Review: Review of feeding conserved forage to horses: recent advances and recommendations

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Short Title: Feeding conserved forage to horses

Abstract: The horse is a non-ruminant herbivore adapted to eating plant-fibre or forage based diets. Some horses are stabled for most or the majority of the day with limited or no access to fresh pasture and are fed preserved forage typically as hay or haylage and sometimes silage. This raises questions with respect to the quality and suitability of these preserved forages (considering production, nutritional content, digestibility as well as hygiene) and required quantities. Especially for performance horses, forage is often replaced with energy dense feedstuffs which can result in a reduction in the proportion of the diet that is forage based. This may adversely affect the health, welfare, behaviour and even performance of the horse. In the past 20 years a large body of research work has contributed to a better and deeper understanding of equine forage needs and the physiological and behavioural consequences if these are not met. Recent nutrient requirement systems have incorporated some, but not all, of this new knowledge into their recommendations. This review paper amalgamates recommendations based on the latest understanding in forage feeding for horses, defining forage types and preservation methods, hygienic quality, feed intake behaviour, typical nutrient composition, digestion and digestibility as well as health and performance implications. Based on this, consensual applied recommendations for feeding preserved forages are provided.

Key words: forage, health, hygiene, behaviour, requirements

Implications: Improved consistency in the terminology used for preserved forages and the adoption of consensual recommended minimal forage intake levels.

Introduction

The horse is a non-ruminant grazing herbivore adapted to eating plant-fibre or forage based diets. A wide range of plant species can be hydrolyzed and/or fermented within its specialized gastro-intestinal tract (GIT), thanks to the presence of a mixed microbial symbiotic population throughout the whole GIT, but particularly in the hindgut, which facilitate fibre digestion (de Fombelle *et al.*, 2003; Dougal *et al.,* 2013). Gastrointestinal tract (GIT) digestion provides energy mainly through the production of short-chain fatty acids (SCFA), mostly acetate, propionate and butyrate, also often described as volatile fatty acids (VFA's) (Merritt and Julliand, 2013). The whole digestive system is well adapted to a trickle (almost continuous intake of small amounts) feeding intake pattern, with the horse naturally foraging for around 10 – 15 hours a day (Ellis, 2010). Historically the energy demands of working horses were too high, and time too short, to be met by forage alone, especially as forage quality was often poor, grazing limited and it was difficult to distribute and transport bulky forages. Therefore, oats, barley, beans and root vegetables were used as a major component of the diet (Stewart, 1838). The inclusion of energy rich feedstuffs (particularly cereals and vegetable oils) in the diets of many horses, especially performance horses, continues today despite the availability of better quality forages (Richards *et al.,* 2006, Lindburg 2013). An increase in starch intake, often in combination with a reduction in the amount of forage provided, can have health, welfare and performance consequences.

Due mainly to environmental conditions and the lack of availability/undesirability of grazing, many horses are fed preserved forages (hay, haylage and sometimes silage), in particular preserved grass, either at specific times of the year or all year round and therefore preserved forages provide all or part of their forage intake. During the 2012 meeting of the European Workshop on Equine Nutrition (EWEN) it was agreed that there was a need for a consensus paper on the topic of preserved forage feeding to horses. The aim of this review paper is therefore to summarize recent findings and to provide consensual applied recommendations for feeding preserved forage.

Forage types and preservation methods

Roughages are high fibre feeds (Morrisson, 1956) generally obtained as a crop residue or a by-product (Ellis *et al.,* 1988) e.g. straw and cereal hulls. Forages are also high fiber feeds obtained by cutting and preserving the whole plant (except roots). Although they define different products, the words forage and roughage are typically used interchangeably. From a behavioural aspect the term ‘foraging’ encompasses all feed intake activities of horses both on pasture and in housing situations.

