Yield Monitors and Yield Mapping

Yield mapping has now become important in Precision Farming as it is considered to be the starting point for its implementation. Having adopted the technology of producing yield maps, farm managers want to make use of the additional information not only in a passive way, for instance by revealing spatial variation, but also in a active way as a support tool for future management decisions. In order to use a yield map in this respect, a higher level of map accuracy is required, especially when decisions may be based on a single yield map. Management decision on farms can broadly be divided into three types:

1. Long term decisions - considering strategies such as crop rotation and temporal yield stability

2. Intermediate decisions - concerned with the next growing season, variety selections, fertilizer and pesticides applications

3. Short term decisions - considering actual field or plant conditions during the growing season.

Currently, the major application of yield maps as decision support tools appears to be for long term and intermediate decisions, especially when yield maps of one field become available over several year.

Introduction

The vast majority of agricultural fields have inherent spatial variability in parameters such as soil type, nutrient availability, drainage status, slope and aspect. Crops grown today respond to this variability to different extents but the end result, at harvest, is yield that varies in quality and quantity across the field.

Knowledge of the variability of yield at harvest can be used in two important ways;

1. It enables the farmer to make more informed management decisions regarding the succeeding crop.

2. It can provide a basis for varying fertilizer application according to a defined strategy.

The variation in final yield represents an integration of effects of spatially variable soil, environment and crop variables. The magnitude of the effect is different for each parameter. In many cases, available nutrient to the crop will have a major effect. For the potential of yield maps to be realized, the effect of different parameters must be "disentangled". Interpretation of yield maps is thus a major challenge to their practical use.

While yield monitors most likely will raise more questions than they answer, the wealth of information they deliver is the basis for making more informed farming decisions. So, if a farmer didn't take advantage of the technology available this year, they will have to wait. It takes several years of harvest data to make decisions on changing inputs and farming practices.

Many farmers believe that yield maps can provide a reliable indication of the yield variations with fields and are placing a high level of confidence on the information provided by such maps. However, confidence levels placed on commercially available yield maps have not been quantified, even though the information provided by yield maps is already being used by many farmers and research organizations. Important decisions and experiments are therefore, being evaluated and quantified, without full knowledge as to the accuracy that can be expected from the information provided by a yield map.

New benefits

Yield mapping is considered by many farmers to be an essential part of precision farming, as data is recorded automatically while harvesting a field. Yield monitoring and mapping offer many other on-farm and off-farm benefits;

- **On-farm**- Real-time information during harvest, easier on-farm testing, better variable-rate management, evaluation of whole-field improvements, and creation of a historical spatial database.

- **Off-farm**- benefits of yield monitoring include more equitable landlord negotiations, crop documentation for identity preserved marketing, "trace back" records for food safety, and documentation of environmental compliance.

Growers who will profit most from yield monitor use are those needing help keeping detailed field-by-field records, those not deterred by the "yield monitor learning curve", and those willing to effectively use additional sources of spatial data.

Beginning Interpretation

> "A yield monitor is a great tool for collecting data and showing you what actually took place in a field. The interpretation of the data is what will lead you to change management practices." Grant Mangold

The practice of "precision mapping" today, is not necessarily precision farming. "We can collect data form a point in time and space, but we have to relate it back to an overall outcome or management for that field. Tools like GPS can be very useful for finding spots in the field for future reference or for record keeping. But we need to keep in mind the limitations of the tools and of our interpretation of the data.

Accurately knowing the yield variability within a field can become the cornerstone of a crop management plan. But first, it's important to know if the yield variability within the field is stable from year to year. We should find out if some areas consistently yield higher from year to year while other areas consistently yield lower. Else we should find if the yield variability pattern changes within the field each year? If the yield pattern is not consistent it's important to determine the cause of this yield instability. Perhaps weather is the cause. It's wise to have several years of yield data before putting too much stock in the yield maps or before making costly management changes. If the purpose of monitoring yield variability is to compare varieties herbicide rates or types, starter fertilizer, or crop injury from a pesticide, one year of data may be helpful as a starting point, however data from several years will be much more helpful.

If the purpose of monitoring is to improve overall management of the field and perhaps modify some of the soil factors, then it seems wise to have 3 to 6 years of data as a starting point. This is the minimum needed to separate out climate-induced variability within a field. It is also necessary to look at why yields are variable, considering controllable and uncontrollable factors. Controllable factors are soil fertility, pests, plant population, variety selection, drainage, and tillage.

