



MORPHOLOGICAL TRAITS OF GRASSES AS PREDICTIVE METRICS FOR PASTURE QUALITY: A COMPREHENSIVE REVIEW

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ABSTRACT

This review evaluates the suitability of morphological traits as desirable forage quality metrics in grass species. Forage evaluation is aimed at improving the performance of animal as it provides important information required for estimating the feeding requirement of the animal to meet their physiological needs. Conventional quality evaluation methods such as the Weende system of forage chemical analyses, Tilley and Terry in vitro digestibility technique, Van Soest, fibre fractionation system, near infra-red reflectance spectroscopy (NIRS), Meinke and Steingas gas production technique, and in vivo animal feeding trials provide reliable nutritive value and are widely used to predict animal performance. However, these methods are often expensive, labour intensive and technically demanding, thereby limiting their applicability in resource constrained production systems. Consequently, a basic, rapid, and affordable field evaluation is needed as an alternative to ensure improved animal performance. Since morphological traits have been shown to modify the key forage nutritive attributes, hence it can be employed as a metric of forage quality. However, constraints such as lack of capacity for direct quantification of critical forage predictive parameters such as crude protein, fibre fraction and digestibility, as well as sensitivity to maturity and variability arising from agronomic practices, limit their reliability as the sole determinant of forage quality. Enhancing predictive accuracy will require integrative approaches that combine morphological traits with maturity indices and management factors. Such an approach may provide a feasible method for improving forage evaluation and contributing to better livestock productivity under field conditions.

Keywords: Forage Quality, Animal Performance, Field Assessment, Integrating Approach

INTRODUCTION

Pasture remains the major source of feed in ruminant production; it provides affordable feed with great nutritive value for sustainable livestock production (Msiza, 2021), reducing the burden of overdependence on conventional feeds and optimizing rangeland use for efficient livestock production. Paramount to productive livestock performance is the assessment of forage quality, measuring the extent of feed intake and utilization of the nutrients, thereby serving as a guide for the forage potential to support animal production. Crucial parameters, including crude protein, fibre fractions and digestibility, are widely adopted as forage quality metrics due to their significant influence on animal performance. However, these parameters can only be estimated through various well outlined laboratory procedures and in vivo animal feeding trials, making it costly, time consuming, and technically demanding. Nonetheless, there is a need for a practical, basic, and cost effective approach as an alternative to laboratory and animal trial methods for quality evaluation, especially in resource limited production systems. Therefore, a field assessment involving morphological characteristics, which have been demonstrated to modify the essential quality parameters could be employed to examine forage quality. Traits such as leaf parameters (leaf area and leaf-stem ratio), stem thickness, plant height, and tiller density are key parameters proven to be strongly associated with quality metrics hence, they are widely investigated and reported. In addition, the morphological traits markedly influence the intake and palatability of grass species (Pauler *et al.*, 2020). This further emphasizes the need to consider them as quality predictors, as both parameters are critical to better livestock productivity. Beyond increasing animal performance, high quality forage has been reported to reduce methane emissions and decrease energy loss in ruminants by efficient conversion of carbohydrates to volatile fatty acids, circumventing

methane production (Sun *et al.*, 2023). This practice ensures improved animal production and environmental safety.

Nonetheless, while the morphological traits of the grasses provide predictive indications on their respective qualities, it is vital that pertinent factors such as species, climatic conditions, and management, which play considerable roles in shaping these traits, are consequently integrated with these factors to make more reliable and informed knowledge. Furthermore, the inclusion of newly discovered traits evaluated in situ and at scale with hindrances accompanying the utilization of such discoveries should also be captured with beneficial details.

Based on their decisive roles in influencing the nutritional composition and digestibility of grass species, morphological traits provide a practical approach for rapid field base assessments in the forage selection for livestock feeding. A clear understanding of these traits can facilitate the selection of grasses with superior productive potential. This review evaluates the current knowledge on the use of grass morphological traits as predictive tools for assessing forage quality. Furthermore, it examines the relationship between specific traits and forage nutritive value, evaluates their applicability for forage assessment, and identifies key limitations associated with their use. The review also highlights existing knowledge gaps and proposes an integrative approach to improve the accuracy and reliability of morphological traits as a forage quality metric, with implications for pasture and productive livestock performance.

Forage Quality Assessments

According to Fulgueira *et al.* (2007), forage quality is defined as the extent of consumption of forage and efficiency of utilization of forage nutrients by animals. Therefore, animal productivity is the most reliable determinant of forage, reflecting the combined effects of nutrient intake, digestibility

and utilization efficiency. They highlighted that six factors, including maturity (harvest date), crop species (differences between grasses and legumes), harvesting and storage technique, environment (moisture, temperature and amount of sunlight), soil fertility and variety or cultivar, impair forage quality. In addition, weeds, insect pests, plant diseases and the presence of bacteria, moulds, and/or some of their metabolites, e.g. mycotoxins can negatively affect forage quality. Forage quality assessment remains a fundamental component of efficient livestock production, providing a basis for supplying nutritionally adequate forage for optimal animal performance. Sustainable animal production relies largely on feeding high quality forage that provides essential nutrients in the appropriate quantity required for physiological requirements.

A range of methods has been developed to evaluate forage quality. Carlier *et al.* (2009) classified forage evaluation into two methods: destructive and non-destructive quality evaluation. Destructive method consists of chemical analysis, *in vitro* digestibility (Tilley and Terry, 1963), and the Van Soest system, while the non-destructive method is near-infrared reflectance spectroscopy (NIRS). Also, sensory evaluation (Schroeder, 2004), *in vivo* digestibility trial, nylon Bag / *in situ* technique (Menke *et al.*, 1979), and prediction equations and feed value indices.