Cut grass air dried/wilted in the field or a barn is termed *hay,* whereas *silage* is forage preserved moist and airtight, and thus fermented (McDonald *et al.,* 1991) The term haylage was originally used to describe silage with a DM content of around 50 % (Gordon *et al.,* 1961) and although haylage (and hay/silage) can be harvested at any stage of plant maturity today *haylages* are typically grown and cut at later growth stages similarly to hay, but baled before becoming dry resulting in DMs typically >50 but <70% although occasionally up to 85% (see Fig. 1 and supplementary Table S1). Hay baled with too high a moisture content due to unsuitable weather conditions at cutting time and especially during wilting, insufficient turning especially if in rows (rather than being wilted widespread which helps speed up wilting, thereby helping to reduce protein degradation and loss of nutrients) etc. allows the development of fungal spores/bacteria and increases the risk of mycotoxin development. To stop undesired microbial growth, roughage/forage therefore has to be preserved under controlled conditions (Fig. 2). Hay and straw should be preserved during conditions of low water activity in the crop (i.e. preserved at a DM content ideally above 85%) and given that the bales will be exposed to air, relative humidity must be lower than required for mould growth at the given temperature (Fig. 2) and therefore ideally <70%. Forages may also be preserved utilizing airtight conditions, with or without lactic acid fermentation. In silage the water soluble carbohydrates in the forage are fermented by anaerobic lactic acid bacteria (naturally occurring on the crop or added as inoculants (Fig. 1). For sufficient lactic acid production to occur, the crop DM content must ideally be around 30% or less and certainly <50 % (Fig. 3). If the acids produced sufficiently increase hydrogen ion concentrations, undesirable microbial growth will be inhibited. To confirm proper ensiling of forages (without butyrate) with a DM 15-50%, pH can be used as an indicator. Weissbach, 1996 and Spörndly *et al.,* 2003 suggest that the pH should be less than: 0.0257 x DM% + 3.71 (Weissbach, 1996) but according to Field and Wilman, 1996 a higher pH (0.0028 x DM(g/kg) + 4.209 (equation estimated from their figure) might be allowed if silage is preserved in bales and not in bunkers. Preservation at higher DM contents relies on maintenance of airtight packaging not a low pH (Mihin, 1940). In haylage/silage bale production, at least 4 layers of film are needed to promote good preservation (Keles *et al.,* 2009; McEniry *et al.,* 2011) but adding layers (6- 10) increases the CO_2 content (Müller, 2005) and for bales to cope with handling, transportation, birds and long-term storage 8 layers or more are recommended (Jacobsson, 2002; Spörndly pers. com.). In haylages with very high DM contents there may be an increased risk of perforation (allowing air entrance and mould growth) by stiff and sharp stems. To facilitate safer preservation and storage such haylages require more layers of film than forages with a lower DM content. Some professional horse haylage producers may use 12-20 layers (Jansson A, pers. com.). More research is needed into the impact of the number of layers used. Mature and rough crop may be difficult to preserve correctly since more air can be trapped in such bales, increasing the risk of localized mould growth. Higher density baling, late tossing, lower dry matter (75%), as well as rain occurring after cutting strongly increased mould counts in hay (Seguin *et al.,* 2010) but baling for haylage when too dry (86-88% DM) also increased mould counts (Martinson *et al.,* 2011).. Bales of forage with very low DM contents (<30 %) are also at risk of losing airtightness due to their heavy weight, plant structure collapse during fermentation, formation of effluent etc. all of which result in increased pressure on the film. In forage with DM content < 40 % *clostridial* fermentation can also occur (McDonald *et al.,* 2002) and the prevalence of *clostridial* fermentation seems to be higher in bales with unchopped vs chopped forage (Pauly, 1999). In well-made haylage, whilst there will still be some microbial activity, reduction in WSC and production of by-products of fermentation this will be much more limited compared with that for silage (Müller *et al.,* 2007; Muhonen *et al.,* 2009).

Figures 1, 2 and 3 here

Nutritional composition

The nutritive value of forage to the horse is determined predominantly by its nutrient content and digestibility, which in turn may be influenced by level of intake and feed interactions. Nutrient content depends on many plant related factors as well as the environment (Buxton, 1996). Herbage maturity at harvest, however, is a key influencer (Virkajärvi *et al.,* 2012). As the plant matures, the fibre fraction increases and crude protein decreases, leading to a decline in digestibility plus overall energy availability (Ragnarsson and Lindberg, 2008; 2010; Müller, 2012) (Fig. 4). Nutrient content is also closely related to plant species and morphology, with legumes typically higher in protein and calcium than grasses. The proportion of leaf to stem will also affect nutritive value, even between cultivars of the same species (Van Soest, 1994; Bélanger and McQueen, 1997).

Figure 4 Here

Forage quality is also influenced by management factors especially fertilizer applications, harvest techniques and storage conditions (Van Soest, 1994; Cookson *et al.,* 2000; Rotz, 2003). Hay nutrient losses are normally higher during harvest (e.g. plant leaves left in the field due to mechanical handling of the dried crop) in contrast with silage where losses are larger during storage, mostly due to fermentation activities, air infiltration and silage effluents (McGechan, 1989, 1990; Dürr, 2004 ; Müller, 2012). Environmental factors affecting herbage development (including temperature, precipitation, solar radiation and soil nutrient availability) obviously can vary with geographical location resulting in a range of climatic and soil conditions.

Not surprisingly forage chemical composition and consequent nutritional value therefore shows a great variation between regions, crop years, harvest time, seasons and even within farming places (see Supplementary Table S1). The variability highlights the importance of forage analysis when designing forage based rations, especially when feeding brood mares, growing and performance horses (Jansson *et al.,* 2012) or those with particular clinical conditions (such as laminitis, HYPP etc.). Ideally mineral content should also be analysed. Legume forages tend to have higher protein and calcium contents than grass forages and this needs to be taken into consideration when formulating the total ration (which should preferably be based on nutrient analysis).

