Use of Unmanned Aerial Vehicle Technologies with Thermal Imaging to Assess Surface Moisture in Pens of Cattle Offered Energy-dense vs. Low-energy Feeding Programs

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Abstract
An experiment was conducted to determine if feedlot pen moisture can be detected using unmanned aerial vehicle (UAV) technologies. Steers were fed either an energy-dense, limit-fed diet or a low-energy, *ad libitum*-fed diet to create differences in the conditions of pen surfaces. The objectives were to: 1) characterize pen surface moisture levels as determined by different feeding programs; and 2) evaluate associations between UAV thermal images and pen surface moisture. Six dirt-floor pens (30 × 50 ft) at the Kansas State University Stocker Unit (Manhattan, KS) housed 14 dairy-beef crossbred steers each (Body weight = 930 ± 85 lb). Pens were assigned to either an energy-dense 64 Mcal/cwt net energy for gain (NEg) limit-fed ration (LIMIT; n = 3) or a low-energy 50 Mcal/cwt NEg *ad libitum* ration (ADLIB; n = 3), and each pen was divided into 15 sampling quadrants (10 × 10 ft). For three consecutive days, a UAV (AUTEL EVO 2) equipped with a thermal sensor (H20T) was flown at an altitude of 100 ft to capture images during morning feeding. Images were processed with Pix4D and ArcGIS, and average luminosity using minimum and maximum red, green, and blue (RGB) ([minRGB + maxRGB]/2) values per quadrant were obtained in Photoshop. Pen floor grab samples (n = 3/quadrant) were analyzed for moisture. Moisture was analyzed using a linear mixed model with fixed effect of treatment and random effects of pen, quadrant nested within pen, and day ($P = 0.025$). Pen moisture was then tested for association with luminosity values from UAV thermal images using a linear mixed model. Luminosity was associated with moisture ($P < 0.001$), supporting its utility as a predictive metric. The equation using luminosity to predict pen floor moisture demonstrated excellent predictive accuracy (Lin's concordance correlation coefficient = 0.98). Results indicate UAV thermal images can characterize pen-level surface moisture, and luminosity values effectively predict pen floor moisture.

Introduction
Beef cattle are often housed in open dirt pens that accumulate manure, urine, and wasted feed. Depending upon management, pen condition can affect cattle performance, animal health, animal welfare, and the surrounding environment. Pen floor conditions are influenced by diet composition, stocking density, and weather. The

combination of these variables directly affects moisture, nutrient accumulation, and surface temperature. Excessive moisture can reduce animal comfort, increase the risk of lameness and digital dermatitis, and elevate pathogen prevalence (Berry and Miller, 2005; Cortes et al., 2021). Conversely, overly dry surfaces contribute to dust generation, which negatively affects air quality and animal well-being (Grandin, 2016).

Traditional pen assessment relies on visual evaluation or score, which is labor-intensive, subjective, and provides limited spatial resolution. Remote sensing technologies, including unmanned aerial vehicles (UAV) equipped with thermal sensors, offer an opportunity to rapidly characterize surface conditions. Limited research has evaluated whether UAV imagery can reliably predict nutrient and moisture conditions in cattle pens. The objectives of this trial were to characterize the pen surface moisture level of cattle pens managed with energy-dense, *ad libitum* or low-energy, limit-fed feeding programs, and to evaluate the association of luminosity derived from thermal images taken using UAV technologies with the pen surface moisture level.

Experimental Procedures

The study was conducted in the summer using six outdoor dirt-surfaced feedlot pens (30 × 50 ft) at the Kansas State University Stocker Unit (Manhattan, KS). Each pen housed 14 dairy × beef crossbred steers (Body weight [BW] = 930 ± 85 lb) on days 111, 112, and 113 of the backgrounding phase. Pens were assigned to one of two dietary treatments: 1) LIMIT: energy-dense limit-fed finishing ration formulated to 64 Mcal/cwt net energy for gain (NEg) or 2) ADLIB: low-energy *ad libitum* ration formulated to 50 Mcal/cwt NEg. The diet composition of the LIMIT ration consisted of dry rolled corn (59%), wet corn gluten (30%), prairie hay (7%), and supplement (4%). The diet composition of the ADLIB ration consisted of dry rolled corn (24%), wet corn gluten (40%), prairie hay (30%), and supplement (6%).

