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Alfalfa Yield and Quality Traits Estimation Based on Fusion Factors and Machine Learning

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Introduction

- Moderate or severe food insecurity levels at global scale have been slowly increasing since 2014, but the increased degree in 2020 may be approximately the sum of the previous five years [1]. One target of Sustainable Development Goal (SDG), a world without hunger and malnutrition by 2030, will need more actions and cooperations between different disciplines through carrying out precision agriculture [2].
- Alfalfa, one of the most critical and stable legumes, is a valuable nutritious crop with a comparatively high yield, which is considered the fourth most valuable field crop in the United States behind corn, soybean, and wheat and is a commercially grown source of forage and feed in the world [3,4]. The amount and quality of alfalfa consumed by livestock are crucial to maintaining their health and milk production. The important components includes dry matter (DM), crude protein (CP), neutral detergent fiber (NDF), nonfibrous carbohydrate (NFC) , minerals and other quality traits.
- Traditional alfalfa production assessment methods are laborious and time-consuming. Remote sensing provides an efficient way to measure yield and nutrition levels at the regional and global scales. Satellites have an irreplaceable advantage in large-scale quality estimation, but their low spatial and temporal resolution largely limits their application to precision agricultural management. Unmanned Aerial Vehicle (UAV)-based remote sensing, on the other hand, overcomes these limitations thanks to the flexibility in the data collection schedule, data accessibility, and the capability of carrying multiple types of sensors.
- This study was designed to (1) investigate the potential of using UAV multispectral for alfalfa yield and quality estimation, (2) Explore the impact of four types of features, environmental factor (EF), vegetation index (VI), statistic feature(SF) and texture feature (TF), on the estimation.

Materials and Methods

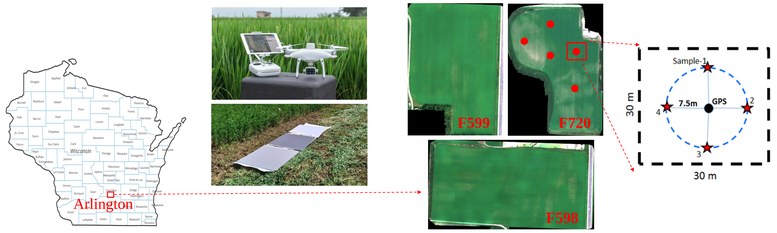
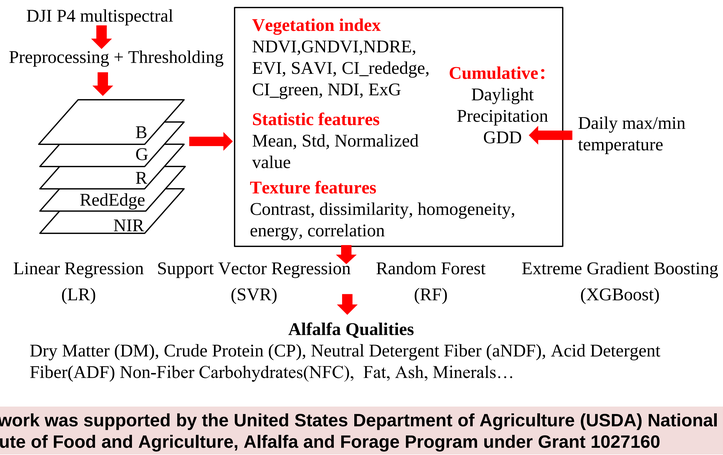


Figure 1. study area in Arlington Agricultural Research Station and sampling sites. F598, F599, F720 represent the name of three field.

- **Field Data:** Alfalfa has **four** cuts from May to August at the end of each month in 2022 and 2023. Between each cut, **three** or **four** times of sampling are considered for each field. There will be about three days interval between two sampling. **Five** or **seven** sites are selected for each sampling in each field.
- **Data acquisition and processing:** The multispectral data were acquired by a DJI phantom 4 multispectral that offers 5 spectral bands and then processed in Pix4D software. VI,SF, and TF were calculated by python based on the thresholded images. Three types of cumulative environmental factors, temperature, precipitation and daylight duration data were collected from national weather service of NOAA[5] and Astronomical Applications Department of the U.S. Naval Observatory [6]. This study used the growing degree days (GDD) calculated from temperature rather than using temperature directly.



