Title: HayAdvisor: An Internet-connected device for informing haymaking decisions

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Abstract. Forage yield and quality are directly influenced by the rate and extent the crop is wilted prior to harvest and storage. However, the producer has few tools for determining when to cut, tracking the progression of the wilting process, and deciding when to intervene with a tedding or raking field operation. Field models exist for predicting drying rate; however, engineers have yet to deploy this research in a way that is accessible to the day-to-day management of hay and forage production.

This work sought to build, test and evaluate a portable, internet-connected device that combines local weather, soil and harvesting conditions to predict wilted alfalfa moisture content. The device automates collection of data and synchronization to the cloud. These data were used to evaluate the utility of an alfalfa field drying rate model for predicting crop moisture status.

Introduction. Each year, more and more decisions on the farm are made using local data. Whether it is the decision to spray a field with a particular herbicide or fertilization maps for next year’s planting season, data is a large driving factor. When it comes to hay production though, many decisions are still being made without local data from the field.

HayAdvisor would allow for the automatic collection, publishing and manipulation of the data to the cloud. Farmers would be able to use these data to know when to cut their alfalfa based on current and future weather patterns. With many weather stations situated near the farmer’s fields, HayAdvisor would give be able to give local, real time predictions.

HayAdvisor has been designed to be cost-effective, easy to move, setup, and maintain. These attributes allow HayAdvisor to be deployed on a field to field basis to attain a more accurate, localized, prediction of drying rate.

Materials and Methods. HayAdvisor was constructed around a cloud-connected microcontroller (Particle Boron LTE, Particle Industries Inc., San Francisco, CA). This device managed data collection, manipulation, and the transfer of the data via cellular network to the cloud. Data was collected every 15 minutes and sent to thingspeak.com, a cloud-based, real-time data analysis platform. The station was powered by a small 6W solar panel with a 6600 mAh lithium polymer battery backup. Three prototypes were constructed, with each revision maintaining the Boron microprocessor while evaluating new sensors. The final version was able to measure humidity, air temperature, soil temperature, soil moisture, leaf wetness, and wind speed.
Humidity and temperature were measured utilizing a monolithic integrated circuit (Si7021, Silicon Laboratories Inc, Austin, TX) that was integrated into our system with a breakout board provided by Adafruit Industries. The board was mounted on the underside of the enclosure and improved the reliability of our system over a previous scheme that employed a T-type thermocouple and humidity sensor (HM1520LF, TE Connectivity Company, Schaffhausen, Switzerland). The Si7021 reports a range of 0-100% with a precision of +/-2%.

Wind speed. A rotating anemometer (Handan Qingsheng Electronic Technology Co., Ltd., Handan City, China) was mounted on a PVC mount approximately 6.5 feet above the ground. The team attempted to calibrate the field anemometer using a fan and a known calibrated device (Anlor RV+, TSI Incorporated, Shoreview, MN) but were unable to obtain repeatable results. The team decided not to pursue alternatives as the anemometer reduced the portability of the system (it couldn’t be tossed in the back of a truck) and wind speed and direction are not utilized in the Rotz and Chen’s (1985) drying rate model.

Solar radiance is the amount of energy hitting the surface of the earth at that specific point in time. Since the solar panel’s (6W 6V model, Voltaic Systems, Brooklyn, NY) outputs vary based on the intensity of the sun, it works as a basic pyranometer and would allow the HayAdvisor device to measure solar radiance while charging its battery. Solar radiance was then determined by voltage and current output of the solar panel and compared to a pyranometer (Amprobe Solar 100, Amprobe, Everett, WA) and a calibration was established.
Leaf wetness is estimated by the presence of surface moisture on a grid of conductive elements. The leaf wetness sensor (Model 6420, Davis Instruments Corp., Hayward, CA) was mounted 1.5 feet above ground level. The sensor was calibrated with a two-point calibration (linear model) of 100% wet and 100% dry.

