

Research Article

Estimation of herbage dry matter intake of dairy cow using wireless bite counter for grazing-based production system: A case study in Ethiopia

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Abstract: *In grazing livestock systems, accurately measuring the intake of individual grazing animals is a critical challenge that must be addressed in order to enhance the overall efficiency of livestock production. Information about the individual herbage dry matter intake (HDMI) of grazing dairy cows is important for efficient use of pasture herbage and to ensure the release of adequate nutrients for maintenance and production. However, practical and reliable methods are not available to measure the intake of pasture by individual dairy cow particularly for grazing based production system for developing countries. Thus, this research was initiated to estimate HDMI using the wireless bite counter system for individual dairy cows in comparison with other methods. A simple, compact bite counter was used to record dairy cow jaw movements to estimate feed intake. The device is composed of a pendulum, a microcontroller, and a transmitter attached to a collar. The utility of the bite counter recordings in estimating intake was experienced for 16 Dairy cows, of which nine were local, and seven Holstein Friesian crossbred dairy cows. The experiment was conducted for two consecutive years (2018 and 2019) during the main rainy seasons (June to October) of Ethiopia. For comparison, cage system intake estimation was also conducted using sixteen individual paddocks established in the grazing land of Andasa Livestock Research Center. The grazing herbage in the paddock dominantly comprised *Cynodon plectostachyus*, *Hyparrhenia rufa*, *Paspalum notatum*, *Setaria viridis* and *Trifolium* species. For the calibration of the bite counter, the correlation between the number of bites measured by personal observation and the values reported by the bite counter was linear, with an R² value of 0.74. The average HDMI using the bite counter was 4.2 kg DM/day and 7.7 Kg DM/d for local and crossbred individual dairy cows, respectively. The estimation of the HDMI using linear regression on the number of bite counts resulted in an R² value of 0.68, indicating a moderate level of accuracy. This suggests that the wireless bite counter presents promising prospects for the swift estimation of HDMI. Furthermore, the ease of attachment of*

the bite counter to cows using a collar and its effective utilization by farmers in the grazing-based dairy production system in Ethiopia highlight its practical applicability in the field.

Keywords: Bite counter, dairy cow, free grazing, herbage intake, jaw movement, paddock

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1. Introduction

Livestock production is the most widespread agricultural livelihood strategy in Africa along the Blue Nile Basin, particularly in Ethiopia (Descheemaeker et al., 2010). Grazing is the primary method of feeding ruminants in tropical regions (Steinfeld et al., 2006). Most livestock production relies on free grazing; however, the actual intake from free grazing is not well understood. Feed intake is regulated by three key factors: bite size, bite rate (bites per minute), and total grazing time (Hodgson, 1990). Present methods for estimating intake by grazing livestock often lack precision and are frequently tedious, expensive, and time-consuming (Macon et al., 2003). Consequently, accurate measurement of feed intake is essential to meet the nutritional requirements of animals and optimize production (Greenwood et al., 2017). Estimating dry matter intake (DMI) is critical for ensuring the supply of adequate nutrients for both maintenance and production. Because feed intake is difficult to measure, farmers frequently worry that their livestock are not being appropriately fed (Holmes and Wilson, 1984). Rapid, practical, and reliable methods for measuring pasture intake by individual livestock over sufficient periods remain unavailable—limiting progress in genetic improvement, livestock and pasture management, and the generation of data for prediction and simulation modeling (Greenwood et al., 2014).

Due to their complexity, few studies have been conducted on the estimation of voluntary intake in grazing ruminants, and it remains very difficult to estimate this parameter easily and with sufficient precision. When intake is measured, it is usually for a single ruminant species on one type of pasture. Indeed, even if, according to the definition of Baumont et al.

