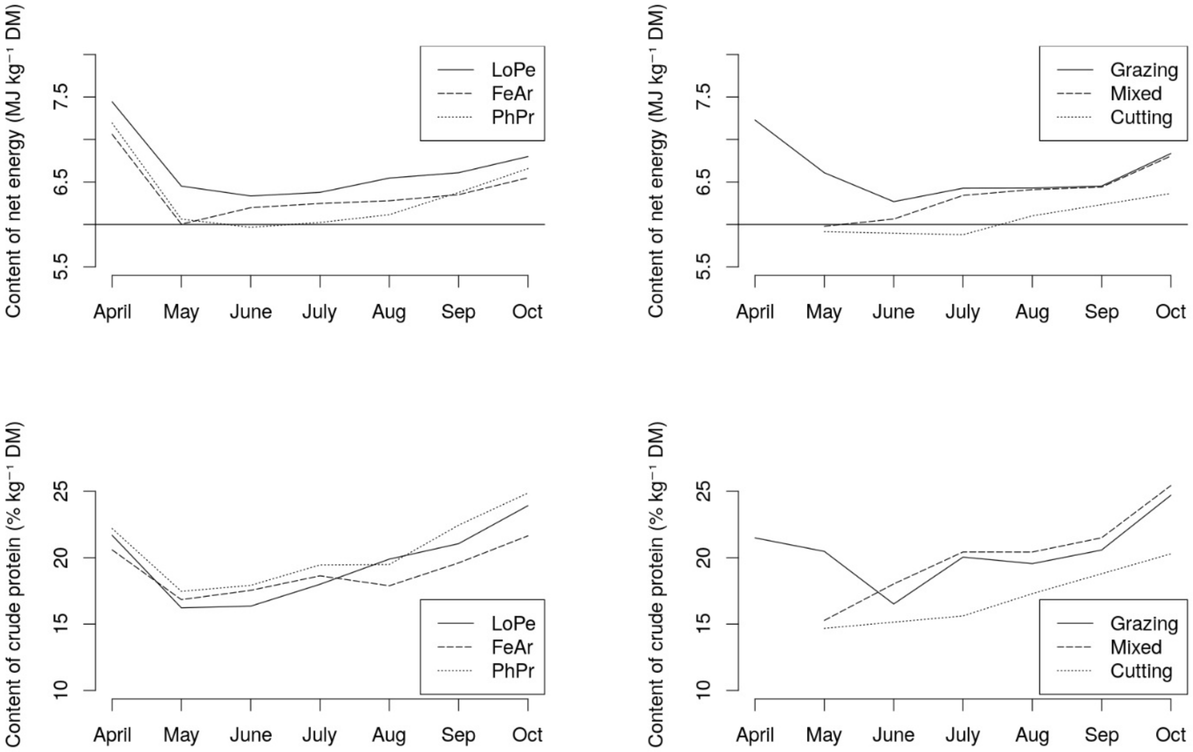

Figure 1: Development of the content of net enery (MJ kg^{-1} DM) and crude protein (% kg^{-1} DM) during the growing season. Left side: *FeAr*: *Festuca arundinacea*, *LoPe*: *Lolium perenne* and *PhPr*: *Phleum pratense*; averaged over years, sites and management. Right side: Simulated grazing system (7 cuts), mixed system (6 cuts) and cutting-only system (4 cuts); averaged over years, sites, and mixtures.

Festuca arundinacea on frequently defoliated grassland

On sites with a high water holding capacity like clay and under conditions of high precipitation, *LoPe* will continue to be the most important species in grassland for dairy. *LoPe* has a high turnover of tillers throughout the year and thus the amount of young plant parts with a high feed quality is higher than in other species (Duchini et al., 2018). Under climate change prolonged periods of droughts, which might decrease the performance of *Lolium perenne,* are predicted to occur more often (IPCC, 2007). Spring and early summer of 2015 were characterized by mainly dry conditions (precipitation in that period was 30% less than the long-term average). Also under the comparatively dry conditions in spring and early summer 2015 *FeAr* had high yields and high contents of net energy and crude protein. For a successful implemetation of *FeAr* the following implications need to be considered:

1) *FeAr* based diets result in a lower milk production compared to *LoPe* (Lee at al., 2018). It has been shown that cows fed with fresh *FeAr* have a lower feed intake and milk production than cows fed with fresh *LoPe* (Lutten and Remmelink, 1984). However, in our experiments, the content of net energy from *FeAr* was on average higher than 6.0 MJ net energy kg^{-1} DM (range from 5.9 MJ to 6.4 MJ net energy kg^{-1} DM) and this can be considered sufficiently high for the nutrition of dairy cows (Spiekers, 2004). In our experiments, the lowest content of net energy and crude protein were found in the cutting-only system (5.8–6.2 MJ net energy kg^{-1} DM; 160–170 g crude protein kg^{-1} DM), while the simulated grazing system had the highest contents of net energy (6.3–6.7 MJ kg^{-1} DM) and crude protein (190–200 g kg^{-1} DM;), (Figure 2, Table 5, and 6). Generally, frequent defoliations lead to a better feed quality, but also to lower DM yields (Frame and Hunt 1971, Chestnutt et al., 1977; Pontes et al., 2007; Donaghy et al. 2008). Frequent defoliation lead to swards with young plants which have a high digestibility and a high content of water-soluble constituents and of crude protein (Terry and Tilley, 1964; Minson et al., 1964). Our results indicate that *FeAr* should preferably be used in grazing and mixed systems to provide an adequate feed quality with young plants with a better digestibility and a higher content of water-soluble constituents and of crude protein (Terry and Tilley, 1964; Minson et al., 1964).

