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Title: Evaluation of PerkinElmer On-Combine Monitor compared to Laboratory Estimates of Soybean Composition

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EXECUTIVE SUMMARY

An on-combine NIRS instrument was used to measure the crude protein and oil composition of whole soybeans harvested in Minnesota trial plots in the 2023 Farmers' Independent Research of Seed Technologies (FIRST) program. FIRST manager Mark Querna, with help from Art Killam of Arthur Ag Consulting, a distributor for PerkinElmer, installed a DA7350 NIRS device within the weight and moisture collection tank of his Case-IH 1640 research combine. During the 2023 harvest, 12 locations including 16 tests with 101 commercial soybean varieties planted in 1,900 small plots were measured with the on-combine device. Soybean grain samples were collected for one variety replicate in each test. Grain samples were analyzed with benchtop DA7250 and FOSS NIRS instruments at the University of Minnesota laboratory, and the results of the lab and field NIRS compositions were compared. The combine-measured protein demonstrated field and variety differences, matching lab measures similar to other research, with r^2=0.56 correlation. The oil content had a lower correlation with r^2=0.19, and further work is needed to determine how moisture content and other factors affect oil measurements. There may be influences like NIRS installation, sample container and NIRS view, grain sample storage and drying, and soybean size contributing to locations and varieties with better correlation between the field and lab composition measures. Overall, the project showed that the on-combine system shows promise for managing soybean crops for protein content outcomes and value capture.

INTRODUCTION

Soybean quality composition is an important factor in several soybean marketing opportunities. For example, contracts for identity preserved soybeans require the harvested crop to attain compositional standards. If those standards are not met, the grower faces stiff penalties, including crop rejection. Typically, the contract crop is harvested and stored in a separate identity preserved bin. Then, the beans are sampled and sent for laboratory analysis. At the lab, bench-top near infrared spectrophotometry (NIRS) analysis is the current industry standard to determine whole-bean and milled oil and protein content. Lab results are not available to farmers for six weeks to several months after harvest. This lack of timely crop quality information reduces the incentive for farmers and buyers alike to expand acres of high quality soybeans for sale to identity-preserved soybean buyers, processors, and end-users.

PerkinElmer now offers an industrial grade NIRS machine (DA 7350) that mounts onto a combine. Their NIRS instruments have been used for many years in industrial food processing plants for in-stream composition measurements. The combine-mounted PerkinElmer NIRS instrument can monitor soybean crude protein and oil content, moisture, and other components "on the fly," allowing farmers to interpret quality as the crop is being harvested. Detecting composition during harvest would greatly improve producers' information about harvested material (Engel et al. 1997). The information could support decisions about segregating loads, enhance transparency of loads to processors, and reduce crop rejection. All of these would support farmers selling their crop at high prices or premiums.

The Farmers' Independent Research of Seed Technologies (FIRST) trials program is organized to deliver yield performance information for Minnesota and Midwestern farmers. FIRST also has funding from the United Soybean Board (USB) to report soybean composition for varieties in the trials.

In 2023, the Minnesota Soybean Research and Promotion Council (MNSRPC) funded this project to collect data with a PerkinElmer on-combine instrument while harvesting FIRST trial plots. A PerkinElmer DA7350 NIRS sensor was installed on a Case-IH 1640 research combine operated by Southern MN FIRST. As part of USB-funded research, a soybean sample is collected from each variety at harvest and sent to collaborator Dr. Seth Naeve's lab at University of Minnesota. FIRST samples are analyzed for crude protein and oil using a bench-top quality analysis instruments.

This report describes the project and resulting comparison of composition data collected a) with the combine-mounted NIRS from soybeans as they are harvested and b) from those same whole soybeans collected and analyzed in the lab at UMN.

LITERATURE REVIEW

A number of companies have introduced commercial on-combine quality monitors based on NIRS sensors (Taylor and Whelan, 2007). Available sensors include the CropScanAg Cropscan 4000vt (Asscheman*, 2024), the PerkinElmer DA 7350 (*PerkinElmer,* 2024*), and the Zeltex EvoNIR-g (Neményi and Milics, 2007*).