(2000), "intake is the maximum quantity of feed that can be eaten by an animal when this is supplied ad libitum as the sole feed," and thus seems easy to quantify, its study is far more complex. In reality, according to Illius and Jessop (1996), intake can be considered a "psychological" phenomenon, involving the integration of many signals, and reflects the flexibility of a biological system evolved to cope with variability in food supply, composition, and animal states. However, it is difficult to estimate pasture intake for free-ranging cattle. For this reason, wireless sensor networks offer new opportunities for rapid estimation of pasture intake (Umemura et al., 2009; Smith et al., 2015). The device is typically composed of a pendulum, a microcontroller, and a transmitter attached to a collar. Sensors and wireless sensor networks provide new opportunities for rapid estimation of pasture intake by larger numbers of livestock under commercial grazing conditions. Technologies exist or are evolving that can generate sensor data aligned with specific behaviours (González et al., 2015; Smith et al., 2015) that relate to the intake of pasture. Despite these advances, there is still no universally accepted strategy for estimating animal dry matter intake (DMI) in grazing systems (Undi et al., 2008).

This paper aimed to measure the Dry Matter Intake (DMI) of grazing dairy cows using a bite counter and other methods, as well as comparing their estimates. The bite counter device, composed of a pendulum, microcontroller, and transmitter attached to a collar, has been shown to effectively record jaw movements and estimate feed intake in grazing cattle (Umemura et al., 2009). Additionally, the estimates of herbage dry matter were compared with a calculated DMI based on the energy requirements for lactation and maintenance

(NEL required) of the cows and the net energy content (NEL) of the herbage, an approach consistent with established nutrient requirement standards for dairy cattle (NASEM, 2021). Furthermore, the study evaluated herbage quality, nutritive value, and biomass of the grazing pasture, estimating dry matter intake for individual animals grazing on free pasture land. Such comprehensive evaluation of forage characteristics is essential for understanding the relationship between pasture conditions and animal intake, as pre-grazing herbage mass significantly affects bite mass, grazing behavior, and dry matter intake (Piña et al., 2020; Rombach et al., 2023). This research contributes valuable insights into the feeding habits and nutritional needs of grazing dairy cows, shedding light on their DMI and overall dietary requirements.

2. Materials and Methods

2.1. Description of the study area

The study area is located approximately 22 km south of Bahir Dar city on the way to Tis Abay, situated at 11°29'N latitude and 37°29'E longitude at an elevation of 1730 meters above sea level in the Amhara Region, Ethiopia Amhara Agricultural Research Institute (ARARI, n.d). The area is characterized by dark clay soils that become seasonally waterlogged and develop deep cracks during dry periods. The region receives approximately 1434 mm of annual rainfall. The mean annual temperature ranges from a maximum of 29.5 °C in March to a minimum of 8.8 °C during the wet season. The research center maintains extensive grazing land covering 360 hectares that has been continuously utilized for livestock grazing over many years (Bitew et al., 2010).

2.2. Experimental design and protocols for estimation of herbage dry matter intake

2.2.1. Estimation of pasture intake using a bite counter (Method 1)

A simple, compact bite counter was used to record dairy cow jaw movements (Supplementary Figure 2). The device is composed of a pendulum, a microcontroller, and a transmitter attached to a collar. Jaw movements were recorded using a system developed by Panasonic Electric Works Co., Ltd. (Kadoma, Osaka, Japan) and consisting of an 8-bit microcontroller (PIC16LF873), a 64-kB nonvolatile memory, and a transmitter with an internal antenna (Figure 1).

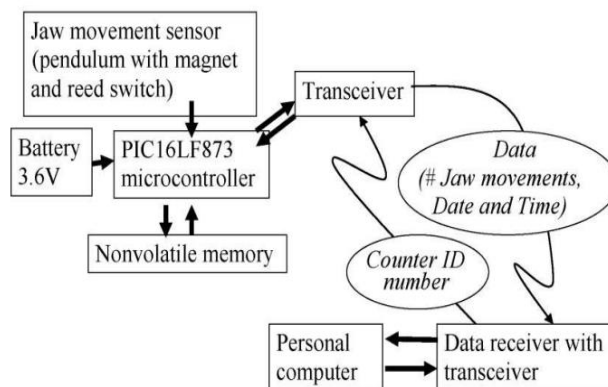


Figure 1: Diagrammatic illustration of the bite counter data access process (Umemura et al., 2009)