The concept of chemical analysis developed by Henneberg and Stohmann in 1857 and referred to as the Weende scheme for the chemical analysis of roughage, involves the quantification of crude protein, crude fibre, crude fat, crude ash, and nitrogen free extract. Chemical analyses prove to be fundamental to estimate forage quality (Colombatto 2000; Undersander and Moore 2002; Redfeam *et al.* 2004). Also, Beever and Mould (2000) showed that forage fibre composition is a major determinant of forage quality with the potential to predict intake and nutritive value in ruminants. The forage samples that exhibit high crude protein and low crude fibre contents are associated with enhanced feed intake and improved digestibility, which consequently results in better animal performance while elevated crude fibre content is associated with reduced digestibility and nutrient utilization. In a study by Riaz *et al.* (2014), crude protein modifies dry matter intake and dry matter digestibility. It was revealed that crude fibre negatively influenced forage digestibility. This is further corroborated by Kaithwas *et al.* (2020) who reported that lower total digestible nutrients (TDN) and dry matter intake (DMI) values for cereal fodders might be due to more fiber and low nutrient digestibility compared to legumes. Furthermore, legumes were richer in protein and lower in fiber, which resulted in higher nutrient digestibility and rumen degradable protein than cereal fodders. Forage with crude protein above 7% is considered suitable for rumen microbial activity (NRC, 2001) while forage below requires supplementation with protein sources for improved fibre degradation, nutrient availability and utilization. A forage crude fibre above 18% is considered poor quality silage therefore, feeding such silage to animals could impair animal performance due to reduced intake and digestibility. Paramount components in Weende scheme is crude protein and crude fibre as principal predictors of forage quality.

In vitro digestibility is a famous forage quality evaluation procedure developed by Tilley and Terry in 1963. It employs the principle of microbial digestion using rumen fluid obtained from sheep and enzyme pepsin on a forage sample within a specific period of time (48 hours rumen fluid and 48 hours pepsin) at 38 °C. Despal *et al.* (2022) examined the accuracy of Tilley and Terry forage quality prediction method

and found that it is more accurate for assessing the *in vivo* digestibility of tropical dairy feedstuffs compared to other *in vitro* methods under trail. As the measure of forage quality depends largely on the digestibility of fibre fractions (NDF, ADF and ADL), the quantity of fibre degraded serves as the expression of forage quality (Weiss and Hall, 2020). Therefore, extent of dry matter and organic matter digestibility indicates the forage quality. Forage with higher digestibility values indicates improved nutrient availability and better productivity. High quality forage shows dry matter digestibility values ranging from 65 to 75% and organic matter digestibility between 60 and 70%, whereas values below 50% for both parameters denote poor quality forage (Arzani, *et al.*, 2013).

Van Soest system of forage quality evaluation is premised on the use of cell wall components to assess the forage quality. The cell content contains total ash, protein, fat, non-structural carbohydrates, organic acids, enzymes, etc. The cell wall (neutral detergent fibre) refers to the hemicellulose, the cellulose and the lignin of the forage. Acid detergent fibre (ADF) content (cellulose and lignin) can be estimated using acid detergent, shulphuric acid, and cetyl trimethylammonium bromide, while subsequent treatment with shulphuric acid and permanganate enables the estimation of cellulose and lignin. NDF content is used for the prediction of feed intake. Forage that exhibits high NDF levels is associated with decreased feed intake and also diminish forage efficiency (Ward 2005). ADF measures the forage digestibility, which decreases with increasing ADF content, forage with low ADF is highly desirable for animal performance. Kellems and Church (1998) cited by Amuda and Tubasen (2023) reported high quality forage contain ADF less than 40% while those with values high than 40% are poor quality forage. Also Sing and Oosting (1992) cited by Amuda and Tubasen (2023) stated desirable feeds comprise 45% NDF while feeds with values ranges between 45% to 65% could be categorized as medium and those above 65% as low quality.

An *in vivo* digestion trial involves the determination of digestibility from feed intake and faecal output. It is the actual measure of animal response as it is the actual reflection of digestion process in animals. However, it is time consuming and expensive. Sample of forage with known nutritional composition is fed to the animals for a certain period of time, and afterwards the total faecal collection is carried out. Collected samples are analyzed for chemical composition then dry and organic matter digestibility is calculated from the values obtained from the analysis (Tassone *et al.*, 2021). In recent times, the new practice, instead of laborious total faecal collection, is the use of internal or external markers and the use of rumen or duodenal cannulas has been reported to measure the flow of digesta (Mohamed and Chaudhry, 2008). Near-infrared reflectance spectroscopy (NIRS) is a nondestructive technique invented by Norris *et al.* (1976). It involves the use of the spectrum, which presents a forage sample after radiation with near-infrared light, to predict all kinds of characteristics like protein, fat, ash, cell wall, lignin content, digestibility, etc. The wavelength of most NIR instruments utilized in forage evaluation ranges from 800 nm to 2500 nm part of the spectrum. When exposed to incident radiation, forage materials reflect, absorb, and transmit portions of infrared energy at specific wavelengths, a response influenced by their underlying chemical structure and composition. The interaction between infra-red light and molecular bonds is the basis for predicting forage composition in NIRS. It is a rapid and reproducible and require samples simple sample preparation. In contrast, accuracy of the results

relies on the g on the lab analysis with which the spectra are standardized and calibrated.

Sensory evaluation involves employing physical parameters such as colour, odour, leaf content, maturity, softness, purity, observations on palatability to determine forage quality (Fulgueira *et al.*, 2027). This method is mostly adopted in preserved forage (silage and hay). They provide crucial information for the quality assessment. The physical parameters are the reflection of the occurrences during the forage preservation, therefore they serve as vital guides in evaluating desirable forage. Such parameters may be instrumental in forage quality evaluation, nonetheless, there is limitation regarding assessment, since they remain both highly subjective and difficult to standardize (Schroeder 2004).

Although the identified forage quality assessment techniques exhibit marked precision in evaluating nutritional composition and digestibility, limitations such as high cost, labour requirement, dependence on well trained and skilled personnel, and need for specialized apparatus hinder their accessibility and routine application. Furthermore, there is a likely occurrence of issues relating to accuracy and reliability in some techniques, specifically, where procedures involved calibration or subjective assessment like in NIRS. Nevertheless, considering multiple evaluation methods for a forage sample may improve prediction accuracy and enhance the reliability of forage assessment.

