Yield monitoring equipment was introduced in the early 1990s and is increasingly considered a conventional practice in modern agriculture. The pioneers of precision agriculture already have generated several years of yield history and have examined different ways of interpreting and processing these data.

Yield Mapping Concept

Yield mapping refers to the process of collecting georeferenced data on crop yield and characteristics, such as moisture content, while the crop is being harvested. Various methods, using a range of sensors, have been developed for mapping crop yields.

The basic components of a grain yield mapping system include:

- Grain flow sensor - determines grain volume harvested
- Grain moisture sensor - compensates for grain moisture variability
- Clean grain elevator speed sensor - used by some mapping sytems to improve accuracy of grain flow measurements
- GPS antenna - receives satellite signal
- Yield monitor display with a GPS receiver - georeference and record data
- Header position sensor - distinguishes measurements logged during turns
- Travel speed sensor - determines the distance the combine travels during a certain logging interval (Sometimes travel speed is measured with a GPS receiver or a radar or ultrasonic sensor.)

Each sensor has to be properly calibrated according to the operator’s manual. Calibration converts the sensor’s signal to physical parameters. A proprietary binary log file is created during harvest to record the output of all sensors as a function of time. This file can be converted to a text format or displayed as a map using the yield monitor vendor’s software.

Processing Yield Maps

The yield calculated at each field location can be displayed on a map using a Geographic Information System (GIS) software package. The raw log file, however, contains points recorded during turns and the sensor measurements do not correspond to the exact harvest locations because grain flow through a combine is a delayed process (unless real-time correction is applied). To eliminate these obvious errors, the raw data is shifted to compensate for the combining delay, and the points corresponding to the header up position are removed. Settings for grain flow delay are combine- and sometimes even crop-specific, but typical values for grain crops range from about 10 to 12 seconds.

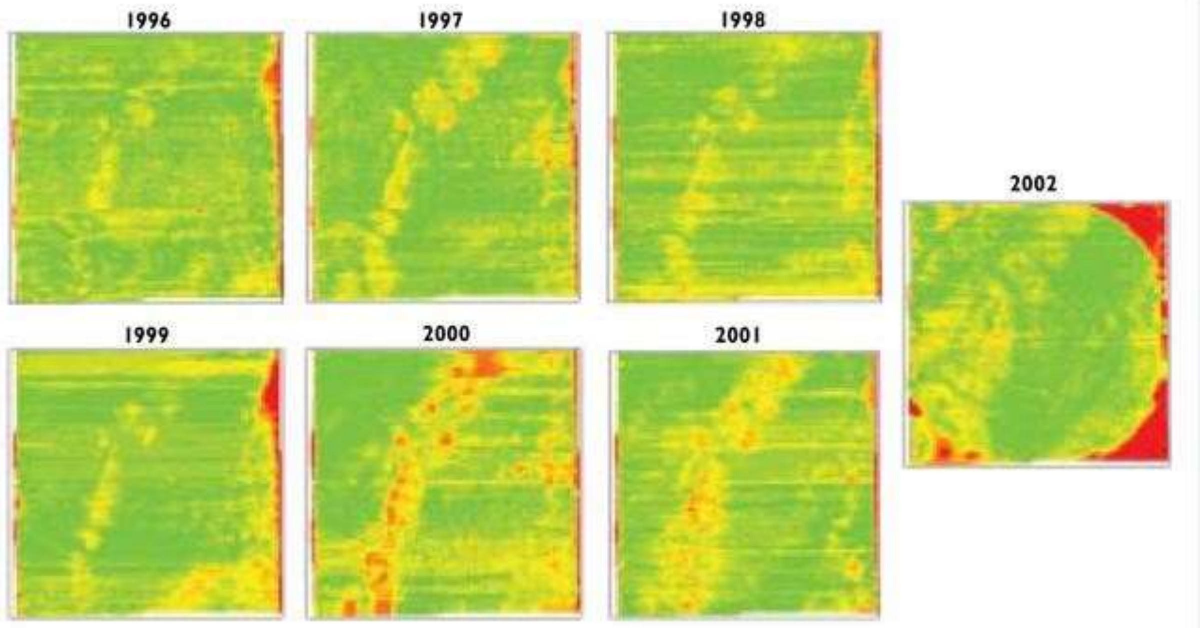
Usually a few points at the beginning and at the end of a pass should be removed as well. These are referred to as start-and end-pass delays. Start-pass delays occur when the combine starts harvesting the crop, but grain flow has not stabilized because the elevator is gradually filling up. Similarly, end-pass delays occur when the combine moves out of the crop and grain flow gradually declines to zero when the elevator is completely emptied. Consult the manufacturer of your yield monitor for the most appropriate settings to use with your combine.

Shifting of raw data to correct for grain flow delay as well as deletion of points that represent header status up and start-and end-pass delays is the primary data filtering procedure built into software supplied with yield mapping systems.