Experimental design and animals for the bite counter

The grazing experiment was conducted from 2018 to 2019 in the main rainy grazing season of Ethiopia (from July to October in each year). In general, each experimental trial consisted of 2 weeks of adaptation to adjust pasture-accustomed cows to the various feeding treatments and measuring devices, followed by data collection. All experimental procedures were in accordance with guidelines for animal welfare and were approved by the Animal Care Committee of the Andassa Livestock Research Center. Before the selection of the experimental cows, all cows passed a medical check. Dairy cows were selected based on their parity, lactation stage and milk yield. Two breeds: Local (Fogera) and Crossbred dairy cows (Fogera crossbred with Holstein Friesian) were used in the grazing experiment (Supplementary Figure 1). A total of seventeen bite counters were used for the experiment, with seven in 2018 and ten in 2019. For the trial, 16 lactating dairy cows were recruited from Andasa Livestock Research Center. The cows were grazed for 8 hours per day in the natural grazing pasture. The utility of the bite counter recordings for estimating feed intake. During the experiment period, all experimental cows grazed as individuals in the paddocks and were also permitted to graze with the herds in a non-restricted/free grazing system. The stocking periods lasted 1 to 3 days for one month and were repeated for the remaining three months. In the meantime, the crossbred lactating cows were supplemented with concentrate in the barn before

milking in the evening time intended to produce more milk yield. All cows had free access to drinking water during the experiment period.

The grazing layout of the dairy cows with a bite counter

The grazing layout of the dairy cows with a bite counter involves placing one cattle with a bite counter in each grazing paddock, as shown in Supplementary Figure 2. Additionally, all the experimental cows with bite counters are allowed to freely range with the group in the free grazing land, as depicted in Supplementary Figure 3. This method allows for accurate monitoring of the grazing behavior of the cows and provides valuable data for research and management purposes.

2.2.2. Estimation of pasture intake using the Cages system in the paddock (Method 2)

A total of 16 (7 in 2018 and 9 in 2019) grazing paddocks were used for clipping after 3-4 days of grazing. The cage was constructed with approximately 1 m² and with a wooden fence and mesh-wire for each paddock (Supplementary Figure 4). Forage inside and outside the cages was clipped from 0.5 m x 0.5m quadrants after grazing. Grazing cages were used to measure forage disappearance before and after grazing. Clipping of forage was done above a 5-cm stubble height of the ground level. The difference between forage inside and outside the grazing cage represented the amount of pasture forage consumed by grazing animals. Experimental paddocks were constructed using locally available wood (Supplementary Figure 5).

These 16 paddock observations were conducted at 1 time. The RPM was calibrated to measure the available DM above a 5 cm stubble height, using seventeen one meter square quadrants (Supplementary Figure 6). The equations for the estimation of DM (g of DM/m²) were developed using the reading of RPM:

Dry matter intake was calculated as follows:

$$\text{DMI (kg day}^{-1}\text{)} = \frac{[\text{DM inside cage (kg ha}^{-1}\text{)} - \text{DM outside cage (kg ha}^{-1}\text{)}] \times \text{area (ha)}}{\text{Number of grazing days}}$$

2.2.3. Estimation of pasture intake using prediction equations (Method 3)

i) Estimation of Forage DMI from Body Weight (BW) and Average Daily Gain (ADG)

Sixteen lactating dairy cows were used in the experiment. BW measurement was taken using ground balance and heart girth. Average daily weight gain (ADG) was calculated from the weight over the grazing period. Pasture Forage DMI estimated from BW and ADG using the equation developed by Minson and McDonald (1987):

$$\text{a) DMI (kg day}^{-1}\text{)} = (1.185 + 0.00454 \times \text{BW} - 0.0000026 \times \text{BW}^2 + 0.315 \text{ADG})^2$$

Where BW=body weight (kg) and ADG= average daily gain (kg/day).

b) DMI = 3 % of the body weight (Undi et al., 2008).

