

YIELD MONITORING TECHNOLOGY FOR IRRIGATED COTTON AND GRAINS IN ARIZONA: HARDWARE AND SOFTWARE SELECTION

Pedro Andrade-Sanchez and John T. Heun

Introduction

The development of commercial-grade yield monitoring technology in the US dates back to the early 1990's when a new paradigm of "site-specific management" was introduced. By 1997, 14.6% of retail crop input dealers were engaged in sales and technical support for yield monitors (Whipker and Akridge, 2009). In 2011, this figure had grown to 35.6% (Whipker and Erickson, 2011). The use of yield monitors is particularly strong in the US-Midwest where large acreage of corn and soybeans are harvested with instrumented grain combines. In the Corn Belt (Illinois, Indiana, Iowa, Missouri, Ohio) yield monitor use grew from 28% of corn acreage in 2001 to 44% in 2005 (Agricultural Resource Management Survey, USDA, ERS/NASS). Prescription-based fertility management is one practical application driving this upward trend in the adoption of yield monitoring technology. For this use, yield monitors with GPS receivers enable collection of geographic data that are analyzed with GIS software to pinpoint yield variation within the field.

In the context of irrigated agriculture of the semi-desert, yield monitors have a place as a management tool to quantify the impact of management practices including water, fertility, plant growth (in cotton), pest control, variety selection, and others. The analysis of field-to-field variability in yield can also be used to improve financial decisions such as levels of crop insurance. Yield maps are a key step to understanding what the main drivers of variability are in a given field and can serve three main purposes: provide real-time yield quantities and other data for short term decision making such as scheduling of harvest operations and harvest equipment management, geo-reference yield data for mapping and spatial analysis for future management decisions, and as a basis to create prescription maps for site-specific chemical applications. There is a wealth of information that can be extracted from yield maps and there are many commercial technologies available to Arizona growers.

The main goal of this publication is to serve as a guide for growers and custom-harvest contractors to assist them in selecting the best option for yield monitoring technology for their operations. When it comes to yield monitoring technology for grains and cotton, growers and custom-harvest

contractors have a wide variety of options to choose from. Selecting the right system requires careful consideration of technical specifications of existing equipment and /or options available in new equipment. This article provides information for a basic understanding of the principles of operation of these systems with the goal of providing a solid base to make good decisions in terms of hardware and software selection.

Commercially-Available Yield Monitoring Technology

Table 1 presents yield monitor options for cotton and grains organized in two categories: a) integrated systems, which mainly come as standard / optional equipment in new harvester machines; and b) generic, stand-alone systems which for the most part are kits to retrofit older existing equipment.

Basic Principle Operation Of Yield Monitors

Yield is expressed in units of mass or volume per unit area. In grain combines, mass (wet and dry), volume, grain moisture content and temperature, area harvested, productivity (i.e. acres harvested per hour), and other parameters are measured and displayed for instantaneous use. Data is recorded at the time of measurement and stored on the internal memory of the display, and/or in an external secondary memory device such as USB flash drive, or compact flash (CF) data card. In order to measure the amount of harvested material, several aspects of operation must be measured. This is done by fitting the harvest machine with electronic sensors in key places. These sensors are connected to control modules, which convert the signals into digital data and pass that data to the field computer via can-bus network.

Harvesting machines equipped with yield monitors have GPS receivers directly connected to the field computer. These receivers output serial data containing machine position, altitude and travel speed data. User-selected delay time is input into the display to approximate the actual position of yield data in the field. Geo-referenced yield measurements are used in mapping and analysis of data. In the case of Trimble

Table 1. Commercially available yield monitoring systems for grains and cotton in North America. List updated as of May 2013.

	Manufacturer	Process/Display Hardware (Trademark/module)	Crops
<i>Integrated</i>			
	AGCO (Massey Ferguson/ Challenger)	C2000, and C2100 (FieldStar II)	Grains ¹
	Case IH	AFS Pro 600, 700	Grains ² and cotton ³
	CLAAS	Cebis(Quantimeter)	Grains ¹
	John Deere	GreenStar, GS2, GS3 (Harvest Doc)	Grains ² and cotton ⁴
<i>Stand-alone</i>			
	ASCI - AGRiplan	AG850	Cotton ^{3,5}
	Ag Leader	Insight*	Grains ¹ and cotton ³
		Edge*, Integra, Versa	Grains ¹
	Loup Electronics	Ceres 8000i	Grains ¹
	Raven	Envizio Pro I, II, Cruiser II (SmartYield)	Grains ¹
	Trimble	CFX-750 and FMX	Grains ¹

¹ Optical sensor (grain flow) plus grain moisture sensor

² Force transducer (grain flow) plus grain moisture sensor

³ Optical sensors (seed-cotton flow) for cotton pickers

⁴ Microwave sensors (seed-cotton flow) for cotton pickers

⁵ Optical sensors (seed-cotton flow) for cotton strippers

* Display out of production but still supported by manufacturer

CFX-750 and FMX, the GPS receivers are integral components of these displays, a convenient feature that reduces hardware connections. Yield monitoring does not need high accuracy GPS, free or low cost differential correction (DGPS) through WAAS or JD SF1 provide adequate quality of position information. One advantage in using Real-time Kinematics (RTK) and other high-end GPS correction systems is that elevation data can be logged and mapped to analyze the effect of land leveling in the observed in-field yield variation in irrigated fields.