Consequently, existing forage evaluation methods are largely laboratory restricted or animal trial procedures, which may impede seamless regular application under field conditions. This necessitates the need for simple, rapid, and affordable approach for quality assessment. Despite the considerable

influence of plant morphological traits on forage nutritive value, they have received relatively limited attention as a metric of forage quality. Morphological parameters such as plant height, leaf dimensions (length and width), leaf-stem ratio, tiller density, and leaf number have been closely linked with forage quality, due to their influence on biomass partitioning, maturity, and the proportion of forage digestible components (Tulu *et al.*, 2024).

Studies have shown that leaf-stem ratio and stage of maturity are key determinants of forage nutritive value, with leafy forage often showing increased crude protein content and digestibility (Mganga *et al.*, 2021). A study by Gelley *et al.* (2017) revealed that crude protein is positively correlated with the proportion of lamina in forage species including switch grass, sorghum × sudan grass, and Bermuda grass. Furthermore, morphological development has been associated with variations in fibre fractions and intake potential, demonstrating its indirect role in determining forage quality (Tulu *et al.*, 2024). Tiller size, architecture, and reproductive status of grasses change as they develop, which subsequently impacts the quality of forage available to grazing animals or harvested. The fibre fraction increases with advanced plant maturity, the increased NDF and ADF result in low feed intake and digestibility of the forage. Interestingly, these parameters can be estimated using simple field equipment, with minimal involvement of technical expertise. Although morphological parameters may have precision deficiency in estimating key nutritive parameters such as dry matter digestibility, crude protein, and fibre fractions, they can provide valuable preliminary insights for proper guides on forage selection and decision making, especially where there is resource scarcity.

Table 1: Comparison of Various Forage Quality Evaluation Methods

Method	Principle	Major Parameters Measured	Advantages	Limitations
CP, digestibility	Quantification of chemical component of forage	CP, CF, EE, Ash, NFE	Widely accepted, quantitative	Time-consuming, required facilities
Intake, digestibility	Cell wall fraction analysis	NDF, ADF, ADL	Good predictor of intake and digestibility	Requires laboratory facilities
Biomass, CP	Simulated rumen digestion	Dry matter digestibility	Good estimate of feeding value	Rumen fluid is needed, high technicality
CP, digestibility, intake	Animal feeding trial	Actual nutrient utilization	Most accurate	Expensive and labour intensive
Biomass, fibre content	Spectral reflectance analysis	Multiple Nutritive parameters	Rapid and non-destructive	Calibration is essential
Yield, persistence	Visual and physical assessment	Colour, odour, texture, maturity	Cheap and simple	Subjective

CP: crude protein CF: crude fibre EE: ether extract NFE: detergent fibre ADL; acid detergent lignin NIRS: Near-Infrared reflectance spectroscopy

Morphological Traits

Table 2: Major Morphological Traits and Their Relevance to Forage Quality

Morphological Traits	Methods of Assessment	Relationship with Forage Quality	Main Quality Indicators Affected
Leaf length	Measure using meter rule	Positive	CP, digestibility
Leaf width	Measure using meter rule	Positive	Intake, digestibility
Leaf number	Count leaves per plant	Positive	Biomass, CP
Leaf-stem ratio	Leaf DM/Stem DM	Strong positive	CP, digestibility, intake
Plant height	Base to apex measurement	Variable with maturity	Biomass, fibre content
Tiller density	Number of tillers per unit area	Positive	Yield, persistence
Stem thickness	Stem diameter measurement	Negative when excessive	Fibre concentration

Morphology of grass deals with the form and how parts of grass are arranged, such that they give a distinct shape that denotes a particular species. Generally, plants exhibit morphological characteristics that emerge from the pattern of shoot system initiation, enlargement, and display, including the growth of roots, tubers, and rhizomes below the ground.

Apart from identification, the morphology and growth patterns of these structures in both natural and managed environments provide insight into their adaptability, productivity, quality, and persistence of forage. These features characterize forages suitability for livestock production.

Numerous studies have demonstrated the impacts of morphological traits of grasses such as leaf morphology including leaf length and width, leaf-stem ratio, leaf sheath and blade texture (Khaled *et al.*, 2006; Moore *et al.*, 2020; Garcia *et al.*, 2021), tiller density (Nelson *et al.*, 1994; Cashman *et al.*, 2016), plant height (Zewdu *et al.*, 2002; Cullen *et al.*, 2017; Gelley *et al.*, 2017; Bell *et al.*, 2021), stem thickness (Lemaire *et al.*, 2019), and root morphology (Hakl *et al.*, 2018), on grass quality. These traits have been verified to be associated with forage quality. In addition, the traits such as leaf length and width, leaf number, leaf-stem ratio, plant height, and tiller density have received notable attention from researchers; this could be attributed to their significant influence on forage desirability for animal performance.

A combination of these parameters can provide preliminary knowledge and insight into the nutritive value of forage. It has been established that forage morphological traits have a significant impact on chemical composition, energy level and feed intake; therefore, it is pertinent to animal performance and management decisions. Since these traits play a significant role in modifying the quality predictive parameters such as nutritional composition, dry matter and organic matter digestibility, while other quality evaluation techniques are predominantly laboratory based, therefore, they can be explored metric as metric tool in field quality assessment.

Leaf Morphology

The relevant leaf morphological traits comprise leaf length and width, leaf-stem ratio, leaf sheath, nature of the leaves, and blade texture. Considering the simplicity and affordability of measuring these parameters using a simple field instrument, such as a meter rule, they provide an empirical and accessible means of evaluating forage quality seamlessly under diverse production systems.