Before sample collection, each pen was divided into 15 quadrants (10 × 10 ft). Sample collection and UAV imaging directly followed morning feeding to capture surface images of the pen while the cattle were occupied at the bunk. Three grab samples (approximately 0.55 lb) of the pen surface material were collected per quadrant and analyzed individually for moisture (dry matter %). Replicates were averaged by quadrant to provide descriptive variables of surface moisture of the pen by quadrant.

An AUTEL EVO II UAV equipped with a thermal sensor (H20T) was flown at an altitude of 100 ft in preplanned flights to take thermal images of the pen surfaces. Relevant pen images were stitched together and processed using Pix4D and visualized in ArcGIS. Quadrant-specific luminosity values were extracted in Adobe Photoshop to provide a unitless measure of relative brightness, calculated from the red, green, and blue (RGB) channels ([minRGB+maxRGB]/2), for statistical analysis.

Sample collection and imaging were conducted across three consecutive days. Weather and temperature were consistent on days 1 and 2, providing stable pen surface conditions. Before day 3 sample and image collection, rainfall occurred, which altered pen moisture levels. On day 3, pens (n = 2) were sampled for moisture analysis, and UAV imaging was completed for all pens. For statistical analysis, pens without direct samples on day 3 were excluded from the dataset.

Statistical analyses were conducted in R version 4.4.2. Linear models were constructed using the lmer function of the lme4 package in R. Moisture was first analyzed using a linear mixed model with fixed effect of treatment and random effects of pen, quadrant nested within pen, and day. When a significant association between treatment and moisture was determined, moisture was then tested for association with luminosity. The relationship was modeled using a linear mixed model with fixed effects of treatment and luminosity and random effects of pen, quadrant nested within pen, and day. The epiR package in R was used to calculate Lin's concordance correlation coefficient (Lin's CCC) between the actual measured moisture and the luminosity predicted moisture to understand the precision and accuracy between moisture and luminosity. Significance was declared at $P \leq 0.05$. Trends were noted at $0.05 < P \leq 0.10$. Lin's CCC values were declared at: > 0.9 excellent; 0.8 - 0.9 good; 0.6 to 0.8 moderate; below 0.6.

Results and Discussion:

Treatment influenced the pen surface moisture. LIMIT resulted in 10% lower ($P < 0.001$) pen-surface moisture than ADLIB (42.1 versus 52.1 ± 8.3%, respectively). Luminosity value consequently was higher ($P = 0.003$) in LIMIT compared to ADLIB (87.4 versus 55.1 ± 7.9, respectively). This outcome supports previous observations that *ad libitum* feeding increases manure output and consequently the surface moisture of the pen accumulation relative to limit-fed cattle. Findings are consistent with previous reports that nutrient intake and feeding strategy directly affect pen condition through differences in excreted manure volume and composition.

When luminosity derived from UAV thermal imagery was added as a fixed effect into the original model, both treatment and luminosity were predictors of pen surface moisture. When predicted by luminosity ($P < 0.001$), LIMIT had lower ($P = 0.014$) surface moisture of the pen compared to ADLIB (43.8 versus 49.8 ± 7.9%). Therefore, luminosity had a strong negative association with measured pen surface moisture. This relationship explains the link between lighter image tones and drier surfaces, indicating that UAV-based imaging can provide a non-invasive proxy for moisture assessment.

Model predictions of the pen by day mean moisture content were closely aligned with observed values, with residuals generally within ±5% across days and treatments. The agreement between observed and predicted values was exceptionally high (Lin's CCC = 0.98; Figure 1). This level of predictive accuracy demonstrates the strong potential of UAV thermal image-derived luminosity as a tool for quantifying cattle pen-surface moisture conditions.

