Is the rye-grass always greener? An evidence review of the nutritional, medicinal and production value of species-rich grassland

Summary

- Species-rich grasslands do not have the same levels of energy and protein as agriculturally improved grasslands, but the herbal component has higher quantities of minerals. Herbs appear to have higher levels of minerals than grass and legume sward components, and legumes have higher protein than herbs and grasses. The use of species-rich grasslands within an agricultural system may reduce the need for mineral licks to maintain healthy livestock.

- Some plant species contain compounds that help prevent or reduce illness. For example, tannins present in bird's-foot-trefoil and sainfoin can reduce intestinal parasites, and nematophagous fungi can reduce faecal egg counts.

- There is some evidence to suggest that livestock grazing herbal leys put on more weight, produce more milk and maintain health, compared with livestock grazing agriculturally improved pasture.

- Consumer panels have found that the produce from livestock that have grazed species-rich grassland is considered to be of better taste and smell.

- In general, there has been little research on the nutritional and medicinal qualities and production value of species-rich grassland. Some research has been undertaken on herbal leys, but the results may not be transferrable onto species-rich grassland. Further zoopharmacognosy studies would provide an insight into whether species-rich grassland can provide antidotes to ailments, and whether individual animals self-medicate.

- In the UK, there has been almost no research on the cultural significance of species rich grasslands for medicinal use. The application of species-rich grassland within this context is declining as the older farming generation is passing. Further studies on ethnoveterinary practices need to be undertaken immediately before this knowledge is lost.

Introduction

Species-rich grasslands have declined by 97% during the later part of the 20th century, often replaced with agriculturally productive commercial grassland (The Wildlife Trusts and Plantlife 2002; The Grasslands Trust 2011). They provide a home for many important and rare species, with 206 priority species (18% of priority species) in lowland grassland and 41 priority species (3.5% of priority species) in upland unimproved grassland (Bullock et al. 2011). The loss of species-rich grassland is very much a consequence of changing farming systems. Older farming generations use descriptive terms for species-rich grassland such as 'well ground' in West Dorset, 'cae ysbyty' (field hospital) in Wales, and 'the shore land' used to describe the partial fields beyond the grass leys along the coast in Scotland. These phrases refer to the cultural use of species-rich grasslands for unwell livestock through the process of self-medication. Generally, expressions used to indicate the medicinal use of species-rich grassland are not used by the younger farming generation, and the practice and tradition of using species-rich grasslands in this manner is being lost.

There are two primary sources of information on plants for use as medicinal remedies:

- ethnoveterinary and traditional medicine, often related through verbal accounts, and
- zoopharmacognosy, which is the study of self-treatment.

The term 'self-medicate' is a common adjective for zoopharmacognosy, but can be difficult to apply to livestock. It suggests that an animal with an ailment can recognise plants, either through learned or innate behaviour such as taste, to resolve the illness. Zoopharmacognosy studies suggest that animals specifically choose to eat certain foods with certain compounds and avoid foods deficient with those compounds when trying to resolve an ailment (Engle 2006). For example, when horses are given free-choice, they may eat two to three times the normal intake for a few months until they have balanced their minerals and then taper off to a maintenance level (Harman 2006). Self-medication is not an alternative to veterinary medicine, but could be used in conjunction to reduce the costs of treatment (Engle 2006). It would also support the maintenance of species-rich grassland for livestock farmers to facilitate the health of their animals through dietary means. However, the process of self-medication would also need to be married with the nutritional requirements of livestock, i.e. whether species-rich grasslands can provide a well-rounded diet containing enough energy and protein.

The free choice of food sources is considered important to an animal's ability to self-medicate, however little is known about grazer selectivity on species-rich grassland (Grayson 2017). The addition of minerals, natural remedies and herbs to feed is not considered optimal (Engle 2006; Harman 2006) as this does not allow an animal to eat the quantity of the compound they require and possibly imposes an artificial level. Plants cannot be assigned to the terms 'toxic' or 'medicinal' as they could be both depending on the requirements of an animal. Other materials consumed in species-rich grassland may also be beneficial in small quantities, including clay (which has been observed to ease digestion), charcoal and ash, fibrous leaves and woody material (which has been observed to scour out intestinal parasites) (Engle 2006).

This evidence gathering paper summarises information from reports, journal papers and anecdotal accounts about the nutritional and medicinal/pharmaceutical properties of species-rich grassland. It also asks whether there is a benefit to human health. Three questions have been outlined:

1. Do species-rich grasslands have a commercial nutritional value for livestock in comparison with agriculturally improved grassland?
2. Do species-rich grasslands have a role in holistic medication? If so, are there any particular species that provide antidotes to ailments?
3. Are there any nutritional benefits to humans from eating livestock reared on species-rich grasslands?

The nutritional requirements of livestock

There are three nutritional elements that livestock require:

- **Energy** – usually expressed as digestible energy (DE) or metabolisable energy (ME). Metabolisable energy consists of nutrients absorbed by the gut (which is digestible energy) that are not excreted. It is measured in megajoules (MJ) per kg of dry matter (DM) of the feed (table 1).
- **Protein** - often expressed as crude protein (CP). It is measured as a percentage of the dry matter (% DM) of the feed and is a simple measure of nitrogen content of the food multiplied by 6.25, as

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it is assumed that nitrogen content of protein is 16%. In feed, it may also be expressed as grams per kilogram of dry matter (g/kg DM) (table 1).

- **Minerals**: seven major minerals (**calcium**, **phosphorus**, **potassium**, **sodium**, chlorine, magnesium and sulphur) and a number of trace elements. Minerals in bold have the highest concentration in an animal's tissues. (Scottish Natural Heritage 2016; Professional Nutrient Management Group 2015; Fuller 2004).

There are physical and biochemical differences between plant species, between different parts of the same plant and between different life stages of the same plant. These are referred to as:

- primary compounds - energy, protein, minerals and vitamins;
- secondary compounds – tannins, alkaloids, terpenes and polyphenols.

Minerals, both major and trace-elements, are not required in the same quantity, but animals can become deficient. Behaviour displayed by animals deficient in minerals is the consumption of soil and faecal pellets (i.e. rodent middens), licking urine patches and eating dead animals. Animals that are not deficient may sniff and lick these items but will not consume them, and will avoid consuming forage that will cause an excess of nutrients (Provenza, Meuret and Gregorini 2015). There are seven macro-nutrients and seven trace-elements that are known to be essential (tables 2 and 3), and boron is a recent addition as it is essential in the formation of bone (pers. comm. Bill Grayson).

Table 1: Average metabolisable energy (ME) and crude protein (CP) required by different types of livestock reared for meat production (Professional Nutrient Management Group 2015; Scottish Natural Heritage 2016).

Type of livestock	Weight/size of animal	Daily energy requirements (MJ/ME/day)	Additional energy requirements for growth (MJ/ME/day)	Crude protein (kg/CP)	Crude Protein (% DM)
Growing beef[1]	per 100 kg live weight	11-12	+47 day for every 1kg of live weight gain	450 CP per kg of live weight gain	9 (dry) -11 (lactating) Growing beef 15-16 Finishing beef 12-14
Dairy cow		Lactating 12 Dry 8,5			Lactating 17-18 Dry 12-14
Growing lambs[2]	10	4.2	+11 per day for growing lambs	67 per day	16
	15	5.7		69 per day	
	20	7.1		70 per day	
	25	8.5		72 per day	
	35	11.7		89 per day	
	45	15.1		107 per day	
Ewe (maintenance)		8			9
Ewe (6 weeks +/- lambing)		10			16

[1] Finishing beef cattle depends on the gender of the individual animal and the breed of the cattle for the frame size. Generally, the finishing live weight for small (330-500 kg), medium (501-590 kg) and large (over 590 kg) heifers is smaller than small (370-550 kg), medium (551-650 kg) and large (over 550 kg) steers (Hybu Cig Cymru 2017).
[2] Daily nutrient requirements of lambs growing at a rate of 150 g per day.

Soils may have a great influence on the availability of nutrients in fodder. Hybu Cig Cymru (2011) report that poorly drained clay soils tend to have more trace-elements than free-draining and sandier soils. Acid soils tend to have fewer trace-elements; and management of these soils, for example through excessive liming, will reduce herbage cobalt levels but increase molybdenum levels, with the knock-on effect of reducing the availability of copper. In general, forbs have higher minerals than grasses. Re-seeding with a rye-grass dominated mixture can lead to a deficiency of trace-elements as does rapid lush grass growth, whilst provision of a more diverse sward can lead to higher trace-element levels. However, Tallowin and Jefferson (1999) found that hay from species-rich grasslands can still be deficient in minerals such as phosphorous and magnesium.

Table 2: Macro-element requirements for different types of livestock (Suttle 2010).

