

From wetland biomass to ruminant feed: influence of maturity stage on fiber fractions and digestibility of cattail (*Typha* spp.)

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ABSTRACT

Forage scarcity and rising feed costs constrain sustainable ruminant production, particularly where conventional roughage is limited. This study evaluated cattail (*Typha* spp.), an abundant wetland biomass, as an unconventional forage by assessing maturity stage and plant fraction effects on fiber composition, in vitro digestibility, and gas production. Fresh *Typha* was harvested from the Hadejia Valley Irrigation Scheme, Nigeria, at five stages: 0.5 m, 1.0 m, 1.5 m, early bloom, and senescence. Samples were separated into stem, leaf, and seed pod fractions, dried, ground, and analyzed using sequential fiber analysis and 48 h in vitro rumen incubation. Timothy hay served as reference forage, while blanks corrected fermentation values. Neutral detergent fiber ranged from 68.2 to 79.2% of dry matter, acid detergent fiber from 41.3 to 54.6%, and acid detergent lignin from 6.3 to 11.9%. Fiber digestibility and cumulative gas production declined with maturity. The 0.5 m stem showed the lowest neutral detergent fiber residue and highest gas production, indicating superior fermentability and energy availability. Mature and senescent fractions had lower digestibility, likely due to lignification and reduced microbial access. Although Timothy hay remained

more digestible, early-harvested *Typha*, particularly stems, demonstrated moderate nutritive value.

Keywords: *Typha spp.*; cattail; unconventional forage; ruminant nutrition; fiber digestibility; neutral detergent fiber; gas production.

INTRODUCTION

Forages remain the biological foundation of ruminant production because they provide fermentable energy, structural carbohydrates, protein, minerals, and vitamins required for rumen function and animal productivity (National Academies of Sciences, Engineering, and Medicine; NASEM, 2021; Wrobel et al., 2025). In grass-based and mixed forage systems, nutritive value is largely determined by the balance between digestible energy, crude protein, neutral detergent fiber (NDF), acid detergent fiber (ADF), lignin, and the extent to which these fractions are degraded in the rumen (Ferreira et al., 2025). Digestible energy is particularly important because fecal output represents the major pathway of gross energy loss, making forage digestibility a central determinant of feed efficiency and productive performance in ruminants (Chen et al., 2021; Galyon et al., 2024). Neutral detergent fiber is a key nutritional indicator because it reflects the structural cell-wall fraction that regulates chewing activity, rumen fill, passage rate, and ruminal fermentation patterns (Allen, 1997; Zhang et al., 2025). Adequate dietary forage NDF is required to maintain rumen mat formation, stimulate saliva secretion, stabilize ruminal pH, and support normal microbial fermentation, particularly in high-producing dairy and small ruminant systems (Zhang et al., 2025). However, excessive NDF can reduce voluntary dry matter intake by increasing physical fill in the rumen, whereas higher NDF digestibility can accelerate fiber disappearance, improve rumen turnover, and enhance energy supply to the animal (Galyon et al., 2024; Vieira et al., 2025). Forage NDF concentration and digestibility are highly variable because they are influenced by plant species, anatomical composition, maturity stage, environmental conditions, and harvest management (Hoffman et al., 2003; Wrobel et al., 2025). As plants mature, stem proportion, lignification, ADF, and undegraded NDF generally increase, while crude protein, cell-wall degradability, and ruminal fermentation potential often decline (Musa et al., 2021; Ferreira et al., 2025). These maturity-related changes are nutritionally important because the digestible and potentially degradable fiber fractions determine both the rate and extent of ruminal fiber utilization, which directly affects intake, nutrient supply, and animal performance (Galyon et al., 2024). *Typha* species have recently attracted attention as unconventional forage resources because they are widely available, highly productive, and may provide an alternative roughage source for ruminants in areas where conventional forages are limited (de Evan et al., 2023). Nevertheless, the feeding value of *Typha*

appears to be strongly affected by maturity, with later growth stages associated with increased fiber accumulation, reduced ruminal degradability, and lower volatile fatty acid production during fermentation (Musa et al., 2021). Although previous work suggests that early-harvested *Typha* may be more suitable for ruminant feeding, information remains limited regarding how maturity modifies its digestibility and potential contribution to ruminant diets under practical feeding conditions (NASEM, 2021 and Wrobel et al., 2025). The effect of plant anatomical components and maturity stage on the lignocellulosic fermentation kinetics of *Typha* have not been rigorously established. Therefore, this study was designed to evaluate the digestibility of *Typha* harvested at different maturity levels, with emphasis on fiber-related indicators that determine ruminal degradability and forage.

