COOPERATIVE EXTENSION SERVICE
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Elements of Precision Agriculture: Basics of Yield Monitor Installation and Operation

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Introduction

Yield monitors are a recent development in agricultural machinery that allow grain producers to assess the effects of weather, soil properties, and management on grain production. They are a logical first step for those who want to begin practicing site-specific crop management or "precision agriculture." The accuracy of these devices depends on appropriate installation, calibration, and operation. Therefore, it is essential that grain producers understand how the yield monitor works to improve their grain enterprise.

This publication is intended to help equipment operators and farm managers select, install, and operate a yield monitor. It explores the costs of establishing a yield monitoring system, the essential components of yield monitors and the functions of those components and methods for ensuring accuracy of the data.

Benefits of Using a Yield Monitor

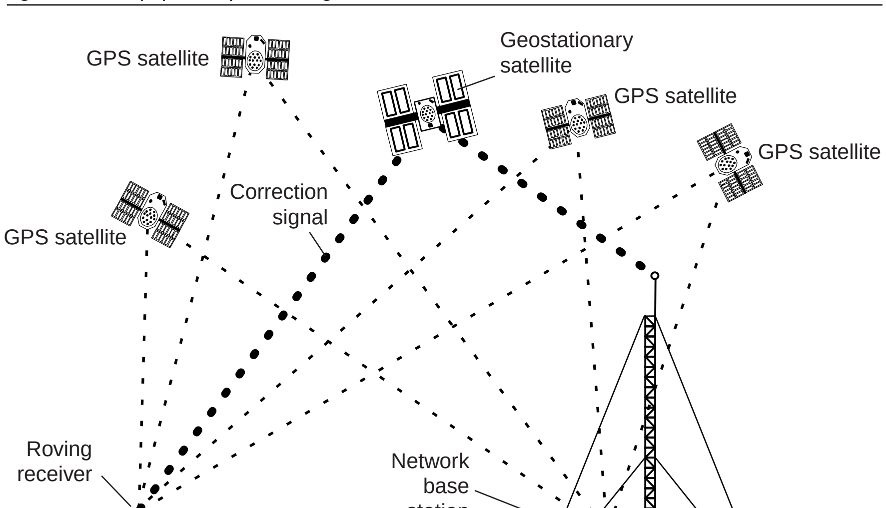
The yield monitor is intended to give the user an accurate assessment of how yields vary within a field. Although a yield monitor can assist grain producers in many aspects of crop management, the device was never intended to replace scales for marketing grain.

A yield monitor by itself can provide useful information and enhance on-farm research. Yield data can be accumulated for a specific load or field, thereby facilitating the comparison of hybrids, varieties, or treatments within test plots. For example, all yield monitors can measure grain mass and harvested area on a load-by-load or field-by-field basis. This feature allows an operator to get instantaneous readout in the field of accumulated grain weight, harvested area, and average yield. With many yield monitors, these values can be exported to a personal computer and stored in nonvolatile memory for further analysis or printing via specialized software packages or more standard word-processing and spreadsheet software. Season summaries of harvested areas might then be used to settle custom harvesting charges or to keep track of production from individual fields when it is impractical to scale grain trucks. With a yield monitor, a producer also can conduct on-farm variety trials or weed control evaluations without the need of a weigh wagon. Such on-farm comparisons help producers fine-tune crop production practices to their soils.

With DGPS

The Differential Global Positioning System (DGPS) is an integration of space- and ground-based segments that together comprise a radio-navigation facility. Initially developed for national security interests, a portion of the DGPS system is available to civilian users. (Figure 1 is a diagrammatic representation of DGPS.) When yield data are used with information generated by a DGPS receiver, a producer can generate yield maps that provide a quick visualization of crop performance within a particular crop production unit. Ultimately, any increased profit realized from incorporating a yield monitor into an operation will come from changes in management practices that result from the identification of problem areas using such yield maps. With DGPS, the benefits of using a yield monitor are even more evident.

Figure 1. Conceptual rendition of GPS satellite differential correction communication for agricultural equipment positioning.



Purchase Considerations

When you make this first move into precision agriculture, your choices are limited by what is available and the level at which you intend to enter the technology. Capital outlays for yield monitoring systems range from $2,000 for a user-installed yield monitor alone to more than $8,000 for a complete turn-key system that includes a yield monitor, DGPS receiver, mapping software package and installation with the purchase or lease of a new combine. Potential purchasers and users of a yield monitoring system may want to consider the following questions:

- Is a yield monitor available for your make and model of combine?
- Are you considering the purchase of a combine from a manufacturer that provides yield monitoring as an option or add-on?
- Do you trade combines frequently?
- Will more than one combine be operated in the same field?
- Will yield monitoring capabilities be obtained from a custom harvester?
- Do you want to generate yield maps or simply obtain field average yield data at harvest?
- Who will download yield data and generate yield maps?
- Do you own a personal computer with color printer and PC card interface?
- Which map generation package will you use?
- How will you archive yield data for future use?
- Will you purchase a DGPS receiver with the yield monitor?
- How will differential correction signals be obtained for the DGPS receiver?
- Will you purchase an integrated package, or will you develop yield monitoring capabilities over several years?
- Can components of the yield monitor be used in other applications (e.g. variable-rate seeding)?

