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Quality of Forages: Current Knowledge and Trends

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Abstract

Cool season grasses are the main component of pasture-based agriculture in temperate regions of the world. In warmer environments, warm season and tropical grasses (typically C4 plants) are commonly used. The continual invention of fresh feeds and forages will be essential in helping ruminant agriculture begin to adjust to the rising temperatures of the globe. Research projects in this area are urgently needed because it typically takes fodder breeding programmes 15 years to generate a new, performance-tested variety that can be included on recommended lists. Having insufficient feed to meet animal demands (feed gap) is a significant element that can limit productivity. When forage yield is low, forage conservation enables a greater supply of higher-quality feed. Greater productivity and improved bale quality will be in demand as commercial hay markets expand and livestock farms grow in size. The feel, texture, smell, and appearance of a hay crop are frequently used by forage buyers and sellers to evaluate and estimate its value. The producer or manager can develop a well-balanced diet, use forages more efficiently in feeding programmes, and more accurately appraise and market available forage lots by evaluating the forages' nutritional value.

Keywords: Forage, feed gap, conserved forage, quality, aflatoxin

1. Introduction

Most of the global population will still rely heavily on livestock in future food security plans. Ruminant production has the potential to increase the efficiency of nutrient usage at both the individual animal and system levels in relation to new feeds and feeding strategies. The continual invention of fresh feeds and forages will be essential in helping ruminant agriculture begin to adjust to the rising temperatures of the globe. A complete diet can be designed to maximize the partitioning of feed nutrients into productive outputs and minimize potentially polluting emissions while minimizing the ability of the animals to select out particular components. These diets, which typically consist of complete mixed rations and complex concentrate feeds with a range of ingredients, may be given to animals which are housed. Semi-intensive systems include those that allow for more flexible diet options while still supporting effective output. These include areas of longer-term pastures that are managed to improve their nutritional characteristics through the application of fertiliser and cutting regimes, or grazing leys that are sown with specific forage species and cultivars and managed to optimize the efficiency of use of feed resources. Cool season grasses are the main component of pasture-based agriculture in temperate regions of the world. These are typically C3 plants, such as ryegrasses (*Lolium* spp.), fescues (*Festuca* spp), timothy (*Phleum pratense*) and cocksfoot/orchard grass (*Dactylus glomerata*). In warmer environments, warm season and tropical grasses (typically C4 plants) such as signalgrasses (*Urochloa* spp. and hybrids), Rhodes grass (*Chloris gayana*) and Napier grass (*Cenchrus purpureus*) are commonly used. Forage maize (*Zea mays*) is a tropical crop that has been successfully bred to enable its cultivation at increasingly northerly latitudes, and while maize silage is a useful feed for ruminant production due to its high concentration of starch, it is an annual crop that is typically harvested in late autumn leaving bare soils prone to erosion. Another C4 plant, Miscanthus spp., has recently and successfully been introduced to Europe as a perennial biomass crop. Its introduction to EU nations has demonstrated the idea that Napier grass or other tropical forage plants could be utilised as part of adaptation to climate change in these regions, despite the fact that its nutritional value is significantly inferior to Napier grass and its morphology and propagation are similar. Research projects in this area are urgently needed because it typically takes fodder breeding programmes 15 years to generate a new, performance-tested variety that can be included on recommended lists. Grassland-based livestock production will become unsustainable for many if there are no reliable, affordable forages available, and consumers or policymakers may not be willing to accept a switch to more concentrate-based diets given the growing need to avoid conflicts with land use for human food production or bioenergy production (Moorby and Fraser, 2021).

Feed gap

In forage-dependent livestock systems in variable production contexts, having insufficient feed to meet animal demands (i.e., a feed gap) is a significant element that can limit productivity and cause land degradation. Agronomists are starting to pay more attention to crop production resilience in relation to the sustainability of agricultural systems. What may need to increase the forage and grazingland systems' adaptability: 1) selecting moderately diverse, site-specific grass-leaf mixtures (grasses-legumes) for use in particular areas; 2) increasing the use of complementary forage species like C3 and C4 grasses to extend the grazing season and act as a weather buffer; 3) implementing moderate defoliation intensities to help stabilise forage production and species composition; and 4) paying closer attention to maintaining and enhancing soil fertility to increase the productivity of desirable forage. An integrative management approach that combines many of these elements would help improve the resilience of forage and grazinglands to sustain high productivity under increasingly erratic and extreme weather (Tracy et al., 2018).