MATERIALS AND METHODS

Sampling

Fresh *Typha* was harvested from Hadejia Valley Irrigation Scheme and Samples were drawn from different irrigation sectors at different maturity levels. The levels of maturities were 0.5 m; 1 m, and 1.5 m height, full bloom, and senescence. After harvesting, approximately 500 g of each sample was placed in a vacuum bag, labeled, frozen, and mailed to the University of Maryland in an insulated styrofoam box. After the sample arrived in MD, it was removed from the box and separated into different components (leaf, stem and seed pods). Each component was weighed, and then a weighed sub-sample was dried in oven at 50°C, and reweighed, followed by grinding in a Wiley mill to pass 5-mm screen, and then reground through a 1-mm screen. The ground samples were used for fiber, in vitro digestibility, dry matter, and ash analyses.

Dry matter content (DM)

Initial dry matter content was established by drying in a KosterTM crop forage tester and weighing with an electronic balance before and after drying. The dry matter content was calculated using equation 1.

$$\text{Dry matter percentage} = \frac{\text{Final weight} - \text{Pan}}{\text{Initial weight} - \text{Pan}} \times 100 \quad (1)$$

In Vitro Digestibility

Experimental factors and treatment

Treatments were arranged in a factorial design with 2-3 plant components (stem, leaf and seed pod) by 5 levels of plant maturity. Timothy hay was a control treatment, and samples with no added substrate (blanks)

were run. The average of measured fiber, VFA, and gases in blanks were subtracted from the values in each sample. Each treatment including blanks and control was replicated five times within 82 flasks.

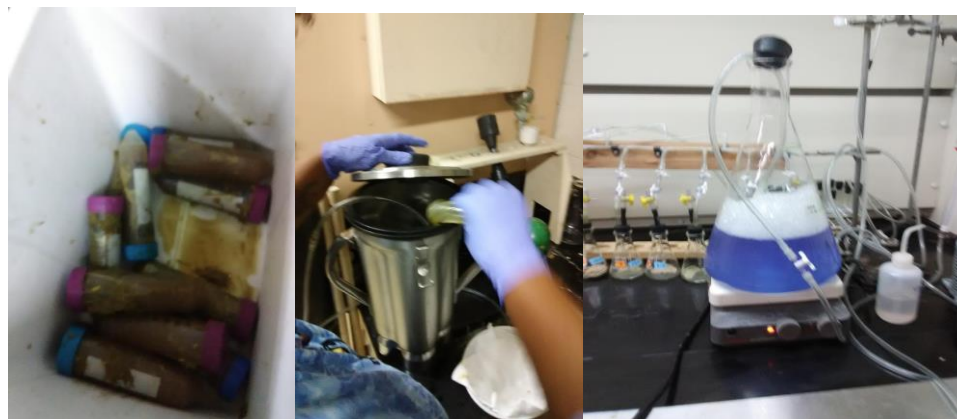


Figure 1. a. Collected rumen fluid; b. Blinding of rumen; c. Media preparation

Rumen fluid

Rumen fluid and solids were collected from a non-lactating cow before morning feeding, and ground in a blender for 20 seconds. After blending, the rumen contents were squeezed through 4 layers of cheese cloth and then glass wool, into a flask under carbon dioxide. Contents were blended and poured while perfusing with CO₂ to maintain anaerobic conditions.

In vitro media

Media were prepared to optimize anaerobic conditions (Goering and Van Soest, 1970) and contained the following ingredients (per litre): distilled water (400 ml), micromineral (0.1 ml), digested casein (2g), macromineral (200 ml), IV buffer (200 ml), rumen fluid (200 ml) and rezazurin (1 ml). The media were bubbled under carbon dioxide to remove air, and then reducing agent (cysteine-HCL and sodium sulfide) was added and solution became clear. The pH was confirmed to be 6.8.