ii) Pasture DMI estimation using forage Net Energy

Animal DMI was estimated using a prediction equation based on individual animal BW and standing forage NEm concentration (NRC 2001). The net energy concentration of the grazing pasture was analyzed using the In Vitro digestibility and NDF content analyzed in the Animal Nutrition laboratory at Shimane University Japan. Thus, the pasture DMI was estimated using the Net Energy Equation:

$$\text{DMI (kg day}^{-1}\text{)} = \text{SBW}^{0.75} \times (0.1493 \times \text{NEm} - 0.046 \times \text{NEm}^2 - 0.0196) \text{ (NRC 1996)}$$

Where SBW^{0.75}: shrunk metabolic body weight (kg)

$$\text{NEm} = (2.0180 + 0.38 \times \text{ADF}) \times 0.7 \text{ (Undi et al., 2008)}$$

2.4.4. Data recording and Laboratory Analysis

The herbage biomass, species composition and the nutritive value data were recorded. Milk yields were recorded at every milking during the milking time. Concurrently with pasture disappearance assessment, herbage samples from the pastures were collected immediately before grazing and after grazing for chemical analysis. All pasture samples were analysed for ash, NDF, acid detergent fibre (ADF), CP, and lipid concentrations, along with organic matter digestibility (OMD) and metabolizable energy (ME) concentration.

The herbage sampling started 24 h before the feces sampling and ended 24 h earlier. These samples were chopped and stored at -20°C for further analysis. The N and C content of herbage and supplement samples were analyzed using the CN coder. The contents of ADF (AOAC International, Cunniff, 1995; method 973.18) and NDF (Cunniff, 1995; method 2002.4) for the herbage and supplement samples were analyzed with Gerhardt Fibertherm (Gerhardt GmbH & Co. KG, Königswinter, Germany). The NDF and ADF contents were separately determined (in parallel). A correction

for the residual ash obtained after 2 h of incineration at 550°C was made for ADF corrected for residual ash and NDF corrected for residual ash (Rombach et al., 2019). The NEL content of herbage was calculated from chemical composition according to Agroscope (2016).

2.4.5. Statistical analyses

Mean pasture DMI day⁻¹ was determined from the slope of linear regression equations for each plot for each pasture measurement meter. Bite counts were converted to true (observed) bites because the counter values are 1.9 times the number actually observed. Individual animal DMI estimates from three different techniques were compared using the PROC MIXED procedure of SAS software (version 9.1, SAS). For comparison of all techniques, the PROC MIXED

procedure was carried out on data pooled by period and paddock. Correlation and Regression analysis were conducted for intake and Jaw movement, as well as biomass and height.

3. Results and Discussion

3.2. Biomass and species composition of the grazing pasture

The mean biomass yield of the grazing land harvested in the main rainy season was 1.17 tons/ha. The biomass yield was affected by season, where high production was recorded in October, followed by September (Figure 2).

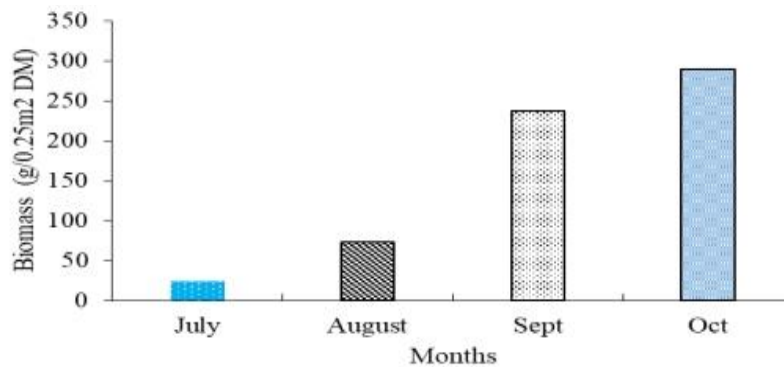


Figure 2: Forage biomass yield across different months

The pastures in the study area were composed of 26.25% grasses (primarily *Pennisetum pedicellatum*, *Clinacanthus nutans*, and *Parthenium hysterophorus*), 70.75% legumes (*Trifolium quartianum* and *T. angustifolium*), and 3% forbs. This species composition reveals a significant imbalance, with legumes heavily dominating the sward. This finding contrasts with the more diverse grass-legume mixtures historically reported for the region (Yihalem, 2004) and, more importantly, with recent assessments of healthy pasture ecosystems.

