Evaluation of Sugarbeet Yield Sensing Systems Operating Concurrently on a Harvester

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INTRODUCTION

Limited research has been directed toward bulk crop (i.e., potato, sugarbeet, etc.) yield monitoring over the last several years (Hofman et al., 1995; Rawlins et al., 1995; Campbell et al., 1994; and Walter et al., 1996). Results have shown that there is the potential to accurately and precisely determine site-specific yield information. Some of this research resulted in the development of the HarvestMaster™ HM-500 yield monitor for sugarbeet yield monitoring. The effects of tare dirt on accuracy and precision have been found to be a concern.

A typical yield monitor has load cells mounted near the end of the outlet conveyor. An advantage of this mounting location is that the maximum amount of tare dirt is removed from the sugarbeets. Research was conducted during the fall of 1996 to determine the effect of different chain support systems on sugarbeet yield monitor accuracy and precision. When product flow sensors were mounted on a short conveyor section, sugarbeets tended to bounce on the conveyor resulting in lower accuracy and precision. However, reducing the length of the chain support system minimized the effects of the bouncing sugarbeets (Hall et al., 1997).

The storage hopper on many harvesters can not be used if accurate site specific yield data are to be collected using a yield monitor on the outlet conveyor. The problem is that the load cells are located after the storage hopper in the product flow stream. Therefore, if the hopper is used, position data relative to yield are lost. Weighing sugarbeets before being loaded into the hopper could overcome this problem. However, some cleaning of the sugarbeets may be lost if they are weighed before they reach the hopper. Tare dirt affects the data and is a concern.

Scrub Chain

Many harvesters use a scrub chain to elevate sugarbeets to the cross conveyor for loading into a truck. A scrub chain is a dual vertical conveyor chain mechanism. Sugarbeets are held between two spring tensioned chains and carried vertically. The two chains operate at slightly different speeds to "scrub" dirt (tare) from the sugarbeets. Some harvesters divert sugarbeets to an on-board storage hopper through the scrub chain. The scrub chain usually contains a near-horizontal discharge conveyor section to carry sugarbeets from the vertical section of the chain to the hopper. If sugarbeet weight could be measured on the scrub chain, use of the hopper would not compromise the site location data.

Entering a higher yielding area of a field results in an increased mass of sugarbeets being elevated by the scrub chain. This requires a larger torque on the driveline to operate the scrub chain. Therefore, the magnitude of the torque transmitted through the scrub chain driveline could be used as an indicator of the mass of sugarbeets being transported by the scrub chain. If the mass of sugarbeets in the scrub chain, the ground speed of the harvester, the speed of the scrub chain, and the harvester width are known, an instantaneous yield can be calculated.

The effect of tare dirt is a primary concern when determining sugarbeet yield when sensing torque used to power the scrub chain. The scrub chain is used to clean dirt from the sugarbeets. Dirt removed from sugarbeets while they are in the scrub chain will affect the torque measurement and consequently the yield measurement.

Load cells could be mounted on the near-horizontal conveyor section of the scrub chain to weigh the sugarbeets before they enter the hopper. Most of the tare dirt has been removed before the sugarbeets reach this location. The primary concern is the short length of the discharge section of the scrub chain conveyor. Research conducted during the 1996 harvest determined that weighing sugarbeets on a relatively short conveyor section resulted in lower accuracy and precision compared to a longer conveyor section (Hall et al. 1997). However, if a small chain support system is used, the accuracy and precision of the yield monitor with the load cell mounted in this position may be acceptable.

Yield Calculation

Product flow sensor (load cell) output, instrument calibration factor, system calibration factor, conveyor speed, ground speed, and harvester width must be known to determine yield. The following equation is used to determine the sugarbeet flow rate over the conveyor.

$$FR = (O - T) \times IC \times CS \times SCF \qquad (1)$$

where:

FR = sugarbeet flow rate, kg/s (lb/sec)
O = torque sensor or load cells output, mV
T = tare value, mV
IC = instrument calibration factor, kg/mV (lb/mV) for the load cells or N-m/mV (ft-lb/mV) for the torque sensor
CS = conveyor speed, m/s (ft/sec)
SCF = system calibration factor, m^{-1} (ft^{-1}) for the load cells or m^{-2} (ft^{-2}) for the torque sensor

The tare value is determined by executing a "retare." To perform a retare operation, the yield monitor determines an average output from the respective product flow sensor while the harvester is operating but not harvesting. This value is subtracted from the total output of the product flow sensor to obtain a net output. The tare value is necessary to eliminate the effects of the weight of the unloaded conveyor chain or the torque needed to operate the empty scrub chain.