Set up and incubation

Dried ground *Typha* samples (0.5 g) were measured into 125-ml flasks and mixed with 40 ml of anaerobic media under CO₂. The flasks were covered with a stopper, seal and purged under CO₂ to have oxygen free supernatant. The stopper has orifice through which a glass tubes is attached. A bloom is attached to the glass tube through two-way control valve. Treatments were incubated for 48 h at 38 °C. Gas generated over a time is store in a bloom before measurement. The stored gas was measured after 4 h, 24 h and 48 h

respectively. After 48 h of digestion the pH was recorded with pH meter. Each treatment was replicated in 3 flasks in 2 separate runs on different days for a total of 6 flasks per treatment.

Sequential Fiber Analysis

After 48 hours of incubation with rumen fluid, samples were subjected to sequential fiber analysis to determine the quantity of remaining fiber fractions after digestion.

Neutral Detergent Fiber (NDF)

The NDF solution was prepared according to Goering and Van Soest (1970) and it contained the following ingredients: distilled water (18 L), sodium lauryl sulfate (SDS, 540g), disodium ethylene diaminetetraacetate (EDTA) dehydrate crystal, reagent grade (335 g), sodium borate dehydrates, reagent grade (NaHPO₄, 82.1 g) and triethylene glycol purified grade (180 ml). After 0 or 48 h incubation, each sample was transferred to a 600-ml beaker then diluted with 100 ml of NDF solution. The samples were refluxed in a beaker for 60 minutes, then contents of the beakers were filtered through pre-warmed Gooch crucibles. After rinsing with hot water, the residues in crucibles were washed in fume hood with acetone, and then dried in oven at 100 °C for at least 8 hours. Crucibles were then weighed, and NDF residue was calculated.

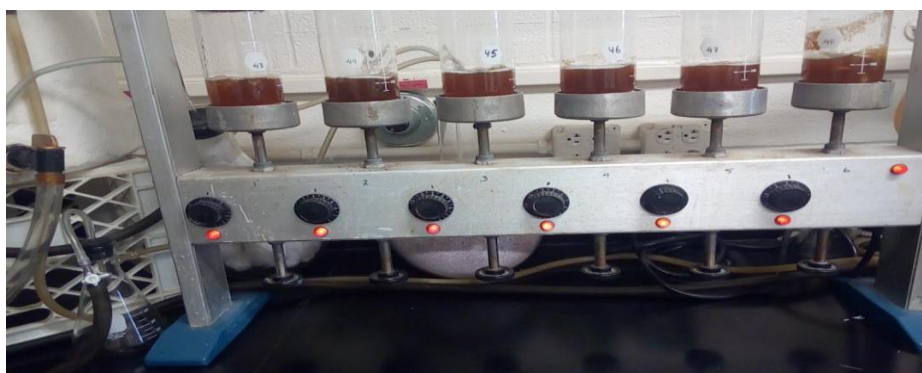


Figure 2. Boiling sample on reflux unit

Acid Detergent Fiber (ADF)

The ADF solution was prepared according to Goering and Van Soest (1970) with the following reagents: distilled water (18 l), Sulfuric acid (H₂SO₄), reagent grade standardized to 1N (100% assay, .272g) and Cetyl trimethylammonium bromide (CTAB), technical grade (360 g) Gooch crucibles with fiber content from initial NDF experiments were placed in a 600 ml beaker, and 100 ml ADF solution was added. The beaker with crucible was

heated to boiling, fiber was separated from the crucible with a rubber spatula and added to the solution, and fiber in solution was refluxed for 60 minutes. Samples were removed and contents returned to crucibles in filtering unit. After removing liquids under suction, each sample was rinsed with hot water. Each sample was rinsed with acetone in fume hood, then dried in an oven at 100 °C. Crucibles were weighed and ADF was calculated.

Acid Detergent Lignin (ADL)

The fraction of cell wall constituents such as neutral detergent fibre, acid detergent fibre, cellulose, hemicellulose and lignin was estimated as per Van Soest et al. (1991). The methods adopted were the modifications of original procedures described by Goering and Van Soest (1970).