Soil moisture and temperature. The soil moisture sensor (VH400, Vegetronix, Inc., Riverton, UT) was buried 4 inches at the base of the station. The sensor response data was translated into soil moisture utilizing a piecewise function provided by the manufacturer. Soil temperature was measured using a Type-T thermocouple. The thermocouple was calibrated with a two-point calibration of water near 0°C and water at 100°C. The soil thermocouple was buried at 8 inches in the soil.

Results and Discussion. The final version of HayAdvisor developed into a platform from which to expand its capability. Though the anemometer was removed, accurate data were obtained from the other mounted sensors. Air temperature, soil temperature and moisture, humidity, and leaf wetness were reliably observed. Additionally, correlations were observed between each variable such as the relationship between humidity and dew point to the leaf wetness value over time (Figure 2).

![Figure 2. Example data collected with the HayAdvisor platform.](image-url)
As the team knew that the summer would be consumed by HayAdvisor hardware development, hay drying data were collected with an established weather station (Field Connect) supplied by John Deere.

Weather station data were correlated with observed hay drying rate over six studies and three cuttings. Alfalfa was cut and conditioned through a set of polyurethane rolls before placing on 4 x 8 ft drying screens. These screens were weighed periodically throughout the wilting period to predict drying rate. On the second day of drying the screens were rotated to simulate a raking operation. Trials typically lasted three days depending on the weather. The initial and final moisture content were determined by loss on drying in an oven at 103 C for 24 hours per ASABE S358.2.

For each measurement period, weather data were averaged and correlated to the loss of moisture. Solar radiation, air temperature, humidity, wind speed, soil temperature and moisture were considered as dependent variables. Several modeling techniques were considered including multiple linear regression, partial least squares regression and gradient boosted decision tree. The gradient boosted decision tree identified response variables that agree with Rotz and Chen. The calibration fit the modelled data explaining about 80% of the variation (Figure 3). To further test this model, data were randomly excluded from the calibration using a technique known as cross-validation. Although these data weren't completely independent, they did demonstrate that our approach would only explain about 30% of the variation in an quasi-independent data set.
Given that our data only represents one drying season, more data would be needed to develop and validate a model that could be widely used among producers. One explanation could be that the model in its current form is missing data to fully explain variation in hay drying rate. At the same time additional variables may be needed to close the variance gap. Accordingly, one variable that we are seeking to model is the impact of windrow density. Based on the data we collected we can add this response variable and that analysis is forthcoming.

**Figure 3.** Feature importance (left) and predicted vs actual drying rate for a decision tree model containing starting moisture content, relative humidity, air temperature, wind speed and soil temperature as response variables.

**Conclusion.** A portable, cloud-connect system was designed and calibrated to capture solar radiation, air temperature, soil moisture and temperature and leaf wetness as response variables to predict hay drying rate. Utilizing these data, relevant variables were identified and a drying rate model was developed to predict alfalfa drying rate over six studies. Although the model fit those data well, it performed poorly in a quasi-independent validation set.

More trials over varying field conditions must be conducted and additional response variables need to be considered before determining whether hay drying rate predictions could be utilized in hay making decisions. Our team seeks to utilize the data collected here to seek additional federal and industry support to perform those studies.

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**References**


Appendix A - Hay Advisor CAD Isometric and Major Components

1x – T-Post
1x – Horizontal T-Post Bracket
1x – Vertical T-Post Bracket
1x – Solar Panel (6W 6V, Voltaic)
1x – Waterproof Enclosure
1x – Particle Boron LTE Board
1x – Thermocouple breakout board (MAX31856)
1x – Temperature and Humidity Sensor (AM2302)
1x – Voltage and Current Sensor (INA219 High Side)
1x – 6400 mAh lithium ion battery
1x – Solar charging (Model 390, Adafruit Systems)
1x – Vegetronix soil moisture sensor (VH400)
1x – T Type Thermocouple