The instantaneous yield is calculated using the following equation:

$$YLD = \frac{36FR}{GS \times W} = \left(\frac{14.85FR}{GS \times W}\right) \quad (2)$$

where:

YLD = sugarbeet yield, t/ha (ton/ac)
FR = sugarbeet flow rate, kg/s (lb/sec)
GS = harvester ground speed, km/h (MPH)
W = harvester width, m (ft)

OBJECTIVES

The objectives of this study were to:

1. Investigate feasibility of sensing torque to determine real-time sugarbeet yield
2. Statistically compare the accuracy and precision of three yield sensing systems
3. Produce site specific yield maps
4. Compare yield maps resulting from three yield sensing devices
5. Determine the effects of mud on yield measurement.

These objectives were established to improve yield map accuracy and precision by exploring alternative weight sensing systems and the effect of tare dirt on yield data. In addition, information was necessary to determine the best location for a load sensor that would permit use of the on-board hopper.

Materials and Methods

Yield Monitor

The HarvestMaster™ HM-500 (HarvestMaster, Inc., Logan, UT) yield monitor consists of four basic components—product flow sensors (load cells), speed sensors, a signal conditioner and conversion unit, and the Pro-2000 handheld computer. A differentially corrected Global Positioning System (DGPS) provided position data. The HM-500 is an "off-the-shelf" yield monitor modified for this project. A torque sensor and a second set of load cells were used as additional inputs to the yield monitor. The yield monitor functioned as a signal conditioning and data collection device.

Product Flow Sensors

Two 227 kg (500 lb) load cells functioned as a product flow sensor and were mounted under the outlet conveyor chain near the discharge (fig. 1). A 127 mm (5 in) diameter idler wheel was mounted on each of the load cells to support the conveyor chain. The output was an analog voltage signal proportional to the mass of sugarbeets on the conveyor. A similar set of load cells was mounted on the discharge section of the scrub chain (fig. 2). A GSE (Farmington Hills, MI) Torkducer™ was installed in the scrub chain driveline. Two aluminum Lovejoy® flexible couplers were used to connect the driveline to the torque sensor (fig. 3).

Speed Sensors

Three speed sensors were used - one for ground speed, one for outlet conveyor speed, and one for scrub chain speed. Magnets were mounted on rotating parts and the speed sensor gave a voltage pulse each time the magnet passed the sensor. One magnet was used on both the outlet conveyor and the scrub chain drive shafts. Ground speed was determined using four magnets mounted on a ground wheel hub. Four magnets were used to minimize the delay in detecting changes in ground speed.

A speed sensor was also used as a stop/start switch. The stop/start switch stopped logging data when the harvester was raised out of the ground, and started logging data when the harvester was lowered into the ground.