RESULTS AND DISCUSSION

In-vitro digestibility of Cattail Harvested at Different Stages

Data for in vitro digestibility is presented in Table 1. NDF values ranged 68.2 to 79.2% while ADF ranged from 41.3 to 54.6% and ADL ranged from 6.3 to 11.9%. The least mature plant has the least NDF and highest NDF digestibility, while the early bloom plant had the highest NDF and lowest digestibility. The NDF residue after 48 hours of digestion is the true digestibility of the DM because the detergent soluble portion of the plant is considered digestible. The NDF residue in the least mature stem (0.5 m height) was the lowest (46.7%), representing 53.3% true digestibility, and it produced the most gas. The mature components were less digestible and produced less gas. This indicates that as the Typha plant matures, it develops resistance to digestion. Not only does the fiber content increase, but also the digestibility of the fiber decreases. Early bloom Typha stem was an exception having greater digestibility than Typha stem at 1-meter or 1.5-meter height, but this might be due to sampling from different locations or obtaining different varieties of Typha. When plant components were compared, the NDF and ADF content of stem was higher than for leaf from the same plant for pre-bloom plants, but the opposite was true for early bloom or senescence plants. Meanwhile, the percentage of the NDF or ADF digested at 48 hours was greater for stem than for leaf. This result was surprising because stem fiber is less digestible than leaf fiber for most plants.

The decrease in NDF and ADF digestibility during maturity is associated with increasing content of acid detergent lignin (ADL), and cross linkage of lignin to plant fiber. See figure below. Although this relationship is

important, using lignin as a predictor of digestibility still leaves a lot of unexplained variation from crop to crop and maturity level.

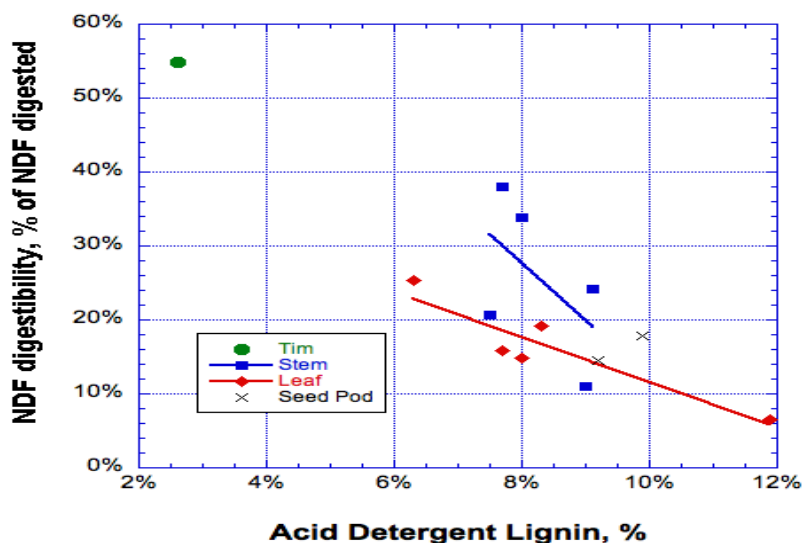


Figure 3. Neutral detergent digestibility and Acid detergent lignin of different parts of fresh Typha grass

Timothy hay is a cool-season grass that is known to be highly digestible as an animal feed. It was digested more than Typha grass. NDF, ADF, and especially ADL of Timothy were lower than for Typha. However, the cow used to obtain rumen fluid was consuming a timothy hay diet so the microorganisms were adapted to this feed, and with adaptation of ruminants to Typha, the digestibility might be improved. The present study shows that Typha taken at early maturity may have a moderate amount of energy as a feedstock for cattle.

Gas production is another indicating parameter of forage digestibility. Forages that produce a large volume of gas have higher digestibility. Blank treatment (rumen only) produced 57.3 ml of gas, and this was subtracted from the total gas for other treatments.