2) The timing of defoliation also has an effect on feed quality as plants are younger. The simulated grazing system in our experiment differed from the mixed system only in the first cutting that occurred four weeks earlier (figure 1 and figure 2). The overall better feed quality of the simulated grazing system can to a great amount be related to the higher contents of net energy and crude protein in the first two cuttings. When defoliated early, swards have a greater proportion of leaf as well as lesser stem and dead dry material (Kennedy et al., 2007) resulting in a better feed quality (Bryan and Prigge, 1994). It can be recommended to especially focus on an early first defoliation of swards rich in *FeAr* to produce high quality grass silage or hay for high yielding dairy cows.

3) Cows and sheep only have a low preference for *FeAr*. This is to some degree caused by higher contents of silicates in *FeAr*. Therefore, if *FeAr* is to be successfully grazed, animals should not be given a choice of more palatable grass species as they would prefer those (Kaiser et al., 2018; Elsäßer et al., 2015).

4) In dry and hot periods in summer increased concentrations of alkaloids produced by endophytes can be found in *FeAr* swards. However, in a study conducted in the mid-1990s, the concentrations of alkaloids in *FeAr* and *LoPe* were found to be too small to cause serious harm to grazing cattle (Oldenburg, 1997). As precaution an infection of a grass sward with endophytes can be detected by a PCR (Doss et al., 1998) or a tissue print immunoassay (Hahn et al., 2003).

Generally, longer dry periods of droughts can have a positive effect on the feed quality (Dumont et al., 2014). All species in our trial had their best feed quality in the dry year 2015. This is in accordance with other trials which also found a better feed quality under drought stress (Sheaffer et al., 1992, Küchenmeister et al., 2013, Hoffstätter-Müncheberg et al., 2013). Moderate water stress leads to a higher forage quality, when plant maturation is delayed as the stems, which are higher in crude fibre content, will then develop slower (Buxton 1996). However, dry periods can result in massive yield loss for swards dominated by *LoPe*. The more drought resistant *FeAr* will then still produce acceptable yields and even high total yields of net energy and crude protein per hectare with a good feed quality. In our experiments *FeAr* mixtures had the highest dry matter yields in 2016 but produced highest total yields of net energy and crude protein in the dry year 2015.

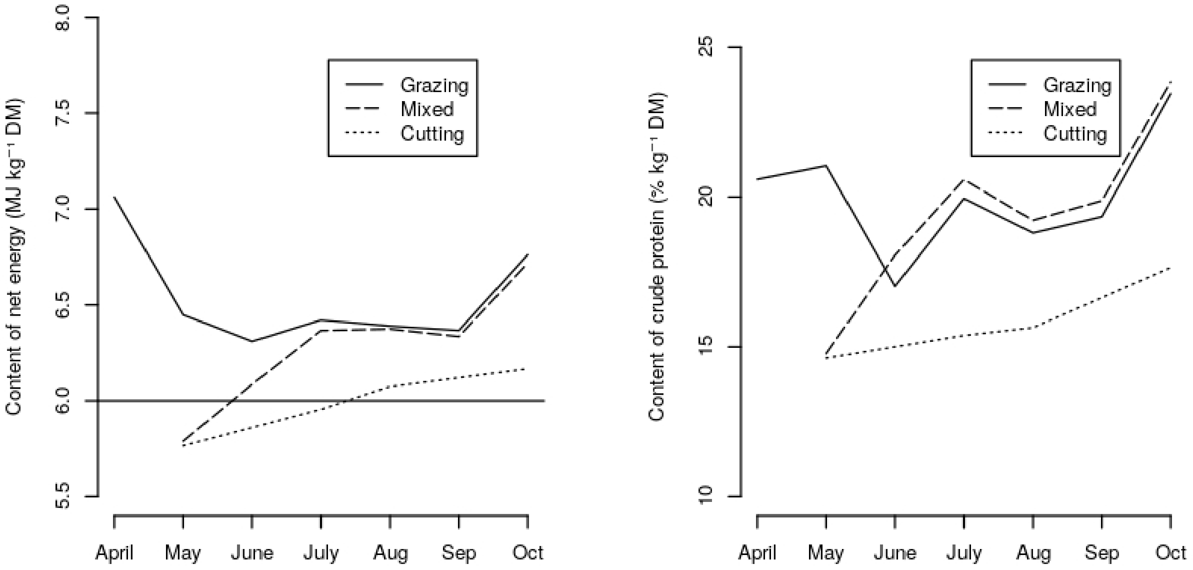

Figure 2. Development of the content of net energy (MJ kg^{-1} DM) and crude protein (% kg^{-1} DM) of *Festuca arundinacea* during the growing season averaged over years and sites in the simulated grazing system (7 cuts), mixed system (6 cuts) and the cutting-only system (4 cuts).

Intensive cutting-only systems

In the cutting-only system in our experiment *FeAr* and *PhPr* mixtures produced a feed quality that could be regarded as insufficient for high-yielding dairy cows, because it falls below the minimum of 6.0 MJ net energy kg^{-1} DM (Spiekers, 2004). Apart from effects of frequency of defoliation, experimental conditions might to some degree also have been contributed to the poorer performance of cutting-only swards. In our experiment we used a fixed schedule of six weeks interval between cuts in the cutting-only system and a modification of the Corral and Fenlon (1978) approach in the simulated grazing and the mixed system that resulted in two instead of one week resolution. Thus, especially in the cutting-only system it might have occurred, that the date of cutting was either slightly too late or too early and that might have negatively affected feed quality and yield.