Mineral	Dietary requirements of pregnant cattle (g/kg of DM)	Dietary requirements of lactating cattle (g/kg of DM)	Dietary requirements of growing calves (g/kg of DM)			Dietary requirements of pregnant sheep carrying twins (g/kg of DM)	Dietary requirements of lactating ewe nursing twins (g/kg of DM)	Dietary requirements of growing sheep (g/kg of DM)	
	600 kg live weight	600 kg live weight	50-100 kg live weight	200-300 kg live weight	400-600 kg live weight	75 kg live weight	75kg live weight	20 kg live weight	40 kg live weight
Calcium (Ca)	2.1 - 3.5	2.9 - 4.8	5.2 - 10.8	3.0 - 5.5	2.6 - 4.3	1.4 - 3.9	2.8 - 3.8	3.7 - 7.0	2.4 - 4.0
Magnesium (Mg)	1.4 - 2.1	1.6 - 2.4	1.1 - 1.5	1.1 - 1.6	1.1 - 1.7	0.45 - 1.1	0.65 - 1.3	0.5 - 0.9	0.5 - 0.9
Phosphorus (P)	1.0 - 2.2	2.3 - 2.6	3.3 - 4.4	1.7 - 2.7	1.0 - 2.3	1.1 - 2.1	2.8	2.4 - 4.1	1.9 - 2.5
Potassium (K)	5.8	6.4 - 7.4	8.4	4.7	6.4 - 7.4				3.0
Sodium (Na)	0.8 - 0.9	1.1 - 1.2		0.65 - 0.7	0.65 - 0.75	0.7 - 1.0	0.76 - 0.83	0.6 - 0.7	0.6 - 0.7
Sulphur (S)	0.8 - 1.5	0.8 - 1.5	1.6 - 1.8	1.0	0.8 - 0.9	1.2 - 1.3	1.8 - 2.1	1.3 - 1.6	0.85 – 1.0
Chlorine (Cl)									

Table 3: The trace-element requirements for different types of livestock (ppm of DM Wookey 1987 and mg/kg of DM Hybu Cig Cymru 2011).

Mineral	Typical levels in pasture (mg/kg DM)	Recommended levels in total diet of pregnant / lactating cattle (mg/kg DM)	Trace-element requirements of pregnant / lactating cattle (ppm of DM)	Recommended levels in total diet of dry cattle (mg/kg DM)	Trace-element requirements of dry cattle (ppm of DM)	Recommended levels in total diet of sheep (mg/kg DM)	Trace-element requirements of sheep (ppm of DM)
Iron (Fe)			50		50		30
Copper[3] (Cu)	2 - 15	8	10	8	10	5	10
Manganese (Mn)	25 - 250	25	20	25	40	25	40
Cobalt (Co)	0.05 - 0.25	0.08	0.1	0.08	0.1	0.11	0.01
Iodine (I)	0.1 - 0.5	0.5	0.5	0.2	0.5		0.08
Zinc (Zn)	20 - 60	25	30	25	30	25	50
Selenium (Se)	0.02 - 0.15	0.05	0.1	0.05	0.1	0.05	0.1

[3] Recommendation of copper depends on levels of molybdenum, sulphur and iron in the pasture which can restrict available copper.

Yield and nutritional value of grassland

The yield of a pasture is measured by the amount of dry matter (DM) produced per annum (table 4). On average, 5.5-5.6 kg/DM of feed is required per day to produce a kg of beef, and the amount of dry matter increases for finishing systems or where dairy cows are being reared for meat to 8-12 kg/DM of feed per day (Professional Nutrient Management Group 2015).The amount of dry matter in silage is very variable, and can be anywhere between 15-35% of fresh weight as the fodder is stored as fermenting wrapped bales or in clamps. The amount of dry matter in hay is much higher, 90-95% of fresh weight, as it is cut later and dried prior to storage (Newton 1993). Thus, hay is much closer to the dry matter intake than silage.

Table 4: Typical figures for the forage quality of different types of grassland (Scottish Natural Heritage 2016; Tallowin & Jefferson 1999; Fisher 2013).

Grassland type	Metabolisable energy (ME) MJ/kg	Protein (CP) % DM	Soil phosphorus g/kg
Improved ryegrass pasture (good)	12	22	4
Improved ryegrass pasture (average)	10.5	18	3
Purple moor grass and rush pasture	6.5 - 8	8 - 12	0.7 - 1.0
Unimproved lowland Meadow	8 - 10	8 - 12	1.0 - 1.5

Digestibility is also a factor in animal nutrition; the higher the digestibility of fodder the greater the consumption by the animal, as the rumen will be able to process the food for absorption in the gut rather than excrete the energy. Metabolisable energy (ME) is another way of describing an animal's consumption; the greater the ME, the greater the intake of forage. Generally, young leaves are the most digestible part of a plant whilst stems are the least digestible, and the digestibility of plants declines as they mature (Crofts and Jefferson 1999). There is a trade-off between digestibility and forage bulk which increases later in the season towards flowering and harvest. The shape of the jaw of sheep mean that they are able to pick-out the most digestible parts of a plant, while the tearing action of cattle mean that they eat a much broader variety of plant parts (Crofts and Jefferson 1999, Rook et al. 2004; Magnificent Meadows 2015).

Tallowin (1997) and Tallowin and Jefferson (1999) state that species-rich grasslands have between 20-80% lower yield compared with agriculturally improved grassland, and the UK National Ecosystem Assessment reports that hay from species-rich grassland is between 2-8 tonnes/hectare, which is less than 30% of the dry matter that can be gathered from silage taken from agriculturally improved grasslands (Bullock et al. 2011). The nutritional value varies between 10-40% below agriculturally improved and intensively managed grassland, depending on the type of species-rich grassland. The result is a lower stocking density on species-rich grassland, with some agriculturally improved grassland with over three times the stocking density (Bullock et al. 2011). The species-rich grasslands with the lowest nutritional values fall within purple moor-grass and rush pasture communities (NVC Communities M22 to M26; Rodwell 1991) where the fibrous material can be greater than in other grasslands, prolonging digestion. Digestibility of hay from species-rich grasslands is about 20% lower than from agriculturally improved grasslands (Bullock et al. 2011). Some lowland and upland meadows (NVC communities MG3, MG5 and MG8; Rodwell 1992) may have energy levels close to those of average improved pasture, but with lower phosphorus and magnesium levels making the forage sub-optimal for maintaining livestock growth and body condition (Tallowin and Jefferson 1999; Bullock et al. 2011). As these species-rich grasslands occur on soils with low levels of phosphorous, this assessment is unsurprising. In calcareous grasslands, a very high ratio of calcium to phosphate may be detrimental to metabolism and bone development. Breed of livestock could be important, and a research study found that Welsh black cattle gained more live weight grazing purple moor-grass and rush pasture compared with a commercial breed (Wright et al. 2000).

Species-rich grassland in the spring and early summer, when they are most palatable, can provide the nutritional requirements for dry cows and ewes, but may not be good enough for finishing beef or lactating animals. As the quality of the forage declines into the autumn, with the plant matter becoming more fibrous and difficult to digest, even dry animals may struggle to meet their nutritional needs (Scottish Natural Heritage 2016). However, this does depend on the breed of livestock, and it may be that traditional breeds fare better than quicker-growing commercial breeds. Wallis de Vries and Schippers (1994) found that cattle selectively foraged in a riverine environment, spending more time consuming forage in this macro-habitat compared with a sand-dune environment. They theorised that the animals were optimising their intake of organic matter (energy) along with macro-nutrients, such as sodium and phosphorous, to balance nutrition and as a result spent more time than expected within one habitat.

A research project undertaken on cattle breed (traditional 'v' commercial) and experience during rearing (extensively grazed unimproved grassland 'v' intensively grazed agriculturally improved grassland) on foraging behaviour aimed to find out how nature and nurture might affect the structure and biodiversity of unimproved grassland (IGER 2008). During the first year following birth, the suckler herds were isolated within their treatment groups, producing four sets of yearlings that were then grazed on purple moor-grass and rush pasture for their second year. The project monitored three groups of two-year old cattle over the course of the research. Foraging behaviour, diet selection and growth of the animals were assessed, and the study found:

- time spent grazing was unaffected by breed or experience during rearing;
- traditional cattle had a higher bite and chew rate than the commercial cattle, and the extensively grazed cattle on unimproved grassland had a higher bite and chew rate than the intensively reared cattle on agriculturally improved grassland. The higher bite and chew rate suggests that the cattle were taking less time selecting and processing forage;
- there was no difference between breed and rearing experience on rumination behaviour, indicating that there were no physical differences in the ingested forage. The chemical composition of the forage was also similar between the four groups of yearlings.
- all two-year old cattle had low growth rates irrespective of breed or rearing experience, which was suspected to be caused by the low digestibility of purple moor-grass *Molinia coerulea*. However, cattle raised on agriculturally improved grassland grew more slowly than cattle that had experienced grazing unimproved grassland as calves. Bite depth was theorised as being the major factor, with extensively reared cattle created a more uniform sward eating only the upper horizon of growth;
- cover of individual plant species or desirable and undesirable components of the sward (i.e. positive and negative indicator species) were not found to be associated with breed or rearing experience.

In conclusion, there was no effect of breed or rearing experience on the grazing behaviour of cattle managed extensively on unimproved grassland which would lead to a change in the botanical composition. However, there may be some degree of experience required for cattle grazing unimproved grasslands to optimise intake. This is further explored in Rook et al. (2004). They summarise evidence of how experience, particularly of young livestock, affects their intake of fodder, with animals lacking in experience of complex environments grazing up to 20% more but taking in up to 40% less food than individuals experienced in this environment. Furthermore, the diet of young animals can lead to preferences for up to two years following this experience. Crofts and Jefferson (1999) review differences between breeds of livestock and their suitability for grazing unimproved grasslands. Thus far, there has been little research into the behaviour of grazing animals relating to breed or adolescent experience, and even less research trying to separate these factors.

Humphries (2015) summarises some results of research undertaken by the Hill Farming Research Organisation into grazing preferences by sheep and cattle. Sheep consumed forage with more live material than dead litter compared with cattle on bent-fescue *Agrostis-Festuca* and mat-grass *Nardus* grasslands. Within mat-grass communities, cattle and sheep both preferred grazing fescues and wavy hair-grass *Deschampsia flexuosa* between tussocks of mat-grass, but as the season progressed and these grasses declined in palatability, cattle started grazing mat-grass whilst sheep did not. On purple moor-grass *Molinia* grasslands the grazing of live fodder and dead litter was comparable between sheep and cattle in spring and summer, but in the autumn sheep grazed other grass species whilst cattle grazed purple moor-grass. This research demonstrates grazing patterns by different types of livestock and change in fodder consumed over the seasons.