Figure 1. Perkin Elmer DA 7350 Instrument

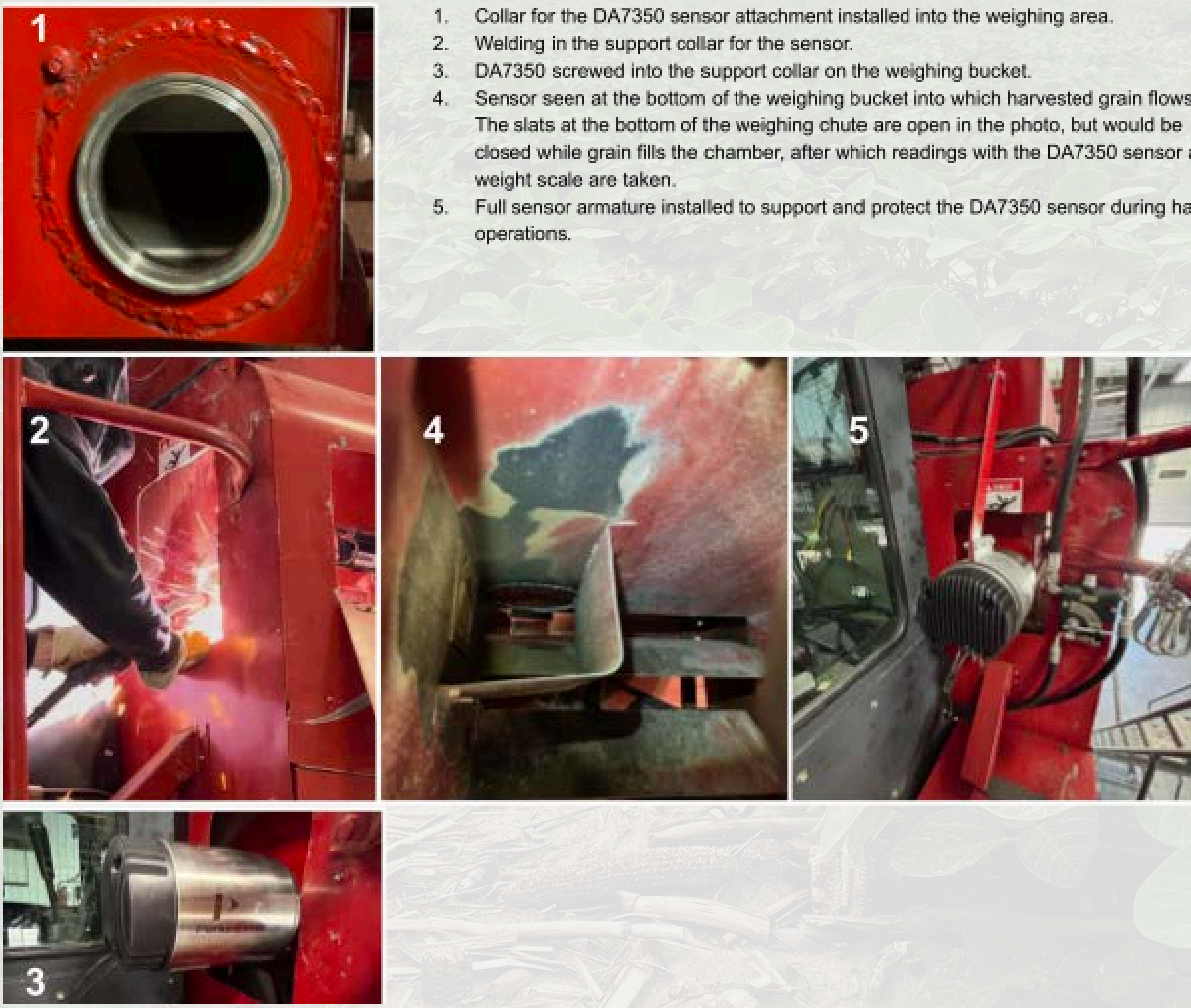
Using on-combine sensors in research settings have demonstrated the potential for in-field quality measurements. In wheat protein mapping studies, the correlation was r^2=0.55 for lab to in-field measures (Long et al., 2004). Rice protein content measured with on-harvester NIRS compared to reference wet chemistry sample results showed a r^2=0.65 correlation (Hidaka et al., 2011). Industry literature indicates a positive return on investment with on-combine NIRS technology (CropScanAg, 2021).

METHODS

A DA7350 PerkinElmer NIRS, leased from Compeer, was installed on a Case-IH 1640 plot combine owned by Southern Minnesota FIRST Manager Mark Querna. Collaborator Art Killam with Arthur Ag Consulting, and a distributor for PerkinElmer, assisted with placement of the NIRS. A support collar for the instrument that allows for screw in assembly was welded inside the grain weight container for the plot combine, and an armature and rubber sleeve were added to support the DA7350 during harvest operations. A smaller collection area was blocked off in the weighing container to be the sample area of the NIRS instrument. The view that the instrument is a one-inch diameter window as shown in Figure 1. Figure 2 includes photos of the installation process completed by Southern Minnesota FIRST managers Mark and John Querna. The DA7350 was set with 2022 calibration equations for soybeans measurements during the 2023 harvest.

There were 12 FIRST locations and 16 tests harvested in southern Minnesota as part of the 2023 FIRST program, including 8 non-GMO soybean trials featuring varieties for the identity-preserved and food-grade markets (Figure 3). There were 110 commercial GMO and non-GMO varieties trialed at these MN testing locations. FIRST trials take place on cooperating farms, and are managed by those growers in the same way as the surrounding field. Each variety is trialed at 4 locations in a geographic area, with 3 replicates in a randomized, latin-square block test design. Each strip has four 30 inch soybean rows (10 ft across) by approximately 39 ft harvested length. For this project, data was collected at over 1,900 small plots at these MN locations. Measurements of soybean yield, moisture, lodging and stand are collected. For more information about FIRST methodology, see documentation online.

Figure 2. Photos of the installation process for the DA7350 NIRS Sensor on Querna's Case IH 1640 research combine in the weighing bucket area.