If the widely use of frequent renovations of swards in order to keep a high proportion of *LoPe* is difficult to maintain, especially under climate change, some farmers might use more maize and concentrates instead of grass silage. In a survey of dairy farmers, farmers of all-year-housing systems used significantly more maize and concentrates than grazing-farmers and only one third of the milk production of the all-year-housing farms was based on grass (Becker et al., 2018). Another possible reaction to drier conditions could be to use irrgation systems or to adapt to a management with lower milk yields.

Cutting-only systems with Phleum pratense and Poa pratensis

In general, *PhPr* complies well with cutting-only systems (Frame, 1992) and the yield is not positively influenced by increasing the number of defoliations (Pontes et al., 2007). On less intensively managed grassland with fewer defoliations, *PhPr* in combination with *PoPr* might be a suitable main grass in mixtures for sand and clay. Under these conditions, the use of *LoPe* is not advantageous when compared with *PhPr* – in our experiment, the total yields of net energy and crude proteinof *PhPr* were not significantly lower than *LoPe* on sand and clay. In more extensive cutting-only systems with only two or three defoliations per year and little N fertilizer, the benefits of an alternative grass species like *PhPr* will further increase.

In animal nutrition, rations with *PhPr* can increase the dry matter intake and the milk yield of dairy cows (Dewhurst et al., 2003, Johnson and Thomson, 1996). In our experiments, we actually analysed the protein content of the respective mixtures in our experiments, not of the single species. For mixtures with *PhPr* as the main speices, the protein content was higher than that of *LoPe* and *FeAr* mixtures, but lower than that of other experiments with pure stands of *PhPr* (Davies and Morgan, 1982; Frame, 1991). However, it can be assumed that *PhPr* in our mixtures contributed substantially to the high contents of crude protein of the mixtures and to the good content of net energy

It might be advantageous to combine *PhPr* and *PoPr* as both grasses have a higher drought resistance than *LoPe* (Spedding and Diekmahns, 1972, Hubbard, 1968) and are well accepted by animals (Moore, 1966, Suter et al., 2009). The comparatively lower persistence of *PhPr* could then even help to establish *PoPr* in a sward as *PoPr* establishes slowly (LfL, 2018). But once established, *PoPr* will contribute to the development of a dense and stable sward (Spedding and Diekmahns, 1972). It seems that the combination of *PhPr* and *PoPr* also contributes to the resilience of swards against drought periods. Though 2015 being the dryest year with a particularly dry spring, the mixtures with *PhPr* and *PoPr* showed the highest yields of net energy and crude protein and had the highest content of crude protein in 2015.

It is well known that only when a first cut is made early enough, the feed qualities will be adequate for high yielding dairy cows. We observed that mixtures with *PhPr* had a high content of net energy which then after a first cut decreased more than for mixtures with *LoPe* and *FeAr*. This could at least partly be explained by difference in morphology: for grasses like *LoPe*, *FeAr*, and *PoPr* the stem and leaf-sheath fractions are at least as digestible as the leaf until the time of ear emergence, but this is not the case for *PhPr*, here the digestibility decreases earlier (Minson et al.,1964). For the conservation of *PhPr* as grass silage, the high content of crude protein can be a drawback as high puffer capacities complicate the production of grass silage (McDonald Henderson, 1962). That is why swards with high proportions of *PhPr* are preferably conserved as hay (Suter et al., 2016). Under conditions of climate change and longer dry periods, the production of hay would become easier and the management of *PhPr* swards would benefit from that.

Outlook

Under conditions of climate change - with predicted longer periods of drought - farmers will be forced to adapt their grassland management. This includes finding alternative grass species to *Lolium perenne* which reacts with smaller yields to drought. To meet the challenges of climate change, a more integrated approach is needed that considers animal nutrition, management and choice of species and mixtures. Instead of focusing on the same main species in their grasslands, mainly *Lolium perenne*, ,farmers might use a wider range of different species that are adapted to prevailing soil conditions and drought periods, and likewise adapt the management of grassland and animal feeding. So far, alternatives like *Festuca arundinacea* or *Phleum pratense* either have smaller yields or lower feed qualities when utilized under the same conditions as *Lolium perenne*. There is a need to develop farm-specific and site-specific procedures by farmers, researchers and advisors to find the best strategy for each farm. For swards with *Festuca arundinacea* this would include increasing the number of defoliations and an early first cut. On peat land, where the pressure of invading *Holcus lanatus* is high, the introduction of more competitive species might be an alternative. On more extensively managed fields, farmers might profit from the relatively high feed quality of *Phleum pratense.* On farms with sufficient water supply or where irrigation is an option, *Lolium perenne* will most likely continue to be the most important species. The negative effects of longer drought periods might be partly compensated by a generally higher feed quality after dry periods and by better conditions for haymaking.

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8 Zusammenfassung

In Regionen mit einem gemässigtem Klima sind als Folge des Klimawandels längere und häufigere Trockenheiten zu erwarten, welche den Anbau von Weidelgras (*Lolium perenne*) erschweren. In dieser Arbeit wurde getestet, ob Rohrschwingel (*Festuca arundinacea*) und Lieschgras (*Phleum pratense*) geeignete Alternativen zu Weidelgras für intensiv bewirtschaftetes Grünland sind. Erträge, Qualitäten und Persitenz der drei Arten wurden über einen Zeitraum von drei Jahren (2014–2016) auf Sand-, Moor- und Marschboden untersucht. Die untersuchten Arten waren dabei Haupart in einer Mischung mit Weißklee und Wiesenrispe. Es wurden drei verschiedene Schnittmanagements genutzt, welche die Art der Nutzung von Grünland in Norddeutschland wieder spiegeln: Weidesystem (7 Schnitte), Mähweide (6 Schitte) und Schnitt (4 Schnitte).