These leaf parameters are crucial for productive animal production, as leaves represent a primary edible component of the forage, and play a decisive role in modifying the nutritional value and productivity of the grass species. The variation in the leaf attributes of grass species emanates from genetic factors, climatic conditions and management practices (Mengistu *et al.*, 2016). The interaction of these factors shapes the leaves as a crucial metric of forage quality. Leaves have been verified to possess higher crude protein, feed intake, and digestibility compared to stems (Mahyuddin *et al.*, 2007; Moore *et al.*, 2020; Mganga *et al.*, 2021). In addition, age is another source of variation in leaf parameters. The leaf parameters rise correspondingly with increasing age, and the quality also diminishes owing to increased accumulation of lignin. The crude protein is higher in the young leaves than old leaves, while fibre content increases as the leaves age (Erkovan *et al.*, 2009; Agnusdei *et al.*, 2012; Qadir *et al.*, 2022). In accordance with several findings, species with considerable leaf area tend to contribute more to biomass than those with paltry leaf area (Price *et al.*, 2014). Aside contributing to biomass yield, high leaf proportion denotes a great forage quality owing to increased feed value underscored by high nutritional composition and digestibility. Naturally, variation exists in the leaf parameters of grass species; some species show morphological adaptations, characterized by notably elongated and broadened leaves. Species possessing more substantial leaf parameters are purported to enhance livestock productivity through their improved leaf nutritional components, intake and digestibility.

Also, management practices such as fertilizer application (Lopes *et al.*, 2017), adequate spacing, timely weeding and proper defoliation (Ansa and Garjila, 2019) enhance leaf

emergence and elongation. Fertilizer application increases soil nutrients, thereby enhancing the overall growth in grass, with leaf emergence and elongation also stimulated. Adequate spacing wards off unwanted competition especially for available soil nutrients, therefore allow optimum utilization of the soil nutrients. This promotes improved growth in grass species and better productivity. Furthermore, adequate spacing allows maximum utilization of soil moisture and better exposure to light, which promotes leaf growth. Timely weeding reduces competition from weeds for resources required for healthy growth. In a weed free pasture or range land, water uptake and light exposure rise, consequently, favour leaf growth and development.

Defoliation has been reported to affect herbage production. Poor defoliation management shifts the grass species beyond phenotypic plasticity. A poorly defoliated pasture may exhibit defects in leaf parameters (Kefyalew *et al.*, 2020; Calsina *et al.*, 2012). Interaction between defoliation and climatic factors such as precipitation and temperature has been revealed in various reports. Proper defoliation promotes compensatory root growth responses under ambient rainfall and temperature while frequent defoliation can exacerbate the negative effects of drought on root length, particularly in desert area.

The photoperiod (Lopes *et al.*, 2017), rainfall and temperature play a crucial role on the leaf morphological traits. Areas with favourable climatic conditions augment leaf parameters that support improved livestock production. Extended photoperiod stimulates growth, increases leaf area, and enhances leaf development in grass species. The cell division and elongation are promoted by longer day length thereby raise the leaf length and width. Sufficient moisture required for efficient growth is supplied by rainfall hence, drought and variability in the amount of rainfall impact leaf growth and development. The optimal temperature varies in grass species; a correlation exists between leaf elongation and temperature, especially in humid temperate regions. Consequently, extreme temperatures can affect leaf development and plant productivity.

The number of leaves is another paramount leaf morphological parameter, pertinent to improving forage quality prediction. It is estimated by simply counting the number of leaves attached to the stem and record. Therefore, enormous priority should be accorded to it to foster productive decisions on forage selection and evaluation. Grasses with greater leaf numbers are generally more desirable for livestock feeding, as they have the potential to offer improved feed value and palatability, thereby optimizing animal performance. The possession of leaves in large numbers in grass species contributes largely to the biomass yield and also raises the leaf-stem ratio. The number of leaves varies in grass species, with some species exhibiting a greater number of leaves than others. The species with a larger proportion of leaves than stem in the total biomass are associated with improved animal performance owing to enhanced voluntary intake and digestibility. Nonetheless, the number of leaves is also influenced by the factors previously described.

The leaf-stem ratio is a prominent factor in livestock feeding, considered the most critical factor in the forage quality assessment due to its inherent nutritional merits that promote improved animal productivity. It is determined by separating the leaves and stems of randomly selected grass, followed by drying and weighing the separated parts, and recording. Afterwards, estimate the leaf-stem ratio as the ratio of leaf dry weight and the dry stem weight. The leaf-stem ratio above a value of one represents a desirable quality, while values below

one depict low quality. The species with long and broad leaves and a large number of leaves usually have high nutritive value, while those with short and narrow leaves and a scanty number of leaves have low nutritive value. The higher the values of the leaf-stem ratio, the more desirable the forage for improved animal performance. Species exhibiting an exceeding leaf-stem ratio have higher crude protein, feed intake, and digestibility. Factors that favour improved leaf parameters, such as leaf length, width, and number of leaves, consequently affect the stem-stem ratio.

Leave parameters form the readily accessible basis of assessing grass quality; they can be easily estimated and provide insightful understanding of forage quality, improve precision, and possess a strong link with quality parameters such as chemical composition and digestibility indices.

Plant Height

Plant height is a crucial morphological trait contributing significantly to forage biomass production (Freeman *et al.*, 2007). It demonstrates the collective effects of growth processes, including leaf elongation, tillering, and canopy development, on which the accumulation of herbage and forage availability are premised. Grass height is commonly determined by vertical measure of the distance from the base of the grass to the apex of the topmost leaf with the aid of simple measuring devices like a meter rule or measuring tape, making it a simple and affordable practice with very useful information for yield and quality determination.

Several studies have demonstrated the strong correlation between forage height and yield. For instance, Wang *et al.*, (2025), reported an increase in *Poa* species yield is attributed to a considerable increase in plant height, which translates to enhanced canopy formation and dry matter accumulation. However, plant height is not a static trait in grasses; it shows great variability, influenced by both genetic traits peculiar to the species and cultivars and external multifactorial effects. Agronomic practices such as fertilizer application, optimal seeding rates, regular weed control, grazing pattern, and adequate spacing markedly alter the forage height (Sbrissia *et al.*, 2018). Likewise, frequency of defoliation modifies height dynamics by altering leaf area recovery and carbohydrate reserves, thereby affecting regrowth potential of the grass (Martins *et al.*, 2021).