Herefordshire Wildlife Trust (2016) analysed hay samples from MG5 lowland meadows to determine whether their nature reserves produced hay and haylage of suitable quality for their tenants. The ME of freshly cut hay varied between 7.2 and 8.7 (table 5). The highest and lowest values were from meadows adjacent to one another at The Parks Nature Reserve. Some of these energy rates fall just below the expected norm for lowland meadows, but this variation could be related to the hay making process.

The relationship between soil acidity and vegetation community is clearly summarised within the National Vegetation Classification system, and Tallowin & Jefferson (1999) noting that the rush pastures of wet acid soils usually have lower ME than lowland meadows. Humphries (2015) states that soil acidity is a critical limiting factor on pasture production and a major factor in soil nutrient cycling. Soil acidity may play a factor in the quality of fodder. In general across the UK, the pH of soils is falling which is influenced by factors such as atmospheric nitrogen deposition and fertiliser inputs (Plantlife and Plant Link 2017). The expected result would be deterioration in the quality of the fodder over the long-term as the soil becomes more acidic. For example, the quality of the forage is lower on more acidic soils on hill farms compared with less acidic in-bye land that may have been agriculturally improved (Humphries 2015). However, the small differences within a vegetation community observed at Herefordshire Wildlife Trust's lowland meadows do not appear to affect the quality of the forage. The hay and haylage samples show that the ME of MG5c meadows (which is the heath grass *Danthonia decumbens* sub-community) is slightly higher than MG5a meadows (the typical meadow vetchling *Lathyrus pratensis* sub-community). The MG5c soils are acidic old red sandstone soils with clay and outcrops of cornstones, leading to localised neutral and limey patches in some grasslands (pers. comm. Sue Holland, Reserves Officer). However if soils become more acidic and the community of plants shifts to a more acid-tolerant sward, the quality of the forage could decrease. Herefordshire Wildlife Trust also observed that the quality of the feed did not appear to degrade over the winter period (table 6), although the samples were not taken on a strict timeline so cannot be used to rigorously determine the potential degradation of forage. The differences between the two types of feed, hay and haylage, may be due to a number of factors, such as the species present within the meadows, timing of the cutting, fermentation of the wrapped haylage compared to the unwrapped hay and storage conditions. Further testing of forage could be undertaken to determine whether the nutrition of forage differs between different types of feed (i.e. hay or haylage), with location across the country considering soil pH and type of substrate, over the growing season and whether there is any degradation over time of storage.

Table 5: The amount of metabolisable energy and crude protein available in hay samples taken from Herefordshire Wildlife Trust Nature Reserves and analysed within five months of hay cutting (Herefordshire Wildlife Trust 2016).

Nature reserve	Soil pH (un-bold historical sample. 2016 sample in bold)	Type of grassland	Hay or haylage	Cutting date	Date of analysis	DM g/kg	ME MJ/kg	DE MJ/kg	CP g/kg
Cadbury Leat Hay	5.1 to **4.8**	MG5c	Hay	July 2016	Sept 2016	914	7.7	9.1	112
Cadbury Main	5.6 to **5.0**	MG5a	Hay	July 2016	Sept 2016	905	7.6	9.3	117
Cethins	5.5 to 5.3 to **5.1**	MG5c	Hay	July 2016	Sept 2016	909	7.7	8.9	112
Crow Wood Meadow	**5.5**	MG5a	Hay	July 2016	Oct 2016	937	7.5	9.0	105
Harisses		MG5c	Hay	July 2016	Sept 2016	916	7.7	9.0	117
The Parks 7 Acre	**5.3**	MG5	Hay	July 2016	Oct 2016	919	7.2	8.9	106
The Parks Home Field		MG5	Hay	July 2016	Dec 2016	922	8.7	9.2	133

Table 6: The amount of metabolisable energy and crude protein available in hay samples taken from Herefordshire Wildlife Trust Nature Reserves and analysed after a winter of storage (Herefordshire Wildlife Trust 2016).

Nature reserve	Soil pH (un-bold historical sample. 2016 sample in bold)	Type of grassland	Hay or haylage	Cutting date	Date of analysis	DM g/kg	ME MJ/kg	DE MJ/kg	CP % (g/kg)
Crow Wood Meadow	6.1 to **5.4**	MG5a	Hay	July 2015	March 2016	911	8.0	9.4	64
The Parks	**5.4**	MG5	Hay	July 2015	March 2016	906	8.0	9.1	84
The Parks	**5.0**	MG5	Haylage	July 2015	March 2016	905	8.1	9.0	88

Tallowin and Jefferson (1999) found that the potassium content of hay was suitable for most productive livestock, but could deteriorate in hay cut after July, sodium content was adequate, but magnesium content of cut herbage was below the requirements of livestock from semi-natural grasslands. This creates a conflict. Hay-making after July reduces the quality of the forage for livestock (Tallowin and Jefferson 1999) and it can also favour competitive species with persistent seeds that are capable of vegetative spread, particularly grasses, and can increase dead litter within a sward restricting seed set and germination of forbs (Pinches et al 2013; Humbert et al. 2012). Cutting too early, which may benefit the quality of the forage as it is taken when the young plants are at their most nutritious, leads to the eventual loss of species diversity by removing flowering stems, thus limiting seed set, and has been found to favour ruderal species (Pinches et al 2013; Humbert et al. 2012). Thus, the best time to make hay is during July after the majority of forbs have set seed, and this is why an earliest cutting July date is often stipulated as part of conservation measures.

There is some evidence to suggest that, although agriculturally improved grasslands may have higher ME and crude protein (CP), grazing just these grasslands does not always result in greater levels of animal growth and produce. Dairy cows grazing mixed species leys (containing perennial rye-grass *Lolium perenne*, white and red clover *Trifolium repens* and *T. pratense*, chicory *Cichorium intybus* and tall fescue *Festuca arundinacea*) were found to have increased milk production, milk solids and a higher dry matter intake per day compared with heifers grazing perennial rye-grass and clover leys (Roca-Fernández et al. 2016). Grayson (2017) reports on a study where dairy cows restricted to perennial rye-grass sought out and selectively ate more nutritional forage as the year progressed to counter the effects of seasonal decline in the quality of fodder. A similar study of ewes found that they produced more milk on mixed species leys (containing chicory, plantain *Plantago* sp., white and red clover) producing heavier lambs with faster weight gain just after birth (Hutton et al. 2011).

Livestock on species-rich grassland have a greater choice of herbs due to the greater forb component of these grasslands. Grayson (2017) summarises a study of a cow grazing a species-rich limestone grassland in the Yorkshire Dales as part of a small extensive herd. The cattle selected areas with a greater abundance of herbs, springs on warmer days and hollows for shelter when the weather was inclement. The sward along these routes was often greener and shorter, and the areas that were not utilised had longer, grassier vegetation with lower herb cover. Samples sent for analysis found the CP to be a third higher in favoured feeding locations. This suggests that livestock grazing can be considered a positive feedback mechanism on species-rich grassland. Herbs gain an advantage over grasses via continual defoliation of competitive species (Crofts and Jefferson 1999), and the greater nutrition of the fodder seems to be drawing livestock back to the same areas to feed (Grayson 2017). However, grazier selectivity is not always positively expressed by livestock and site managers, and it can be considered a problem when animals consume desirable species and avoid undesirable species (Grayson 2017). Thus, there is a fine line of timing, duration and grazing intensity on species-rich grasslands to sustain the nutritional requirements for animals maintaining the diversity and quality of the forage, without under or over-stocking both of which cause a decline in ME, CP and minerals.

The Farmer Network (2017) carried out a study comparing in-bye land with rough pasture on three types of farms; relatively ‘low farms’ at around 1000ft altitude, which were generally ex-dairy and had relatively ‘good’ ground compared with the ‘hill farms’ and the purely ‘conservation grazing sites’. The low farms had very little difference in forage quality between the in-bye agriculturally improved grassland (adjacent grassland to the farm buildings) and the rough grazing, increasing in CP between 15-20% from April to October, and ME by 10-13 MJ/kg in both 2015 and 2016. The forage quality differed between the in-bye and rough grazing on the hill farms, but to a lesser extent than expected with some overlap. The CP of the in-bye land was far more stable, between 15-20% and is comparable to the in-bye and rough pasture of the low farms. The rough grazing had a fall in CP from ~17% in April to ~6% in October 2015, but in 2016 there was a rise in CP from ~6% in April to ~17% in August. ME of the hill farms was far more consistent ranging from 8-12 MJ/kg over the spring, summer and autumn in 2015 and 11-12 MJ/kg over the same period in 2016 of both the in-bye and rough pasture, and is comparable to the low farms. The conservation grazing sites for both the in-bye and rough pasture echoed the results of the rough pasture of the hill farms. As breeds of cattle differed between farms, it was not possible to come to any conclusions about weight gain associated with the different types of grassland. Further testing is still being undertaken by the Farmer Network (pers. comm. Kate Gascoyne, The Farmer Network).