Digestion and Digestibility

Digestion can be defined as the process in the gastrointestinal tract by which forage constituents are converted by physical and chemical breakdown into substances (mainly SCFA) that can be absorbed and assimilated by the body (Argenzio *et al.,* 1974). Water soluble, as well as enzymatically digestible carbohydrates (WSC, starch non-starch polysaccharides, soluble fibre) are digested from the stomach onwards along the whole GIT as long as they are not trapped within insoluble fibre. Insoluble fibre digestion depends exclusively on microorganisms that have the ability to hydrolyze the predominant β1-4 linked polysaccharides of cell walls. It occurs primarily in the horse's hindgut with a limited amount of fermentation in the foregut (de Fombelle *et al.,* 2003; Jouany *et al.*, 2009). The extent of any forage digestion depends on both the fibrolytic microbial activity of the hindgut ecosystem and the total time during which parietal components are exposed to this activity (Merritt and Julliand, 2013). This duration is defined as the mean retention time (MRT) of digesta (Miyaji *et al.,* 2008b).

Several intrinsic and extrinsic factors can affect forage digestion and digestibility (digestibility = total nutrient/energy ingested minus nutrient/energy excreted and expressed as % of total ingested). The Influence of intrinsic factors such as horse breed, individuality and age has been studied on forage digestion and digestibility. It has been anecdotally suggested, for example, that 'easy keepers' may have higher digestion efficiency than other horses. However, in a controlled study (Ragnarsson and Jansson, 2011) where two haylages (cut at early and late maturity stage) were fed to both Icelandic horses (easy keepers) and Standardbred horses no such effect could be observed (Table 1). Recent studies also showed that DM, organic matter and neutral detergent fibre fraction apparent digestibility were not different between weaned foals (6 and 12 months) and adults (14 years) (Ringler *et al.,* 2009; Earing *et* *al.,* 2013), which complemented and confirmed previous data reporting no variation of total apparent digestibility of DM between weanlings (5 months), and those aged 8 and 12 months old (Cymbaluk *et al.,* 1989). At two months of age, the SCFAs profile of foal's faeces remained constant and cellulolytic bacterial concentration was comparable with adult values suggesting that the fibre-degrading capacity in foals was established by two months of age (Faubladier *et al.,* 2013).

Extrinsic factors such as botanical characteristics are known to influence growth and metabolism of plants, and therefore their nutritive value as forages. In horses, the average DM digestibility decreased significantly in forages having higher NDF and lower crude protein contents (Edouard *et al.,* 2008). More specifically, alfalfa has higher DM and CP digestibility coefficients than tall fescue, caucasian bluestem (Crozier *et al.,* 1997), coastal Bermuda grass (Sturgeon *et al.,* 2000; Potts *et al.,* 2010) and Matua grass (Sturgeon *et al.,* 2000). Alfalfa also had higher OM digestibility than grass hays (LaCasha *et al.,* 1999) and more specifically coastal Bermuda grass (Potts *et al.,* 2010). Digestion and energy and crude protein content of forage is greatly affected by the stage of maturity of plants (Fig 4; Table 2).

The type of forage preservation, however, appears to have limited impact on apparent digestibility. When hay and haylage originating from the same crop (same harvest/batch) were compared, digestibility did not differ (Bergero and Peiretti, 2011) although when hay and silage from the same crop was compared, digestibility was slightly higher in silage compared to hay (Muhonen *et al.,* 2008b). Feed changes from hay to silage or haylage (even from the same harvest/batch) may, however, affect the microflora as well as the DM of the hindgut contents (Muhonen et al 2008, Muhonen 2009) Similarly changes between forage batches with different CP contents should be made slowly, as colonic pH, for example, has been shown not to be stable within 3 weeks after such a change (Muhonen *et al.,* 2008a) although further studies are needed to assess the importance of these alterations.. Until we do know more it is recommended that changes between forage batches should therefore be made carefully to minimise the risk of disturbances. In support of these recommendations the incidence of certain types of colic has been shown to increase especially in the first 7 days (but up to 28days) after a change in forage feeding (Hillyer et al 2002).

Insert Table 1 and 2

Hygienic quality

This is a key issue, as forages fed to horses have often been reported to be of poor hygienic quality (Wichert *et al.,* 2008) which can lead to significant health problems for example, mould spore exposure, especially from Aspergillus fumigatus has been implicated in the aetiology of recurrent airway obstruction in horses (Pirie 2014). Although the term “poor hygienic quality” is not well defined, it may include biological contaminants (e.g. pests, microorganism and their related toxins), chemical contaminants (e.g. fertilizer, heavy metals), and physical contaminants such as soil. In that context, feed hygiene, as stated by EU legislation (Regulation (EC) No 183/2005), includes all aspects that must be considered in order to produce, sell and feed a safe feedstuff that will not result in any harmful effects on the animal, and therefore applies to forage as well. EU legislation (EC No 32/2002) defines maximum acceptable levels for a variety of contaminants in feedstuffs including for heavy metals, aflatoxin B1, rye ergot and substances such as pesticides.

