Remote Sensing-Based Estimation of Alfalfa (*Medicago Sativa* L.) Forage Yield & Quality Under Drought Using Multispectral & LiDAR Imagery

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For sustaining forage production in changing climates, timely information is required for forage availability and its utilization at any time of the year. Within field variability of alfalfa yield and quality can be assessed utilizing remote sensing equipments, especially using advance multispectral and LiDAR. Such technologies can provide insight to forage yield gaps due to biotic or abiotic factors (salinity, drought, traffic etc.). To understand the variability in alfalfa field and to test the applicability of remote sensing sensors, a research experiment was conducted in Davis, CA, USA during year 2020. The experiment included irrigation treatments (ranging from 100% ET to 60% summer cutoff to 60% and 40% sustained deficits) applied to an alfalfa field during 2nd year of drought imposition. Unmanned aerial vehicles (UAVs), equipped with multispectral (6 selected harvests) and LiDAR sensors (4 selected harvests), were used to understand the spatial-temporal variability in yield and quality of alfalfa during 2020. The UAV flights were conducted around solar noon just before harvest. Hundreds of alfalfa samples were collected over a range of soil moisture conditions to measure the forage biomass and quality assessment along with plant height and used to predict yields. Models were created for both multispectral and LiDAR datasets, respectively. The stepwise regression model predicted the dry matter yield (R^2= 0.82, RMSE= 0.692 Mg ha^{-1}) better than the support vector machine (SVM, R^2= 0.81, RMSE= 0.709 Mg ha^{-1}) and random forest (RF, R^2= 0.79, RMSE= 0.738 Mg ha^{-1}) algorithms, based on data from multispectral images. The trained multispectral model (using vegetation indices, UAV estimated plant height) was also used to estimate the yield in an independent harvest area (11.15 m^2), and successfully predicted dry matter yields (R^2= 0.83, RMSE= 0.926 Mg ha^{-1}). Similarly, LiDAR also performed well for an independent harvest area (11.15 m^2) with an R^2= 0.91, RMSE= 0.425 Mg ha^{-1}. Both the sensors were successful in the development of yield maps and yield predictions while performance in forage quality predictions (crude protein (CP), neutral detergent fiber (NDF)) was lower (CP (R^2= 0.4, RMSE= 13.481 g kg^{-1}), NDF (R^2= 0.58, RMSE= 29.145 g kg^{-1}). Multi-spectral sensor and LiDAR differ in mechanism, availability and cost. Timing of image capture using multispectral and LiDAR did have an effect on the prediction equations. These prediction equations should be tested more widely. Once built, these UAV based model had the capability of producing yield and quality variability maps. These spatial-temporal maps can be utilized for diagnosing crop problems and estimating yield and quality variability in alfalfa, especially due to drought, with due attention to stage of growth.

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