Estimating forage biomass using unmanned ground and aerial vehicles

Koc, B. A.[*]; Singh, J.[*]; Aguerre, M. J.[†]

[*]Department of Agricultural Sciences, Clemson University
[†]Department of Animal and Veterinary Sciences, Clemson University

Keywords: Unmanned aerial vehicles; unmanned ground vehicles; compressed height; biomass; forage yield.

Abstract

The assessment of the amount of biomass in the field is one of the critical factors that helps to manage and optimize numerous operations associated with forage management in the livestock industry. Pasture management decisions about stocking rate, grazing duration, and fertilizer application rate depend on accurate forage availability measurements. The objective of this study was to develop different nondestructive methods of forage biomass estimation using unmanned vehicles based on the relationship between crop height (CH) and the measured above-ground biomass. The unmanned vehicle-based methods were developed and tested on Alfalfa (*Medicago Sativa*) and Tall Fescue (*Schedonorus phoenix* (Scop.) Holub) fields. The real-time compressed crop height was measured using the ultrasound proximal sensor and a compression ski installed on the unmanned ground vehicle (UGV) and orthomosaic from aerial images was used for plot identification for site-specific analysis. The experiment was carried out before and after harvest to calculate the harvested CH to generate its regression relation with wet and dry biomass yield of forage. The results show that these systems produce promising results with R-square values of 0.8 and 0.5 for biomass estimation in Alfalfa and Tall Fescue respectively. These methods will significantly reduce the on-field destructive forage sampling for biomass estimation and aid in predicting the available biomass along with reducing the human efforts and resources for performing biomass sampling tasks, resulting in reduction of time and cost.

Introduction

The availability of sufficient forage biomass to meet the nutrients requirements is one of the main goals of livestock production systems. Accurate measurement of forage mass helps cattle managers to precisely determine stocking rates and duration of grazing. The imbalance between the stocking rate and available forage mass is one of the major problems among US cattle producers (Mulliniks et al. 2015). Obtaining estimates of forage mass in a pasture remains a difficult task. The difficulty is due to measurements that need to be done before and after grazing on standing grass in pastures (Yule et al., 2010). Current forage mass estimation techniques are time-consuming, and labor-intensive, or their accuracies are not high enough to be accepted by the producers. Depending on the geographic location, season and climatic conditions, livestock producers might have only one growing season for their forage, whereas other areas might have multiple growing seasons in a year (Mulliniks et al. 2015). The destructive clip and weigh method of biomass estimation is not time- and labor-efficient (McGowan, 1979; Harmoney et al., 1997). In addition, the data collected from some random samples is extrapolated to determine the biomass availability of an entire field, hence deprioritizing the spatial variations. Hence, automated systems for biomass estimation may help overcoming these challenges. In the available methods of nondestructive height estimation, signal time-of-flight based ultrasound and lidar sensors do the job in reference to the known ground point (Pittman et al. 2015). The overall objective of this research was to develop and test the use of a nondestructive biomass estimation system for forage crops (Alfalfa and Tall Fescue) in large fields.

Methods

Overall planning of the experiment

Forage biomass evaluation was conducted in two 2-acre fields planted with either Alfalfa or Tall Fescue, at the Simpson Research Farm, Clemson University, located in Pendleton, South Carolina (34°37′38.0″ N 82°43′33.5″W). The CH measurements were conducted before and after the mechanical harvest, and the difference of both gave the harvested height of these forage crops. The biomass of every plot from each field was harvested using a plot forage harvester (Carter Manufacturing Co., Brookston, IN). After weighing the harvested biomass, samples from each plot were dried at 55°C in a forced-air oven for 48 h. The resulting dry matter fraction (DMF) was used to estimate the dry biomass yield (DBY) from the wet biomass yield (WBY) (kg/ha). Pre- and post-harvest surveys for both crops were conducted on the same day to get the best results, irrespective of the temperature differences, weather conditions, and delay effects. The following sets of data were collected on each experimental setup: 1) Installation and positioning of ground control points (GCPs) with RTK-GPS device; 2) Pre-harvest CH measurements with ultrasound sensor mounted on UGV; 3) Harvesting of plots and collection of forage samples from each plot for lab testing; 4) Post-harvest aerial survey with RGB camera mounted on unmanned aerial vehicle (UAV) to build orthomosaic; 5) Post-harvest CH measurement with ultrasound sensor mounted on UGV. All the data collection, processing and assessment work was conducted in projected coordinate system: WGS 1984 UTM Zone 17N using ESRI ArcGIS Pro.