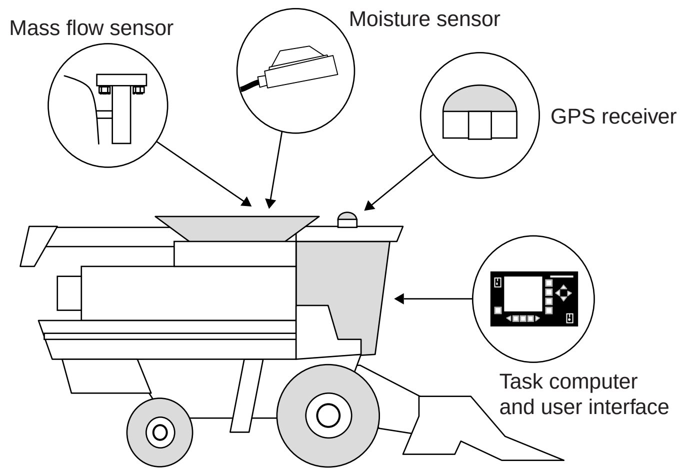
Yield Monitor Components

Yield monitors are a combination of several components, as shown in Figure 2. They typically include several different sensors and other components, including a data storage device, user interface (display and key pad), and a task computer located in the combine cab, which controls the integration and interaction of these components. The sensors measure the mass or the volume of grain flow (grain flow sensors), separator speed, ground speed, grain moisture, and header height. The sensors are interfaced with both analog to digital and direct digital inputs. Yield is determined as a product of the various parameters being sensed. It is important to understand the function of these components to further understand the interaction of the yield monitor, the combine operator, and the combine dynamics.

Grain Flow Sensors

The most essential component of any yield monitoring system is the sensor used to measure the mass or volume of clean grain moving through the separator of a combine. While the nature of mass-flow or volumetric-flow sensing may vary by manufacturer, these devices are almost always located at or near the top of the clean grain elevator, as shown in Figure 3.

Figure 2. Components of a grain yield monitoring system on a typical combine installation.

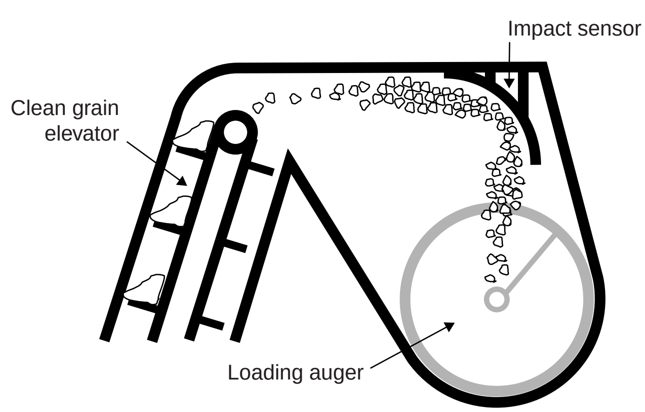


Mass-Flow Sensing

The most common approach is mass-flow sensing, which is accomplished by assessing the impact force of grain hitting a plate. The paddles of the clean grain elevator accelerate grain as the chain makes a 180° turn at the top of the elevator. The centrifugal acceleration generated as the paddles make this turn causes the grain to separate from the paddles. Grain then contacts the elevator enclosure and falls toward the base of the bin loading auger. It is at this location, where grain impacts the elevator housing, that impact-type sensors are positioned.

An **impact sensor** measures the mass flow rate of grain through a combine by sensing the force of grain as it impacts a plate or beam, using either a strain gage or a linear potentiometer to measure deflection of the beams or various members holding the plate. Because the impact sensor is the most prevalent type of grain flow sensor in the United States, it is the primary focus of this publication. Three other sensors—radiation-based, photoelectric, and paddle wheels—are also explained because they have been incorporated into a number of commercially viable products.

Figure 3. Typical installation of a mass-flow sensor in the clean grain elevator housing.



Volumetric-Flow Sensing

Radiation sensors measure the mass flow of grain passing between a radiation source and sensor, usually mounted on the top of the clean grain elevator. The presence of grain between the source and sensor attenuates or diminishes the amplitude of radiation incident on the sensor and is a function of the mass of grain between them.

Photoelectric sensors measure the volume of grain contained on each paddle of the clean grain elevator. One or more light sources and paired sensors are placed opposite one another across the clean grain elevator housing, and the volumetric flow of grain is correlated with the timing of the light circuit interruptions. Timing these interruption periods provides an estimate of volumetric grain flow. A drawback to this system is the potential for errors if the combine is operated on hillsides, whereby grain is forced to one side of the elevator paddles.

Volumetric flow can also be measured by using a **paddle wheel** at the base of the loading auger tank. The paddle wheel is rotated at a controlled speed to ensure that the region between adjacent paddles is filled with grain. The wheel rotates to a new position, allowing grain to accumulate in the space between the next two paddles. Grain volume is then determined by recording the number of paddle wheel revolutions.