Livestock browsing more woody vegetation, possibly in the form of silvopasture, is not commonly practiced in the UK yet as an agricultural practice. Behaviour varies considerably between types of animal with goats browsing a greater percentage of their diet than sheep or cattle. Breed and experience of an individual may also influence the amount of browse consumed. The New Forest is an example of silvopasture based upon the historic use of the commons. Tubbs (1986) describes livestock selectivity feeding in the New Forest on a daily and seasonal basis. Ponies were observed to arrive earlier in the morning at the grass lawns and leave later in the afternoon compared to the time they spent on reseeded grassland. Investigation of the forage quality of the reseeded grassland revealed that it was of poorer productivity. In the afternoon, ponies moved to graze valley mires, lowland heathland, gorse and woodland, particularly overnight for shelter, before returning to the lawns in the morning. Cattle had similar behaviour but avoided grazing valley mires. On an annual basis, grass comprised more than 90% of pony diet between May and July from all of the habitats they frequented, but declined to 40% of forage consumed by February before slowly increasing again during the spring. Between September and May it was replaced with gorse, tree leaves and twigs (notably holly), moss, heather and bracken fronds in August and September. Grass in the diet of cattle varied from 65% in mid-winter, including supplementary feed, to 80% in mid-summer. Heather formed 20% of the diet in summer and 10% during winter. Even though cattle were observed browsing scrub and trees, there was none of this material in the analysis of dung. As a consequence, the wet heaths and valley mires were considered as important a source of grass as the lawns with palatable species such as jointed rush *Juncus articulatus*, sharp-flowered rush *J. acutiflorus* and bulbous rush *J. bulbosus*. During the autumn, the animals appeared to favour acid grasslands dominated by bristle bent *Agrostis curtisii* and purple-moor-grass *Molinia coerulea*. Browse also increased in significance, particularly heather *Calluna vulgaris*, but not cross-leaved heath *Erica tetralix* and bell heather *E. cinerea* which was avoided by ponies and cattle. During the spring, the ponies selectively grazed dwarf gorse *Ulex minor*, and if there was an acorn crop in the autumn the ponies and cattle would divert from their normal grazing pattern to hoover the nuts from the woodland floor. Deer were also observed to eat grass, and had an even higher amount of browse in their diet including broadleaved trees, shrub leaves and twigs. Deer also avoided bog myrtle *Myrica gale* as well as crossed-leaved heath and bell heather, and were seldom observed to eat gorse, bristle bent or purple moor-grass. Within a farmed landscape, Grayson (2017) reports on an individual cow and calf selecting to eat ivy *Hedera* spp. provided as part of an overwinter supplementary feed, and cattle routinely consuming blackthorn leaves in the height of summer. Further research on the role that browsing plays within the diet of livestock and how this can be affected by experience of animals would increase our knowledge of the importance that this type of forage has for livestock.

Minerals present in grasslands

Land management, soils and micro-climate all affect vegetation growth rate and consequently impact on metabolisable energy (ME), crude protein (CP) and mineral components of grasslands. Geographical location, particularly latitude and elevation above sea level, is also a key factor influencing levels of minerals. For example, copper deficiency can affect an unborn lamb’s nervous system and cobalt deficiency can result in poor growth levels and a lower immunity response in ewes (Humphries 2015).

Grayson (2016a and 2016b) analysed the ME, CP and minerals of a hay meadow and a limestone grassland (table 7 and appendix). The sward and management of the two areas differ:

- School Field, Silverdale, Lancashire – a combination of MG5 lowland meadow and MG6 semi-improved grassland managed as traditional hay meadow under successive agri-environment schemes since 1992. No chemical inputs have been spread on the meadow since 1987 but well-rotted farm yard manure (composted for at least 2 years) is spread at 20 t/ha once every 4-5 years. The grassland has a single cut in late summer followed by aftermath grazing with cattle in the autumn and winter sheep grazing. Initially, supplementary feeding of species-rich hay was undertaken on the meadow to establish new species (i.e. yellow rattle *Rhinanthus minor*, red clover *Trifolium pratense* and common knapweed *Centaurea nigra*).
- Over Pasture, Ingleborough, North Yorkshire – CG9 Blue moor-grass *Sesleria albicans* dominated upland limestone grassland at c 400 m a.s.l. The grassland is a National Nature Reserve, Site of Scientific Interest and a Special Area of Conservation for the limestone grassland, and no fertilisers or pesticides have been used for 25 years. Until 2014, the limestone grassland was just grazed with sheep at 0.1-0.2 LU/ha leading to a rank and grass dominated sward. More recently the grassland has been grazed with cattle at 0.3-0.5 LU/ha throughout the year opening the sward and resulting in a more diverse forb community (pers. comm. Bill Grayson).

The test results show that the herb component of the meadow had a greater amount of ME, CP and minerals compared with the grass component (table 7):

- ME: In comparison with the typical ranges of forage, the grass component of the lowland meadow was below the average expected ME whilst the herb component was above the expected ME for this type of grassland. The limestone pasture had high ME, which was close to the average ME of rye-grass pasture.
- CP: The CP of the grass component of the lowland meadow was very low, less than half of the CP of the herb component. The CP of the limestone grassland was just below the CP of the herb component of the lowland grassland, and above that of the fresh hay samples analysed by Herefordshire Wildlife Trust (table 5).
- Dry matter (DM): The amount of DM was lower in the limestone grassland suggesting that there is less fodder available. Thus, even though the energy and protein appear to be quite high in the limestone grassland, the amount of forage for livestock restricts the number of animals and would limit growth if too many animals are grazing the pasture at any one time.
- Minerals: The amounts of the macro-elements calcium, magnesium, phosphorous and, in particular, sodium were lower in the limestone pasture compared with the herb and grass components of the hay meadow. Sulphur was higher in the limestone pasture compared with the grass meadow component, but lower than the herb meadow component, and the amount of potassium was much higher in the limestone pasture, nearly two thirds greater than the grass component of the meadow and almost twice the quantity in the herb component. This could demonstrate the value of farms having different types of grassland that could provide different primary compounds adding to the nutritional diet of livestock. Calcium, magnesium, sodium and sulphur macro-nutrients within the herb component of the Lancashire MG5 grassland were relatively high in comparison to forage samples taken from other MG5 grasslands and grass-clover-herb leys in Denmark, and the potassium concentration in the limestone grassland sward was higher than most other species-rich grasslands but not of the grass-clover-herb leys.

The affect of location, soil and vegetation community on ME, CP and mineral content is uncertain, as there have been relatively few tests of species-rich grassland that can be compared to local agriculturally improved grassland. Location is known to affect the fatty acid composition of meat, leading to regional variations in flavour (Wood et al 2007). Further forage samples should be undertaken to examine local and regional differences in nutritional quality, as well as differences between grass, herb and legume components of the sward.

Pirhofer-Waltz et al. (2011) undertook an experiment investigating the potential for forage herbs to improve mineral consumption by livestock. Their conclusion was that herbal leys can provide a greater amount of minerals than grass-only leys. In particular, herbs contained higher quantities of the macro-nutrients phosphorous, magnesium, potassium and sulphur, and micronutrients zinc and boron, than grasses. A separate analysis of the trial plots found that the application of slurry indirectly reduced the mineral concentrations of calcium, sulphur, copper and boron in the sward as the fertiliser increased the proportion of mineral-poor grasses. However, grasses had higher concentrations of manganese and molybdenum compared with the herbs. This result concurs with a previous study of an extensively-managed semi-natural grassland in Spain. Higher concentrations of phosphorous, potassium, iron and zinc were found in herbs compared with legumes and grasses, and higher concentrations of nitrogen, calcium, magnesium and copper in legumes compared with grasses (García-Ciudad et al. 1997). Concentrations of phosphorous, magnesium and sodium were too low from the individual sward components for the requirements of livestock, but calcium, copper and zinc in the legume and herb components, and potassium, manganese and iron in all three components were adequate to meet livestock requirements. Wilman and Derrick (2009) found that concentrations of the major minerals were greater in six herb species, potentially increasing uptake of minerals in sheep where the forbs were present. Magnesium was found to be on average 70% higher in chickweed *Stellaria media*, dandelion *Taraxacum officinale* agg. broadleaved dock *Rumex obtusifolius*, ribwort plantain *Plantago lanceolata* and corn spurrey *Spergula arvensis*. However, the concentration of water-soluble carbohydrate was lower in these forbs. Chickweed was particularly high in phosphorous and potassium, dandelion in potassium and magnesium, broadleaved dock in magnesium, ribwort plantain in calcium, and corn spurrey in magnesium and sodium.

Table 7: Metabolisable energy, crude protein and mineral quantities present in the grass and herb component of a grass-clover-herb mix grown to determine macro- and micro-nutrient concentrations (Pirhofer-Waltz et al. 2011), hay meadow and limestone pastures (Grayson 2016a and 2016b), a neutral hay meadow (High Weald AONB 2003) and semi-natural and agriculturally improved grasslands (Tallowin and Jefferson 1999). See appendix for ME, CP and mineral composition of other forage samples.