Several parameters can be used to evaluate hygienic quality including feel (e.g. dry, clammy), smell (e.g. typical, mouldy), colour (e.g. green, bleached), macroscopic findings (e.g. presence of sand, soil, dead animals) and/or microbial evaluation (Wichert *et al.,* 2008, Kamphues 2013, Wolf *et al.,* 2014). Knowing the DM content is key, as discussed above, as microorganisms need water for survival and multiplication (Kamphues 2013). A macroscopic evaluation should routinely be undertaken for obvious moulds, as well as the presence of sand/soil and other potential contaminants especially poisonous plants. Senecio spp., and Taxus baccata have been suggested to be the main poisonous plants for horses (Berny et al., 2010) although regionally other poisonous plants may be important e.g. vitamin D-intoxication via Golden oat grass in parts of Germany (Bockisch et al., 2015).

Much attention is given to the microbiological analysis of feedstuffs but there are significant effects of the analytical methods used. Pre-treatment, incubation temperature, type of incubation substrate and incubation duration can all significantly influence what is cultivated (Raymond *et al.,* 2000; Müller *et al.,* 2011). For example, the growth of thermophilic bacteria such as actinomyces is supported by an incubation temperature of 55°C for three days, whereas the growth of mesophilic aerobic bacteria is supported by a lower incubation temperature (25°C), but a longer incubation time (7 days, Raymond et al., 2000). In some European countries, the characterization and benchmarking for bacteria, moulds and yeasts in feedstuffs has been standardized (Tables 3 and 4) to provide upper acceptable levels of contamination which are thought not to have any adverse effects on horse health. For this purpose microorganisms are classified as being either epiphytic (i.e. normal contaminants that are present even under optimal conditions) or spoilage inducing. Importantly, both types may impact health (e.g. respiratory problems by moulds). However, it should be emphasised that whilst these benchmark levels can be used to describe spoilage, the consequences on equine health through exceeding the benchmark levels requires more in-depth evaluation.

Undesirable bacteria, moulds and yeasts multiply under adverse conditions such as rainfall, high humidity, and high ambient temperatures or due to vectors like mites. As outlined above a DM content of >85% reduces microbial activity

Mycotoxins such as ergot alkaloids, , zearalenone, deoxynivalenol, fumonisin B1 and B2, ochratoxin A or aflatoxin B1 are secondary metabolites produced by fungi that are capable of causing toxicity (see review Riet-Correa *et al.,* 2013). However, little is known about the impact of mycotoxins on equine health status. Several mycotoxins are designated as undesirable substances with maximum levels in human food, whereas only aflatoxin B1 and rye-ergot are currently designated as undesirable substances with maximum levels for animal feedstuffs. Further analyses, therefore, may be required including detailed mycotoxin determinations e.g. clinical signs of leukoencephalomalacia requires fumonisin analysis especially when corn silage with corn cobs is being fed to the affected horses. Whilst it is impossible to fully eliminate mycotoxins, it is important to reduce contamination by optimizing harvesting and storage conditions.

Botulism occurs following exposure to toxins (8 different serotypes) produced by anaerobic spore-forming bacterium *Clostridium botulinum* and other botulinum toxin-producing clostridia (Galey 2001). In adult horses, food-borne botulism is acquired by the ingestion of preformed toxins (mainly type B, C or A). Feeding big bale silage or haylage have been often associated with botulism outbreaks in horses, mules or cattle (e.g. Ricketts *et al.,* 1984; Divers *et al.,* 1986; Wollanke 2004; Myllykoski *et al.,* 2009), although there have been outbreaks linked with hay feeding (Wichtel and Whitlock 1991; Johnson *et al.,* 2010) . Botulinum toxin production typically occurs due to contamination with animals, soil or poultry slurry. Equivocal results have been reported regarding the potential risk of silage or haylage contamination with Clostridium botulinum spores through using the wastage from biogas anaerobic digesters for fertilization (Müller *et al.,* 2013; Neuhaus *et al,* 2015).

Methods of sampling

A good sampling procedure is crucial so that any analysis (e.g. nutrients, microbial counts) represents the mean value for the whole batch. For the official feed control EU legislation (EC No 691/2013) suggests for example that 5 up to 40 individual samples should be aggregated to form an initial overall sample of between 1 (low specific gravity, e.g. hay or straw) and 4 kg as fed (e.g. silage). .