The goal is to increase profit by improving management of controllable factors, or inputs. But there is an up-front cost for yield monitors, so each farmer must understand and use them wisely to make them pay. Yield monitors can be a cost-effective management tool or a costly gadget.

On-the-go yield monitors generate a lot of hype and enthusiasm among farmers. Data from the monitors are often expressed in color-coded yield maps for whole fields or farms. But such maps aren't automatically beneficial to farmers. There's much more to collecting, understanding, and managing collected yield data than developing colorful maps.

For the data to be reliable, you need to know that the yield monitor is properly calibrated. Indications are that factors such as constant travel speed of the combine and slope of the field influence the accuracy of the data. In summary, purchase a trustworthy monitor; properly calibrate it before putting too much emphasis on a yield map. The time spent accumulating yield maps can be devoted to setting goals and laying out a plan for taking advantage of what the technology can offer.

Finally, for those farmers who hire crop consultants, using a yield monitor may be a benefit. We as farmers will be able to precisely measure the value of their recommendations.

High Yields.... Key to Economic Successes

HIGH YIELDS...KEY TO ECONOMIC SUCCESS IN GRAIN PRODUCTION

Maintaining a profitable grain crop production system has been a challenge over the past couple of years with depressed market prices. Weather problems have dealt a double blow to some farmers. Those who have worked to develop high yield systems have been better able to survive the economic and weather stresses. Sound agronomic management leads to better profits regardless of the market price. Prices rise and fall, weather patterns change, but the farmer who focuses on building and implementing an agronomic plan for maintaining high yields is on the best course for a sustainable production system.

Managing for high yields is the farmers' best strategy to maximize profits. Farmers have little control over the forces impacting the market, but having more grain to sell at whatever the price gives them the best chance to make a profit. Higher yields in the aggregate may have a depressing effect on grain markets, but an individual farmer must constantly work toward higher yields to maximize profits.

A successful high-yield management system should be based on a realistic yield goal…probably a yield that can be met or exceeded one or two years out of five. That provides a challenge without unreasonable risk. Components of a high yield system are based on experience and common sense and an awareness of relevant research and technology developments. The first step is cataloging available resources. Knowing the yield potential of the soil types on the farm, and especially any limitations they have, is a good place to start. Study the soil survey information available from the National Resources Conservation Service (NRCS). Review past yield records for each field on the farm and any information available from neighboring farms. Build a plan to make the best use of the physical, financial, and management resources available. Then implement the plan, monitor the results, and refine the system. The commitment to plan, implement, review, and refine is essential to a successful high-yield management system.

Many farmers have a growing database of geographically referenced information that provides specific insight into the limitations and potentials for each field. Studying these databases and making sound agronomic interpretation of them can give new insight into opportunities to increase yield. Adjustments in management systems may be possible by reallocating resources without substantial increases in input costs. Fine-tuning management plans based on available on-farm data may provide the best opportunity for farmers in the future to maintain a profitable crop production system.

Having a high-yield system in place provides the greatest flexibility in dealing with low crop prices. It reduces the risk if you need to cut back on some inputs for one season. If exceptionally good growing conditions prevail, the system is able to function at full capacity. When poor conditions are encountered, the components of a high yield system will also provide the best opportunity to reduce losses. Planning for a good year is the best way to ensure one–if you take action to implement that plan.

Harold Reetz 1998

Methods for Measuring Crop Yield

There are two ways to measure crop yields

1) Collect and weigh

   For centuries farmers have used this method to weigh the crop after it has been harvested, and is normally expressed as specific unit of weight (such as bushels, hundred weight, pounds,) per acre.

2) Instantaneous Yield Monitors

   Measure and record yields continuously as the combine travels across the field. Some systems record each data point separately (when connected to a DGPS receiver) and other systems collect a number of points that are then processed to provide load summary data.

   Some systems measure crop volume while other systems weigh the crop. All systems have the capability to measure the area harvested for each recorded weight or volume.

   Most systems measure grain moisture continuously.

Basic Yield Monitor Components

To determine instantaneous crop yield, three items must be known.

1) Flow rate through the harvester's separating system.

   The flow rate is measured in units of volume or mass per unit time (bus or pounds per second).

2) The harvester's travel speed

Measured in units of distance per unit of time (miles per hour or foot per second).

3) . The width harvested

Cutting width is measured in feet, inches, or number of rows.