Beyond increasing biomass production, consideration of plant height in species selection and evaluation of forage provides several advantages, such as enhanced grazing efficiency, suppression of weeds, and facilitated mechanical harvesting. Plant height is strongly linked with regrowth, and it is one of the crucial traits largely considered for forage breeding. The selection for plant height is largely considered a prerequisite for regrowth and yield. According to Freeman *et al.* (2007), the individual plant height taken before the reproductive stage serve as a reliable metric for biomass yield of the forage crop, it was also demonstrated further that the product of plant height and index of Normalized Difference Vegetation Index (NDVI) showed the greatest correlation with by-plant forage yield on an area basis. Using NDVI alone is insufficient for determine the forage yield in an area, plant height becomes a reliable predictor in connection with NDVI.

Studies have linked forage height with forage accumulation. The frequency of defoliation and height of grazing are predominant factors for forage accumulation. Lower residual height stemming from high defoliation intensity causes slow accumulation rates of forage due to a longer period required to attain maximum canopy. Maintaining a good height provides an advantage for a short regrowth interval (Martins *et al.*, 2021).

Forage height impacts grazing directly through bite mass. Forage of higher plant height provides a better depth for grazing, thereby increasing the bite mass per unit area. This enhances dry matter intake and grazing efficiency. Defoliation period, height of grazing and defoliation is largely modified by plant height. A taller forage provides a better height for grazing and defoliation in which in turn promotes swift regrowth and forage accumulation. Baldissera *et al.* (2016) described canopy height as a cutting criterion. It was reported that canopy height and leaf index area have strong correlation with forage production and sward structure, they are adopted as a cutting criterion which reflects canopy interception. Macedo *et al.* (2021) showed that canopy height is essential for estimating light interception and determining the ideal defoliation period. The forage height determines the light intervention. As the height increased the leaf index area also increases while light penetration reduces and light penetration increases. The optimum height at which defoliation can take place is determined by the light intervention at a certain height in which optimum biomass production can be attained. The taller species provide a huge opportunity for improved yield at a height that also facilitates rapid regrowth and accumulation of forage.

Linking maturity and height of the plants together could assist in discerning how increased height may influence nutrient availability and digestibility. Since height increases correspondingly with age, then the occurrence during maturity can be attributed to the height. In a study by Wilman *et al.* (1998), it was observed that the forage harvested earlier at a lower height constituted lower lignin and neutral detergent fibre than the forage harvested later at a higher height. Huhtanen *et al.* (1994) showed that increasing maturity in forage elevate cell wall constituent, decreasing crude protein content of the forage. At a lower height, high foliage proportion, and at a vegetative stage of growth, a grass plant tends to be rich in protein and highly digestible. However, as it approaches maturity, the constituents of cell wall material becomes abundant, and the proportion of cell contents declines. Consequently, an increase in the fibre fraction (Neutral Detergent Fibre) and a decrease in the crude protein content, which lowers digestibility and metabolizable energy (Finch *et al.*, 2002). Bell *et al.* (2018) showed that the dry matter digestibility of pasture is positively correlated with pasture crude protein concentration. Therefore, cutting at a desirable height could prevent the concerns associated with maturity.

Bell *et al.* (2020) revealed that change in pasture biomass and height affect nutrient levels, causes seasonal variations in botanical content, abundance, and maturity. An elevation in pasture height diminishes dry matter content while enhancing sugars, nitrate nitrogen, and ash content. During plant growth, the sugar content increases as the stem to leaf ratio rises, with sugars mainly stored in the stem of the grass plant (Finch *et al.*, 2002). It was observed that taller species are less digestible (Frame & Laidlaw, 2011), but possessed significantly high dry matter and Neutral Detergent Fibre, but minute sugars, ash, dry matter digestibility, oil, nitrate nitrogen and metabolizable energy. According to Zewdu *et al.* (2002), neutral detergent fibre (NDF), acid detergent fibre (ADF), and acid detergent lignin (ADL) of Napier grass were considerably modified by height at cutting. He further affirmed that the reduction in dry matter digestibility with increasing growth in tropical grasses is widely attributed to an increase in structural components, including cell walls.

Conclusively, the height of grass is not just a fundamental predictive parameter of growth in grass species but also a great metric of nutritional composition. Consideration of

height as a profound predictive metric should receive more attention as the height provide invaluable information that supports improve ruminant production.

Tiller Density

According to Jewiss (1972), a tiller can be referred to as the basal shoot or side shoot that emerges from the base of plants. Kirby and Faris (1972) describe a tiller in relation to wheat as a structure that initiates as a bud, grows in length and leaf number, and may survive to produce an ear. Hussein (2014) stated that tillers are branches produced by vegetative axillary meristems that form in the leaf axil of lower leaves of the plant. They further explained that tiller development occurs in three stages, comprising axillary meristem initiation, bud development, and outgrowth of the axillary bud into a tiller. Wilson (1998) narrated that dry matter accumulation, yield components, and grain yield are merits derived from the tillers. Jewish (1972) revealed that tillering is crucial in the establishment, regeneration, or perennation of a grass sward, particularly for regrowth after cutting or grazing. Gruss and Moore (2005) reported that tillers can emerge in two main ways, including intravaginal and extravaginal. Intravaginal growth involves the vertical growth of the tiller inside the leaf sheath, while in extravaginal, growth of the tiller occurs laterally through older leaf sheaths. In grass species, they primarily function in shaping sward structure.

Based on Kays and Harper (1974), tiller density refers to the number of tillers per unit area, which becomes independent of the initial sowing density through the action of multiplication, growth, and death of tillers and genets while tillering, is the process in cereals and herbage grasses where a hierarchy of shoots (tillers) is produced.

