PRECISION FARMING
Profitability

Precision Farming Profitability

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INTRODUCTION

Use of new farming practices is driven by profits. This was true in the 1920s when Midwestern producers first planted hybrid seed corn. It was true in the 1970s and 1980s when some producers decided that no-till fit their operations, while their neighbors chose other tillage options. It is still true in the 21st Century when producers are trying to make decisions about using precision farming. The purpose of this book is to help identify those precision farming technologies that will make money for Corn Belt farmers in the next few years.

Precision Farming Has Evolved

The phrases "precision farming" and "site-specific farming" are sometimes used interchangeably, but there is an important distinction. *Site-specific farming* is the time proven idea of crop management: doing the right thing, at the right time, in the right place. Unlike whole field management, site-specific farming varies inputs and other practices within fields. From the beginning of agriculture, site-specific has been the ideal. When farm work was done by hand and with horses, it was easy to manage one part of a field differently from other parts. But with mechanization there was money to be made with "one-size-fits-all" crop recipes that could be implemented quickly on large fields. Precision farming technology now offers the opportunity of being site-specific on a commercial scale.

Precision farming is defined as using information technologies to tailor soil and crop management to fit the specific conditions found within a field. Precision farming involves technologies that depend on global positioning systems (GPS) and other electronics to gather crop information. Information obtained through these technologies can help farmers effectively implement site-specific management plans. Yield monitoring and variable rate fertilizer application have received the

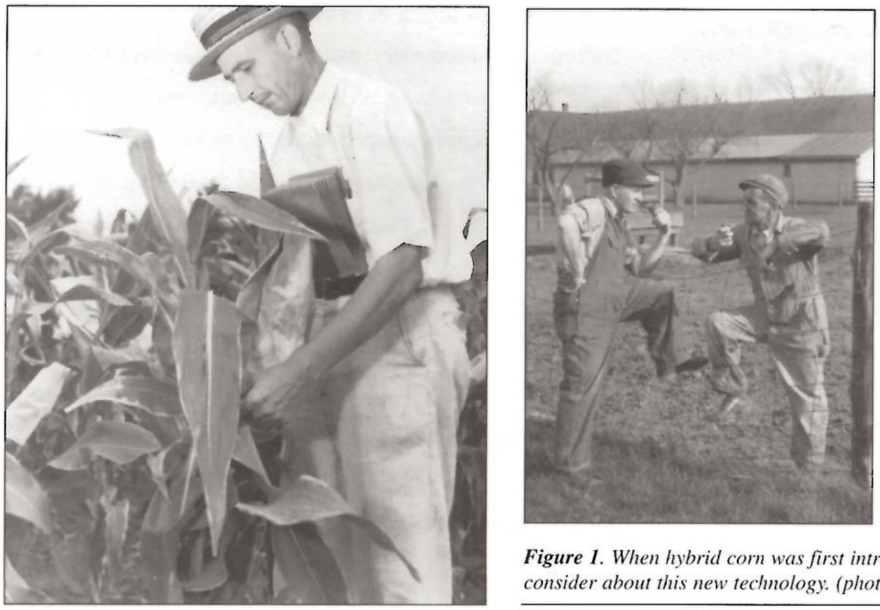


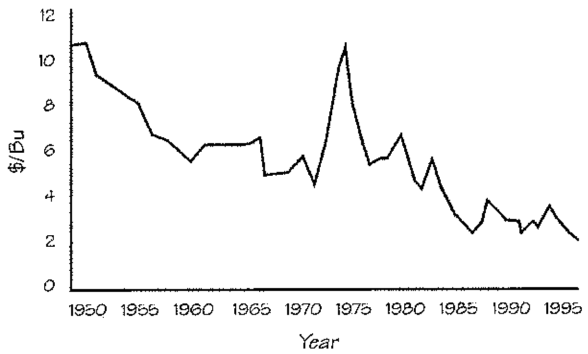
Figure 1*. When hybrid corn was first introduced, farmers had many choices to consider about this new technology. (photos provided by J.C. Allen & Son Inc.)*

most publicity, but precision farming also includes within-field weed management, GPS guidance, and many other applications. Producers can and should pick and choose among those technologies for those that best fit their circumstances. This book will provide information to help choose the precision technologies that help them lower their unit cost of production.

Site-specific farming using "manual methods" can increase yields and efficiency of input use, but it usually requires substantial time and attention be devoted to relatively small areas. Manual methods include "eyeballing" soils to vary fertilizer and seeding rates, and patch spraying. Economic survival in modern agriculture requires management on a larger scale. Precision farming technologies allow site-specific management on this larger scale.

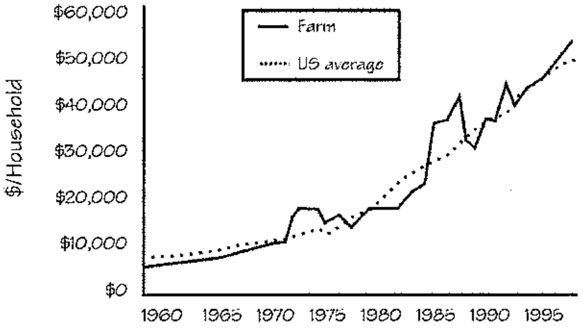
The Time is Right

Some farmers argue that new technology is a luxury to be indulged in only when grain prices are high and yields are good. History shows that new technology is necessary for difficult economic times. Some of the largest changes in U.S. agriculture occurred during the toughest times, when farmers used the new technology to lower their cost of production and stay in business. For example, both hybrid seed and mechanization came into widespread use in the Corn Belt during the depression era of the 1930s. Hybrid seed increased yields and mechanization allowed farmers to work more acres. Higher yields and reduced labor costs per bushel allowed farmers in the 1930s to lower unit costs enough to stay in business.



Source: USDA/NASS, 2000; Bureau of Labor Statistics, 2000

Figure 2. Real corn prices - 1999 dollars.



Source: USDA/ERS, 2000

Figure 3. Average household income.

Over time the real prices of farm products have been declining. For example, except for a few years in the mid-1970s, there has been a steady decline in the inflation-adjusted value of a bushel of corn (Figure 2). In terms of consumer goods that a dollar would buy in 1999, the price of corn has dropped from over $10 per bushel in 1950 to under $2 per bushel in 2000. This price decline is an uncomfortable situation for producers. Farm families expect and earn incomes similar to their urban cousins (Figure 3) at the same time that the value of their products is declining.

Lowering Unit Costs of Production

Individually, producers' main business survival tool has been and continues to be lowering unit cost of production. Individual producers have very little power to change prices they receive. Good marketing can add a few cents here and there. The political process may stabilize prices and in some cases slow the decline. Still, in the long run, the pressure toward lower farm prices is almost inevitable.

Most people live in cities and towns. They benefit from lower farm prices. An important part of the U.S. economy's success is based on its ability to feed its population cheaply and export food. If farm programs are judged on long-term maintenance of high farm prices, they are almost a total failure. Basing the long-term farm business survival strategy on government help is very risky.

Unit costs of production are calculated as the total cost of production divided by the total number of units produced:

Unit Cost of Production = Total Cost/Total Yield

Profits exist if the unit cost of production is less than the selling price:

Selling Price
- Unit Cost of Production
Profit per Unit

In some cases, profit per unit can be increased by lower input use. This is the approach of those who advocate "low input" agriculture. But if yields are reduced by more than costs, this approach may actually increase per unit costs and decrease profits. In most cases, lower unit costs will require additional input, in particular additional investment. The payoff comes when the increase in yield is proportionally greater than the increase in cost.

Using precision farming technologies can help lower unit costs by increasing yields and in some cases by lowering overall costs. It should be noted that yields can be measured in both quality and quantity. For example, yields can be increased when producers:

- Use yield maps to choose better hybrids and varieties;
- Use variable rate lime application to correct low pH "islands" in otherwise high fertility fields; and
- Use site-specific weed control to reduce weed pressure.

In some cases, site specific management can reduce fertilizer and other input application, but this is not as common as precision farming pioneers hoped. Research indicates that the more common pattern is for overall nutrient application to be about the same, but that the fertilizer is redistributed in the field.

In addition, producers can, in some cases, farm more efficiently by using GPS and other precision farming technologies. One of the early success stories in this area is the use of GPS guidance to reduce skip and overlap in pesticide application.

About this Book

It is often said that precision farming has raised more questions than it has answered. This book will not make a producer an overnight precision farming expert, but the hope is that it will help the producer *ask the right questions* for their own operations. Use of precision farming technology is often a team effort. It is a rare individual who has the combination of agronomic, economic and electronic skills needed to be successful at precision farming. In a few cases that team will be composed of farm family members and/or farm employees, but in most cases producers will need to rely on outside services to complete the knowledge loop. Those services might come from the agronomist at a local cooperative, a crop consultant or a technical service hot line, but in any case the importance of *"asking the right questions"* is magnified.

This text focuses on using precision farming technology profitably in the Corn Belt. It will emphasize corn, soybeans and wheat. The same principles apply to other crops in other regions, but the exact techniques will vary with local conditions. A key result of economic research on precision farming is that the profitability is site-specific.

Use of precision farming technology also may have important environmental and health benefits, but are not dealt with in this book. For example, site-specific management may reduce the pesticide, nitrogen and other farm chemicals in ground and surface water. This book concentrates on profits because unless precision farming is profitable, it will not be used voluntarily and the environmental benefits will not be achieved. From the perspective of the general non-farm public, precision farming profits are the first steps in realizing the potential environmental benefits.

The next section of this book outlines site-specific management practices using precision farming technologies that are proven and show relatively quick profits. The third part of the book is a reference section. It is intended to provide more of the technical details on precision farming technologies in the second section. The final section is a glossary that defines precision farming words and phrases.

1

CHAPTER

ESTIMATING PRECISION FARMING BENEFITS

By Jess Lowenberg-DeBoer

Learning Objectives

In this chapter you will learn:

1. How to estimate precision farming benefits using a partial budget;
2. How to calculate information costs over a period of several years;
3. How to identify costs often omitted from precision farming budgets; and
4. Difficulties in determining yield advantages when using precision farming techniques.

Introduction

Information is a farm input just like seed, fertilizer, pesticides and fuel. Basic budgeting principles apply. Information only has value if it changes decisions. Unused information is no different than extra seed or unspread fertilizer. Unlike many farm inputs, the economics of precision agriculture is site-specific. Profitability of precision technology differs from farm to farm due to differences in soils, management and microclimate. These site-specific profit differences make it essential for producers to examine profits for their farms.

The change in net revenue that results from adopting a new precision farming practice may be estimated on a per acre or per field basis using partial budgeting. Information that is applied over several years is treated as a durable input.

Partial budgeting on a per acre or per field basis has been the most common tool applied to estimate the profitability of precision farming. A partial budget focuses on only those cost and revenue items that change when using new practices. It subtracts cost changes from revenue changes to estimate the change in net revenue that results from adopting a new practice:

Profit Change = Revenue Change - Cost Change

A more complete profitability analysis would include whole farm impacts and changes in yield and cost risks, but the partial budget is a good way to start looking at average profitability.

Estimating Cost Changes

In most cases, it is easier to estimate the change in cost than it is the change in revenue. The cost changes are particularly easy to deal with when precision farming services are contracted through a fertilizer dealer or crop consultant. In that case the change in cost is simply the new fee.

When precision farming information collection, analysis and implementation are done with farm labor and equipment owned by the farming operation, the cost calculation is only slightly more complicated.

Estimating revenue is more difficult, mainly due to weather variability. In most cases precision farming costs do not depend on weather, while the yield response in a given year to precision farming practices can vary widely with rainfall and other weather factors.

Problems often occur in precision farming cost calculations when information is used for several years and when certain costs are omitted. Precision farming information that is used for several years might include soil tests, topography maps and bare soil aerial photographs. Soil tests are frequently done on a 3- to 5-year cycle depending on the crop rotation. Topography and the soil color in aerial photographs change only very slowly. This kind of information might be used for 10 years or more.

When information is used for several years it is treated as a durable asset. The annual cost of using any durable asset has two components:

1) Opportunity cost of money invested
2) Depreciation

The opportunity cost of funds invested in precision farming information is the profit from the best alternative use. For example, if instead of investing in precision farming, a producer would have paid down debt, the opportunity cost of money would be the interest rate on the debt. The opportunity cost might also be determined by potential returns to other new technologies, enterprises or management practices. Alternatives might include returns to storage facilities that would allow marketing of identity-preserved grain, investment in a new niche crop enterprise, or an off-farm investment. The calculations are easiest if those alternative returns are expressed as an annual rate, similar to an interest rate. In that case, the opportunity cost of money invested is the total invested multiplied by the interest rate.

The depreciation charge is an estimate of how much of the value of an asset is used up in a year. It has very little to do with depreciation for income tax purposes. The easiest way to estimate depreciation is to assume that an equal portion of the value is used up each year. This is the "Straight Line" method:

Straight Line Depreciation = Investment/Useful Life

If a producer invested $8/acre in soil tests and the soil are sampled every four years, the annual straight line depreciation would be $2/acre.

Table 1. Annualizing Information Costs: The example of P and K grid soil tests for a 40-acre field with a 4-Year soil sampling cycle.

Item	Unit	Quantity	Value/Unit	Amount
Soil Sampling Labor*	hour	3.25	$10.00	$32.50
Soil Test Lab Analysis	test	13	$ 7.50	+$97.50
Total Variable Cost				$130.00
Opportunity Cost of Capital (10% Interest)				$13.00
Depreciation (Straight line over 4 years)				+$32.50
Annualized Cost for a 40-acre Field				$45.50
Annualized Cost Per Acre				$1.14

* *Source: Swinton and Lowenberg-DeBoer, 1998.*

There are many alternative methods of estimating both opportunity costs of capital and depreciation. The method favored by most economists is the so-called "sinking fund" method, which estimates an even annual payment with the same present value as the investment. The Swinton and Lowenberg-DeBoer chapter cited in the "Further Information" section at the end of this section outlines how the sinking fund approach would be applied to information costs.

An example of annual cost estimation is given in Table 1 for grid soil testing on a farm which already has a four wheeler and GPS. The budget includes the added cost of soil testing labor and lab analysis. The example assumes an approximately 3-acre grid, 15 minutes needed to collect and package each sample, and a 10% opportunity cost of capital. The $130 for the 40-acre field is important for cash flow purposes, but it overstates the cost of having the soil test information in any one year. It would be very difficult for any intensive soil-sampling program to show a profit if all the costs are charged to the first year. The $45.50 for the field, or $1.14/acre, is an estimate of the annual economic cost of that information. The word "estimate" should be emphasized. No method of estimating annual costs is perfect. The real test of any annualization method is if it leads to profitable decisions.

Omitted Costs - Economic analysis of precision farming too often focuses on changes in input quantities and costs. Other costs include:

- **Data collection** - For example, soil sampling, satellite images, crop scouting.

- **Data analysis** - Someone must spend time converting the raw data into usable information.

- **Software** - Often specialized software is needed to analyze the data and develop recommendation maps.

- **Skill** - Farmers are not born with the ability to analyze precision farming data. This is a learned skill. Learning takes time from other activities and may require taking courses, participating in workshops or attending field days.

The cost most commonly neglected is that of acquiring precision farming skills. This cost is most easily estimated when those skills are purchased as a service from a crop consultant, but they do not disappear when family members or farm employees develop them. The cost of formalized learning is relatively easy to identify. Examples include workshop fees, travel costs to attend conferences, books and other materials purchased. The cost of learning on-the-job is difficult to assess. For example what is the cost of a day of harvesting time taken learning how to operate and calibrate a yield monitor? Even if on-the-job learning is not given an explicit cost estimate, it should be recognized that it is expensive.

Because of rapidly changing technology, precision farming skills depreciate rapidly. However, they are commonly usable for more than one year, so annual costs should be estimated.

Cost changes can be both positive and negative. In some cases input costs decline enough to offset increases in information, analysis and implementation costs.

Estimating Revenue Changes

Revenue changes from precision farming are commonly thought of in terms of yield, but a broader range of revenue impacts are possible including:

Quality improvements - For example, the new protein analysis available on yield monitors can help wheat producers market higher quality grain for a premium.

Opening niche markets - Precision farming gives producers greater control over crop production and moves them closer to "producing to specification." Producers who use precision farming tools have an advantage in contract negotiations.

Satisfying regulatory requirements - "As-applied-maps" and other precision farming data can help document compliance with environmental regulations. In effect, this gives the farm a "license to produce."

Improved marketing logistics - Immediate information from yield monitors can help producers schedule drying and storage. In some cases, it may be possible to improve market timing by taking advantage of early season premiums, while still satisfying contractual obligations.

Some key problems in estimating the benefits of precision agriculture are:

Evidence of yield gains - Yield gains and crop quality improvements are the principal in-field source of revenue increases anticipated from precision agriculture, but it has been difficult to measure these. The Sauder Farm trials (Finck, 1998) show one of the few examples of a statistically significant yield increase from precision agricultural management.

Side-by-side comparisons are no longer convincing - One side may happen to have the better soil, a favorable microclimate or received a rain shower at a crucial time. Strip trials or some other planned experiment may be needed to detect differences. Luckily, yield monitors and computers have made on-farm experimentation much more practical.

CHRIS HAEKER

Manager, Royster-Clark, Inc.
Roann, IN

Chris Haeker was an early adopter of site-specific farming methods - driven by concerns of being a good steward of land and water resources. “Why put something out there that doesn't belong? We've had too much of that in the past and it has to stop,” says Haeker.

“We've got to watch what we are doing to this ground,” emphasizes Haeker, manager of Royster-Clark, a dealership in Roann, Indiana. “We've got rivers that are being monitored.”

Haeker says site-specific farming is a real issue for some dealers. “They fight it because their sales will go down. We may sell less product, but we're also providing a service,” adds Haeker, “and we charge for that service.”

That's the next issue for dealers - getting farmers to pay for this service. “Dealers have a lot of expertise and no one wants to pay for it,” she explains. “If a $2 per acre electronic fee is going to replace $10 of product, it's a no brainer,” Haeker says.

Haeker also believes site-specific farming will enable younger farmers to build their businesses. She explains it this way. “The old guy who's over 60 likely owns his ground and can afford to mess up. The younger farmer can't. This electronic information allows us to be a whole lot more efficient.”

Table 2. Partial budget example for corn production in Central Illinois with precision agriculture technology on 1300-acre farm.

Item	Unit	Quantity	Value/Unit	Amount/Acre[1]
Change in Yield	bu/acre	15.32	$2.30	$35.24
Change in Equipment Cost (10% discount rate; 3 year depreciation; for other items-see text)				
Yield Monitor	item	1.00	$4,000	$1.42
GPS Receiver	item	1.00	$6,000	$2.13
Planter and Anhydrous Controllers	item	1.00	$5,000	$3.56
Laptop Computer (for controllers)	item	1.00	$3,000	$2.13
Total Increase in Equipment Cost				$9.25
Average Change in Fertilizer Cost				
Nitrogen	lbs/acre	-0.44	$0.25	-$0.11
Phosphorus	lbs/acre	-14.66	$0.30	-$4.40
Potassium	lbs/acre	-3.33	$0.13	-$0.43
Sulfur	lbs/acre	2.17	$0.21	$0.46
Zinc	lbs/acre	0.11	$2.36	$0.26
Boron	lbs/acre	0.05	$7.17	$0.36
Total Change in Fertilizer Cost				-$3.87
Change in Seed Cost[1]	bags/acre	0.01	$90.00	$0.48
Change in Soil Sampling Cost	acre	1.00	$5.00	$5.00
Change in Fertilizer Application Cost	acre	1.00	$5.00	$5.00
Consulting Charge	farm	1.00	$650	$0.50
Net Return to Site-specific Management				$18.88

Source: Swinton and Lowenberg-DeBoer, 1999, Finck 1998.

1) Numbers do not sum perfectly due to rounding. Change in seed use is about 426 kernel/acre or with 80,000 kernel bags, about 0.00533 bags/acre.

It may not be possible to see the difference - Precision agriculture is about fine-tuning production systems. Sensors may be able to measure yield and quality differences that cannot detect by visual inspection. Computer analysis may be able to identify patterns previously unnoticed.

Benefits may be specific to a farming operation - Precision farming is about fine tuning management to soils, microclimate, management skills and marketing opportunities. Finding the synergies can provide a competitive advantage. More of the knowledge required to find those positive interactions will be local, a result of close observation and on-farm testing. Those benefits will need to be measured on the farm where they occur.

Many benefits are measurable only at the whole farm level - For example, if a producer uses yield maps and soil testing to help diagnose a nematode problem, that knowledge will probably affect rotations and other management on the entire farm not just on the field where nematodes were first found. On-farm trials are not very useful for measuring these benefits.

Some benefits are earned off the farm - Gains made by using remote sensing data to improve marketing, sprayer as-applied maps to document food safety or yield monitor data in farm rental negotiations may exceed those for variable-rate application.

Partial Budget Example

The partial budgeting example in Table 2 is based on results from on-farm trials of site-specific management by soil type on the 1300 acre Sauder farm in central Illinois (Finck, 1998). The basis for comparison is a conventional whole field system with uniform application of fertilizer and a constant planting rate. On this farm the major benefit of site-specific management was an increased corn yield on the lower yield potential soils. The average corn yield increase over three years on all soil types was about 15 bu/acre for the GPS-based system. The yield changes were estimated from 3 years of yield monitor data on strip trials covering about 200 acres each year. Yields in each strip were estimated by soil type.

Equipment costs were estimated using a 10% opportunity cost of capital and straight line depreciation over a 3-year useful life. In addition to the annual cost of capital and depreciation charge, there is 0.9% of the purchase price allocated for property taxes and insurance, and 2.0% for repairs and maintenance based on experience with other farm equipment. The short useful life was a conservative assumption used because of rapid technological change. The laptop computer, and the planter and anhydrous controller were only used on corn, so their costs are allocated over 650 acres.

The useful life of site-specific management equipment may be similar to that of computers and other electronic equipment. Under these conditions the annual cost of yield monitor and GPS is about $3.55/acre.

Overall fertilizer material costs decreased slightly (-$3.87/acre), but not enough to cover the increased cost of soil sampling ($5.00/acre) and variable-rate application ($5.00/acre). Applications of NPK decreased, while micronutrient applications increased slightly.

In this example, overall seed costs did not change much because increased seeding rate on high yield soils almost balanced reduced seeding rate on lower productivity soils. With uniform seeding, planted population was 33,200 seeds/acre. With variable-rate seeding, rates varied from 32,000 to 36,000 seeds/acre.

The consulting fee is spread over all farm acres. It reflects the cost of the increased knowledge component of precision agriculture. Knowledge costs are incurred whether the farmer buys consulting services or develops the necessary skills on the farm.

Overall the estimated net return to precision agricultural management in this case was $18.88/acre. This does not include whole farm benefits in the farmland rental market. Crop share landlords are particularly attracted by the higher yields with precision agriculture at little or no cost to the landowner who normally pays part of the seed, fertilizer and pesticide cost, but not equipment cost.

Out Sourcing

One of the key economic choices for producers is whether to hire precision agriculture services or to develop the capacity on-farm. Custom operators can provide certain services more cheaply. This is the case when the service requires such a large capital investment that it must be spread over many farms to be profitable, for example, a multi-product fertilizer applicator.

In other cases, the choice is a question of time. And, as every farmer knows, time is money. Consider: Is the service timely? Would there be enough on-farm labor to handle the additional work? Then, there is often a choice between a low technology option, which would require additional time, and high technology alternative, which is quicker, but more expensive. Quality and reliability of the service must also be considered.

The profitability of precision agricultural services can be estimated with the same type of budget outlined in Table 2. Estimating a budget with on-farm labor and a second with hired services can usually make the trade-off clearer. Often this requires adding some estimate of the value of time with and without the hired service.

Time has an opportunity cost just like capital. What would on-farm labor be doing instead, if precision agriculture services were hired? On most Midwest farms, time at planting and harvest is very valuable. University studies often estimate the value of planting and harvest time at several hundred dollars per hour, but at other times of the year the opportunity cost is much lower.

For tasks which require development of new skills, the choice between using hired and on-farm help is one of long run strategy. This issue is particularly important for the skills needed to analyze yield monitor and other data. Compared to other farm activities, the cost of a computer and software to analyze data is not large. But cost in time and effort to learn how to do the analysis can be major.

Precision agriculture technology can be analyzed like any other new technology. Information is an input in the production process like seed, fertilizer, chemicals or fuel. Information has value if it leads to better decisions. If information is used over multiple years, it should be treated as a durable input. In most cases, it has been more difficult to estimate the benefits of precision agriculture, than the costs. For field technologies, on-farm trial design and analysis need to recognize the variability of the site. The economics of precision agriculture are site-specific. Profitability is likely to vary from farm to farm because of soils, previous management, microclimates, and other factors.

Further Information

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Proper application of information is critical to the success of site-specific farming. How it is used can improve a producer's net return. So can the selection of seed varieties. To better determine suitable plant hybrids and varieties, a farmer can conduct an on-farm test.

2
CHAPTER

OPPORTUNITIES FOR ON-FARM VARIETY PERFORMANCE TESTING USING GPS-ENABLED TECHNOLOGIES

By Robert Nielsen

Learning Objectives

In this chapter you will learn:

1. Why testing hybrids and/or varieties on a specific farm may provide producers with beneficial information;
2. Some of the opportunities and limitations for using yield monitors versus weigh wagons;
3. How field layout designs for on-farm hybrid and variety testing impact test results; and
4. The value of replication in conducting on farm variety testing.

Introduction

Hybrid or variety selection is a critical decision because of its impact on profitability. The opportunity to conduct on-farm performance testing of hybrids or varieties is as attractive as ever for many producers.

Many farmers have conducted such tests for years either in conjunction with a seed company variety testing program or independently. Rather than using a yield monitor, a weigh wagon or farm scales were used to weigh individual loads from variety strips in the field.

GPS-enabled technologies are now more readily available than ever before. Tools such as GPS-enabled yield monitors offer farmers new opportunities to actively participate in field-scale research activities on their own farms. GPS-enabled yield monitors may enhance producers' abilities for making those critical hybrid and variety selection decisions.

In this chapter, opportunities and limitations of on-farm hybrid and variety testing are discussed, as well as how those situations can be enhanced through use of GPS-enabled yield monitors.

Opportunities & limitations for on-farm variety performance testing

Opportunities

On-farm testing is a viable tool to evaluate varietal traits that are strongly determined by genetics. Regardless of growing conditions, hybrid differences are reasonably consistent for such traits as seedling vigor, disease tolerance, plant and ear height, pollination timing and grain maturity date.

On-farm testing allows a farmer to evaluate variety performance "on your farm," where soils and other yield influencing factors may be different from the conditions of company or university trials. Farmers often believe that such differences exist and are important for selecting varieties for their operation.

On-farm testing sometimes gives the farmer an opportunity to acquire some portion of his/her seed corn or soybeans at little or no expense from seed dealers who would like to "place" their varieties on that farm. This is particularly true if one is growing a company-sponsored on-farm variety test. Even if seed was provided by the company, seed cost differences should be included in the evaluation of alternative genetics.

Limitations

Variety performance data from on-farm testing are usually limited to several years at a single location. Consequently, the farmer will be greatly limited in his/her ability to estimate the stability of variety performance across a range of growing conditions. This is unfortunate because the greatest influence on a variety's performance from year to year is the variability in the weather itself and its influence on pest development.

The primary benefits of widespread testing (multiple locations and years) are the increased ability to test under different weather patterns and to estimate the stability of variety performance. The collective advantage of multiple testing locations is that one's ability to predict variety performance in following years is greatly enhanced (Hicks et al., 1992; Lauer & Hudelson, 1997). Note: Individual seed company variety plots, in and of themselves, have little value to the farmer or to the company. However, the aggregation of the performance data from hundreds of individual farmer plots is of great value to the seed company in terms of assessing variety performance and stability. Consequently, one's ability to assess the stability of variety performance across a range of weather and pest conditions is severely limited when conducting on-farm tests at a single location for only a few years.

On-farm tests should complement variety performance data from other sources that have the ability to aggregate multiple locations of variety testing. Examples of such sources include other on-farm trials, university variety trials, seed company trials and local county Extension trials.

Substantial within-field variability for yield-influencing factors can interfere with the tests ability to detect differences in variety performance. Individual variety plots that are planter/combine width and hundreds, if not thousands, of feet long may be dramatically variable from one plot to another simply due to variability among plots for soil type, fertility, drainage and topography.