Components

1) Flow Sensor

Commercially available yield sensors are based on either on of two different principles for measuring the mass flow of grain:

1. Volumetric – a volume of grain is measured and then converted into mass by using the equation: Density = Mass * Volume.

2. Mass flow detection – a measurement to determine grain mass.

There is a clear distinction between volume and mass flow rate. The volumetric meter is a measure of the rate of mass of material conveyed while the bulk density remains constant.

The components are found in most instantaneous yield monitoring systems.

- Impact Force Sensor

- Plate Displacement Sensor

Impact Force and Plate Displacement Mass flow sensors can be sub-divided in two distinct types:

1. True mass flow meters – have a sensing element that reacts to the mass flow of solids through the instrument.

2. Inferential mass flow meters – determine both the instantaneous solids concentration and flow velocity within the sensing element and multiply these two measurements to give mass flow rate.

- Volume Measurement Systems

This system measures grain volume with the clean grain system. There two types of volume sensors currently being marketed. The **photo sensor** monitor uses a light source and a receiving sensor to detect the degree to which a combine's clean grain elevator is loaded. A photo sensor is a device used to detect light. The radiant energy is converted into an electrical signal. Measurements of light and dark periods by the photo sensor are used to estimate grain volume flow rates through the clean grain system.

Much research has compared the performance of a mass detection system and a volumetric based system. They concluded that the overall performance of both yield sensors were very similar. However, it was noted that when using the volumetric system, the variation of specific weight within the crop on measurement accuracy was highly significant. Volume measuring systems, accuracy is only guaranteed if regular measurements of the crop density are taken and manually programmed into the yield sensor's computer. Research has also noted that grain bulk density will change continuously with varying field conditions, and volumetric systems require considerable effort in maintaining an accurate calibration. Also noted that in theory a yield sensor based on the principle of mass detection compensates for any variation in grain density. Yield data derived from such a sensor has the advantage of not being influenced by any variation in crop density that may exist within fields.

- Radiometric System
- Load cell System

2) Moisture sensor

Grain moisture content will also vary within fields. If not taken into account when interpreting a yield map, the information that the map provides to the farmer may be open to misinterpretation.

The problem is associated with the fact that varying grain moisture contents do not allow a direct comparison of grain yield from different parts of the same field. Obviously, if the grain moisture content varies within fields, then the grain yield will also vary as the moisture contained within the grain is a proportion of the grain weight. Therefore, depending on when and where the crop was harvested within the field, the yield may vary accordingly. This is due to changes in grain moisture content and not as a result of an actual increase in the amount of grain.

When a farmer makes a direct comparison of yield levels from year to year, grain moisture content needs to be considered. In these circumstances grain weight would be corrected to a standard moisture content, allowing direct comparison of yield levels within fields and across multiple years.

3) Ground Speed Sensor

- Shaft Speed Sensor
- Radar and Ultrasonic Sensor
- GPS-Based Speed Measurement

4) Harvester position switch

Controls the calculation of harvested acreage. When the sensor detects the header in the raised position, area counting is suspended. When lowered to a reasonable cutting height acre accumulation is resumed.

5) Display console

The console connects to all of the sensors that supply information needed to calculate harvested yield. In addition to sensor inputs, the display console receives inputs from the combine operator. The operator can input, width of harvest, field or load information to permit tagging or referencing of the yield and moisture data.

Calibration and Yield Mapping

Calibration

The types of calibration that are required by yield monitoring systems vary by monitor type. Regardless of the type of monitor, YIELDS are not measured directly. Instead, measurements of force, displacement, or volume, speed of material flow, moisture content, harvester travel speed, and working width are combined to produce an estimate of crop yield. Crop yield is a derived, or calculated, value.

Calibration is performed to ensure that sensor data and operator input are properly used by a monitor to produce a final output in units of harvest units per acre. In addition, force and displacement sensing grain flow meters must be calibrated to nullify, or cancel, the effects of machine vibration on yield readings.

Most calibration processes involve comparing the weights of several loads estimated by a yield monitor with those measured on a separate set of scales. The actual weights are then entered into the yield monitor. Software within the yield monitor console then computes a set of calibration curves.

To properly calibrate a yield monitor, the requirement is to harvest at different speeds, harvest widths, and a number of loads.

Yield Data Collection

With the basic components describe above an operator can instantaneously observe yield, speed, moisture content, and other information as this data “flashes” on the monitor console.