Element	Unit	Grass-clover-herb ley on sandy loam soils (trial plots) Denmark		Lowland meadow (MG5) Somerset		Lowland meadow (MG5) Lincolnshire	Lowland meadow (MG5) Lancashire		Lowland meadow (MG5) East Sussex	Limestone pasture (CG9) North Yorkshire	Purple moor-grass and rush pasture (M23) Devon	Fen meadow (M24) Devon	Species-poor rush pasture (MG10) Somerset
							Grass	Herb					
Management		0 kg/ha N fertiliser	200 kg/ha N fertiliser	Cut	Cut & grazed	Cut	Cut	Cut	Cut	Grazed	Grazed	Grazed	Cut & grazed
Dry matter (DM)	g/kg						507	343		267			
Metabolisable energy (ME)	MJ/kg/DM						7.6	10.2		10.6	6.5	6.5	7.9
Crude protein (CP)	g/kg/DM						56.9	129		126			
Nitrogen (N)	g/kg/DM	18.1 - 23.5	16.4 - 31.1										
Calcium (Ca)	g/kg/DM	12.2 - 15.2	8.4 - 14.7	12.2	4.5	8.4	8.38	16.0		4.79	2.9	2.9	3.2
Magnesium (Mg)	g/kg/DM	2.5 - 2.9	2.0 - 3.1	3.0	2.2	1.8	1.62	2.96		1.45	1.2	1.6	1.2
Phosphorous (P)	g/kg/DM	2.6 - 4.4	2.8 - 4.3				1.71	2.92		1.68			
Potassium (K)	g/kg/DM	23.3 - 34.4	23.1 - 31.58	6.3	4.1	22.6	5.70	9.95		17.3	12.4	10.4	9.1
Sodium (Na)	g/kg/DM	0.9 - 1.2	1.1 - 1.2	6.0	4.8	0.6	4.44	5.22		0.24	2.3	1.8	2.1
Sulphur (S)	g/kg/DM	1.9 - 3.1	1.6 - 3.1				1.33	2.61		2.14			
Iron (Fe)	mg/kg/DM	55.4 - 73.9	52.0 - 75.7				209	235	406.4	111			
Copper (Cu)	mg/kg/DM	5.1 - 9.7	4.9 - 9.4				4.99	8.14	7.6	6.06			
Manganese (Mn)	mg/kg/DM	53.9 - 60.3	49.2 - 60.9				156	294	400	494			
Zinc (Zn)	mg/kg/DM	18.2 - 30.1	28.3 - 38.4				24.6	44.4	47.5	31.8			
Boron (B)	mg/kg/DM	14.4 - 20.6	10.8 - 19.5				8.14	27.6		5.66			
Molybdenum (Mo)	mg/kg/DM	0.8 - 0.9	0.7 - 1.0						0.4				
Selenium (S)	mg/kg/DM								0.05				
Iodine (I)	mg/kg/DM								0.41				
Cobalt (Co)	mg/kg/DM								0.18				
Chromium (Cr)	mg/kg/DM	0.2-0.21	0.2										

Medicinal evidence of species-rich grassland

Provenza, Meuret and Gregorini (2015) summarise some of the biomechanics and grazing choice observed by livestock in species-rich grassland. An animal can consume over fifty different species per day, depending on the type of grassland and browsing ability, but the bulk of material eaten comes from 3-5 species. The phyto-chemical interactions of this diverse diet are not well known, and could be affected by the physiology of each type of livestock, and may differ according to previous experience, age of the individual, and the mix and sequence of plants that the animal consumes at any one time. Mineral supplements can be used to provide essential major and trace-elements, but they are also present in the tissues of some plant species, and providing livestock access to richer forage sources may enable them to obtain these trace-elements through grazing and self-medication. Sanga, Provenza and Villaba (2011) report that self-medication may be a learnt behaviour with lambs kept with their mothers consuming more mineral-rich foods, and a 'healthier' diet compared with lambs separated from their mothers.

Livestock will naturally regulate their intake of energy and protein. The balance of metabolisable energy (ME), crude protein (CP) and minerals is maintained through nutrient-specific feedbacks, but there can be negative 'unhealthy' feedbacks, especially within the diet of young animals which can be carried into adulthood. For example, lambs fed a low energy or protein diet have been found to eat non-nutritive foods as adults that ferment at a similar rate, and can suffer from toxicity if allowed a higher energy or protein diet. However, lambs have been observed to eat foods with specific amino acids where these are lacking in their diet and can be found within their available forage, and this is considered a form of self-medication to correct the deficiency. Lactating cows fed protein supplements have been observed to avoid eating high protein plants (i.e. legumes) and parts of plants (i.e. new growth) in mixed swards, but when fed an energy-rich diet during lactation will select high protein species and plant parts (Provenza, Meuret and Gregorini 2015). This opens the nature versus nurture debate considering whether self-medication is a learnt behaviour or intuitive response.

There is evidence that plants present in species-rich grasslands can help reduce illness. For example, pastures rich in plant species that contain tannins (such as common bird's-foot-trefoil *Lotus corniculatus*) can enable ungulates to alleviate bloat, improve protein use, enhance immune response and reproductive efficiency (Provenza, Meuret and Gregorini 2015; Engle 2006). Excess secondary compounds are excreted in urine as amino acids, which also takes energy, and animals self-regulate the intake of these compounds, for example by increasing the time between feeding. Diets rich in secondary compounds actively encourage gut bacteria that can digest these amino acids that animals would otherwise be unable to digest. Grain-rich diets encourage gut bacteria that can digest starch, while high-forage diets encourage gut bacteria that can digest cellulose. Thus, the diet of young livestock and/or changing the diet of adult animals too fast can affect their ability to consume foods (Provenza, Meuret and Gregorini 2015), and familiarity as a young animal may be essential for an individual to maintain a healthy diet.

Endo-parasites (i.e. nematodes) and ecto-parasites (i.e. fleas, ticks, lice and mites) can cause illness, discomfort and prevent an animal from gaining weight. These can be treated using medicinal chemotherapeutics (i.e. anthelmintics, insecticides and repellents), but some organisms are becoming resistant and there are environmental concerns about the knock-on effect of the chemicals. For example, ivermectins can kill soil organisms and invertebrates that consume dung, preventing the natural decomposition of faecal matter. Very few plants used in ethnoveterinary and traditional medicines have been rigorously tested, and some of the plants may also cause toxic reactions in some types of ungulates and can have similar residues to the chemotherepeutics, or not be nutritious enough to sustain an animal if a single species is the bulk of the food consumed (Athanasiadou and Kyriazakis 2004; Iaison and Villalba 2006; Ketzis 2006). Lambs grazing perennial rye-grass *Lolium perenne* and white clover *Trifolium repens* leys have been found to have a higher mean nematode faecal egg counts compared with lambs grazing chicory *Cichorium intybus* or common bird's foot trefoil (Deane et al. 2002), suggesting that the active compounds in these plants could reduce endo-parasite burden. However, the amount of the secondary compound contained with the vegetative matter of a species may be quite low, and may not have the antiparasitic affect that has been observed (Athanasiadou and Kyriazakis 2004). Further testing of species believed to contain medicinal properties should be undertaken to ascertain the levels of secondary compounds within plant tissues and extrapolate the likelihood that a species is the cause of lower parasitic loads.

No single plant species contains all of the ME, CP and minerals an animal requires to maintain a healthy body, and solely consuming a diet rich in energy and protein does not meet the need for minerals. Thus, plants with different root depths and mineral acquisitions, such as the forage found in species-rich grasslands, may provide a more balanced diet than grassland that is less botanically diverse. Cattle have been observed to spend less time at any one place in lower diversity grasslands compared with the time spent grazing at a single location in species-rich grassland (Provenza, Meuret and Gregorini 2015). Turner (1951) undertook a cattle preference test of 35 different forbs. The most favoured species were sheep's or garden parsley *Petroselinum crispum*, ribwort plantain *Plantago lanceolata* and chicory, followed by salad burnet *Poterium sanguisorba*, kidney vetch *Anthyllis vulneraria*, sainfoin *Onobrychis viciifolia* and alsike clover *Trifolium hybridum* (Foster 1988). Of these plants, only ribwort plantain, salad burnet, kidney vetch and sainfoin (native on the chalk, particularly in the area surrounding Salisbury Plain but historically introduced into grasslands elsewhere in the UK for fodder (Preston, Pearman and Dines 2002)) are likely to be found in species-rich grassland. Other species tested are usually considered constituents of herbal leys.

Cattle supplementary fed species-rich hay and haylage scattered in piles over grassland have been observed to move from pile to pile, selecting heaps containing greater amounts of herbage which is often darker in colour and produces a 'sweeter' fragrance compared with the sharper grass fragrance (Grayson 2017). One species that seems to be particularly favoured by livestock is ribwort plantain. Sheep and cattle have been observed to actively seek out and eat leaves in dried fodder (pers. comm. Claire Cornish, Nibblers Forum). It has also been found to have consistently higher ME, CP and minerals compared with grasses (pers. comm. Bill Grayson, Nibblers Forum; see appendix for comparisons of test results). A livestock manager of Hebridean sheep observed how they selected different species at different times of the year. They were seen to search through long grass eating the flower heads of common sorrel *Rumex acetosa*, selecting leaves, flowers and seed heads of hogweed *Heracleum sphondylium* and use tall hogweed stems to rub their heads on, like deer rubbing the velvet off antlers. The sheep had also been observed to consume cleavers *Galium aparine*, seeming to make a definite journey to find it and spend considerable time chewing the plant, and will consume common nettle *Urtica dioica* particularly when other forage is old and fibrous. The same livestock manager had observed cattle selectively eating common bird's-foot-trefoil amongst quite tall grass, and all of the plant parts had been consumed on some occasions suggesting that it is a clear preference (pers. comm. Sue Holland).

Another benefit of livestock consuming a diverse diet is avoidance of toxicity from secondary compounds as the herbage gathered in any single mouthful is more diverse (Provenza, Meuret and Gregorini 2015). Turner (1951) carried out an experiment with dairy cows grazing a simple 'v' diverse grassland ley. The milk yield from a simple mixture of five species, including cock's-foot *Dactylis glomerata*, perennial rye-grass, red clover *Trifolium pratense* and white clover, had a lower milk yield than the more diverse ley of 25 species, including chicory, salad burnet, sheep's or garden parsley, kidney vetch, yarrow *Achillea millefolium*, lucerne *Medicago sativa* ssp. *sativa* and American sweet clover or ribbed melilot *Melilotus officinalis*. The milk yield consistently increased when the cows were moved onto the diverse ley, even when there was less forage present (Brunetti 2006). This suggests that a more diverse food source may increase productivity where specific species are present, but the leys used are still comparatively poor compared to the diversity of species-rich grassland.