As with any on-farm testing, variety performance testing requires a certain amount of your time and resources that may be alternatively spent on other farming activities. This limitation may seem minor when planning for the test in mid-winter but can become a major issue when faced with the feverish pace of the planting or harvest seasons.

Opportunities & limitations for using yield monitors versus weigh wagons

Opportunities

Using a yield monitor for variety testing requires less time and is logistically simpler at harvest than using a weigh wagon. Consequently, using a yield monitor may allow farmers to compare a greater number of varieties than when using a weigh wagon.

Coupled with the appropriate GIS analysis software, using a GPS-enabled yield monitor for variety testing provides the opportunity for assessing the yield stability across soil-related conditions among varieties.

> **Example 1.** The yield of hybrid A averages 120 bu/acre but varies from zero to 240 bu/acre down the strip plots of the hybrid. Hybrid B, on the other hand, also averages 120 bu/acre but only varies from 90 to 150 bu/acre. Farmers can conclude that hybrid B has the greater yield stability across the conditions that exist in that field.

Example 2. Hybrid A outperforms Hybrid B on the light-colored, well-drained areas of the field. Hybrid B outperforms Hybrid A on the darker, more poorly drained areas of the field. If this contrast in performance was consistent across years, one could decide to position those hybrids specifically to those areas of the field.

Limitations

Differences among the varieties for grain characteristics and grain moisture content may require calibrating the yield monitor separately for each variety and, thus, require additional planted area for each variety in the test. Improperly calibrated yield monitors may result in inaccurate yield comparisons among varieties. Loss of GPS signal or electronic malfunction of the yield monitor may limit your ability to measure and record the harvest data. Be prepared to use a weigh wagon or farm scales in the event of such problems occurring.

Field layout designs for on-farm variety testing

Split Planter Two-Variety Comparisons

The simplest form of on-farm variety testing involves filling half of the planter with one variety and the other half with another variety, then planting a field as usual. Assuming a farmer plants back and forth across the field from one side to the other, the result will be multiple side-by-side replicates of the two varieties, each planted to the number of rows equal to that of the planter (Figure 1). If one's combine header width is equal to the planter width (or half the planter width), this design is one of the simplest to implement.

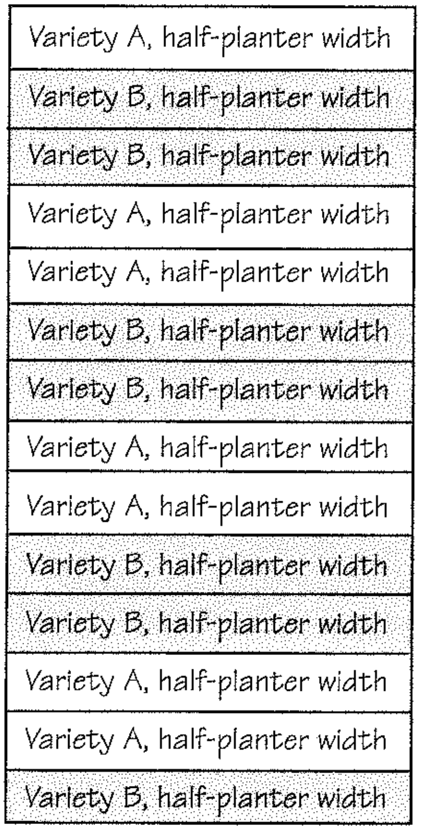
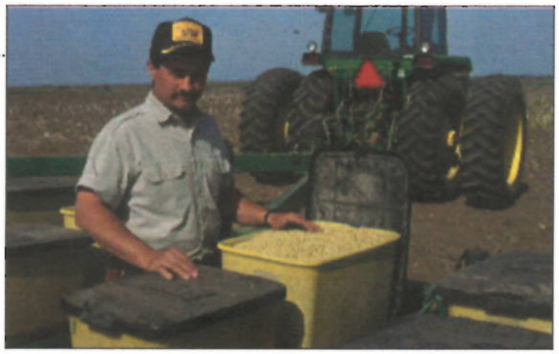


Figure 1. Replicated split planter variety trail.

CHUCK MYERS

Lyons, NE



Like many farmers, Chuck Myers says it may be too early to tell if the site-specific farming practices he is using on the farm add to the bottom line. But he can detail several examples where it has saved him money and influenced his fertilizer and seed purchases for the 1700 acres he farms in Nebraska.

Myers started with a yield monitor in the combine in 1996. For the last three years he has also used it in the tractor to map where the different seed varieties are planted in the spring.

"It allows me to make my entire farm somewhat of a test plot," explains Myers. "Then in the fall those maps coordinate with what I did in the spring. It has really helped in evaluating seed varieties."

Myers has also noticed a significant benefit with variable-rate lime applications. On one particular 125-acre field Myers recalls traditional soil tests indicated a need for two tons of lime. However, the soil grids called for less than one and one-half tons.

"We found through the soil grid one third of the field didn't need any lime at all and another third needed almost triple the rate," says Myers. "Overall, we ended up putting less lime on the field and we put it where we needed it."

Putting the lime where it's needed is important because of the problems associated with high pH in the soil and the effectiveness of certain herbicides.

"The yield maps are worthless if you don't analyze," adds Myers. Consequently, Myers finds the time to analyze and compare all his maps.

As an example, Myers discusses the issue of a consistently low yield area in a field. "Through analyzing the maps I found this area coordinated with the soil grid which showed a deficiency in zinc. Over the last few years we increased the application of zinc in that area." Myers says that while it takes time to analyze the data, it appears we are making progress. "The yields are increasing."

Knowledge has value according to Myers. "Just knowing what's out there is worth quite a bit."

Multiple Variety Comparisons

If farmers want to compare more than two varieties, the split planter technique will not be the one of choice. Rather, he/she will need to plant whole-planter widths of each variety, emptying and filling seed hoppers each time varieties are switched. The challenge to testing multiple varieties is that replication is still important for assuring the quality of the yield data that results from the test.

In addition to the need for replication, the sequence of the varieties within each replicate should be random. Such randomization minimizes the opportunity for unforeseen experimental error or for variability to unduly affect any one variety's performance. The sequence of varieties can be randomly assigned to each replicate by simply drawing numbers out of a hat.

For example, farmers should plant two or three complete replicates of the varieties to be compared, i.e. plant replicate #1 of all the varieties, then replicate #2 of the same varieties. Figure 2 illustrates an example of an on-farm strip plot for comparing six varieties. Three replicates of the six varieties will be planted, for a total of 18 individual plots. The variety sequence should be re-randomized within each replicate. Each plot is equal to one or two widths of the planter and/or combine.

Replicate #1, Variety A
Replicate #1, Variety C
Replicate #1, Variety E
Replicate #1, Variety B
Replicate #1, Variety F
Replicate #1, Variety D
Replicate #2, Variety F
Replicate #2, Variety C
Replicate #2, Variety A
Replicate #2, Variety D
Replicate #2, Variety E
Replicate #2, Variety B
Replicate #3, Variety A
Replicate #3, Variety E
Replicate #3, Variety F
Replicate #3, Variety B
Replicate #3, Variety C
Replicate #3, Variety D

Figure 2. Randomized replicated trial comparing 6 varieties.

Profits from Variety and Hybrid Choice

One bushel per acre yield increase from better choice of hybrids and varieties would be enough to pay for a yield monitor and GPS, according to Jess Lowenberg-DeBoer, director of the Purdue University Site-Specific Management Center.

"Say we have a farmer with 2000 acres of corn and soybeans," he says, "and he increases his average yields over the whole farm by one bushel per acre by doing additional on-farm testing. That would pay for a $7,000 yield monitor and GPS the first year, even at current grain prices."

In that case, the profits come from hybrid and variety choice in latter years, and from all the other benefits of yield monitor use, including diagnosing drainage and pest problems, Lowenberg-DeBoer says. On a 1000-acre farm the payback period would be two or three years.

"Some of my colleagues at the university wonder if a producer can really increase yields by one bushel per acre by better choice of genetics with a yield monitor," he says." Many farmers are convinced that they can. I have asked that question to thousands of farmers, and they always say yes."

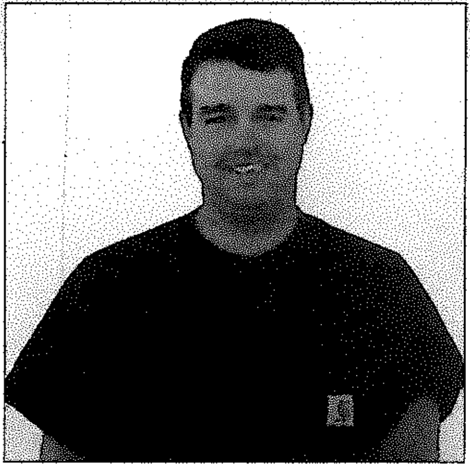
Making that one bushel an acre increase would probably mean planning ahead and doing some split-planter trials or other replicated tests, Lowenberg-DeBoer says.

"Just looking at yield maps spread on the kitchen table in December probably won't be enough to make reliable choices," he says. "There is so much variability in most fields, that the difference of a few bushels will get lost unless you have many replications."

Because there are hundreds of hybrids and varieties available, and farmers can only test a few each year, they need to make full use of university and company information to narrow down their choices to the most promising genetics.

MATT ELLIS

Wilmington, OH



Site-specific farming techniques and precision farming tools enabled Matt Ellis to return to the family farm after college and build a business. Realizing there wasn't enough land and livestock to support his return to the farm after college, Ellis purchased a RoGater® in 1994 and started a custom application service with the local dealer. And since then, Ellis says he's continued to learn.

For Ellis, precision farming has meant lots of work but many rewards. He's seen the technology grow, and producers he works with learn and adapt both technologies and practices.

"Another benefit," adds Ellis, "is the good records we can generate through knowing exactly what and how much has been applied where. Yield maps have also helped with the record keeping efforts."

This kind of specific attention to any given field has helped Ellis and others better understand and become more aware of how and where the crop yields - as well as why it does or doesn't.

Further Information

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Partial Budget Template For Estimating Whole Farm Yield Monitor Profits from Hybrid and Variety Choice, and Improved Marketing[1]

Item	Unit	Quantity	Value/Unit	Amount
Change in Revenue:				
Yield increases for whole farming operation[2]	______	______	______	______
Corn	______	______	______	______
Soybeans	______	______	______	______
Wheat	______	______	______	______
Other crops	______	______	______	______
Price changes (due to better quality and/or marketing)[3]				
Corn	______	______	______	______
Soybeans	______	______	______	______
Wheat	______	______	______	______
Other crops	______	______	______	______
Total change in annual revenue (sum of all the revenue changes)				______
Change in Costs:				
Annualized costs of equipment and other durable items[4]				
Yield monitor (useful life = ___years)[5]	______	______	______	______
GPS (useful life = ___years)[5]	______	______	______	______
Software (useful life = ___years)[5]	______	______	______	______
Training (useful life = ___years)[5]	______	______	______	______
Other (useful life = ___years)	______	______	______	______
Variable costs				
Differential correction	______	______	______	______
Repairs and maintenance	______	______	______	______
Consultant fees	______	______	______	______
Office supplies	______	______	______	______
Extra seed costs	______	______	______	______
Other	______	______	______	______
Total change in annual cost (sum of all the annual cost changes)				______
Whole farm annual net return (Subtract annual cost change from annual revenue change)				______
Per acre net return (Divide net return by acres farmed, _______acres)				______

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1) The other major source of yield monitor benefits is in diagnosing crop problems (e.g. pests, drainage). Budgets to estimate profits from those would require lines for the costs of implementing solutions (e.g. tile, chemical application).

2) The quantity in this line should be the change in production for the whole farm.

3) The price here should be the change in price for the whole farm operation by crop. The quantity should be amount of grain for which price was increased.

4) Include anything that is used for more than one year.

5) Most of these items will be obsolete before they are worn out. As a conservative estimate a three year useful life is suggested. The amount in this case is the annualized cost. The simplest way to calculate the annualized cost is depreciation plus opportunity cost of capital. If the item has no salvage value, the straight line depreciation would be the purchase price, divided by the useful life. The opportunity cost of capital is the rate of return on alternative investments multiplied by the purchase price.

Yield maps can show the total area affected by drainage problems and the potential benefits of drainage installation. Having several years of data increase the reliability of yield advantage and profitability estimates for improved drainage.

3
CHAPTER

MAKING DRAINAGE DECISIONS

By Jane Frankenberger, Jess Lowenberg-DeBoer, Sam Parsons, R. Mack Strickland

Learning Objectives

In this chapter you will learn:

1. How yield maps can help define drainage problems and how those maps can be used to make effective drainage decisions;
2. How to estimate the yield boosts from improved drainage in a field;
3. How to estimate benefits and costs of a drainage system; and
4. How to calculate profitability of a drainage system.

Introduction

Identifying drainage problems is often cited as one of the most important benefits of yield maps. Drainage contractors have experienced unprecedented demand for their services in the last few years. This fact is often attributed to increased information from yield maps. As farmers see the yield effects of poor drainage in full-color maps of their fields, many are making significant investments to improve field drainage, usually through installing subsurface tile drains.

For example, the maps in Figure 1 show yield maps from the same field before and after tiling wet spots. In 1998 before tiling, almost 6 acres of this 75-acre soybean field were not harvested at all and another 16 yielded less than 40 bu/acre. After tiling in the fall of 1998, the 1999 yield map shows that the entire field was harvested, and that yield was more uniform. The poorly drained areas are still visible, but are more productive than before.

Drainage *problems* can be easily identified using yield maps, but drainage *decisions* are still usually not easy to make. Although areas of poor drainage in a field are obvious, the return on an investment in drainage takes more consideration. This chapter will discuss what can be learned about drainage from yield maps, discuss how site-specific information can be used to make drainage decisions, explore the benefits and costs of drainage, and give examples of how a decision might be made on a particular field.

Using site-specific information to identify drainage needs

Many farmers claim that drainage problems are among the most clearly identifiable problems demonstrated by site-specific farming techniques. However, before they can identify poor drainage as the cause of low yield in parts of a field, farmers usually already know about drainage problems from years of fieldwork and observation. But they may not be able to quantify the effects of the poor drainage on yield, and therefore on profit, until their yield monitor quantifies what they already knew.

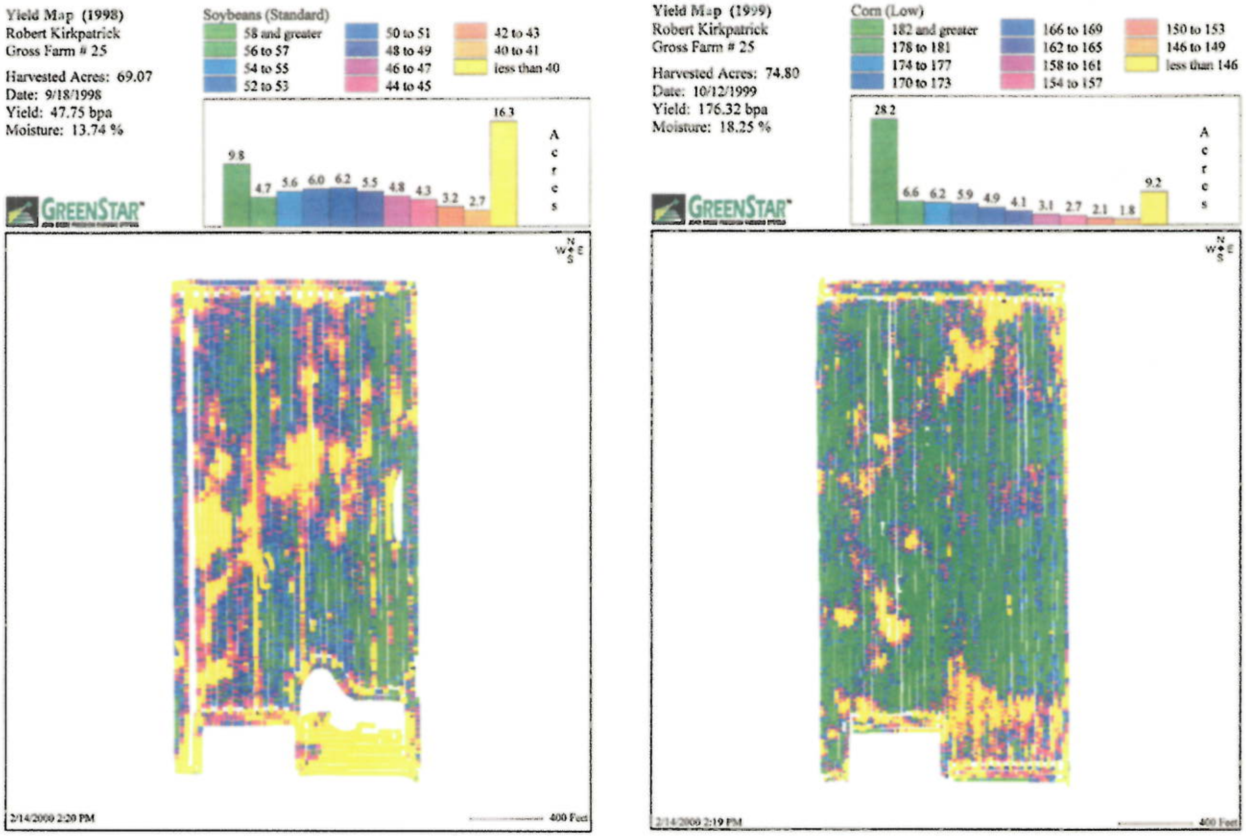

Figure 1. *Yield on a 75-acre field before and after drainage improvements. (yield maps provided by Kirkpatrick farm)*

Yield Maps

Yield maps can often be used to learn about both the size of the area affected and the magnitude of drainage problems. Farmers may have assumed that poor drainage only affects the lowest spots in a field, where water ponds or where crops are clearly stunted or even entirely drowned out. However, the yield effect of a drainage problem usually extends far beyond the clearly visible "wet spot," and yield maps often make this evident. Yield maps also help quantify the difference between the yield in areas of good drainage and poor drainage, which can be helpful in making decisions about whether, and where, drainage investments are needed. Although many factors can contribute to differences in yield within a field (seeding rate, fertility, varieties, soil compaction), the yield difference between an area with poor drainage, and an area of similar soil that has been drained can help farmers estimate potential improvements from drainage. This yield benefit has been difficult to estimate through research, because studies cannot be carried out on all possible soil types, and because research fields may have a different response to drainage than other fields with the same soil type.

Other Site-Specific Information

One of the major economic losses due to poor drainage is lower field efficiency. Farming around low areas increases work time and decreases machine use efficiency. Compaction may result from farming short rows between poorly drained areas. Most producers do not need yield maps to identify this problem, but as-applied maps and yield maps can be a useful documentation of the effects of drainage problems on field efficiency. With the maps it is easier to show a landowner the extent of the problem or to identify a problem that occurred when a family member or employee was operating the equipment.

Site-specific fertility maps can be used to identify areas that have been fertilized but have not produced a good crop for several years, suggesting that the remaining problem is drainage.

Also, maps of fertility and organic matter can be used to estimate yield potential of poorly drained areas before installing drainage systems, because improved drainage in areas with low yield potential may not be a good investment.

Year-To-Year Variability

It is a good idea to have several years of yield maps before making drainage decisions. The area of saturated soils and the yield effect may vary widely from one year to the next. One yield map from a very wet year may be misleading if this kind of weather is rare in the area. Likewise, a yield map from a dry year may not say anything about drainage needs.

The number of years of yield maps needed to make a drainage decision is a judgment call which depends on the soils, topography, climate, overall profitability of the crops, other information available on that field, risk bearing ability and other factors. In much of the Eastern Corn Belt the soils, topography and climate lead to an excess of water during some period of almost every crop season. In that case, a single yield map from a very wet year would provide an estimate of the maximum extent of crop losses due to saturated soils. Additional yield maps would help fine-tune that crop loss estimate, but probably would not reveal anything dramatically different.

RODNEY RULON

Arcadia, IN

"Precision farming techniques are tools in a farmer's overall management plan that help farmers make adjustments and adaptations incrementally and spatially, over time," says Indiana farmer Rodney Rulon. Here's how Rulon made the maps (Figure 2) in this chapter work for him.

"I began by looking at the soil types, drainage, fertility, weather, and used these as resources. And as I took a look at the field from what I knew about its history, I knew that the heavier soils were most poorly drained, the lighter soils were up the hills. I saw soil types that had the greatest yield potential were most poorly drained and that was lost potential income - as well as I could estimate as much as 200 bushels per acre lost potential."

Rulon chose to drain the low areas because in this case, he stood to gain the most by draining those heavy soils. "Rather than a traditional pattern tiling design, I developed one based on the map data we had on the field. One advantage to this approach is that by adapting the drainage to go where it was needed most to impact yield, we were able to make a solid plan that works."

(photo provided by Purdue Agriculture Magazine, winter 2000)

The landlord saw results - and has achieved better yields for a couple of years. Rulon showed the landlord that using this information helped improve this field situation. "As an added benefit, the landlord can afford to put in some more tile. If everything was an ideal situation, there'd be time and money to put in all the tile you wanted any time. But in real life, sometimes you can only do a little at a time, so it might as well be where it counts the most," Rulon adds.

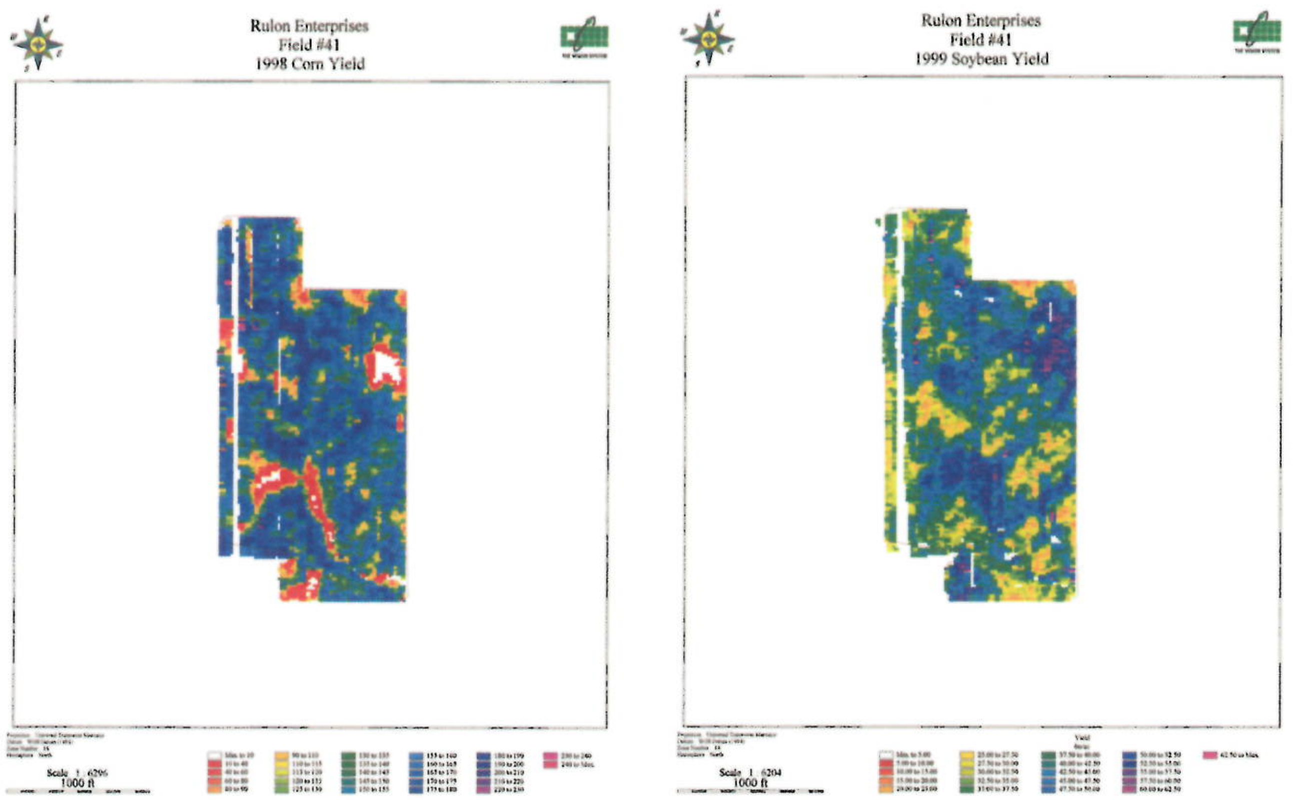

Figure 2. *The most poorly drained areas in 1998 on the left, clearly had the highest yield in 1999 shown on the right.*

In most cases, historical weather data and other information should be used in addition to yield maps. Historical weather data would help estimate the chances of having a wet year. Because of long-term weather patterns, until 20 or 30 years of yield maps are available, it will be difficult to estimate the chances of a drainage problem from yield maps alone.

Experience with similar soils should be factored into the decision. If drainage made a dramatic difference in yields on similar soils on another field, a single yield map in a wet year may be enough to identify the areas needing drainage on a newly acquired farm. The yield benefits from drainage could be estimated from experience on other fields.

Most crop decisions are an exercise in risk management. Drainage decisions are no exception. A large well-financed farming operation may be willing to take a risk on drainage based on a single yield map. Before the advent of yield monitors and other precision farming tools, many of these operations drained newly acquired land without any site-specific data. In most cases that decision was based on long experience with similar soils. A single yield map could help fine-tune that drainage decision by more accurately locating the areas affected and the degree of yield loss. Smaller operations and/or those with less risk-bearing ability may need a higher degree of certainty about the potential benefits of drainage and for that reason may need several years of yield mapping information.

Benefits of drainage

Artificial drainage is needed in many soils of the Eastern Corn Belt because the natural drainage is not sufficient to remove the excess water. The excess of precipitation over crop water use typical from late fall through the spring creates a water surplus in the crop root zone, unless water can freely drain out of the soil profile. Many soils do not drain freely, however. Some soils have a slowly permeable subsurface layer that restricts vertical drainage. Some low-lying soils may also be poorly drained because of seepage from upslope areas, or because they are in a depression area with no outlet.

Timely Operations

Poor drainage prevents timely field operations in the spring. Because driving on a wet field can lead to soil compaction, soil must be adequately dry before planting can take place. Waiting for the soil to drain often leads to yield loss. Corn yields are estimated to drop 1-2 bushels per acre for each day that planting is delayed after May 10. Some farmers don't wait for soils to drain adequately before planting, and often compact the soil, which leads to drainage problems and lower yield down the road.

Product effectiveness can be reduced if side-dressing nitrogen or herbicide application cannot be done at the optimum time due to poor drainage. Yield and crop quality may suffer if harvest is delayed due to wet soils.

Improved Crop Growth

Excess water in the crop root zone impedes growth because roots need oxygen. If roots are not able to penetrate deeply enough into the soil profile when the soil is saturated, the plant is more likely to suffer drought stress later in the summer when water is scarce. In a well drained soil the root system develops more fully in the spring, enabling the plant to have access to deeper soil moisture in the dry periods of mid-summer.

Yield Potential of Poorly Drained Soils

The effects of poor drainage on yield are particularly important economically. Many poorly drained soils have a higher yield potential than soils that are well drained. Most poorly drained soils are fine textured (silt or clay) and have high organic matter. This allows them to hold plenty of moisture even when drained, while many naturally well drained soils hold less water and become too dry later in the summer. When using yield maps to estimate yield increases from drainage. Many farmers opt to compare the poorly drained areas to areas of the field with the highest yield -- not the whole field average.

In general, soils cannot be "over-drained." Only excess, freely draining water can flow through tile drains. When the soil moisture level goes below that, flow in the drains stops. On a few low-lying sandy soils, drainage installation could actually lower yields. Although these soils are poorly drained during wet periods, usually due to a restricting layer that impedes drainage, they hold little water when drained. Such soils might be identified from many years of yield maps because they yield less than the surrounding areas during a dry year as well as a wet year, while a more typical poorly drained soil might often out-perform other parts of the field in a dry year. They can also be identified from soil survey maps, which many farmers digitize or obtain in digital form and overlay with their yield maps.

Costs of drainage

Successful drainage system installation involves much more than just burying tile. One thing to consider very early in the process is whether a suitable outlet is available and has adequate capacity. If potential outlets are too far away, or there is an obstacle such as a major road between the field and the outlet, or if the outlet is not low enough to function in wet weather, subsurface drainage may not be feasible, no matter how badly improved drainage is needed. The outlet may be a "legal drain," shared by multiple landowners and maintained by a legal entity such as a drainage board (laws vary for each state).