Crop height measurement using unmanned vehicles

For measuring crop height, an ultrasound sensor installed in the 4-wheel driven ground vehicle was used, along with a ski shaped acrylic plate named "compression ski". For the positioning of the ground vehicle, the RTK-GPS rover (Emlid Reach RS+) was installed on a metallic frame on the ground vehicle at 1.83 m height from ground level, for clear exposure of satellites and better positioning. The ultrasound sensor was mounted at a fixed distance from the compression ski when it was placed on a flat ground and as the ground vehicle moves over the plant canopy, the compression ski gets lifted upwards with the crop's topography, changing the distance between the ultrasound sensor and the compression ski, which was used to estimate the crop height at each data point collected by the ground vehicle in the field. The readings were taken after every 0.15 meters that the ground vehicle traveled in the field with the help of RTK-GPS. The HP Envy x360 Linux operating system-based laptop was used to collect, save, and merge the ultrasound and RTK-GPS data, read from serial ports using a Python script. The same process was replicated before and after the harvesting. The ground vehicle was driven through the fields following an alternating side-by-side transect, covering the entire field. The harvesting of field was done by making 44 plots of 0.91 x 3 m^2 for Alfalfa field and 65 plots of 0.91 x 4.57 m^2 for Tall Fescue field depending on the orientation and the geometry of the fields. After harvesting the plots, the sample of each plot was weighed and subsamples were collected and processed in the laboratory for the dry matter fraction assessment of each plot. To identify the harvested plots in the field, the post-harvest orthomosaic was created using the aerial images of the field captured by the Survey-3 RGB camera (MAPIR Inc., San Diego, CA), mounted on a DJI Mavic Pro (DJI, Shenzhen, China) drone. The third-party application Drone Deploy (dronedeploy.com) was used to create the mission flight plan for the aerial survey, with 75% forward and side overlaps. The crosshatch flight path was adapted to capture the aerial images. The flight height was kept 45.72 m, for Alfalfa crop whereas it was set to 18.29 m for Tall Fescue experimental fields. The height of 18.29 meters for Tall Fescue was chosen to keep it standard as per the parameters selected by MacInnis (2022), whereas 45.72 meters was adapted to check the resolution of orthomosaics at higher flight height, and to cover the large area in shorter duration. The images were captured around the solar noon of the experiment day to ensure better quality and minimal shadow effects and were further postprocessed in the Agisoft Metashape Pro software (Agisoft LLC, St. Petersburg, Russia) to build orthomosaics from these aerial images (Fig. 1). The image processing in Agisoft Metashape Pro

Figure 1. UAV-based orthomosaic for harvested plot identification.

followed the standard set of parameters, i.e., ultra-high quality and moderate filtering to ensure best and most accurate results for each field.

Data processing and analysis in ArcGIS Pro

For the analysis of the recorded data, the CH readings from UGV, post-harvest orthomosaics from UAV, and the GCPs were imported into ArcGIS Pro. The post-harvest orthomosaic was first georeferenced using the GCPs, and then the harvested plot boundaries were identified and marked as a polygon feature to perform statistical analysis on CH in those harvested regions using 'Summarize Within' tool in ArcGIS Pro. This process was replicated for both pre- and post-harvest ground vehicle measurements. The final summarized CH data was exported and compared with the wet and dry yield data for the respective plots in Microsoft Excel for regression analysis and building the prediction model.

Results and Discussions

The results obtained from the collected and processed data showed a significant variation in biomass yield with the crop height. The linear trends in Alfalfa (Figure 2) and Tall Fescue (Figure 3) depict the increase in biomass yield with the increase in CH. At zero canopy height there is no biomass yield available; hence, the trend lines were made to pass through the zero-intercept resulting in R-square values of 0.81 and 0.50 in wet biomass and 0.82 and 0.51 in dry biomass for Alfalfa and Tall Fescue, respectively. The lower R-square value observed for Tall Fescue is likely due to the low amount of biomass in the experimental field. Negative values of CH in Tall Fescue are due to the sensor's capacity to read minimal distance. The higher flight altitude (45.72 m) for the Alfalfa assessments did not create much difficulty in detection of plots manually, but lower flight altitude (18.29 m) in case of Tall Fescue resulted in more accurate results, making it a preferable choice, if battery and time of operation are not a concern.

