Recent advances and future technology for silage harvesting

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Introduction:

Silage harvest is a very time and machinery intensive process that requires specific harvest timing to produce high quality animal feed. In the United States, over 4 million hectares were dedicated to silage/haylage production in 2018 (USDA-NASS, 2019). The agricultural sector has been the beneficiary of gains in efficiency and production quality through the development and implementation of new technologies in recent years. Advancements in machine control, sensors, and crop monitoring have improved silage production efficiency and feed quality. This discussion will cover the current state-of-the-art as well as look to new technologies that have the potential to revolutionize silage production in the future.

Forage Harvest Logistics and Compaction:

Unlike other crops, silage harvest is unique in that there is no material storage on-board the harvest machine. This requires a fleet of support vehicles to collect the harvested material and transport it to the storage facility. This harvest method presents challenges for machinery movement and coordination during harvest along with soil health and compaction. Harrigan (2003) assessed cycle times of transport vehicles during corn silage harvest. This work showed that the harvester worked 85% of the available time for harvest. Buckmaster and Hilton (2005) developed a computer model to simulate silage harvest and assess different machinery configurations to improve silage harvest efficiency. This work developed equations to define harvester utilization and transport vehicle capacity requirement. Harmon et al. (2018) assessed two differing silage harvest operations for harvest efficiency. Total utilization of the forage harvester was found to be 65%. Transport vehicle efficiency found that semi-tractor/trailer transport vehicles were the most efficient with medium sized straight trucks and tractor-towed carts to be slightly less efficient. Dudenhoeffer et al. (2018) simulated the forage harvest cycle and developed an online tool for assessing machine performance and the effect of the addition of new machines to the fleet. This body of work shows that cycle times and machinery movement during forage harvest is not always optimized. Previous research has also focused on the optimization of forage harvester cycle times. While the forage harvester is the most expensive piece of machinery in the process, an argument should be made that the material flow at the storage site is more influential to optimizing feed quality.

Utilization of many machines to achieve alfalfa silage harvest has an impact on soil compaction and re-growth of the crop. A current study at the University of Wisconsin-Madison is investigating the effect of wheel traffic on alfalfa re-growth. Alfalfa plots were grown during the 2019 growing season with three blocked tillage treatments. One block received fall and spring tillage, one block received spring tillage only, and the third block was planted with no tillage applied. A fourth replication of the machinery traffic passes was completed in an established field of alfalfa that was in its second growing season. Seven machinery traffic treatments were applied after each harvest (table 1).

Table 1: Machinery traffic treatments applied to alfalfa plots in 2019 to assess the effect on yield and quality parameters.

Treatment	Name	Description
1	Single Pass Silage	One application of compaction immediately after harvest covering the entire plot
2	Three Pass Silage	Three applications of compaction. One immediately after harvest, one 24 hours after harvest and one 26 hours after harvest. Full plot application.
3	Five Pass Silage	Five applications of compaction. One immediately after harvest, two passes 24 hours after harvest, and two passes 26 hours after harvest. Full plot application.
4	Simulated Silage	Two wheel tracks applied within the plot. One pass immediately after harvest, one pass 24 hours after harvest, and two passes 26 hour after harvest.
5	Three Pass Hay	Three applications of compaction. One immediately after harvest, one 48 hours after harvest and one 56 hours after harvest. Full plot application.
6	Five Pass Hay	Five applications of compaction. One immediately after harvest, two passes 48 hours after harvest, and two passes 52 hours after harvest. Full plot application.
7	Zero Compaction (control)	No machine traffic applied.

In addition to yield measurements, samples were collected to determine moisture content and forage quality, soil compaction was measured prior to application of compaction and post application of compaction, and Unmanned Aerial Vehicle based remote sensing data was collected prior and post compaction application. Data from this study is currently undergoing analysis. Preliminary results utilizing the Mixed Procedure in SAS 9.3 show that traffic application had an impact on alfalfa yield (P-value = 0.0023, alpha = 0.05). Table 2 shows the yield results from the compaction study. There were no significant statistical differences found between no-compaction, simulated silage, and single pass silage. Three and five compaction treatments yielded between 4.0 Mg ha^{-1} and 1.2 Mg ha^{-1} less than the lower compaction treatments. Moisture content was approximately 75% wet basis at harvest. These preliminary results show that minimizing wheel traffic or implementing controlled traffic could have a substantial impact on alfalfa yield.

Table 2. Yield results from alfalfa compaction treatments during the 2019 growing season.

Treatment	Mean Yield (Mg/ha)	Standard Error (Mg/ha)
7. No-Compaction	16.8[a]	0.51
1. Single Pass Silage	14.6[ab]	0.48
4. Simulated Silage	14.3[ab]	0.54
5. Three Pass Hay	13.1[b]	0.51
3. Five Pass Silage	13.1[b]	0.51
2. Three Pass Silage	13.1[b]	0.51
6. Five Pass Hay	12.8[b]	0.51

* Letters denote statistically significant differences (alpha = 0.05)

Remote Sensing and Unmanned Aerial Vehicles:

Those in production agriculture currently have a lot of interest in monitoring crop health during the growing season using remote sensing and Unmanned Aerial Vehicles (UAVs). Utilizing these tools, producers and crop consultants can identify problem areas within their fields and make adjustments to crop inputs. The goal of this in-season data collection is to optimize crop production and/or quality. Figure 1 shows two different types of UAVs. Fixed-wing and hybrid UAVs fly horizontally similarly to an airplane (Figure 1, left). These devices fly approximately 97 km h^{-1} and cover more area at generally lower resolution. Rotor type UAVs fly more like a helicopter and cover less area at a slower speed (Figure 1, right). These machines are able to hover in a single location and collect high resolution imagery of smaller areas within the field.