Identifying the location and condition of any existing tile in the field may help in deciding what kind of drainage is needed and its potential benefits. Most fields in poorly drained soils that have been cropped for many years already have some kind of drainage system. It may not be adequate, but it probably already has an effect on yield. It is always important to contact the Natural Resources Conservation Service (NRCS) for a wetland determination before making any drainage changes to a field.

Drainage System Design

A subsurface drainage system consists of a network of drainage tiles (typically perforated plastic tubing or concrete pipes) that lead to the outlet. Laterals are small, perforated drainage tiles that take in water from the soil and convey it to the larger main drains, or "mains." Laterals and mains are usually arranged in one of two ways: to drain only the wet spots in a field, or in a parallel pattern that drains the entire field evenly. In some fields, only a few depressions or poorly drained soils are responsible for the yield loss. In this case, a network of tile drains can be installed focusing on only the wet spots, connecting wet and/or low areas as needed to drain those areas. This type of drainage system is typically used on undulating or rolling land containing various soil types and isolated wet areas. The other type of system is known as a parallel system (often called a complete or grid system), which consists of parallel lateral drains flowing into a main drain. A parallel system is typically used to drain the entire field on flat, regular fields with uniform soils.

Yield maps can be used to help decide what type of system to install in a particular field. If overall yield is fairly even across the field, but reduced due to drainage problems, a parallel system is probably preferable. However, if clear "wet spots" and drainageways can be seen in the yield map, draining only the wet spots may be a better investment.

Spacing of drains has an important impact on drainage system performance and on cost. Most states have drain spacing recommendations for each soil type or drainage group in the state, which provides a rough estimate based on general experience with such soils. Many farmers are using information from their yield maps to determine spacing. They may install tile at 100-foot spacing, and then see if yield decreases midpoint between the tiles, after which they put another tile in the middle. Most farmers learn by installing different spacings and seeing how they perform.

Typical Costs

Costs of a drainage system include materials, installation for laterals, mains, connections, and other components such as outlet protection, crossings, junction boxes, and pressure relief wells. Laterals (typically 4-inch diameter) cost from 60 cents to $1.20 per foot, installed. The costs of the main drains depend on their diameter, which is based on the total area to be drained and the slope of the drain. (A smaller pipe can be used to drain the same area on a steeper slope.) The cost of mains ranges from around $1.30 per foot for 6-inch tile to around $8.50 per foot for 18-inch tile, installed. (All costs are averages and local costs may be different.) Prices are often negotiated based on time of year and volume of drainage work done. Drainage installation while the crop is in the field usually costs less than after harvest or earlier in the spring.

Obviously, average per-acre costs of a drainage system are very different depending on what type of system is installed and how closely spaced the tiles are. A parallel system with 100-foot spacing requires about 400 feet of laterals per acre, plus mains, connections, and other components, often totaling $400 to $600 per acre. Draining only the wet spots in a field costs much less.

Estimating Drainage Profits

Drainage is a long-term decision with uncertain consequences. Any estimate of benefits needs to deal with risk and time. The risk in a drainage investment is mainly related to uncertainty about yield effects:

- How large is the yield boost with drainage?
- How often will yields be increased? Every year? One year out of five?

In the past, producers depended on yield reports from small plot trials to estimate what effect drainage might have on their farm. Because of the high cost of doing such trials, only a few were carried out. Trials could not be carried out for all major soil types. Those plots were often on research stations. Management there was different from that in producer fields. Drainage trials are long term. By the time the data was published it was years old and used very different genetics from current hybrids and varieties. Today's yield monitors, GPS and GIS can help provide more reliable estimates of yield benefits that lower the risk of drainage investments.

With yield monitor information, a producer can identify drainage zones and estimate the current yield and potential yield with drainage in each zone. An example for corn is given in Table 1. A similar table would be needed for soybeans or any other crops grown. In Table 1, four zones are used. Zone A is the area that is drowned out almost every year. Zone B is the area around the drowned out zone in which corn is severely stunted by saturated soils, but some grain is still harvested. Zone C is an area in which yields are affected in some particularly wet years. Four zones is only an example. The number of zones in a given field depends on the yield map data. With a GIS, it would be easy to estimate the area of each zone.

Table 1. Estimating the yield boost from drainage with yield monitor data in a 100-acre field.

Zone	Size	Yield Without Drainage	Yield With Drainage	Increased Production
	acres	-----------*bu/acre*	*bu/acre*-----------	*bu*
A	2	0	180	360
B	5	50	180	650
C	8	100	180	640
D	85	160	160	0

Total Increase with Drainage, bu	1650
Average Increase in the Drained Area, bu/acre	110
Average Increase for the Whole Field, bu/acre	16.5

The yield without drainage would simply be the yield for each area averaged over the number of years of data.

This average would best be calculated by crop, so that in five years of yield maps from a corn/soybean rotation there would be two or three years of corn yields to average.

An alternative would be to calculate relative yields by dividing all yields by an estimate of the potential yield. Most commonly this potential yield would be estimated by the highest yield for that field or soil type. The relative yield could then be averaged over all crops. One problem with this approach is that some crops are more tolerant of poor drainage than others.

The increased yield from drainage management depends more on the expected yield with drainage than any other factor. That might best be estimated by average yields on similar soils on the same farm that have been drained. Information on yields with drainage from a neighbor's farm could also be used if management was similar.

If no information is available on similar soils with drainage, an alternative would be to use the yield from the highest yielding part of the field or the farm. This approach is based on the observation that drained soils often become the highest yielding parts of the farm.

The difference between the yield increase in each zone multiplied by the area gives the production boost for the zone. The sum of the increases in each zone is the added production for the field. This might also be expressed as per acre yield increase on drained land or for the whole field. The yield increase per drained acre can be quite large if production was previously reduced to almost zero by saturated soils. On those same fields the overall field yield increase may be quite modest if the poorly drained area is a relatively small part of the field, or if yield is only slightly reduced by poor drainage.

The example in Table 1 assumes that only the 15 acres of "wet spots" are affected by drainage. Area D is naturally well drained and has a somewhat lower yield potential. With systematic drainage the whole field may be affected, but the calculations are the same.

The reliability of the yield advantage information will depend on the number of years of yield maps available. If 50 years of yield maps were available, the estimate would probably be very accurate, including effect of any long-term weather cycles. A yield map from one wet year might help locate the zones, but could only put an upper limit on the yield boost that could be had with drainage.

Time - has two main effects in budgets: depreciation and opportunity costs of investment. For taxes it is wise to deduct an investment as quickly as possible. For management purposes, a more accurate picture is obtained when investment costs are allocated over time.

Table 2. Partial budget example for drainage calculated for corn/soybean rotation on a whole field basis.

Item	Unit	Quantity	Value/Unit	Amount
Corn Yield Increase (Table1)	bu	1650	$2.00	+$3,300.00
Corn Fertility Cost Increase	bu	1650	$0.35	-$577.50
Soybean Yield Increase	bu	240	$5.00	+$1,200.00
Soybean Fertility Cost Increase	bu	240	$0.25	-$60.00
Hauling Cost	bu	1890	$0.20	-$378.00
Drying Cost	bu	1650	$0.25	-$412.50
Average Annual Gross Benefit (sum+/- benefits above ÷2)				$1,536.00
Annualized Drainage Cost (for 15 acres)	acre			$1,050.00
Net Benefit Annually Before Tax, per field				$486.00
Net Benefit Annually Before Tax, per drained acre (15 acres)				$32.40
Net Benefit Annually Before Tax, per whole field acre (100 acres)				$4.86

Depreciation is a way of spreading the cost of a durable investment over the life of that item. There are many ways of calculating depreciation, including some that are only useful when doing income taxes. The easiest is the so-called "straight line" depreciation calculated by dividing investment by the number of years it will be used. If drainage for the 15 acres in Table 1 cost $7,500 and was expected to be used for 25 years, the annual depreciation would be $300 per year for the 100-acre field, about $20 per drained acre, or $3.00 per whole field acre.

If money were not invested in drainage, it could be used elsewhere. It might be used to pay off debt, to purchase new equipment, to buy land or to invest in the stock market. The opportunity cost is the return on the alternative use of that money. The most conservative estimate of that opportunity cost is often the interest rate on debt. The real opportunity cost is almost always much higher than the interest rate on savings or certificates of deposit because both drainage and most other investment alternatives are higher risk. In recent years, the upper end of the opportunity cost range would be long run returns on the stock market. Depending on the stocks and years included in the average, the stock market returns have often been in the 15% to 20% range. If the opportunity cost is 10% annually, then the annual opportunity cost on a $7,500 investment is $750 for this field (Table1), $50.00 per drained acre, or $7.50 per whole field acre.

Net Benefit - The first step in economic analysis is usually a partial budget. The increased costs are subtracted from the increased benefits. The costs of drainage are usually easy to find. Drainage contractors are usually more than happy to provide an estimate to potential customers. It is also important to take into account crop costs that change when yield increases, mainly soil fertility, harvesting, hauling and drying.

Added soil fertility costs depend on previous management. If the fields were managed site-specifically and each zone received only the fertilizer for its average yield, then fertilizer cost would rise because expected yields would go up. In recent years, the cost of a soil fertility maintenance plan for phosphate (P), potassium (K), nitrogen and lime would be $0.30 to $0.35 per bushel of corn harvested and $0.20 to $0.25 per bushel of soybeans.

If the field was under whole-field management with uniform fertilizer rates based on the whole field yield potential, then fertilizer costs may not rise at all. Enough P and K are probably built up from years of fertilizer, but low yields, to support the higher yield on the drained land for years to come.

Table 2 shows an example partial budget for a corn/soybean rotation. The corn yield increase is from Table 1. A similar process estimated the soybean yield increase. The table assumes that additional fertilizer would be needed to maintain soil fertility at the higher yields. The hauling cost is charged on both corn and soybeans. Drying is charged only on the corn. The average annual gross benefit is the average of the increased value of corn and soybean produced, minus soil fertility, hauling and drying cost.

The drainage cost assumes a $7,500 investment with a 10% opportunity cost. The $1,050 annual cost is the $750 opportunity cost, plus the $300 depreciation assuming a 25-year life.

The partial budget can be done on a whole field basis, on a per drained acre basis or per whole field acre. The answer should be the same in all cases.

The after tax benefits depend on the income bracket, but drainage investments can generate substantial tax savings. In some cases, drainage investments can be "expensed" (that is directly deducted the first year from taxable income) up $20,000 per return in 2000, $24,000 in 2001 and 2002, and $25,000 after 2002. For someone in the 28% income tax rate bracket, a $7,500 drainage investment that can be expensed can generate $2,100 tax savings. Depreciation for tax purposes on drainage is on a 15-year schedule. In most case drainage lasts longer than the useful life for tax purposes. So even when drainage is depreciated it generates some tax savings because tax deductions occur faster than the rate at which the investment wears out or becomes obsolete.

The partial budget in Table 2 assumes that only wet spots are drained. A partial budget for systematic drainage of the whole field would be done in the same way. The only difference would be that the net benefit per drained acre and net benefit per whole field acre would be the same.

Summary

Site-specific information such as yield maps can provide information that can help in making drainage decisions. Partial budgets are needed to define the average profitability benefit of drainage improvements, based on estimates of yield improvements. Any conclusions are more reliable with more years of data, because weather conditions vary widely from year to year.

Partial Budget Template For Estimating Whole Field Profits from Drainage and Other Land Improvement[1]

Item	Unit	Quantity	Value/Unit	Amount
Change in revenue:				
Yield increases for the field[2]				
Corn	______	________	________	________
Soybeans	______	________	________	________
Wheat	______	________	________	________
Other crops	______	________	________	________
Total change in annual revenue (sum of all the revenue changes)				
Change in costs:				
Annualized costs of drainage and other land improvements[3]				
Tile (useful life =___years)[3]	______	________	________	________
Surface drainage (useful life =___years)[3]	______	________	________	________
Soil conservation structures	______	________	________	________
(useful life = ___years)[3]	______	________	________	________
Other (useful life = ___years)	______	________	________	________
Change in variable costs[4]				
Consultant fees	______	________	________	________
Repairs and maintenance	______	________	________	________
Other[5]	______	________	________	________
Total change in annual cost (sum of all the annual cost changes)				________
Whole field annual net return (Subtract annual cost change from annual revenue change)				________
Per acre net return (Divide net return by field area, _______acres[6])				________

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1) In addition to drainage, this same basic budget structure can be used to evaluate other land improvements, such as terracing, windbreak planting or removal,and land leveling.

2) The quantity in this line should be the change in production for the whole field. See Chapter 3 for suggestions on using yield monitor data to estimate potential yield increases. For a rotation, the yield increase should be the average over the rotation. For example, if the field is in a corn/soybean rotation, the quantity would be 50% of the corn increase and 50% of the soybean increase.

3) Include anything that is used for more than one year. See Chapter 3 for suggestions on estimating annual costs of drainage tile. Cost allocation for surface drainage, soil conservation structures and windbreaks would be similar. Typically, these investments have very long economic lives, often 20 years or more. It is important to include all costs in the investment. For example, the "purchase price" for a waterway could include surveying and earthmoving costs, plus any costs for seeding.

4) These are incremental costs. Typically, land improvements have large fixed costs and little if any recurring variable costs.

5) Other costs might include changes in seed, fertilizer, pesticides, grain drying, grain hauling and other costs with higher yields or if land is put into or taken out of production.

6) When land is taken out of production (e.g. for drainage ditches, waterways, etc.) or put into production by drainage or tree clearing, it is not clear what field area should be used for this estimate. In those cases, the whole field estimate is usually a better indicator of profitability.

Site-specific soil fertility management is helping producers better understand what nutrients are needed where - allowing them to better respond to crop needs. Ultimately, long-term soil fertility management can significantly impact the producer's bottom-line.

4

CHAPTER

MANAGING LONG-TERM SOIL FERTILITY

By Sylvie Brouder, Jess Lowenberg-DeBoer

Learning Objectives

In this chapter you will learn

1. How to determine if a field may profit from variable rate fertilizer or lime management;
2. How to collect a representative soil sample for variable rate fertility management;
3. How to allocate the costs of soil information over time; and
4. Key difficulties in estimating profits from site-specific soil fertility management.

Introduction

Achieving maximum yields depends on the environment and the farmer's skill in identifying and managing productivity factors. All plants require varying amounts of 14 different mineral elements that are predominately accumulated by their root systems from the soil. The term soil fertility refers to the "plant availability" of these nutrients in soil during the growing season. In addition to the quantity and availability of soil nutrients, the concept of soil fertility also includes how the nutrients are protected from losses and how easily roots function in the soil.

Farmers have long known that land units they consider as individual fields for legal, geographic or economies-of-scale purposes can have significant within field variability in nutrient status. Variable-rate (VR) fertilizer and lime application has been conducted in a rough manner throughout the history of production agriculture. University of Illinois professors Lindsey and Bauer put out the first bulletin on site-specific lime management in 1929. Thus it is not surprising that the first, commercially available pieces of equipment for intensification of site-specific management were for VR fertilizer application.

The label "variable-rate" covers a wide range of soil fertility management approaches. At the most basic level, each approach includes some type of intensive soil sampling and application practices that varies the amount of fertilizer applied from one part of the field to another. Information from the intensive soil sampling is used to develop recommendations on how much fertilizer to apply to each part of the field. This chapter will introduce the main approaches to variable rate fertilizer management, explain why it is so difficult to determine profitability and provide some guidelines on determining variable-rate profits.

How does one know if soil variability is costing money related to fertility management?

As with most technology, the cost can be significant and the farmer must weigh investment in VR technology for fertilizer management with productivity, resource use efficiency and environmental benefits. Variable-rate fertilization is one of the hardest site-specific management practices to analyze for profitability. Clearly, variable-rate application of fertilizers or lime will not pay if a field is relatively uniform in fertility, nor will it pay if the variability in the nutrient status is substantial but all in the "high" availability range. In these situations, not only is there no reason to vary applications, but ideally, the farmer would not have had to spend too much on fertility assessment to determine that a field was not a good candidate for VR fertilizer or lime inputs.

On the other hand, if a field is variable in fertility, a uniform application rate will lead to over-application in some areas and under-application in others. The over-application may represent a loss of investment in fertilizer depending on the nutrient and potential for loss, while the under-application can result in lost yield as well as a reduction in crop residue to the soil which may lead to increased erosion or other related problems. Through a combination of direct and indirect effects, over- and under-application of lime can both lead to reduced yields. For reasons discussed below, the best way to characterize soil fertility remains "soil testing," the collection and laboratory analysis of soil samples, which is laborious and costly. Therefore, one of the greatest challenges to VR fertility management is to determine which fields are likely VR investments *before* engaging in intensive soil sampling and testing activities.

Can yield maps or other productivity indicators be used to identify manageable, within field variation in soil fertility?

Yield maps identifying within field variability are certainly a starting point for a farmer to question whether uniform, whole field management of fertilizer and lime is the best option. However, a yield map just shows that the variability exists but it does not identify the cause. Yield at harvest is an integration of dozens of environmental and cultural factors that impacted the crop throughout its growth. Research has shown that yield maps and the variability that they show often change significantly from year to year, reflecting the dynamic nature of the interaction of yield limiting cultural and environmental factors. Several years of yield mapping showing consistent patterns are a much better indication that yield limitations are soil related then a single year's map. The same can be said for remotely sensed images of crop color or vegetation density.

Other indications that manageable within field variability in soil fertility exists can be found in published soil survey maps. Aerial photos of bare soil showing soil color differences can be an indication of significant differences in soil productivity within a field. Historical photos may show discontinued farming practices, such as feedlot locations that can create large in-field differences in nutrient supply.

Knowledge about previous fertility practices and any existing soil test information can also be helpful in trying to decide how intensively to sample a field. That is true even if the soil test records are for samples collected on a whole field or soil type within-field basis. If soil test levels are generally low, it is unlikely that there will be any advantage to intensively sampling to identify variability.

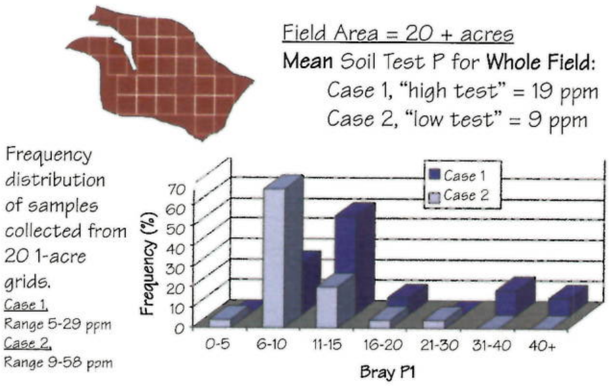

***Figure 1**. When the average soil test value for the whole field is low it is unlikely that more than a few acres can be high testing. However, when the average value is high, there may be a range of high and low testing areas across the field.*

Intensive soil sampling will likely just confirm that fertility is low everywhere, requiring generally high, uniform rates of fertilizer (Figure 1). However, if average soil tests for whole fields or large areas within a field are sufficient but the land has been in intensive agricultural production for many years, it is quite possible that the mean soil test levels mask a broad range in soil test values. This is because high productivity has typically only been achieved with high applications rates of fertilizers or manure to build soil test levels.

Uneven nutrient export related to differences in soil productivity and inherent differences in soil chemistry, and uneven nutrient applications, especially of manure, can all create within field variation in soil fertility in highly managed farms. Certainly, if a field has already been broken into two or more smaller areas in a previous soil test and the results show marked variability, there is a good chance that further intensifying sampling to better characterize variability will be profitable.

Finally, it is also important to remember that not all variability in a field represents a management opportunity. Soil sampling research has shown that in some fields half or more of the variation that exists across a whole field can exist within a small area of 10 to 20 square feet around a point within that field (Figure 2). Thus, an added challenge in soil fertility assessment is identifying the broad, manageable patterns not manageable with current technology.

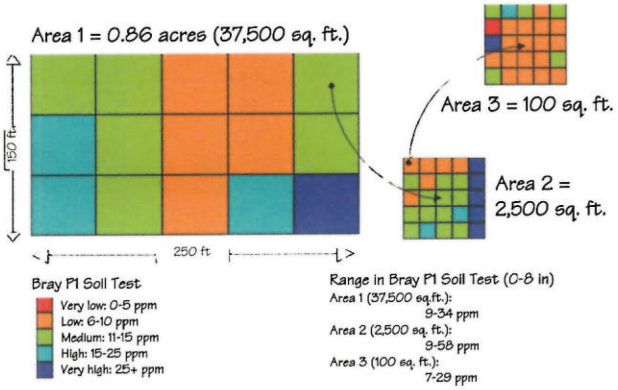

***Figure 2.** An example of field variation in Bray P1 soil test.*

How is soil fertility assessed?

Decades of research and farmer experience have shown that soil testing is fundamental to selecting economic rates of fertilizers and lime. While other areas of precision farming have seen rapid technological advances or complete changes in methodologies, the cornerstone of soil fertility management, especially for P (Phosphorus), K (Potassium) and liming needs, remains soil testing, the laboratory analysis of sample(s) collected from the field.

How is a representative soil sample collected?

The objective of soil sampling is to obtain an accurate representation of the field for the purposes of identifying fertilizer and lime rates that will provide the greatest economic return while collecting the fewest possible number of samples. If the field is not uniform in nutrient status then the objective is to characterize the variation and locate the extremes. Two approaches, grid sampling and zone sampling, are being routinely used to create application maps for VR fertilizer and lime application. As discussed below, neither approach is new to agricultural soil testing but they have been modified (intensified) to map variability on a much finer scale than was attempted prior to the availability of VR application equipment.

Sampling Strategies Described

Grid sampling: Gridding is a systematic approach where a field is sub-divided into smaller units of equal area (typically squares) and a separate soil sample is collected from each grid unit. The underlying assumption of this approach is that variability exists but it is randomly distributed. In other words, the person collecting the soil sample has no particular knowledge to guide them in where to look. This strategy is appealing to many because of its simplicity.

Research in many states has shown that a good sampling density is approximately 1 sample per acre (200 to 220 ft. grid) especially if the farmer is going to collect samples from only one *point* within the grid unit (see below for discussion of "point" vs. "area" composite sampling). This density of samples is intensive enough to identify the manageable variability. However, many farmers view this as too expensive and commercial sampling densities are typically on the order of 1 sample per 2.5 to 5 acres. According to surveys conducted by agricultural economist Jay Akridge at Purdue University, in 2000 about 42% of fertilizer dealers in the U.S. offered intensive soil sampling by grid. Unfortunately, when such larger grids are point sampled too much information may be lost, resulting in no advantage over the sparse sampling strategies practiced prior to commercial VR technology such as obtaining whole field averages.

Zone sampling: A zone sampling strategy uses preexisting knowledge about a field to delineate areas that are expected to be relatively similar. The pattern of nutrient availability in the field is not assumed to be randomly distributed or entirely unknown, but rather that there is some logical reason to anticipate a distribution. A composite sample is then collected from each area. In one of its simplest forms, a "zones" sampling strategy can be based solely on soil type. This is the historical strategy for soil testing in Indiana where fields often have multiple soil types that strongly influence variation in soil properties related to fertility such as pH, CEC and organic matter. The 2000 Purdue survey mentioned above indicated that about 30% of fertilizer dealers nationwide offered soil type sampling services.

The major disadvantage to sampling by zones based on soil type alone is that it fails to identify some natural variation within soil types and variation that results from historical uses of the land that have been discontinued. Other information to consider in identifying zones within a field includes topography, which can vary substantially within a soil unit. Leachable and erodable nutrients tend to accumulate in zones with lower relative topography. Depressions are often higher in organic matter content leading to higher levels of nutrients such as N (Nitrogen) that are derived primarily from OM. However, if depressions are regularly saturated they may be lower in N.

Aerial photographs of bare soil showing changes in soil color or variation in soil moisture, records (including aerial photos) of historical land use such as the location of feedlots and drainage tile can be invaluable. Electrical conductivity measurements, remotely sensed images of previous crops and yield maps may also be helpful. As mentioned above, yield maps characterize within field variability and many who have invested in the technology ask if these maps can be used to identify nutrient zones for VR fertility management. Since yield is an integrator of so many environmental factors, yield maps alone have not been found to consistently identify nutrient management zones. However, they can be used as supplemental information to fine tune zones in an ongoing, soil testing program in long-term fertility management.

Each approach to defining management zones has its advantages and disadvantages. No method for identifying management zones has yet proven itself generally better than another. It is likely that the best management zones methods will differ from place to place depending on soil type(s), climate, topography, crops and rotations and management.

Selecting and customizing a soil sampling strategy: There are no set guidelines for when one strategy will be better than another. When selecting a soil sampling strategy, farmers should consider their equipment and the amount of management they want to do as well as their pre-existing knowledge about field variability in fertility. A grid strategy will be useful when:

1. The field history is unknown but variability is suspected,
2. Topography is relatively uniform,
3. The inputs to be varied are lime, P or K and/or
4. Manure has been applied.

A "zones" strategy may be a better choice when:

1. Relatively low fertility levels are expected,
2. Soil survey maps indicate distinct soil types within a field,
3. Topographic differences are present and related to productivity,
4. The primary input to be varied is N and/or
5. There is no history of manure application.

As mapping software has become more advanced and researchers and farmers have become more knowledgeable about soil fertility variation, sampling strategies have become more complex. Simple, regular grids are often offset to account for regular field patterns such as banded fertilizer. Zones sampling strategies may consider numerous crop and soil data layers collected in multiple years. And, regardless of whether fields are gridded, zoned or handled in some custom combination of both, money can likely be saved by intensifying sampling (increasing the number of grid units or using smaller area zones) in regions of the field where variability is expected to be high and decreasing sample intensity in areas with low expected variability (see Reference C for more details).

Sample Collection Methods

Recent research has emphasized the importance of the correct strategy for collecting soil samples as the quality of test results and subsequent fertilizer recommendations will be no better than the quality of the sample. There are two additional aspects that are also critical to collecting a representative soil sample: (1) the number and location of individual "cores" that make up a "soil sample" and (2) the depth of the individual cores.

How many "cores" make up a "soil sample"?

Because fields contain small-scale patterns of variation, the soil test value of a single core is not likely to be representative of the true average soil test value in that area of the field (Figure 3). Examples of small-scale patterns include the distribution of individual fertilizer particles, the clumping of organic matter or even variability due to earthworm activity or the random deposit from livestock. Since this scale of variability is not a management concern, a single "soil sample" should always be a composite of multiple cores.

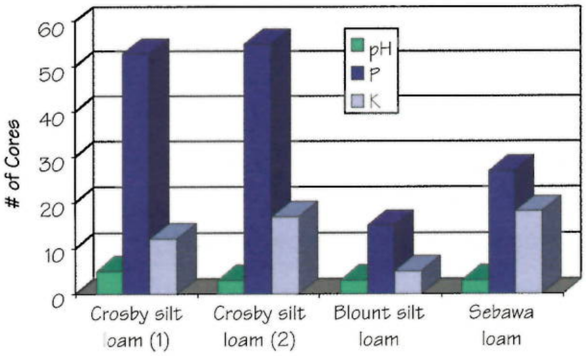

Figure 3. *Minimum number of cores to estimate the true mean soil test value in 1000 sq. ft.*

In a zones sampling strategy, the soil sample is made up of cores collected from random locations within each zone. When fields are gridded, the composite may also be collected from random locations over the whole area of the grid or it may be collected from a smaller "point" area within the grid. Whether grids are "area" or "point" sampled should depend on the size of the grid units and

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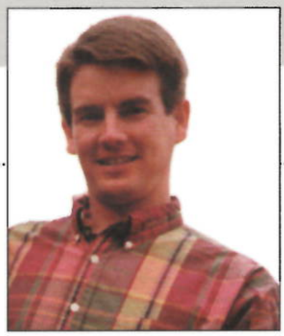

"I can't honestly say we have had one customer or retailer who has come to us and said that this was the worst money they had spent." Frontier Labs Manager Jim Finstad is proud of that record.

Frontier Labs is a full-scale soil testing lab and grid sampling business in Clear Lake, Iowa. They have grid sampled nearly 400,000 acres the last 4 years. Finstad says everyone has seen some form of a benefit from this service.

Lime content has been the most surprising to customers. "Farmers say, 'I didn't know I needed that much!' or 'I thought I needed more.' "

Finstad believes the greatest opportunities lie in bringing all data together from the yield maps, variable-rate applications, and grid samples.