Various factors contribute to shaping tiller density; this ranges from management practices (Nelson *et al.*, 2020) such as fertilizer application, climatic conditions, such as photoperiod (Veras, *et al.*, 2020), altitude (Wassie *et al.*, 2018), period of defoliation (Wassie *et al.*, 2018), hormone (Zhang *et al.*, 2022; Luo *et al.*, 2021; McSteen *et al.*, 2009, light intensity and light quality, stocking density and grazing pattern, and genetic factors.

Relevance of Tiller Density to Grass Quality

Tillering capacity of a grass species is a profound feature substantiate its suitability for sustainable livestock production, due to its decisive role in influencing biomass yield and feed value. It can be basically estimated by using meter rule or any other well calibrated distance measuring devices. The circumference of the area covered by randomly selected grasses are measured from both side of the grasses. It influences several key quality parameters such as biomass yield, canopy formation, regrowth, persistence, and nutritional components, imperative for sustainable forage production. Tiller density is a reliable quality metric as it plays a prominent role in the quality parameters highlighted earlier. Biomass yield remains a critical priority in pasture establishment. Increased biomass and dry matter yields not only provide more feed for optimal performance of the animals but can also provide an excess, which can be conserved as hay or silage to ensure a continuous feed supply during drought periods.

Hendriks *et al.* (2016) demonstrated tiller density as a measure of persistence in tall fescue and perennial ryegrass. It was established that tiller density played a substantial role

in grass species persistence, as tall fescue grass with 4 leaves/tiller was able to withstand frequent grazing better than ryegrass species with 3 leaves/tiller. The study by de Lima Veras *et al.* (2020) further emphasized that the advantage of cultivars that have a higher total population density is that tillers are essential for the persistence of pastures due to their enhanced efficiency in the use of resources such as water, nutrients, and light (Lopes, *et al.*, 2011) which promotes a quick recovery after a period of scarcity of these factors (Gurgel *et al.*, 2017). Veras *et al.* (2020) also attributed increased forage mass in *Panicum maximum* cultivars (Massai and Tamani) to high total population density.

Large tiller number favours increase in the forage biomass than those with fewer ones. This can be explained by the morphogenic characteristics, such as leaf appearance and elongation rate, leaf life duration, and stem elongation rate, which influence the tillering dynamics and determine the structural responses in tropical grasses. This finding is also corroborated by Wassie *et al.* (2018), the tillers generate more leaves which become expanded to cover more area and, in consequence, raise the leaf area index. This promote formation of canopy and increase light interception at the rate that increases forage accumulation thereby improve grass productivity. As more tillers emerge, the number of leaves increase considerably, the rise in the proportion of leaves results in an increase grass quality. Leaves have been confirmed to possess more nutritional value than stems. Leaves contain higher crude protein and less fibre than stems. High crude protein promotes digestibility through supplying nitrogen to the rumen microbes, thereby increasing the activity of rumen microbes. This enhances the formation of short chain fatty acids, the immediate source of energy for animals. With high leave proportion, the rumen retention time decreases due to low fibre content. This improves the performance of the animal tremendously.

Tiller density contributes considerably to the height of defoliation, emphasize by its impact in canopy formation. The grass species with higher number of tillers produces a denser canopy in a shorter time, thereby can be defoliated or grazed at a lesser height when the nutritional component is at peak in forage, without negative impact on their regrowth. In contrast, those with less number of tillers in which the formation of canopy occurs at a later period consequently results in decrease forage nutritive value. The merits of considering grass of high tiller density lie extends beyond increased biomass yield but also shorten the defoliation period without adverse effect on the regrowth. The grass that possesses few tillers requires more time for canopy formation therefore, forage accumulation is negatively impacted resulting in a declined yield, low light interception, delayed defoliation and regrowth. The grass species with high dense network of tillers tends to utilize resources (light, water, nutrient) efficiently, capture more PAR and enhance photosynthetic activities resulting in increased biomass production.

Grasses with high tiller density have ability to withstand grazing pressure than those with low tiller density due to the possession of multiple tillers which provide sustainable food reserves and numerous reproductive buds. Persistence is an essential quality required for successful pasture production and animal feeding. Withstanding a grazing pressure provides an opportunity for frequent grazing and proper regrowth, which ensure quick recovery and continuous availability of forage for the animals.

Table 3: Relationship between Morphological Traits and Forage Nutritive Parameters

Traits	Crude Protein	NDF	ADF	Digestibility	Voluntary Intake
Leaf length	↑	↓	↓	↑	↑
Leaf width	↑	↓	↓	↑	↑
Leaf number	↑	↓	↓	↑	↑
Leaf-stem ratio	↑↑	↓↓	↓↓	↑↑	↑↑
Plant height (early stage)	↑	↓	↓	↑	↑
Plant height (late stage)	↓	↑	↑	↓	↓
Tiller density	↑	↓	↓	↑	↑
Stem thickness	↓	↑	↑	↓	↓

Table 4: Factors Affecting Morphological Traits and Forage Quality

Factor	Morphological Effect	Effects on Forage Quality
Plant maturity	Increased stem proportion	Reduced CP, increased fibre
Fertilizer application	Enhanced leaf growth	Improved nutritive value
Plant spacing	Increased leaf expansion	Better quality and biomass
Defoliation management	Affects regrowth and tillering	Alters quality and persistence
Temperature	Influences leaf elongation	Affects productivity
Rainfall	Influences growth rate	Affects nutrient composition
Photoperiod	Modifies leaf development	Influences biomass production

Limitations to the Use of Morphological Parameters as a Forage Quality Metric.

The sole use of morphological parameters as a quality metric is accompanied by limitations. The direct quantification of critical nutritional components such as crude protein, fibre fractions, and digestibility indices (dry matter and organic matter) required for improved prediction of animal performance and meeting physiological requirements is not achievable using morphological assessment.

