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Integrating remote sensing and in pasture weighing technology to estimate dry matter intake for grazing beef cattle

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Key words: Precision livestock technology, dry matter intake, beef cattle

Abstract
Precision livestock technology (PLT) can improve sustainability of beef production on rangelands. Key to the advancement of PLT is the integration of technologies and data streams with animal nutrition models to better inform management decisions. Knowing dry matter intake (DMI) is essential for setting stocking rates and estimating forage removal by grazing beef cattle; however, estimating DMI for grazing cattle is difficult due to dynamic changes in forage quality and animal weight throughout a grazing season. A study was conducted from 2021-2023 at the South Dakota State University Cottonwood Field Station (Cottonwood, SD, USA) to estimate daily DMI for grazing steers. The objectives of our study were to 1) utilize machine learning (ML) to predict daily estimates of forage quality, 2) estimate average daily gain (ADG) using in pasture weighing systems, and 3) incorporate forage quality and ADG estimates into animal nutrition models to predict individual animal DMI. From 2021-2023, bi-weekly forage samples were collected and used to train a multivariate random forest model to predict daily acid detergent fiber (ADF) based on climate and imagery metrics derived from Google Earth Engine. Root mean square error of prediction was 2.6 with a 0.81 correlation between predicted and observed values of ADF. SmartScales™ (C-Lock Inc., Rapid City, SD, USA) were deployed in six pastures to estimate daily animal weights for grazing steers. Smoothing splines were used to estimate ADG allowing for non-linear changes in animal performance. Daily estimates of ADF and ADG were used to calculate daily DMI for individual animals using equations from the Nutrient Requirements of Beef Cattle. Overall, average DMI estimates for individuals ranged from 2-3% of body weight, which is within expectations for free ranging livestock. This paper address how big data, technology, and machine learning can be integrated to better aid grazing monitoring and forage demands for livestock.

Introduction
The promise of precision livestock technology (PLT) is to increase operation efficiency and reduce the associated environmental footprint of grazing on rangeland systems. A suite of recent novel technologies

such as remote sensing products to estimate plant fractional cover and net primary production (Jones et al. 2017) and in-pasture weighing systems (Parsons et al. 2023) has enhanced our ability to measure and manage livestock production within rangeland systems. Individually, these technologies can increase the temporal and spatial resolution of data collection that can help inform management decisions at finer scales; however, integration of multiple different technology platforms with machine learning and animal nutrition models is needed to maximize the impact of PLT.

Estimating dry matter intake (DMI) is essential for beef producers to identify more efficient animals and optimize cattle performance. In addition, DMI is an essential component for calculating stocking rates and estimating forage utilization from grazing animals. Estimation of DMI for cattle grazing on extensive rangelands is difficult due to changes in environmental factors, forage quality, and animals' physiological state, which can result in large variability among animals grazing in the same pasture (Galyean and Gunter 2016). Traditionally, fixed estimates of DMI such as 3% of body weight (BW) have been used to calculate forage demands for grazing animals; however, this doesn't account for the dynamic changes in forage quality, animal BW, and DMI inherent within rangeland systems. Previous work has demonstrated the use of models to predict DMI required to achieve a specified level of performance based on animal nutrition equations to determine net energy required for a given animal BW and average daily gain (ADG) (Anele et al. 2014). The integration of in-pasture weighing systems to measure individual animal performance and BW, remote sensing to estimate daily forage quality, and animal nutrition equations may be able to estimate DMI for grazing beef cattle. The objectives of our study were to 1) utilize machine learning (ML) to predict daily estimates of forage quality, 2) estimate average daily gain (ADG) and daily BW using in pasture weighing systems, and 3) incorporate forage quality and ADG estimates into animal nutrition models to predict individual animal DMI.

Methods

Study Site

Research for this study was conducted at the South Dakota State University Cottonwood Field Station (CFS), Cottonwood, SD, USA (43.960297, -101.857913) from 2021-2023. Rangeland at the CFS is typical of a Northern Great Plains mixed-grass prairie, consisting primarily of western wheatgrass (*Pascopyrum smithii* Rydb.), green needlegrass (*Nassella viridula* Trin.), buffalograss (*Bouteloua dactyloides* Nutt.), and blue grama (*Bouteloua gracilis* Willd. Ex Kunth.). This study was overlaid on a long-term experimental grazing study setup as a randomized complete block with three levels of stocking rate replicated in two pastures each (heavy (1.78 AUM/ha), moderate (0.99 AUM/ha), and light (0.79 AUM/ha)) for a total of six pastures. In each of three years, yearling steers (n = 116, 131, 127 in 2021, 2022, 2023, respectively) were stratified by BW into one of six pastures. Steers in 2021 grazed from June 10 to August 17, steers in 2022 grazed from June 8 to August 21, and steers in 2023 grazed from June 6 to August 30.