Parallel zu dem Feldversuch wurden mittels einer Befragung die Unterschiede und Gemeinsamkeiten von Milchviehbetrieben mit und ohne Weidehaltung untersucht. Es wurde erhoben, wie die Vor- und Nachteile von Weidehaltung und Stallhaltung durch Landwirte bewertet werden und ob sich die Betriebsstrukturen der Betriebstypen unterscheiden.

Rohrschwingel hatte auf allen Böden und in allen Managements eine signifikant höhere Beständigkeit (92% Masseanteil nach drei Jahren) und höhere Erträge (13,8 t TM ha^{-1}) als Weidelgras (82% Masseanteil nach drei Jahren; 11,3 t TM ha^{-1}) und Lieschgras (52% Masseanteil nach drei Jahren; 10,4 t TM ha^{-1}). Lieschgras wurde auf Sand und Marsch durch den Mischungspartner Wiesenrispe (Massenanteil Wiesenrispe Sand: 18%; Marsch: 30%) verdrängt und auf dem Moor durch Wolliges Honiggras (Massenanteil Wolliges Honiggras: 49%). Auf Marsch und Sand war Weidelgras beständiger als Lieschgras, auf dem Moor wurde es ebenso wie Lieschgras von Wolligem Honiggras verdrängt (Massenanteil 26%), wenn auch in einem geringeren Ausmaß. Rohrschwingel hatte im Moor die höchste Konkurrenzkraft, Wolliges Honiggras hatte hier nur einen Massenanteil von 18%. Das Management hatte keinen Effekt auf die Beständigkeit der Gräser.

Während Weidelgras (103 kg TM ha^{-1} Tag^{-1}; Weidesystem) und Lieschgras (87 kg TM ha^{-1} Tag^{-1}; Weidesystem) insbesondere im Frühling hohe Wachstumsraten zeigten, gab es bei Rohrschwingel (90 kg TM ha^{-1} Tag^{-1}; Weidesystem) im Spätsommer eine zweite Phase sehr hoher Wachstumsraten. Auch in dem trockenen Jahr 2015 erbrachte Rohrschwingel (13,8 t TM ha^{-1} Jahr^{-1}) im Gegensatz zu Weidelgras (10,8 t TM ha^{-1} Jahr^{-1}) weiterhin hohe Erträge.

Weidelgras erwies sich auch in diesem Versuch als die Art mit der besten Futterqualität (6,43 MJ NEL kg^{-1} TM, 17,7% XP kg^{-1} TM). Trotz der neuen Züchtungen können mit Rohrschwingel (6,17 MJ NEL kg^{-1} TM; 17,6% XP kg^{-1} TM) nicht die gleichen Qualitäten erreicht werden. Lieschgras hatte einen geringeren Energiegehalt (6,07 MJ NEL kg^{-1} TM) und einen höheren Proteingehalt (18,7% XP kg^{-1} TM) als Weidelgras. Im Moor wurde der hohe Proteingehalt in der Lieschgrasmischung auch durch das proteinreiche Wollige Honiggras verursacht. Auf der Weide wurden die besten Futterqualitäten (6,5 MJ NEL kg^{-1} TM; 19,4 % XP kg^{-1} TM) und die geringsten Futtermengen (11,2 t TM ha^{-1} Jahr^{-1}) erreicht, im Schnittsystem war es umgekehrt (5,9 9MJ NEL kg^{-1} TM; 16,2% XP kg^{-}

^{1} TM; 12,2 t TM ha^{-1} Jahr^{-1}). Die Mähweide liegt in Ertrag (12,0 t TM ha^{-1} Jahr^{-1}) und Qualität (6,19 MJ NEL kg^{-1} TM; 18,4% XP kg^{-1} TM) zwischen der Weide und dem Schnitt-System.

Ebenso wie der Feldversuch ergab auch die Befragung große Unterschiede zwischen Milchproduktionssystemen mit Weidehaltung und Systemen, in denen die Weide keine oder kaum eine Bedeutung hat. Betriebe, auf denen je Kuh mindestens 1.000 m^{2} Weide zur Verfügung stehen und die Weide einen Teil zur Ernährung der Milchkühe beiträgt, erreichen geringere Milchleistungen je Kuh (8.270 kg Milch Kuh^{-1} Jahr^{-1}), hatten weniger Kühe (n=69) und mehr Grünland je Kuh (2.800 m^{2}) als Betriebe mit sehr wenig Weideflächen (109 Kühe pro Betrieb, 9.524 kg Milch Kuh^{-1} Jahr^{-1}) oder ganzjähriger Stallhaltung (138 Kühe pro Betriebe, 9.404 kg Milch Kuh^{-1} Jahr^{-1}). Betriebsleiter von Weidebetrieben stehen Weidehaltung positiver gegenüber als Leiterinnen von Betrieben mit sehr wenig Weidefläche je Kuh. Sie schätzen geringere Futterkosten, weniger Arbeitsaufwand und Vorteile für die Tiergesundheit und Fruchtbarkeit durch die Weidehaltung. Fast 50% der zur Milcherzeugung nötigen Energie stammt hier von Gras, Grassilage und Heu, während es bei Betrieben mit ganzjähriger Stallhaltung nur 23% und bei Betrieben mit wenig Weide 28% sind. Auf den Betrieben mit ganzjähriger Stallhaltung gab es eine große Übereinstimmung mit den negativen Aspekten der Weidehaltung (verringerte Milchleistung, ungeeignet für große Herden, unzureichender Zugang der Herde zu den Weiden).