The principles of cotton yield monitoring are very similar to grain yield monitoring. Mass flow (seed-cotton and lint per second), area harvested, speed, and productivity (ac/hr) are measured. Integrated machine systems can also display and record machine performance, such as fuel consumption. The field computer display, GPS, and can-bus network and sensor signal conversion modules are very similar in function and appearance to grain combines.

Sensors And Components Of Electronic Yield Monitors

Cotton pickers and grain combine flow sensors

Mass flow rate is determined with sensors that measure mass material over a given length of time. There are three types of flow sensors that are used to measure flow in grain combine and cotton yield monitors. These are force impact plate, optical and microwave sensors. A force impact plate is a metal plate with a force transducer attached, suspended inside the top of the clean grain elevator. Grain travels up the elevator by chain and paddle system. At the top of the elevator, grain is thrown at the impact plate which converts the force of the grain into an electrical signal. Ag Leader Integra, John Deere Green Star, Massey-Fergusson and Challenger (Field Star II), and Case IH AFS equipped grain combines all use force-impact plates.

CLAAS Lexion series combines use an optical sensor near the top of the grain elevator instead of an impact plate to measure grain flow. CLAAS describes the system operation: "... During volume measurement in the grain elevator, a photo cell records filling of the individual paddles. Using appropriate correction factors, including the lateral and transverse tilt of the machine among other things, the QUANTIMETER automatically determines the precise quantity harvested..." (URL 1, 2013). Other manufacturers including Loup Electronics, Raven, and Trimble displays support this type of sensors/module hardware.

Optical sensors are also used to measure mass flow in cotton yield monitors. These sensors have an emitter and receiver portion that mounts on opposite sides of the ducts that direct the flow of cotton to the basket. Five parallel beams of infrared light cross the duct. As the seed cotton moves through the duct and breaks the beams, the light is modulated and is converted into an electrical signal proportional to the mass of cotton moving through the light beams. A magnetic reluctance sensor on the blower fan provides information to the system on the speed of the cotton through the duct, which is a main component of flow rate. Ag Leader and Case IH systems use optical flow sensors. Because individual rows are harvested in cotton, more flow sensors are required than on grain combines. 2, 4, and 6 row flow sensor configurations are available for optical systems.

The third type of flow sensor is used exclusively in cotton and is described by John Deere: *"The cotton mass-flow sensors transmit beams of microwave energy... A portion of this energy reflects off the moving piece of cotton and returns to the sensor where the reflected energy is detected. Yield data is then carried to the display where it meets the geo-referencing data from the receiver"* (URL 2, 2013). The microwave sensors act in a way like a radar system, bouncing microwaves off of the cotton seed and 'seeing' how much there is in a given period of time. The microwaves can penetrate the plastic ducts so there is no need to cut holes to mount the sensors. On John Deere pickers with metal ducts, the microwave sensors are positioned between the duct outputs and basket in view of the flow of cotton exiting the ductwork. Blower fan speed is also a critical component of flow rate in the case of this microwave type flow sensor system.

Auger-shaft or blower fan speed sensor

As a critical part of product flow rate measurements, the speed of the product through the mass flow sensor must be measured. This is done by placing a magnetic reluctance type sensor on the end of a spinning shaft. In the case of grain combines, this is likely an auger shaft or other shaft connected to the elevator chain. A magnet is clamped to the end of a shaft and the sensor is positioned to the point of almost contacting the rotating magnet; the magnet induces a voltage inside the sensor's internal wire coil as it passes the tip of the sensor. This is interpreted as a pulse by the system; one pulse per shaft revolution. Counting the pulses over a period of time provides rpm of the shaft and depending on the sprocket size driving the elevator chain, rpm is converted into how fast the grain moves up the elevator- the speed of the grain through the flow sensor.