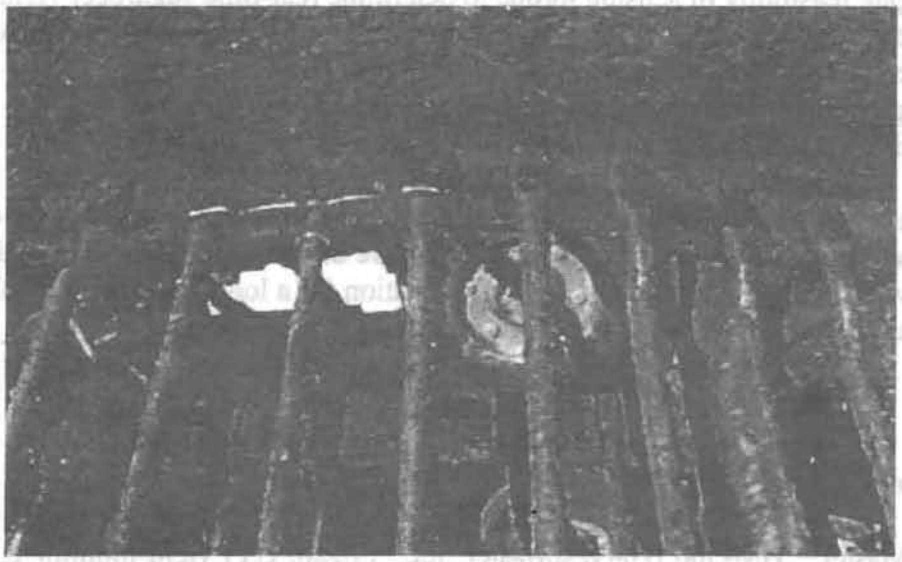

Figure 1 - Load cell based product flow sensor.

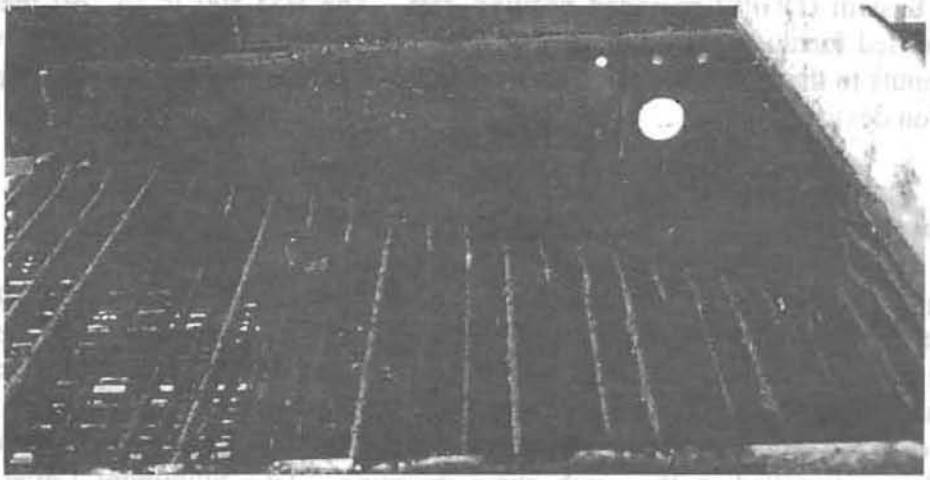

Figure 2 - Scrub chain weight sensing system.

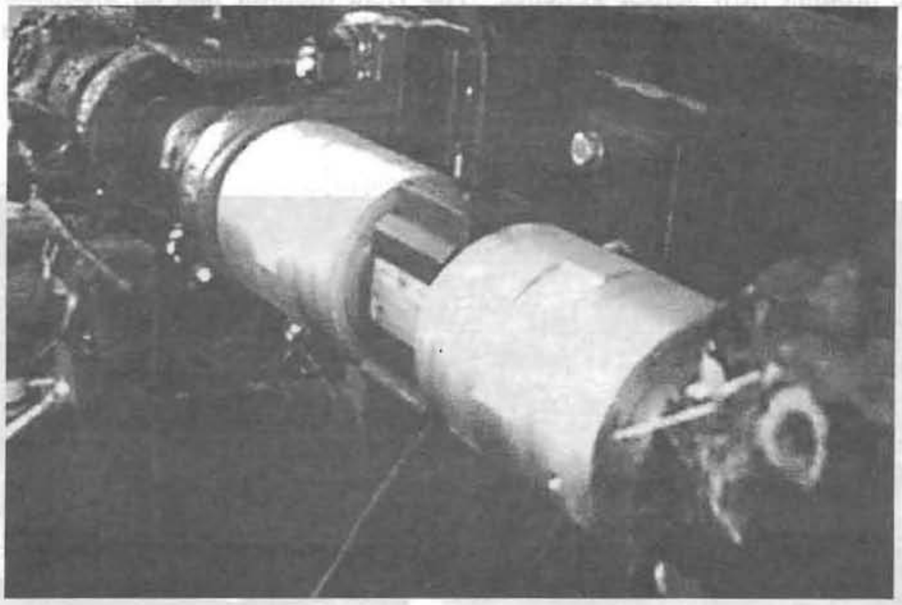

Figure 3 - Torque sensor weight sensing system.