Wenn auf einem Betrieb weniger als 1.000 m^{2} Weide je Kuh zur Verfügung stehen, dient die Weide nur noch als Auslauf. Die Landwirtinnen und Landwirte von Betrieben mit Auslauf-Weiden gehen davon aus, dass die Weide einen positiven Effekt auf die Gesundheit und Fruchtbarkeit hat. Abgesehen von diesen beiden Faktoren wird die Weide auf Betrieben mit Auslauf-Weiden ähnlich beurteilt wie auf Stallbetrieben.

9 Bewirtschaftung von Grünland – Ausblick

Die Bewirtschaftung von Dauergrünland wird auch weiterhin starken Veränderungen unterworfen sein. Einige sind schon jetzt abzusehen und bieten Landwirtinnen die Möglichkeit, sich darauf vorzubereiten. Durch die Speicherung von Niederschlägen und die Entwicklung von Bewässerungssystemen können die negativen Auswirkungen von häufigeren Dürren abgemildert werden. Einige Standorte werden von dem Klimawandel wahrscheinlich profitieren, während für den Großteil die Bedingungen schwieriger werden. Die Wahl von an die sich wandelnden Bedingungen angepasste Gräser, Schnitthäufigkeiten und ein entsprechendes Wassermanagement sind Möglichkeiten, mit denen die Betriebe reagieren können. Betriebe, die sich in Regionen befinden, in denen auch in Zukunft mit ausreichend Niederschlägen zu rechnen ist beziehungsweise Böden mit einer hohen Wasserspeicherkapazität haben oder Bewässerung nutzen können, werden aufgrund der hohen Futterqualität wahrscheinlich auch weiterhin hauptsächlich Weidelgras einsetzen.

Die Fähigkeit von Rohrschwingel, auch längere Trockenphasen zu überstehen (Norris, 1982; Gilliand et al., 2010; Turner et al., 2012), macht dieses Gras auf trockeneren Standorten zu einer möglichen Alternative zu Weidelgras. Aufgrund der hohen Konkurrenzkraft und der Fähigkeit, sich im Moor gegen Wolliges Honiggras durchzusetzen, wird Rohrschwingel dort in Zukunft wahrscheinlich häufiger angebaut, unter anderen auch um klimaschädliche Neuansaaten (Kayser et al., 2018) zu vermeiden. Die Futtermengen und die insgesamt mit Rohrschwingel erzeugbaren Energie- und Proteinerträge sind trotz der geringeren Futterqualität signifikant höher als bei Weidelgras. Die im Vergleich zu Weidelgras geringere Futterqualtität ist immer noch ausreichend für die Fütterung von Milchkühen (Spiekers, 2004), durch häufige Entblätterung bei Weidenutzung kann die Futterqualität von Rohrschwingel gesteigert werden. Der Qualitätsrückgang beim Futter bei einer klimabedingten Umstellung von Weidelgras auf Rohrschwingel fällt durch den positiven Effekt von Trockenphasen auf die Qualität (Hoffstätter-Müncheberg et al., 2013; Dumont et al., 2014) eventuell etwas geringer aus, als Untersuchungen von Rohrschwingel bei ausreichender Wasserversorgung erwarten lassen.

Beim Anbau von Rohrschwingel und von Weidelgras ist in Zukunft zu beachten, dass bei vermehrten Trockenheiten die Gefahr einer Infektion der Gräser mit Endophyten besteht, welche die Futteraufnahme und die Leistung von Weidetieren hemmen kann (Pedersen et al., 1990). Um die davon ausgehenden Gefahren zu verhindern, können bereits bestehende Tests, die das Vorhandensein von schädlichen Endophyten feststellen, weiter entwickelt werden (Doss et al., 1998), (Hahn et al., 2003).

Eine weitere Möglichkeit auf dem Moor die Notwendigkeit von Neuansaaten hinauszuzögern, ist die gezielte Nutzung des dort wachsenden Wolligen Honiggrases. Die Erträge der sich eingestellten Narbenzusammensetzung aus Lieschgras und Wolligem Hongigras (9,2 t TM ha^{-1}) auf dem Moor waren kaum geringer als die von Weidelgras auf den Moorflächen (10,0 t TM ha^{-1}), die Unterschiede lassen sich nicht signifikant absichern. Der Energiegehalt der Grünlandbestände mit Lieschgras und

Wolligem Honiggras (6,2 MJ NEL kg TM^{-1}) war geringer als bei Weidelgras (6,4 MJ NEL kg TM^{-1}, 19,3% TM), der Proteingehalt (20,4%) war jedoch signifikant erhöht. Da es einen großen Teil der Grasnarben im Moor besetzt, trägt Wolliges Honiggras oft zu einem großen Teil zur Ernährung der Milchkühe bei. Durch gezielte züchterische Bearbeitung und Erforschung der besten Nutzungszeitpunkte könnte Wolliges Honiggras besser an die Bedürfnisse der Betriebe angepasst werden.

Lieschgras eignet sich nur bedingt für den Anbau auf intensiv bewirtschaftetem Grünland in Norddeutschland, da es von konkurrenzstärkeren Arten verdrängt wird. Allerdings eignet es sich als Etablierungspartner für Wiesenrispe. Wiesenrispe hat eine etwas bessere Trockenheitstoleranz als Weidelgras und eine etwas bessere Qualität als Rohrschwingel (Frame, 1991; Whyte et al., 1959; Watson and More, 1962) und bietet sich deshalb für einige Standorte als Kompromiss an.