Fisher et al. (1996) experimented sowing single forb species into a standard grass mix. Species that competed well with the grasses and produced an annual yield greater than 20 tonnes/DM/ha were common knapweed *Centaurea nigra*, oxeye daisy *Leucanthemum vulgare*, ribwort plantain, salad burnet, common bird's-foot-trefoil, chicory, red clover *Trifolium pratense* and white clover. Yorkshire fog *Holcus lanatus* and perennial rye-grass were both found to suppress the yield of forb species, while rough meadow grass *Poa trivialis*, sweet vernal grass *Anthoxanthum odoratum* and crested dog's-tail *Cynosurus cristatus* allowed the highest yield of forbs. The inclusion of white clover in the mixes increased the yield of grasses, whilst the use of rosette forming forb species increased forb yield. The management of the plots did not provide any consistent levels of herbage nitrogen, mineral contents or yields, but there was some evidence to support the opinion that forbs can result in greater mineral levels in herbage compared with grass-only swards.

Medicinal benefits of individual species

Fungus (Mycelia)

Soil mycelia may also play a role in maintaining the health of livestock. Nematophagous fungi can trap nematodes as the hyphae spread through the soil. Over 200 species are known to occur, and some of the more virulent strains have been used to control plant- and animal-nematodes (Nordbring-Hertz, Jansson & Tunlid 2011; Godfrey and Dodson 2006). Studies have found that nematophagous fungi administered to sheep pass through the gut reducing faecal egg counts. However, it is not know how nematophagous fungi would naturally infect livestock. They are more likely to be ingested by grazing animals, such as sheep and cattle, which could consume the mycelia with small quantities of soil with grazing grassland. Browsers, such as goats, are less likely to be exposed to the mycelia as they consume foliage above the soil level (Godfrey and Dodson 2006). There is no information about the prevalence of nematophagous fungi in species-rich grassland compared with less diverse grassland.

Grasses, rushes and sedges (Monocotyledons)

Some grasses have been sampled for mineral content (table 9 and appendix). There is little in the literature about direct benefits to livestock consuming grasses, but generally there are greater concentrations of major minerals and trace-elements in herbage compared to grasses (Wilman and Derrick 2009). However, depending on the habitat, grasses can form a major component of forage. For example, between May to August, sheep's fescue *Festuca ovina* is a major contribution to the diet of sheep let onto rough grazing of hill farms and, in spring, sweet vernal grass *Anthoxanthum odoratum* is grazed before it flowers (Humphries 2015). Newton (1993) summarises information on grasses from a range of sources, including that perennial rye-grass *Lolium perenne* seems to be inferior to other grasses that can be components of species-rich grassland, i.e. crested dog's-tail *Cynosurus cristatus*, in the absence of artificial nitrogen fertiliser (Frame 1990).

Forbs (Dicotyledons)

There has been some research on certain species that have traditionally been used for livestock remedies (tables 8 and 10). The high levels of tannins in common and greater bird's-foot trefoil *Lotus corniculatus* and *L. pedunculatus*, and sainfoin *Onobrychis viciifolia* have both been found to reduce nematode infestations (Burke undated; Deane et al. 2002; Keatinge 2004, Rook et al. 2004). However, a certain amount of these species may need to be ingested to have any medicinal benefit, as a Swedish study found that low consumption of common bird's-foot-trefoil and white clover *Trifolium repens* made no difference to faecal egg counts (Godfrey and Dobson 2006). Lower nematode levels on grassland with bird's-foot trefoil has been attributed to fewer infective stage larvae on the plant, which is thought to be an effect of the sward structure where bird's-foot-trefoil is present on the development, survival and migration of nematodes. A comparison of perennial rye-grass and common bird's-foot-trefoil plots spread with *Teladorsagia circumcincta* egg infested sheep droppings found at least a 58% and 63% reduction of eggs on the trefoil plot on days 14 and 35 following spreading (Marley et al. 2006).

Although it is considered of low nutritive value, historical records attribute some usefulness of bird's-foot-trefoil (Fairbairn and Thomas 1959). Other beneficial effects of bird's-foot-trefoil include good growth rate with higher carcass weight, reduction in methane gas emissions from cattle, increased ovulation and mating success of ewes with higher numbers of lambs per ewe, and more wool (Burke undated; Engle 2006; Woodward et al. 2006; Barry et al. 2004; Ramirez-Restrepo et al. 2002; Wang et al. 1996). The only reported negative effect of livestock grazing bird's-foot-trefoil was in terms of the odour and tainting the flavour of meat, but this is thought to be less of a concern when bird's-foot-trefoil is present within a diverse sward (Burke undated). The tannins also enable livestock to cope with higher levels of terpene- and alkaloid-rich plants (Provenza, Meuret and Gregorini 2015).

Sainfoin *Onobrychis viciifolia* also has the advantage that it has a high crude protein content which contributes to high daily gains in livestock weight, but the degree of research undertaken on sainfoin is less than that of other species (Burke undated; Scharenberg et al. 2005; Ortiz and Smith 2015). A study in Denmark found that lambs grazing a pure stand of sainfoin for five weeks showed a 50% decline in faecal egg counts compared to lambs solely grazing white clover (Hamsborg 2001), and high daily weight gain has been associated with a lower nematode worm burden as well as high protein content of grazing sainfoin swards (Heckendown et al. 2007). As a plant it is extremely drought tolerant and can survive in poorer soils (Ortiz and Smith 2015).

Ribwort plantain *Plantago lanceolata* has been found to have higher sodium and cobalt than perennial rye-grass *Lolium perenne*, similar calcium, copper and zinc to white clover, and lower potassium and manganese than either of these species (Burke undated; Rumball et al. 1997). It has a high mineral content, being rich in phosphate and calcium, and considered to be highly palatable to livestock being preferred by animals in hay (Foster 1998; Turner 1955). The concentrations of nutrients vary between the stem and leaf, with higher concentrations of all nutrients except phosphate in the stem and 50% more fibre in the stem (Foster 1998), but the stem reduces in palatability approximately 25 days after the seed head appears (Burke undated). The merits of using ribwort plantain in forage crops presented by Judson and Moorehead (2011) are that it makes a desirable crop for the quantity of forage produced, rapidly degrades in the rumen increasing intake, increases sheep performance (particularly lactating ewes and post-weaning), increases trace-elements particularly copper, cobalt and selenium, and reduces endo-parasites.

Yarrow *Achillea millefolium* is known to be deep rooted, drought resistant and contain high levels of CP, and contains two alkaloids, achillein and moschatin, that have medicinal qualities (Foster 1988; Turner 1955). It can accumulate phosphorous, potassium, zinc and manganese in its tissues. Deep rooted plants are thought to be able to draw-up nutrients where they are unavailable in the topsoil. For example, common knapweed *Centaurea nigra* thrives in soils with low phosphorous, which has been partially alluded to the deep rooted habit of the plant to reach deeper soil depths (Turner 1955). Salad burnet *Poterium sanguisorba* is also deep rooted, relatively drought resistant and thought to draw up calcium from the sub-soil when grown on a ley with acidic topsoil (Foster 1988; Turner 1955). High cover of dandelion *Taraxacum* agg. is thought to be an indicator of soil calcium deficiency. It has high levels of protein and the minerals sulphur, potassium, copper, iron, zinc and manganese. It is relatively rich in phosphate, but low in calcium and boron (Brunetti 2006). Other species have not been examined at all, such as the legume kidney vetch *Anthyllis vulneraria* which may have high protein levels and is considered to be drought resistant (Burke undated).

Table 8: Summary of the medicinal effects of some plant species.

Effect	**Species**
Reduces and stops **bleeding**	Yarrow *Achillea millefolium* (Brunetti 2006)
Relieves **bloat**	Caraway *Carum carvi* (Foster 1988), sainfoin *Onobrychis viciifolia* (Ortiz and Smith 2015)
Diuretic	Dandelion *Taraxacum* agg. (Brunetti 2006).
Increased **growth** of the animal	Common bird's-foot trefoil *Lotus corniculatus* and greater bird's-foot-trefoil *L. pedunculatus* (Ramirez-Restrepo et al. 2002); ribwort plantain *Plantago lanceolata* (Rumball et al. 1997; Moorhead et al. 2002)
Reduces **nematode infestation**	Common bird's-foot trefoil *Lotus corniculatus* and greater bird's-foot-trefoil *L. pedunculatus* (Burke undated Deane et al. 2002; Marley et al. 2006), sainfoin *Onobrychis viciifolia* (Ortiz and Smith 2015; Burke undated; Hamsborg 2001); wild thyme *Thymus polytrichus* (Turner 1955)
Increases **ovulation**	Common bird's-foot trefoil *Lotus corniculatus* and greater bird's-foot-trefoil *L. pedunculatus* (Burke undated)
Reduces **methane**	Common bird's-foot trefoil *Lotus corniculatus* and greater bird's-foot-trefoil *L. pedunculatus* (Burke undated; Woodward et al. 2004); sainfoin *Onobrychis viciifolia* (LegumePlus 2017)
Increases **milk yield**	Common bird's-foot trefoil *Lotus corniculatus* and greater bird's-foot-trefoil *L. pedunculatus* (Burke undated; Barry et al. 2004; Wang et al. 1996)
Increases **protein absorption**	Sainfoin *Onobrychis viciifolia* (LegumePlus 2017)
increases **reproductive** success (more offspring and lower post-natal abortion)	Common bird's-foot trefoil *Lotus corniculatus* and greater bird's-foot-trefoil *L. pedunculatus* (Burke undated; Barry et al. 2004)
Reduces **scour** (diarrhoea)	Salad burnet *Poterium sanguisorba* (Foster 1988)
Increases **wool production**	Common bird's-foot trefoil *Lotus corniculatus* and greater bird's-foot-trefoil *L. pedunculatus* (Burke undated; Barry et al. 2004; Ramirez-Restrepo et al. 2002)

Table 9: Macro-nutrients and trace-elements present in different grasses. See appendix for ME, CP and mineral composition of other species.