Conserved forage (silage and hay)

When forage yield is low, forage conservation enables a greater supply of higher-quality feed. Despite the fact that haymaking and ensiling have been used for many years, study is still required to 1) understand the factors that affect quality during harvest and storage, and 2) design workable solutions to reduce losses and improve quality. There are some noteworthy trends in forage harvesting for silage. Kernel processing of maize, once confined to Europe, has become popular in North America. Due to more contract harvesting and bigger farms, self-propelled forage harvesters have a larger market share. Mergers, bigger harvesters, and rakes all assist increase productivity and forage quality. Finally, to meet the fibre requirements of high-production dairy animals, producers are lengthening cutting times. The last two trends emphasise the importance of effective silo management. The variety of silo types has increased throughout time. The recent advancements of pressed bag and wrapped bale silages are significant. These more recent varieties enable small farms to produce high-quality silage and make it simpler to separate silages by quality. The problem of disposing of the bigger amounts of plastic, however, is getting worse. All types of silos might benefit from alternatives like edible or biodegradable films, which would ease labour and environmental concerns. Due to the high surface to volume ratio of wrapped bales, deterioration and listeria contamination are more frequent. Improved pathogen growth and spoiling control techniques are required. When most crops are ensiled, a significant amount of true protein is broken down, which lowers ruminants' ability to use nitrogen. Silage quality can be improved by additives. Improved inoculants that attempt to increase aerobic stability are beginning to enter the market, but it's unclear how well they'll do overall. Although they have not yet delivered on their promise, enzymes that break down plant cell walls, provide sugar for fermentation, and improve the digestibility of the silage do offer some promise. Although they are used less frequently, acids and sugars are nevertheless crucial in some ensiling settings. Three types of balers are used to package dry hay: small square, large round and large square balers. Due of labour shortages, the little square is becoming less popular in industrialised nations, although it is still useful in underdeveloped nations where there is still an abundance of farm labour. Because of its productivity and affordable ownership and running expenses, the large round is the most widely used baler in the world. Large square balers have continued to expand because of their high production and shippable package. Hay farmers have difficulty getting their crops dry enough (20% moisture) to avoid excessive storage losses brought on by microbial activity. With a rise in bale density, this becomes increasingly crucial. For small square, big round, and large square balers, the typical bale densities are roughly 130, 190, and 240 kg m^{-3}, respectively. In order to increase the quality of dry hay in humid areas, forage researchers and producers are designing bale ventilation and drying systems, using preservatives like propionic acid, and studying intensive conditioning methods to enhance field drying rates. To minimise leaf loss in arid areas, farmers only bale after dew buildup has softened brittle plant tissue. Systems are being developed that will use a fine water mist to soften plant tissue at the baler. Greater productivity and improved bale quality will be in demand as commercial hay markets expand and livestock farms grow in size (Muck and Shinners, 2021).

Forage quality

The feel, texture, smell, and appearance of a hay crop are frequently used by forage buyers and sellers to evaluate and estimate its value. This method of evaluating fodder quality is likely to result in poor and expensive decisions on feeding and purchase. The producer or manager can develop a well-balanced diet, use forages more efficiently in feeding programmes, and more accurately appraise and market available forage lots by evaluating the forages' nutritional value. The amount of nutrition that can be obtained from a particular lot of forage and the presence or concentration of any hazardous substances that could impair animal performance or endanger animal health are what determine the forage's nutritional value. To ascertain whether the forage is of sufficient quality, one must combine the forage's nutritional value with hypotheses or projections about how much of it an animal could consume. To produce the least expensive ration for the animals being fed, it is critical to comprehend the quality of the forage being used. Protein, mineral, and vitamin content can be estimated quite simply. However, a forage crop's main source of energy is primarily in the form of fibrous material. To evaluate fibre content and digestibility, a number of analytical techniques have been developed. Additionally, these projections have been calibrated to forecast animal performance and nutrition. Feeds made from byproducts and commodities tend to be more expensive. Of course, supplying high-quality feed (whether in the form of pasture, hay, baleage/haylage, or silage) is also not cheap. However, given current feed prices, premium forage is more affordable than the majority of fed supplements. A reduced digestibility forage won't provide the nutrients an animal needs without supplementation, raising the cost of production. As a result, increasing amounts of supplements are required to suit the needs of the animal (Hancock et al., 2014).