In-field NIRS data was collected for each mini-strip plot in the FIRST testing plan, for all three replicates per genetic variety in the test. Each plot's NIRS compositional information was stored in on-board software and recorded by Mark Querna's harvest team. Also during plot harvest, FIRST collected "grab" samples of soybeans that are packaged and sent for quality analysis at the University of Minnesota, with the support of the United Soybean Board. Samples were stored in plastic bags for 1-5 weeks between collection and laboratory analysis (Figure 4).

Figure 3. FIRST Minnesota locations where on-combine NIRS was used to collect soybean compositional data (left). Photo of FIRST Managers Mark and John Querna, collaborator and host farmers, Keith and Brian Schrader with Querna's plot combine at Nerstrand, MN on October 23, 2023.

At the University of Minnesota Crop Science lab, samples are first tested for moisture using a Perkin Elmer AM-5200A. Anything higher than 12% moisture is put in a drying oven overnight. If below 12%, or once dried below 12%, the samples are cleaned of any foreign material. The soybeans are then scanned, whole, on the NIRS instrument of choice, either DA7250 or FOSS. The lab's benchtop PerkinElmer instrument was set with 2023 calibration equations, and included additional calibration using wet lab comparisons for offsets of -0.4542 for protein and +0.9403 for oil. In data review, the calibration equations for 2022 (on-combine) and 2023 (benchtop) instruments produced very similar values. The laboratory results were then reported in FIRST's public Region Summary reports (see all reports).

Figure 4. Soybean grain samples collected during FIRST harvest operations for later analysis at the University of Minnesota. Samples are stored in plastic bags for up to several weeks before being measured for moisture, some dried, and scanned with benchtop NIRS instruments to estimate protein and oil content.

In order to understand the variability of NIRS measurements in a stable setting, Dr. Seth Naeve and research collaborator Jesse Christenson at the University of Minnesota kindly shared some repeatability and precision studies for whole soybean measurements. For benchtop NIRS measurements in their lab, sensors readings were collected for the same sample of whole soybeans repeatedly, repositioning in the sample vessel, mixing and re-packing. They estimate that around 0.1% and 0.01% average variation in crude protein and oil content measures, respectively. Also note, the on-combine NIRS instrument “sees” a small sample of soybeans, approximately 1.5 inches in diameter. In the lab situation, the whole bean sample is slowly turned to allow for more soybeans to be viewed by the sensor. Further, there was a storage time for the samples between when soybeans were measured in the field and as samples in the lab. The effects of storage time and method, drying, and grain moisture between the field and laboratory quality scans probably contributed to differences in scanned quality measurements as well.

The data from the in-field and laboratory quality analysis were paired to compare the results per plot and variety, with protein and oil content are reported on a dry-basis for both instruments. Analysis was completed by FIRST with review by university and industry collaborators.

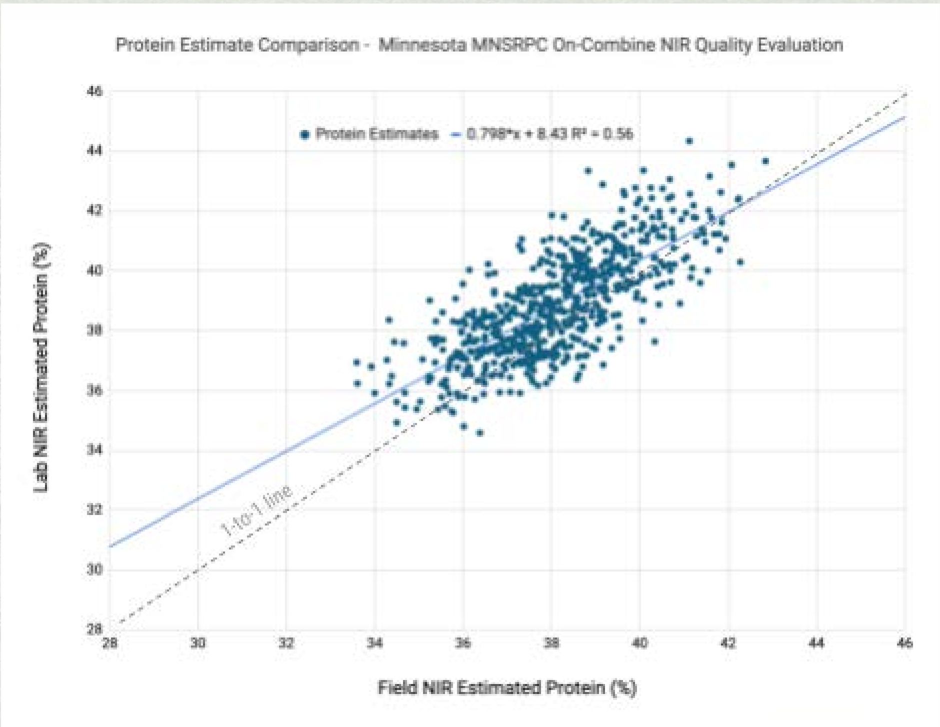
RESULTS

Figure 5 shows comparisons of lab NIRS to on-combine NIRS estimates of crude protein and oil content (%). Linear regression and statistical analysis showed that correspondence between lab and field protein had an r^2=0.56 and r^2=0.19 for protein and oil, respectively. It is important to note that the laboratory and field NIRS instruments were similar but different models and used slightly different calibration equations to produce the results. In the data review, there were some indications that soybean moisture content had an effect on in-field and lab oil estimates (Figure 6), while protein was unaffected. There were several weeks in which the soybean grain samples were stored in plastic bags, with some samples dried before lab measurements. Changes to the NIRS spectral readings may be due to differences in the soybeans themselves between the in-field and laboratory scans.