	Unit	Red fescue	Meadow fescue	Timothy		Perennial rye-grass		Cock's-foot	
		Festuca rubra	*Festuca pratensis*	*Phleum pratense*		*Lolium perenne*		*Dactylis glomerata*	
Calcium (Ca)	% DM				0.34		0.65		
Magnesium (Mg)	% DM	0.27	0.44	0.36	0.10	0.35	0.35	0.36	0.36
Phosphorous (P)	% DM	0.57	0.58	0.44	0.26	0.59	0.59	0.59	0.59
Potassium (K)	% DM	2.19	2.47	0.27	2.17	2.38	2.38	2.78	2.78
Sodium (Na)	% DM	0.05	0.2	0.17		0.19	0.19	0.17	0.17
Chlorine (Cl)	% DM	0.46	0.46	0.7		0.51	0.51	0.31	0.31
Iron (Fe)	ppm	275	250	408		252	252	200	200
Copper (Cu)	ppm	10.03	9.05	7.06		8.05	8.5	10	10
Manganese (Mn)	ppm	26.02	29.02	25.03		21.06	21.6	45.05	45.5
Cobalt (Co)	ppm	0.19	0.16	0.15		0.15	0.15	0.14	0.14
Reference		Wookey 1987	Wookey 1987	Wookey 1987	Brunetti 2006 (from Vengris et al. 1953)	Wookey 1987	Foster 1988 (from Thomas et al. 1952)	Wookey 1987	Foster 1988 (from Thomas et al. 1952)

Table 10: Macro-nutrients and trace-elements present in yarrow, common bird's-foot-trefoil, ribwort plantain and salad burnet. See appendix for ME, CP and mineral composition of other species.

	Unit	**Yarrow**				**Common bird's-foot-trefoil**		**Ribwort plantain**					**Salad burnet**		
		Achillea millefolium				*Lotus corniculatus*		**Plantago lanceolata**					*Poterium sanguisorba*		
Nitrogen (N)	% DM														
	g/kg/DM						30.20 - 33.20					15.70 - 16.20			14.50
Calcium (Ca)	% DM		1.08	1.80	0.82				2.25	2.32	2.55			1.84	
	g/kg/DM						11.20 - 11.40					12.60 - 18.70			17.60
Magnesium (Mg)	% DM	0.98		0.98	0.18	1.27		1.01		1.01	0.46		1.82	1.82	
	g/kg/DM						2.50 - 2.60					2.60 - 2.90			4.70
Phosphorous (P)	% DM	0.91	0.91	0.91	0.31	0.79		0.75	1.07	0.75	0.30		0.62	0.62	
	g/kg/DM						3.00					3.00 - 4.60			2.80
Potassium (K)	% DM	4.42	2.81	4.42	2.35	2.77		3.31	3.37	3.31	2.10		2.22	2.22	
	g/kg/DM						28.60 - 29.30					28.70 - 31.20			19.70
Sodium (Na)	% DM	0.06		0.06		0.18		0.40		0.40			0.07	0.07	
	g/kg/DM						0.30 - 0.50					0.40 - 0.70			0.30
Sulphur (S)	% DM														
	g/kg/DM						2.30 - 2.50					2.40 - 4.90			1.90
Chlorine (Cl)	% DM	0.53	0.92	0.53		0.56		0.62	2.27	0.62			0.15	0.15	
	g/kg/DM														
Iron (Fe)	ppm	294.00		294.00		383.00		490.00		490.00			249.00	249.00	
	mg/kg/DM						77.60 - 81.40					57.10 - 69.90			70.90
Copper (Cu)	ppm	10.06		10.60		7.03		10.05		10.50			8.00	8.00	
	mg/kg/DM						6.20 - 9.00					6.60 - 9.70			5.80
Manganese (Mn)	ppm	48.03		48.30		43.04		35.03		35.30			31.02	31.20	
	mg/kg/DM						50.50 - 52.40					27.30 - 39.20			69.80
Cobalt (Co)	ppm	0.17		0.17		0.20		0.20		0.20			0.18	0.18	
	mg/kg/DM														
Zinc (Zn)	ppm														
	mg/kg/DM						27.70 - 30.80					23.30 - 38.30			22.50
Boron (B)	ppm														
	mg/kg/DM						18.30 - 24.00					19.80 - 20.80			29.10
Molybdenum (Mo)	ppm														
	mg/kg/DM						1.10 - 1.70					0.40			1.00
Chromium (Cr)	ppm														
	mg/kg/DM						0.20					0.20			0.20
Reference		Wookey 1987	Foster 1988 (from Fagan & Watkins 1932)	Foster 1988 (from Thomas et al. 1952)	Brunetti 2006 (from Vengris et al. 1953)	Wookey 1987	Pirhofer-Waltz et al. (2011)	Wookey 1987	Foster 1988 (from Fagan & Watkins 1932)	Foster 1988 (from Thomas et al. 1952)	Brunetti 2006 (from Vengris et al. 1953)	Pirhofer-Waltz et al. (2011)	Wookey 1987	Foster 1988 (from Thomas et al. 1952)	Pirhofer-Waltz et al. (2011)

Human health benefits

Provenza, Meuret and Gregorini (2015) discuss the role of taste and functional palates which are guided by flavour-feedback interactions linked with the variety of foods on offer and how cultures learn to use them. People often desire food that tastes richer than blander food, but there are many qualities that people search for when purchasing food including cost, taste and healthiness.

Links have been lost between species-rich grassland and livestock which can lead to the loss of phytochemical richness (i.e. minerals) and taste in diets. Natural flavours of foods and nutritional qualities are being replaced by artificial flavours and nutrient supplements (i.e. fortified cereals). The ability to eat meat or consume milk or cheese from livestock reared on species-rich grassland may restore this lost link and increase the phytochemical richness of foods naturally. Provenza, Meuret and Gregorini (2015) summarise that foods are now changed to be:

- altered – to remove a nutrient or replace a nutrient with another substance;
- enriched – to add nutrients;
- fortified – to increase the amount of nutrients;
- supplemented – people take additional supplements to replace lost nutrients where these are not available in foods.

These practices may negatively affect flavour-nutrient learning and health as people do not associate particular tastes with nutrients. 'Cravings' are a response to nutrient deficiencies, and can be observed in different forms, i.e. for fat in lean meat diets, cod liver oil with rickets, fruit with scurvy, salt with salt deprivation and for people exhibiting 'pica' diets with specific and unusual food such as dirt (Provenza, Meuret and Gregorini 2015).

Some forbs can impart flavours onto meats. Taste panels have judged lamb odour and flavour in meat where the animal has grazed ribwort plantain *Plantago lanceolata*, chicory *Cichorium intybus* and perennial rye-grass *Lolium perenne* to be significantly less intense than meat from an animal that has grazed common bird's-foot trefoil *Lotus corniculatus* or clover *Trifolium* sp. (Rumball et al. 1997), and the flavour of beef from grass-fed cattle (silage or grazing fresh grass) was preferred (Wood et al 2007). However, the intensity of the flavour can be off-putting. For example, a British panel scored grass-fed British meat higher than a Spanish panel that found the flavour too intense (Wood et al 2007).

The amount of poly-unsaturated fatty acid chains, such as omega-3, in feed is affected by several factors, including:

- Drying and conserving forage, i.e. making hay, haylage or silage, which reduces fatty acids; this is thought to be due to oxidation by plant lipases and lipoxygenases taking place primarily during field wilting and drying. This reduces the amount of these fatty acids found in milk (Wood et al 2007).
- Time of year or season of consumption/harvesting; a link has been established between the amount of chlorophyll in the plant tissue and long-chain fatty acids (Wood et al 2007). Plant growth is also a factor, with differing quantities of chlorophyll associated with primary growth, flowering re-growth after grazing, harvesting and late-season growth. These factors have been related to levels of long-chain fatty acids, crude protein and water-soluble carbohydrates in some studies, but in others long-chain fatty acids and crude protein were independent of botanical composition and plant life-stage.

A study by the University of Bristol (2008) found that a combination of traditional breeds, diverse pastures and traditional processing methods can produce high levels of nutritional value and quality in meat and dairy products that would be attractive to consumers. These ideas are mainly being taken up by small specialist groups of farmers and abattoirs working together, although the messages are also of interest to the bigger processor and supermarket groupings.

The evidence differs between types of products, meat or dairy, because the farming systems are very different. Dairy often requires higher energy and protein intake and, as a consequence, is generally undertaken on agriculturally improved pastures with some herbal leys being used, particularly within organic farming. With meat production, the energy and protein requirements are lower and there is a higher proportion of species-rich pasture. There may also be differences between traditional and commercial breeds of livestock, particularly with regard to growth on different types of forage. Traditional breeds take longer to mature and are used more widely on species-rich grassland, as the farming industry consider these types of grasslands to provide inadequate fodder, both dry food and fresh pasture, for faster growing commercial breeds.

Meat-based products

Beef, both traditional and commercial breeds, produced on a grass diet has higher quantities of 'yellow fat', found to be tastier than concentrate-fed beef (University of Bristol 2008), and some fatty acids, such as omega-3 poly-unsaturated fatty acids and conjugated linoleic acid, which have recognised health benefits (Wood et al. 2007). A study into the possible links between biodiverse grassland and fatty acid composition identified that certain compounds were increased by the type of grassland, particularly long-chain fatty acids, vitamin E, carotenes and terpenes; this benefited meat quality including colour, shelf-life and flavour (Wood et al. 2007; University of Bristol 2008). However, tannins in plants like sainfoin have been shown to reduce rumen bacteria which can produce 'off-flavours' like skatole that taint the flavour of meat (Provenza, Meuret and Gregorini 2015; Ortiz and Smith 2015).

A meta-analysis of studies found that organic meat contained 23% more poly-unsaturated fatty acids and 47% more omega-3 poly-unsaturated fatty acids than conventionally reared meat. The main factor influencing these levels of long-chain fatty acids was the high grazing/forage diet of organically reared livestock (Średnicka-Tober et al 2016).