In trockenen Jahren und bei generell längeren Trockenphasen kann durch die Ernte und Lagerung von Heu anstelle von Grassilage ein weiterer Ausgleich geschaffen werden. Häufigere Trockenheiten vereinfachen die Gewinnung von Heu, welches höhere Energiegehalte hat als Grassilage. Außerdem verursacht der hohe Proteingehalt bei der Heugewinung im Gegensatz zur Grassilage keine Probleme, was auch den Anbau von proteinreichen Gemischen mit Lieschgras und Wolligem Honiggras vereinfacht.

Trotz aller Anpassungsmöglichkeiten geht der Klimawandel letztlich allerdings für den Großteil der Grünlandstandorte mit Einbußen einher. Auch für intensiv bewirtschaftetes Grünland im atlantischen Klima steht zu hoffen, dass eine Reduzierung des Ausstoßes von klimaschädlichen Gasen durchgesetzt wird und gemäß dem Pariser Abkommen der Anstieg der weltweiten Durchschnittstemperatur auf 1,5° C begrenzt werden kann (European Commission, 2019).

Es ist zu beachten, dass auch die intensive Landwirtschaft durch einen hohen Einsatz von Mineraldünger, fossilen Brennstoffen und aus Südamerika importieren Futtermitteln einen wichtigen Anteil an den Treibhausgasemissionen und dem Klimawandel hat. Neben einer Anpassung an die Folgen des Klimawandels ist daher auch eine Umstellung auf eine klimafreundlichere Bewirtschaftungsweise erforderlich. Für die Milchviehbetriebe bietet sich hierbei eine grünlandbasierte Milchproduktion mit wenig oder ohne den Einsatz von Kraftfutter und importierten Futtermitteln an.

Falls durch den Klimawandel viele heute noch für den Anbau von Lebensmitteln genutzte Flächen unnutzbar werden, ist es in letzter Konsequenz auch möglich, dass ein großer Anteil der jetzt als Dauergrünland bezeichneten Flächen direkt für den Anbau von Lebensmitteln genutzt wird. Marginale Standorte, die aufgrund zu geringer Gewinne kaum bewirtschaftet werden, könnten in Zukunft wieder an Bedeutung für die Erzeugung von Milch und Fleisch gewinnen. Der Begriff Dauergrünland trifft folglich für viele Standorte nicht zu, Aussehen und Funktion von Dauergrünland sind weniger beständig, als der Begriff „Dauer“ impliziert.

10 Summary

In regions with a moderate climate, longer and more frequent droughts are to be expected as a result of climate change, which will make it more difficult to grow perennial ryegrass (*Lolium perenne*). In this thesis it was tested whether tall fescue (*Festuca arundinacea*) and timothy (*Phleum pratense*) are suitable alternatives to perennial ryegrass for intensively managed grassland. Yields, qualities and persistence of the three species were investigated over a period of three years (2014–2016) on sandy soil, peat soil and clay. The investigated species were the main species in a mixture with white clover and smooth meadow grass. Three different cutting frequencies were used, reflecting the use of grassland in Northern Germany: simulated grazing (7 cuts), mixed system (6 cuts) and cutting-only system (4 cuts).

Parallel to the field trial, the differences and similarities of dairy farms with and without grazing were investigated with a survey. It was surveyed how the advantages and disadvantages of grazing and all-year-housing are evaluated by farmers and whether the farm structures of the farm types differ.

Tall fescue had a significantly higher resistance (92% mass proportion after three years) and higher yields (13.8 t DM ha^{-1}) than perennial ryegrass (mass proportion after three years: 82%; 11.3 t DM ha^{-1}) and timothy (mass proportion after three years: 52%; 10.4 t DM ha^{-1}) on all soils and in all managements. Timothy was displaced on sand and clay by the mixture partner smooth meadow grass (*Poa pratensis*, on sand: 18%; clay: 30%) and on the peat soil by Yorkshire fog (*Holcus lanatus*, mass proportion: 49%). On clay and sand, perennial ryegrass was more persistent than timothy grass, on peat it was displaced by Yorkshire fog (mass percentage 26%), too, although to a lesser extent. Tall fescue had the highest persistence on peat soil, the mass proportion of Yorkshire fog was only 18%. The management had no effect on the persistence of the grasses.

While perennial ryegrass (103 kg DM ha^{-1} day^{-1}; pasture system) and timothy (87 kg DM ha^{-1} day^{-1}; pasture system) showed high growth rates especially in spring, tall fescue (on average 90 kg DM ha^{-1} day^{-1}; pasture system) showed a second phase of very high growth rates in late summer. Even in the dry year 2015, tall fescue (13.8 t DM ha^{-1} year^{-1}) had higher yields than perennial ryegrass (10.8 t DM ha^{-1} year^{-1}).

Perennial ryegrass had the best forage quality (6.43 MJ net energy kg^{-1} DM, 17.7% crude protein kg^{-1} DM). In spite of the new breedings, it is not possible to achieve the same qualities with tall fescue (6.17 MJ net energy kg^{-1} DM; 17.6% crude protein kg^{-1} DM). Timothy had a lower energy content (6.07 MJ net energy kg^{-1} DM) and a higher protein content (18.7% crude protein kg^{-1} DM) than perennial ryegrass. On peat soil, the high protein content of Timothy grass was also caused by the protein-rich Yorkshire fog. On the pasture the best forage qualities (6.5 MJ net energy kg^{-1} DM; 19.4 % crude protein kg^{-1} DM) and the lowest forage yields (11.2 t DM ha^{-1} year^{-1}) were achieved in the cutting system it was the other way round (5.9 MJ net energy kg^{-1} DM; 16.2% crude protein kg^{-1} DM; 12.2 t DM ha^{-1} year^{-1}). In terms of yield (12.0 t DM ha^{-1} year^{-1}) and quality (6.19 MJ net energy kg^{-1}

DM; 18.4 % crude protein kg^{-1} DM), the mixed system is between the simulated grazing and the cutting-only system.