Today, many combines can be purchased with factory-installed yield monitors. After-market yield monitors are also available for installation on late-model combines. The flow-measuring device (impact plate) is placed in the service door at the top of the clean grain elevator, or in an opening at the top of the elevator. In some cases, the impact sensor can be mounted only by cutting a hole in the top of the clean grain elevator housing.

The proper installation of a yield monitor requires positioning the mass-flow sensor relative to the position of the upper elevator sprocket. A new adjustment mechanism must also be installed on the lower end of the clean grain elevator. After calibration, only the lower sprocket should be changed to adjust elevator chain tension. Any movement of the top elevator sprocket changes the impact angle of grain, thereby requiring a new calibration. Calibration of the flow sensor refers to the correlation of the mass flow rate of grain, in pounds per second, to the magnitude and frequency of the impact force. The geometry of the impact plate relative to the elevator paddles must be maintained after calibration of the yield monitor to assure accurate data collection.

Separator Speed Sensor and Ground Speed Sensor

Essential to the yield monitoring process is the determination of both separator speed and ground speed. **Separator speed** is determined using a simple magnetic sensor on one of the separator shafts. This sensor generates a square wave with a frequency that is proportional to the speed at which a ferrous block passes the magnetic pick-up. These sensors were originally installed on combines to monitor cylinder and fan speeds. The clean grain elevator speed is a multiple separator speed, and it must be known for mass flow rate calibration. By monitoring the speed of a shaft directly coupled to the elevator drive, a simple ratio can be used to determine the frequency of paddles passing the impact plate and can be used for mass flow rate signal conditioning. Most after-market yield monitor manufacturers provide cables that allow the installer to tap into this speed signal.

Distance traveled is simply a product of **ground speed** (velocity) and sampling time. Ground speed can be easily measured using the existing magnetic pick-up provided by the combine manufacturer. A square wave is generated as ferrous gear teeth within the transmission pass the magnetic pick-up. Ground speed is a constant multiple of this generated frequency and is determined during the calibration of the yield monitor.

Once ground speed is known, the distance traveled by the combine during a sampling period is determined by multiplying the ground speed by the time of the sampling period. As an example, assume a combine is traveling 4.0 miles (253,440 inches) per hour. If a sampling period of 1 second is used to store yield data, the combine has traveled 70.4 inches within that sampling period. As will be illustrated later, this value—termed "distance traveled"—is stored as part of the yield data file and is needed for determining "harvested area," which is a product of distance traveled and the effective header width during one cycle.

One of the problems with this approach is measurement error due to wheel slippage. Radar provides an alternative method for measuring ground speed and is preferable when compared to the magnetic sensor pick-up. It is not subject to wheel slip errors, which can be an important factor when combines are operated in unfavorable conditions such as on wet soil. However, radar is also susceptible to errors, especially when operating in high residue environments. Wind-induced movement of weeds or plant stubble may generate erroneous radar reflections.

More recently, yield monitor manufacturers have begun using the velocity determined by a DGPS receiver, but there are some drawbacks to this method. A functioning GPS receiver must be present if using it for speed determination. Operation of the yield monitor may not be possible when GPS signals are not available. Also, GPS speed determination is subject to the same errors as position determinations. This is not a great concern, however, because GPS velocity is always more accurate than position determinations.

Grain Moisture Sensors

Measuring the moisture content of the grain is also an important element of yield monitoring. Producers are concerned about moisture content from the perspective of harvesting, drying, and storing grain, plus the cost of drying or dockage at the elevator. Sensing this moisture content at the time of harvest allows yield data to be corrected to reflect a true marketable weight of grain. Moisture sensing is also useful at harvest to allow the combine operator to determine the suitability of a particular field for harvest and perhaps the delivery destination of the grain—storage, drying, or the local elevator.

Moisture content is determined by sensing the dielectric properties of the harvested grain. The level of moisture within the grain affects the grain's capacitance (its ability to store an electrical charge), which is sensed by confining a predetermined volume of grain between two conductive metal surfaces. For most yield monitors, this is accomplished by installing a moisture sensor either on the tank-loading auger or on the side of the clean grain elevator, as shown in Figure 4.

Today, most moisture sensors are mounted on the side of the clean grain elevator. This location is better than mounting the sensor on the tank-loading auger because the sensors encounter less grain flow, reducing the buildup of debris on the sensor plates. This buildup introduces bias into the moisture measurements. The moisture sensor is essentially a conductive shell or metal plates with an electrically isolated internal metal fin. As grain rises in the clean grain elevator, a small amount enters the top of the moisture sensor and moves between the metal plates. A small paddle wheel located in the bottom of the sensor housing ensures that grain always covers the plates. The paddle wheel also controls the rate at which grain reenters the clean grain elevator.

Users should check the moisture sensor periodically and clean the plates when the combine is operated in weedy or wet grains. These conditions can cause a buildup of dirt or plant residue on the sensing elements, which interferes with grain moisture measurements.

