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Remote sensing to estimate yield of field crops

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Up until the 1990s, estimating how much a field yielded in forage crops like corn silage and alfalfa required the use of a weigh wagon, truck, or farm scale. While knowing yield per field is useful for inventory management and to identify where field-based management changes can be made, knowing where high and low or variable yielding areas are within fields facilitates zone-specific management, which is likely to benefit yield, reduce the environmental impact of overapplication, and increase return on investment of inputs like seed and fertilizer over time.

YIELD MONITOR SYSTEMS

Harvester-mounted yield monitor systems were developed in the early 1990s, with the advent of sensors and information technologies. A yield monitor system is a suite of three sensors attached to the harvester for measuring the harvested mass flow, moisture, and location using a GPS unit. The first yield monitor systems were installed on combines to harvest grain crops like corn, wheat, and soybeans. Systems have advanced since then, and sensors suitable to determine not just grain but also forage yield were brought to the market. For corn silage, such systems are mounted on the chopper. For crops like alfalfa and grass, the sensors are located on the harvester and not the mower. This increases the accuracy of the flow measurement but reduces the ability to locate yield values to smaller grid cells as mowed rows are typically merged into larger rows.

While errors occur with sensor-based collection of yield data, forage-based systems are inherently more prone to data errors. Accurate maps can be generated with proper in-field calibration and post-harvest data cleaning. Data cleaning software such as Yield Editor (USDA-ARS; data.nal.usda.gov/dataset/yield-editor-207) have been developed to simplify data cleaning. Work is ongoing to facilitate automated data cleaning, so that farmers do not have to become data-cleaning experts.

REMOTE SENSING

Not everyone has harvesters equipped with yield monitor systems and as mentioned, maps that have not been properly cleaned can be misleading. In addition, when a crop is mowed first and then merged into rows, yield monitor systems on the harvester will generate low-resolution maps. Such challenges could potentially be eliminated if yield estimation can be done remotely using drones and satellites (remote sensing).

Remote sensing (Figure 1) is acquiring data using sensors that are not in contact with the object. A simple example is an infrared thermometer versus a traditional thermometer. In both cases the temperature is being measured, but the infrared thermometer does not touch the object while the traditional thermometer does.

With corn, several studies have shown the potential of using remotely sensed images from drones and satellites as a proxy to estimate crop yield at different scales county, whole-field, sub-field, and plot scale. Currently, there is no straightforward process to accurately estimate the yield on a sub-field (zone-based) scale across a large range of farms and fields. Early studies focused typically on grain-crop yield estimations for a limited geographic area, using models that fit the specific locations and conditions. Work is ongoing at Cornell University to evaluate the accuracy of various approaches to estimate yield across multiple years and multiple fields and regions, for both grain and silage corn, and to derive yield-stability-based management zones from satellite imagery.

With perennial forage crops, the primary interest in remote sensing relates to the estimation of both yield and forage quality, with the goal of predicting optimum harvest date. Previous research determined that data gathered with a spectrometer (an instrument that measures reflectance over a specific portion of the light spectrum) positioned above an alfalfa canopy can estimate forage quality and yield reasonably well.

DRONES WITH SENSORS

Over the years, sensors attached to drones have been used to capture crop responses by scanning above the canopy. These sensors capture color and infrared signals of the crop in the form of images. These signals (basically a grid of numbers) are mathematically manipulated to calculate vegetation indices. The vegetation indices are used as an approximate measure for crop yield and other crop responses (crop stress, nutrient deficiencies). Earlier work, at a smaller scale, has shown that normalized difference vegetation index (NDVI) derived from drone images can be a good proxy to estimate yield. This can be useful for estimating yields for smaller areas, and especially research plots. Current work at Cornell University is focused on including weather and topographic information for developing models to estimate corn grain and silage yield across multiple fields.

SATELLITES FOR AGRICULTURE

Unlike drones, satellites in space do not need pilots to capture images of Earth's surface at frequent intervals. Before 2015, there were satellites that provided images at five- to 15-days intervals. In 2015, Planet Labs© launched the "Doves" satellite constellation that provides images every single day. Moreover, the image resolution (the ground distance that each image pixel covers) of earlier satellites ranged from 10 to 30 m per pixel (medium), while the

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Doves satellites produce images at three m per pixel (high). Satellite data may now allow an estimate of the yield and quality of alfalfa with a precision and accuracy similar to that of a field spectrometer. Collaborative projects are ongoing to evaluate the use of satellite imagery for the estimation of corn silage and grain yield (Box 1) and for alfalfa yield and quality (Box 2).

Because satellite satellite images can only be collected on a fixed schedule, cloud cover is a major issue, but with daily imagery from Planet's Dove imagery, it is often possible to get cloud-free images on a weekly basis. Another challenge for forage crops is that the dense vegetation cover can saturate optical sensors. Such signal saturation can make data less meaningful. For perennial forage crops with multiple harvests per season, changes in canopy structures over the season can increase the complexity of yield and quality estimation.