Roughages, like as straw and cereal hulls, are high-fiber diets that are typically obtained from crop residues or byproducts. Forages are high-fiber feeds that are produced by harvesting and conserving the entire plant (except roots). The terms "forage" and "roughage," though they refer to different items, are frequently used interchangeably. The term "foraging" refers to all feed intake behaviours on pasture and in housing conditions from a behavioural perspective. Hay is defined as cut grass that has been air dried or wilted in a field or barn, whereas silage is feed that has been retained moist and airtight and has fermented. 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 similar to hay, but baled before becoming dry, resulting in DMs typically >50 but 70% although occasionally up to 85%. The term "haylage" was originally used to describe silage with a DM content of around 50%. Inadequate turning, particularly if in rows (rather than being wilted widely, which helps speed up wilting and helps reduce protein degradation and loss of nutrients), etc. cause hay to be baled with too high of a moisture content, which promotes the growth of fungal spores and bacteria and raises the risk of mycotoxin development. Roughage/forage must therefore be preserved under controlled settings to stop unwanted microbial growth. Given that the bales will be exposed to air, relative humidity must be lower than that needed for mould growth at the given temperature, and is therefore ideally 70%. 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%). Airtight conditions can be used to preserve forages, either with or without lactic acid fermentation. Anaerobic lactic acid bacteria ferment the water-soluble carbohydrates in the forage to make silage (naturally occurring on the crop or added as inoculants). Crop DM concentration must preferably be around 30% or less and definitely be around 50% for sufficient lactic acid generation to occur. Unwanted microbial development will be prevented if the generated acids raise hydrogen ion concentrations to a sufficient level. pH can be used as an indicator to indicate proper ensiling of forages (without butyrate) with a DM 15% to 50% (Harris et al., 2017).

The primary element influencing forage quality is maturity. The amount of protein and minerals that can be digested is higher in young, green vegetative growth than it is as the plants mature. Less leaves, more stems, and more fibre (NDF) are seen in older forage. Lignin is deposited more as plants get older. The plant's strength and rigidity come from lignin. In addition, plants use lignin as a natural chemical defence against attacks from bacteria, fungi, and insects. The forage is protected against digestion owing to the method the plant utilises to offer this defence. As a result, lignin makes the forage far less digestible and less able to meet the animal's energy requirements. Although the amount of total dry matter (DM) yield grows as forage matures from the vegetative to reproductive stages of growth, there comes a point where this increase in DM yield (digestible yield) stops. Harvesting the crop as soon as the forage reaches the suggested stage for harvesting is essential due to the impact of increased maturity on quality. It is generally established that the digestibility and nutritional value of various forage species vary. Grass NDF is often substantially higher than that of legumes. Legumes are therefore typically more digestible than grasses. Similar to warm season grasses, cool season grasses are often lower in NDF and more digestible. The NDF digestibility varies amongst various forage types, too. For instance, a grass with 60% NDF in a cool season may actually be less digestible than a grass in a warm season. This is because these forage species and types produce different kinds of fibre and lignin. There can occasionally be variances even between forage species (Hancock et al., 2014).

Fodder legumes are special because they can produce high-quality forage to improve animal performance and because they can use atmospheric N, which reduces the need for soil N for legume plants to grow. For each species of legume, an efficient rhizobia strain must infect the root hairs in order for biological N_2 fixation to occur. Producers that cultivate legumes for forage have the opportunity to take use of both advantages. However, a variety of variables, such as legume species, management techniques, and environment, affect both forage quality and biological N2 fixation, which determines their contribution to a forage-livestock system (Evers, 2011).