"If you look at the big picture, we aren't using precision farming as well as we should be. We need to bring all these maps together and see where we can do a better job," Finstad explains. "The future has to be integrating all the data and getting the full value out of it."

the type of application map that will be drawn. Point sampling is required to draw contoured input maps that vary rates within a grid unit but the input maps may not be very meaningful if grid units are too large. A properly collected composite sample does a better job of representing all parts of the larger grid units (greater than 1 acre) because all areas have an equal chance of being sampled.

A "zones" approach is typically lower in laboratory cost than grid sampling as fewer total samples are collected, but commercial soil testing programs often use grid systems with point sampling not only because of simplicity, but because it requires less labor. The person collecting the sample stops once in each grid unit and walks around the vehicle to collect the cores. In contrast, composite sampling requires a stop for each core within a unit.

Why does the depth of the core collected matter so much?

Soil testing/fertilizer recommendation programs have traditionally been based on samples acquired from the "tillage layer" of soil. The correlation/calibration data that are used to convert a laboratory test result into a fertilizer recommendation used only samples collected to a specific soil depth. Unless fields are moldboard plowed, nutrients tend to accumulate in surface soil. Chiseling does not prevent this stratification from occurring, and both chiseled and no-tilled fields may have two times the available K and ten times the available P in the top two inches when compared to the availability below eight inches. Thus it is critical that collected samples be to the recommended depth. For most states, recommendations for P and K are based on a 6- or 8-inch sample depth, regardless of tillage system. With conservation tillage, some states recommend that a 4-inch sample be collected to determine the lime requirement. Other states recommend that shallow samples (0 to 2 inches) be collected from no-till fields, especially when pH related herbicide effectiveness problems are anticipated.

How does one interpret a soil test result?

Conversion of soil test results into an application map involves interpretation, and philosophical differences exist as to the best approach to managing fertilizer. At present there are three prevailing approaches to soil fertility management, namely nutrient build-up and maintenance, nutrient sufficiency, and cation saturation ratio. Applying these different concepts to the interpretation of soil test values can produce significantly different fertilizer recommendations. It is important for the farmer to understand why these differences exist.

The build-up and maintenance approach involves applying large quantities of nutrients to low testing soils to rapidly build test levels to the point where those nutrients will not limit yields. Once soil test levels have been built, smaller quantities of nutrients are regularly applied to maintain the non-limiting soil test levels. This practice has been called "feeding the soil." It is especially applicable to low mobility nutrients like P and K.

In comparison, the sufficiency level approach is more conservative in rates applied (lower short-term fertilizer cost) but potentially riskier in terms of nutrient related yield loss. Since the objective is to provide only for the needs of the crop and not build soil test levels, total amounts of nutrients are typically lower and extra fertilizer cannot be luxury consumed or leached or eroded away. However, with a sufficiency level approach, a farmer is not insured against temporary financial emergency or bad weather that can prevent him from "feeding" the crop in any given year.

The cation saturation ratio concept applies only to cations and is based on the idea that maximum yields can only be achieved when there is an ideal ratio of Ca (Calcium) to Mg (Magnesium) to K in the soil. However, research has consistently shown that plants can yield optimally over a range of ratios. Furthermore, even if the ratio of these nutrients is "ideal," a nutrient deficiency can still exist. To avoid this problem, the cation ratio approach can be combined with a nutrient maintenance approach but this can result in some very high fertilizer recommendations.

How often should soils be retested?

In addition to fertilizer and manure application, the nutrient status of soil can be increased through material brought down by rain, decomposition of plant residues and weathering of soil. Soil fertility is depleted by plant uptake, by soil erosion and leaching, and by the chemical transformation of plant-available nutrient forms to unavailable forms. It seems logical that a farmer should be able to estimate the current fertility status of the soil by adding the gains and subtracting the losses from a previously taken soil test. Unfortunately, there are several factors that cannot be determined with a great deal of accuracy and thus soil tests need to be periodically retaken. Historically, guidelines for long-term fertility management have recommended retesting a field approximately every 3 to 4 years, with sandier soils tested more frequently and heavier soils less frequently.

Further details regarding sampling strategies, numbers of cores, timing and location of retesting, seasonal effects on soil test values and a discussion of the suitability of "old" calibrations of the soil tests for use with precision agriculture are presented in Reference C on Soil Sampling and Analysis.

How does one assess the need for variable-rate N application?

Variable-rate N application requires some special consideration. Since N is easily transformed in the soil and can be lost in high rainfall environments, determining the N needs of the crop from a direct measure of soil N is typically not practical, cost effective or even feasible. Current N recommendations typically rely heavily on an N balance approach to determining the N fertilizer needs of a corn crop. The balance approach estimates the total N needs of the plant as well as the soil's ability to supply N to the root. The amount of fertilizer required is based on the difference between these two estimates. This calculation can be made on a whole field basis or on the basis of separate zones within a field.

Given the N needs of the crop are a principle factor, yield maps collected over multiple years will be useful in identifying management zones with different yield potentials and thus different N uptake requirements. A good rule of thumb to determine the total N required by the grain and the vegetative portion of the plant is to multiply expected yield by a factor of 1 -1.2 pounds of nitrogen per bushel (check state recommendations).

The soil's ability to supply N is often strongly related to drainage and other factors related to soil type including percent organic matter, depth of the rooting zone and soil texture. Therefore, soil surveys, aerial photos showing soil color change, drainage and topographic maps and soil test results will all be useful. For example, footslope positions tend to have higher organic matter content and higher levels of mobile nutrients including N. This usually corresponds to higher yields as long as poor drainage does not lead to extensive ponding.

In some regions of the Cornbelt, electrical conductivity (EC) measures have been successful at pattern detection for defining N management zones. For these regions, the within field variation in EC has reflected differences in water related properties that, in turn, determine yields. Example are the claypan soils of Missouri and Illinois. There EC variability has been found to be strongly related to differences in topsoil thickness, which is a critical factor limiting soil productivity. N rate adjustments for corn based on the EC have been successfully demonstrated. However, it should be noted that the interpretation of EC readings will vary from one region to the next. In general, with the exception of claypan soils, few guidelines exist on how to apply EC information to N management.

When is it profitable to use variable-rate application to address soil variability?

The first step in economic analysis of site-specific fertilizer management is a partial budget:

Change in Revenue
- Change in Costs
____
Change in Profits

The change in revenue is price multiplied by the change in yield. The difficulties in showing profitability of site-specific soil fertility management come mainly from problems in measuring yield changes.

The costs of site-specific management are relatively easy to estimate, but many budgets omit costs or have trouble allocating them over time.

Yields - Economic research suggests that profitable site-specific management will probably mean higher yields. Reductions in fertilizer use are often not enough to pay for the extra costs of soil testing and variable-rate application. Nationwide, the most common outcome in site-specific fertilizer trials is that fertilizer use stays about the same, but is redistributed within fields, with some areas receiving higher rates and others less.

Showing yield increases from site-specific management in field trials is difficult because of spatial variation. The old standard "side-by-side" trial may give misleading results if one side is different from the other. The higher yield on one side may be due to the site-specific management, or it might be due to the way that water flows on that field, or soil type, or cropping history. Even fields that look perfectly uniform may mask subsoil differences or may have slight differences in topography that affect yields.

Statisticians are still arguing about the best way to carry out trials of site-specific management, but it is safe to say that reliable comparisons usually require more than a

Table 1. Range of prices for site-specific soil fertility management services.

Service	Average	Maximum	Minimum
	per acre	*per acre*	*per acre*
Soil Sampling with GPS	$6.19	$9.50	$3.00
Field Mapping with GPS	$3.24	$7.00	$0.50
Agronomic Recommendations	$1.34	$3.00	$0.00
Fertilizer Application:			
Manual Variable-Rate	$4.56	$7.00	$2.00
GPS Variable-Rate Single Product	$5.64	$7.50	$3.00
GPS Variable-Rate Multiple Product	$7.78	$9.50	$5.00

Source: Akridge and Whipker, 2000.

simple side-by-side field trial. Several replications are usually needed. It may be necessary to make comparisons by soil type, not just by strips the length of the field. (See the on-farm research chapter in the reference section).

Another problem is related to the fact that site-specific management is about fine-tuning. Yield gains of 1 or 2 bushels per acre may be enough to pay for the extra soil sampling and variable-rate application costs, but such differences are impossible to see in high yielding crops and even difficult to detect reliably with statistics.

The alternative to field trials is estimation of yields using a model. This model may be as simple as a response curve that gives expected yields at various soil fertility levels or as complex as a computer simulation.

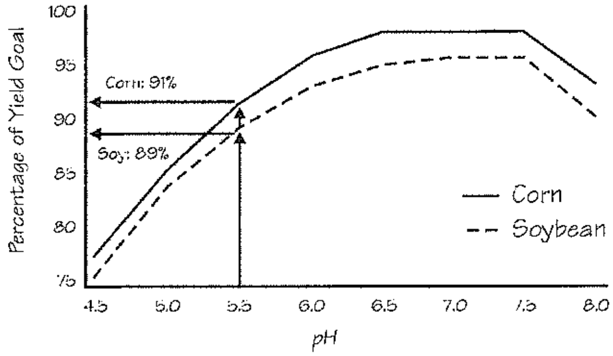

Figure 4. Corn and soybean relative yield response to soil pH on selected soils (Bongiovanni and Lowenberg-DeBoer, 1998).

Use of a model has the advantage of providing a timely estimate, no need to wait for three or four years of yield trials. The disadvantage is that even the most complex models are a simplification of reality. Models never include all the factors that affect yields. This is a problem because site-specific management may correct one soil fertility problem, but other factors may still limit yields. For example, an expected yield increase from lime application (Figure 4) may not occur because of low subsoil water holding capacity or drainage problems.

Costs - The key to cost estimation for site-specific fertility management is to seek out all costs that change and to allocate those costs over time appropriately. Costs that might change include:

- field mapping and development of management zones
- digitized soil maps
- aerial photographs
- collecting soil samples
- lab analysis
- soil map interpretation and fertilizer recommendations
- variable-rate application fees
- amount of fertilizer applied
- equipment and software
- training

In the past, fertilizer dealers often "bundled" soil testing and recommendation costs into fertilizer cost. With site-specific management, those costs become larger relative to the price of the material and there is competitive pressure to "unbundle," that is, to charge for each service and product separately. The prices on these unbundled services vary widely (Table 1) so it pays to shop around. The fee for variable-rate application is typically about $3/acre to $5/acre more than uniform application.

Cost allocation is important when inputs are used over several years. This is easy to see for equipment, but not so obvious for data, training and fertilizer with carryover effects. Time has two main effects in budgets: depreciation and opportunity costs of investment. For taxes it is wise to deduct an investment as quickly as possible. For management purposes, a more accurate picture is obtained when investment costs are allocated accurately over time.

Depreciation is a way of spreading the cost of a durable investment over the life of that item. The easiest is the so-called "straight-line" depreciation calculated by dividing investment by the number of years it will be used. A 2-ton/acre lime application costing $36/acre, which has effects over four years, might be depreciated at $9/acre/year. Similarly, the costs of a digitized soil map purchased for $100 might be allocated over 10 years or more.

If money were not invested in site-specific management, it could be used elsewhere. It might be used to pay off debt, to purchase new equipment, to buy land or invest in the stock market. The opportunity cost is the return on the alternative use of that money. If the opportunity cost of money is 10%, the cost of investing in lime for $36/acre is the $9/acre depreciation, plus the $3.60/acre as the opportunity cost (10% of $36).

Table 2. *Lime rates and expected pH by zone with uniform and site-specific lime application.*

Figure 5	**Initial**	--------------Uniform-------------		------------Site-specific----------	
Zone	**Zone pH**	**Lime Rate**	**Expected pH**	**Lime Rate**	**Expected pH**
		--ton/acre--		--ton/acre--	
Northeast	4.5	2	5.2	6	6.5
Middle	5.5	2	6.2	3	6.5
Southwest	7.0	2	7.7	0	7.0

Table 3. *Expected yields from uniform and site-specific lime application on a 10-acre field.*

Figure 5 Crop & Zone	**Expected Yield at Initial pH**	**Expected Yield with Uniform Lime**	**Expected Yield with Site-specific Lime**
	-----------------------------	--bu/acre--	-----------------------------
Corn			
Northeast	107.8	123.2	138.2
Middle	163.8	174.6	176.4
Southwest	176.4	172.8	176.4
Field Average	150.8	158.6	164.9
Soybeans			
Northeast	34.2	38.7	42.8
Middle	53.4	56.4	57.0
Southwest	57.0	55.8	57.0
Field Average	48.7	50.9	52.7

Variable-Rate Lime Example - A corn and soybean producer is thinking about variable-rate lime application and would like to use a 10-acre field as an example (Figure 5). The field has been divided into 3 management zones by soil types: Northeast, Middle and Southwest. The Middle zone is 4 acres and the other two zones are 3 acres each.

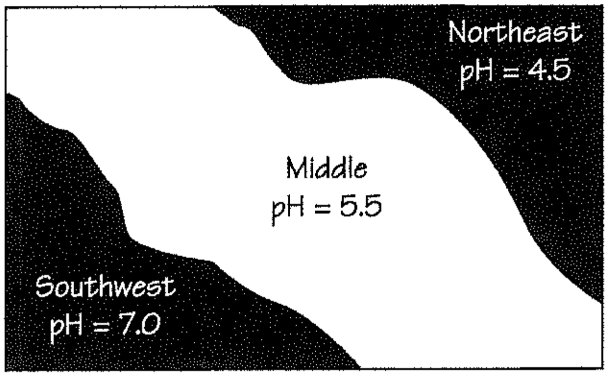

Figure 5. Simulated 10-acre field divided into 3 management groups.

The producer has a composite soil test done in each zone and finds that the pH varies from 4.5 in the northeast zone to 7.0 in the southwest zone. The middle zone has an intermediate value of 5.5. For comparison purposes this producer also has done a whole field composite soil test, which shows a pH level of 5.8. Based on yield monitor data the yield potentials are estimated as: Northeast, corn=140 bu/acre, soybeans=40 bu/acre; Middle and Southwest, corn=180 bu/acre, and soybeans= 60 bu/acre.

One way to make a decision about variable-rate lime is to do an on-farm trial. Unfortunately, lime trials typically take at least fours years and are often difficult to interpret because pH interacts with many other factors. One alternative is to use pH response curves for corn and soybeans (Figure 5) to estimate yields. The response curves provide estimates of "relative yield," which is expressed as a percentage of the yield potential. For example, in the middle zone at pH = 5.5, he finds that the soybean response curve is at 89% of potential and the corn response curve is at 91% of potential. For the middle zone, the expected yields without lime would be 163.8 bu/acre for corn (0.91*180) and 53.4 bu/acre for soybeans (0.89*60). The response curve yield estimates increase up to a pH of 6.8 and then decline above 7.5. The yield cuts at high pH are linked to damage from some soil applied herbicide and micronutrient deficiencies.

It takes about 3 ton/acre of lime to raise pH one point. For whole field management with a pH of 5.8, his strategy would be to apply 2 ton/acre of lime. In terms of the response curves, this leaves the pH in the northeast zone still at relatively low yields (Table 2), the middle zone close to optimum and the high pH zone pushed into the range of declining yields. Uniform application of two ton/acre results in an estimated production increase of 78.6 bu of corn for the field. Soybean production increases an estimated 21.9 bu for the field.

For the site-specific strategy, he would apply 6 ton/acre in the low pH zone in the northeast corner of the field, 3 ton/acre in the middle zone and nothing in the relatively high pH zone in the southwest corner. This is a total of 24 tons for the field, slightly above the 20 tons used for the whole field management. In terms of the response curves, site-specific management puts pH close to the optimum in all zones. The economic optimum pH is probably a little lower than the one that gives the maximum yield. From pH 6.5 to 6.8, yield increases very little and probably would not cover the cost of lime. Compared to yields at the initial pH level, site-specific management results in a corn production increase of 141.5 bu and a soybean increase of 40.1 bu for the field.

He uses the costs from his local fertilizer dealer for sampling by soil type ($6/acre), variable-rate application ($6/acre) and lime $18/ton. The dealer is willing to make the lime recommendation map without extra charge, if he buys the lime from him. A composite whole field soil test costs $7. Uniform spreading is $3/acre. For the variable-rate spreading the estimates assume that the spreader travels over the whole field, even though some parts do not receive lime.

The example assumes corn at $2.25/bu and soybeans at $5.50/bu. With a fertility maintenance cost of $0.35/bu for corn and $0.25/bu for soybeans, corn drying at $0.25/bu and hauling at $0.20/bu, the net return per added bushel is $1.45/bu for corn and $5.05 for soybeans.

In a corn/soybean rotation, the gross annual benefit can be estimated as the average value of the corn and soybean yield increase. For example, for the value of the extra corn produced by site-specific management the calculation is 141.54 bushels multiplied by $1.45 equals $205.23 (Table 4).

Soil testing and lime application only occurs once in the four-year soil sampling cycle, so those costs need to be allocated. In Table 4 this was done using straight-line depreciation (one fourth of the cost allocated to each year) and a 10% opportunity cost of capital. The annual costs in Table 4 are (0.25 + 0.1) = 0.35 multiplied by the total cost in each category. Uniform lime application at a rate of 2 ton/acre has an estimated cost of $138.95/year for the field, or almost $14/acre. Site-specific lime application has a cost of $193.20/year for the field or about $19.32/acre.

The budget example (Table 4) indicates that the whole field application of 2 tons of lime loses a little money. This is mainly because it leaves the northeast zone at a low pH and it pushes pH too high in the southwest zone. The site-specific management is modestly profitable, $37.21 for the field or $3.72/acre. This is a typical result for site-specific lime management. No one will become rich from site-specific lime, but it seems to be a consistently profitable practice for corn and soybean producers in areas of high pH variability.

Table 4. Expected annual profits from variable-rate lime on a 10-acre field.

Item	Uniform	Site-specific	Difference
Annual Value of Yield Increase:			
Corn	$113.97	$205.23	$91.26
Soybeans	$110.60	$202.25	$91.66
Average Gain over Rotation	$112.28	$203.74	$91.46
Annual Costs:			
Soil Testing	$2.45	$21.00	$18.55
Application Fee	$10.50	$21.00	$10.50
Lime	$126.00	$151.20	$25.20
Total Cost	$138.95	$193.20	$54.25
Average Net per field/year	-$26.67	$10.54	$37.21
Average Net per acre/year	-$2.67	$1.05	$3.72

At $3/bu corn and $7/bu soybeans the annual per acre site-specific advantage rises to $7.44/acre. It is more profitable to fine tune management of crops with higher prices. At $2/bu corn and $5/bu soybeans, no lime application is profitable for this field, but site-specific loses $2.48/acre less than the uniform application.

This rough estimate misses several potentially important costs and benefits of site-specific management. The $6/acre soil test probably includes more than just pH. It probably includes phosphate, potassium, CEC and other site-specific information. A more accurate calculation would spread the cost of the soil test over the various tests.

This estimate does not take into account the pH decline in the second, third and fourth years due to calcium removed in the crop and acidification from nitrogen application. In the Eastern Cornbelt corn production consumes the equivalent of 0.35 ton/acre of lime annually. Soybean production consumes about 0.15 ton/acre annually. If 3 tons of lime are needed to increase soil pH by one point, this means that pH drops about 0.12 for each corn year and 0.05 for each soybean season.

Further Information

Akridge, Jay, and Linda Whipker, "2000 Precision Agricultural Services and Enhanced Seed Dealership Survey Results," staff paper No. 00-04, Center for Agricultural Business, Purdue University, West Lafayette, IN, June 2000. Also available at www.purdue.edu/ssmc.

Bongiovanni, Rodolfo, and J. Lowenberg-DeBoer, "Economics of Variable-Rate Lime in Indiana," in Precision Agriculture, P.C. Robert, R.H. Rust, and W.E. Larson, eds., ASA/CSSA/SSA, Madison, Wisconsin, 1998, p. 1653-1666.

Partial Budget Template For Estimating Whole Farm Profits from VRT Fertilizer

Item	Unit	Quantity	Value/Unit	Amount
Change in revenue:				
Yield increases for whole farming operation[1]				
Corn	______	______	______	______
Soybeans	______	______	______	______
Wheat	______	______	______	______
Other crops	______	______	______	______
Total change in annual revenue (sum of all the revenue changes)				______
Change in costs:				
Annualized costs of equipment and other durable items[2]				
VRT equipment (useful life =___years)[3]	______	______	______	______
GPS (useful life = ___years)[3]	______	______	______	______
Software (useful life = ___years)[3]	______	______	______	______
Training (useful life = ___years)[3]	______	______	______	______
Other (useful life = ___years)	______	______	______	______
Change in variable costs[4]				
Soil testing and analysis	______	______	______	______
VRT application fees	______	______	______	______
Crop consultant fees	______	______	______	______
Differential correction annual fee	______	______	______	______
Repairs and maintenance	______	______	______	______
Office supplies	______	______	______	______
Fertilizer[5]				
Lime	______	______	______	______
Phosphate	______	______	______	______
Potassium	______	______	______	______
Nitrogen	______	______	______	______
Micro Nutrients	______	______	______	______
Other (e.g. extra grain drying, hauling)	______	______	______	______
Total change in annual cost (sum of all the annual cost changes)				______
Whole farm annual net return (Subtract annual cost change from annual revenue change)				______
Per acre net return (Divide net return by acres farmed, _______acres)				______

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1) The quantity in this line should be the change in production for the whole farm. If the main benefit of spatial management is the reduction in fertilizer quantity used, the yield changes might all be zero.

2) Include anything that is used for more than one year.

3) See Chapter 1 for suggestions on estimating annual costs of equipment and other durable investments.

4) These are incremental costs. Soil testing and other costs should be allocated over soil sampling cycle.

5) Many fertilizers have carryover effects for several years. If the farm has a stable rotation (e.g. 50/50 corn/soybean) and a constant soil sampling and fertilizer application cycle (e.g. P & K every two years before corn, lime every 4 years), the simplest approach is to list average annual amounts and expenditures here. If crop acreage, fertilizer application, soil testing varies substantially from year to year, fertilizer costs should be allocated over time in the same way that equipment costs are. There may be cost increases or costs savings on any item. If fertilizer quantity is reduced, the quantity in these lines is negative and the amount is a cost savings.

Effective and efficient weed control may become more attainable through the use of site-specific management methods, global positioning systems (GPS) and variable-rate technologies (VRT).

5
CHAPTER

INCREASING COST EFFECTIVENESS OF WEED CONTROL

By Case Medlin, Jess Lowenberg-DeBoer

Learning Objectives

In this chapter you will learn

1. Important benefits of site-specific herbicide management;
2. How GPS guidance systems are used in effective weed management programs;
3. The costs and benefits of GPS systems in on-farm weed management situations; and
4. How some farmers are utilizing Variable-Rate Technologies (VRT) to effectively manage weeds and cut costs.

Introduction

Weeds and farmers have been competing for yield as long as farmers have been around. Site-specific weed management may offer farmers some new, more effective methods of putting the odds in their favor. The GPS guidance systems, yield monitors and site-specific weed maps combined with the farmer's years of experience all offer substantial benefits in accurate and effective weed control.

Site-Specific Weed Management Poses Some Challenges

Site-specific weed management is currently the newest and least advanced of the site-specific technologies. Some day, it could easily offer the greatest economical and environmental benefits. University and industry researchers continue to work to make site-specific herbicide application systems available to producers. However, the complexities of the weed-soil-climate-environment-crop interactions continue to pose challenges.

Consider an example. Many soil fertility conditions remain relatively constant over a period of several years -- so grid sampling soil nutrients is required every several years. That's why several years of site-specific fertilizer applications may be based on a soil nutrient map made years earlier. However, the geography and composition of weed populations can change considerably within just one growing season and even more drastically across several growing seasons. These fluctuating weed populations may be a result of pre-plant tillage practices, herbicide applications, fertilizer applications, climatic conditions, multiple weed flushes, in-season cultivation, or crop harvest patterns.

These scenarios can lead to poor decisions regarding need for weed management. Producers are well aware that often weeds tend to be isolated into patches within fields.

***Figure 1**. Many perennial weeds, such as johnsongrass, exist as distinct patches in fields. Control of johnsongrass in a soybean crop is relatively easy with herbicides, but could be expensive if treating the entire field.*

In many instances, large portions of fields are weed-free, while other areas have high weed populations. Ultimately, the challenges of variability continue to test producer ingenuity. Perhaps one day, this technology will lead to GPS/GIS-controlled sprayer injection systems that will vary the herbicide or rate based on weed populations.

Increasing Herbicide Placement/Accuracy

Site-specific herbicide management will ultimately benefit:

- Crop producers by decreasing herbicide input costs, providing optimum herbicide placement, and maximizing net return of herbicide treatments, and
- The environment by limiting the amount of herbicides sprayed to only those weed-infested areas.

Currently there are a limited number of automated site-specific herbicide application systems on the market, however, there are several practices being implemented. Most of these practices either limit herbicide applications or increase the accuracy of herbicide placement. Perhaps the easiest management practice for commercial applicators (and producers with large acreage) to implement is a GPS guidance system on their pesticide applicators.

GPS - Its Use and Potential Are Growing

GPS guidance systems are used in all types of agricultural operations. Useful particularly in applying weed control chemicals, GPS could potentially replace foam markers. These systems also help operators reduce skips and overlaps

Use of GPS in chemical application with ground equipment has grown quickly. In the last two years, the use of GPS guidance has gone from almost nothing to being used by 29% of fertilizer dealers who offer custom application. Crop producers also are starting to use the systems.

The Lightbar

In its most basic form, GPS guidance consists of a horizontal "lightbar" in a plastic case 12 to 18 inches long linked to a GPS receiver. The operator watches a bar of light. If the light is on the centerline, the machine is on target. If a bar of light extends to the left, the machine is off the path to the left and needs to be corrected. If a bar of light extends to the right, the machine is off to the right. The lightbar can be mounted inside or outside of the cab. Similar GPS guidance systems have been used for aerial application since the early 1990s. GPS is an excellent way to improve accuracy and speed of uniform application. Other uses on the farm, including variable-rate application and yield monitoring, might make it more valuable to some innovators.

***Figure 2**. Lightbar.*

TED BIEHL

UAP Richter
Urbana, IN

Analysis is needed to reap the greatest return from precision farming techniques. That's the attitude of Ted Biehl of UAP Richter, Urbana, Indiana. He has been involved with the fertilizer business the past 28 years, and for the past five years in variable-rate fertilizer application. The business has expanded to include grid soil testing, and storage and analysis of yield map data.

"Site-specific farming has explained a lot of situations about what is going on in the field, but it has created an immense amount of work for the farmer and the dealer to analyze this data." Biehl hopes farmers will soon see the benefits of accumulating years of yield maps.

"I just handed a farmer 60 pages of yield maps to analyze," explains Biehl. "I'd say the yield maps have shown wet areas and dry areas, very clearly. In some cases, I'd say it showed where we applied lime. We see cost effectiveness with fertilizer application, but we don't yet see the yield increases like we'd like to think we should."

Biehl emphasizes his belief that data collected and not utilized is not beneficial. He says if farmers are to see positive results of precision farming techniques, they must accurately analyze data in a timely fashion.

More advanced systems have a screen showing the swath of the machine as it moves through the field. Early models only allowed straight line parallel swaths, but now software is available for any contour. Areas covered with previous swaths are indicated on the screen. These systems have the capacity to generate "as-applied" maps showing previous coverage and the application pattern.

GPS vs. Foam Markers

Potential advantages of GPS guidance for producers include:

- **GPS parallel swathing is more reliable and more accurate than foam markers** - According to Scott Azbell of Agro-Chem in Wabash, Ind., using foam markers could cause about 10 percent of the field to either be skipped or overlapped. With GPS, the skip and overlap rate drops to about five percent. Some tests have shown that experienced operators see the skip and overlap rate with GPS drop as low as 1.5 percent.

- **GPS guidance allows accuracy at higher speeds** - A test done in New Zealand showed a 13 percent higher speed with GPS guidance than with a foam marker. A similar test in California showed a 20 percent higher speed.

- **With spinner spreaders GPS guidance is the only possibility** - Azbell said foam markers cannot be used effectively with spinner spreaders. The spreaders have no boom on which the foam equipment can be installed. Due to the spread width, a foam marker in the center of the machine path is difficult to see from the next swath. "One of the forces driving GPS guidance in our area is dry application, especially lime," Azbell said. "Variable - rate lime to manage pH is a proven practice. Lime is applied with spinner spreaders which can't use foam markers."