Table 1. In-Vitro Digestibility of stem, leaf, seed of Typha plant and Timothy hay

Sample Type	T=0 h % of DM remaining			T=48 % of DM remaining			T=48 h % of NDF digested			GasPro*
	NDF	ADF	ADL	NDF	ADF	ADL	NDF	ADF	ADL	
0.5 m stem	75.3	49.4	7.7	46.7	31.8	6.9	38.0	35.6	10.9	55.6
0.5 m leaf	68.2	41.3	6.3	50.9	33.6	6.7	25.3	18.8	-7.1	41.3
1 m stem	74.0	47.7	7.5	58.6	40.0	10.1	20.7	16.1	-35.5	39.2
1 m leaf	72.2	46.8	8.0	61.4	41.2	8.8	14.9	11.8	-8.8	20.2
1.5 m stem	75.7	46.6	9.1	57.3	37.3	8.4	24.2	20.1	6.9	38.5
1.5 m leaf	69.6	44.9	7.7	58.6	37.8	8.8	15.8	15.7	-14.7	37.8
Early bloom stem	72.7	46.7	8.0	48.1	32.8	7.4	33.8	29.7	8.1	54.0
Early bloom leaf	79.2	49.3	8.3	64.1	41.5	7.9	19.2	15.9	4.6	22.8
Early bloom seed	75.1	39.4	9.2	64.2	36.7	10.9	14.5	7.0	-18.4	5.8
Senescence stem	75.9	48.1	9.0	67.6	47.1	11.4	11.0	2.1	-27.6	28.7
Senescence leaf	78.5	54.6	11.9	73.3	49.5	13.8	6.6	9.4	-15.3	8.2
Senescence seed	73.7	40.0	9.9	60.6	35.5	10.4	17.9	11.3	-4.4	34.5
Timothy hay	63.5	31.0	2.6	28.6	17.3	4.1	54.9	44.1	-58.4	104.5

The least mature plant produced the highest volume of gas during 48 h of incubation (55.6 ml) while the senescence (last maturity) of leaf produced the least volume (8.2 ml). This may be attributed to the lignified properties of the grass decreasing the digestibility as the plant matures. Younger plants contained less lignin, and therefore can be more easily digested and fermented. However, as plant continues to grow, its lignin crosslinks with fiber which makes it harder to digest.

Chemical composition of Cattail harvested at different Stage

The truly digestible DM can be calculated as the digestible NDF plus the DM that is soluble in the detergent solution. The detergent soluble DM comprises cell contents including starch, sugars, protein, pectins, and minerals, and these are considered readily digestible. Therefore, the digestible NDF and cell contents together is an indicator of the true digestibility. The figure below shows the digestibility declines with increasing maturity. The seed pod digestible nutrients actually increase as it stores nutrients in later maturity. Note that the stem provides more digestible nutrients per gram than the leaf across maturity levels. This result occurs because the stem fiber is more digestible, even though the stem has higher fiber concentration than the leaf. The in-vitro digestibility data demonstrate that both fiber composition and plant maturity strongly influence the nutritional value of *Typha* for ruminants. Neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) increased with plant maturity, while fiber digestibility and gas production declined, consistent with patterns reported for other forages (Musa et al., 2021; Zhang et al., 2025).

The least mature stems (0.5 m height) exhibited the lowest NDF residue (46.7%), representing the highest true NDF digestibility (53.3%) and the greatest cumulative gas production, indicating that younger *Typha* plants are more readily fermented due to lower lignin content and reduced lignin-fiber cross-linking (Allen, 1997; Mertens, 1987). In contrast, mature components, including stems and leaves at early bloom or senescence stages, were less digestible and produced less gas, confirming that as the plant develops, structural complexity and recalcitrant fiber accumulation restrict microbial access (Nocek & Russell, 1988; Hoffman et al., 2003).