STAY TUNED

Because of greater accessibility and technological advancements in remote sensing and imagery processing, we can now tap into high-resolution and high-frequency imagery. Remotely sensed data will become more useful for farmers over time as we explore the data and learn to estimate and predict yield and forage quality at farm, field, and within-field scales. Stay tuned for advances in yield and quality prediction models for your farm as science develops. ▮

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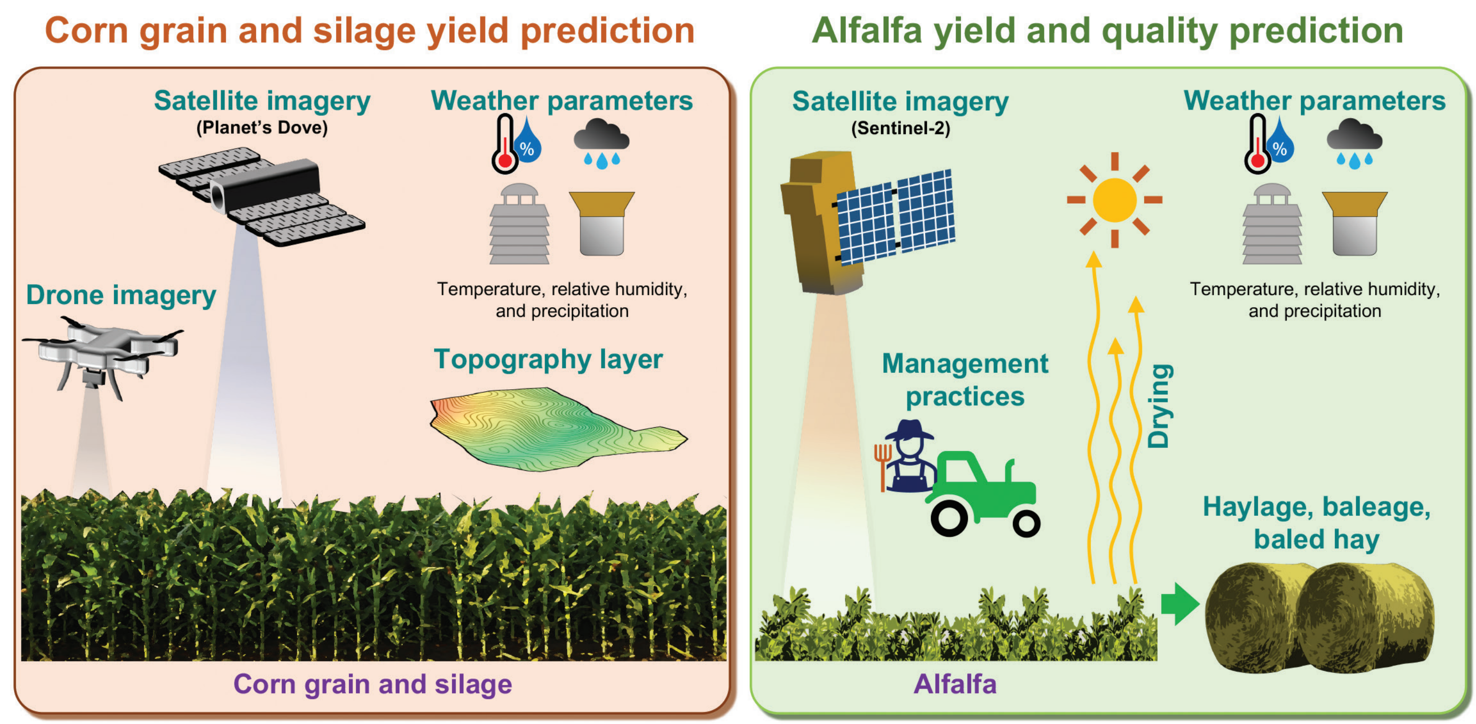
FIGURE 1

Yield prediction approaches for corn grain, silage, and alfalfa yield and quality prediction using remotely sensed data may make yield estimation accessible to more farmers in future years.



BOX 1: CORN GRAIN AND SILAGE PREDICTION PROJECT

This Northern New York Agricultural Development Program (NNYADP) and USDA-NIFA funded project was initiated in 2020 by Cornell University and is conducted in collaboration with researchers at the Rochester Institute of Technology. The focus is to develop models to convert drone imagery, satellite imagery from Planet's CubeSat platform, weather (precipitation, temperature, growing degree days, etc.), and topographic information into yield maps for corn grain and silage.

BOX 2: ALFALFA YIELD AND QUALITY PREDICTION PROJECT

A USDA project was initiated in 2021 by the University of Wisconsin, Purdue University, and Cornell University. A web-based program will be developed to provide timely estimates of alfalfa yield and quality at the field scale for optimizing harvest scheduling. Data collected by Sentinel-1 (radar sensor) and Sentinel-2 (optical sensor) satellites will be combined with CubeSat data, along with weather data, to generate models for predicting economically optimum harvest date.