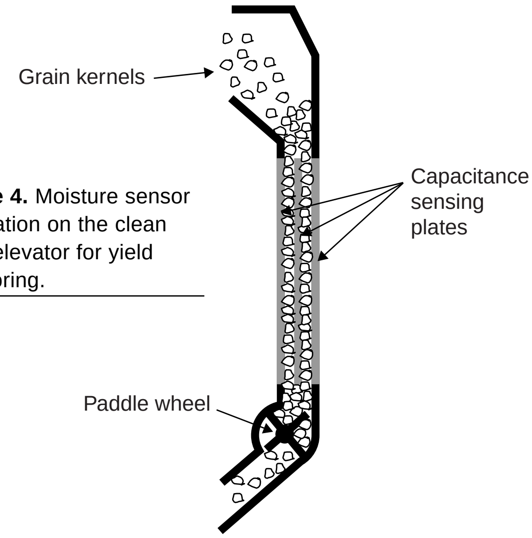


Figure 4. Moisture sensor installation on the clean grain elevator for yield monitoring.

Task Computer

A task computer located in the cab of the combine serves several functions: it integrates and calibrates the sensors; converts their output signals into data for storage, display, and later use; contains the DGPS receiver interface, external data storage devices, and user interface (display and keyboard); and controls the interaction of these devices. Downloading a new program or changing the program chip in the yield monitor reconfigures and upgrades the yield monitor.

Data Storage Devices

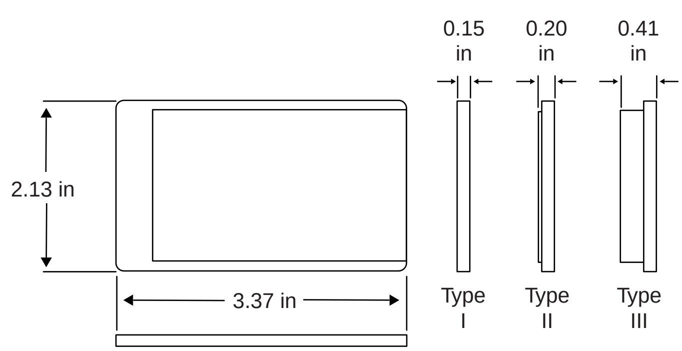
Data are downloaded or transferred from the yield monitor to a desktop or laptop computer using a Personal Computer Memory Card Industry Association (PCMCIA) standard memory card. Industry has moved toward adopting the term “PC card” or “PC card interface” for the PCMCIA-type devices. These cards can be divided into two types: static random access memory (SRAM) and dynamic random access memory (DRAM). DRAM cards require continual refreshing of the charged memory locations to maintain data integrity. Unfortunately, the continual refreshing of volatile memory locations requires power, making this type of card unsuitable for data transfer. SRAM cards enjoy a long read/write cycle life, making them a better choice for precision agriculture applications. As with the DRAM cards, the memory of SRAM cards is also volatile; therefore, a battery is required to preserve data stored on the card when it is removed from a powered system. Most PC card users should periodically check battery levels to prevent data loss. However, most yield monitors provide a battery voltage level check after formatting a PC card. The manufacturer usually recommends a replacement interval of two years.

Choosing the right type of PC card, as identified by its thickness, is as important as choosing the right category of card. PC card standards allow for Type I, II, III, and IV cards. All types of card measure 2.13 inches in width, 3.37 inches in length, but they vary in thickness: 0.15 inches for Type I, 0.20 inches for Type II, or 0.41 inches for Type III. The connectors’ pin spacings and support rails are all the same size. However, the spacing between adjacent cards determines which card type a device can accept. Figure 5 shows the differences in the types of cards and card construction. Memory access times for SRAM cards vary from 80 to 250 nanoseconds (ns), or 0.00008 to 0.00025 seconds.

The data transfer medium used in most yield monitors is a static, battery-backup SRAM Type II PC card, with a storage capacity of one to two megabytes (Mb). It is essential to check with yield monitor manufacturers before purchasing these cards, as their devices may be limited to a specific type and speed.

The majority of data collected during field operation of the combine is stored directly on the PC card. Therefore, a card with adequate storage space must be present in the yield monitor or mapping processor boxes whenever yield data are to be logged. More than 30 hours of yield data can be logged at one-second intervals on a 2-Mb card. Most grain producers believe that it is important to have two cards so that they can be interchanged on a daily basis.

Figure 5. PCMCIA card dimensions and typical cross section.



DGPS Receiver Interface

To generate yield maps, yield data must be geographically referenced (in the form of a latitude and longitude position) using a DGPS receiver. In the interest of national security, errors are intentionally incorporated into the civilian GPS signal information (C/A Code) rendering GPS coordinate fixes too inaccurate for generating yield maps. Therefore, civilians must obtain differential correction data from a fixed second source to reduce the error of the GPS positioning services used. Availability and accuracy of correction signals may limit the type of correction service many producers can use. The U.S. Coast Guard is one source of free correction information. The radio beacon signals are considered "local" correction signals. Errors associated with these correction services are proportional to the distance from the base station and signal transmitter. Producers can also subscribe to one of several private-sector correction service providers, which use geostationary communication satellites to broadcast their correction signal; these correction services are considered "wide area" in that they are available over a significant portion of the North American continent. Subscription fees accompany these services, ranging up to $800 per year. Wide-area correction signals are transmitted via C-Band (3.75 to 4.5 GHz) or L-Band (1.6 GHz) carriers. A diagrammatic representation of wide-area DGPS is presented in Figure 1.