Neutral Detergent Fiber (NDF) and Acid Detergent Fiber (ADF), two components of plant tissue composition, have been linked to forage DM digestibility, or the percentage of ingested DM that is metabolised by ruminant animals. The NDF concentration represents an estimate of cell wall content, while the ADF concentration is an estimate of the more lignified cell wall content. In order to predict the decline of these properties with plant ageing, the nutritional value of forage is typically assessed by correlating the nutritive value attributes to plant phenology. Domestic herbivores' need for forage is typically determined by two characteristics: 1) the concentration in crude protein (%CP), which roughly equates to the concentration of nitrogen (%N), with %CP = 6.25 %N, and 2) the concentration in metabolizable energy, or the portion of the forage's total energy that may be digested and metabolised by animals. The digestibility (%D) of fodder can be used to express the percentage of forage mass that is consumed by animals. Digestibility can be measured directly on animals through the dry mass balance between ingestion and feces excretion or more simply estimated by in vitro digestion of forage samples in an artificial rumen (%ivD). Forages may be related to chemical properties of plant tissues that indicate the level of rumen breakdown. These chemical traits are the concentrations of lignin (%), acid detergent fibre (%), and neutral detergent fibre (%). The entire forage mass (W) can be divided into three fractions: NDF-ADF, which corresponds to the cell wall fraction and has a moderate level of degradability; W-ADF, which would be the highly digestible plant tissues (%D=100%), roughly corresponding to cytoplasmic components; and ADF, which would be the non-degradable cell wall. In the first approximation, the ratio between these three plant tissue fractions thus determines the whole plant's digestibility. But as the digestibility of the ADF fraction is very variable, the use of these three biochemical fractions for predicting the energy value of forages through chemical analysis is very unprecise (Lemaire and Belanger, 2019).

The requirement for adequate amounts of minerals in the diet to guarantee excellent health and performance is one of the many components of herbage quality that are significant for ruminants. However, managing the mineral intake of ruminants fed on grassland can be difficult since mineral concentrations in the herbage depend on a variety of parameters, such as the species composition of the sward (Kuusela, 2006), the season (Hgh-Jensen et al., 2006), and fertiliztion (Soder and Stout, 2003). The plant species that are sown in temporary grasslands fall into three major functional categories: grasses, forage legumes, and forage herbs. If mineral concentrations are below what is considered ideal for animal nutrition, it may be difficult to provide an appropriate mineral supply in the diets of ruminants fed primarily on grassland herbage. Although little is known about the mineral contents of forage herbs, forage herbs can be added to grassland seed mixtures to increase the mineral content of the herbage. Both conventional and organic livestock production systems are permitted to employ mineral supplementation to meet the needs of the animals (Pirhofer-Walzl et al., 2011).

It is well recognised that environmental conditions significantly affect the quality of forage plants, particularly those growing in situations with various levels of stress. Forage yield and quality can vary significantly between seasons and years as a result of these pressures. When a plant's growth is hampered by an environmental issue, such as an unfavourable temperature range, standing water, a dry period, shade, or a lack of nutrients in the soil, stress results. Temperature often has a bigger impact on grasses' ability to be digested than other environmental conditions, mostly because it affects leaf-to-stem ratios, increases the amount of indigestible cell walls, and simultaneously lowers the amount of nonstructural carbohydrates. Contrarily, while shade decreases yields, it often has minimal and inconsistent effects on the quality of feed in grasses and legumes. Generally speaking, the impact of drought on the quality of fodder is minimal or even positive, especially if the stress on the leaf mass is not severe. Finally, it has been discovered that the impact of soil nutrients on the feed quality, which consists primarily of grasses, is negligible. N fertiliser application leads to better yield and more crude protein. Through various ways, adding S and Ca to soils that lack these minerals can improve the forage's ability to be digested. Through enhanced rumen fermentation, forage digestibility may be increased by addressing S deficit through fertilisation or animal feed additives. Digestibility appears to increase when calcium is used as fertiliser because plant cell walls appear to alter. Condensed tannins (CTs), which are significant secondary metabolites in some temperate and tropical legume species, have been demonstrated to influence quality characteristics of forage legumes with varied quantities. The ability of forage legumes to increase animal productivity is constrained by the high concentration of CT that can impair their intake and general nutritional quality (Lascano et al., 2001).