Conclusions

The timely and accurate estimation of biomass could help optimize forage management strategies and practices. The results of this study demonstrated the potential usefulness of a UGV as a tool for precise biomass estimations, but we observed a better coefficient of determination of wet and dry biomass for Alfalfa than for Tall Fescue.

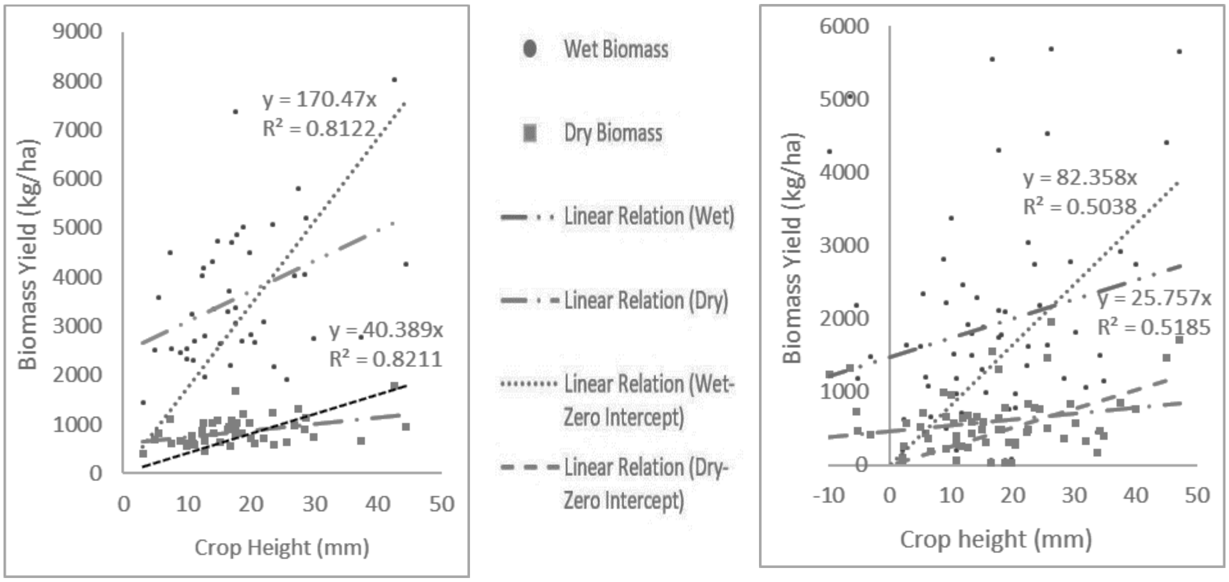

Figure 2. UGV-based estimation for Alfalfa.

Figure 3. UGV-based estimation for Tall Fescue

References

Earle, D. F., and McGowan, A. A. (1979). Evaluation and calibration of an automated rising plate meter for estimating dry matter yield of pasture. *Australian Journal of Experimental Agriculture, 19*(98), 337-343. https://doi.org/10.1071/EA9790337

Harmoney, K. R., Moore, K. J., George, J. R., Brummer, E. C., and Russell, J. R. (1997). Determination of pasture biomass using four indirect methods. *Agronomy Journal, 89*(4), 665-672.

MacInnis B. M. (2022). Pasture biomass estimation using crop surface modelling and vegetation indices. *Master Thesis, Clemson University, SC.*

Mulliniks J. T., Rius A. G., Edwards M. A., Edwards S. R., Hobbs J. D., Nave R. L. G. 2015. FORAGES AND PASTURES SYMPOSIUM: Improving efficiency of production in pasture- and range-based beef and dairy systems. J. Anim. Sci. 93:2609–2615. doi: 10.2527/jas.2014-8595

Pittman, J. J., Arnall, D. B., Interrante, S. M., Moffet, C. A., and Butler, T. J. (2015). Estimation of biomass and canopy height in bermudagrass, alfalfa, and wheat using ultrasonic, laser, and spectral sensors. Sensors (Basel, Switzerland), 15(2), 2920-2943. doi:10.3390/s150202920

Yule, I. J., Lawrence H., and Murray R.. . 2010. Pasture yield measurement with the c-dax pasturemeter. In: Stafford, J., and J. Schepers, editors. Proceedings of the 10th International Conference on Precision Agriculture; July 18 to 21, 2010; Denver, CO. Amsterdam (the Netherlands): Springer.

Acknowledgement

This study was funded by Agriculture Systems and Technology Program of USDA-NIFA (Project No. 2020-67021-31960)