When you purchase an integrated package that includes a yield monitor, a DGPS receiver, software, and a personal computer, the supplier must ensure that all components are compatible with one another. However, if you opt to move into yield monitoring component by component rather than buying an integrated system, you will need to know how to select and integrate a DGPS receiver into your system. Use extreme caution when swapping components between systems, and read all manuals and make sure you understand the implications of connecting components.

Currently, most yield monitor manufacturers utilize an RS-232 serial interface (a common interface for data transfer in the personal computer industry) to communicate data from the DGPS receiver to the yield monitor. An RS-232 interface typically uses a DB9 connector that has nine pins, but only two wires are required when transferring data between the DGPS receiver and the yield monitor. Most DGPS receivers used in mobile applications require a 12-volt DC supply. However, receiver manufacturers allow a sizable deviation from this power specification by typically allowing receivers to operate between 8 and 12 volts DC. Some system integrators now use a CAN (Controller Area Network) local-area network for transfer of data. Communications remain serial in nature; however, the RS-232 protocol is no longer applicable.

Data output from DGPS receivers intended for use with yield monitors must conform to the NMEA (National Marine Electronics Association) 0183 data format. This data format consists of several different character strings. All strings begin with a "**$**" and five-character code and end with both a carriage return (**<CR>**) and line feed (**<LF>**). Data in the character string come between the five-character address field and the carriage return. For DGPS receivers, the five-character string consists of two parts, the talker and the mnemonic ("nee-mon'-ic") code. An example of one of the more common NMEA data strings is **$GPRMC**, where **GP** refers to the talker (a GPS receiver), and **RMC** is the mnemonic code for *Recommended Minimum Specific*. A $GPRMC character string might look like the following:

$GPRMC,164259.00,A,3819.2665,N,08510.6114,W,000.1,157.8,
270296,0.000,E*25<CR><LF>

The format of this string is:

$GPRMC,hhmmss.ss,a,ddmm.mmmm,n,dddmm.mmmm,
w,z.z,y.y,ddmmyy,d.d,v,CC<CR><LF>

where:

hhmmss.ss = *Universal Time Coordinate (UTC) of position fix*
hh = hours (00 ... 24)
mm = minutes (00 … 59)
ss.ss = seconds (00.0000 … 59.9999)
a = *status (A - valid or V - invalid)*
ddmm.mmmm = *latitude of position*
dd = degrees (00 … 90)
mm.mmmm = minutes (00.0000 … 59.9999)
n = *direction (N - North or S - South)*
dddmm.mmmm = *longitude of position*
ddd = degrees (000 … 180)
mm.mmmm = minutes (00.0000 … 59.9999)
w = *direction (E - East or W - West)*
z.z = *Ground Speed in knots (0.0 …..)*
y.y = *Track Made Good or reference to true North (0.0 … 359.9)*
ddmmyy = *Universal Time Coordinate date of position fix*
dd = day (01 … 31)
mm = month (01 … 12)
yy = year (00 … 99)
d.d = *magnetic variation (0.0 … 180.0)*
v = *variation sense (E - East or W - West)*
CC = *check sum (hex 00 … 7F)*

Installation Considerations

Two options exist when investing in a yield monitor. If you are purchasing or leasing a new combine, you may order a factory-installed yield monitor with it. Whether buying or leasing, the customer should expect a fully functioning system and reasonable support from the manufacturer installing the system.

The second option is to purchase a yield monitor from an after-market supplier. While these yield monitors may be installed on either new or used combines, most yield monitor manufacturers support mainly late-model combines and tend to shy away from adapting yield monitors to older combines. They perceive this as a shrinking market and therefore cannot justify development costs for these models. Late-model combines warrant their attention, and, to this end, they have responded quite well.

Installing your own yield monitor can result in substantial savings. With the savings, however, comes the potential for frustration. Be certain you are willing to accept some risk and frustration when you decide to go it alone. The following discussion is a summary of several users' experiences and suggestions and is intended to reduce your frustration level.

Instructions

Prior to installation, **read the instructions several times**.

Installation Kit

Installation requires cutting several openings and drilling several holes in the sheet metal of your combine. Depending on the type of moisture sensor used, you also may be required to remove a section of auger flighting from the tank-loading auger. Yield monitor installation also affords you the opportunity to replace elevator flights and chain, bearings, or augers. **Acquire the necessary replacement parts in advance of the installation**. Yield monitor manufacturers prepackage several tools, templates, and replacement bearings to make your job easier. Familiarize yourself with all of the parts in the installation kit prior to cutting or drilling holes.

Templates

Manufacturers provide templates to help accurately locate required openings for both the mass-flow sensor and the moisture sensor. If your combine has a service door for the clean grain elevator that is close to the desired location of the mass-flow sensor, a new door may be provided to mount this sensor. Otherwise, you must locate a template and cut a new opening.