Table 3 and 4 here

Forage Intake Behaviour and Welfare considerations

Free-ranging horses perform 10-15 individual feed-bouts/day and forage for 12.5±2.5 hours per day with recordings as high as 18 hours (Ellis, 2010, Supplementary Table S2). 'Non-foraging' bouts are rarely longer than 3 hours duration (2±1.3) (Souris *et al.,* 2005; Van Dierendonck *et al.,* 1996; Hallam *et al.,* 2012, Ellis *et al.,* 2015;). Even when stabled, horses tend to spend a minimum time (8.5-12 hrs/day) on foraging related behaviours, at times 'topping up' their food intake behaviour by ingesting wood-shavings and performing coprophagy for up to 3hrs per day (Ellis *et al.,* 2006, Ellis

2010). Curtis *et al.* (2011) suggested the potential for wood-shaving intakes of up to 3.5kg in a few individuals fed DM restricted diets as part of a weight loss programme and this is in line with considerable amounts of woodshavings reported in the stomach of horses on a low forage diet (Boswinkel et al 2007) . Intake times for chopped lucerne/alfalfa are about twice as fast as those for long hay (Ellis, 2010). Chopping very late cut hay to 3.5 cm particle length did not shorten intake times in 8 horses but adding chopped forage (~2.5cm or 4cm) to pellets at 30% inclusion rate doubled concentrate feed intake times (Ellis and Hill, 2002; Ellis *et al.,* 2005). Replacing hay with ground-hay pellets reduces chewing time/kg by 75% (Ellis *et al.,* 2010) which may partially explain the increased intakes (to 4-5% of BW) seen by Argo *et al.* (2002) and Henneke and Callaham (2009) when they fed only pellets compared to a chaff-feed or hay. Elia *et al.* (2010) found that foraging through wood-shaving bedding increased by 3.5 hrs/day, when feeding just hay pellets compared to feeding hay. This strong motivation to spend a minimum of 8 (stabled) to 12 (grazing) hours on intake behaviours, irrelevant of the energy density or composition of feedstuffs is supported by many studies on voluntary intake behaviour (Supplementary Table S2) and night time observations of stabled horses (Ellis *et al.,* 2015). In addition stabled horses rest for 3-4 hours maximum before re-commencing foraging-related behavior (Ellis et al., 2015).

Furthermore, in a race horse population of 2900 animals, those fed <6.8kg/day of forage showed a significant increase in abnormal behaviours including oral stereotypies and weaving (McGreevy *et al.,* 1995). Lack of foraging opportunity has been directly linked to the onset of oral stereotypies in foals (Nicol *et al.,* 2002) and to possible stereotypic pre-cursor behaviour (increased water play and drinking, locomotion) in 3 out of 5 feed-restricted ponies (Dugdale *et al.,* 2010). Appetitive behaviours have a positive feedback on motivation through the brain's pleasure centres which become active as the horse pursues its goal (McBride and Hemmings, 2005). If the motivation to forage/chew is not fulfilled, other behaviours may replace the original goal achievement behaviour as highlighted in several mammals (Hughes and Duncan, 1988).

Health considerations

Horses as previously stated are adapted to a slow and almost continual intake of a diet rich in structural fibre and low in rapidly hydrolysable carbohydrates. For many commonly encountered equine health issues, forage feeding management is an important factor in helping to reduce risk and maintain health.

Particle length influences motility and transit time within the GI tract, as larger particles move more slowly (Drogoul *et al.,* 2000) and forage also influences gastric emptying rate and/or the passage rate through the small intestine (Jensen *et al.,* 2012). A more stable (Willing *et al.,* 2009) and diverse microbial population, with a larger core, is found when a forage only diet is fed especially compared to a sugar and starch rich ration (Dougal *et al.,* 2014). Stabling and feeding preserved forage results in a change in gut motility and higher DM faeces despite an increased water intake (Williams *et al.,* 2011, 2015). Horses have a lower pH in the proximal stomach during early morning (1:00–9:00 AM), when stomach-fill tends to be lower especially in stabled animals (Husted *et al.,* 2008). It is therefore not surprising that several nutritional risk factors for equine gastric ulcer syndrome (EGUS), colic and diarrhea have been identified and many of them are related to limited, reduced or a changed intake of forage (see table 5).

Recurrent airway obstruction (RAO) is the most common cause of chronic coughing in horses in temperate countries, with up to 14% prevalence in the UK (Hotchkiss *et al.,* 2007). This lower airway inflammatory disease results in a range of clinical signs from exercise intolerance/poor performance, to severe expiratory dyspnea (Pirie *et al.,* 2002; Pirie *et al.,* 2003; McGorum and Pirie 2008). Exposure to airborne organic dust (mostly endotoxins) via stabling and feeding of hay/straw with a high mould count plays a primary role (Couetil and Ward 2003) as discussed above.