For instance, Desta and Molla (2021) found that productive grazing lands in the Ethiopian highlands typically feature a more equitable grass-legume balance and higher grass species diversity. The current heavy reliance on a few legume species, coupled with the presence of the invasive *Parthenium hysterophorus*, suggests a degraded pasture. It is, therefore, concluded that the biomass yield from the grazing land in the study area is poor, characterized by an unbalanced species composition and low diversity.

3.3. Herbage nutritive value of the grazing pasture

The chemical composition of the herbage and the supplements fed during the experimental periods is shown in Table 1. The NDF concentration in the Napier grass used was lower than that in the natural-grassland hay and that of the grazing grasses (Table 1). In contrast, the higher crude-protein concentration in the Napier

grass than in the natural-grassland hay and the grazing grasses resulted in the cows feed the highest crude-protein. The variations in chemical composition reported in the present experiment are also in agreement with those reported by Delagarde et al. (2000) for samples of perennial ryegrass.

Table 1: Chemical compositions of the grazing pasture and feed ingredients

Feed	Chemical composition (% DM)					
	CP	EE	NDF	ADF	ADL	CA
Grazed pasture	2.5	1.7	77.8	46.5	5.9	7.0
Napier grass	8.2	1.8	68.3	42.9	6.7	11.9
Natural-grassland hay	4.1	1.5	72.1	48.2	8.3	11.1
Concentrate	19.4	5.9	29.9	18.6	3.5	10.3

Source of data?

ADF, acid detergent fiber; ADL, acid detergent lignin; CA, crude ash; CP, crude protein; DM, dry matter; EE, ether-extracted fat; NDF, neutral detergent fiber (Nobuyuki et al., 2021).

3.4. Correlation between grazing pasture biomass and height

The study revealed a significant positive correlation between grazing pasture height and biomass ($r^2 = 0.89$; Fig. 3), suggesting that sward height can serve as a reliable non-destructive indicator for estimating biomass in grazing lands. This finding aligns with previous research of Nieto-Sierra et al. (2024), who also noted a strong correlation between undisturbed sward height and herbage mass in tropical pastures. The importance of accurate measurement and calibration techniques in assessing herbage mass in tropical pasture ecosystems is underscored by these

results, emphasizing the critical role of sward height as a key indicator in such studies.

The five iso-nitrogenous diets (30% CP), which were calculated in micro-Excel were formulated with graded replacement levels of fishmeal by earthworm meal: T₀₀% (100% fishmeal), T₂₅%, T₅₀%, T₇₅%, and T₁₀₀% (100% earthworm meal) (Table 3). The replaced quantity of the treatment was adjusted using corn flow with the proximate analysis results indicated in Table 2.

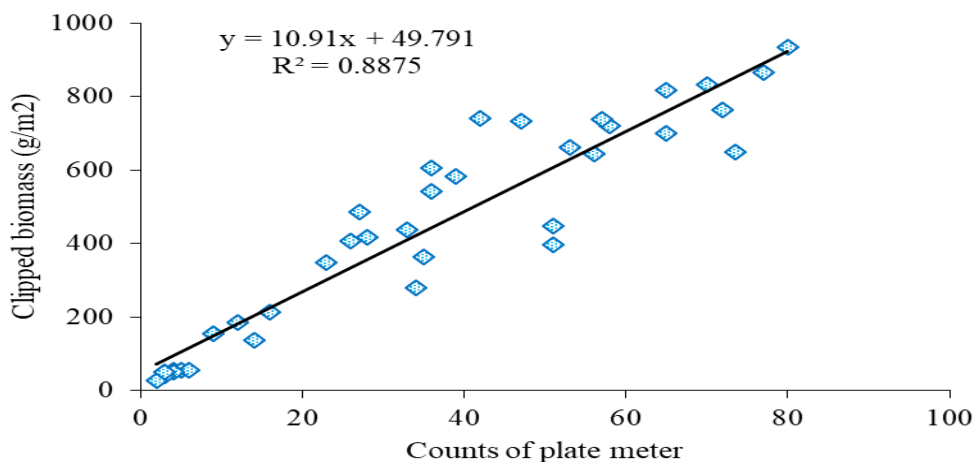


Figure 3: The correlation between clipping and plate meter for the estimation of biomass.