Yield History Evaluation

Evaluating the temporal (year-to-year) variation of yield distribution within the field is an essential step in defining field areas with potentially high and low yields. Several approaches can be used to evaluate temporal effects on yield. One approach is to calculate the relative (normalized) yield for each point or grid cell. Normalized yield can be defined as the ratio of the actual yield to the field average:

When growing conditions in a field vary considerably, such as irrigated and dryland areas or different crops or varieties grown in different areas, normalization should be done separately for those areas, with the resulting relative yields recombined into one data file for the whole field. The following figure shows a relative yield history for a field with corn (soybean in the southern half in 2000) grown using furrow-irrigation (until 2001) and center-pivot irrigation (in 2002).

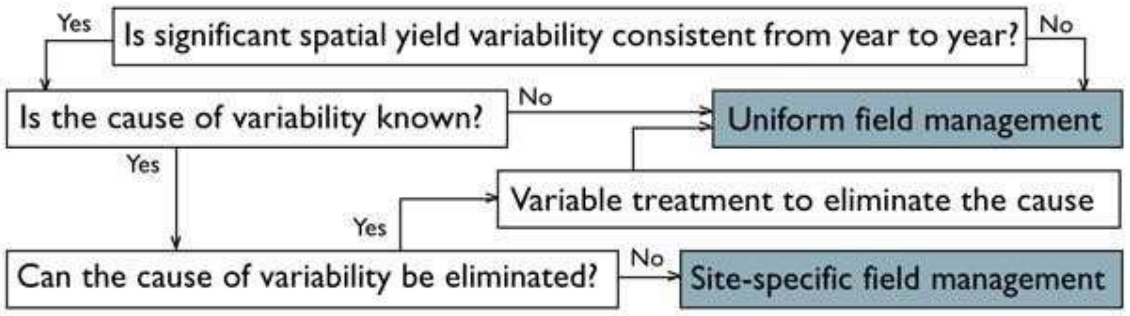


Maps of relative yield of corn and soybean grown during a seven-year period (red indicates low-yielding areas and green indicates higher than average yields).

Potential Applications

Yield maps represent the output of crop production. On one hand this information can be used to investigate the existence of spatially variable yield limiting factors. On the other hand, the yield history can be used to define spatially variable yield goals that may allow varying inputs according to expected field productivity.

The following flowchart illustrates the process one might follow in deciding whether to invest in site-specific crop management, based on analysis of yield maps. If yield variability across the field cannot be explained by any spatially inconsistent field property, uniform management may be appropriate. Site-specific management becomes a promising strategy if yield patterns are consistent from year to year and can be correlated to one or more field properties (e.g. nutrient supply, topography, past management, etc.).



If the causes for yield variation are known and can be eliminated permanently, the entire area could be brought to similar growing conditions and managed uniformly thereafter. This concept was one of the earliest philosophies behind precision agriculture, but is likely only feasible for certain field properties. For example, variable rate liming can be used to correct acidic areas in a field. In this case, the yield map is used only to investigate whether low soil pH is a yield-limiting factor, and the soil map is used to prescribe variable application rates. Another example would be localized deep soil tillage to alleviate compaction in selected field areas.

Most yield limiting factors cannot be modified permanently through single measures because of economic or practical constraints. Consequently, site-specific crop management may be used to appropriately account for the existing spatial variability in attainable yield and/or soil properties.

Summary

Yield maps are one of the most valuable sources of spatial data for precision agriculture. In developing these maps, it is essential to remove the data points that do not accurately represent the yield at a corresponding location. Map averaging or smoothing is usually done to aid data interpretation. A long yield history is essential to avoid drawing conclusions that are affected by the weather or other unpredictable factors during a particular year. Typically, at least five years of yield maps are desired. Processed yield maps can be used to investigate factors affecting the yield or to prescribe variable rate applications of agricultural inputs according to spatially variable yield goals (yield potential). Producers interested in precision farming should, however, always evaluate different management approaches to identify those that provide the greatest benefit at a particular site.

CROP PRODUCTION MODELING

A broad range of spatially explicit crop response models is needed to evaluate the efficacy of precision agriculture methods and provide the basis for precise recommendations. Many models for predicting how crops respond to climate, nutrients, water, light, and other conditions already exist, yet most of these do not include a spatial component appropriate to precision agriculture applications (Sadler and Russell, 1997).

GIS can provide the means to run the model continuously across an extensive area using data that reflect continually varying conditions. Time series and other temporal analyses can aid in predicting final crop yield. Current models may be extended to account for spatial effects, such as edge effects along field boundaries. In the ecological and biometeorological literature, however, several spatially explicit models have been developed to predict hourly, daily, and annual rates of evapotranspiration and photosynthesis, and several spatially distributed hydrologic models predict surface and subsurface flows. Meso- scale climate models can resolve cells as small as 5 to 10 kilometers for predicting weather conditions.

Pests are not dispersed evenly throughout the environment. To the extent that the factors influencing their spatial distribution are understood, their dispersion and potential for damage can be modeled. GIS can be used for spatially variable data for these factors. As with crop response models, a distinct pest model can be run continuously across a landscape, using GIS to input data to the model and display results (loosely coupled model), or a spatially explicit model can be created within the GIS software (tightly coupled model). GIS can provide the basis for multiscalar effects, for example, incorporating results of a regional pest pressure model into a system for generating within-field recommendations based on locally variable conditions.