In contrast, laboratory chemical analyses quantify the nutritional composition of the forage, thereby providing more detailed information for increased prediction accuracy. Digestibility trials could further estimate the proportion of nutrients available for utilization. These techniques enable more informed decisions regarding nutritive value and animal performance, highlighting the constraints associated with the reliance on sole morphological traits.

Nelson *et al.* (1994) identified plant maturity as the principal factor influencing the morphology. As the plants age, the proportion of stem increases, the leaf stem-stem ration declines, resulting in increased fibre accumulation and the nutritive value diminishes (Moore, 2020). This temporal effect could distort the outcome of the assessment; for instance, a mature plant may exhibit a relatively high leaf proportion yet possess low digestibility due to lignification. Therefore, the stage of growth at the time of measurement must be considered when interpreting morphological data for improved prediction.

Furthermore, agronomic factors such as seed rate, planting density, and fertilizer application significantly influence morphological characteristics. For instance, fertilizer application has been shown to enhance crude protein content and reduce fibre fractions, while also promoting rapid growth. As a result, fertilized and unfertilized forages may possess similar morphological features (e.g., plant height) but with a marked variation in nutritive value due to differences in growth rate and chemical composition. Similarly, variations in planting density and sowing time can affect plant structure and nutrient utilization, thereby influencing forage quality independently of morphology. Under such conditions, reliance on sole physical traits may lead to inconsistent or misleading conclusions.

Generally, while morphological parameters serve as a quick and affordable approach for initial forage quality evaluation, their limitations, particularly in accounting for quantitative nutritional variation and environmental and management influences, necessitate the need for the integration of laboratory and animal feeding trial evaluation techniques for more accurate and reliable forage quality prediction.

CONCLUSION

While conventional forage quality evaluation methods provide more accurate and quantitative assessments, their application is often hindered by cost and technical requirements. Morphological traits provide a basic and swift alternative field assessment due to their close link to plant structure and maturity. Nonetheless, the constraints in their inability to directly quantify essential nutritional parameters such as crude protein, fibre fraction and digestibility, and sensitivity to factors including plant age and agronomic factors like fertilization, seed rate and plant spacing hinder their reliability as a solitary quality metric. Therefore, integrating morphological traits with maturity indices and agronomic factors presents a more reliable approach for improving forage quality prediction and supporting effective decision-making in forage management systems.

REFERENCES

- Agnusdei, M. G., Di Marco, O. N., Nening, F. R., & Aello, M. S. (2012). Leaf blade nutritional quality of Rhodes grass (*Chloris gayana*) as affected by leaf age and length. *Crop and Pasture Science*, 62(12), 1098–1105.
- Amuda, A., & Tubasen, P. J. (2023). Physico-Chemical Properties and In Vitro Fermentation Evaluation of Ensiled Guinea Grass (*Panicum Maximum*) With Different Protein Additives. *International Journal of Environmental Pollution and Environmental Modelling*, 6(2), 57–69.
- Beever, D. E., & Mould, F. L. (2000). *Forage evaluation for efficient ruminant livestock production*.
- Bell, M. J., Huggett, Z. J., Slinger, K. R., & Roos, F. (2021). Effect of pasture cover and height on nutrient concentrations