- Data can be collected every 1,2,3, or 5 seconds.

- The monitor can store an extensive record of crop production, using PCMCIA (Personal Computer Memory Card International Association) card.

Yield Mapping

Yield maps are based on sets of instantaneous yield data points collects with the yield sensor compotes and a DGPS receiver.

The complete precision farming system consists of many elements and brings together a number of different technologies. The success of the precision farming system relies on the integration of all the different elements into a single system that can be operated at the farm level. Many of the elements are required to be automatic. For example, the main task of the combine operator is to drive the combine to harvest the field and not to collect yield information used to generate yield maps. Therefore, the yield mapping system employed to collect yield data must be automatic.

Yield mapping is the process of continuously recording the grain flow through the combine harvester while at the same time integrating with actual harvest position in the field. The yield and position data is transferred to a computer where interpolation techniques are used to generate a yield map of the field.

Once the data is collected users need special computer software to generated yield maps. Most collected data is stored in a binary format. Binary files store digital data very efficiently, but this data must be converted to standard text files in order for most yield mapping software to process the data.

The yield map provides information to the farmer detailing which are the better and poorer yielding parts of the field. The yield map does not provide information as the cause of the yield variation. The farmer is required to use a combination of local knowledge and other sources of data to interpret the maps to make crop management decisions to improve the profitability of the field.

Issues to Consider

Originally harvest machines were not developed to record and determine site-specific information. The functions of a harvest machine were designed to;

- Extract, cut, or pickup the crop
- Convey the gathered crop to a separating system
- Thresh or clean the crop and separate the desired material
- Store and transfer the harvested crop to a truck or storage vehicle to be taken away from the field.

To date, instantaneous grain yield monitors are the most accurate tools available for measuring crop yield on a site-specific basis. How ever they are not perfect. Errors can be generated with the yield components;

Potential yield map operational errors

The process of measuring and recording instantaneous yield with a combine and its position within a field is susceptible to a number of errors. Care must be taken to minimize such errors contained in the raw data set to insure the quality of the data. Errors within both the instantaneous yield readings and the data providing the position of the yield reading within the field will influence the presentation of the yield map after interpolation has been carried out on the raw data. Yield maps containing such errors may therefore influence the strategy and decisions that are made by the farmer or agronomist.

Types of errors

According to Mark Moore in his 1997 master thesis, defined eight types of errors when using a yield monitor;

1. **Grain specific weight**—this error is more prevalent with volume type yield monitors. Systems based on the principal of mass flow detection are not susceptible to this error.

2. **Moisture sensor**—The measurement of grain moisture content along side grain yield is an important variable to consider to allow the measured weight of grain or yield to be corrected for a constant grain moisture level. The grain yield is normally corrected to 14% moisture content. This becomes increasingly important when comparisons are to be made between yield levels in different parts of the field, between different fields, and for the same field between different seasons.

3. **Measured area**—the measured area is calculated by multiplying the cutter bar width by the distance traveled by the combine. The width of the cutter bar and rolling circumference of the wheel is entered into the combine's computer by the operator. As these values are not monitored during harvest, they are assumed to be constant until manually adjusted. If they deviate from the programmed values, then errors are introduced into the raw yield data set when converting grain flow, measured at the yield sensor, into grain yield.

4. **Delay for yield**—this is the true position related to the measured grain flow. This represents the time delay from the crop being cut (true position), and traveling through the combine to the point where the grain flow is measured by the yield sensor.

5. **Lead-time**—there is a period of time that is required for the combine to fill with grain once it has entered the crop. The lead time is, the time lapse that is required for the combine to reach a stage when is has filled with grain and is giving a true reading on the yield sensor. From this point reliable yield data can be logged.

6. **Lag-time**—this is time required by the combine to empty of grain once is has stopped cutting the crop at the cutter bar. The lag time represents the time that true yield data can be logged once the combine's cutter bar has left the standing crop.

7. **Delayed positioning**—this is the offset of the GPS antenna. For practical reasons it is not possible to mount the GPS antenna directly over the cutter bar and it is normally mounted on the cab roof of the combine. The location of the GPS antenna on the cab roof introduces a "positioning offset".

8. **Turning on headlines without cutting any crop**—errors are recorded in raw data when the combine is turning on the headland with no grain being cut. In this instance a zero yield will be recorded in the data string, which will influence the processed yield map.