- **GPS guidance is easy to use** - Anyone can learn to use GPS guidance systems. Though younger operators might learn faster because they are more accustomed to computer use, the systems are not difficult for anyone to learn with a little practice.

- **GPS provides effective guidance over growing crops** - With solid seeded crops, the foam tends to fall through the canopy to the ground where it is almost invisible, contributing to skipping or overlapping. GPS is not affected by crop height.

- **GPS guidance allows operation when visibility is poor** - GPS guidance works at night, in dust or fog. This lengthens working time during critical planting and spraying periods. In many areas nighttime is best for spraying because of low wind speed.

- **GPS guidance is less affected by weather** - In some semi-arid areas low humidity, heat and large field size combine to make foam markers ineffective. The foam sometimes evaporates before the operator makes the return swath. GPS guidance works at any temperature, including low temperatures when foam systems freeze.

- **GPS guidance has lower recurring costs** - GPS guidance has no moving parts or tubes to clog. Depending on the manufacturer, software updates for GPS guidance are usually free to system owners. Current GPS guidance technology could be eclipsed by new technology before it wears out. Foam marker systems require foam, dye and tank cleaner.

The primary recurring cost for GPS guidance is satellite differential correction. Typically, this costs about $800 per year for each GPS unit. Many producers already have GPS for yield monitoring and pay a differential correction fee. For them, GPS guidance has almost no recurring costs. It is possible to use GPS guidance with Coast Guard beacon differential correction. This may be adequate for some applications, like application of dry fertilizer with a spinner spreader. According to Azbell, accuracy for spraying should be within six inches or 10 centimeters.

- **GPS guidance reduces operator fatigue and eye strain** - With the lightbar mounted directly in front, GPS guidance operators do not need to look backward or sideways. They can drive accurate swaths while looking straight ahead.

KEITH ANDERSON

West Point, NE

Variable-rate applications of fertilizer and lime are being adopted throughout the Midwest and Keith Anderson of West Point, Nebraska, decided to give variable-rate herbicide application a try at the suggestion of his local co-op.

"It worked out fine. The dealer said a lot of growers were really interested and satisfied with it," comments Anderson. "Cost-wise I don't think I saved any money.

But as for weed control, it worked real well." Anderson used a pre-emergence herbicide. He plans to use variable-rate technology on another field.

- **GPS guidance has lower set-up time** - Foam markers have tanks to fill and dyes to change. GPS guidance begins working approximately 30 seconds after the machine is switched on.

- **GPS guidance is not affected by wind or boom bounce** - Blowing foam or a foam system bouncing at the end of a long boom over rough ground may introduce substantial error. GPS systems are not affect by rough land or wind.

- **GPS guidance reduces chemical use, by reducing overlaps** - If a 10 percent overlap is reduced to five percent, chemical use also is reduced by five percent. Not only is this good for the environment, it's good for the bottom line.

- **GPS guidance reduces need to enter already sprayed areas** - According to Steve Hawkins, Assistant Director of Purdue University Agricultural Centers, GPS guidance allows the operator to mark where spraying stopped without dismounting.

GPS Guidance Cost

The most frequently mentioned disadvantage of GPS guidance is the up-front cost. Costs range from about $3,000 for a farmer who already has a GPS to over $14,500 for a custom applicator.

A basic system with GPS and lightbar can be purchased for about $7,000. According to Azbell, the biggest differences between the farmer and custom systems are speed, screen display and the ability to provide as-applied maps.

"Some of the cheaper GPS guidance units that you see advertised are slow. It is like using a computer with 286 chips," Azbell said. "They are also strictly lightbar units, with no screen display or map making ability."

Foam marker system prices range from $900 to $2,800. According to Azbell, speed also is an issue in foam systems. The lower cost foam systems are slower and work adequately when application is done with a tractor. Commercial applicators operating at 20 mph need more foam output than lower cost systems can provide.

The useful life of the GPS units is hard to estimate because of the short period they have been available. Azbell recommends users try to recover costs in three years. Foam marker systems often last five years or more, Azbell said

"The GPS guidance system will work longer than three years, but by that time it will probably be obsolete," Azbell said. "It will still do everything you originally wanted it to do, but something much better will be on the market."

Cost and benefits vary widely depending on the crop, acreage covered, swathing accuracy achieved and other factors. Table 1 provides examples of GPS guidance costs and benefits for two scenarios: producer buying a complete system including GPS and lightbar, and a producer who already has a GPS.

Both scenarios show GPS guidance as increasing per acre costs, compared to the foam marker method. The per acre costs almost double for the producer who already has a GPS. For the producer starting from scratch guidance costs increase by a factor of six. This means that for producers the key to determining the profitability of GPS guidance is on the benefit side.

The benefits estimated in Table 1 focus on only the opportunity cost of sprayer operation and the cost of extra chemical and fertilizer at $10/acre. Azbell's estimate of the percentage overlap is used, 10 percent with foam markers and 5 percent with GPS guidance. For simplicity, the example assumes operators are very cautious and make only overlaps, no skips.

"Operators tend to overlap more than they skip in order not to show the obvious misses to the farmer's eye," said Roz Buick, Trimble Navigation, Christchurch, New Zealand. "When watching the foam marker at the end of the boom the tendency to overlap is greater than to skip."

The machine cost of overlaps is estimated at the custom rate, $4.40 per acre for producers with tractor units and $5 per acre for commercial custom application. In most cases, the custom application rate is a good estimate of labor and machine costs including depreciation, fuel, lubricant and repairs. For the custom applicator, the custom rate is what the applicator would earn if the operator and machine were spraying another field instead of overlapping swaths.

The estimation of the economic impact of skips is complicated because the effect of crop yield varies by crop, the weed population and how long term weed seed bank effects are valued. A skip is much more costly in a higher value crop, such as sugar beets, potatoes, or seed crops, than it would be in bulk commodity corn, soybeans and wheat. If the skip occurs in a very clean field, the yield effect may be minimal, but in a heavily infested field the yield may drop to almost zero. Weed scientists suggest that the greatest economic effect of skips may be on creating a seed bank that will lead to management problems in future years.

Table 1. Cost and benefit examples for GPS guidance and foam marker use on a 1500-acre farm.

Item	Foam Marker	GPS Guidance	Lightbar Only*
Costs:			
Purchase Price, $	$1000	$7000	$3000
Useful Life, years	5	3	3
Annualized Cost, $/yr	$300	$3033	$1300
Recurring Cost:			
Foam, $/yr	$336	0	0
Differential Correction, $/yr	0	$800	0
Annual Cost, $/yr	$636	$3833	$1300
Annual Cost, $/acre/yr**	$0.21	$1.28	$0.43
Benefits in Reducing Overlap:			
Percent of Area Overlapped	10%	5%	5%
Overlap Acres**	300	150	150
Machine Cost			
$/acre	$4.40	$4.40	$4.40
$/yr	$1320	$660	$660
Extra Chemical and Fertilizer, $/yr	$3000	$1500	$1500
Overlap Cost, $/yr	$4320	$2160	$2160
Overlap Cost, $/acre/yr**	$1.44	$0.72	$0.72
GPS net benefit, $/acre/yr		-$0.35	$0.50

Source: Lowenberg-DeBoer, 1999.

** Assumes producer already has DGPS.*

*** Assumes 3000 acres sprayed each year (2 x 1500-acre farm size).*

This is a conservative estimate of GPS guidance benefits, which does not include many of the advantages outlined above. In this example, the producer who does not own a GPS would need about 2,000 acres to break even. Sensitivity testing shows that the break-even acreage for the lightbar is only 600 acres for producers with GPS.

Variable-Rate Herbicide Applications

Variable-rate fertilizer applications have been used for a number of years. However, only recently have producers and commercial applicators started using variable-rate herbicide applications. Variable-rate herbicide applications can be discussed in two separate groups:

- Soil-applied herbicide applications
- Post-emergence herbicide applications

In general, the equipment needed to make variable-rate liquid fertilizer applications can also be used to make variable-rate soil-applied herbicide applications. First, one needs a map of the soil property(ies) for varying the herbicide rate and the herbicide rate ranges intended for each category. The rest is very similar to variable-rate applications of fertilizers.

Variable-Rate Soil-Applied Herbicide Applications

To anyone who has ever read a herbicide label, it is obvious that site-specific herbicide applications of soil-applied products are needed. Rates of these products are usually dependent on a number of soil properties including soil texture, soil organic matter, soil pH, and the cation exchange capacity of the soil (Figure 2). Since each herbicide family has different chemical properties, the degree of impact by the changing soil conditions may have a pronounced or minimal impact on the herbicide rate change (Table 2).

Table 2. *The rates of most soil applied herbicides vary dramatically based on soil texture, soil organic matter, soil pH, soil cation exchange capacity, or a combination of these factors. Site-specific application of these herbicides may result in fewer cases of crop response and improved weed control.*

Herbicide Rate Based on Soil Texture and Soil Organic Matter (OM) Content			
	Soil texture		
	Coarse	Medium	Fine
Axiom At[1]	<3% OM = 1.5 to 1.75 lb/acre >3% OM = 2 to 2.25 lb/acre	<3% OM = 2 to 2.75 lb/acre >3% OM = 2.5 to 3 lb/acre	<3% OM = 2.75 to 3 lb/acre >3% OM = 3 to 3.5 lb/acre
Balance WDG[2]	<1.5% OM = not recommended >1.5% OM = 1 - 1.25 oz/acre	<1.5% OM = 1.25 to 1.75 oz/acre >1.5% OM= 1.5 to 2 oz/acre	<1.5% OM = 1.5 to 2 oz/acre >1.5% OM= 1.5 to 2.5 oz/acre
Bicep II Magnum[3]	2.4 qt./acre	2.4 to 3 qt./acre	3 qt./acre
Frontier 6.0[4]	<3% OM = 20 to 24 fl. oz/acre >3% OM = 24 to 28 fl. oz/acre	<3% OM = 24 to 28 fl. oz/acre >3% OM = 28 to 32 fl. oz/acre	<3% OM = 28 to 32 fl. oz/acre >3% OM = 32 fl. oz/acre
Leadoff[5]	<3% OM = 2.5 to 3 pt/acre >3% OM = 3 to 3.5 pt/acre	<3% OM = 3 to 4 pt/acre >3% OM = 4 to 4.5 pt/acre	<3% OM = 4 to 4.5 pt/acre >3% OM = 4.5 to 5 pt/acre

[1] Trademark of Bayer Corporation
[2] Trademark of Aventis CropSciences
[3] Trademark of Novartis Crop Protection
[4] Trademark of Trademark of BASF AG
[5] Trademark of E.I. DuPont de Nemours and Company

Figure 2*. Soil factors can vary significantly across a large production field. Many herbicides are safest to the crop and most effective on the weed when applied at specific rates. Therefore, VRT applications based on soil pH, soil O.M, or soil texture variability should be very beneficial in the future.*

Benefits of using variable-rate herbicide applications may result from reduced crop injury from excessive herbicide applications in areas requiring lower rates, improved weed control from higher rates when needed, reduced applications to areas that may experience negative effects of herbicides, and increased profitability of weed management (Figure 3).

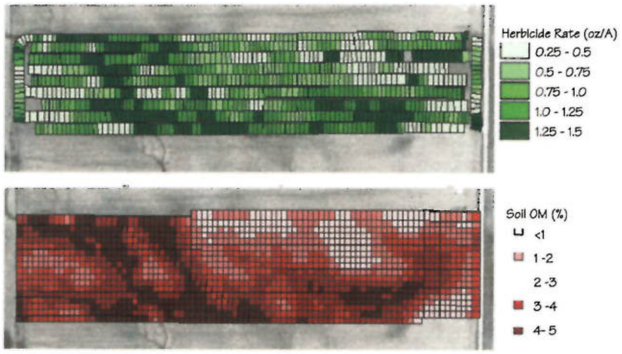

Figure 3*. VRT application of soil-applied herbicides is currently possible with some slight equipment modifications. Based on previously acquired soil parameters, one can vary a herbicide rate based on soil organic matter, texture, pH, or a combination of these parameters. The top map illustrates the rate changes needed to appropriately apply the herbicide based on soil organic matter. (provided by Marshall Beatty, Purdue University)*

Variable-Rate Post-Emergence Herbicide Applications

In general the goal of variable-rate soil-applied herbicide applications is, "reduce the rate in some areas and increase the rate in other areas as needed," however, the entire field still receives herbicide applications. The goal of variable-rate post-emergence herbicide applications is to treat only those areas where weeds are present. With herbicides that are taken up through the foliage, any herbicide that reaches the soil is bound to the soil surface or degraded, rendering it useless for controlling the weed. Unfortunately, as with the VRT equipment for spraying the soil-applied products, there are few automated VRT systems for applying post-emergence products.

The first challenge of VRT applications of post-emergence herbicides is locating the weeds. Weed maps can be developed from knowledge of past years weed infestations, data collected at harvest with a yield monitor, data collected by in-season crop scouts, or by visual analysis of the field by the applicator. Since weeds tend to spread through seed and/or vegetatively, they are likely to infest the same areas of the field the following years. Thus, the capability of returning to treat marked weed patches or visually identifying weeds on the go is critical for most successful site-specific weed management systems.

Site-Specific Weed Scouting Methods

With site-specific fertilizer applications, the first key to accurate fertilizer applications is accurate mapping of soil nutrients. For accurate site-specific post-emergence herbicide applications, an accurate assessment of the weed infestations in the field must first be made. Several methods may be used to accomplish this task.

KENT BREWER

Clinton County, IN

"Variable-rate herbicide applications have benefited my production system." So says Clinton County, Indiana, farmer Kent Brewer. (Figure 4)

Figure 4. *Kent Brewer believes reducing soil-applied herbicide rates on sandier ground has resulted in less crop injury and reduced herbicide costs for his operation.*

"I started using variable-rate technology by grid-sampling the soils on my farm in 1994. Once I saw the variability of the soil conditions, I started a variable-rate fertility program." Brewer says he could easily see the impact patchy weed distributions had on crop yield. "That meant there was waste involved in broadcast applications of soil-applied herbicides."

For Brewer, the next logical step was to vary the rate of these products to match the changing environmental conditions across the field. Since he already had detailed soil texture, soil organic matter, and soil pH maps constructed, much of the work was already done. Brewer's automated sprayer simply varied the herbicide rate accordingly. His equipment allows him to carry and VRT apply 3 chemicals simultaneously (Figure 5 & 6).

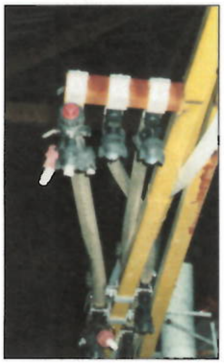

Figure 5. *Kent Brewer's applicator is equipped with three separate spray booms for delivering three different application volumes. The boom selection is automated through the Mid-Tech controller.*

Figure 6. *Brewer's applicator is equipped with an Ag Leader GPS system (a), a Mid-Tech rate controller (b), and two Mid-Tech roller pumps (c), each with its own tank for carrying concentrated herbicide.*

"Overall," says Brewer, "I've reduced my total herbicide usage by leaving a system of blanket applying herbicide rates at the high end of the scale to variable-rate applications based on soil texture and soil productivity."

Brewer says he's confident that he is receiving maximum yield from his most productive soils and has not sacrificed weed control on his sandier, less productive soils. "That's particularly important as new products with marginal crop safety are marketed." Brewer adds, "Producers cannot afford crop injury, extra herbicide expense, or yield reduction due to poor weed control. VRT herbicide applications will be essential to profitability in the future."

This weed management system has also allowed him to become more environmentally conscious. Brewer is now able to eliminate atrazine applications on highly leachable soils, and to soils within setback areas around ponds and streams.

DAVID ESHELMAN

Cass County, IN

"The savings from variable-rate herbicide application are well worth the equipment modification cost," says Cass County, Indiana farmer David Eshelman. Eshelman modified his Spra-Coupe® for making more appropriate VRT postemergence herbicide applications. Eshelman equipped his sprayer with two Mid-Tech roller pumps for metering the desired herbicide volumes directly from tanks of concentrated herbicide. The herbicide is then injected into the spray boom were it mixes with the water carrier before being applied.

"I also use a radar based speedometer for more accurate ground speed assessment," says Eshelman. "Since herbicide application rates are determined by the land area being covered, it is important to have the capability to continually monitor ground speed. This also allows me to change my speed without manually changing the flow rate, the computer makes the adjustments automatically."

This is particularly important since his sprayer carries three different herbicides at once and can vary the rate of two of them simultaneously.

Since there are no automated systems currently available for sensing weeds within the crop canopy and applying postemergence herbicides accordingly, Eshelman relies on his visual assessment of the weeds. "I make the decision to change the herbicide rate or eliminate the application in a given area of a field," says Eshelman. "I simply make the adjustments through the Mid-Tech Controller. Making these judgment-calls requires a good knowledge of the weeds present in the field or good weed identification skills, something that you can develop with time," ensures Eshelman.

***Figure** 7. David Eshelman uses a 6-wheeler to spray small weed patches. This applicator is equipped with its own spray boom and hand wand for spraying weeds in the field or along fence rows.*

Eshelman has been very successful using this system in Liberty Link® corn and Roundup Ready® soybeans. In his Roundup Ready® soybean program, Eshelman will plant his fields and wait approximately seven to ten days prior to applying a burndown herbicide. This extends his weed control window at least 10 to 14 days longer than a traditional system where the burndown herbicide is applied prior to planting.

"During my burndown application, I apply a blanket rate of a soil herbicide and use the broadspectrum activity of Roundup to control emerged weeds," continues Eshelman. "My worst weeds are usually giant ragweed and Canada thistle. With my application system, I increase the Roundup rate in areas with large giant ragweed plants, decrease the Roundup rate were there are smaller plants, or eliminate its application to areas where there are no emerged weeds."

Although he is quick to point out the herbicide cost savings, Eshelman also realizes the importance of reducing herbicide inputs into the environment. For this and other economic reasons, Eshelman has equipped a six-wheeler with a spray tank, broadcast boom, and hand wand for controlling small weed patches in the field or along roadsides (Figure 7).

The first potential method involves the use of a GPS yield monitor equipped with a "marking unit" to map weedy areas for special treatment the next year. Often, weed patches that are visible from the cab of the combine were not visible from the perimeter of the field earlier during the growing season. Since weeds tend to spread through seed and/or vegetatively, they are likely to infest the same areas of the field the following years. Marking these weed patches with a GPS yield monitor should be successful for mapping invading weed species for future treatment or to map distinct areas of fields that contain a species requiring a special control measure.

Although many different weed-scouting methods are currently being used, the goal of each system is the accurate assessment of weed populations across the field. It is currently impossible to account for each weed in any given field, therefore most crop scouts are faced with sacrificing accuracy for time spent in the field. To address this issue, many agencies have outfitted their crop scouts with motorcycles for covering more crop acreage in less time. This allows each scout to cover more acres in a day's time and also to make more accurate assessments of conditions within a given field. If the scout determines individual production areas within a field needing special treatment, the information can be quickly passed onto the applicator that can adjust herbicide mix or rate as needed.

The potential benefits from implementing an accurate and intensive weed scouting system are actually three-fold. First, input costs associated with applying some of the more expensive herbicides for special weeds could be reduced. Second, control of these species could be increased with the application of the most efficacious herbicide. Finally, eliminating competition by the weed could increase crop yield (Table 3).

***Table 3**. Estimated net gains resulting from broadcast and site-specific herbicide management systems in non-transgenic soybean at four locations. The increase in net gain from site-specific application versus broadcast application may result from avoiding herbicide application in weed-free areas, appropriate herbicide application for a given weed-complex, reduced or increased herbicide rates for certain weed species, or a combination of these factors.*

	Herbicide Management System	
Location	**Broadcast**[a]	**Site-specific**[b]
	- dollars gained per treated acre -	
Field 1	13.19	41.10
Field 2	79.10	84.45
Field 3	38.79	65.15
Field 4	-11.44	76.02

[a] Simulated application of one treatment to the entire field.
[b] Simulated application of optimum herbicide treatments to individual areas.

Further Information

Lowenberg-DeBoer, J., 'GPS Based Guidance Systems for Agriculture," Site-specific Management Center, Purdue University, West Lafayette, IN, November 1999. http://www.purdue.edu/ssmc

Partial Budget Template For Estimating Whole Farm Profits from Spatial Weed Management[1]

Item	Unit	Quantity	Value/Unit	Amount
Change in revenue:				
Yield increases for whole farming operation[2]				
Corn				
Soybeans				
Wheat				
Other crops				
Total change in annual revenue (sum of all the revenue changes)				
Change in costs:				
Annualized costs of equipment and other durable items[3]				
VRT spray equipment (useful life =___years)[4]				
GPS (useful life = ___years)[4]				
Software (useful life = ___years)[4]				
Training (useful life = ___years)[4]				
Other (useful life = ___years)				
Change in variable costs[5]				
Differential correction annual fee				
VRT application fees				
Repairs and maintenance				
Consultant fees				
Office supplies				
Herbicide[6]				
Extra fertilizer, grain drying, hauling				
Other				
Total change in annual cost (sum of all the annual cost changes)				
Whole farm annual net return (Subtract annual cost change from annual revenue change)				
Per acre net return (Divide net return by acres farmed, _______acres)				

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1) This might include patch spraying and varying herbicide rates or products within a field.

2) The quantity in this line should be the change in production for the whole farm. If the main benefit of spatial management is the reduction in herbicide use, the yield changes might all be zero.

3) Include anything that is used for more than one year. These are incremental costs. For example, if the farm operation already has a GPS for yield monitoring, the extra cost of using that GPS in weed management is almost zero.

4) Most of these items will be obsolete before they are worn out. As a conservative estimate a three-year useful life is suggested for the GPS, software and electronic items. The amount in this case is the annualized cost. The simplest way to calculate the annualized cost is depreciation plus opportunity cost of capital. If the item has no salvage value, the straight line depreciation would be the purchase price, divided by the useful life. If the item has a salvage value, subtract the salvage value from the purchase price and divide the resulting number by the useful life. The opportunity cost of capital is the rate of return on alternative investments times the purchase price.

5) These are incremental costs. For example, if the farm operation already pays for differential correction for yield monitoring, the cost of using that DGPS for weed management may be zero.

6) There may be cost increases or costs savings on any item. In particular, for the herbicide there may be cost savings, if spatial management means applying herbicide over a smaller area than before.

A

REFERENCE

GLOBAL POSITIONING SYSTEMS

By Mark Morgan, Sam Parsons, Dan Ess

The letters "GPS" stand for Global Positioning System. When coupled with differential correction (DC) -- to produce "Differential GPS" (or DGPS) - it provides an answer to the question: **Where am I**? It is simply a "position locator" technique for people, ATVs, spreader trucks, sprayers, planters, combines, etc. No more, no less.

True, the term "GPS" has been used to refer to the overall concept of site-specific or precision farming. But DGPS really represents only one of several technologies that is necessary (but not sufficient) to carry out site-specific farming practices.

DPGS is the "heart of the matter" when it comes to site-specific farming activities! It is needed for mapping yields, field boundaries, weedy areas, or soil sampling sites, and for using variable-rate application and seeding equipment. GPS positioning using a simple, handheld receiver purchased for under $200 will not be adequate for most site-specific farming activities. DGPS of some sort must be used to obtain position estimates within 3 - 6 feet.

GPS: What It Is & How It Works

GPS was developed by the U.S. Department of Defense (beginning in the late-1970s) to serve as a worldwide navigational aid for both military and civilian use. It became "fully-operational" in the mid-1990s. The system is composed of a constellation of about 24 satellites orbiting the Earth at very high altitudes -- each satellite circles the Earth twice a day at more than 11,000 miles above the surface.

Each satellite continuously transmits a low energy radio signal containing a "data message" which includes information about its location, its atomic clock status, and its general condition. These things are all monitored at military ground support stations and are updated as needed.

These data messages can be "read" and interpreted by GPS receivers everywhere, on the ground, at sea, or in the air. Civilian GPS receivers do not require a license to operate, and there is no direct charge for using the GPS signals.

Using the information from various satellites, a GPS receiver employs a mathematical "ranging" method to estimate its (the receiver's) x-y-z position in a 3-dimensional (3D), theoretical, universal coordinate system. These x-y-z values are then converted into latitude and longitude (horizontal position) on the earth's surface, and altitude (vertical position) above sea level. But remember, in actuality, the x-y-z values computed represent the receiver's antenna position.

So the GPS satellites serve as reference points for this "position" computation (to answer the "Where am I?" question).

If one asks: how do they do that? Believe that the answer is NOT simple! It involves measuring the time required for GPS signals to travel from satellites to a GPS receiver -- at approximately the speed of light -- or at 186,000 miles per second. These time measurements are converted into distances between the receiver and each satellite. Then, by applying sophisticated trigonometry algorithms to compensate for "timing errors," the exact distance from each satellite can be determined. This is rather simple in concept (the software is not), and permits relatively inexpensive, though very accurate clocks to be used in GPS receivers, versus the megabucks atomic clocks on-board the satellites.

Since there are twenty-four orbiting GPS satellites, a minimum of six to eight should be directly "visible" to a GPS receiver antenna at any point in time (Figure 1). In some areas, obstacles like trees or buildings can block the signals from one or more satellites. Also, the particular set of satellites in the receiver's view changes over time, since the satellites are orbiting, not geo-stationary satellites -- with some moving out of view and others coming into view. Signals from at least 4 satellites -- MINIMUM -- are required to compute a "good" 3D position -- Figure 1. [Three satellites may be adequate for "reasonable" 2-dimensional (2D) horizontal position estimates.]

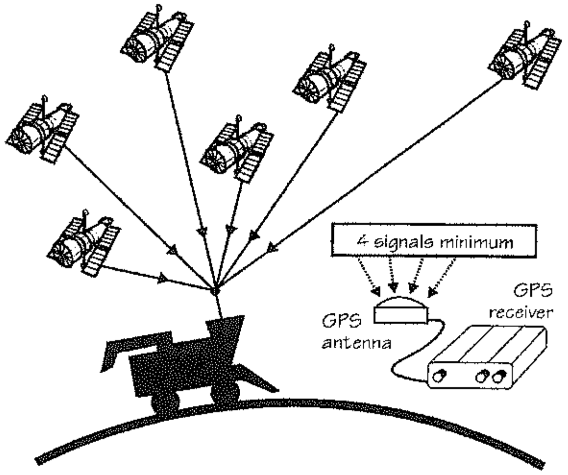


Figure 1. Several satellites are visible to GPS antenna.

GPS Receiver Requirements

For mobile applications, like equipment moving across crop fields, the GPS receiver should have 5 or more tracking "channels." A channel is the receiver circuitry necessary to tune the signal from a single GPS satellite. The "extra" channel (beyond the minimum 4 needed for good 3D position estimates) can be dedicated to scan for satellites just coming into view (to replace one soon to go out of view), or to find satellites with better spacing (satellites more uniformly spread apart is better). Generally, receivers designed with more channels are more accurate. More channels, more sophistication and functions, and greater accuracy also usually implies higher initial cost. So remember that not all GPS receivers are created equal, in number of channels, circuitry, software algorithms, and especially accuracy.

Remember, too, that a different receiver is not required for each and every job that needs GPS. These units can be "moved around" -- used on combines during harvest, then, at other times, shifted to ATVs, tractors, spreader trucks, etc.

GPS Accuracy Without Differential Correction (DC)

Despite the "precision" built into GPS satellites and receivers, the 2D/3D computations (to answer the "Where am I?" question) *can be* somewhat poor when DC is not used. Some sources of "error" include:

- *Satellite clocks*, though very accurate (and expensive), are not perfect -- slight inaccuracies can lead to errors in computations.
- *Satellite orbits*, likewise, can change slightly from those predicted and intended, resulting in computational errors.
- *Earth's atmosphere* slows down GPS signals -- leading to errors in the satellite-to-receiver distance calculations.
- *Multipath error* is caused by GPS signals bouncing off local obstructions like trees or buildings, and arriving at a receiver antenna slightly later than the direct-path signal causing interference with the direct signal and "noisy" results.
- *GPS receivers* are not perfect either, so internal "noise" and other problems can result in computation errors.

In addition to these somewhat "unavoidable" sources of error, the most significant error in earlier times was *intentional error* called Selective Availability (SA).