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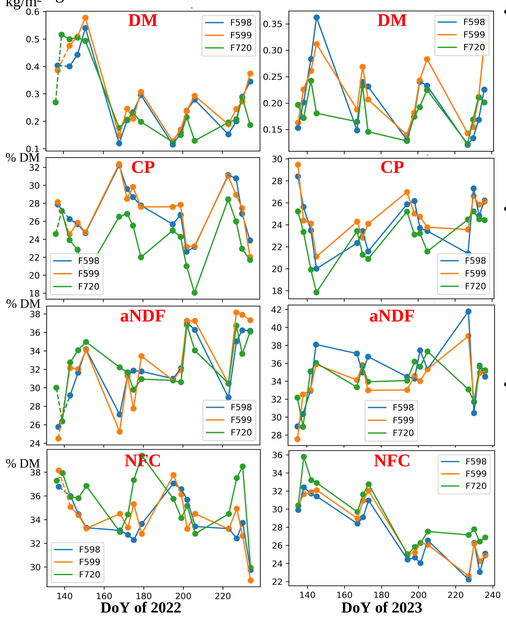
Results and Discussion

- Before the first harvest, alfalfa has a long period to accumulate nutrients, and its plant height is also the highest, resulting in the highest dry matter content and relatively higher nutrient levels. After the first harvest, alfalfa re-enters the early growth stage of its growth cycle, so it may maintain relatively high nutrient levels, such as protein, but the DM content decreases significantly. Subsequent frequent harvests put physiological stress on the plant, leading to significant reductions.



- Overall, the quality of alfalfa in 2023 is significantly lower than that of 2022. There is a notable decrease in DM, CP, and NFC, while the fiber content is on the rise. This trend is expected to lead to livestock feeling fuller more easily, resulting in a reduction in nutrient intake.
- DM: the most significant difference is observed in May, with peak variances of 0.58 and 0.36, while the differences in the other three months are relatively small, with most data falling within the range of 0.1 to 0.3 kg/m^2.
- For CP, there is a slight overall decrease in most data of 2023, particularly noticeable in the June. Regarding fiber, the content in 2023 is higher than that in 2022, especially in May and June. In terms of NFC, the overall content in 2023 is lower than that in 2022, marking the most substantial difference among the four comparison groups.

Figure 2. Trends of four alfalfa qualities in 2022 and 2023

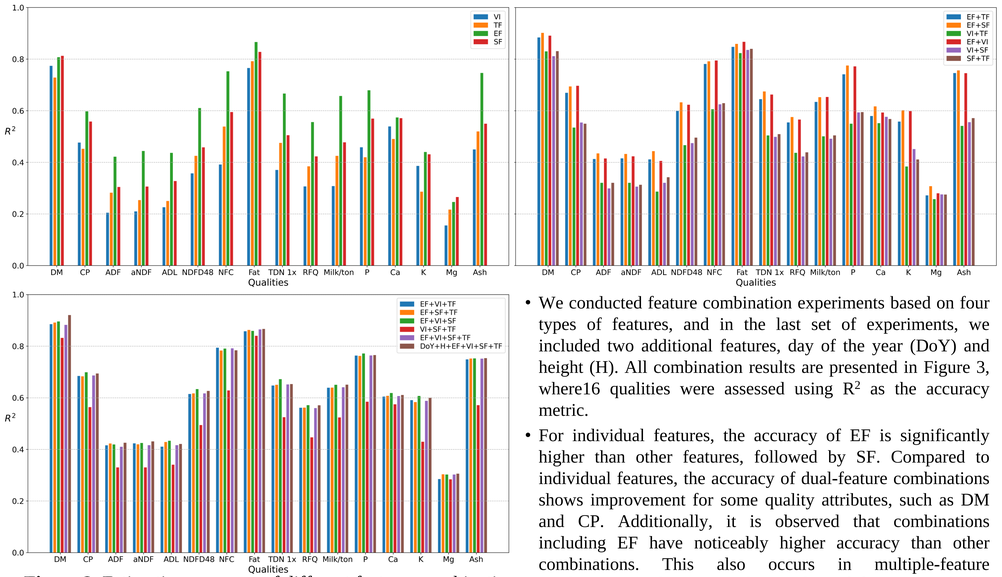


Figure 3. Estimation accuracy of different features combination

- We conducted feature combination experiments based on four types of features, and in the last set of experiments, we included two additional features, day of the year (DoY) and height (H). All combination results are presented in Figure 3, where16 qualities were assessed using R^2 as the accuracy metric.
- For individual features, the accuracy of EF is significantly higher than other features, followed by SF. Compared to individual features, the accuracy of dual-feature combinations shows improvement for some quality attributes, such as DM and CP. Additionally, it is observed that combinations including EF have noticeably higher accuracy than other combinations. This also occurs in multiple-feature combinations. The greater the number of feature types, the smaller the differences between different combinations.