Like the field trial, the survey revealed large differences between milk production systems with grazing and systems in which pasture has little or no importance. Farms with at least 1,000 m^2 of pasture per cow, where pasture contributes to the nutrition of the dairy cows have lower milk yields per cow (8,270 kg milk cow^{-1} $year^{-1}$), fewer cows (n=69) and more grassland per cow (2,800 m^2) than farms with little pasture (109 cows per farm, 9,524 kg milk cow^{-1} $year^{-1}$) or all-year-housing farms (138 cows per farm, 9,404 kg milk cow^{-1} $year^{-1}$). Managers of grazing farms are more positive about grazing than managers of farms with little or no pasture for cows. They appreciate lower fodder costs, less workload and the positive effects of grazing on animal health and fertility. On grazing farms, almost 50 % of the energy needed for the milk production comes from grass, grass silage and hay, compared to 23 % on farms with all-year-housing and 28% on farms with little pasture. Managers of all-year-housing farms agree with the negative aspects of grazing (reduced milk yield, unsuitable for large herds, insufficient access of the herd to pasture).

If a farm has less than 1,000 m^2 of pasture per cow, grazing no longer contributes to the nutrition of the cows. Farmers from these farms think, that grazing has a positive effect on health and fertility. Apart from these two factors, there opinion equals the opinions from managers from all-year-housing farms.

Despite the different conditions, all farms are subject to the same requirements for the end product milk, receive mostly the same prices, compete for land in the same markets and pay the same prices for inputs. They are exposed to the same climatic variations and have similar soils. The consequences of climate change will affect all farms equally and all farms will have to adapt. The conditions for perennial ryegrass are somewhat more favourable on pasture land than on grassland, which is only used for grass-silage and hay. As a significant part of the land of grazing farms is used only for winter fodder production and is not grazed, all types of farms face the same difficulties in growing perennial ryegrass and are likely to use other grass species than perennial ryegrass in the future.

11 Résumé

Pour les années futures et dans les régions au climat tempéré, des sécheresses plus longues et plus fréquentes sont à prévoir en raison du changement climatique, ce qui rend la culture du ray-grass anglais (*Lolium perenne*) plus difficile. Au cours de ce travail, il a été testé si fétuque élevée (*Festuca arundinacea)* et fléole des prés (*Phleum pratense*) constituent des alternatives au ray-rass anglais pour les prairies gérées de manière intensive. Les rendements, les qualités et la persistance des trois espèces ont été examinés sur une période de trois ans (2014–2016) sur des sols sableux, argileux et marécageux.

Les espèces examinées étaient les principales espèces dans un mélange de semences avec trèfle blanc (Trifolium repens) et pâturin des prés (*Poa pratensis*). Trois fréquences de coupe différentes ont été utilisées, qui reflètent les types dutilisation des prairies et pâturages dans le nord de lAllemagne: pâturage (7 coupes), prairie + pâturage (6 coupes) et prairie (4 coupes).

Parallèlement à lessai sur le terrain, les différences et similitudes entre les expl oitations laitières avec et sans pâturage ont été examinées au moyen dune enquête.

L'idée d'une telle enquête était d'une part, d'identifier comment les agriculteurs évaluent les avantages et inconvénients liés au pâturage par rapport aux avantages et inconvénients du maintien à l'étable et dautre part, dévaluer si les structures des exploitations étudiées diffèrent selon le type délevage choisi par les agriculteurs.

Le fétuque élevée avait une persistance significativement plus élevée (proportion massique de 92% après trois ans) et des rendements plus élevés (13,8 t MS ha^{-1} an^{-1}) que ray-grass anglais (82% proportion massique après trois ans, 11,3 t MS ha^{-1} an^{-1}) et fléole des prés (52% de la fraction massique après trois ans; 10,4 t MS ha^{-1} an^{-1}). Fléole des prés a été déplacée sur le sol sableux et sur le sol argileux par pâturin des prés, (proportion massique de pâturin des prés sur sol sableux: 18%; au marais: 30%) et sur le sol marécageux en association avec houlque laineuse (*Holcus lanatus,* proportion massique: 49%). Sur les sols argileux et sableux, ray-grass anglais était plus persistente que fléole des prés. Par contre, sur les sols marécageux, ray-grass anglais était, comme fléole des prés, remplacée par houlque laineuse (proportion massique de 26%), quoique dans une moindre mesure. Fétuque élevée avait la plus grande persistence sur le sol marécageux, houlque laineuse navait quune proportion de masse de 18 % dans ce cas de figure.

Alors que ray-grass anglais (103 kg MS jour^{-1} ha^{-1}, pâturage) et fléole des prés (87 kg MS jour^{-1} ha^{-1}, pâturage) ont montré des taux de croissance élevés, surtout au printemps, fétuque élevée avait à la fin de lété (90 kg MS jour^{-1} ha^{-1}; système de pâturage) une deuxième phase de taux de croissance très élevés. Au cours de lannée sèche 2015, fétuque élevée (13,8 t MS ha^{-1} an^{-1}) a continué à produire des rendements élevés contrairement au ray-grass anglais (10,8 t MS ha^{-1} an^{-1}).