Code of practice for reducing errors

Having quantified potential error sources caused by variations in grain density / moisture content, yield meter performance and the actual operation of the combine in the field, it is possible to suggest a code of practice that can be adopted by the combine operator to reduce errors within raw yield data sets.

1. Re-calibrate the yield sensor as often as is possible, especially in the case of volumetric yield measurement.

2. Check regularly for and remove any crop residue built up on the yield sensor, especially for yield monitors that give no advance warning of residue build up.

3. Always keep the cutter bar width full with crop wherever possible, by harvesting in straight lines.

4. Reduce the number of narrow finishes by traversing the combine backwards and forwards from one side of the field. Or in the case of small grains, the operator should harvest in a circular method rounding the corners, to keep the combine full at all times.

5. Always lift the cutter bar above the pre-determined height at the end of each harvest run to activate the automatic cut-off switch.

6. Conduct repeated experiments to derive time delays for delay for yield, lead and lag to suit individual driving techniques and crop conditions.

7. Reduce delay for yield errors by avoiding sudden changes in forward speed.

8. Maintain a constant lead-time by lowering the cutter bar at the same point when entering the crop after a headland turn.

9. Maintain a constant lag time by raising the cutter bar at the same point after exiting the crop.

10. If possible avoid mid-run stop / starts.

Summary

The adopted procedure for harvesting a field while collecting yield data can influence the accuracy of the data enormously, especially if the operator is unaware of the potential errors and harvests the field in a normal manner.

Until such time manufacturers of yield mapping systems are able to automatically compensates for operational errors particular care must be taken by the combine operator to reduce operational errors. Errors associated with lead and lag time, can result in large concentration of errors at the beginning and end of each run. This in turn is less likely to be smoothed by the interpolation process causing false yield depressions.

Other important aspect to consider during the yield data collection is the “delay for yield” setting and maintaining the cutter bar full with crop wherever possible. Again if care is not taken with the above false yield depressions will be present in the resulting yield map, although not the extent of those caused by lead and lag time errors. In practice, this is due the reduced concentration of delay for yield and cutting width errors during harvesting the field.

The opportunities to profit from yield monitor use will continue to increase in the future. This will occur as new and better sensors are developed and yield monitors become more integrated with other precision farming information systems. In the near future, better on-combine tools will be available to measure crop quality traits such as kernel quality and oil, protein and starch content. Eventually combines will be able to segregate grain based on these quality criteria and allow the grower to capture this value through identity preserved marketing. Software tools are even now being developed to enable much more powerful statistical and graphical analysis of multiple layers of spatial data. In addition, yield monitors will be linked to other information management systems that will assist with employee management and optimizing field operation logistics. Yield monitor data will eventually be useful as an input into new comprehensive crop simulation models that will help growers better manage production risk. Then as now, yield monitoring will make good growers better by giving them new information management tools to optimize inputs and outputs and better manage their farm operations.

The monitor's primary function is to collect yield data. Sounds pretty straightforward, right? Well, in reality, yield monitors give you the answers without telling you why or how it happened. The key is to go back, ask the right questions and determine how. Was it weed or insect pressure? Was it drier or wetter than last year? How were the fertility levels? Did you try a new variety this year? What about soil compaction? The list goes on.

Perhaps the biggest drawback to using a yield monitor is it may cause some farmers to react too quickly or jump to conclusions without knowing all the facts. Don't make knee jerk reactions. Yield data is only one piece of the puzzle. You need to put it together with everything else before implementing change.

Yield monitors can be like truth serum, and some crop consultants would prefer that farmers wouldn't pay much attention to them. They'd rather impress the farmer with precision mapping products. And some crop consultants seem to want to make recommendations and decisions for the farmer. Consultants can sell some farmers on this, but the bottom line is it's hard to make testimonials out of things that are not working. Improving the management of the controllable factors affecting crop yields is the primary benefit of on-the-go yield monitoring.

Advanced Subjects

Understanding the Data Output

```
-96.654251,47.811195,0.34,966001322,1,5,317,19.0,33,1,982085,F4:LO152,L1: ,WHEAT,7,0,887.1,
```

Different types of outputs in ASCII text outputs

Manually calculating Yield data

Yield Stability

Data Normalization

Coefficient of variability

Importance of Histograms

Determining yield goals

Other harvest Event Attributes

Marking weeds, rocks, problems areas of field

Contouring Yield Data

Understanding the use of legends

Best contouring methods for data sets

Converting point data into rasterized vector cells