3.5. Estimation of herbage dry matter intake using a bite counter

The herbage dry matter intake estimated using bite counter is presented in Table 2. The dry matter intake was 4.2 and 6.7 kg DM day⁻¹ for local and HF crossbred, respectively. This agreed with the previous studies on red deer (Heydon et al., 1993). This pattern could be related to either higher energy requirements during peak lactation (which decrease towards weaning), or greater herbage availability in early summer, followed by a slight decrease when plants reach maturity. Heydon et al. (1993) found that both reproductive and non-reproductive red deer hinds exhibited the same DMI declines from July to October, with lactating hinds having significantly higher intakes, and the difference decreased as weaning approached. Most estimates of intake for cattle and sheep grazing ranges in the Western United States fall within the range of 40 to 90 g DM/Wkg^{0.75} or from 1 to 2.8% of body weight. This observation shows that it is possible to use the bite counter since

the dairy cows can graze wearing it even though they struggled at the beginning of tying the equipment (Figure 5).

Information about individual herbage DMI (HDMI) allows estimating the nutrient supply from pastures and determining an adapted optional supplementation in the barn that may improve efficiency and lead to higher acceptance in practice. Furthermore, information about intake compared with production can be used to assess the nutrient and energy efficiency of individual grazing dairy cows and may enable selection for this trait (Rombach et al., 2019). To improve the predictability of daily herbage intake and, hence, develop more efficient grazing management systems, it is necessary to understand how the cow grazes or adapts its grazing behaviour throughout the day and to changes in sward condition (Barrett et al., 2001). In conditions that were similar to those in our study, Kaufmann et al. (2011) found a mean deviation between estimated and weighed DMI of 0.2 kg for cows fed in the barn with fresh herbage.

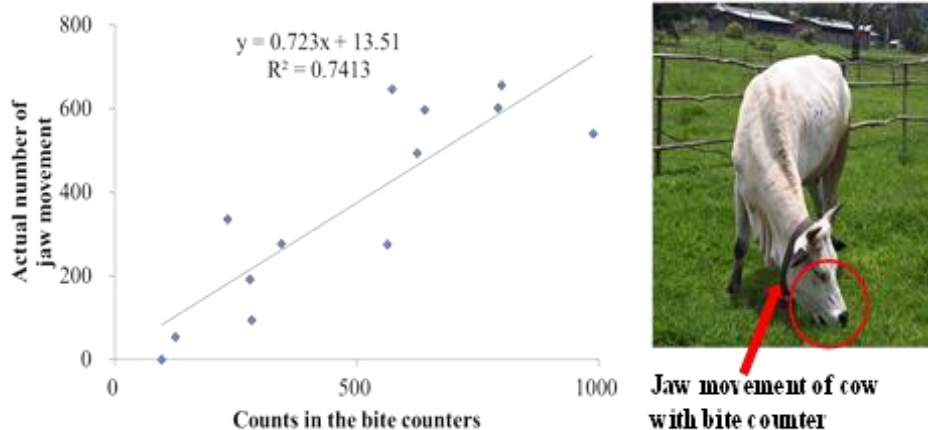


Figure 4: Correlation between jaw movement and bite counter

Table 2: Herbage dry matter intake of the grazing cows wear a bite counter

Breed	x-actual jaw movement	Jaw movement For grazing (10 ⁴ times/cow)	Feed intake/hr	Feed intake (Kg DM)/day
Local breed	422.03	0.04	0.18	4.2
HF crossbred	3105.07	0.31	0.27	6.7
Over all	1763.55	0.18	0.22	5.5

The relation between manual jaw count and counts made by jaw movement counter; $y=0.723x + 13.51$ (y is the value of the bite counter, x is actual jaw movement and $R^2=0.74$). The relationship between bite for grazing and feed intake; $y=6.82x+ 2.45$ (y is Feed intake, x is Jaw movement for grazing and $R^2=0.77$) (Umemura et al., 2009).