DGPS Receiver

A Concord BR6-183 DGPS receiver (Case-Concord, Fargo, ND) provided latitude and longitude coordinates accurate to approximately 3 m (10 ft). An FM signal from Differential Corrections, Inc. (Cupertino, CA) provided the differential correction.

Signal Conditioning and Conversion Unit (SCCU)

The SCCU is the heart of the yield monitor. It collects signals from all components of the yield monitor and the DGPS. A low-pass filter eliminates components of the product flow sensor signals that exceed 3 Hz. The SCCU samples and digitizes the filtered signals at 25 Hz and applies a 25-point average to them to obtain one data point per second. The SCCU also converts the output from the speed sensors into frequency values so travel speeds can be calculated.

Handheld Computer

The Pro-2000 (HarvestMaster, Logan, UT) is a 286 DOS-based computer. It uses the frequency values from the speed sensors and the digitized signals from the load cells and torque sensor to calculate yield values. It also stores the date, time, position, yield, ground speed, flow rate, and accumulated mass data. It was mounted in the tractor cab for convenience.

PROCEDURE

Three product flow sensors were operated concurrently on a 1997 WIC Mini-tank Harvester (Amity Technology, Fargo, ND) (fig. 4). A HarvestMaster HM-500 (HarvestMaster, Logan, UT) yield monitor was modified by the manufacturer to accommodate input signals from the three separate product flow sensor systems. The yield monitor had an independent truckload accumulation feature as well as having independent yield values written to a data file for each sensor system.

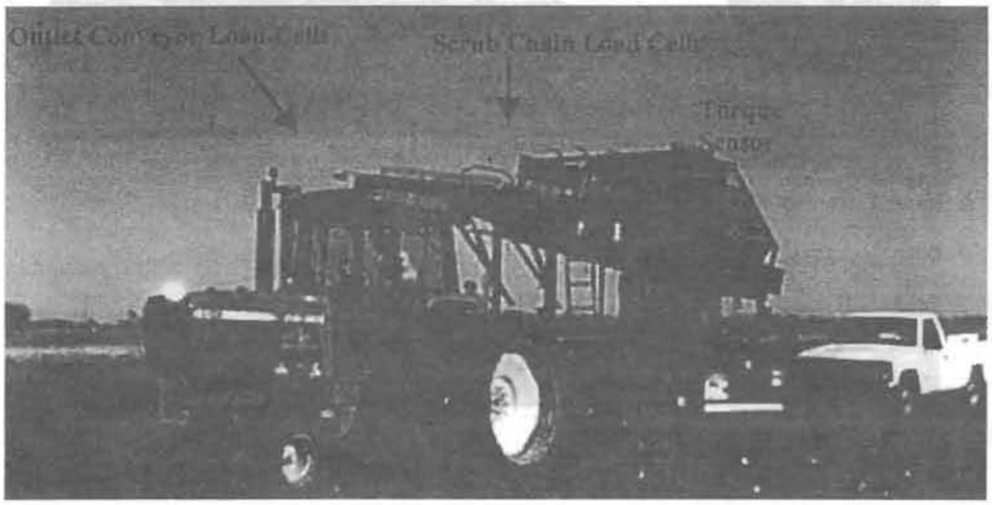

Figure 4 - 1997 WIC mini-tank harvester equipped with weight sensing systems.

Raw Data Collection

A CR-10 data logger (Campbell Scientific, Logan, UT) was used to collect raw digitized signals from each product flow sensor system. Wires were spliced into the output signal leads from each weight sensor and input into the data logger. Signals from the product flow sensors were sampled and recorded at 16 Hz.

A tare value was determined by gathering raw data from the weighing systems when a retare was preformed. The tare data were then imported into a spreadsheet and a 16-point moving average was applied to obtain a value for each second. An overall average was then calculated over the entire retare, approximately 25 seconds in duration.

Raw data were gathered for approximately 5 minutes on two separate harvester passes. These data were used to calculate flow rates and yields using the tare value previously found. The conveyor and ground speeds were noted from the output of the yield monitor. These speeds were assumed constant throughout the data collection period. The flow rates and yields were graphed and compared to the respective flow rates and yields recorded in the yield monitor data file. Raw data were collected for approximately 1.5 minutes with the harvester operating, but stationary. The data signals were used to calculate weight accumulations and the accumulations were graphed.