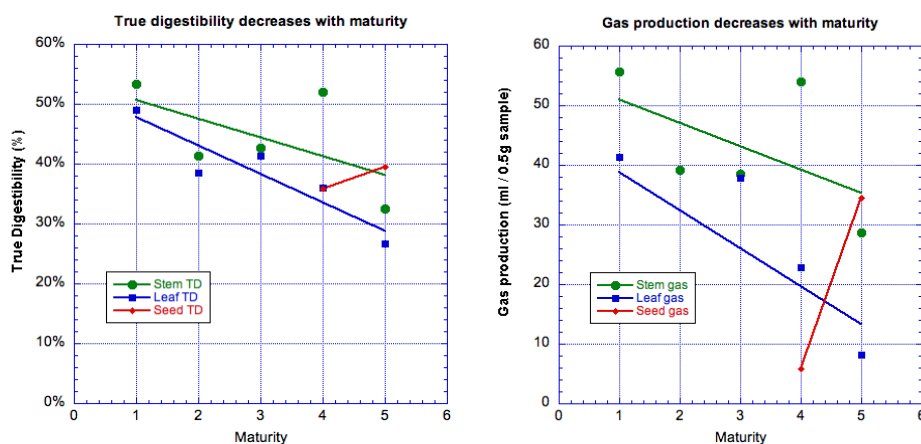


Figure 4. The gas production over 48 hours of digestion also decreases with maturity because only digested nutrients release gas. The figure below shows the same trends and the one above.

Interestingly, early-bloom stems exhibited slightly higher digestibility than 1 m or 1.5 m stems, likely due to variability in sampling location, microenvironmental conditions, or *Typha* variety (de Evan et al., 2023). These findings are consistent with previous work highlighting that forage fiber digestibility is highly heterogeneous across plant species, maturity stages, and anatomical fractions (Wrobel et al., 2025; Vieira et al., 2025). Comparisons between stems and leaves revealed further complexity. Pre-bloom stems had higher NDF and ADF than leaves, yet their fiber digestibility after 48 h of incubation was greater than that of leaves, an unexpected outcome given that stem tissue typically contains more structural carbohydrate and lignin (Goering & Van Soest, 1970; Allen and Oba, 1996). This may reflect the unique anatomical and chemical composition of *Typha* stems, including greater vascular and parenchyma cell content that is more accessible to rumen microbes. Lignification appears to be the primary driver of the observed decrease in digestibility during maturity, as ADL content increases and limits microbial degradation, but variation remains even at similar lignin concentrations, suggesting other factors such as fiber architecture, cross-linking, and phenolic compounds also play a role (Mertens, 1987; Chen et al., 2021). Gas production profiles aligned with digestibility trends, as younger stems produced more gas than mature leaves, underscoring that gas volume is a reliable proxy for fermentability and energy availability (Galyon et al., 2024). Notably, stems provided more digestible nutrients per gram than leaves

across maturity stages, likely because the higher fiber concentration in stems was offset by higher NDF degradability, highlighting the potential of early-harvest Typha as a moderate-energy feedstock for cattle. Adaptation of rumen microorganisms to Typha could further enhance digestibility, particularly when ruminants transition from timothy hay diets to Typha-based feeds (Hoffman et al., 2003; de Evan et al., 2023).

CONCLUSION

Typha forage quality is strongly affected by plant maturity and tissue type. Younger stems (0.5 m) exhibited the highest NDF digestibility and gas production, while mature stems and leaves were less digestible due to higher lignin and fiber content. Early-harvest Typha, particularly stems, provides moderate energy and digestible nutrients, indicating its potential as an unconventional forage for ruminants in areas with limited conventional feeds. Strategic harvest at early maturity can maximize its nutritional value and fermentability.

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REFERENCES

- Allen, M. S. (1997). Relationship between fermentation acid production in the rumen and the requirement for physically effective fiber. *Journal of Dairy Science*, 80(7), 1447–1462. [https://doi.org/10.3168/jds.S0022-0302\(97\)76109-0](https://doi.org/10.3168/jds.S0022-0302(97)76109-0)
- Allen, M., and Oba, M. (1996). Fiber digestibility of forages. In *Proceedings of the 57th Minnesota Nutrition Conference, Protiva Technical Symposium, Extension Special Programs* (pp. 151–171). University of Minnesota, St. Paul.
- Chen, H., Wang, C., Huasai, S., and Chen, A. (2021). Effects of dietary forage to concentrate ratio on nutrient digestibility, ruminal fermentation and rumen bacterial composition in Angus cows. *Scientific Reports*, 11(1), 17023. <https://doi.org/10.1038/s41598-021-96580-5>