- in diverse swards in the UK. *Grassland Science*, 67(3), 267–272.
- Cullen, B. R., Bullen, D., Hutcheson, C., Jacobs, J. L., & Deighton, M. H. (2017). Changes in nutritive characteristics associated with plant height, and nutrient selection by dairy cows grazing four perennial pasture grasses. *Animal Production Science*, 57(7), 1392–1397.
- de Lima Veras, E. L., Difante, G. D. S., Chaves Gurgel, A. L., Graciano da Costa, A. B., Gomes Rodrigues, J., Marques Costa, C., ... & Ramon Costa, P. (2020). Tillering and structural characteristics of Panicum cultivars in the Brazilian semiarid region. *Sustainability*, 12(9), 3849.
- Erkovan, H. I., Gullap, M. K., Dascı, M., & Koc, A. (2009). Changes in leaf area index, forage quality and above-ground biomass in grazed and ungrazed rangelands of Eastern Anatolia Region. *Journal of Agricultural Sciences*, 15(3), 217–223.
- Freeman, K. W., Girma, K., Arnall, D. B., Mullen, R. W., Martin, K. L., Teal, R. K., & Raun, W. R. (2007). By-plant prediction of corn forage biomass and nitrogen uptake at various growth stages using remote sensing and plant height. *Agronomy Journal*, 99(2), 530–536.
- Garcia, L. F., Silva, G. P., Geremia, E. V., Goulart, L. B. L., Dias, C. T. D. S., & da Silva, S. C. (2021). Central rib and the nutritive value of leaves in forage grasses. *Scientific Reports*, 11(1), 5440.
- Gelley, C. H., Nave, R. L., & Bates, G. E. (2017). Influence of height-based management on forage nutritive value of four warm-season forage grasses. *Crop, Forage & Turfgrass Management*, 3(1), 1–9.
- Gurgel, A. L. C., Difante, G. S., Emerenciano Neto, J. V., Souza, J. S., Veras, E. L. L., Costa, A. B. G., & Roberto, F. F. S. (2017). Forage structure and performance of sheep raised on Massai grass during the dry season in response to wet season management. *Boletim de Indústria Animal*, 86–95.
- Hakl, J., Písarčík, M., Fuksa, P., & Šantrůček, J. (2018). Development of lucerne root morphology traits in lucerne-grass mixture in relation to forage yield and root disease score. *Field Crops Research*, 226, 66–73.
- Huhtanen, P., & Jaakkola, S. (1994). Influence of grass maturity and diet on ruminal dry matter and neutral detergent fibre digestion kinetics. *Archives of Animal Nutrition*, 47(2), 153–167.
- Hussien, A., Tavakol, E., Horner, D. S., Muñoz-Amatriain, M., Muehlbauer, G. J., & Rossini, L. (2014). Genetics of tillering in rice and barley. *The Plant Genome*, 7(1), plantgenome2013-10.
- Kaithwas, M., Singh, S., Prusty, S., Mondal, G., & Kundu, S. S. (2020). Evaluation of legume and cereal fodders for carbohydrate and protein fractions, nutrient digestibility, energy and forage quality. *Range Management and Agroforestry*, 41(1), 126–132.
- Kays, S., & Harper, J. L. (1974). The regulation of plant and tiller density in a grass sward. *The Journal of Ecology*, 97–105.
- Kellems, R. O., & Church, D. C. (1998). *Livestock feeds and feeding* (4th Ed.). Prentice-Hall.
- Khaled, R. A. H., Duru, M., Decruyenaere, V., Jouany, C., & Cruz, P. (2006). Using leaf traits to rank native grasses according to their nutritive value. *Rangeland Ecology & Management*, 59(6), 648–654.
- Kirby, E. J. M., & Faris, D. G. (1972). The effect of plant density on tiller growth and morphology in barley. *The Journal of Agricultural Science*, 78(2), 281–288.
- Lopes, M. N., Cândido, M. J., Pompeu, C. F., da Silva, R. G., & Bezerra, F. M. (2011). After-cut structural components of Massai grass under five nitrogen fertilizer levels. *Revista Ciência Agronômica*, 42(2), 518–525.
- Luo, Z., Janssen, B. J., & Snowden, K. C. (2021). The molecular and genetic regulation of shoot branching. *Plant Physiology*, 187(3), 1033–1044.
- Mahyuddin, P. (2007). Chemical composition of leaf and stem of tropical grasses at different stages of growth. *Animal Production*, 9(3).
- Martins, C. D. M., Schmitt, D., Duchini, P. G., Miqueloto, T., & Sbrissia, A. F. (2021). Defoliation intensity and leaf area index recovery in defoliated swards: Implications for forage accumulation. *Scientia Agricola*, 78, e20190095.
- McSteen, P. (2009). Hormonal regulation of branching in grasses. *Plant Physiology*, 149(1), 46–55.
- Mganga, K. Z., Ndathi, A. J., Wambua, S. M., Bosma, L., Kaindi, E. M., Kioko, T., & Musimba, N. K. (2021). Forage value of vegetative leaf and stem biomass fractions of selected grasses indigenous to African rangelands. *Animal Production Science*, 61(14), 1476–1483.
- Moore, K. J., Lenssen, A. W., & Fales, S. L. (2020). Factors affecting forage quality. In *Forages: The science of grassland agriculture* (Vol. 2, pp. 701–717).
- Nelson, C. J., & Moore, K. J. (2020). Grass morphology. In *Forages: The science of grassland agriculture* (Vol. 2, pp. 23–49).
- National Research Council. (2001). *Nutrient requirements of sheep* (7th rev. ed.). National Academy Press.
- Netto, R. T., Fernandes, L. S., Cunha, J. C., & Roberto, F. F. S. (2011). Estrutura do pasto e desempenho de ovinos em resíduo pós-corte em capim-massai adubado com cinco doses de nitrogênio. *Revista Ciência Agronômica*, 42, 518–525.
- Pauler, C. M., Isselstein, J., Suter, M., Berard, J., Braunbeck, T., & Schneider, M. K. (2020). Choosy grazers: Influence of plant traits on forage selection by three cattle breeds. *Functional Ecology*, 34(5), 980–992.
- Riaz, M. Q., Südekum, K. H., Clauss, M., & Jayanegara, A. (2014). Voluntary feed intake and digestibility of four domestic ruminant species as influenced by dietary constituents: A meta-analysis. *Livestock Science*, 162, 76–85.
- Robins, J. G., Bauchan, G. R., & Brummer, E. C. (2007). Genetic mapping forage yield, plant height, and regrowth at

multiple harvests in tetraploid alfalfa (*Medicago sativa* L.). *Crop Science*, 47(1), 11–18.

Sbrissia, A. F., Duchini, P. G., Zanini, G. D., Santos, G. T., Padilha, D. A., & Schmitt, D. (2018). Defoliation strategies in pastures submitted to intermittent stocking method: Underlying mechanisms buffering forage accumulation over a range of grazing heights. *Crop Science*, 58(2), 945–954.

Schroeder, J. W. (2004). *Forage nutrition for ruminants (AS-1250)*. North Dakota State University.

Sun, J., Zhao, G., & Li, M. M. (2023). Using nutritional strategies to mitigate ruminal methane emissions from ruminants. *Frontiers of Agricultural Science and Engineering*, 10(3), 390–402.

Tassone, S., Fortina, R., Mabrouki, S., Hachana, Y., & Barbera, S. (2021). Comparison of in vivo and in vitro digestibility in rabbits. *Animals*, 11, 3267.

Tilley, J. M. A., & Terry, D. R. (1963). A two-stage technique for the in vitro digestion of forage crops. *Grass and Forage Science*, 18(2), 104–111.

Wang, X., Wang, J., Li, E., Guo, Y., & Li, W. (2025). Plant height is the main factor driving forage yield of *Poa* species under different row spacings and seeding rates in the Qilian Mountains. *Frontiers in Plant Science*, 16, 1535937.

Wilman, D., & Moghaddam, P. R. (1998). In vitro digestibility and neutral detergent fibre and lignin contents of plant parts of nine forage species. *The Journal of Agricultural Science*, 131(1), 51–58.

Wu, G., Wilson, L. T., & McClung, A. M. (1998). Contribution of rice tillers to dry matter accumulation and yield. *Agronomy Journal*, 90(3), 317–323.

Zewdu, T., Baars, R. M. T., & Yami, A. (2002). Effect of plant height at cutting, source and level of fertiliser on yield and nutritional quality of Napier grass (*Pennisetum purpureum* [L.] Schumach.). *African Journal of Range and Forage Science*, 19(2), 123–128.

Zhang, L., Fang, W., Chen, F., & Song, A. (2022). The role of transcription factors in the regulation of plant shoot branching. *Plants*, 11(15), 1997.



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