Traditional breed beef had the same level of quality (observed through dip, muscle pH, marbling fat, colour and taste) as commercial breeds but, when the animals were grazing species-rich grassland, the eating quality of traditional breed beef was rated higher by both a trained taste panel and a separate consumer panel. Consumer preference also increased for beef aged for longer (20-28 days compared to 10 days) and aging on the bone (dry aging) compared with aging in a vacuum bag (wet aging) which increased scores for tenderness, juiciness and beef flavour (University of Bristol 2008). In America, there is a consumer preference for meat from livestock finished on legume-rich leys (fescue Festuca - sainfoin *Onobrychis viciifolia* pasture) (Ortiz and Smith 2015). Rook et al. (2004) reports that out of two local cattle breeds in Northern Spain, one had been bred for meat and has higher conformation and growth rates but poorer maternal aptitude, whilst the other breed that had not been selectively reared had better maternal aptitude as was more suited for rougher terrain, and was preferred by consumer panels.

Dunn et al. (2005) and Whittington et al. (2006) report that vitamin E levels were higher in lambs grazing herb-rich grassland, particularly heather, compared with improved grassland. The muscle fat contents were similar across all grazing habitats, except heather and moorland which had higher levels of fatty acids. Flavour scores for meat from moorland and salt-marsh lamb scored highest. Fat from lambs grazing improved pasture scored highest for abnormal odour and lowest in lamb flavour. This study indicates that lambs grazing unimproved pasture produce meat that is of high quality and tastes good.

Dairy-based products

Cheese produced from livestock reared on species-rich grassland can have enhanced flavour and phyto-chemical richness compared to cheese produced from livestock reared on less diverse habitat (Provenza, Meuret and Gregorini 2015). Terpenes are known to affect the sensory characteristics of cheese. They are found in much higher quantities in cheese from animals with access to fodder with higher levels of forbs (Coulon et al. 2004). Tannins in sainfoin and bird's-foot-trefoil *Lotus corniculatus* can alter digestive processes in the rumen increasing the levels of poly-unsaturated fatty acids, and feeding a sainfoin silage diet to dairy cattle has been found to increase the amount of linolenic acid, which is an omega-3 fatty acid, in milk and cheese (Ortiz and Smith 2015).

Coulon et al. (2004) undertook a literature review of factors affecting the sensory characteristics of cheese, including dietary components for dairy cows, finding that:

- maize fodder produced whiter, firmer cheese that was rated lower than cheese produced from cows given silage or hay;
- cheese from cows grazing a northern-facing highland pasture were less firm, more melting and pastier compared with a southern-facing pasture. The cheese was also stronger (saltier and bitter with sweet odours and a sour aroma) from cows grazing the northern-facing slope, and was milder with fruity flavours from the southern-facing slope;

- cheese from cows grazing alpine meadows (>2200m) were saltier, sharper and more acidic than from cows grazing mid-altitude pasture;
- cows fed natural Auvergne hay produced less melting and less bitter cheese compared to cows fed cock's-foot *Dactylis glomerata* hay;
- cheese texture can differ, being more cohesive, ductile and elastic from cows grazing valleys compared to highlands, and more sandy on nitrophilic grasslands compared to wet meadows; and
- taste tests rated upland cheeses as being more 'pungent' and 'animal' compared to lowland cheeses.

Conclusion

There is some information about the nutritional, medicinal and production value of priority grasslands that can be used to answer the three questions outlined at the beginning of this review. However, the information is not easy to find and interpret, and there has been relatively little research compared to testing undertaken on agricultural and herbal leys.

Do species-rich grasslands have a commercial nutritional value for livestock in comparison with agriculturally improved grassland?

The evidence indicates that the metabolisable energy (ME) and crude protein (CP) of most species-rich grasslands is not equivalent to that of agriculturally improved grasslands. However, there is some evidence to suggest that swards in species-rich grasslands can provide some nutritional value, particularly when used in conjunction with agriculturally improved grasslands. This is particularly the case for minerals, where the diversity within the forage of species-rich grasslands can improve ingestion of minerals that are less available in improved grassland. As a result, grazing livestock on species-rich grassland could reduce the need for mineral licks where the balance of minerals is adequate. In addition, there appears to be higher levels of most minerals within the herb content of grasslands compared with grasses and legumes. Legumes have high protein, which would be expected due to their nitrogen fixing capabilities. However, the studies splitting swards into different components are few, and more research is required to provide adequate supporting evidence. The size of the herd and type of grassland may also affect ME, CP and mineral availability for livestock, and over-grazing could lead to deficiencies. There is some evidence to suggest that livestock reared on herbal leys may do better, i.e. higher growth rate or milk yield etc., compared with animals grazing agriculturally improved grassland, but the number of studies of species-rich grassland is severely lacking and it is uncertain whether the results from herbal leys can be carried through to reflect the situation on species-rich grasslands. Further testing of different types of grassland would also be recommended as the majority of samples of fresh forage, hay and haylage have been taken from lowland meadows (NVC community MG5), but the single sample from an upland limestone grassland (CG9) indicates that it may have high ME, CP and mineral levels, but a lower sward growth rate limiting the number of animals that can be grazed at any one time.

Do species-rich grasslands have a role in holistic medication? If so, are there any particular species that provide antidotes to ailments?

Engle (2006) summarised some practices that livestock managers could undertake to enable animals to self-medicate:

- encourage behavioural self-regulation by providing highly diverse forage appropriate for the adaptive spectrum of the species;
- investigate the medicinal potential of native plants that are usually considered 'toxic'. Tolerating a few specimens may provide essential medicinal compounds to livestock.
- provide access to rubbing posts, mud, and aromatic herbs.
- enable access to sub-soils for clays and chalks, or provide clay blocks to ruminant stock.
- allow access to chewing wood or barks.

This study emphasised the importance of species-rich grassland as a method of livestock obtaining a balanced diet with all of the elements required to maintain a healthy body. However, there is a lack of information about the mineral composition of different types of species-rich grassland and how they may compare to agriculturally improved swards within a local environment, i.e. with the same soils. There is also a lack of information about the mineral contents of individual species, which could differ considerably throughout the growing season, and part of the plant that is eaten. The majority of the nutritional tests have been undertaken on species associated with herbal leys, rather than forage from species-rich grasslands, and species associated with these grasslands. The results of the surveys indicate that bird's-foot-trefoil *Lotus* sp. and sainfoin *Onobrychis viciifolia* can reduce endo-parasites. No conclusion can be reached about whether the ability of an animal to 'self-medicate' is a learnt or innate behaviour, but there does seem to be evidence that it could be a taught behaviour with young animals learning from their mothers if they have already experienced a diverse diet from species-rich grassland.

Are there any nutritional benefits to humans from eating livestock reared on species-rich grasslands?

The available evidence suggests that beneficial long-chain fatty acids are present in higher quantities in meat and milk from animals grazed on species-rich grasslands. In addition, taste is also usually considered of greater quality, except where a specific forage species is eaten in high quantities tainting the taste of the produce. The habitat can be a selling point for produce, such as salt-marsh lamb, or location may be a selling point, such as Dartmoor Conservation Meat, which is livestock grazed in a way to support the ecology of the moorland. However, consumers from different places rate the taste of produce differently, i.e. more or less intense. This could be a moving baseline, with the potential that people eating blander products, particularly as children, may not like the stronger taste of products from animals grazing species-rich grassland.

This evidence review did not find any accounts from farmers observing the behaviour of their animals put onto species-rich grassland for self-medication. There are accounts from other countries where holistic practices may be more widespread due to the cost of veterinary medicine. The loss of this knowledge and traditional practice as the older farming generation declines, also risks less recognition of the value of species-rich grasslands as a forage source to provide a balanced diet and to resolve ailments in unwell livestock. Ethnoveterinary studies with the older farming generation should be undertaken to capture this traditional practice and reference the cultural use of species-rich grasslands.

Research priorities

- Testing of forage, both fresh swards and stored feed, to determine whether the nutrition of forage differs between:
  - different types of feed, i.e. fresh fodder, silage, hay or haylage; and
  - different components of the sward, i.e. herbs, grasses and legumes.

  Other factors that are likely to influence the quality of the forage are location across the country, soil pH and type of substrate, the time when the sample was collected within the growing season and degradation of the forage over time in storage. Metabolisable energy, crude protein and mineral composition should all be tested.

- Testing of individual species within species-rich grasslands for metabolisable energy, crude protein and mineral composition, and identifying any potential medicinal properties that are part of plant secondary metabolites. Tests could compare:
  - differences between species;
  - differences within a species growing in different types of grassland communities, on different soils, at different latitudes and altitudes;
  - differences between plant parts, i.e. leaf, stem, flower; and
  - differences over the growing season, particularly pre- and post-flowering.

- Separating the experience of livestock grazing unimproved grassland from breed. For example, within a breed is there a difference in forage preferences and consumption between experienced individuals compared to naive individuals.

- Browsing and silvopasture systems and the role that more woody vegetation and species associated with scrub and woodland play within the diet of livestock.

- Ethnoveterinary research into the cultural 'medicinal' uses of species-rich grassland.

It is expected that some of this research may be quite costly or time-related, and thus incorporation of the themes into funding proposals for practical conservation projects or academic research as components of the work may help alleviate this limitation.

Note from the author and acknowledgements

The information summarised in this evidence review is a combination of reports, papers and anecdotal descriptions. It was not possible to do a full extensive search of medical or zoological texts, including peer-reviewed journal articles, and there may be more information available on this subject.

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The appendix is a separate spreadsheet of the ME, CP and mineral composition of fodder from different types of grasslands, monocotyledons and dicotyledons.