Ray-grass anglais était lespèce avec la meilleure qualité de fourrage (6,43 M J net energie kg^{-1} MS; 17,7% protéine brute kg^{-1} MS). Malgré les nouveaux cultivars, fétuque élevée (6,17 MJ net energie kg^{-1} MS; 17,6% protéine brute kg^{-1} MS) ne peut pas atteindre les mêmes qualités que ray-grass anglais. Fléole des prés avait une teneur énergétique inférieure (6,07 MJ net energie kg^{-1} MS) et une teneur en protéines plus élevée (18,7% protéine brute kg^{-1} MS) que ray-grass anglais. Sur le sol marécageux, la teneur élevée en protéines de fléole des prés était également causée par houlque laineuse qui est riche en protéines. La gestion du pâturage navait aucun effet sur la persistance des graminées. Les trois espèces de graminées ont montré les meilleures qualités de fourrage (6,5 MJ net énergie kg^{-1} MS; 19,4% protéine brute kg^{-1} MS) et les rendements les plus faibles (11.2 t MS ha^{-1} an^{-1}) dans le système conduit en pâturage. Dans le système de prairie pour récolte de fourrages, les qualités de fourrage étaient les plus faibles (5,9 MJ net énergie kg^{-1} MS; 16,2% protéine brute kg^{-1} MS), et les rendements étaient les plus hauts (12.2 t MS ha^{-1} an^{-1}). Dans le système alternant récolte de fourrages et pâturage, le rendement (12.0 t MS ha^{-1} an^{-1}) et la qualité de fourrage (6,19 MJ NEL kg^{-1} MS; 18,4% protéine brute kg^{-1} MS) étaient intermédiaires, c'est-à-dire compris entre les résultats observés dans le cadre des deux autres systèmes étudiés.

Tout comme lessai sur le terrain, lenquête a également révélé des différences majeures entre les modes de gestion de pâturage. En effet, les exploitations dotées d'au moins 1000 m^2 de pâturage par vache et où le pâturage contribue à l'alimentation des vaches laitières ont des rendements laitiers plus faibles par vache (8.270 kg de lait par vache par an), moins de vaches (n = 69) et plus de surfaces de prairies par vache (2.800 m^2).

L'enquête a également mis en évidence que les fermes orientées vers le pâturage des animaux sont plus convaincus des avantages de ce type de gestion de pâturage que les agriculteurs des fermes où les vaches ont peu ou pas daccès aux pâturages.

Les éleveurs pratiquant la mise en pâture apprécient des coûts d'alimentation inférieurs, moins de main- dœuvre et des avantages pour la santé animale et la fertilité grâce au pâturage. Dans les fermes avec pâturage, près de 50% de l'énergie nécessaire à la production laitière provient de l'herbe, de lensilage dherbe et du foin. Dans les fermes sans pâturage, seulement 23% de l 'énergie nécessaire à la production laitière provient de lherbe. Enfin, dans les fermes avec peu de pâturage, 28% de l'énergie nécessaire à la production laitière provient de lherbe.

Les fermes sans pâturage ont en moyenne 138 vaches par ferme et 9.404 kg de lait par vache par an. Les agriculteurs de ces fermes mettent généralement en avant les aspects négatifs de la gestion des pâturages (rendement laitier réduit, inadapté aux grands troupeaux, accès insuffisant du troupeau aux pâturages). Sil y a moins de 1.000 m^2 de pâturage disponible par vache dans une ferme, le pâturage ne contribue plus à l´alimentation des vaches. Les agriculteurs de fermes avec très peu de pâturages (109 vaches par ferme, 9.524 kg de lait par vache par an) supposent que les pâturages ont un effet positif sur la santé et la fertilité. En dehors de ces deux facteurs, ils ne voient pas dautres avantages au pâturage.

Bien qu'œuvrant dans des conditions différentes, toutes les exploitations laitières sont soumises aux mêmes exigences pour le lait, leur produit final. Elles reçoivent souvent les mêmes prix, se font concurrence pour les terres sur les mêmes marchés et ont des coûts de production comparables.

Elles sont exposées aux mêmes fluctuations climatiques et ont des sols similaires. Les conséquences du changement climatique affectent toutes les entreprises de la même manière et toutes les entreprises devront sy adapter. Les conditions pour ray-grass anglais sont un peu plus favorables sur les pâturages que sur les prairies. Etant donné quune partie considérable de terrain des fermes de pâturage est uniquement utilisée pour produire du fourrage dhiver et nest pas pâturée, tous les types dexploitations sont confrontés aux mêmes difficultés pour la culture du ray-grass anglais et sont susceptibles dutiliser à lavenir des herbes autres que le ray-grass.

12 Literaturverzeichnis

Die hier aufgeführten Quellen beziehen sich auf die Abschnitte 1–2 und 8–10. Für die Abschnitte 3–7 befindet sich die Auflistung der Quellen am Ende des jeweiligen Kapitels.

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14 Erklärungen

1. Hiermit erkläre ich, dass diese Arbeit weder in gleicher noch in ähnlicher Form bereits anderen Prüfungsbehörden vorgelegen hat. Weiter erkläre ich, dass ich mich an keiner anderen Hochschule um einen Doktorgrad beworben habe.

Göttingen, den ...17.12.2020......................

....
(Unterschrift)

2. Hiermit erkläre ich eidesstattlich, dass diese Dissertation selbständig und ohne unerlaubte Hilfe angefertigt wurde.

Göttingen, den....17.12.2020................

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(Unterschrift)