- de Evan, T., Musa, A. R., Marcos, C. N., Alao, J. S., Iglesias, E., Escribano, F., and Carro, M. D. (2023). Ensiling *Typha* (*Typha latifolia*) forage with different additives for ruminant feeding: In vitro studies. *Applied Sciences*, 13(11), 6546. <https://doi.org/10.3390/app13116546>.
- Ferreira, A. L. O., Silva, J. P., and Costa, R. L. (2025). Rumen degradation of lignin and its influence on forage fiber utilization. *Journal of Animal and Feed Sciences*, 34(1), 45–58.
- Galyon, H., Corl, B. A., and Ferreira, G. (2024). Ruminal passage rate and digestibility of fiber from dairy cows consuming diets containing alfalfa and orchard grass hays with different concentrations of undegradable neutral detergent fiber. *Journal of Dairy Science*, 107(12), 10751–10760. <https://doi.org/10.3168/jds.2024-25264>
- Goering, H. K., and Van Soest, P. J. (1970). Forage fiber analyses: Apparatus, reagents, procedures, and some applications (Agriculture Handbook No. 379). USDA-ARS.
- Hoffman, P. C., Combs, D. K., Linden, D. R., Chase, L. E., and Shaver, R. D. (2003). Factors affecting forage fiber composition and digestibility in dairy cattle diets. *Journal of Dairy Science*, 86(11), 3817–3828.
- Hoffman, P. C., Combs, D. K., Linden, D. R., Chase, L. E., and Shaver, R. D. (2003). Factors affecting forage fiber composition and digestibility in dairy cattle diets. *Journal of Dairy Science*, 86(11), 3817–3828. [https://doi.org/10.3168/jds.S0022-0302\(03\)73905-0](https://doi.org/10.3168/jds.S0022-0302(03)73905-0)
- Mertens, D. R. (1987). Predicting intake and digestibility using mathematical models of ruminal function. *Journal of Animal Science*, 64(6), 1548–1558. <https://doi.org/10.2527/jas1987.6461548x>
- Mertens, D. R. (1987). Predicting intake and digestibility using mathematical models of ruminal function. *Journal of Animal Science*, 64(6), 1548–1558. <https://doi.org/10.2527/jas1987.6461548x>
- Musa, A. R., de Evan, T., Makinde, O. J., Alao, J. S., Iglesias, E., Escribano, F., and Carro, M. D. (2021). Influence of maturity stage on nutritive value of *Typha* for ruminants. *Nigerian Journal of Animal Science*, 23(1), 214–218.
- National Academies of Sciences, Engineering, and Medicine. (2021). Nutrient requirements of dairy cattle: Eighth revised edition. National Academies Press. <https://www.nap.edu/catalog/25806/nutrient-requirements-of-dairy-cattle-eighth-revised-edition>
- National Research Council. (1989). Nutritional requirements of dairy cattle (6th rev. ed.). National Academy Press, Washington, DC. <https://doi.org/10.17226/10014>
- Nocek, J. E., and Russell, J. B. (1988). Protein and energy as an integrated system: Relationship of ruminal protein and carbohydrate availability to microbial synthesis and milk production. *Journal of Dairy Science*, 71(8), 2070–2107.

- Vieira, D. J. C., Grigoletto, N. T. S., Poletti, G., Chesini, R. G., Diepersloot, E. C., Takiya, C. S., Ferraretto, L. F., and Rennó, F. P. (2025). Impact of decreasing undigested neutral detergent fiber concentration in corn silage-based diets for dairy cows: Nutrient digestibility, ruminal fermentation, feeding behavior, and performance. *Journal of Dairy Science*, 108(8), 8462–8475. <https://doi.org/10.3168/jds.2025-26388>
- Wrobel, B., Zielewicz, W., & Paszkiewicz-Jasińska, A. (2025). Improving forage quality from permanent grasslands to enhance ruminant productivity. *Agriculture*, 15(13), 1438.
- Zhang, Z., Li, F., Li, F., Wang, Z., Guo, L., Weng, X., Sun, X., He, Z., Meng, X., Liang, Z., and Li, X. (2025). Influence of dietary forage neutral detergent fiber on ruminal fermentation, chewing activity, nutrient digestion, and ruminal microbiota of Hu sheep. *Animals*, 15(3), 314. <https://doi.org/10.3390/ani15030314>.