In Figure 7, the protein and oil estimates for the lab and field NIRS measure comparison at each trial location are shown. The graphs indicate that some locations had better correlation between the lab and field NIRS estimates than others. Some reasons may be that the bean size and hulls were more or less uniform or moisture conditions were different at the better correlated locations.

Since the FIRST trials test the same variety at at least 4 locations, and in many cases 8 or more locations, we can compare the results of the field and lab NIRS estimates for the same variety across multiple locations. Figure 8 shows the results for a subset of 24 varieties in the trials with each point on the plots representing a ministrip, field and sample lab measurement, at a different location. The data show that the on-combine sensor was able to pick up differences in quality for different varieties, especially when the range of quality produced in the variety was larger across multiple sites. For example, **Viking 1700N** conventional soybean had a large range of protein content at 8 locations it was tested, and the correlation was r^2=0.90 between the lab and in-field crude protein estimates.

Figure 5. Scatter plot of laboratory NIRS (y-axis) and on-combine field NIRS (x-axis) estimates of protein content (top) and oil content (bottom), dry-basis values for all estimates. Click for interactive charts.



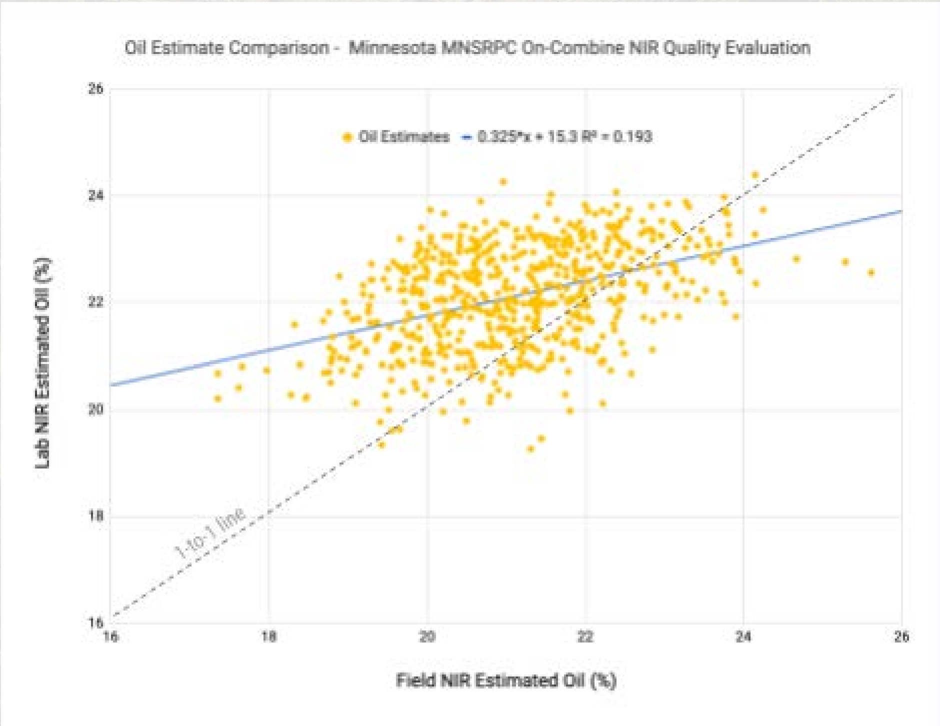
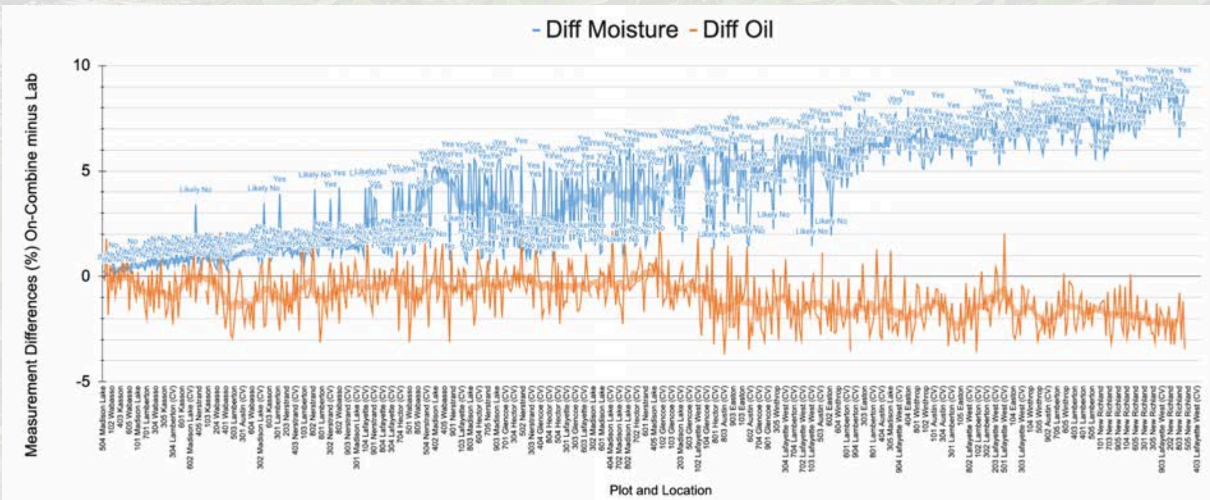