This was a process sometimes referred to as "dithering," whereby slightly inaccurate clock and orbital information was fed to the GPS satellites for transmittal in their data messages. Military GPS receivers, of course, *knew* about these inaccuracies, and therefore were unaffected. The justification for SA was to limit accuracy of GPS to "hostile" forces. In a U.S. Presidential Directive (May 1996), a promise was made to "end SA within the decade." SA was deactivated on May 1, 2000.

It is important to note that even though SA has been eliminated, there will still be a need to improve accuracy using DC for site-specific farming purposes. Before SA was deactivated, positional estimates with civilian GPS receivers could be off by as much as 100 meters, that's +/-330 feet (with no DC). With SA deactivated, this has improved to 20 meters, or +/-66 feet (with no DC).

DC can compensate for essentially all of the errors associated with satellite clocks and orbits (noted previously), and about 90% of atmospheric-caused errors. However, DC cannot correct multipath errors or the internal "noise" in GPS receivers. Even so, the use of DC can bring "current position" estimates to within 3 feet or so from "true" - acceptable accuracy for most site-specific farming uses today. Fortunately, DC is permitted.

How Differential Correction (DC) Works

DC uses a fairly simple concept: (1) Use GPS to compute the distance between a *stationary* receiver with a *known* position and each satellite in view. (2) The difference in the "computed" and "known" distances is the DC ... for each of the satellites ... for that particular position calculation (at that moment). The beauty of it -- most (but not all) signal errors that occur will be common to *other* GPS receivers within a few hundred miles which are using the same GPS satellites. So, *this* calculated DC can also be used by those other GPS receivers to improve *their* accuracy.

With DGPS, the receiver at the known position (which calculates the DC) is usually called the base station, or reference station (Figure 2). All the other receivers (which need to use the DC) are called rovers, or mobile units. And, the "true" position of the base station must be known with greater accuracy than the accuracy desired of the mobile units.

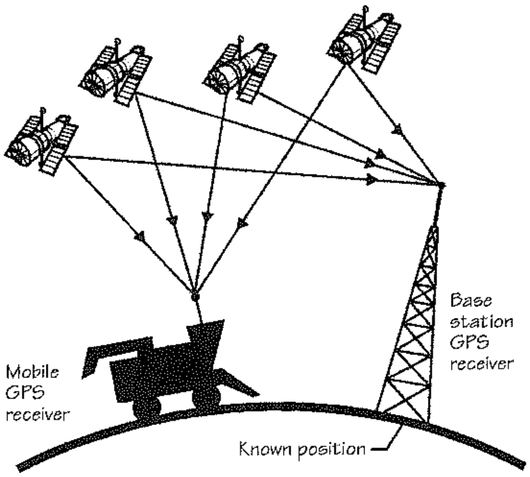


Figure 2. Base station for differential correction.

At the base station, the stream of calculated DC values can be recorded (with the times at which the values were calculated) for later use -- called "postprocessing" correction. Postprocessing involves "correcting," at some later time, the position values of a mobile GPS receiver--values that were computed and stored during some activity. Such a procedure *might* be acceptable, say, for the sites where soil samples were pulled, or for correcting mapping data (before mapping) such as weedy patches (obtained while scouting) or yield and moisture information (obtained during harvest). But postprocessing is NOT workable for variable-rate application activities which use on-board application maps - discussed elsewhere. Otherwise, that stream of DC values can be made available immediately for use by mobile units -- called "real-time" correction.

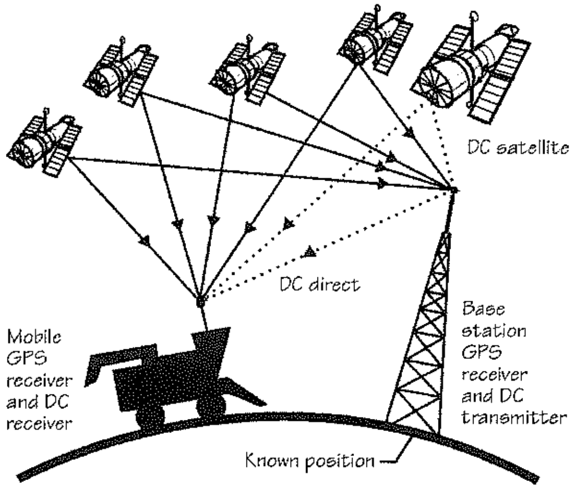


Figure 3. Alternative DC delivery methods.

Options for Real-Time DGPS

Real-time DGPS is the most common form of DGPS being used for **site-specific** farming activities and is required for variable-rate application of lime, N-P-K, herbicides and seed using on-board application maps. Currently, there are two methods being used to send real-time DC values to mobile GPS receivers -- direct and indirect (Figure 3). Both methods require a special DC (radio) receiver coupled to the GPS receiver on mobile equipment -- so that corrected position values can be logged or used "on-the-fly."

The indirect method -- sending DC values to a geo-stationary satellite for re-broadcast -- provides a wider area of coverage than the direct method, and may be less susceptible to "line-of-sight" interference. The rebroadcast values typically include information from several base stations, with user options for selecting the nearest base station, or employing a weighted average to surrounding or nearby base stations. The cost of this service includes an annual subscription fee, plus the purchase of an onboard DC receiver for mobile units.

There are three possibilities for receiving DC values directly from a base station:

- *Regional AM-like beacon services.* The U.S. Coast Guard and Army Corps of Engineers have established a network of GPS base stations -- at selected seaport cities along the coasts, and along interior lakes and waterways -- as a navigational aid to the shipping industry. DC values are continuously broadcast via an AM-like signal which can range from only 35 miles to as much as 250 miles from each site. There is no direct cost for this signal; all that's required is a compatible receiver. Also, this system may not provide coverage of the entire Cornbelt. However, a future Wide Area Augmentation System (WAAS), being developed by the FAA, may provide DC for the entire U.S.

- *Operate one's own base station.* This option requires the setup of a base station, complete with the capability of broadcasting the DC values to mobile equipment -- and the expertise to operate and maintain the base station. A relatively expensive option for an individual farmer, this option probably compensates better for local phenomena that can affect GPS accuracy (local weather effects), but its range is usually limited to 3-5 miles, depending on broadcast power.

- *Local FM or FM-sideband services.* Some companies have set up special base stations, or contracted with existing FM radio stations to operate DC base stations. User requirements: an FM receiver tuned to the particular frequency for that service, and payment of an annual subscription fee. These services are not available in all areas, and the range of coverage is limited to "typical" FM radio reception distances (~60 miles). The receiver on the mobile unit usually scans for additional signals in areas with multi-station coverage -- and uses the strongest signal. Multi-station coverage is desirable from the user's standpoint -- so that GPS-related activities needing real-time DC can continue, even if the strongest-signal station goes down ("off the air") for some reason.

What Accuracy Is Needed

DGPS accuracy for agriculture is a frequent discussion topic: sub-meter accuracy, sub-foot accuracy, centimeter accuracy, etc. Good questions include: How much accuracy is really needed? and What do the accuracy terms *really* mean?

"Centimeter" accuracy (1 centimeter is about 3/8 of an inch) may be extremely important for recording the locations of military land mines, or for some surveying purposes ... or for auto-guidance of cultivator and planter tractors, or rowcrop harvesters (like corn combines). Too, "sub-foot" accuracy may be desirable for recording soil sampling sites (if periodic re-sampling from the same in-field sites is the goal) ... or when replacing the visual marker system with an auto-guidance method for broadcast sprayers or fertilizer spreaders ... or to make sure that a control system turns the pesticide or liquid manure flow on-off at exactly some prescribed distance from an "environmentally-sensitive" area in or near the field. But for most current site-specific farming activities, the "cost" of such accuracy may not be warranted -- unless one really wants to do these things!

For most farmer-owned and -operated equipment, "sub-meter" accuracy (1 meter is about 3.3 feet) may be quite adequate, for the time being -- unless one really dislikes those "wavy lines" on the various field maps that are generated. [And even these can be "corrected" in a post-processing mode, if one has the patience!] Regardless of the accuracy level desired, recognize that GPS accuracy specifications are based on statistical methods and terminology related to the percentage of time one should expect to be within a certain distance from the "true" location. Most DGPS receivers used in site-specific farming activities are in this "sub-meter" category, i.e. they produce a position estimate within 1 meter of the "true" position, 68% of the time.

What DGPS Accuracy Terms Mean

Because of the inherent errors in this dynamic position-locating system (satellites, atmosphere, receivers, etc.), not even a *stationary* DGPS receiver will output a stream of position values (computed every second, 2 seconds, etc.) that are *identical*. Some will be closer to the "true" position, others will be farther away. Thus, statistics and "accuracy" specifications go hand in hand.

One statistical measure of accuracy that's sometimes used for this *stationary* situation is CEP, or Circular Error Probable. This refers to the smallest radius of a circle which will enclose 50% of the computed GPS positions (Figure 4). Thus, if 50% of the GPS computed positions (over a long period of time) fall within 3 feet of true, the accuracy is said to be 3 feet CEP. Note that the *other* 50% of computed positions would be more than 3 feet from the true position.

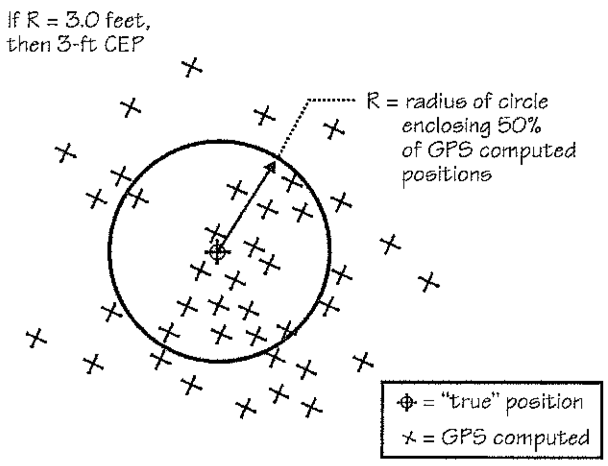


Figure 4. Accuracy based on circular error probable (CEP) computations.

Other accuracy terms sometimes used are RMS and 2DRMS. Here, the RMS stands for Root Mean Square, and is approximately equivalent to the statistical term Standard Deviation (SD). The magnitude of the SD indicates the "spread" of a frequency distribution. A small SD indicates a "narrower" distribution (more points closer to the mean -- or true position). Conversely, a large SD indicates a wider dispersion (more points farther from true). So, if the positions computed by a DGPS receiver were "normally" distributed about the true position -- as in Figure 5, then about 68% of the computed positions would be within 1 SD, with about 95% within 2 SDs. And ... an accuracy specification of 2.5 feet RMS (about 1 SD) would indicate that about 68% of the computed positions (over a long period of time) would fall within 2.5 feet of true, while 95% would fall within 2 SDs of true (2DRMS), or 2 SD = 2 x 2.5 feet = 5 feet.

So, what is sub-meter or sub-foot accuracy for a given DGPS receiver? No one knows unless the statistical-basis for the accuracy value is stated.

Other DGPS Receiver Performance Criteria

When purchasing GPS and DC receivers separately, or as a single combination unit, comparing several specifications and performance criteria may be helpful to make the decision.

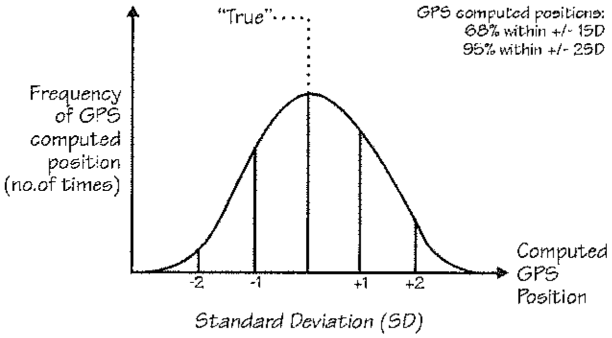


Figure 5. Accuracy based on standard deviation (SD) computations.

Most common differential-ready GPS receivers have 8 to 12 channels, one or two RS-232 serial ports to connect to a computer or monitor, provide NMEA-0183 output format and receive RTCM SC-104 type differential signal inputs. Another performance characteristic that may be important when comparing DGPS receivers is the "update rate" or number of position fixes per second. Common receivers provide a position fix once per second, but higher cost models or options, can increase this to 10 positions per second. Ten or more position fixes per second are required for better performance during parallel swathing or automatic guidance applications.

Further Information

GPS World Online - http://www.gpsworld.com/
Sam Wormley's GPS News -
http://www.cnde.iastate.edu/staff/swormley/gps/news.html
Trimble Navigation Limited - http://www.trimble.com
U.S. Coast Guard Navigation Center -
http://www.navcen.uscg.mil/GPS/

B
REFERENCE

YIELD MONITORING AND MAPPING

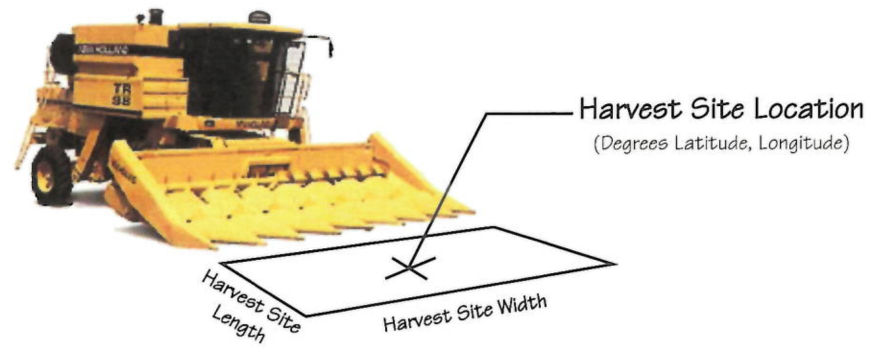
By Sam Parsons, R. Mack Strickland, Robert Nielsen, Keith Morris

Concepts, Equipment and Techniques For Yield Monitoring and Mapping

Farmers have always known that yields vary throughout their fields. But it was not until the advent of modern yield monitors in the early 1990s that they were able to tell how much. This section looks at the concepts, equipment and techniques needed for yield monitoring and mapping.

Basis for Yield Monitoring and Mapping

Yield monitors are designed to obtain and record information for very small harvest areas or "sites" in a field (Figure 1). Each site has a specific *width* - the harvested swath width; a specific *length* - the distance the combine moves during the monitor's data logging interval (usually 1-5 seconds); and a unique *location* - the global coordinates of degrees latitude and longitude. Yield monitors also estimate and record the *moisture content* and *amount of grain* from each site. Grain yield - "wet" or "dry" basis - is computed as the amount of grain from each site divided by the area of that particular harvest site. Maps can then be made which show the locations of all these harvest sites, and the yields and moisture associated with them.



Harvest speed	Travel distance (site length*)
3 mph	4.4 feet/sec
4 mph	5.9 feet/sec
5 mph	7.3 feet/sec
6 mph	8.8 feet/sec

*For 1-sec logging interval.

Harvest Site Specifications

Location - Computed by DGPS unit.
Width - Set by combine operator.
Length - Computed as travel distance.
Grain Volume - Computed from grain flow and moisture sensor data, and "standard" bushel information.

Area and Yield Calculations

$$\text{Harvest Site Area (acres)} = \frac{\text{Length (ft)} \times \text{Width (ft)}}{43{,}560\ (\text{ft}^2/\text{acre})}$$

$$\text{Harvest Site Yield (bu/acre)} = \frac{\text{Grain Volume (bu)}}{\text{Harvest Site Area (acre)}}$$

Figure 1. Harvest Site. Imaginary harvest "sites" are the basis for all yield monitoring and mapping. For a 1-second data logging interval, a yield monitor on a combine operating at 4 mph with a 20-foot effective swath width will record data for nearly 30,000 harvest sites in an 80-acre field. As the combine speed and swath width change, so does the size of individual harvest sites.

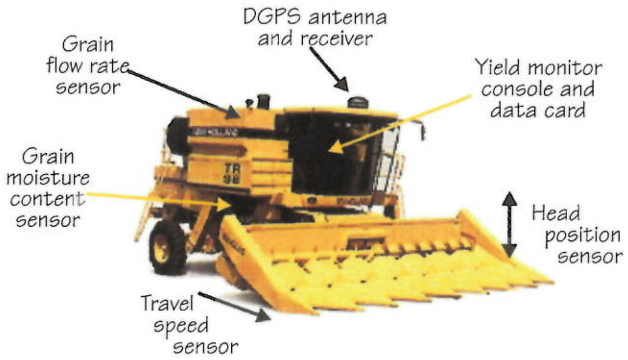


Figure 2. *Combine components for Yield Monitoring and Mapping. To view/observe on-the-go harvest data (only, but no mapping) all the components shown are needed except the DGPS antenna-receiver and the data card used to store mapping data.*

Yield Monitor Components

All yield monitors collecting data for later mapping need the following on-board components (Figure 2).

1 - **Grain flow sensor**. Usually located at or near the top of the combine's clean grain elevator.

2 - **Grain moisture sensor**. Attached to the clean grain elevator. Some early yield monitor models had it located in the loading auger for the grain tank (the "bubble-up" tube).

3 - **Speed sensor** (or speedometer). The 3 types commonly used: (a) magnetic sensor in the combine's drive-train, (b) radar or sonar speed "gun," or (c) the DGPS receiver on the combine.

4 - **DGPS receiver/antenna**. The antenna is typically located at a "high point" on the combine, and centered on the header. In addition to longitude-latitude, some yield monitors also record elevation for each harvest site (for the DGPS antenna).

5 - **Header position sensor** which tells the yield monitor to start or continue collecting harvest site and location data (header lowered or down), and to stop when the header is raised.

6 - **Yield monitor console** (in the combine cab) - so the operator can visually monitor harvest data as it's happening, *and* enter swath width, calibration and other needed information. This unit may also collect, process and store data from the various sensors, or that function may be done by a second electronic unit, tucked away somewhere in the cab. The computer chip and coded instructions which accomplish all of this is referred to as *firmware*.

7 - **Data card and card slot** located somewhere in the on-board yield monitor system to store mapping information. The large volume of data needed for yield mapping would overwhelm the monitor's firmware and memory if it were stored internally. So, during harvest, this data is stored on a removable and reusable data card, technically known as a PCMCIA card - Personal Computer Memory Card International Association card. Data cards also provide a way to transfer the mapping data (and other information) between the on-board system and another computer.

8 - **Marking system** (optional) which many yield monitors have (or can be fitted with). This allows the operator to "mark" (electronically) the location of special things observed during harvest - like weed patches, drown-outs, tile holes, rocks, etc. Specially designated buttons on the unit (or console) are used to place these "marks" on the data card, for later display (or printing) with yield or moisture maps. This can be an aid in later yield map interpretation, or provide directions back to an in-field problem area.

Yield Monitor Setup

Prior to the initial harvest, various items must be set up within the yield monitor's firmware - to tell it how things are to be done or handled on this farm with this particular combine. These include things like data logging interval (if changeable), preliminary calibration settings for sensors, header swath widths, and the weight and moisture for "dry" bushel calculations for the crops to be harvested. In addition, the data card to be used must be initializing, and, to save field time later on, the fields, crops, and loads to be harvested (see later discussion) can also be entered. With software from the manufacturer, much of this setup process can be done on a separate office computer. The file is then copied to the data card and transferred to the in-cab console.

Field, Crop and Load IDs

To facilitate mapping and analysis, yield monitoring data must be electronically tagged or labeled with an identifier - a Field-ID (or "field name"), a Crop-ID (or "crop name"), and a Load-ID (or "load name"). As the combine is moved from field to field, the operator selects these IDs from a pre-entered list. If not pre-entered, the IDs for the new or next field, crop or load can be entered by the operator using the in-cab console buttons.

Field-IDs are usually entered as the *real* names used for fields, and Crop-IDs are the planted crops. Load-IDs, however, can be whatever harvest areas the operator wants! They can, but need not have anything to do with *actual* truck or wagon "loads" of grain. A whole field can be tagged with a single Load-ID, or each and every harvest pass can be given a different Load-ID.

Load-IDs provide a means for performing sensor calibrations (discussed later) and for doing on-farm testing of various practices within a field and crop - to study tillage, hybrids, herbicides, etc. Load-IDs can also be used to investigate special in-field areas of concern - like the effects (on yield) of overgrown fence rows, or woods at a field boundary, or end-row compaction, or other factors (Figure 3). The generous and thoughtful use of Load-IDs can significantly increase the management information *potential* of a yield monitoring system.

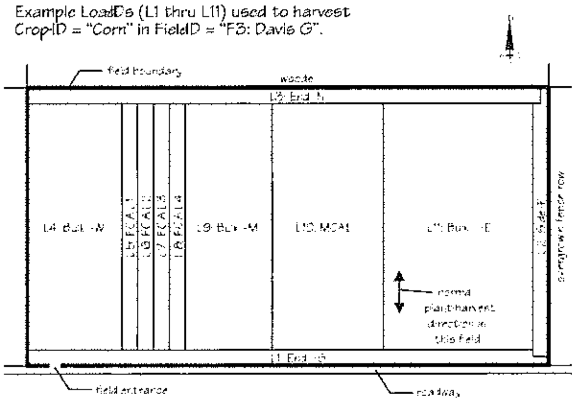


Figure 3. Load Identifiers. Load numbers and labels (Load-IDs) set by the combine operator will appear in Yield Summary tables when harvest is complete, providing area, production and yield details for each one. The "CAL" loads shown here illustrate calibration loads for the monitors sensors: L5 to L8 for the flow sensor; L10 for the moisture sensor. With most yield monitors, calibration does not have to be done in the first field on the first day of harvest for each crop - calibration data obtained later can be applied to harvest data obtained earlier.

During Harvest

Most in-cab consoles can display things like current and average yield and moisture, current harvest rate and speed, and various harvest totals (in acres, bushels or pounds). Some consoles can also display the combine travel path - an as-you-go "map" that shows where the combine is and traces where it has already harvested in the field (Figure 4).

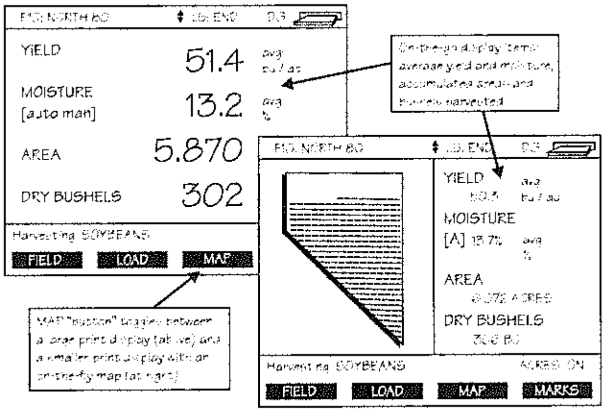
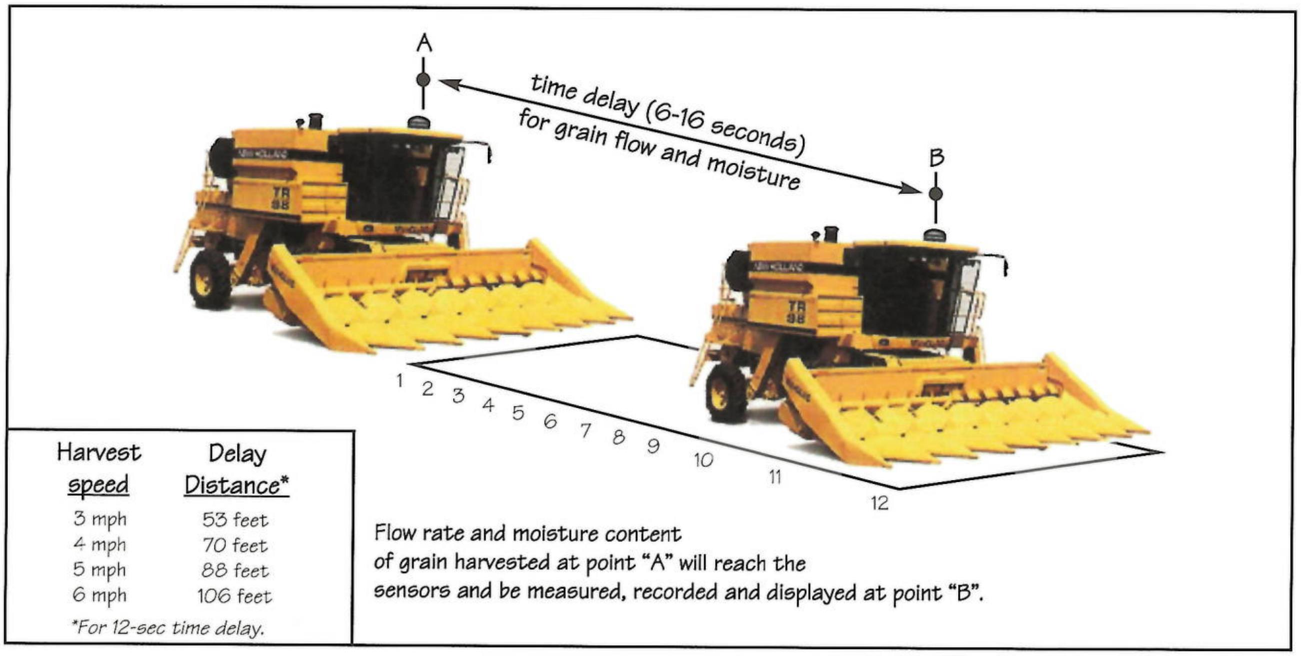


Figure 4. Travel Map. Some yield monitor consoles can display an as-you-go map showing where the combine is and a trace of where it has already harvested in the current field, in addition to various current, average and accumulated harvest data.



Harvest speed	Delay Distance*
3 mph	53 feet
4 mph	70 feet
5 mph	88 feet
6 mph	106 feet

*For 12-sec time delay.

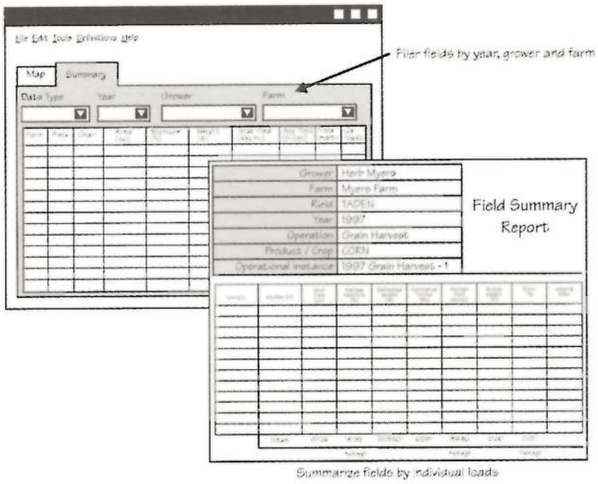
Figure 5. *Time Delay. Instantaneous harvest data that are based on grain flow and moisture content will not be "current" when displayed on the yield monitor console because of the time required for grain to move through the combine - from the header to the location of the flow rate and moisture sensors. This offset must be "corrected" during map generation in order to have "geographically-correct" yield and moisture maps.*

Some display items will be up-to-date as displayed, but others - "current" yield and moisture - will relate to harvest sites some distance (and time) behind the combine. This is because of the time it takes for grain to move through the combine, from the point of harvest up front to the location of the grain flow and moisture sensors (Figure 5). The value of this "time delay" may be 6-16 seconds, depending on the combine make and model and other factors. This time delay must be accounted for to get "geographically-correct" yield and moisture maps.

Note of Caution: Even if on-the-go display items seem reasonable and everything seems to be working as intended, *don't assume* that harvest data is being recorded properly on the data card. The card's contents should be checked periodically with a mapping program - either daily, or (at most) every two days. "Lost mapping data" can *never* be recovered, and if something isn't working right, it's better to lose only a day or two of data, rather than data for half (or all) of the harvest season.

Yield Summaries

Most yield monitors maintain an internal tally of acres, grain amounts and harvest moisture for each Load-ID. This permits "yield summaries" to be generated after harvest, showing load, crop and field totals (acres, pounds, bushels) and averages (bushels per acre, moisture). Simple yield summaries (by field or by loads within a field) can also be displayed on the in-cab console of some yield monitors during harvest. All yield monitors provide a means of producing the more detailed summaries (Figure 6). This is done by transferring the data from the in-cab system onto a separate computer, via the data card, then using appropriate software to read the data, and to display or print the table(s).