Truckload Error Evaluation

The truckload weight recorded by the yield monitor for each weight sensing system was compared to the actual truckload weight obtained from piling station scale tickets. The following equation was used to calculate truckload error:

$$Truckload \quad Error = \frac{MW - AW}{AW} \times 100\% \qquad (3)$$

Where:

MW = Truckload net weight from the yield monitor, t (ton)

AW = Truckload net weight from scale tickets, t (ton)

The mean and standard deviation of the truckload errors were calculated for each field and for the entire harvest and were plotted. The usefulness of the mean is limited, since it is directly related to the system calibration factor. A mean greater than zero indicates that the system calibration factor was too high. Conversely, a mean less than zero indicates that the system calibration factor was too low. The standard deviation, however, is a measure of consistency or precision. As long as the calibration factor is not changed extensively, it indicates how much precision can be expected from the yield monitor.

An ANOVA was performed on the means of the standard deviations to determine significant differences. Data from each product flow sensor were regarded as individual treatments. Truckload errors for each treatment were divided into groups of 5, 10, 15, and harvest day groups. Standard deviations were calculated for each group to give replicated values for the standard deviation of each treatment.

Yield Map Generation

Because high truckload errors occurred, the yield data were corrected before yield maps were developed. Since each truckload was identified in the yield data file, the area covered when loading a truck could be calculated. A yield correction value was determined for each truckload by dividing the difference between the measured and actual truckload weight by the number of hectares (acres) required to load that truck. This correction value was then added to the recorded yields for that truckload to obtain corrected yield values. This process was repeated for each truckload in that field. The corrected yield values were then imported into AgLink for Windows™ software to generate a yield map.

Yield Map Comparison

The corresponding yield values for each weight sensing system were subtracted from each other to generate yield difference maps. The torque sensor map data were subtracted from the outlet conveyor system map data, the scrub chain system map data were subtracted from the outlet conveyor system map data, and the torque sensor system map data were subtracted from the scrub chain system map data. These maps show how the systems respond relative to each other in different areas of the field. For example, these maps could indicate whether the torque sensor gives higher yield values than the outlet load cells in muddy areas of the field.

RESULTS AND DISCUSSION

Raw Data

Figure 5 shows the flow rates calculated from the data gathered with the CR-10. A 16-pt moving average was applied to the raw data. The 16-pt moving average was then averaged again over the 4-second logging interval to obtain a single value for each 4-second interval.

Figure 5 shows a strong relationship between the sugarbeet flow rates from each weight sensing system. The first 15 seconds show the flow rates increasing from zero to approximately 23 to 35 kg/s (50 to 70 lbs/s). Since the harvester was empty at time zero, the increase in flow rates shows the harvester filling to an approximately steady-state condition. The flow variation from approximately 20 to 170 seconds is assumed to be yield variation in the field, since the ground and conveyor speeds remained constant.

Figure 5 clearly shows the lag time between each weight sensing system measuring the same sugarbeets. A valley in the plot of the flow rate measurement is shown at the 50 second mark for the torque sensor, at the 53 second mark for the scrub chain load cells, and at the 59 second mark for the outlet conveyor load cells. The same lag time appears repeatedly through the entire plot.

Figure 6 shows the accumulations recorded with the harvester in a stationary position and operating empty. The negative accumulations in Figure 4 show that mud falls from the conveyor chains as the harvester is operating empty and stationary. As mud falls from the conveyor chains and is not replaced by new mud, the output from the product flow sensors decreases. Since the output from each product flow sensor is subtracted from its respective tare value, the net output is negative. Therefore, a negative flow rate is generated and a negative accumulation occurs. The torque sensor was affected most.

