Precision beef dry matter intake estimation on extensive rangelands

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Abstract

Measuring grazing beef cattle dry matter intake (DMI) is a significant challenge. The DMI value is required to determine stocking rates and supplementation requirements. The variation in estimated DMI of grazing cattle introduces tremendous error at the herd level since estimated DMI is based on full body weight (BW) multiplied by a percentage of BW. The BW percentage varies depending on animal class, production phase, and forage nutrient composition. Although Animal Unit Months are used to simplify this calculation for rangeland systems to determine the duration that cattle can graze, there is tremendous opportunity to leverage precision technology to account for the individual animal variation and subsequent impacts on herd-level decisions. Therefore, the objective of this study was to build a precision system model (PSM) to evaluate the differences in modeled DMI compared to the traditional herd-level method using initial body weight (BW). The model evaluated hectares needed and total forage consumption using daily individual heifer BW (kg) (n = 60; precision data) grazing dormant native rangeland for 175 days in South Dakota using a SmartScale™. The traditional versus the PSM method resulted in an additional 73.41 ha required. Sensitivity analysis of percent BW (1.8 to 2.7%) resulted in a 33 and 39% difference in forage consumption and hectares required, respectively. Applying precision data provides more precise DMI estimates and shows the advantages and disadvantages of herd-level estimates. The use of PSM helps to identify high-leverage precision tools to minimize a performance gap like overgrazing extensive rangeland systems.

Keywords: grazing, dry matter intake, modeling, beef, rangelands

Introduction

Measuring the dry matter intake (DMI) —the amount of feed consumed per day on a moisture-free basis - of grazing beef cattle is a significant challenge from both a basic and applied research and production aspect. For estimating forage utilization and the amount of land area required for cattle grazing extensive rangelands, it is essential to determine the animal unit months (AUMs). For AUMs, the amount of forage needed per animal unit (AU) is defined as a 454 kg cow consuming 2.6% of body weight (BW) on a dry matter basis, thus equating to 354 kg forage being consumed over a month (1 AUM) (Smart et al., 2020). The DMI is required to determine stocking rates and supplementation requirements. The variation in estimated DMI of grazing cattle introduces tremendous error at the herd level since estimated DMI is based on full BW multiplied by a percentage of BW. The percentage of BW varies depending on animal class, production phase (e.g., lactating vs. dry), and forage quality (NASEM, 2016). For example, a lactating cow eating low-quality forage (<52% total digestible nutrients) consumes approximately 2.2% of BW on a dry matter basis, whereas a lactating cow eating high-quality forage (> 59% total digestible nutrients) 2.7% of BW on a dry matter basis (Ehlert and Brennan, 2021; NASEM, 2016). Differences in DMI and BW can significantly affect stocking rates. For example, a 227 kg heifer consuming 2.5% of BW on rangeland with 700 kg ha^{-1} available for consumption (i.e., 25% of total forage; 2800 kg ha^{-1}) would require 0.54 ha AUM^{-1}, whereas a 381 kg heifer consuming 2.5% of BW would require 0.42 ha AUM^{-1}. Traditionally, stocking rate estimates have been based on knowledge of rangeland stocking capacity from land manager experience, initial animal BW (if known), and forage utilization measurements. Frequently, initial herd level average BW is used to calculate AUMs and subsequently stocking rate; however, herd level averages may not adequately account for the variability in initial individual animal BW, changes over time due to cattle daily growth [BW + Δ kg d^{-1} (daily gain)], or differences in % BW of DMI. Not accounting for this individual animal variability can have a proportional scaling effect from individual livestock operations to landscape scale estimates of AUMs required. The exclusion of individual animal BW data can result in potentially overgrazing forage resources and subsequently have negative impacts on natural resources and animal production.

Until recently, reliable individual daily BW measurement tools for grazing systems were not viable for research or production. The advent of precision data collection for rangeland cattle has made it possible to weigh cattle on pasture in real time and provides new insight into individual animal weights throughout the grazing season. As the role of precision technology grows in extensive rangeland systems, a critical question is how previously unattainable data can be leveraged in precision system models (PSM; Menendez et al., 2022). Using PSMs will help evaluate complex tradeoffs relative to ranch management objectives such as animal efficiency, managing variability in forage resources (surplus and shortfall), environmental impact, and mental models. Deploying a PSM to estimate individual DMI using precision weighing technology may help to identify performance gaps in stocking rates, maximize forage utilization, and prevent overgrazing. Therefore, the objective of this study was to build a PSM to evaluate the differences in modeled DMI integrated with real-time individual BW data in a rangeland setting.