Grower	Herb Myers
Farm	Myers Farm
Field	1ADEN
Year	1997
Operation	Grain Harvest
Product / Crop	CORN
Operational instance	1997 Grain Harvest - 1

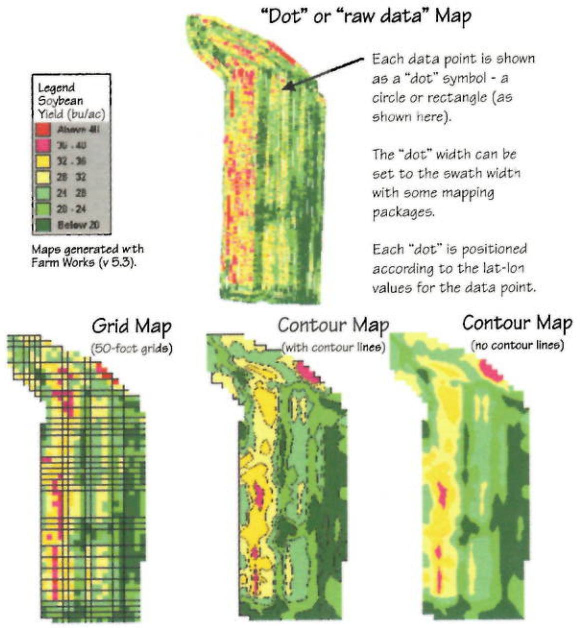
Figure 6. Yield Summaries. Yield monitor data can be sorted in various ways for display or printing when harvest for a farm, crop or field is complete.

Creating Maps

Yield, moisture and elevation maps (if elevation is recorded in the yield data files) can be produced using mapping software from the yield monitor manufacturer, or from other sources. The software must be capable of reading the proprietary format of the harvest site data on the data card (unique for each yield monitor). And it must shift grain flow and moisture values to account for the "time delay" discussed previously.

A variety of map styles are possible. The simplest is called a "raw data" or "dot" map (Figure 7). With this map style, the actual location of each harvest site recorded during harvest is used to locate a "dot" on the map (using latitude-longitude values). A color is then assigned to each dot based on a map legend. For instance, the legend might be set up to use a green dot to indicate the yield (at that point in the field) is in the range of 110-129 bu/acre, a yellow dot 130-149 bu/acre, a red dot 160-179 bu/acre, etc.

Other types of maps can be generated after performing additional "processing" of the data. Most mapping software begins this process by placing imaginary, equal-size grid cells (or squares) over the field. Then a value (for yield, moisture or elevation) is computed for each small cell. This step is done with sophisticated data interpolation methods, and specific assumptions about the relationships among measured data points in the field. Once the cell values are estimated, various types of maps can be generated - smoothed or contour maps, 3-dimensional (3-D) surface maps, etc. - providing alternate ways of viewing, studying, understanding and interpreting yield monitor data (Figure 7).



Each data point is shown as a "dot" symbol - a circle or rectangle (as shown here).

The "dot" width can be set to the swath width with some mapping packages.

Each "dot" is positioned according to the lat-lon values for the data point.

Maps generated wth Farm Works (v 5.3).

Figure 7. Optional Map Styles. Most mapping software allows the user to choose the map style, the legend increments and colors, and other details related to viewing and printing maps based on yield monitor data.

Mapping software usually provides both on-screen viewing and hardcopy printing options for maps. In some communities, there are businesses which provide data card reading, data archiving and map printing services - for a fee - relieving the producer of these tasks.

Yield Monitor Calibration and Operation

Careful yield monitor setup, calibration and operation are needed to assure the overall accuracy of yield summaries and a realistic assessment of in-field yield variability (reliable maps). Each yield monitor sensor - for grain flow, grain moisture and temperature, combine speed and header up/down position - needs to be initially set or calibrated. Yield monitor manufacturers provide step-by-step instructions for this. This section reviews some of the basics related to grain flow and moisture sensors.

Calibrating Grain Flow Sensors

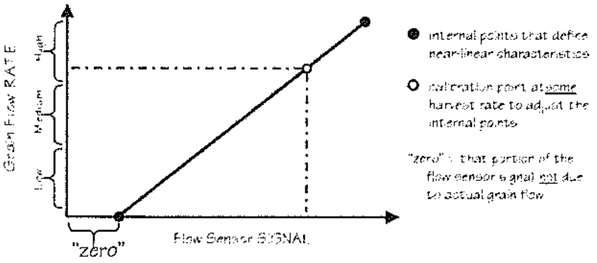
Different types of grain flow sensors are used with yield monitors. Some use an *impact force (mass flow) sensor* to estimate flow in pounds per second. With these, a curved impact plate is located at the top of the clean grain elevator. The sensor signal transmitted to the yield monitor console, indicating flow rate, is based on the amount of displacement or deflection of the impact plate as it is struck by the grain stream.

Another yield monitor uses an *optical (volumetric flow) sensor* to estimate flow in bushels per second. This sensor has a light source on one side of the clean grain elevator and a light detector on the opposite side. Grain carried by the paddles cuts through the light beam, changing the amount of light detected by the photosensor - which changes the electric signal sent to the yield monitor console.

To estimate grain flow for immediate display and for internal yield summaries, the yield monitor firmware uses an "electronic calibration curve" (Figure 8). This is an imaginary graph of estimated grain flow vs. electric signal values received from the flow sensor. [Note - To accomplish mapping, this internal calibration curve must be transferred (as a data file) onto the data card, then into the computer which will generate the maps.]

To check or improve the settings and accuracy of this calibration curve, one or more "calibration loads" must be harvested and weighed.

(a) Example "near-straight" (near-linear) grain flow calibration curve.



(b) Example "not-straight" (non-linear) grain flow calibration curve.

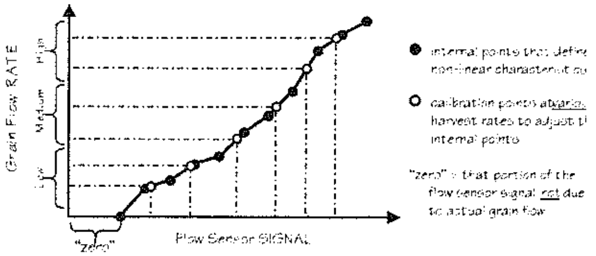


Figure 8. Calibration Curves for Grain Flow Sensors. The characteristics of the particular grain flow rate sensor will determine the complexity of the calibration process needed to insure the accuracy of yield monitor data and in-field variability.

A *calibration load* begins with the combine grain tank empty, and the operator setting a new calibration Load-ID in the console. Then, harvest proceeds until a quantity of grain is accumulated - typically 3,000-6,000 pounds (about 50-100 bushels) or more. Then, the grain is off-loaded (grain tank empty again), and weighed.

The actual weight for that calibration Load-ID is then entered into the yield monitor console. The firmware compares the actual weight with the accumulated total weight estimated by the yield monitor during the harvest of *that* Load-ID - and makes any needed adjustments in the calibration curve. Before proceeding with normal harvest or another calibration load, a different Load-ID must be set in the console.

Calibration loads should be weighed *with well-calibrated weigh wagons or buggies* (on-site), or *well-calibrated platform scales* (at a remote site). Harvesting and yield monitoring can continue (with different Load-IDs) if a lot of time is needed to get the actual scale weights - these can be entered later when they are available.

The number of calibration loads required is dictated by the characteristics of the specific flow sensor. Some sensors need only one calibration load (near-linear example in Figure 8). Even so, two or more loads are probably better. Others need 3-6 calibration loads at *different harvest rates*, that is, at different "bushels per hour" levels (non-linear example in Figure 8). This can be done by harvesting separate calibration loads at different speeds or at different swath widths - intentionally selected for specific segments of the internal calibration curve. When multiple calibration loads are needed, each one should be about the same size.

Choosing *where* to harvest calibration loads should be done carefully, especially when harvesting fields that are *not* relatively flat. Variable topography - both up/down slope, and side slope harvesting - can affect the accuracy of flow sensors. For this, one yield monitor uses "pitch and slope sensors" for automatic on-the-go corrections to its internal calibration curve.

Flow Sensor Calibration - Other Issues

For on-the-go tweaking of the internal calibration curve, most yield monitors use a speed counter on the clean grain elevator - another sensor, no calibration needed, but it must work! Most require flow sensor calibration for *each* type of grain to be harvested, for each Crop-ID. And all have a "zero-verification" process, either manual or automatic, to compensate for any part of the sensor signal - sent to the console - that is *not* due to legitimate grain flow. With the impact-type sensors, part of the signal may be due to vibration; with the volumetric (optical) sensor, the thickness of the elevator paddles must be "zeroed-out." The volumetric-type sensor also requires the checking and periodic entry of test weight information.

General re-calibration recommendations are not well documented. Some yield monitor manufacturers suggest that if initial calibration is done carefully - *and right* - there may be little need for additional calibration during the current season, or possibly the next! Generally, a "load" or two needs to be checked "periodically" - to provide assurance that all is well, or to signal a need for more calibration if poor accuracy is discovered. If repairs or adjustments in and around the flow sensor (or the clean grain elevator) are performed, total re-calibration will usually be needed. This will prompt a change in Crop-ID also, say from "Beans" to "Beans2," or from "Corn" to "Corn2," so the *new* calibration curve will not be applied to the "crop" harvested before the repair or adjustment.

Calibrating Grain Moisture Sensors

Most yield monitors use a *capacitance-type* moisture sensor - which is not too accurate at very low (8-10%) or very high (26-28%) moisture levels. It is also "sensitive" to grain temperature, and to any buildup or coating of wet, sticky material on its metal surfaces.

The monitor's temperature sensor should be calibrated first, using an actual thermometer reading, rather than a "reported" temperature from some remote location. This usually needs to be done only once, and is applicable to all grain types harvested. The firmware compares the "sensed" (estimated) temperature with the actual temperature entered, and computes an "offset" for the temperature sensor. This step is important, and should not be skipped.

To calibrate the grain moisture sensor, a "moisture load" is harvested (similar to the "calibration load" for the flow sensor). One load is needed to calibrate the moisture sensor for *each* type of grain. The actual moisture of the grain should be determined using a *well-calibrated moisture tester*. When the actual moisture is entered, the firmware compares that value to the estimated average moisture measured and computed for *that* load, and computes a moisture "offset." One yield monitor manufacturer suggests: obtain actual moisture for only *one* "load" of grain, consisting of *one or two* combine hoppers, with relatively *uniform* in-field moisture conditions, and enter an average moisture reading based on *several* grain samples pulled from that load.

Sources of Yield Monitor Error

Grain yield monitors are "pretty good" but they are not perfect. There is potential for error in every sensor and in every step of the "indirect-measurement" processes involved. Generally speaking, most managers and combine operators would prefer *minimal yield monitor errors* in three broad categories: (1) harvested grain totals - in pounds or bushels, (2) grain yield levels - in bushels per acre, and (3) grain yield locations - where various yield levels occur throughout a field.

Errors in Harvested Grain Totals

Accuracy in the amount of grain harvested begins with the flow rate and moisture sensors and how well they are calibrated for the actual harvest conditions encountered. If both sensors are well calibrated and accurate, then producers can easily switch back and forth between grain weight information (in pounds) and grain volume estimates (in bushels).

Total grain amounts will also be affected by the way in which the yield monitor's firmware handles things like the "ramp-up" flow at the start of a harvest pass. Grain flow past the flow rate sensor does not jump from zero to "full flow" instantaneously (Figure 9). Rather, it builds up over a few seconds - with some of these flow rate levels being well below the "calibrated" flow rates. This same condition occurs at the end of a harvest pass, as the combine cleans-out, with some "ramp-down" flow rates well below normal. The ramp-up/ramp-down condition also occurs as the combine harvests across "no-crop" areas, like grassed waterways or drown-out spots.

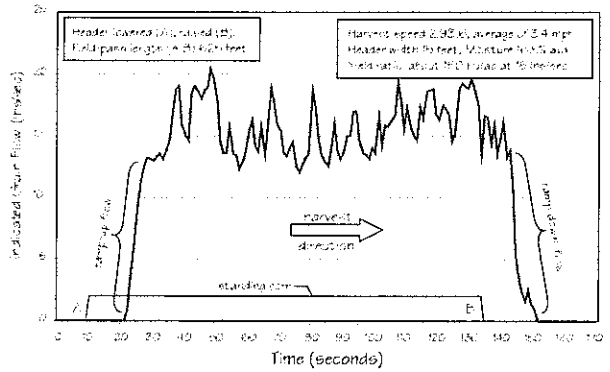


Figure 9. Yield Monitor Instantaneous Flow Rates. The first grain reaches the flow sensor a few seconds after the header is lowered to enter the standing crop, and the flow rate ramps up to some "full-flow" level. After the header is raised and exits the standing crop, the flow rate continues at some "full-flow" rate for a few seconds and then ramps down to zero.

Errors in Grain Yield Estimates

Grain yield is a computed value - it is not "measured" directly. The quantity of grain harvested from a given site (in bushels) divided by the area of that harvest site (in acres) gives yield (in bushels per acre). So, the accuracy of yield estimates depends on the accuracy of the grain quantity and harvest area estimates.

For yield monitors with volumetric flow sensors, wet bushels are estimated (measured), dry bushels computed. For yield monitors with mass flow sensors, both wet and dry bushels are computed. So for accuracy, well-calibrated flow rate and moisture sensors are required for the grain quantities used in the yield calculations.

Wet-bushel amounts are "shrunk" to get dry bushels when harvesting at higher moisture levels. However, moisture can sometimes fall below the standard (dry) bushel moisture content - in some situations when harvesting soybeans, for instance. In this case, some yield monitors permit (optional) dry bushels to be computed the same as wet bushels. That is, the drier grain amount is not "expanded" to the standard moisture. While this may be more "accurate" for the number of bushels sold off-farm, for instance, it leads to erroneous productivity comparisons from an agronomic standpoint.

Harvest site area, the divisor used to compute bushels per acre, is obtained by multiplying the distance in the direction of combine travel by the effective swath width (Figure 1). The accuracy of the travel distance values (and "instantaneous" yield for each harvest site) depends on the source and accuracy of the speed information. If a magnetic sensor in the combine's drive-train is used, errors can occur due to changing conditions, even if the sensor has been calibrated properly. Over-estimation of the travel speed and distance can occur (1) due to a reduction in rolling radius - the tires "squat" more as the grain tank fills, even on solid ground, and (2) due to tire slippage - when operating up-slope or when the soil surface is slippery. This gives lower-than-actual computed yields. Conversely, higher-than-actual computed yields result when operating down-slope with less wheel slip.

The accuracy of a well-calibrated radar sensor can also change due to changes in surface roughness (amount of cornstalks, other residue). And, if the DGPS receiver is used as the speed source, the speed estimation accuracy is related to positional accuracy. One manufacturer advertises that their ag-related DGPS receivers (with sub-meter positional accuracy) can provide a speed accuracy within 0.1 mph, that is, speed errors of less than 2.5% at 4 mph.

The accuracy of the accumulated distance (and total area) for a field or load requires a well-calibrated header position sensor, plus consistent header up/down practices by the combine operator. Since most operators tend to lower the header an instant before it enters the standing crop, and to raise it an instant after the last standing crop is cut/gathered, Field-ID and Load-ID areas tend to be slightly over-estimated - by 1-3% in row-crops and by 2-4% in solid-seeded crops according to one yield monitor manufacturer. Those over-estimates, however, are not the *sole responsibility* of header position sensor calibration or the operator habits in raising-lowering the header - speed sensor accuracy and swath width settings also play a role in this.

Note - Some yield monitors permit "field area calibration" - when harvest is complete - a process of entering the actual harvest area of a field (its tillable crop acres). The firmware will then compare the *measured (estimated) field area* accumulated to the *actual field area* entered, and make appropriate and proportional adjustments to Field-ID and Load-ID area data re-computing yield levels as well for the yield summaries.

The other computed-area factor, effective swath width, is not a measured and computed value like travel distance. It is set (or entered) by the operator. Setting the swath width for each header (which is "crop" specific) is critical to yield monitor accuracy. And, until an accurate, reliable and cost-effective "swath width sensor" is available, this will continue to be the responsibility of the combine operator! Once entered, the swath width setting can remain unchanged, except when less-than-full-swath situations are encountered - like the harvesting of point rows, or when finishing a land or field with a partial swath. For these cases, yield monitors allow the swath width setting to be reduced *temporarily* (sometimes with an audible alarm to remind the operator of the reduced setting). Failure to reduce swath width for these situations will produce erroneous yield estimates - because the reduced grain flow will be applied to an artificially wide swath width. But even for "normal" harvesting, setting the "correct" swath width may not be easy. Most yield monitors require that the effective swath width be entered not in feet and/or inches, but as row width (in inches) and number of rows harvested with each pass. For rowed crops this is straight forward - number of rows harvested each pass times the planted row width gives effective swath width, for both row-crop headers and for grain platform headers. The only "error" in this approach is if the "effective row width" is not the same as the "planter row width." This could happen if the planter marker was not set right (either intentionally or accidentally), or if the marker was set correctly, but the tractor operator consistently drove to one side or the other of the marker on each pass.

For harvesting solid-stand crops (seeded in 6- to 10-inch rows) with grain platform headers, some yield monitor manufacturers suggest that an imaginary 12-inch row width be entered into the yield monitor console (regardless of the actual row spacing of the seeding equipment). The number of rows is then entered to reflect the "true" cutting width of the header. For instance, a 12-inch row spacing and 15 rows could be entered for a header with a 15-foot cutting platform. This "12-inch row width" method, they claim, also allows temporary swath width reduction in easier-to-see one-foot increments when harvesting a partial swath.

Some yield monitor manufacturers also suggest that the number of rows be set one row less than the maximum, e.g., to 14 rows in the previous 15-foot example. This, they claim, would reflect an operator's inability to maintain a "full" cutting width while harvesting. This technique would result in reasonable yield estimates when actually harvesting at the narrower width, but it also over-estimates yields (by 3-7%) in areas of the field where a "full" cutting width is achieved. Numerous factors should be considered when deciding how to set the effective swath width for the yield monitor - including the crop type and condition, combine operator's skill, grain platform and crop divider design, harvest field pattern used, and ground conditions and topography of the field.

Errors in Grain Yield Locations

For interpreting yield and moisture maps, a high degree of accuracy in grain yield and moisture "location" data is desirable - regardless of the map style. There are several factors which can lead to inaccurate location information. One was discussed earlier - the time required for grain to move from the header to the grain flow and moisture sensors (Figure 5). This "time delay" must be reconciled to match grain quantities and moisture with the appropriate longitude and latitude values within the field. With current mapping software, this time delay is assumed to be constant for a particular combine. But in reality, it is not a constant - it changes based on travel speed and combine loading. And its actual magnitude, used for mapping, is also affected by the fore-and-aft position of the DGPS antenna on the combine.

Another location error is based on the "mixing" of grain as it moves into and through the combine. Grain gathered at the outer edges of a wide header may reach the feeder housing a second or more later than grain gathered at the center of the header. A portion of the grain moving through the feeder housing at any point in time may separate at the threshing unit and move directly to the cleaning shoe and on to the clean grain elevator. The rest will reach the cleaning shoe later, after moving through the separator. And some of it may circle back through the tailings return system. As a result, a particular flow rate or moisture content measurement may be based on grain harvested from 2-5 separate and sequential "field sites." So, a single value may be made-up of various amounts of grain coming from in-field locations that were 10-25 feet apart in the direction of travel.

Location errors can also occur based on the accuracy and quality of the DGPS receiver estimates of longitude and latitude - discussed elsewhere. A related error source, however, can be lateral (side-to-side) location errors which can occur if the DGPS antenna is not centered on the effective swath width of the combine. Such errors can be "masked" in processed maps, but need not be a concern if the antenna is positioned correctly. Finally, where does the firmware place the latitude-longitude value for a "field site" when a longer data logging interval is used (3-5 seconds, for instance). Is the recorded location value for the first second, the last second or the middle second? This is more of an issue at higher harvest speeds.

Interpreting Yield Maps

One of the major reasons for doing grain yield monitoring and mapping is to assess infield yield variability. To determine if there are differences in crop production and yield in different parts of a field. And to determine the significance or magnitude of those differences. The goal is then to determine, if possible, the reasons for those differences - what caused them. And, ultimately, to determine if changes are needed, or warranted, which could improve the profitability, efficiency and/or sustainability of crop production in that field! The objective for most producers may not be to eliminate the variability (which is nearly impossible), but, rather, to understand it, to change it, if justified and possible, and to manage for it - in a way that makes sense from both a crop production and an environmental standpoint.

There are at least two general approaches to assessing yield variability in a given field. One involves a visual assessment of the yield map; the other uses analytical tools available with mapping software. Both can be influenced by the type of map, and by the format used to display or print the yield map.

Yield Map Presentation - Dot vs. Processed

Dot maps (explained previously) are excellent for recognizing problems that occurred during the actual harvesting and yield monitoring-mapping activity. Areas or strips of missing data on a dot map, for instance, can indicate loss of GPS signal - that may have gone unnoticed during harvest. Parallel passes that are not parallel on a dot map (drift together or apart, or even cross-over) indicates inaccuracy in the DGPS signal or the receiver computations for latitude-longitude. A "saw-tooth" pattern at the ends of the field, where the header enters and leaves the crop, can indicate an incorrect setting of the "time delay" value or problems in the way grain flow ramp-up/ramp-down is being handled. Processed-data maps (smoothed or contour, 3-D, etc.) tend to "mask" these factors, but may be better for seeing more general yield trends.

Yield Map Presentation - Map Legends

The number of yield increments (number of different colors) and the yield range for each increment will affect the viewing and ease of interpreting yield maps. For instance, a yield map with only two yield increments and colors (above and below field average) may not show enough detail for assessing real variability. But a yield map with 20 increments and colors may show too much detail to make much sense of.

There is no "standard" set of yield increments or color combinations for yield maps. Most mapping software provides a "default" legend for each type of crop, which can be customized for the preferences of individual managers or operators. Usually a wide set of choices for map legend customization is available. And what is chosen will be influenced by the immediate needs or purposes of the user.

Some producers, for instance, might start by using three yield increments - low, medium and high, with the middle one a few bushels on either side of the field's average yield. If the field average was, say, 130 bu/acre, the legend might be set to give a 3-color map showing areas below 110 bu/acre, 110-150 bu/A, and over 150 bu/acre. Some mapping software automatically computes the number of acres represented in each yield increment. So, in this 3-color example, the middle increment might be adjusted (by trial-and-error or via a mapping function provided) to generate a map with "equal field areas" in each yield increment - if that were desired. Many producers typically make yield maps with 4-6 colors (seldom over 10). The possibilities are endless.

In addition to ranges used for map legend yield increments, color selection is usually optional with most mapping software. Color selection is important, as is consistency. Using the same colors to represent higher yields and the same color to denote intermediate and lower yields - consistently - is a good practice.

Visual Interpretation of Yield Maps

Recognizing various patterns may help explain some yield variability. Yield differences due to soils, topography, insect or disease activity, etc. usually do not occur in nature as straight or near-straight lines. So low-yielding areas or strips with straight or near-straight boundaries are probably the result of some human activity: a former smaller "field" treated differently, a more recent field equipment malfunction or poor adjustment, an incorrect swath width set or reset in the yield monitor console, a hybrid or variety change during seeding, etc. Yield differences due to more "natural causes" will usually have more irregular-shaped boundaries. So, an intimate knowledge of the field characteristics, and its history (both recent and more distant past), is usually essential for correctly interpreting yield maps.

Visual interpretation of yield maps can also be greatly enhanced with mapping software that permits the overlay of other information - if it's available. This might include things like soil maps, tile line maps, weed patch boundaries (marked during yield monitoring), insect and disease activity (from scouting reports), etc.

Analytical Interpretation of Yield Maps

The "how much?" yield variability question can be investigated in several ways. Most mapping software provides various on-screen tools for generating various statistics about areas within a field - small or large areas, regular or irregular shapes, etc. With these, the user can "draw" a boundary around a low- or high-yielding area of interest, and get additional information - the size of the area (acres), total production harvested (bushels), average yield (bu/ac), average moisture, etc.

Developing Spatial Data and Databases

As the yield database for a field is built, and yield maps from 2 or more years become available, simple interpretation methods may prove to be inadequate. For instance, some high (or low) yielding areas in a given field may be consistently high (or low) year after year. But, what's going on when a low-yielding area in one year turns-out to be a high-yielding area the next, or vice versa? Obviously, the cause-and-effect yield relationships at work may not be simple, and are probably quite complicated. The analysis of and development of cause-and-effect yield relationships (using multiple map layers - yield, soils, nutrients, etc.) will require the use of geographic information systems (GISs) - which are discussed elsewhere, and probably new and sophisticated techniques, some of which may not have been discovered yet.

Should a producer wait to begin yield monitoring, until these "proven" data analysis techniques are available? Probably not, for it may happen "tomorrow" or the next day. In the meantime, the experience and management skills needed for collecting, analyzing and interpreting spatial data can be developed - and that is something that will be needed in the years ahead. It may be applicable only to crop yields today - but tomorrow it may be applicable to other crop attribute characteristics, like protein and oil content, and the niche marketing opportunities that the development and commercialization of those combine-mounted sensors will bring.

C

REFERENCE

SOIL SAMPLING AND ANALYSIS

By Sylvie Brouder, Mark Morgan

Economically optimum management of P, K and lime is a four-step process. Representative soil samples are collected from the field, the soil is analyzed in the laboratory, the test result is interpreted as to whether nutrients or acidity are limiting crop production, and a decision is made about the amount of nutrient that will be most profitable to add. In the following section, we will present details on soil sampling strategies and collection methods that were beyond the scope of Chapter 4: Managing Long-term Fertility. We will also discuss whether laboratory soil tests and recommendations developed for whole-field management are suitable for the precision agriculture era.

Soil Sample Collection Methods, Strategies and Technique

Since the beginning of soil testing as a component of commercial agriculture, testing programs have contained advice on the number of individual cores that need to be composited for a representative "soil sample."

Regardless of what the farmer wants to do with soil test information, a single core soil sample is never recommended because of the risk of collecting an un-representative core (the "cow pie" effect). If sampling by "zones," a soil sample should be an "area composite." If sampling by grids, one will need to choose between an "area composite" and a "multiple core grid point" sample.

Area composite sampling: Multiple cores are collected from an area and thoroughly mixed together (Figure 1). The area can be a grid unit in a grid sampling strategy or it can be a larger area or "zone" in a zone sampling strategy. The cores can be collected from random locations within the area or in a set pattern. Typically, a zigzag collection pattern is recommended. The number of cores collected per sample should increase with the size of the area. Soil samples collected from large zones should be composed of 10 to 20 cores.

At a minimum, a soil sample should be composed of no fewer than 5 to 8 cores, even if the sample area is less than 2 acres, but an 8 to 12 core composite is optimal.

The assumption with this sampling pattern is that variation within the collection area is less than variation between adjacent collection areas. Fertilizer rates derived from this approach are varied between areas, but a single rate is applied within an area (Figure 3).

Multiple core grid-point sampling: A multiple core composite sample is collected from the area around a point that marks (as shown in Figure 2):

(1) The center of a grid,
(2) The point where grid lines intersect in a square grid, or
(3) A random, geo-referenced point within the grid.

The last approach, sometimes called "unaligned sampling" has the advantage of avoiding straight-line patterns in the field. Such patterns are relatively common and are often produced by past management. For example, old field boundaries or a broken spreader that put all the fertilizer in a 3-foot wide band.