In cotton pickers, the same type of sensor is used to measure air speed through the ducts. It is placed on the end of the blower fan shaft. In most cases, the machine already has a sensor in that position regardless if there is a yield monitor system on board or not. The fan speed is typically displayed in the cab for the operator to view. Integrated and after-market systems both make use of the sensor that is already there. In this case, there is usually a gear mounted on the end of the fan shaft and the sensor has an internal magnet that creates the magnetic field for the sensor. As the gear teeth move past the sensor, they 'short out' the magnetic field away from the internal coil and back again. The motion of the field through the coil produces an AC voltage signal proportional to shaft rpm and coupled with some known air speeds for a given shaft speed, air speed can be measured, therefore, the speed of cotton moving through the ducts can be estimated.

Moisture sensor

To measure grain moisture content, typically a capacitive type sensor is fitted to the lower portion of the clean grain elevator. The sensor is placed into contact with the flow of grain. The capacitance of the harvested product depends on its moisture content. The more moisture the grain contains, the higher its capacitance will be. The capacitance measurement is translated into moisture content as a percent of total mass. Because 'wet' grain is what is directly measured by the flow sensor, the moisture content readings are used to calculate the 'dry' mass or volume of the yield.

Header height sensor

Header height sensors are used on both types of harvest machinery to monitor the area harvested. When they are properly calibrated, they automatically turn on when the header is in the lowered operating position and off when in the upper, non-operating position. It is a position sensor. The sensor is comprised of a potentiometer, like a volume knob on an older stereo system or electric guitar. As the knob is rotated, the resistance changes and voltage output increases or decreases depending on the direction of rotation. In the case of harvest machines, the sensor is typically mounted under the cab, above and near the center of the header. A long threaded rod is attached to the sensor (instead of a knob) with a chain at the other end of the rod, connecting it to the header.

Machine speed

The machine speed can come from two sources. The first option is the transmission speed sensor. The other option is taking speed from the GPS system, which is required for geo-referenced yield monitoring anyway. The GPS based-speed information is a more accurate measurement of vehicle speed because it is immune to wheel slippage and uneven terrain. Vehicle (machine) speed is used to calculate the area being harvested. Inaccurate speed will falsely increase or lower the yield results in the field computer. The GPS based speed does not need to be calibrated while the machine based speed must be, and so it makes sense to use it as the primary source of vehicle speed.



Figure 1. Yield monitoring system components in a yield monitor system installed on a conventional grain combine harvester (Case-IH 1440) in Central Arizona. From top-left corner in clockwise order: AgLeader Insight display; mass-flow sensor; header position sensor; and grain moisture sensor.

Software Options

During harvest a yield monitoring system will be continuously collecting and logging information internally at the display. Data is organized by season and crop, and by hierarchy of Client, Farm, and Field. After the harvest operation, farm managers can transfer these files to a computer for data processing and analysis. Common media used for data transfer include PCMCIA and CF cards, as well as USB flash drives. Different yield monitor systems will generate yield data in different electronic formats identified by their file extensions. The software in the PC must be able to recognize the particular file format.

Proprietary software

Large manufacturers of harvesting equipment such as John Deere and Case I-H provide software developed specifically to deal with the files generated by equipment of their own brand. In this category we find: a) John Deere Apex (http://stellarsupport.deere.com/en_US/products/apex/); and b) Case IH AFS (<http://www.caseihafs.com>).

These software packages are tools for farm management. Their functionality extends beyond mapping yield information generated during the harvest operation. Software in this category supports yield monitoring systems that are fully integrated through the CAN-bus of the machine, therefore machine operational parameters such as fuel consumption, engine performance, GPS-based elevation, etc. are variables recorded and available to the user in addition to computed variables such as machine productivity (i.e. time per unit area)

and fuel efficiency (i.e. gallons of fuel per acre, per cotton bale, ton of wheat, etc). Figure 2 shows screen shots of JD Apex v. 2.7.0.88. These images illustrate the extended functionality of this software to display raw yield data and interpolated elevation maps. Notice that more than one cotton picker was used in this field, but only one was instrumented with a yield monitor system. The next figure shows the computer interface that the user will face in the PC environment

Investing In A Yield Monitor

The first step is to identify what electronic systems are on existing machines, like tractors and sprayers. Most likely, auto-guidance is already being used on another tractor system. The display consoles previously mentioned have the ability to do other things, like yield monitoring, in addition to tractor guidance. It makes sense to explore what capabilities you have already invested in, and to make use of it by sharing displays and GPS between machines.

In the case of purchasing new harvesting machines, likely there is already a preference for a particular brand. New harvest machines come with integrated yield monitor systems in most cases. When ordering a new machine, verify with the dealer that everything necessary for a functional yield monitor is included: differential or RTK quality GPS, display console, wire harnesses, sensors, and GIS software. GIS software goes hand-in-hand with the machine hardware components. Without it, there is no way to map and analyze the data.