Figure 6. Plotting moisture difference (blue) and oil difference (orange) between combine and lab readings, ordered by on-combine grain moisture content, with oven drying marked with labels on the moisture difference readings. For lower on-combine grain moisture (toward left), oil content estimates differed by approximately -0.5% on average. Higher moisture soybeans coming from the field (toward right) at higher than 12% moisture content, with lab soybean samples usually dried, had oil content estimates differing by about 1.5% on average.



A heatmap provides a good view of the field and variety variability of the results, visually comparing data between the on-combine and lab measures in a “quality monitor” similar to a yield monitor map (Figure 9). For protein content, the on-combine analyzer picked up the variety differences in each strip well, as well as the magnitude of the difference, as illustrated by the similarity of the field and lab analysis heatmaps. For oil, the results were mixed, with the extreme highs and lows detected fairly well. These results may have to do with the calibrations and biased used in the instrumentation as well as challenges with measuring oil/fat content with NIRS technology.

Figure 7. Scatter plots of laboratory NIRS (y-axis) and on-combine field NIRS (x-axis) estimates of protein content (top) and oil content (bottom) at each of the Minnesota plot locations. Click for interactive charts.

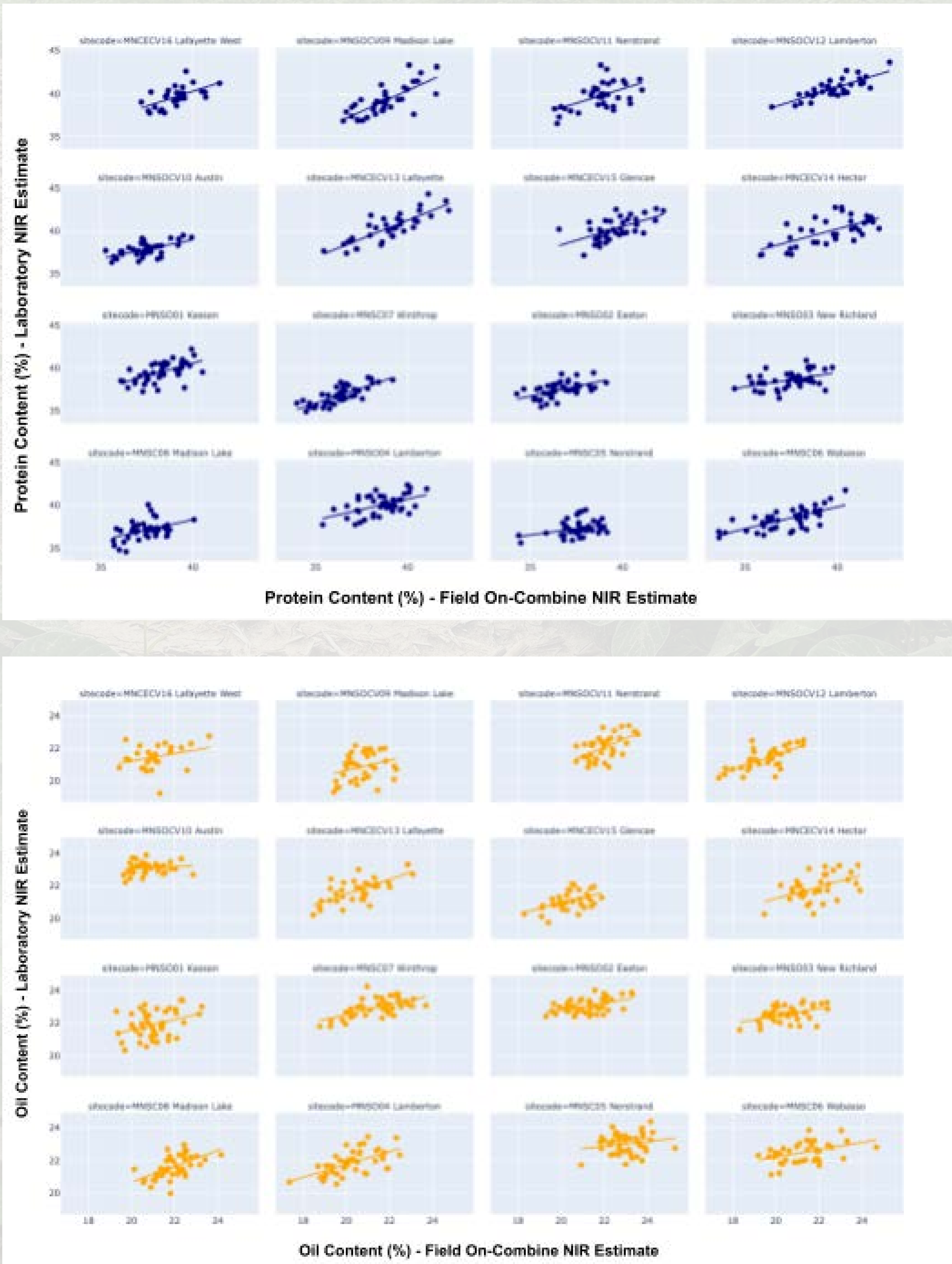
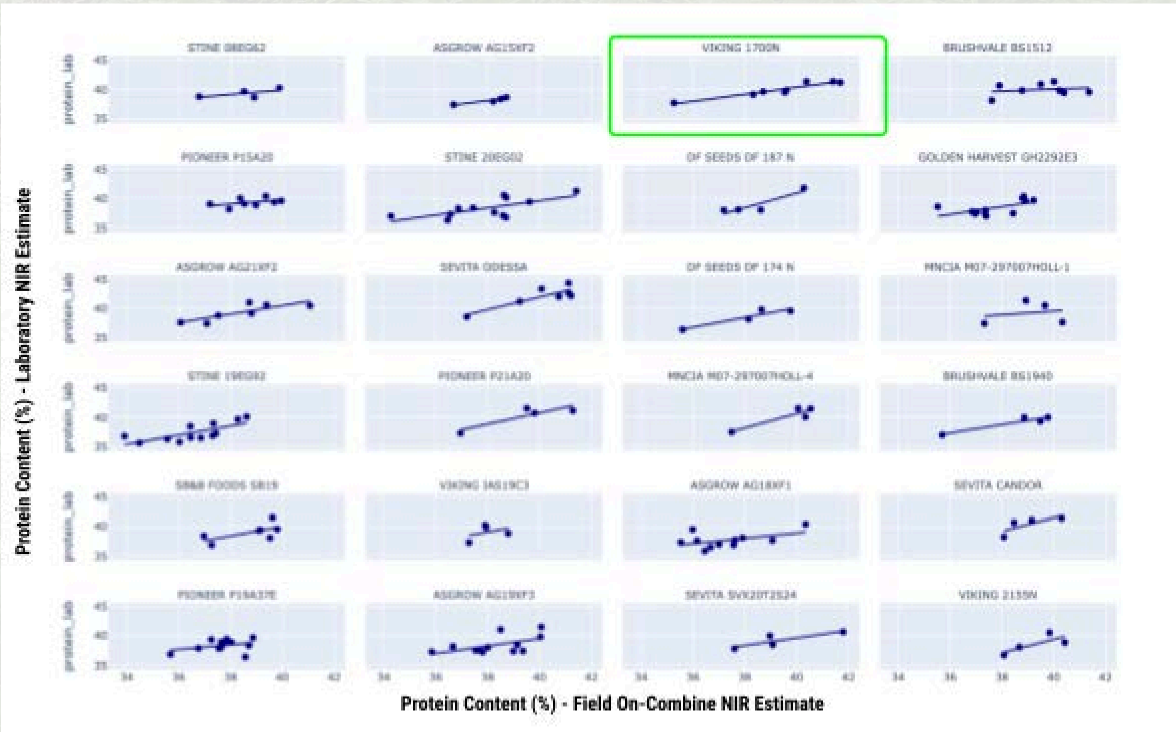
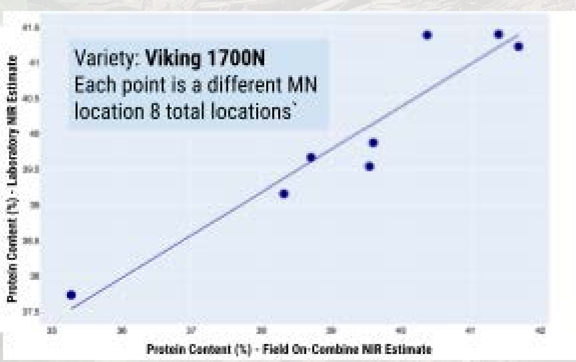


Figure 8. Variety specific comparison, subset of 24 varieties with measurements across multiple locations (top). The figure illustrates how some of the conventional varieties have higher protein values at all locations (values higher on x- and y-axes, e.g. VIKING 2155N, lower right plot). The highlighted variety, Viking 1700N, in the is shown in a larger view in the second graphs (protein - bottom left, oil - bottom right). It had r^2=0.90 correspondence between lab and field protein content.