Remote Sensing

Forage quality was estimated by clipping five bi-weekly georeferenced forage samples from May to October in 2021-2022 across each of the six experimental pastures. Forage samples were dried for 72 hrs in an oven at 60˚C and weighed for biomass. After weighing, samples were ground in a Wiley mill (Thomas Scientific, Swedesboro, NJ, USA) with a 1 mm sieve. Forage digestibility was analysed for neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) using a fiber analyzer (ANKOM 200 Fiber Analyzer, ANKOM Inc., Macedon, NY, USA). To develop a predictive model, dependent variables were extracted from Google Earth Engine (GEE) for each sample location using an Application Programming Interface (API) developed in Python. Climate predictor variables were derived from the GRIDMET dataset and included daily cumulative and percent of 40-year normal precipitation and growing degree days (Abatzoglou 2012). Season long normalized difference vegetation index (NDVI) values were extracted for each clip plot pixel from the Sentinel-2 satellite imagery dataset. For each pixel, a cubic spline was fit and used to estimate daily NDVI values and the estimated NDVI for the day the plot was clipped was used as a predictor variable in the model. A multivariate random forest model was trained with ADF as the dependent variable and climate and satellite imagery metrics as the predictor variables. This model was then used to predict daily ADF values for each pasture.

Animal performance
Daily animal BW were measured using SmartScales™ technology (C-Lock Inc., Rapid City, SD, USA). Briefly, SmartScale™ is an in-pasture weighing technology that is placed in front of existing water tanks that measure animal BW while drinking by recording RFID tag data and front-end weight, which is converted to full BW through a linear transformation (Brennan et al. 2023). Spurious weights were removed from the dataset using robust regression technique (Parsons et al. 2023). For each individual animal, smoothing splines were fit with BW as the dependent variable and date as the independent variable. Smoothing splines models were then used to predict daily BW for each steer allowing for non-linear dynamics of animal growth. Daily ADG was estimated as the difference between modelled BW on consecutive days.

Dry Matter Intake Calculations
Individual steer growth performance and daily forage ADF determinations to were used to estimate the daily DMI required for gain. Briefly, a DMI function (DMI_{func}) was developed in program R. The DMI_{func} takes the inputs of ADF to estimate ME, initial BW (BW_t), final BW (BW_{t+1}), and days on feed to determine daily gain. Daily ADF values for each pasture were derived using the random forest model described above; BW_t and BW_{t+1} were derived from the smoothing spline model described above for each steer, with days on feed set to one in the function. Metabolizable energy was determined based upon estimating total digestible nutrients from ADF, and mathematically converting to digestible energy, metabolized energy, and forage net energy for maintenance and growth based on equations outlined in NASEM (2016).

Results
On average, estimates of DMI as a percentage of BW ranged from 2.39% to 2.80% over the entire trial period (Table 1). The daily estimate of DMI as a percentage of BW for each individual steer ranged from 1.19% to 10.86%. Averaged over the course of the grazing season, as a percent of BW, DMI estimates are well within expected ranges for grazing cattle. Daily estimates above 4.5% DMI as a percentage of BW represent 1.8% of all observations, and of those 53% occurred during the first and last week of the trial. This indicates that higher estimates of DMI are likely the result of the smoothing splines over estimating ADG at the beginning or end of the trial period, perhaps due to daily weight data being less sparse within these time frames.

In addition, for each grazing steer, we calculated cumulative DMI over the course of each grazing season (Figure 1). Cumulative estimates of DMI at the herd level ranged from 497 kg in the heavy graze pastures in 2022 to 967 kg in the light graze pastures in 2023. Differences in cumulative intake between years is likely driven by the number of grazing days and average herd BW. Results presented in Figure 1 can be used to estimate forage removal by grazing livestock and subsequently inform rotational grazing decisions when desired utilization has been reached.