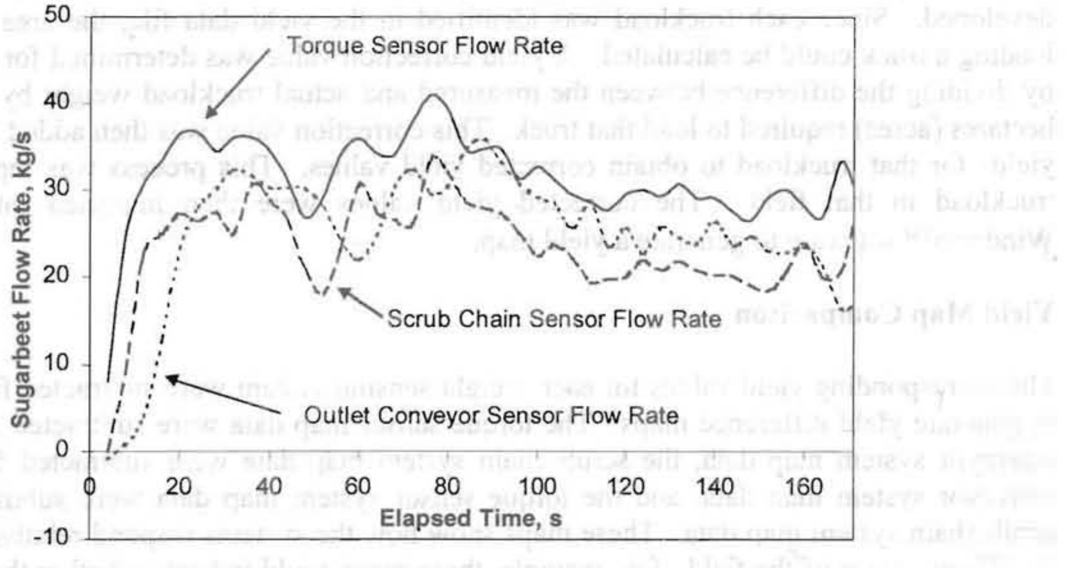

Figure 5 - Flow rate changes with elapsed time.

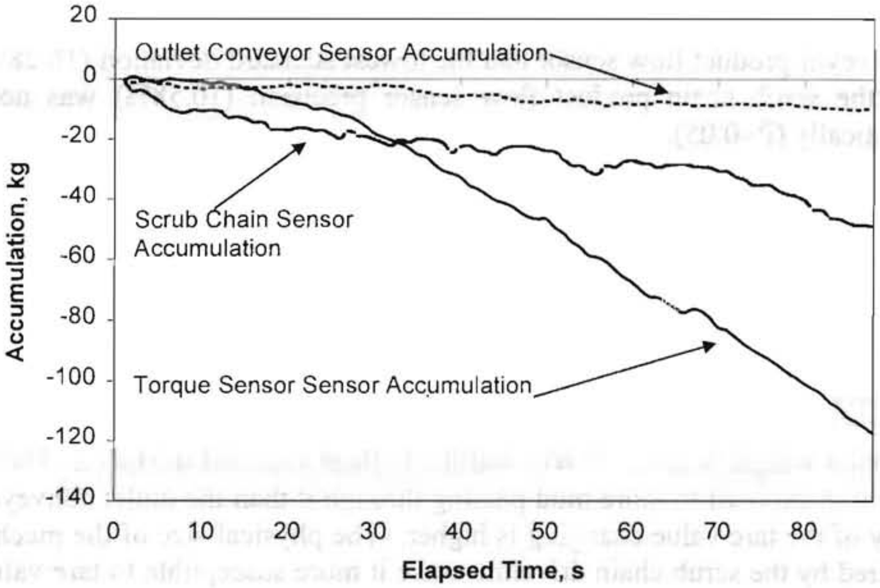

Figure 6 - Stationary harvester weight accumulations.

Truckload Error

Approximately 280 truckloads were harvested. Figure 7 shows the outlet conveyor sensor-truckload error for all truckloads. The mean and standard deviation were found to be 10.24% and 10.28%, respectively. The scrub chain sensor mean and standard deviation were found to be 5.25% and 10.58%, respectively. The torque sensor mean and standard deviation were found to be 12.91% and 16.97%, respectively. The calibration factors varied only slightly over the entire harvest.