Materials and methods

The study was conducted from November 2021 through June 2022 at the South Dakota State University Cottonwood Field Station (CFS; Cottonwood, SD). The CFS is located in the Northern Great Plains mixed-grass prairie (43.989107 N, -101.857228 E). The elevation at the station ranges from 710 to 784 m. The climate is an arid cold steppe (Beck et al., 2018). The long-term average annual precipitation for the area is 432 mm (1981-2010; NOAA, 2022).

We utilized individual daily BW of spring-born Angus heifer calves (n = 60) grazing dormant native rangeland. The dominant forage species on the fall and winter pastures include western wheatgrass (*Pascopyrum smithii*), crested wheatgrass (*Agropyron cristatum*), buffalo grass (*Bouteloua dactyloides*), and blue grama (*Bouteloua gracilis*) (Dunn et al., 2010). The heifer data was derived from a study to compare differences in yearling heifer growth and reproductive performance between conventional and precision-delivered supplementation on grazing dormant winter range. Heifers (initial BW = 237.6 ± 15.5 kg) were allocated to one of two treatment groups, control or precision, and grazed dormant native range from November 2021 to May 2022 (Figure 1). Both treatment groups were supplemented with 2.27 kg hd^{-1} d^{-1} of pelleted dried distiller's grains with solubles (DDGS). Supplement was delivered to the control group in a traditional bunk fed method and the precision group supplement was offered with a Super Smartfeed™ (C-Lock Inc.). Individual daily BW was measured using SmartScales™ (C-Lock Inc. Rapid City, SD). Individual animals were tagged with a radio frequency identification device (RFID) to pair weight measurements to each animal. The data collected from the SmartScale™ was downloaded through an Automated Programming Interface (API) into Program R for statistical computing. The R code was used to clean, filter, and organize data into longitudinal data frames.

Figure 1: Dormant winter pasture and heifers (left) and SmartScale™ (right).

An AUM model was constructed in Vensim DSS™, a dynamic-visually based modeling software. Equations described in the online South Dakota State University (SDSU) grazing calculator were utilized in the AUM model (Ehlert and Brennan, 2022). Fixed parameters for the model can be found in Table 1. Forage data was collected at the beginning and end of the trial using a grid sampling technique for each pasture (n = 10 per pasture) to provide initial available forage values (kg dry matter ha^{-1}). Static values (i.e., the same BW for each animal each day) were used to compare the AUM model outputs and the SDSU grazing calculator outputs to ensure mathematical accuracy and that double-accounting was avoided. Next, a 'precision data' AUM model (AUM$_{PSM}$) component was built in Vensim DSS to integrate daily individual BW data. The precision data were integrated into Vensim DSS™ using the subscript function that imported precision data from Excel™. A 3D smoothing function was applied to raw weight data to minimize variation due to rumen- fill etc. The AUM$_{PSM}$ included a discrete (daily time step, delta time = 1) first-order differential equation to aggregate the daily estimated DMI and hectares needed for each animal into monthly herd level values. Thus, the model output was total hectares needed per month to meet cattle nutrient requirements and total forage consumed at a herd level. Three scenarios (described below) were simulated to determine differences in total hectares of pasture needed per month over a 167 d period of the 175 d grazing trial [8 d or n = 480 BW (kg) were removed from the total dataset due to missing BW values]. All simulations were based on the DMI estimation method using %BW described above. Model parameters were the same in each scenario except for the BW parameter (Table 1). The scenarios were selected to represent the typical AUM method compared to estimated AUM using precision BW data.

Table 1: Model parameters used in the three scenarios for the heifer stocking rate calculations based on the 'take-half-leave-half' method (25% waste, 25% consumed).

Model Parameters	Value	Unit
Available Forage	917.78	kg ha^{-1}
Harvest Efficiency	0.25	Dimensionless
Days per Month	30	Day
Number of Cattle	60	Head
Percent BW	2.5	%
Body Weight	-	kg

Scenario 1 applied traditional rangeland AUM estimation methods based on average initial herd BW on November 17th, 2022, calculated from the precision BW data. Scenario 2 consisted of calculating a mid-season average weight based on initial weight (243.45 kg) and desired end weight (381.02 kg) from November 10, 2021, to June 1, 2022 (the entire study period 204 d; average daily gain = 0.68 kg d^{-1}). The impetus behind this scenario was to account for changing BW at a herd level at mid-season in the attempt to capture the same expected variation in BW throughout the grazing period. To obtain an average mid-season herd BW, we calculated the BW on February 7, 2022, of the 167 d study period (i.e., the middle) using an average daily gain of 0.68 kg d^{-1} from November 17^{th} (243.45 kg) needed to achieve 381.02 kg at the end of the grazing trial (June 1, 2022; 204 d). Scenario 3 utilized daily BW measurements from the precision scales for each of the 60 heifers and changed each day over a 167 d period (Table 2) with the AUM_{PSM}.