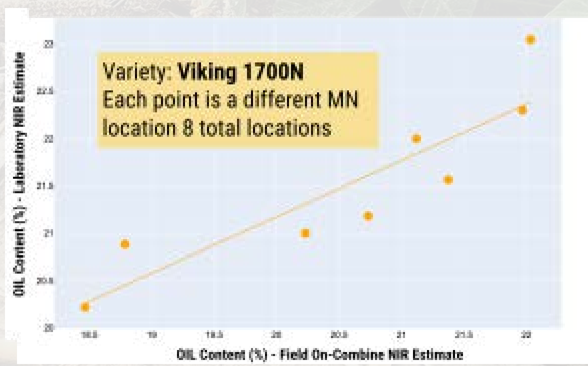
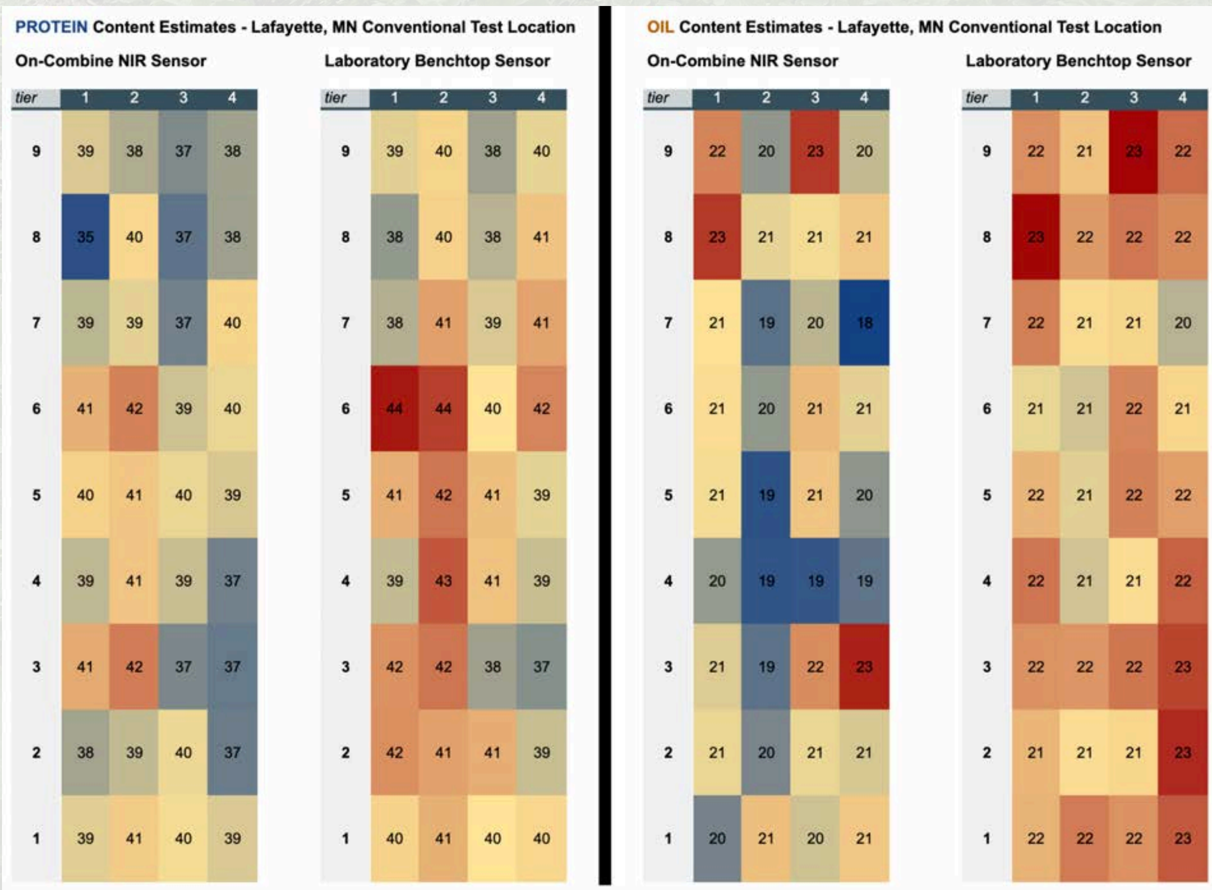


Figure 9. In-field heatmaps showing the **Protein** (left) and **Oil** (right) content estimates in FIRST ministrip plots at Lafayette, MN. For protein, on-combine and laboratory NIRS showed good correspondence in high and low values. Oil content comparison was mixed, with extreme high and low values appearing to have better detection.



DISCUSSION

The on-combine PerkinElmer NIRS detector shows promise for detecting protein content in real-time during harvest. The correspondence between lab and in-field NIRS estimates of protein (r^2=0.56) were similar to other studies with small grains measurements using on-harvester NIRS sensors. The oil content detections appear to have more challenges, with smaller range of soybean oil content among varieties and less sensitivity to differences observed in this study. More work is needed to determine how lab and in-field NIRS measurements are compared and calibrated for both protein and oil composition.

Overall, the genetic variation in the FIRST trials provided a good demonstration for producers of the potential for new marketing strategies and decisions supported by the in-field quality data availability.

Collecting the information in the research combine did prove challenging for researcher Mark Querna. In the FIRST trials, research managers record grain weight (for yield), moisture, lodging scores as they harvest, and this project added recording NIRS instrument notes. Better data collection set-up will be addressed for future studies.