The mass flow sensor must be centered on the paddles of the clean grain elevator, so use caution in positioning the template before cutting or drilling. Two openings on the side of the clean grain elevator are required for the installation of most moisture sensors. Some manufacturers fabricate openings on the side of the clean grain elevator for moisture sensors along with the proper mounting area for the flow sensor. **If you use a cutting torch to make these openings, extreme caution is advised.** Most areas in the cleaning and separating regions of the combine tend to accumulate dust, dirt, and plant material, and this accumulation, combined with grease and oil, creates an extreme fire hazard. A much better alternative is to use a jigsaw with a fine-tooth metal cutting blade or a high-speed air tool with a circular cut-off blade. In either case, holes must be drilled at the corners of the rectangular opening. Hand filing may be required to remove burrs around the opening.

Moving the Chain Tensioning Device

After installing the moisture sensor and the mass-flow sensor, the remaining modification is to move the chain tensioning device on the lower end of the clean grain elevator. This procedure is more machine-specific than the other modifications. **The fixed position of the upper chain tensioner is crucial to the long-term calibration and operation of your yield monitor**. Any movement or readjustment of the upper tensioning device will require recalibration of the yield monitor. Provisions are made by manufacturers to install a new chain tensioning device at the lower end of the elevator. While this resolves the adjustment problem after fixing the position of the upper shaft, the amount of adjustment is limited. You should keep half-links on hand for periodic adjustments due to wear and stretching of the elevator chain.

Routing the Wiring Harnesses and Mounting the User Interface

The remainder of the yield monitor installation process involves routing the wiring harnesses and mounting both the user interface and the mapping processor. **Proper location of the user interface is crucial for keypad operation and display visibility.** The display must be viewed on a regular basis, and the operator may wish to observe several monitor features at one time. A series of keystrokes is usually required to change the display mode and enter new data. As the user becomes familiar with the various monitor functions, using the yield monitor becomes routine. Some operators rely on the mass flow readout values to determine how full the cylinder is and whether the ground speed of the combine should be adjusted to match the capacity of the threshing and separating mechanisms.

Cable routing seems to be straightforward; however, this activity is perhaps the single greatest source of trouble in most installations. One of the weak links on agricultural machinery is electrical connections. The quality of the connectors themselves has increased considerably in the last 20 years. However, the best connectors cannot make up for poor cable routing. The combine has numerous moving parts that come in contact with the wiring harnesses. Rotating parts quickly wear away insulation and cause short circuits. Cables routed where excessive vibration or continual bending exists can result in open circuits as the braided copper wires harden and break. Flowing grain within the grain tank generates large frictional forces that pull at the cabling. Over time, these forces tend to pull the wires from the connector or separate the pins within the connector. In either case, the general rule is to appropriately route wires and use plenty of wire ties to secure cables in place. Leaving slack at the cable connectors enables them to be easily separated for troubleshooting and reduces strain at the connector. When installing cables, resist the temptation to shorten them as this may affect system performance. Often the electrical resistance of a conductor must be considered in the design of sensors and antennas. Therefore, changing the length of a wire/cable could alter the electrical response of a component. Pre-harvest checks of combines with yield monitors should include cable inspection.

Calibrating a Yield Monitor

Yield monitor manufacturers make every effort to build accuracy into their systems; however, every combine and installation may have different errors. Sources of errors in the data produced by the yield monitor include material transport delays within the combine, effective swath width, moisture content, and mass flow determinations. What has evolved are systems that must be calibrated for each grain type. Four elements must be considered when calibrating a new yield monitor:

- distance,
- header height,
- mass flow rate of grain, and
- grain moisture content.

Distance

Using the wheel speed sensor in the transmission to determine ground speed requires calibration to relate the actual distance traveled to a specific number of pulses from the sensor. The sensor is calibrated by operating the combine over a known distance (e.g., 400 feet or length specified by the manufacturer) at typical harvest speed and field condition. The yield monitor then generates a scale factor to correct recorded speed. When calibrating the speed sensor, you should match the actual operating conditions of the combine at harvest as closely as possible. For example, operate a loaded combine on soft ground or a hillside if this is typical of field conditions at harvest. Ground speed radar must be calibrated in the same manner. However, yield monitors that rely on the use of GPS for ground speed determination do not require calibration for speed.

Header Height

Header height determination is important as it establishes the beginning and ending of data logging and area accumulation. There are principally three different methods for sensing header height. One method is a magnetic sensor that opens a contact when the header reaches a predetermined position. A second method uses a rotary potentiometer for sensing the angle or elevation of the header. At the option of the combine operator, the start and stop positions determined by the potentiometer can be adjusted on a control panel located in the combine cab. The third method involves tracking the length of time the header height control switch is in the "up" or "down" positions. Once the actuation time exceeds a predetermined value (e.g., 1.5 seconds), area accumulation and data logging is either turned on or off, depending on whether the header is being lowered or raised.

Regardless of the methodology used to initiate or terminate data logging and area accumulation, combine operators are urged to read the operator's manual and thoroughly understand the operation of this feature because the quality and integrity of yield data depend heavily on its use.

Mass Flow Rate of Grain

To calibrate the mass flow sensor, producers must collect data regarding the weight of grain harvested over a certain interval and then enter the actual weight of grain harvested into the yield monitor. This interval might consist of one to several combine tank loads. Based on a defined approach, the yield monitor uses this information to fit a calibration curve, or a series of factors, to the particular impact sensor, grain type, and combine/sensor geometry. If any of these factors change, the system must be recalibrated. Changes in grain properties such as test weight and moisture content may require more frequent calibration.