Weather conditions were stable during days 1 and 2, providing consistent baselines for moisture and imaging. However, rainfall before day 3 increased overall moisture levels (Figure 1), which was evident in both direct sampling and UAV imagery. These weather-related differences highlight how external environmental factors influence pen conditions and the potential utility of UAV monitoring for capturing changes and the rate of dissipation due to precipitation events.

These findings demonstrate that UAV-derived imagery can distinguish surface moisture influenced by feeding program and accurately predict surface moisture across days and environmental conditions. Integrating this approach into routine feedlot management could allow facilities to identify wetter pen conditions, guide decisions around cleaning, bedding, or drainage, and ultimately improve cattle health and comfort while mitigating the risk of nutrient runoff.

Implications

The UAV thermal image-derived luminosity values provide a practical tool to confidently (Lin's CCC = 0.98) quantify the pen surface moisture and detect feeding program effects, offering precision management opportunities to improve animal health and environmental outcomes.

References

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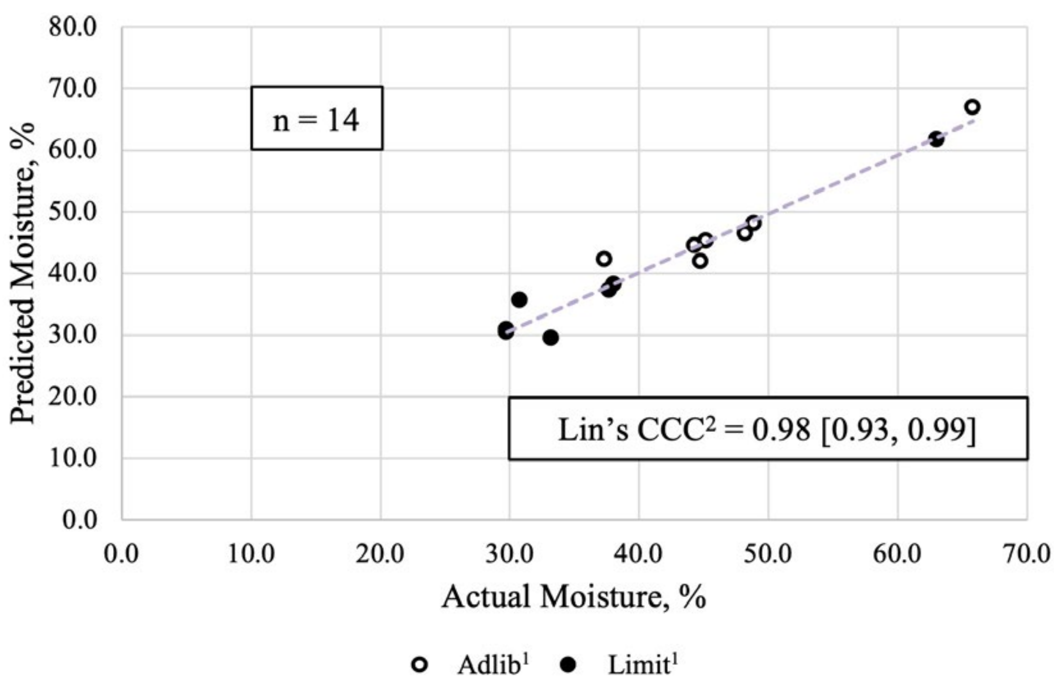

Figure 1. Relationship between observed and predicted mean moisture values for pen by day

[1] Treatment: ADLIB = low-energy *ad libitum* (50 Mcal/cwt net energy for gain [NEg]); LIMIT = energy-dense limit-fed (64 Mcal/cwt NEg).

[2] Lin's concordance correlation coefficient: > 0.9 excellent; 0.8 - 0.9 good; 0.6 to 0.8 moderate; below 0.6.