Mycotoxins and aflatoxins

Certain Aspergillus flavus strains, which are present in a variety of agricultural crops, are the primary producers of aflatoxins. Aflatoxin incidence can be extremely common and widespread in many lower-income nations, posing major public health concerns. Due to contaminated feeds, aflatoxins can have a significant impact on the health of cattle and poultry. Additionally, due to rigorous regulation in high-value markets, they considerably restrict the growth of international trade. Aflatoxin contamination can occur not only during crop production but also during the storage, shipping, processing, and handling processes due to their high stability. In order to reduce aflatoxin exposure, novel evidence-based methods are urgently needed. The most cutting-edge prospective solution for reducing aflatoxin contamination in crops to date is biological control, which makes use of the competitive exclusion of toxic strains by non-toxic ones. Commercial applications of this technique are made in the pre-harvest stages of groundnuts, maize, cottonseed, and pistachios. A number of more efficient technologies, including irradiation, ozone fumigation, chemical and biological control agents, and improved packing materials, can also reduce the contamination of agricultural products with aflatoxins after harvest. However, for long-term solutions to reduce aflatoxins contamination, which improves food security, reduces malnutrition, and supports economic sustainability, integrated use of these pre- and post-harvest technologies is still necessary (Udomkun et al., 2017).

Numerous mycotoxins frequently contaminate some diets, although the majority of studies have concentrated on the prevalence and toxicology of a particular mycotoxin. Worldwide regulations do not take the cumulative impacts of mycotoxins into account. However, numerous studies have documented the worldwide natural co-occurrence of mycotoxins. Most of the published data has concerned the major mycotoxins aflatoxins (AFs), ochratoxin A (OTA), zearalenone (ZEA), fumonisins (FUM) and trichothecenes (TCTs), especially deoxynivalenol (DON). Among the 127 mycotoxin combinations mentioned in the literature, the most frequent ones in samples of cereals and derived cereal products are AFs+FUM, DON+ZEA, AFs+OTA, and FUM+ZEA. However, only a few research included details on the number of co-occurring mycotoxins, the percentage of samples that were also infected, and the most common combinations discovered (Smith et al., 2016).

Alternative and novel feeds

Current difficulties to ruminant-based food production include environmental issues, climate change, and escalating competition for arable land between food, feed, and fuel. Therefore, in addition to the use of new resources, more sustainable feed production is required. New ones, such vegetable and fruit leftovers, are being examined in addition to the several food industry side streams (milling, sugar, starch, alcohol, or plant oil) that are already in use, but their conservation is difficult and their production is frequently seasonal. As an example of oilseed by-products, lipid-rich camelina (Camelina sativa) expeller has the potential to reduce methane emissions by enhancing ruminant milk and meat fat with bioactive trans-11 18:1 and cis-9, trans-11 18:2 fatty acids. Although faba beans (*Vicia faba*), peas (*Pisum sativum*), and lupins (*Lupinus* sp.) have lower methionine contents than soya bean meal (*Glycine max*), their effects on lactation performance and growth in ruminants are comparable. The most prevalent source of carbohydrates is wood, but agroforestry methods of feeding ruminants are uncommon in temperate regions. Due to cellulose and lignin linkages, ruminants have a difficult time using untreated wood, although various processing techniques can increase usability. In the tropics, ruminants can get extra protein from the leaves of fodder plants such Leucaena species, Flemingia species, and cassava (*Manihot esculenta*). A food-feed production system combines the cultivation of grass for ruminant feeding with the leaves and byproducts of on-farm food production. Smallholder farms can use it to sustainably increase animal performance. Detoxified jatropha (*Jatropha* sp.) meal is a notable substitute protein source for larger-scale animal production. The independence of production from arable land and weather is a major benefit of single-cell protein (bacteria, yeast, fungus, and microalgae) and aquatic biomass (seaweed, duckweed) over land crops. Depending on the species and growth conditions, these meals have a wide range of chemical compositions. For ruminants, microalgae have demonstrated good potential as lipid and protein supplements (e.g. Schizochytrium sp. and Spirulina platensis). A variety of cutting-edge or underutilised feeds have the potential to enhance or replace the conventional crops in ruminant diets. The most likely candidates to replace or supplement the traditional crops in the near future are N-fixing grain legumes, oilseeds like camelina, and increased use of food and/or fuel sector byproducts, particularly in temperate regions. Microalgae and duckweed with high yield potential, along with waste products from the wood sector, may eventually become economically competitive feed solutions on a global scale (Halmemies-Beauchet-Filleau et al., 2018).