- With the increase in planting years, there is a noticeable decline in the quality of alfalfa, subsequently affecting livestock nutrition intake and milk production.
- Selecting meaningful features as inputs can effectively increase the accuracy of alfalfa yield and quality estimation. EF have the most significant impact on the estimation of both alfalfa yield and quality, while TF have the least impact.
- The method based on multispectral UAV images and EF demonstrates strong capabilities in estimating alfalfa DM. It also provides accurate estimation for CP and NFC. However, the evaluation for aNDF is relatively poorer, suggesting a need for further exploration of features that exhibit stronger correlations with aNDF, ADF (acid detergent fiber), and other related factors.

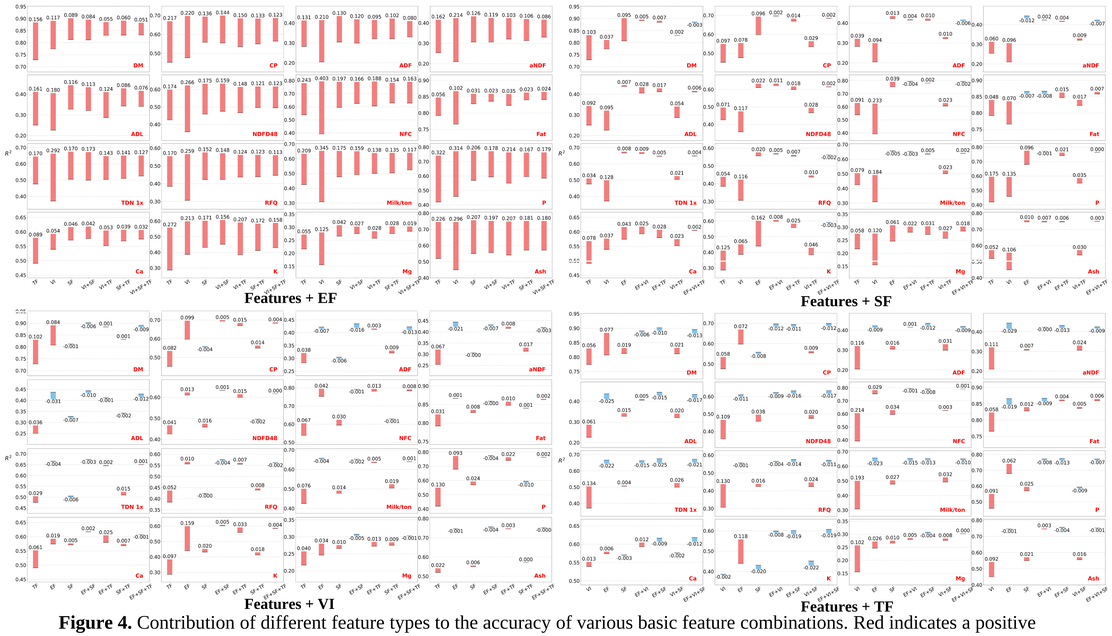


Figure 4. Contribution of different feature types to the accuracy of various basic feature combinations. Red indicates a positive contribution, while blue indicates a negative contribution.

- Based on the accuracy results of different feature combinations in Figure 3, we analyzed the contributions of four feature types in various feature combinations, also using R^2 as the measurement metric. Results are shown in Figure 4.
- EF show a significant improvement for all types of combinations, with a smaller improvement as the number of basic feature combinations increases.
- VI exhibit a noticeable improvement for EF and TF, but for complex basic feature combinations, the improvement is minimal and may even result in reduced accuracy.
- SF contribute significantly to the improvement of a single basic feature but provide marginal enhancement for complex basic feature combinations, with rare occurrences of reduced accuracy.
- TF contribute partially to the improvement of VI and EF, but for other basic features, there are instances of a substantial decrease in accuracy.

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