The management strategies for horses at increased risk of several conditions, such as certain forms of laminitis (including those with the Equine Metabolic Syndrome and Pituitary Pars Intermedia Dysfunction) as well as various muscular disorders including the Equine Rhabdomyolysis Syndrome, includes reducing the intake of non-structural carbohydrates (NSC) (MacLeay *et al.,* 2000;, McKenzie *et al.,* 2003; Valentine *et al.,* 2001; Hunt *et al.,* 2008). Such horses are often put on restricted or no pasture access (especially when the levels of fructans, starch and sugar are high or there is a high herbage yield) and are fed a diet based on preserved forage or forage replacers (e.g. commercial fibre based products) with a known and low content of NSC (<10-12% DM) to minimize post-feeding glycemic and insulinaemic responses (Borgia *et al.,* 2011; Geor and Harris 2013; Harris *et al.,* 2013). Recent observations also indicate that forage CP content might be of importance for the insulin response (Ringmark and Jansson 2013).

Table 5 here

Performance considerations

Historically, the use of forage in diets of performance horses has been limited (Jansson and Harris 2013). Recent studies (Connysson *et al.,* 2006; Muhonen *et al.,* 2008b; Connysson *et al.,* 2010; Essén-Gustavsson *et al.,* 2010; Jansson and Lindberg 2012; Ringmark *et al.,* 2012; Ringmark *et al.,* 2015) show that forage-only diets can meet the high energy requirements of horses in very heavy training (equal to or more than twice maintenance requirements) if the energy density is high enough. The energy density of such forage must correspond to at least 10.5 MJ ME/kg DM (Jansson and Lindberg 2012; Ringmark 2014). These studies indicate no adverse effects on performance with exception for slightly lower (ca -10 %) muscle glycogen contents within 3 days after high intensity work compared to a high starch diet (Jansson and Lindberg 2012). However, very high muscle glycogen contents and indications of rapid glycogen recovery have been documented on forage-only diets providing crude protein intakes above current feeding recommendations and forage WSC contents of 8.5-13.5 % of DM (Essén-Gustavsson *et al.,* 2010; Ringmark, 2014). In the study by Jansson and Lindberg (2012) plasma lactate response was decreased, venous pH and blood glucose was increased during exercise on the forage-only diet compared to the traditional high starch diet, indicating a metabolic pattern that might improve performance. A recent study (Ringmark 2014) has also shown that it is possible to get Standardbred yearlings into racing condition at the age of 3, and also to win races, on a high-energy forage diet supplemented only with minerals and vitamins. Horses also maintained plasma volume longer during 12 h of feed deprivation on a forage only-diet compared to a high starch diet (Connysson *et al.,* 2010). Altogether these studies suggest that high energy preserved forage can be an alternative to high starch feeds in exercising horses and that such diets might promote both health and performance.

Author's Recommendations for best practice

Based on the above and other published work (as well as personal views where stated).

A. The general use of the following terms is recommended

I. *haylage* for forages stored airtight and with DM content ≥ 50%.
II. *silage* for forages stored airtight with DM contents below 50%
III. *hay* for forage preserved at a DM content ideally above 85%

B. To fully understand the value of a forage, and its impact as part of the horse's diet, nutrient analysis is recommended and an estimation of the energy content should be made. This becomes particular important when feeding horses with health disorders (e.g. low BCS, obesity, laminitis, PSSM).

C. Hygienic quality of forages must be a key consideration as poor hygienic quality can lead to significant health problems. As a minimum, regular visual and olfactory inspection should be undertaken and poor quality forage appropriately disposed of. Benchmarks for microorganism contamination should be considered.

D. Changes in forage should be done gradually especially if the nutrient composition (energy, protein, WSC) is unknown or known to differ considerably due to changes in plant-species, growth stage and preservation technique. In such instances at least 2 and possibly more than 3 weeks adaptation period may be required.

In terms of forage requirements for horses it is recommended that:

1. The basis of any horse's diet should be fresh or preserved forage (recommended particle length >2.5 cm) offered ideally ad libitum or spread throughout the day to avoid prolonged periods (i.e. >4-5hrs) in a stable without foraging opportunity. However, in older horses with chewing difficulties, using ground high fibre products in a soaked mash form may be beneficial.
2. A horse requires sufficient forage fed in a form that supports species specific feed intake behaviour ideally for a minimum of 8 hrs and preferably 10 hours/24hrs.
3. The amount of preserved forage in the ration should be calculated on a g DM /kg BW rather than % of ration or an as-fed basis due to the great variation in DM content of different forages.
4. The lower limit of daily forage intake should be 15g DM/kg BW in addition to complementary (concentrate/compound) feeding, with an absolute minimum recommendation of 12.5g DM/kg BW. Previously recommended minimums of forage at 8-10g DM per kg BW/day are not acceptable according to the latest understanding of equine ethological needs and health considerations.
5. Any lower amounts should only be fed solus (i.e. no other fibre provision), under exceptional clinical circumstances (e.g. as low energy providing hays for animals undergoing severe restriction for weight loss purposes, post-surgery etc.), under veterinary supervision and with an appropriate forage vitamin/mineral/protein balancer.
6. Straw, if required, should be introduced into the diet very slowly, which helps the horse to adapt its chewing behavior and reduce the risk of impaction, although this remains a significant risk with certain individuals. The risk of gastric ulceration also