Although the approach is similar from manufacturer to manufacturer, the quantity and nature of the internal calibration approach differs. While the factory or default calibration numbers provide a reasonable starting point, they are not a substitute for on-farm calibration. At the very least, one truckload of grain must be weighed. One manufacturer recommends weighing several individual combine tank loads of grain. This process is greatly simplified when a weigh wagon with digital readout is available for obtaining load weights.

Grain Moisture Content

Moisture sensor calibration is limited to providing an offset or bias to correct the moisture content of the grain. The offset is a constant that can be either positive or negative. It is difficult to find a suitable method of determining the actual moisture content so that an offset can be entered into the yield monitor. This is further compounded by considering the variability that exists as the combine moves through the field. More importantly, a sample of grain from the moisture sensor or tank-loading auger must be collected, analyzed, and then compared with the moisture sensor reading from the instant in time when the grain passed over the sensor to arrive at an accurate offset. In short, this is not a simple operation because of the moisture content variation at harvest and the transport delay within the combine separator.

Operators are urged to use caution when adjusting moisture offsets, particularly when considering the accuracy of the moisture-measuring device that will be used to determine the reference moisture content of the grain. Offsets vary with grain type, and each grain type requires calibration to determine the appropriate offset.

Yield Monitor Data

Once a yield monitor has been properly installed and calibrated, it allows producers to observe many parameters "on the go" during harvest. Instantaneous yield, average yield, mass flow rate through the combine, area harvested, and moisture content can all be displayed on the monitor with the touch of a button. Yield monitors also store a summary of this data for each load and field. These data summaries can be downloaded via the PCMCIA card or an RS-232 serial link to the office or a laptop PC. These exported summary files can be opened in spreadsheets for further data analysis, used for record keeping, or entered into income tax programs. These data are obtained without DGPS.

When the yield monitor is linked to a DGPS receiver, geographically referenced data is available for download to the office PC using a PCMCIA card. This data can be expanded and exported to several software packages. The nature of the data recorded by the yield monitor and how these data are related to the sensors should be considered. The following "Advanced" export data format is nearly universal:

```
ddd.dddddd,dd.dddddd,mm.mm,tttttttt,n,lll,www,cc.c,
kk,ppppp,ssssss,Fnn:bbbbbbbb,Lnn:bbbbbbbb,gggggggggg,
sss, ppp,aaaa
```

where:

ddd.dddddd = *longitude (degrees, + East and - West)*
dd.dddddd = *latitude (degrees, + North and - South)*
mm.mm = *grain mass flow (pounds per second)*
tttttttt = *GPS time (seconds)*
n = *cycle period (seconds)*
lll = *distance traveled in cycle period (inches)*

www = *effective swath width (inches)*
cc.c = *moisture content (percent wet basis)*
kk = *status (bits 0 thru 4 - header down)*
ppppp = *pass number*
ssssss = *yield monitor serial number*
Fnn:bbbbbbbb = *field ID (number and name)*
Lnn.bbbbbbbb = *load ID (number and name)*
gggggggggg = *grain type*
sss = GPS status
ppp = point dilution of precision (PDOP)
aaaa = altitude (feet)

A typical exported data string might look as follows,

-85.238446,38.308450,8.36,838257850,1,54,348,28.3,
33,0, 950304,"F4:901","L1:CLARK","Wheat",12,64,813

It is obvious from this character string that wheat is the grain being harvested in field 901 and that the operator has chosen "Clark" as a load ID. Not as obvious is the yield in bushels per acre. As you look at the character string, you can determine that 8.36 pounds of wheat at a moisture content of 28.3 percent was harvested as the combine traveled 54 inches in a one-second cycle. The effective combine header width was set by the operator at 348 inches (29 feet). To arrive at the marketable yield in bushels per acre for this one-second cycle, the mass flow rate of grain at a particular moisture content must be corrected to reflect marketable bushels. To accomplish this, the wet mass flow value must be multiplied by a ratio of moisture content differences,

$$m_{market} = \frac{100\% - MC_{harvest}}{100\% - MC_{market}} \times m_{harvest}$$

where m_{market} is the corrected mass flow rate of grain in pounds/second, $m_{harvest}$ is the mass flow of moist grain at a moisture content of $MC_{harvest}$ (%). MC_{market} represents the moisture content used as a basis for marketing, i.e., *13.0 percent* for soybeans, *13.5 percent* for wheat, *14.5 percent* for barley, or *15.0 percent* for corn. Using this approach, we find the marketable mass flow rate of grain to be:

$$6.93\ lb/s = \frac{100\% - 28.3\%}{100\% - 13.5\%} \times 8.36\ lb/s$$

Next, we must determine the yield on a per acre basis. To accomplish this, the corrected mass flow rate is multiplied by the data logging interval and then divided by the area harvested by the combine during the logging interval. The form of this calculation is:

$$Y = \frac{m_{market} \times t_{sample}}{d \times w \times \rho_{grain}}$$

where Y is the corrected yield (bushels per acre), t_{sample} is the data logging interval (seconds), d is distance traveled in the data logging period (inches), w is the effective width of the combine header (inches), and ρ_{grain} is the mass density of a particular grain (pounds per bushel). Typical mass densities used for conversion from mass or weight to the volumetric measure of bushels are *60.0 pounds per bushel* for soybeans and wheat, *48.0 pounds per bushel* for barley, and *56.0 pounds per bushel* for shelled corn. Substituting in the appropriate numbers and conversion factors results in:

$$34.9\ bu/ac = \frac{6.93\ lb/s \times 1s}{54\ in \times 384\ in \times 60\ lb/bu} \times \left(\frac{144\ in^2}{1\ ft^2}\right) \times \left(\frac{43{,}560\ ft^2}{1\ ac}\right)$$

Thus, for the previously exported yield data string, we find the average yield for this logging interval to be 34.9 bushels per acre. The reported yield has been corrected to a marketable volume of grain per acre.

The following shows a popular exported file format referred to as "Basic":

ddd.dddddd,dd.dddddd,yyy.y,cc.c,ssssss,Fnn:bbbbbbbb,
Lnn:bbbbbbbb,gggggggggg

where:
ddd.dddddd = *longitude (degrees, + East and - West)*
dd.dddddd = *latitude (degrees, + North and - South)*
yyy.y = *grain yield (marketable bushels per acre)*
cc.c = *moisture content (percent wet basis)*
ssssss = *yield monitor serial number*
Fnn:bbbbbbbb = *field ID (number and name)*
Lnn.bbbbbbbb = *load ID (number and name)*
gggggggggg = *grain type.*

The "Basic" format is a simplified version of the "Advanced" format with the estimated marketable yield (bushels per acres) presented rather than the mass flow (pounds per second) of grain.

Sources of Yield Measurement Errors

Properly calibrated yield monitors exhibit good correlation with scales used for marketing. Conversely, larger errors can be expected with poorly calibrated yield monitors. As previously mentioned, it is important to spend time calibrating a yield monitor. Carefully consider all factors involved in the process. Grain carts with load cells offer an easy in-field determination of grain weights. *Yield monitor calibration will be no more accurate than the methods used during the calibration process.* If the grain cart load cells are out of calibration, this error will be transferred to the yield monitor.

Another source of error is the moisture sensing method. This is not to say that the sensing technology is at fault. Rather, it is a question of whether a consistent volume of grain makes good electrical contact with the sensing plates. Anything altering this situation skews the moisture content measurement. As an example, a buildup or accumulation of plant residue on the sensing plate(s) can result in significant errors in moisture content determination. This type of error is common when harvesting wheat or soybeans in fields where actively growing broadleaf weeds and grasses are present. You should periodically check the moisture-sensing plates for residue when harvesting in wet or weedy fields.

Errors in ground speed calibration carry over into yield determination as they affect the calculated harvested area. The only positive note about speed calibration errors is that they tend to be consistent and proportional, thereby enabling correction at a future date.

Effective header width is also an important source of error when determining yield. When harvesting with a corn head, this determination is easy, as each row is within a specified distance of adjacent rows and the combine header width is a multiple of this value.

For soybeans and other small grains requiring the use of a platform header, operators have greater latitude to harvest these crops using various header widths while traveling in directions other than that in which the crop was sown. Both factors combine to create a situation where the complete cutter-bar width may not be fully utilized. In these cases the operator must estimate the effective swath width and enter this number in the yield monitor. The effective swath width will also vary between equipment operators. It is possible to decrement the effective header width through the user interface when needed. However, this process requires the operator to divert attention from the harvest operation and is therefore undesirable. Combines operating in point rows or partial header widths skew the data toward lower point and average yield values.

Generating Yield Maps

In view of the efforts to reduce or eliminate errors in yield monitor data, several factors must be considered when moving to the next step, which is the generation of yield maps. An accurate relationship of mass flow to field position is essential. Unfortunately, dynamics associated with material flow at the header and within the combine create a delay between when the crop is gathered and when the grain arrives at the mass flow sensor. A typical delay between when the header engages a crop to when grain reaches the top of the clean grain elevator is 12 seconds. Similarly, when the combine reaches the end of a pass, grain flow continues at the mass flow sensor for another 8 seconds. While these transport delays do not affect grain mass determination, difficulty is encountered when trying to register yields with field positions determined using DGPS. To facilitate registration, material transport delays present in all yield monitors can be corrected using post-processing software where the user specifies “start of pass delay” and “end of pass delay” values in seconds. Mass flow rates are then moved back in time to conform to the position at which the header engages the grain.

Summary

Yield monitors provide a new and powerful tool for grain production. Yield monitor installation, calibration, operation, and purchase considerations are discussed in this publication. Yield monitors have many benefits. One is that operators can quickly view crop performance during harvest. A second benefit is that this yield data can be transferred to a personal computer and summarized on a field-by-field or total-farm basis for tax or record keeping purposes. A third benefit is that this information can be geographically referenced for the generation of yield maps, which provide year-to-year comparisons of high- and low-yielding areas of a field throughout a crop rotation sequence.

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