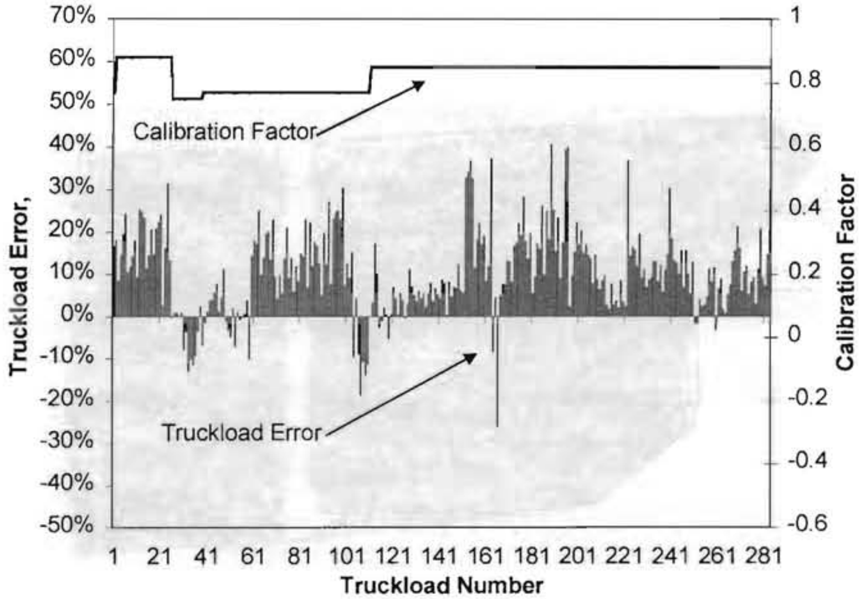

Figure 7 - Outlet conveyor product flow sensor-truckload error graph.

The outlet conveyor product flow sensor had the lowest standard deviation (10.28%) of the three systems, but the scrub chain product flow sensor precision (10.58%) was not significantly different statistically ($P<0.05$).

Standard deviations were high for the three product flow sensors. The wet and muddy conditions experienced during the harvest are the suspected cause. Muddy conditions cause the tare value for each weight sensing system to vary more than in dry conditions. The yield monitor assumes a constant tare value between retare functions. If the actual tare value varies during that time, high truckload errors and high standard deviations result. It becomes imperative that retares are performed often in muddy conditions.

The torque sensor weight sensing system had the highest standard deviation. The scrub chain is located where it is exposed to more mud passing through it than the outlet conveyor. Therefore, the probability of the tare value changing is higher. The physical size of the mechanism and the systems powered by the scrub chain driveline make it more susceptible to tare value changes. A small increase in mud clinging to the entire chain can increase the torque required to power the mechanism. In contrast, the load cells measure only discrete amounts of the conveyor chain at any given time. Therefore, the amount of mud clinging to the scrub chain causes a large change in the tare value of the torque sensor system and a small change in the tare value of a load cell system.

Yield Map Comparison

Figure 8 is a yield map of the University of Minnesota – Crookston NW Experiment Station Field 13. The white areas of the map represent the low yielding areas of the field, down to 0 t/ha (0 ton/acre). The darkest areas represent the high yielding areas of the field, up to 77 t/ha (34 ton/acre). The white strip down the center of the map is a drainage ditch where no sugarbeets were harvested.

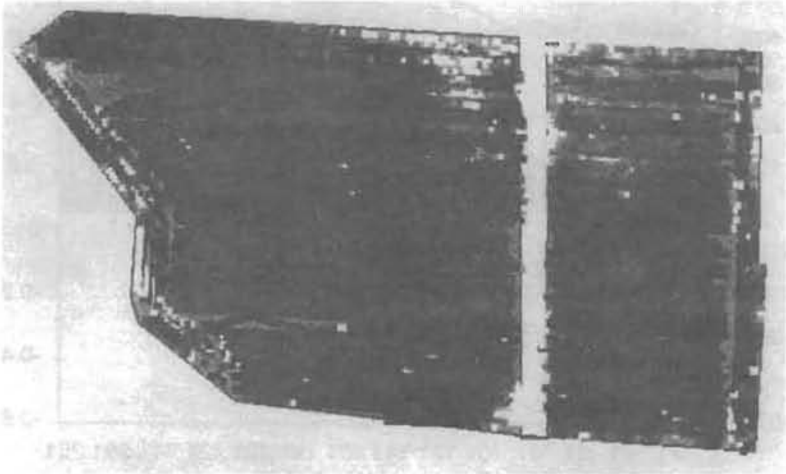

Figure 8 - UMC Field 13 yield map.