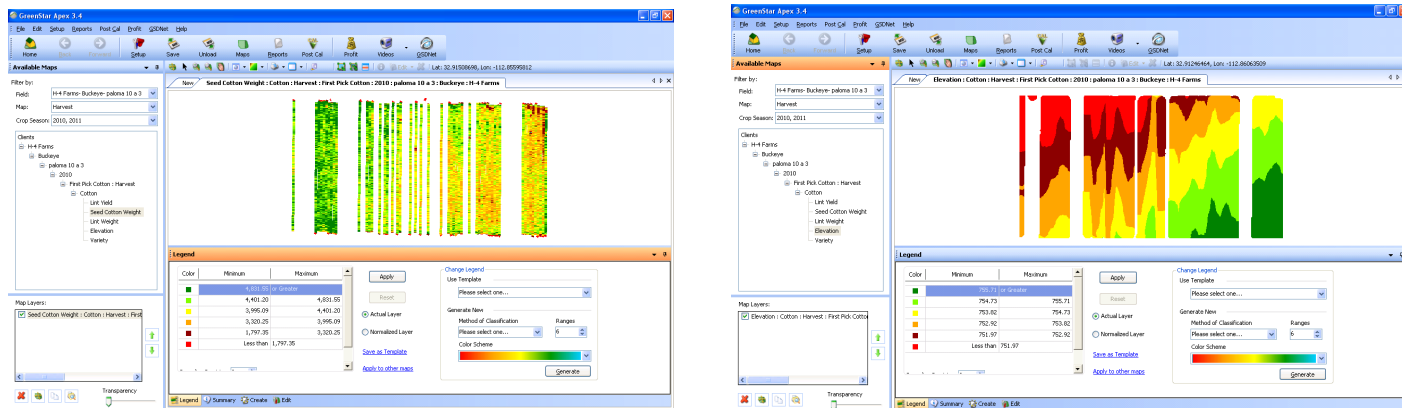


Figure 2. Screen-shot views of yield monitor data from a cotton field in Central Arizona. Image on the left is raw yield data and on the right is an interpolated map of GPS-based elevation.

An older machine without an integrated yield monitor can be retrofitted with a system. If this is not practical or the system doesn't have the desired functionality, a stand-alone system can be purchased. Keep in mind, these stand-alone systems, such as Ag Leader Insight, are also multifunctional systems and can be used for tillage, planting, guidance, variable rate, grain, cotton yield monitoring and more. Planning to make use of more than a single function will help pay back the cost of the system faster. We encourage growers to consult with their local machinery dealers on new equipment options, retrofit kits, and GIS software.

Citations

Whipker, L. D., and J. T. Akridge. 2009. 2009 Precision agricultural services dealership survey results. Working Paper #09-16. CropLife Magazine and Center for Food and Agricultural Business. Dept. of Agricultural Economics, Purdue University.

Whipker, L. D., and B. Erickson. 2011. The State Of Precision Agriculture 2011. 15th Precision agricultural services dealership survey results. CropLife Magazine and Center for Food and Agricultural Business. Dept. of Agricultural Economics, Purdue University

USDA Economic Research Service (USDA-ERS) and National Agricultural Statistics Service (NASS). 2005 Annual Agricultural Resource Management Survey (ARMS).

URL 1. http://www.claas.com/cl-pw/en/products/combindes/lexion-670-620/technik/06_kornbergung/start,bpSite=35108,lang=en_UK.html

URL 2. http://www.deere.com/wps/dcom/en_US/products/equipment/cotton_harvesting/7760_cotton_picker/7760_cotton_picker.page?



**COLLEGE OF AGRICULTURE
AND LIFE SCIENCES**
COOPERATIVE EXTENSION

THE UNIVERSITY OF ARIZONA
COLLEGE OF AGRICULTURE AND LIFE SCIENCES
TUCSON, ARIZONA 85721

PEDRO ANDRADE-SANCHEZ
Assistant Specialist Precision Ag, Assistant Professor

JOHN T. HEUN
Research Specialist

CONTACT:
PEDRO ANDRADE-SANCHEZ
pandrade@cals.arizona.edu

This information has been reviewed by University faculty.
cals.arizona.edu/pubs/crops/az1596.pdf

Other titles from Arizona Cooperative Extension can be found at:
cals.arizona.edu/pubs

Any products, services or organizations that are mentioned, shown or indirectly implied in this publication do not imply endorsement by The University of Arizona.

Issued in furtherance of Cooperative Extension work, acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture, Jeffrey C. Silvertooth, Associate Dean & Director, Economic Development & Extension, College of Agriculture and Life Sciences, The University of Arizona.

The University of Arizona is an equal opportunity, affirmative action institution. The University does not discriminate on the basis of race, color, religion, sex, national origin, age, disability, veteran status, or sexual orientation in its programs and activities.