may increase when straw is the main roughage. Some of the authors (PH, AE, VJ, NL) *personally recommend* that not more than 30% of the forage DM ration should be straw (other than for donkeys). Others (AJ, IV) may recommend higher proportions providing the straw is of a good hygienic standard and the overall ration is balanced for protein vitamins, minerals and trace elements.

7. For horses requiring increased energy intake due to reproduction status or work level, less mature forages that have a higher energy content, should be considered. Forages cut at an earlier plant maturity stage are less likely to require protein supplementation.

8. Intakes above those recommended here may be fed or consumed by horses, as long as a healthy energy balance (body condition) is maintained. If body weight increases even when feeding the minimum recommended intake, a forage with a lower energy content should be fed rather than reducing the dry matter forage intake.

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Table 1. *Coefficients of total tract apparent digestibility in Icelandic and Standardbred horses fed the same early and late cut forages (after Ragnarsson and Jansson, 2011)*

	Early cut Icelandic	Early cut Standardbred	Late cut Icelandic	Late cut Standardbred	SE
OM	0.536[a]	0.565[b]	0.431	0.427	0.006
CP	0.636	0.660	0.478	0.479	0.012
NDF	0.517	0.536	0.322	0.320	0.008
ADF	-	-	-	-	-
Energy	0.517[a]	0.540[b]	0.407	0.400	0.007

[a, b,] Values in the same row without common superscripts differ ($p<0.05$) and indicate breed differences.

OM : Organic matter, CP : Crude Protein; NDF : Neutral detergent fibre; ADF : Acid Detergent fibre

Table 2. *Coefficients of total tract apparent digestibility of haylages cut (first cut) at different stages of maturity (after Ragnarsson and Lindberg 2008; Ragnarsson and Lindberg, 2009)*

	Timothy haylage					Mixed grass haylage				
	Cut 1	Cut 2	Cut 3	Cut 4	SE	Cut 1	Cut 2	Cut 3	Cut 4	SE
DM	0.716^{a}	0.626^{b}	0.513^{c}	0.457^{d}	0.011	0.691^{a}	0.616^{b}	0.619^{b}	0.556^{c}	0.010
OM	0.747^{a}	0.647^{b}	0.527^{c}	0.485^{c}	0.010	0.710^{a}	0.630^{b}	0.640^{b}	0.578^{c}	0.010
CP	0.809^{a}	0.735^{b}	0.642^{c}	0.639^{c}	0.014	0.765^{a}	0.740^{ab}	0.708^{ab}	0.688^{b}	0.015
NDF	0.770^{a}	0.646^{b}	0.516^{c}	0.440^{d}	0.009	0.717^{a}	0.584^{bc}	0.594^{b}	0.520^{c}	0.013
ADF	0.746^{a}	0.629^{b}	0.480^{c}	0.400^{d}	0.008	0.685^{a}	0.545^{b}	0.555^{b}	0.485^{b}	0.017
Energy	0.733^{a}	0.633^{b}	0.515^{c}	0.468^{c}	0.006	0.670^{a}	0.600^{b}	0.595^{b}	0.560^{b}	0.011

$^{a, b, c,}$ Values in the same row without common superscript differ ($p<0.05$).

DM : Dry matter; OM : Organic matter, CP : Crude Protein; NDF : Neutral detergent fibre; ADF : Acid Detergent fibre

Table 3: *Classification of microorganisms in feedstuffs according to Kamphues (2013)*

Microorganism	Classification	Category	Species examples
Aerobic bacteria	Epiphytic	1	*Flavobacterium*
			Pseudomonas
			Xanthomonas
			Erwinia
	Spoilage	2	*Bacillus spp*
			Staphylococcus
			Micrococcus
		3	*Streptomyces spp.*
Aerobic moulds	Epiphytic	4	*Verticillium*
			Acremonium
			Fusarium
			Aurebasidium
	Spoilage	5	*Aspergillus*
			Penicillium
			Scopulariopsis
			Wallemia
		6	*Mucor* spp.
Yeasts	Spoilage	7	All species

Table 4: *Benchmark for microorganisms in feedstuffs (cfu per g feed) according to Kamphues (2013)*

	Aerobic bacteria x 10^6 cfu, g			Moulds x 10^3 cfu, g			Yeasts x 10^3, g
Category[1]	1	2	3	4	5	6	7
Hay	30	2	0.15	200	100	3	150
Straw	100	2	0.15	200	100	5	400
Grass silage	0.2	0.2	0.01	5	5	5	200
Corn silage	0.4	0.2	0.03	5	5	5	1000