3.6. Comparison of different methods for pasture dry matter intake

The herbage dry matter intake estimated using the different techniques is presented in Table 3. In a grazing situation, the clipping cutting method and the n-alkanes method have not been compared to our knowledge. Reeves et al. (1996) concluded that herbage intake estimates from pre- and post-grazing mass, estimated with the rising plate meter, were not acceptable because of large errors in estimating tropical grass intake. In the present study, a large difference in herbage intake estimated with the clipping method was found between 16.2 and 18.6 kg of DM. The cows increased in BW; the estimation by the sward cutting technique seemed to underestimate DMI. The sward cutting method gave fast results; 24 h after the postgrazing cut, herbage intake could be

calculated. The utilization of the n-alkanes method proved to be a more time-consuming approach, requiring over a month before the necessary data on herbage intake became accessible. In addition, the n-alkanes method needs expensive equipment for measuring and analyzing materials, whereas the sward cutting method is much less expensive. Pasture disappearance techniques show high variability in estimating pasture biomass (Smit et al., 2005). Pasture intake estimates by the plate meter are often higher than for other techniques (Sanderson et al., 2001). Intake estimates obtained using pasture-disappearance and chemical-marker methods are often not correlated (Macon et al., 2003), particularly concerning the precision of estimating individual feed intake of grazing animals offered low, declining pasture availability.

Table 3: Pasture intake estimates of dairy cows using different methods

Intake estimation techniques	Local	HF Crossbred	Average
Bite counter	4.2	6.7	5.5
Clipping Biomass	5.4	7.7	6.6
Plate meter Biomass	7.7	9.1	8.4
Body weight (3%)	7.5	9	8.3
Nem	6.4	7.3	6.8

3.6. Pasture Intake and Milk Yield

Estimates of pasture intake of the local dairy cow of 4 kg/d produce 0.71 L/day, while the HF crossbred produced 1.72, which consumed 6.7 kg/d grazing pasture, 2.03 kg/d concentrate diet, and 2.85 kg/d improved forage (Table 4). This result showed that the lactating dairy cows can produce milk depending on the good grazing pasture, but the recent problem in our country is the alarming decline of grazing land for subsistence small-holder dairy production.

In line with this study, Peyraud et al. (2001) reported that although pasture herbage has widely been identified as the cheapest source of nutrients for dairy cows, the decline in grazing may be the result of larger herds, fragmentation or lack of land, development of automatic milking systems, and farmer expectations regarding productivity in a pasture-based system. In the Genetic Algorithm (GA) model, feeding protein and concentrate supplements reduced HDMI. The substitution rate observed in our study (0.63 kg of HDMI/kg of concentrate) falls within the range of 0.58 to 0.71 kg of HDMI/kg of concentrate reported by Faverdin et al. (2011).

Table 4: Pasture intake, supplementary diet, and milk yield of dairy cows

Breed	Pasture intake (kg/d)	Supplement feed		Milk yield (L/d)
		Concentrate(kg/d)	Improved Forage(kg/d)	
Local	4.0	0	0	0.71
HF crossbred	6.7	2.03	2.85	1.72
Average	5.35	1.01	1.43	1.215

4. Conclusion

The study revealed that the average biomass yield of the grazing land during the main rainy season was 1.17 tons/ha, with pastures consisting of various grass species. The herbage dry matter intake, as measured by the bite counter, was found to be 4.2 kg DM/day for local dairy cows and 7.7 kg DM/day for crossbred cows. Linear regression analysis showed an R^2 value of 0.68, indicating a strong relationship between the number of bite counts and herbage dry matter intake. The wireless bite counter presents a promising tool for quickly estimating herbage intake in free grazing systems. Its ease of attachment to cows via a collar makes it a practical option for farmers in Ethiopia utilizing grazing-based dairy production systems. As such, further research and implementation of this technology are recommended to enhance productivity and efficiency in dairy farming practices in Ethiopia.

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Data Availability Statement

Data will be made available on request.

Conflicts of Interest

The authors declare no conflict of interest.

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