A crop growth model could be used as a decision aid for determining different yields based on varying plant populations, which could help a producer decide when to plant or replant areas within a field based on plant population data and risk factors for various soil types. Having to make a decision to replant a field that is in a questionable condition is perhaps the hardest decision a producer faces. Any information to aid such decisions and reduce risk would be valuable.

In many crop production areas, landscape factors can cause dramatic variations in yield. Landscape elements affect many properties relevant to plant growth, including soil texture, soil organic matter, and temperature. Landscape morphology affects soil moisture available to crops by its influence on drainage and catchment area. Soil surveys typically do not have sufficient resolution to capture this variability in enough detail to support precision recommendations; even field- based sampling on a regular grid may miss relevant soil-landscape features. Stratifying sampling density on the basis of landscape features may be more cost effective and informative than a simple grid.

GIS allow users to create and manage digital elevation or digital terrain models created by photogrammetric methods (analysis of stereo pairs of aerial photographs) with new techniques using interoferometric radar or by continuous three-dimensional coordinate measurements with in-field equipment. Precise recommendations can be made to the extent that the relationships are understood between soil properties and surface morphology (i.e., slope, slope length, aspect, curvature, landscape position, catchment area, and drainage) derived from digital elevation or digital terrain models. Crop models do not offer a panacea for problem solving; they are limited in their ability to simulate various parts of a biological system.

Most of the crop and pest models available or developed to date were not designed to be used for man- aging spatial and temporal variation. It is not clear whether a predictive model, an explanatory model, or a hybrid approach will be more appropriate for precision agriculture. Alternatively, data mining and other techniques may be used to extract valuable information from large amounts of stored data. However, crop modeling is currently an important tool for gaining a theoretical understanding of a crop production system.

Crop Modeling:

Crop models are mathematical models used to quantitatively describe the effects of various factors, such as climatic and soil conditions, field management, crop varieties and more, on crop physiological processes from a systems perspective.

A model is a simplified representation of a system or a process. A model is a computer program, which describes the mechanism of the process or a system. Modelling is based on the assumption that any given process can be expressed in a form of mathematical statement or set of statements or a sets of statements to depict the real world system.

Modelling is classified into

- **Descriptive modelling and**
- **Explanatory modelling**

1. **Descriptive Modelling**

Descriptive model is a mathematical statements or a sets of statements, which describe the real world phenomena or events and the interrelationship between the factors involved in the process. The important aspects of descriptive modelling are as follows.

- Segmentation of Process The main process will be segmented into different subgroups, so that all variables of that main process will be accounted. For example, soil water availability is the main process and the sub groups are soil physical, chemical and biological properties as well as the plant community present in the soil.

- Segmentation Based on Importance The most important processes are identified in the system and due importance are given accordingly. For example in growth and development of a plant, the most important events are photosynthesis and respiration. Hence, photosynthesis and respiration process will be given more weightage than other process of the events. It does not mean that the other process will not be taken into account, the other processes are also included with due weightage.

- Interlinking of Different Processes Interlinking of interconnected process must be done for effective imitation of the processes or system of real world phenomena. For example, the soil water availability depends on rainfall, irrigation, solar radiation, soil temperature, evaporation, transpiration, soil colour, etc., and all the processes have to be interlinked in the study of soil water availability as sub process.

- Weightage of Important Processes Different weightage will be given for different processes of model based on its importance in the particular system. In the soil nutrient dynamics, much importance will be given to nitrogen followed by phosphorus, potassium and so on.

2. **Explanatory Modelling**

The explanatory models describe why and how the things works or why and how the phenomena is the way it is. The explanatory models are being used as a substitute for full explanatory model now a days, because full explanatory model is too long and cumbersome in the modelling. Hence, explanatory models describe, why and how for important process instead of all process, which is available in the model. Few examples of explanatory models are explanatory model of illness; the patient explanatory model (Kleinman model); explanatory model of health diseases among South Asian Immigrants; and explanatory model of health inequalities (WHO).

3. **Deterministic Modelling**

Deterministic model is a mathematical model, which produces outcome precisely through relationship among state variable and events with initial conditions, without any random variation. Hence, it will produce same output of the given input at all time. Example: Chemical reactions.

4. **Stochastic Model**

Stochastic model is a mathematical model, which estimates the probability distributions inputs into potential outcomes by allowing for random variation in inputs over the period of time. The standard time series techniques is being used for making random variation in fluctuations observed in historical data for a selected period. Large number of simulation (stochastic projection) is used to produce potential outcome for the random variable inputs. Simulation is the process of building models and analyzing the system. z Discrete model: The state variables change only at a countable number of points in time. These points in time are the ones at which the event occurs/change in state. Example: Statistical model , Continuous model: The state variables change in a continuous way, and not abruptly from one state to another (infinite number of states). Example: Crop Simulation Model.