Discussion
Estimating DMI for grazing cattle is difficult. Previous methods have utilized animal nutrition equations, forage clip plots, and forage marker techniques, all of which have their challenges that balance precision of

estimates, time and effort, and costs. For example, estimating forage disappearance with utilization cages can be used to estimate DMI at the herd level but fails to capture individual animal variability. Likewise, approaches that estimate DMI using animal nutrition equations rely on ADG estimates over monthly time frames and may not consider day to day variability of environmental conditions of the grazing animals (Undi et al. 2008). To our knowledge, this is the first attempt to estimate daily DMI for grazing beef cattle by integrating PLT to more accurately account for dynamic changes in forage quality and animal weight gain over an entire grazing season.

The objective of this paper was to demonstrate how technology and animal nutrition models could be integrated to make predictions on DMI for grazing cattle. Though this model considers daily estimates of forage quality and BW, other factors such as ambient temperature and forage availability can also impact DMI. Factors such as ambient temperature or heat stress equations could be incorporated into energy maintenance estimates to help refine predictions. In addition, these results can be used to determine the impact that stocking rate, rotational grazing patterns, or heat stress have on daily DMI and subsequent ADG to help optimize livestock production.

Often in the field of rangeland management, stocking rates are set based on average forage production, average herd BW, and a constant percentage of BW for estimating DMI. Given the high variability in forage production and quality between wet and dry years, this approach will likely miss grazing management targets within a given year as stocking rates often don't account for the dynamic nature of animal BW and forage quality. The objective of PLT is to utilize technology to generate real time data collection, which can be integrated into models to inform decision making allowing land managers to better hit their production goals either at the individual animal or herd level.

Table 1: Mean estimates of daily dry matter intake (DMI kg), DMI as a percentage of body weight (% BW), average daily gain (ADG kg/head/day), and acid detergent fiber (ADF) for steers grazing native range over 3 years at the South Dakota State University Cottonwood Field Station (Cottonwood, SD). USA).

Year	Stocking Rate	Daily DMI	% BW	ADG	ADF
2021	Heavy	9.62	2.39	0.79	32.17
	Moderate	10.95	2.69	0.88	34.21
	Light	10.32	2.57	0.82	34.23
2022	Heavy	7.66	2.39	0.65	33.06
	Moderate	8.00	2.73	0.75	34.29
	Light	9.30	2.58	0.76	34.31
2023	Heavy	10.27	2.59	0.91	32.37
	Moderate	9.92	2.72	0.88	33.76
	Light	11.26	2.80	0.89	33.89

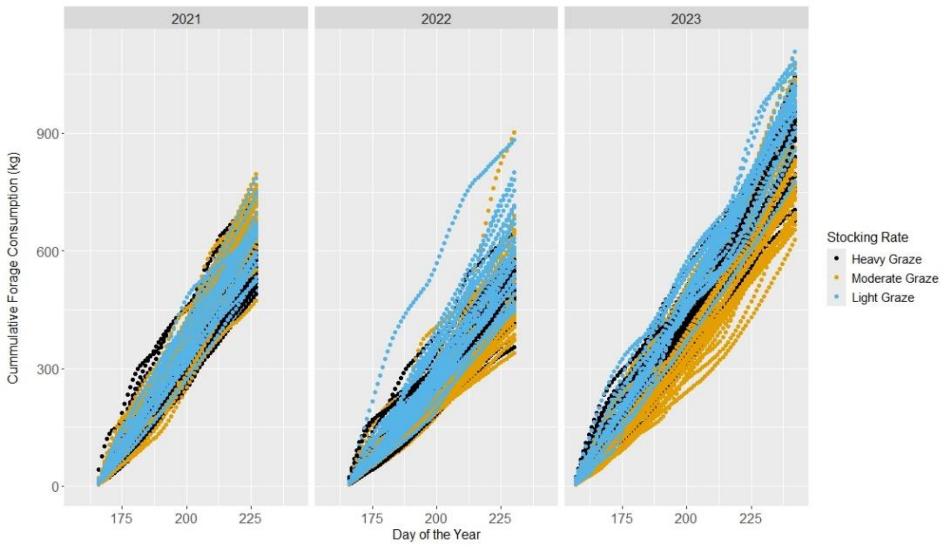

Figure 1: Cumulative estimates of forage consumption for each individual steer over three grazing seasons and three stocking rates.

Acknowledgements

This work was funded by grants from the USDA, the National Institute of Food and Agriculture (NIFA) (2022-67022-37023 & 2022-69014-36670). Animal work described herein was approved by the South Dakota State University Animal Care and Use Committee (2014-021E).

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