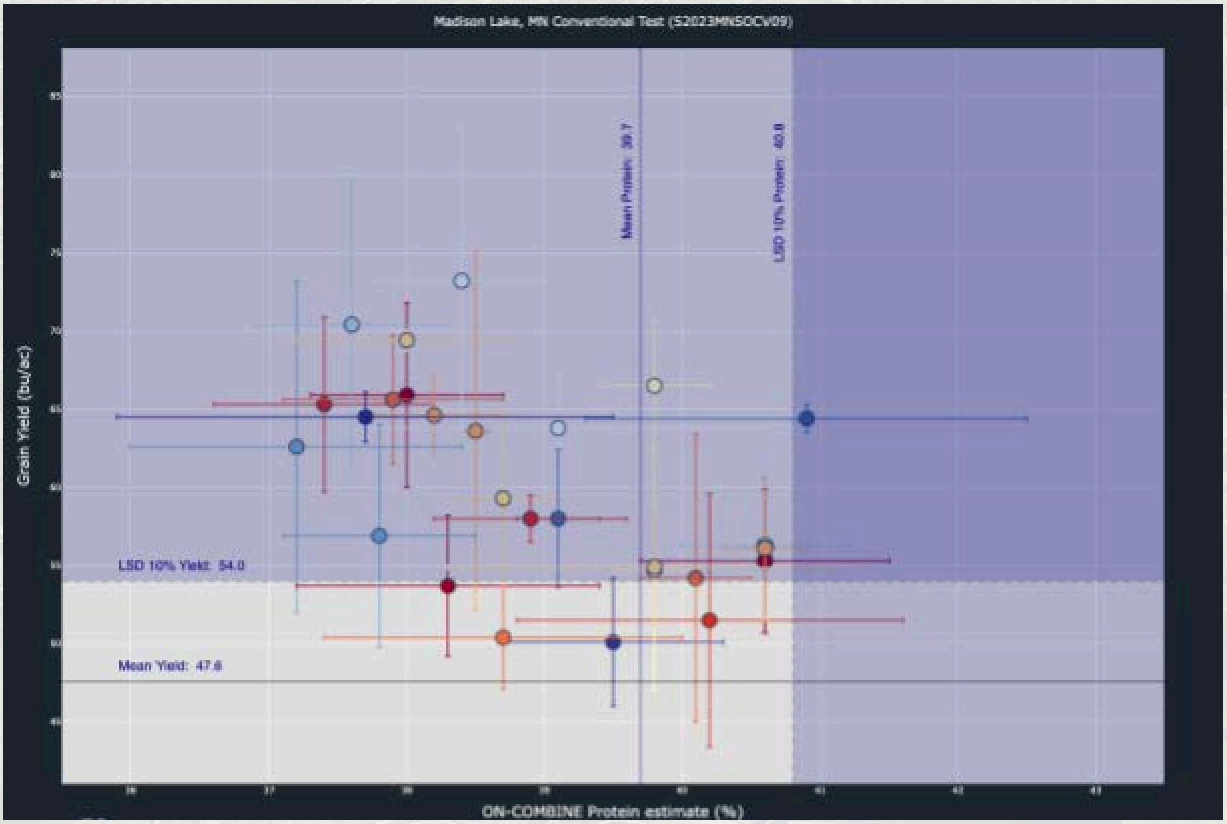
Follow-up studies should improve aspects of the methodology to better compare in-field to laboratory NIRS measurements. For example, grain samples were stored in plastic bags for several weeks, after which some soybeans samples were dried before lab measurements. Grain moisture content and spectral changes due to soybean storage and drying may contribute to differences between the laboratory and in-field measurements. Reviewers suggested that controlled studies be carried out that reduce the difference in time, storage, and drying between the field and lab measurements.

Overall, the genetic variation in the FIRST trials provided a good demonstration for producers on the potential for new marketing strategies and decisions supported by the in-field quality data availability. Generally, there was good detection of the variety differences in quality from plot to plot using the on-combine sensor, with protein magnitude differences aligning fairly well, while oil content appeared to need larger differences for detection.

FUTURE WORK Data collection of quality parameters could allow FIRST to report information about yield and quality together on Harvest Reports within 1-2 days of harvest. For many years, FIRST corn silage reports presented yield and quality graphs of milk per acre versus milk per ton (e.g. 2023 Martinsburg, PA Corn Silage Harvest Report, pg. 2). Figure 10 shows how a graphic might look that illustrates data from all 3 replicates for yield and protein content to determine the Least Significant Difference (LSD 10% level) and variety performance.

The project demonstrated a new technology available to growers. Collecting soybean compositional data, particularly protein content, could be helpful in making timely storage decisions at harvest. With on-combine NIRS grain analysis during harvest, growers could have near instantaneous information for contract fulfillment, which could give great opportunities for grower profitability.

Figure 10. Prototype graphic that illustrates the test results for conventional varieties in the 2023 Madison Lake, MN FIRST trial (Harvest Report PDF) with both yield (y-axis) and protein content (x-axis) results. Click on the interactive graph to view variety information.



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