Figure 1. Deployment of rotor-type and hybrid fixed-wing Unmanned Aerial Vehicles for remote sensing data collection in Wisconsin, U.S.A. Undergraduate and graduate students obtained Remote Pilot Licesnes from the U.S. Federal Aviation Administration in order to conduct this research.

Utilizing the visible light spectrum and spectra within the Near-Infrared range, we can produce vegetative indices that provide indication of crop health and vigor during the growing season. Figure 2 shows a Normalized Difference Vegetative Index (NDVI) image of the alfalfa compaction study described above. This image was collected with a rotor-type UAV approximately 10 days after compaction was applied. Red areas show locations of high crop stress, yellow areas are medium crop stress, and green areas are low crop stress. This data can provide producers valuable information regarding plant health and give them the opportunity to adjust inputs to correct problem areas.

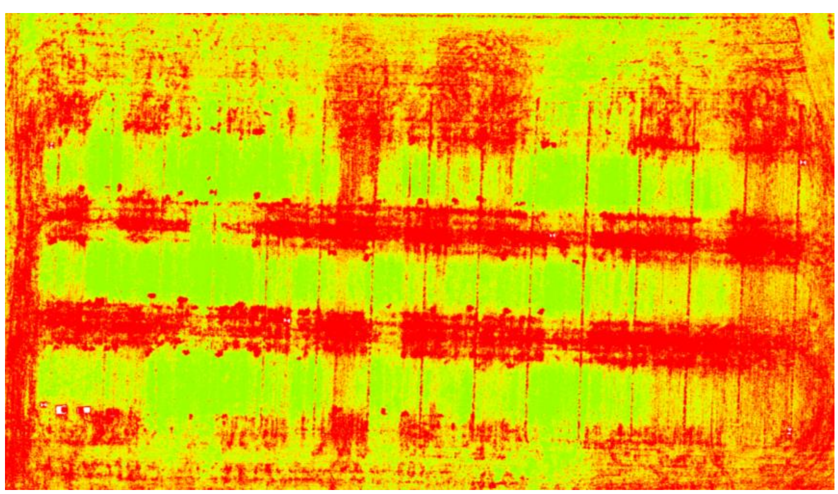

Figure 2. Orthomosaic image of Normalized Difference Vegetative Index (NDVI) for the alfalfa compaction wheel traffic study. High traffic plots can be seen in red and yellow compared to green areas with low traffic.

Kernel Processing:

Corn silage is an important crop for dairy producers in Wisconsin, U.S.A. Utilizing forage harvesters to chop and process this crop provides a feed supply for animals over the entire year. Kernel processing on the machine is a very important process to producing high-quality corn silage. Reducing the kernel size allows for easier digestion, higher starch availability, and increased milk production (Cooke & Bernard, 2005; Johnson et al., 2003; Shinners et al., 2000; Weiss & Wyatt, 2000).

Image processing can be effectively used for particle size analysis of agricultural materials (Igathinathane & Leslie, 2007; Igathinathane et al., 2008; Igathinathane et al., 2009; Savoie et al., 2014). Drewry et al. (2019) utilized image processing to determine Kernel Processing Score for chopped and processed corn silage. This method was found to be well correlated with traditional sieving methods and showed that mechanical sieving reduced the particle size of the corn kernels during measurement. From this effort a smart phone app was developed so that producers and custom harvesters can check the performance of their kernel processors during harvest rather than relying on sending a sample to the lab. Figure 3 shows the home screen of the app called SilageSnap that can be used for kernel processor performance determination. This app utilizes a size reference within the image (a U.S. coin or 1 Euro or ½ Euro coin) to determine the size of every particle in the image. Maximum inscribed circle diameter is applied to each particle to so that results correlate well to sieving results. To date the app has nearly 1,000 downloads, is free to use, and is available in the iTunes and Google Play stores.

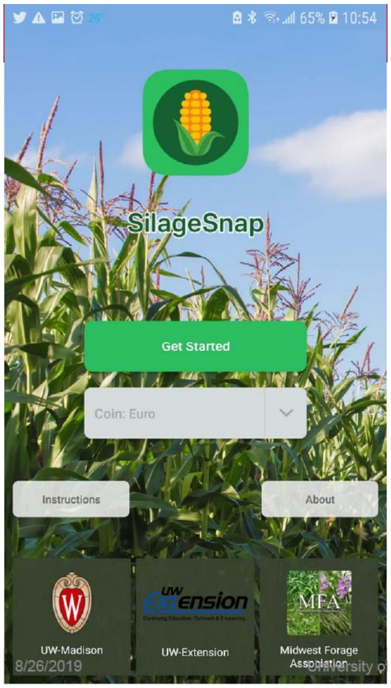

Figure 3. SilageSnap smart phone app for determining corn silage kernel processing score during harvest.

Conclusion:

There have been many technological advancements in hay and forage harvest in recent years. Utilizing advancements in machine controls, machine communication, and novel data collection methods producers are better equipped to manage crop and feed production. Future advancements will only improve these management strategies and optimize forage production.

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