[1]Categories; 1: Epiphytic bacteria; 2 and 3: Spoilage indicating bacteria; 4: Epiphytic moulds; 5 and 6: Spoilage indicating moulds; 7: yeasts all species

Table 5 *Some suggested forage related risk factors for gastric ulcers and colic (see also Andrews et al., 2015, Durham, 2013)*

Disease	**Risk factor**	**Possible (non-exclusive) explanation**	**Ref**
Gastric ulcers - squamous	Frequency of forage feeding. Intervals > 6h may increase risk of ulcers	Decreased production of saliva, slower passage rate and reduced buffering capacity in the stomach	Luthersson *et al.,* 2009
Gastric ulcers - squamous	Straw as the main forage source in horses/ponies may increase risk of ulcers	Straw may provide low levels of additional buffering support (low in protein, low in calcium). Straw may create mucosal irritation, and may affect the nature of the fibrous mat within the stomach. In addition, the potential for poor hygienic quality (including increased risk of mycotoxins) may play a role.	Luthersson *et al.,* 2009 Wichert *et al.,* 2008
Gastric ulcer - glandular	Feeding alfalfa chaff increased the number of glandular ulcers compared to	The glandular lesions could be a result of mechanical injury caused by the very small particles/physical	Fedtke *et al.,* 2015

	hay or alfalfa pellets in weanlings or adult horses	properties of the alfalfa chaff	
Colic – in general	Reduced intake of grass*, limited intake of forage. Importantly a change in the type of forage fed. * NB Horses with duodenitis-proximal jejunitis were were significantly more likely to have grazed pasture than the control population (Cohen et al., 2006)	Any change in forage intake will cause changes in the microflora in the hindgut. This may cause increased risk of dysfermentation, change in motility, and several physiological changes in the GI tract. A change in hay within previous 2 weeks may increase risk of colic between 4.9 to 10 times.	Cohen *et al.,* 2000 Hassel *et al.,* 2004 Hillyer *et al.,* 2002 Hudson *et al.,* 2001 Eg. Change of hay within two weeks without adaptation (Tinker *et al.,* 1997; Cohen *et al.,* 1999). Change between two silages with different crude protein content (Muhonen *et al.,* 2008). Change from hay to haylage or silage from the same botanical origin (Muhonen *et al.,* 2009).
Colic - impaction	Feeding costal Bermuda hay	Indigestible fibers have reduced water holding and releasing capacity, can cause changes in the microflora and can cause altered motility	Little and Blikslager 2002

Figures

Figure 1. A very schematic overview giving some definitions and characteristics of hay, haylage and silage (WSC=water soluble carbohydrates) made without additives. It is important to note that DM content (and water activity) will determine the potential for fermentation so are linked with lactate production. .In general as lactate starts to be produced the WSC and pH will start to reduce, although other factors can influence pH (including buffer capacity). The WSC of any preserved crop will be lower than the fresh forage it originated from due to respiration (plant and microbial) post harvesting but the WSC content of haylage compared with the hay from the same fresh pasture will depend on whether there have been any lactic acid (or VFA production) If there is virtually no lactic acid (or VFA) production, then there will be no decrease in total WSC in haylage compared to hay (Muhonen et al 2009).

Figure 2. A schematic figure on how minimum required air humidity (relative humidity, RH) for mould growth varies with ambient temperature (adapted from Lehmann, 1971).

Figure 3. The relationship between airtight stored grass forage dry matter (DM) and lactate content. At DM contents higher than 50 % (dotted line) the lactate content is very low. Data from Wilkinson *et al.,* 1976 (3 observations, 16- 45%DM); Müller, 2007 (10 observations 29-68%DM); Muhonen, 2008 (8 observations, 36-81%DM); Ragnarsson, 2009 (8 observations, 36-81%) and Sarkijärvi *et al.,* 2012 (6 observations, 36-55%DM). All observations are from grass forage preserved in wrapped bales except for Wilkinson *et al.,* 1976 which were in silos. Forages were preserved without additives except 6 observations, with lactic acid inoculant, from Muhonen, 2008 and formic acid inoculant in the Sarkijärvi *et al.,* 2012 observations. Data fits (R^2=0.84) the equation: $y = 0,0406x^2 - 5,4306x + 179.3$ and the equation is relevant in the interval 16-70 % DM.

Figure 4. A schematic illustration (not to scale)of the maturation of plants and the effect on dry matter content (NB in Southern European countries the increase in DM is more dramatic than for Northern Europe as illustrated by the two lines), digestible plus metabolizable (ME) and Net (NE) energy plus digestible protein content on a wet matter (WM) basis. The extent of such changes may be affected by environmental conditions as well as management practices.