Table 2: Scenario parameters for body weight (BW).

Scenario	Value	Unit
1: Average Initial BW	243.45	kg
2: Desired Mid-Season BW	301.53	kg
3: Individual Precision BW	individual weights	kg hd^{-1} d^{-1}

We conducted a Monte Carlo analysis (10,000 runs) to determine the percentiles of potential variation from percent BW on PSM calculations on a daily basis impacting total hectares required and total forage used for the 167 d period. The BW parameters ranged from 1.8 to 2.7% using a univariate-normal distribution in Vensim™.

Results

The greatest difference in total area needed was 73.41 ha between scenarios 1 and 3; however, using an estimated mid-season average (scenario 2) only resulted in 10.03 ha less than the precision estimate (scenario 3; Figure 2). Simulations were deterministic and did not have a probability distribution. The sensitivity analysis results of forage consumption from variation in %BW ranged from 56,019 to 84,014 kg on day 167, increasing as the grazing trial progressed (Figure 3A). Similar to estimated forage consumption, the sensitivity analysis of total hectares required, from variation in %BW, ranged from 244 to 366 haon day 167 and increased as the trial progressed (Figure 3B).

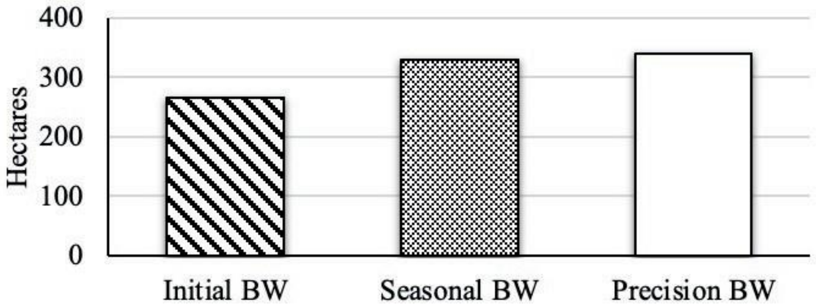

Figure 2: Simulated area (ha) to graze 60 heifers for 167 d based on body weight (BW) dry matter intake estimation in scenario 1 (initial herd BW), scenario 2 (herd mid-season BW) and scenario 3 (precision BW).

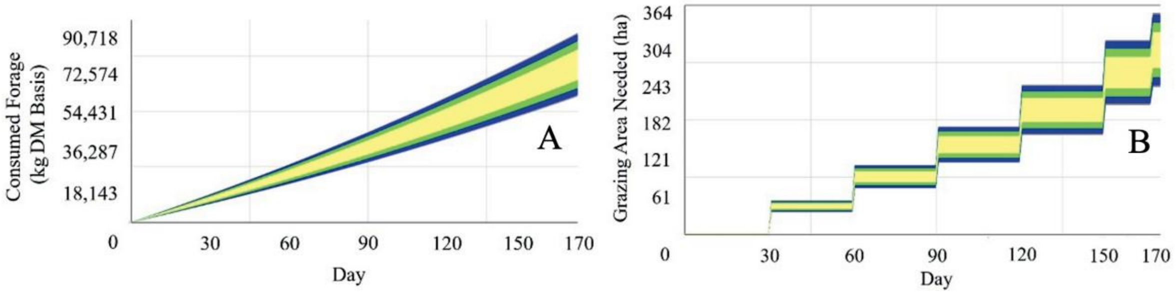

Figure 3: The percentiles of potential variation of daily total forage consumed (kg DM basis) from changes to % body weight (BW) over a 167 d period (Panel A). The percentiles of potential daily variation in the area needed (ha) over the simulation period (167 d) from changes to % BW values (Panel B) (Yellow = 50%, Green = 75% and Blue = 95%).

Discussion

As expected, considerable differences existed between the traditional AUM method and the precision-informed AUM_{PSM} method, caused by individual animal BW. Differences between scenarios 1 and 3 were amplified over time as BW became increasingly influential to AUM estimates. This indicates that obtaining initial BW before turn-out for grazing is a critical management factor and that precision weighing can aid both traditional and precision AUM estimates. A mid-season average captured similar results as the precision-informed AUM estimate (~3% difference). However, this agreement was found using expected daily gain based on a well-developed nutrition plan (grazing and supplement) and from a sample population that was culled to represent a similar weight range. It is unlikely that such cattle uniformity exists for the typical rancher and, therefore, would have more variability. Thus, an opportunity exists to evaluate how many ranchers use initial or mid-season BW and the different qualities of BW data available. Evaluating the usefulness of tools like precision weighing is essential for effective adoption and avoidance of technologies that do not yield returns.