Figure 9 shows the difference between the map produced from the torque sensor data and the map produced from the scrub chain product flow sensor data. White represents areas where the torque sensor measured at least 4.5 t/ha (2 ton/acre) less than the scrub chain sensor. Black represents areas where the torque sensor measured at least 4.5 t/ha (2 ton/acre) more than the scrub chain sensor.

Figure 9 shows that the torque sensor system measured higher yield than the scrub chain system in low yielding areas of a field. The same relationship exists between the torque sensor system and the outlet conveyor system. However, comparing the difference between the outlet conveyor yield map and scrub chain sensor yield map shows no distinct relationship.

The torque sensor measuring higher yield in low yielding areas of the field is a secondary relationship. The gap in the center of the field is a drainage ditch, where the water flows north. The area of low yield along the north end is a drown-out area. Immediately prior to harvesting this field, approximately 76-mm (3-in) of rain was received. Therefore, this area of the field was extremely wet and muddy. The soil conditions during harvest of the high yielding areas were much drier than in the low yielding areas. Therefore, the primary relationship is that the torque sensor measured more yield in wet areas than in dry areas.

Figure 9 also shows that the torque sensor measured lower yields in the high yielding areas than the scrub chain sensor. Once again, this is a secondary relationship. Each system was calibrated over entire truckloads. During the loading of each truckload, the harvester passed through both wet and dry areas of the field. If the torque sensor measured more yield than the other sensors in the muddy areas of the field, it had to measure less yield than the other sensors in the dry areas of the field to obtain a correct measurement for the entire truckload. Therefore, the measurement of lower yield by the torque sensor in the dry areas of the field was a direct result of the measurement of higher yields in the muddy areas of the field.

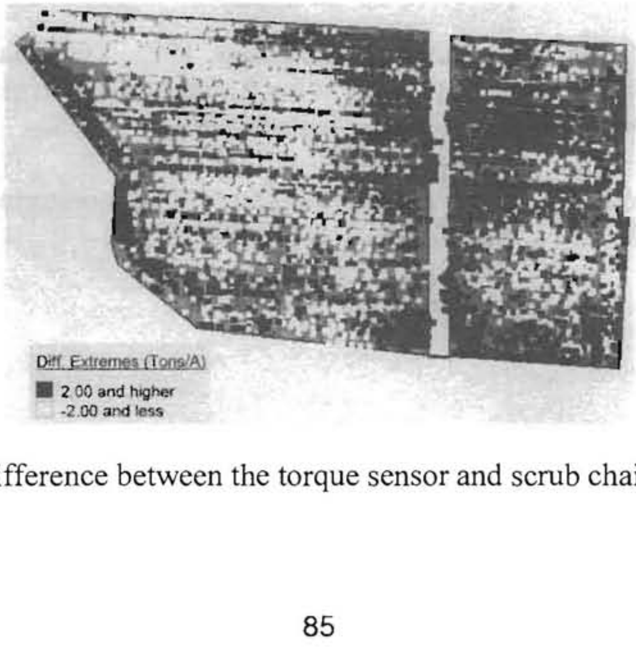

Figure 9 - Map of the difference between the torque sensor and scrub chain sensor yield data.

The yield data should be corrected for the truckload error if it is 5% or greater. For a 45 t/ha (20 ton/acre) yield, 5% truckload error on a 13.6 t (15 ton) truckload equates to 2.24 t/ha (1 ton/acre) error on each individual yield data point. The 5% error level was selected as a practical value and one which would have economic significance.

CONCLUSIONS

Based on this study, a torque sensor located in the scrub chain driveline will detect variations in sugarbeet yield. However, this system was significantly less accurate and precise than the two other systems used in the study. Standard deviation differences between the outlet conveyor and the scrub chain weight sensing systems were not significant. This study shows that the harvester hopper can be used at the same time site-specific yield data are collected by using a weight sensing system in the discharge portion of the scrub chain. Since the scrub chain system allows the use of the hopper, it would be the recommended system. High standard deviations were most likely caused by muddy conditions and tare dirt. This indicates the need for frequent retare, especially in muddy conditions. The torque sensing system measured higher yield than the other systems in muddy areas. This would be expected, since significant cleaning takes place in the scrub chain.

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