Livestock diets

Forage crops can either be fed directly to cattle or processed through pre-digestion or partial drying. Animal feeds can be classed as bulky feeds or concentrates as a result of this processing. Bulky feeds, also known as fodder, are made from the aforementioned grass, cereal, and legume cropping. Examples of these crops include alfalfa, lolium, or a combination of the two. Animals can receive this fodder directly by grazing on pasture land, or they can receive it in a processed form such as hay (when the water content is greater than 15%) or dry (pelleted) biomass. Concentrates are typically biproducts of the preparation of cereal, oilseed, and legume seeds for use as food, biofuel, and textiles. Additionally, high energy feedstuffs including sugar-rich agricultural molasses and animal-derived lipids, such as fish bycatch discards, can be included. Therefore, the diet of livestock can consist entirely of forage or primarily of forage with concentrate addition. Concentrate supplementation is used to make up for nutrient shortages in the forage supply, increase animal performance (like milk production), or during particularly difficult developmental stages, including calving. Forage crops can be produced in mixed species farming to help the environment and offer nutrition. Improved nutritional quality can be achieved by providing cattle with diversified grazing pastures or by combining feeds. For instance, alfalfa can be planted alone or in conjunction with a variety of different grass species because it is the highest-yielding perennial forage legume and generates more protein per unit area than other forage legumes. Carbohydrates make about 50–80% of the dry matter (DM) in forage crops; if this percentage is too low, grains can be supplied as supplements. Insoluble structural saccharides like cellulose and hemicellulose, as well as storage forms like starch and water-soluble polymers, are the main types of carbohydrates (e.g., fructans). For both non-ruminant and ruminant animals, they are converted into simple sugars by the breaking of glycosidic linkages, or by microbial digestion and subsequent animal absorption (ruminants only). Rapid vegetative biomass formation is the most desirable characteristic of a healthy forage crop, especially those that undergo significant cutting throughout the growing season, despite the necessity to guarantee appropriate nutritional content, particularly in the end-product feed. The most crucial nutrients for cattle in forage crop vegetative biomass are proteins and water-soluble carbohydrates (WSCs), and ideally, these should retain their post-harvest quality. Epiphytic bacteria that live on and inside the plant may be crucial for crop nutrition and health, and some microbes can fix atmospheric nitrogen within the root systems of legume plants. Animal feed eaten by cattle may be easier for livestock to digest and absorb if bacteria living with plants are present. By producing certain binding molecules and/or siderophores, these bacteria may enhance the intake of trace elements in the animal stomach. In low input systems like those cultivated in the tropics, the rhizosphere microbiome is crucial for nutrient cycling and uptake in the soil. Research on the composition of the rhizosphere microbiome and the inoculation of new forage crops with advantageous microbes are likely to be priorities for future crops. As the vulnerability of the plants to these pressures differs between cultivars and species, mixed species farming also benefits disease and harsh weather tolerance. Forage breeding has focussed on monoculture selection regimes and there is scope for better mixed species crops that could be included in trials for new varieties (Capstaff and Miller, 2018).

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