Precision system modeling focuses on identifying high-leverage precision measurement or management tools to minimize a performance gap (Menendez et al., 2022). Grazing models like APEX use growth functions based on mean animal weights (Fang et al., 2022). Although models can incorporate probabilistic functions, the variation applied is random for each animal at any given time-point, which does not reflect grazing behavior or environmental responses affecting performance, while precision BW data is representative of such variations. Thus, the next step in PSM is to identify feedback mechanisms that more adequately represent individual BW variation. These mechanisms will likely include other data streams (e.g., climate data on heat stress) to model this individual variation. Thus, PSM will help to further separate rangeland animals into different groups of efficiency/quality. For example, the variation of total forage consumed and hectares needed caused by the sensitivity analysis of %BW for each heifer (Figure 3AB) indicates that individual animal consumption rates (kg dry matter d^{-1}) are impactful. As more information is collected about feed-efficient grazing cattle, there is a potential to select animals with similar efficiency levels to minimize this variation. Applying precision data and derived model coefficients provides more precise DMI estimates and shows the advantages and disadvantages of herd level estimates, especially in the context of changing cattle demands and forage nutrient composition and availability throughout the grazing season. For instance, unlike the data used in the current study, where nutrient quality and availability are fixed resources (i.e., dormant forage), most livestock grazing capitalizes on seasonal changes in forage availability and quality. Adjusting stocking rates to these changes is important for rotational grazing. Precision BW estimates can help producers finetune stocking rates for future pastures (dynamic pasture adjustment using AUM_{PSM}). Further, virtual fencing has made these potential AUM_{PSM} informed rotations feasible because physical labor and infrastructure (e.g., water) requirements are minimized (Menendez et al., 2022). Grazing livestock research and production are focused on the 'margins' like performance and costs, with the aim to maximize rangeland resources (Dunn et al., 2010). It has been estimated that 20-40% of US grasslands are overgrazed (Piipponen et al., 2021). Heavy grazing has been shown to be as profitable as more lightly grazed systems in years with average precipitation; however, limitations in forage productivity and water infiltration are extreme during drought. Precision system models help to answer complex questions regarding the impact of precision livestock technologies on marginal increases in animal productivity at a local and supply chain level (Menendez and Tedeschi, 2020). While comparison of scenarios 1 and 3 indicate local ranch-level benefits, especially for extensive systems (Figure 2), viewing supply chain impacts supports efforts for marginal improvements at the local level (e.g., climate-smart commodities). For example, the current number of heifers in South Dakota (US) is 375,000 (USDA-NASS, 2022). We extrapolated our results to a state level using the following equation (1):

$$Hectares\ Overgrazed = \frac{\text{rV!UVY\%}}{\text{rV!UVY}_{\&}} * Difference\ in\ Hectares \quad (1)$$

where hectares overgrazed is the number of additional hectares required for a specific grazing period, $Heifers_S$ is the current number of heifers in the state, $Heifers_L$ is the local Angus heifers used in the current study (n = 60), and the difference in hectares (Δ ha) is the difference between the modeled results of scenarios 1 and 3 (Table 3).

Table 3: Extrapolation of scenarios 1 and 3 to estimate hectares required for a 167 d period at a state level based on January 2023 state heifer numbers.

Scenario	ha	Δ ha	State ha Required	Area Overgrazed ha
1	265.55	-	1,659,687	-
3	338.96	73.41	2,118,500	458,812

Conclusions

Using technologies like SmartScales™ is a high-leverage decision because minimal investment is needed to obtain data that provides more precise stocking rate estimates. As data increase for animal classes and grazing periods (e.g., winter, summer), more precise stocking estimates can be obtained to maximize pasture use relative to production goals (harvest efficiency; Smart et al., 2010). However, more investigation is needed for non-growing animal classes like mature cows that are likely to have much less variation in DMI over the grazing season. Practical steps are needed to evaluate how precision data can be integrated into PSM to guide precision data collection efforts. A next step is using precision-informed forage nutrient composition data from remote sensing and DMI equations that include net energy for maintenance (NASEM, 2016). Additionally, using PSM to evaluate local ranch and supply chain level impacts will provide quantitative justification for specific precision livestock tool use or future development.

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