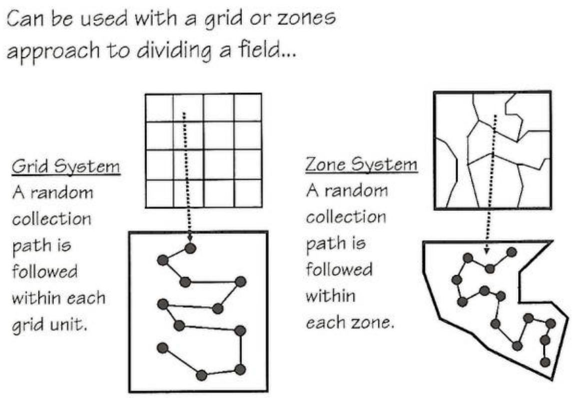


***Figure 1**. Strategies for collecting soil samples. Area composite sampling: soil test values represent an area.*

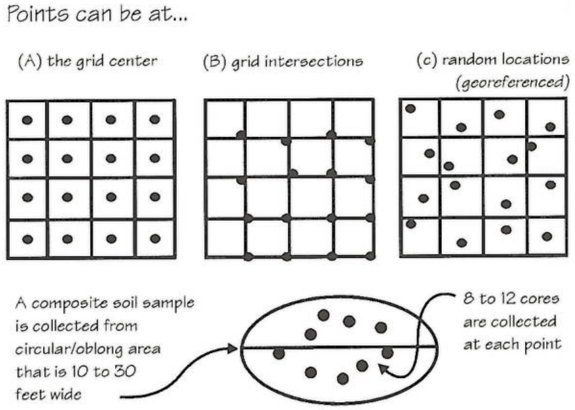


***Figure 2**. Strategies for collecting soil samples. Multiple core grid point sampling: Soil test values represent a point.*

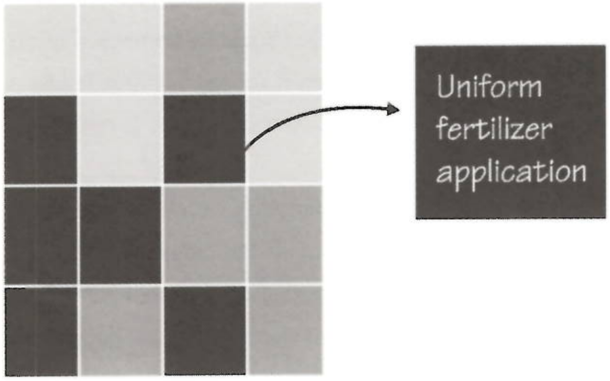


***Figure 3**. Strategies for drawing input maps. With area sampling the application map will have uniform rates for each separately sampled area or zone. Rates may vary between neighboring areas or zones.*

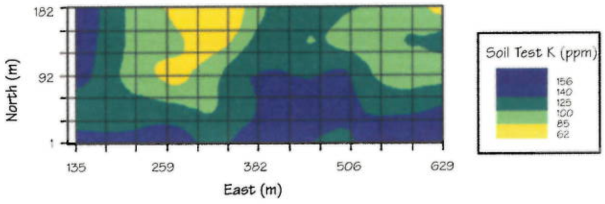


***Figure 4**. Strategies for drawing input maps. With point sampling, statistical programs are used to estimate the soil test levels in areas where cores were not collected. Application maps that vary rates within a grid unit can then be drawn. Alternatively, this contoured soil test map can be used to develop maps that apply the most appropriate uniform rate to a given grid unit.*

In grid-point sampling, the area from which the sample is collected is usually circular or oblong in shape, and between10 and 30 feet wide. A minimum of 5 to 8 cores should be taken; an 8 to 12 core composite is optimal.

The underlying assumption of "point" sampling is that soil test values from areas of the field that are not tested can be predicted from neighboring point samples. In other words, if soil test P levels for two neighboring grid units are 10 and 20 ppm P, respectively, then the soil test P values between the two grid points are expected to be between 10 and 20 ppm. The main drawback with this approach to sampling is that the larger the grid, the more likely it becomes that there is *no* relationship between sampled "points" in neighboring grid units. Therefore, grid point sampling is best used when fields are divided into small grid units. A number of studies have shown that the distance between points in a field needs to be less than 330 feet or smaller than 2.5-acre grids. A **1-acre** grid unit has consistently been found to be small enough for "spatial dependence" in soil test P, K, and pH to exist between points.

Grid-point sampling is required if the objective is to use geostatistical mapping software to draw contoured input maps for a field (Figure 4). The software uses special statistical techniques to estimate soil test values for all unsampled locations within the field based on the values at sampled locations. The resulting maps vary the input rate within the grid unit. Alternatively, the "estimated" soil test values within the grid can be used with the sampled "point" value to determine an optimal, uniform rate for the entire grid unit.

Importance of Sample Depth: The original correlation and calibration of soil tests was based on samples collected from the tillage layer of test fields that were moldboard plowed, then the common tillage practice. The reasons for basing correlation and calibration on this depth were both logical and practical. Most of the crop's roots were in this zone, and, with adequate moisture, most of the nutrients acquired were from this zone. Also, with fertilizer application, most of the nutrient buildup occurred in this zone and it was relatively easy to collect a 6- or 8-inch core from most soils.

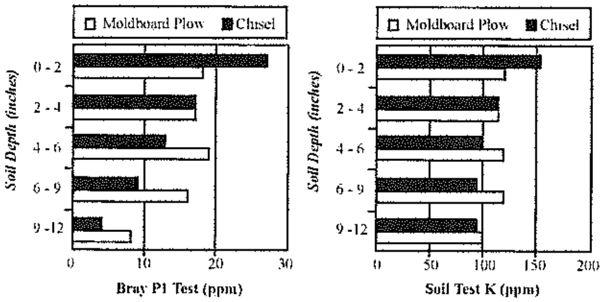


Figure 5. Moldboard plowing used to thoroughly mix the soil in the plow layer. Current tillage practices including chiseling allow nutrients to become highly concentrated in the surface soil. The result is that cores must be collected to a consistent depth or soil testing results will be inconsistent as shown in Table 1.

Today, few farmers moldboard plow and nutrients are no longer uniformly distributed throughout the tillage zone. In chisel and shallow till, disk- or field cultivator-based systems as well as continuous no-till systems, stratification of P, K, and pH occurs (Figure 5). However, studies in the Eastern Cornbelt have shown that the 6- or 8-inch sample depth is still appropriate to determine the P and K needs of the plant and the lime requirement in soils that are minimally tilled. So long as moisture is sufficient, the plant can change root growth patterns in the tillage layer to mirror the nutrient availability. In continuous no-till, sampling to determine the lime requirement has to be altered to reflect the fact that lime is relatively immobile. An unincorporated lime application will only affect the surface in a few inches of the soil. Therefore, in continuous no-till with surface lime applications, recommendations need to be based on a 4-inch sample depth.

Nutrient stratification now makes it necessary to tightly control sampling depth. When tillage zones were well mixed by plowing, poor depth control had little effect on the soil test value. But in reduced tillage situations, large errors in soil test values can occur when collected cores are too shallow or too deep (Table 1).

Table 1. The effect of the depth of the core on the soil test values from fields that were moldboard plowed or chiseled.

	Soil Test P (Bray 1, ppm)		Soil Test K (ppm)	
Core Depth	**Plow**	**Chisel**	**Plow**	**Chisel**
0-2 inches	18	27	120	155
0-4 inches	18	22	118	135
0-6 inches	18	19	118	123
0-9 inches	17	16	119	114
0-12 inches	15	13	114	109

When should soils be tested?

Most farmers are aware that season, extreme weather patterns and crop rotation can affect a soil test result. In mid-summer, pH readings can vary due to movement of salts with wetting and drying of the soil. In late winter, K levels in heavy textured soils can be higher as freezing and thawing releases K from clay. However, it is important to understand that differences related to these factors are generally relatively small, and reliable information can be obtained at most times of the year so long as intact cores can be collected to the recommended sample depth.

The most critical factor in deciding when to sample is getting information back in time to use it. In most situations, October to December sampling for determining spring fertilizer applications and March to April sampling for fall applications are recommended. These two time periods generally have lower amounts of testing variability associated with them. This time frame provides good opportunity to thoroughly review the test results and plan the program before actually needing to make the application.

When, where and how should soils be retested?

In intensively managed systems, soil fertility will tend to change with time in the following ways:

- Soil acidity will increase over time from rainfall leaching and crop removal of basic elements and through the addition of acidifying fertilizers, particularly N;
- Immobile nutrients that are sufficient for the current year's top yields may become marginal following several years of high production and or fixation reactions in the soil;
- Soil salinity can increase in irrigated production, and
- Nutrient imbalances can occur.

While it is tempting to use knowledge of fertilizer inputs and yields (nutrient removal) to estimate soil fertility levels over time, this balance sheet approach simply does not work very well. There are too many complex interactions and poorly characterized processes that affect the nutrient status in the soil. An accurate soil fertility map of a field will require periodic retesting.

The three principal factors to consider when deciding on a time frame for retesting a field are the cation exchange capacity (CEC) of the soil, the historical soil test levels, and the cropping system.

In general, soils with high CEC and high soil test levels should be tested every 3 to 4 years. If soil has a high CEC, it will hold cation nutrients better and the pH will remain stable over longer time periods. With regular fertilizer applications to replace crop removal, soil test levels will not drop below critical levels in a time frame of 3 to 4 years. In contrast, soils with low CEC and/or low initial soil test levels need to be retested more frequently. When the CEC is low (less than 7) cations such as potassium, magnesium, and ammonium can be leached through the root zone and soil pH will be more likely to change rapidly. For example, irrigated, continuous corn grown on a low CEC sandy loam soil should be tested every 2 years.

When initial fertility levels are low, testing should also be done more frequently to ensure added nutrients are sufficient. Retesting should be done every 2 years on any field where major changes in pH or soil fertility are being attempted.

Finally, corn grown continuously or in rotation with soybean on high testing silt loam soil but *without* any fertilizer additions should be retested every 2 years, as should any fields where crops with high nutrient demand are being grown such as alfalfa or continuous silage corn production.

Some farmers have asked if the cost of spatially intensifying the number of samples collected in a field can be offset simply by sampling the field less frequently. The short answer to this question is no. Gaining knowledge about spatial variability at the expense of knowledge of temporal variability (variability in time) is unlikely to be a profitable trade-off for the reason discussed above as to why soil test values change over time. The best mindset with which to approach re-sampling is not to plan on stretching the time frame but to anticipate using previous test results to adjust sampling schemes, including reducing sampling intensity. This can be achieved by combining into one sampling unit adjacent zones or grid units that had similar soil test results in the initial sampling (Figure 6).

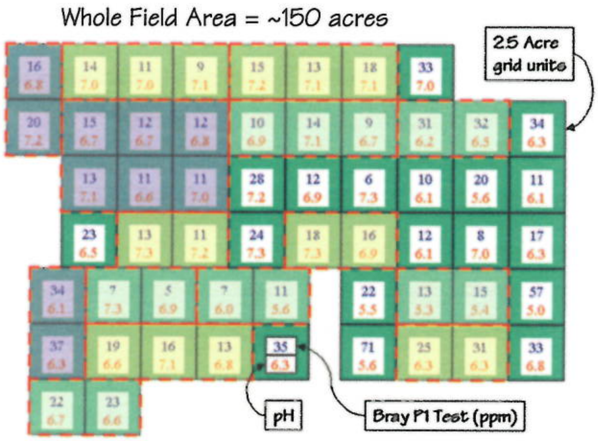


Figure 6. *Initially sampled on a 2.5 acre grid (area composite sample), similar adjacent grid units have been combined for re-sampling. The number of samples has been reduced from 56 to 33. Re-sampling "grid size" now ranges from 2.5 to 15 acres.*

How accurate is the testing lab?

Even though soils should be expected to vary, when a soil test result is not as expected, many are quick to question whether the testing lab is producing "good numbers." Most commercial testing labs participate in a national sample exchange program called the North American Proficiency Testing (NAPT) Program. In the NAPT program, labs perform routine soil tests on unknown samples to demonstrate that they can accurately and precisely estimate the "true" soil test value. A lab is generally judged to be proficient if their analytical results are within 10 percent of the "true" value.

Most states will review a laboratory's performance in the NAPT program and officially certify successful labs. If the laboratory performance is in question, contact the state's Cooperative Extension Service for information on state certification programs. It is important to remember, however, that variability exists in the analytical process and even the most accurate and precise labs have an acceptable margin of error (Table 2). When comparing two soil test results, it is helpful to think not of the actual values but of the range within which the "true" values actually lie.

Table 2. *Acceptable commercial testing laboratory performance in Indiana for common soil tests.*

Analyte	Method	Acceptable Performance	Example	
			True Value	Acceptable Lab Result
pH	Water	Within 0.2 units of "true" value	5.3	5.1 to 5.5
	SMP Buffer	Within 0.2 pH units of "true" value	6.6	6.4 to 6.8
Phosphorous	Bray 1	Within 20% or 1 ppm of "true" value Use larger number	4 ppm 20 ppm	3 to 5 ppm 16 to 24 ppm
Potassium	1 N Ammonium Acetate	Within 15% or 15 ppm of "true" value Use larger number	70 ppm 150 ppm	55 to 85 ppm 127 to 173 ppm

Are current soil tests and their calibrations good enough for precision agriculture?

Many fertilizer recommendations in use today were developed (correlated and calibrated) in the 1950s and '60s. Most were developed on a statewide or regional basis and represent averages across many soil types and microclimates. Therefore, it is reasonable to ask whether the soil tests and associated recommendations can be used to meet the soil-specific objectives of managing within field variability in soil fertility.

Answering this question requires the evaluation of both the database from the original experiments and the suitability of the historical interpretation of the original experiments. Reviews of past research show that the science behind the soil-testing database is good. Today, the principle problem with the soil tests themselves is that field correlation and calibration is no longer being extensively performed. Therefore changes or improvements in extraction chemistry or methodology are being evaluated only on their lab performance relative to old test procedures. They are not documented with respect to direct crop response and fertilizer use. The result can be similar to the game of "telephone" where the message gets subtly but progressively altered as it is passed along.

Fertilizer recommendations represent the judgement of the agronomists who interpreted the correlation and calibration data. Using soil test values to make sound fertilizer management decisions relies not only on an enormous amount of background research but on a great deal of field experience and common sense regarding profitable management decisions for the time. Therefore, fertilizer recommendations derived in the '50s and '60s are likely to be overgenerous for several reasons, including:

- inexpensive fertilizer, large yield responses with no yield penalty for over application and lack of awareness of environmental impacts of N and P;
- lack of rigorous statistical analysis of response data, and
- an understanding that when just one core of a multi-core composite is collected from a nutrient hot spot, the soil test value for the composite is artificially high and the field appears to be less responsive than it really is.

Thus, to a certain extent, improving current recommendations for the objectives of soil-specific management simply involves reinterpreting original calibration experiments using a more statistical approach to the data and updated knowledge on profitable nutrient management.

Reinterpreting the original correlation/calibration experiments will also permit us to recover some soil and environmental specificity. The soil-testing database is composed of the results from numerous field trials conducted in multiple years, each characterized by specific environmental conditions. Much of the site-specific nature of this database was lost, however, when data were combined to create broadly applicable recommendations.

For example, in many states different correlation curves were initially developed for different subsoil P and K levels. Some of these soil-specific curves were commonly in use until as recently as 1985 when efforts to regionalize recommendations combined the information into a more broadly applicable set of guidelines. Since 1995, Ohio, Michigan and Indiana have used one set of recommendations to cover the entire tri-state region where soils can range from mucks to heavy clays to sands. Such recommendations are compromises that are not intended to be terribly wrong anywhere, but, for this same reason, they may not be exactly the best for any given spot in a field. Improving recommendations for site-specific management will require re-analyzing the original data to highlight the specificity, not smooth it over.

Fully realizing the potential of variable-rate nutrient management will require some new research. In addition to field calibration of new soil testing methods, research is needed on the effect of landscape position on P and K availability. Also, not many field studies to establish crop responses to lime and to determine the soil-specific lime requirement have been conducted, and more data is needed for P, K, and lime addition for conservation tillage systems.

Finally, most nutrient recommendations are based on a yield goal. Several methods exist for developing site-specific yield goals. Some producers use yield maps to find the highest yield ever produced in a given management zone. Others use the average of the last five years of data, excluding drought years. Some producers add a percentage to their expected yields to allow for genetic improvement in hybrids and varieties. And some also consider the results of economic analysis that suggests that profitability may affect yields. When grain prices are high relative to production costs, it pays to shoot for a higher yield. Research is required to show which of these approaches consistently results in the most profitable amount of fertilizer applied.

For now, recommendations developed for whole-field management are a good place to start. With re-analysis and new research, they will likely be improved for local soil, climate and other environmental conditions. Yield monitor data and simple on-farm research designs may allow groups of producers to adjust fertilizer recommendations for their farms.

D
REFERENCE

REMOTE SENSING

By Chris Johannsen, Paul Carter

Remote Sensing in Agriculture

When the first farmer looked out over his crop to admire it or possibly to observe the condition of the plants, he was employing remote sensing principles. His eyes were the sensors and his brain processed the data observed. From an historical standpoint, remote sensing began with the invention and development of photographic capabilities, which improved the abilities of the human eye and provided a permanent record of visual information. Since that time, pictures have been taken from hot air balloons in the 1800s to early aircraft flights to modern aircraft and now satellites. The use of high altitude, Earth surface observation aircraft began in the 1950s and satellites with Landsat 1 (formerly ERTS-1) launched 23 July 1972. Remote sensing used in agriculture began as early as the 1930s and many advances in technologies have taken place since that time. The full extent of its potential has not yet been realized.

A Definition

Remote sensing is the collection and interpretation of information about an object from a remote vantage point without making physical contact. Lillesand and Kiefer (2000) state "Remote sensing is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation." The distance from the object could be less than an inch to many miles, depending on the sensor system used and the information desired.

Remote sensing technology has seen many changes in the past five years. From the tractor, farmers are using sensors that measure soil and plant parameters; from an airplane, researchers are obtaining aerial photography and digital images showing anomalies within a field; from satellites scientists will be obtaining images with spatial resolutions that previously were top secret. The major changes are that from satellite altitudes one is able to:

1) image or see with more detail, a smaller piece of land,
2) define more precisely the specific colors or light responses reflecting off of the field and
3) obtain data on a regular interval of every other day or every 5 to 7 days (Johannsen, 1994, 1996a, 1996b).

These make it possible for farmers:

- To view small problem areas in a field,
- To determine the problem by interpreting remotely-sensed data, and
- To receive data/information on a regular basis.

Remote sensing offers farmers some new tools, new ideas, and new methods to improve or enhance their field management.

Pictures and Images

Familiar satellites images include the weather views captured by NOAA satellites or the views of Mt. St. Helens after the volcanic explosion on 18 May 1980. Many aerial flyers have taken photographs of many farmsteads and sold them to the owners. The USDA has obtained aerial photos and slides of all agricultural counties in the U.S. nearly every year for purposes of measuring acreage and checking compliance. The use of digital cameras makes it possible for a farmer to shoot an image of a diseased plant and send the image by mail or via email attachment to their local university to obtain a possible identification. All of the commercial satellite companies have obtained aerial images with similar sensors as found on satellites to obtain coverage and examples prior to launch. Many more images that are specializing in agriculture are now available. Companies are trying to develop a market for their expertise in collecting pictures and images of farm fields.

If it is not a photograph, then what is it?

Most images used in remote sensing are not of the typical "picture format" familiar to most viewers. The images collected with this technology are of the "digital format" (for computer viewing) and consist of "bands" or "slices" of the electromagnetic spectrum. The different colors of the spectrum displayed (visible wavelengths) are divided into many different shades. Similar to the boxes of crayons used when in school, there were the 12-color boxes or one could get the 64-crayon box. Each color can represent a specific band or slice of the visible spectrum. Usually only a narrow portion or band of the entire spectrum is of interest in remote sensing.

Light from the sun is the normal source for the energy used in remote sensing and any other light source would be too expensive and impractical. The greatest amount of Sun energy is of the visible area of the spectrum, what one normally sees with the human eye, but newer technology equipment research is being accomplished with other areas of the spectrum where there is less energy response (Figure 1). Infrared images are of the area just past the visible part of the electromagnetic spectrum and of considerable importance to remote sensing. Sensors have been developed to detect reflected and emitted light responses from this area. Thermal or heat measurements, often confused with the near and middle reflective infrared images, are the common "color infra-red" images. The thermal infrared images are rarely used since it is difficult to obtain high spatial resolution. Weather is a major concern to remote sensing in that none of the current imaging systems can look through clouds. This is where radar is of interest. Areas of the country where clouds persist much of the growing season can be imaged with radar. Canadian Radarsat is the first commercial company to sell satellite-derived radar images.

Radar is relatively new to agriculture and is considered an active system. It involves sending out waves of energy that impact targets and send back signals that can be measured and recorded with a receiving antenna. Radar is not a new technology, as it has been used for nearly 60

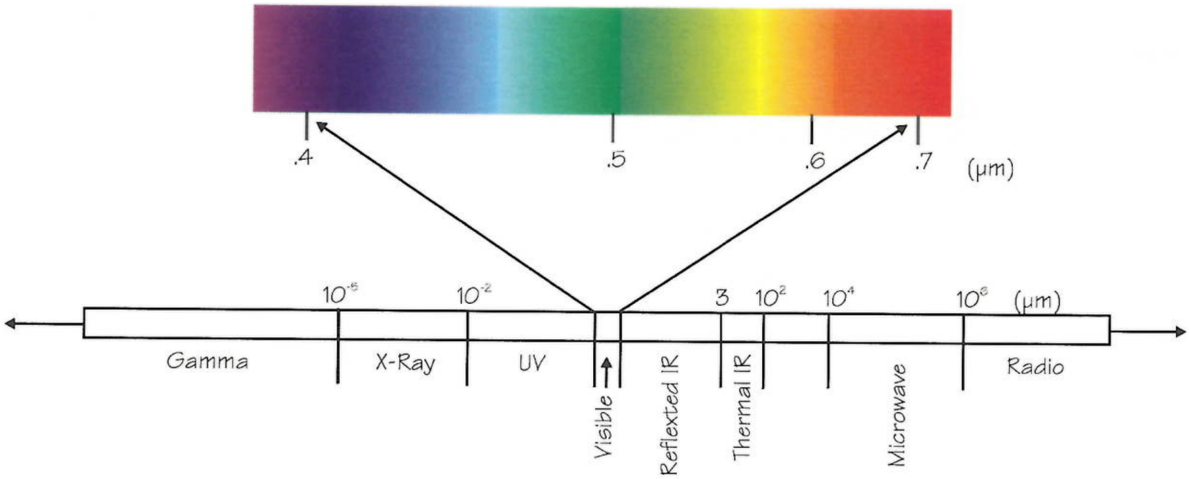


Figure 1. Electromagnetic Spectrum

years. It has the advantage of being able to look through clouds and will also perform well at night, not needing a light source.

Where can one get pictures or images?

Sources of remote sensing information presently include many different types of platforms for holding the sensor device. Sensors mounted on aircraft and satellite platforms provide the majority of the data used today in precision agriculture. Some companies with aircraft platforms include Positive Systems, Inc., GeoFlight (GER), and EMERGE (ConAgra). Companies with satellite platforms include Orbimage, EarthWatch, EarthScan, Space Imaging (IKONOS), and SPOT. This list mentions only a few of the many possible providers of pictures or images. One might use a standard 35 mm camera, have a friend or hire a plane and pilot to fly over the fields in question and get some infrared or standard color photographs for reference use. Vehicle or tractor-mounted sensors have long been considered as another source, but the system technology for support is not well developed. These sensors are called "real time" sensors and used with direct application of products. Precision agriculture will use a broad array of remote sensing collection techniques to gather data about crops and soils for decision making, as no one source is able to answer all of the questions of a consultant or producer (Figure 2).

***Figure 2**. Sensor Platforms: Left, ground measurements: right top, satellites with an variety of sensors: right bottom, aircraft with sensors at bottom of plane.*

Commercial systems developers are beginning to integrate many independently used technology hardware and software, making an integrated precision agriculture system more viable and potentially profitable to farm producers.

Value-Added Products

As the definition of remote sensing implies, measurements of soil moisture or plant nutrient levels are not made directly. Therefore, inferences need to be made to find relationships between sensor data collected and soil or plant conditions actually measured (Figure 3). Once correlation between the sensor data and the actually measured data is established, it is possible to make inferences covering large areas for which it is impossible to make actual ground-based measurements. These data are not useable in the raw collected form and must be processed within a formula to make meaningful categories for the user. One of these is called the vegetation index, which uses several bands of data in a mathematical formula and reduces them to a single number.

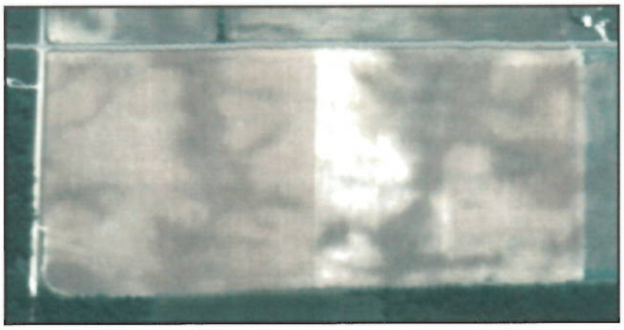


***Figure 3**. Soil Color Image: Field on the left has been recently tilled. Field on the right has a drier surface where soils with higher organic matter are more discernable.*

What does one need and how often?

The question from producers "What do I need?" requires the assistance of trained agronomic consultants. The data types and the frequency of acquisition will depend on the field problems to be detected, the geographic areas, the crop species and amount of risk that a producer is willing to accept. Risk is a factor that only each individual producer will be able to answer considering the investment that they are willing to make which also answers the frequency of acquiring data. Frequent acquisitions such as every week or two weeks may not be needed in later growth stages as when the crop is vigorously growing.

Applications of Remote Sensing Data

The data are used for a variety of disciplines ranging from military surveillance, industrial and urban land use planning, agricultural crop and soil observation and management to inventory of natural resources. Our focus is agricultural applications.

In an agricultural application, these methods are an attractive alternative to typical crop scouting due to the capacity to cover large areas quickly and repeatedly while providing a permanent record of the observations. The potential for remote sensing is for collecting observations of areas that are difficult or impossible to access under current scouting methods and for more efficient reporting of crop conditions. With a minimum amount of ground sampling, remote sensing data will permit identification and area measurements of crops, assessment of crop stress, possible yield forecasts, range surveys, and mapping of major soil boundaries (Bauer, 1975). Early detection of crop problems can help to prevent losses later in the season. Providing corrective measures can be and are applied before permanent plant damage results (Space Imaging, 1999).

Remote sensing of vegetation is useful for generally detecting healthy plants and those that are under stress. The spatial patterns observed might reveal distinctive and descriptive traits of specific stresses (anomalies) which can assist consultants and producers in a diagnosis of the stress (Figure 4 and 5). Crop stress could be caused by many different factors: nutrition, weed infestation, water damage or chemical damage to name a few. Other spatial patterns may be caused by invasion of various weed species. Images can provide valuable bare soil patterns that are often referred to as soil color images. They also give other useful soil characteristic information such as organic matter and surface texture that can be used to help manage field operations of variable-rate chemical or seeding applications.

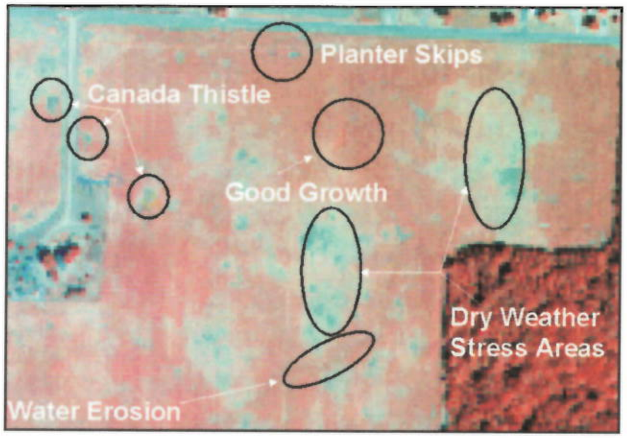


Figure 4. *Anomaly Detection Image: A corn field with a variety of conditions that make provide unusual but distinctive patterns.*

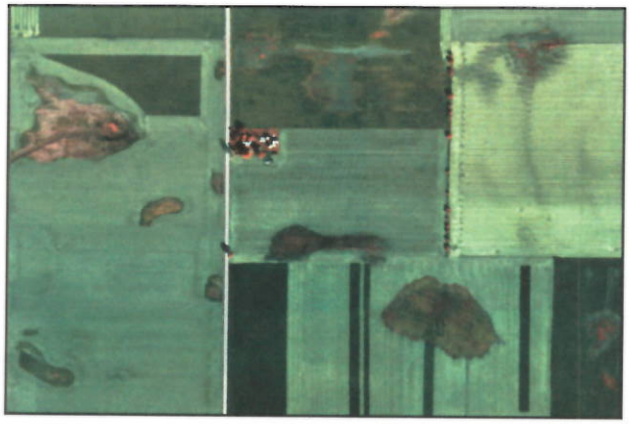


Figure 5. *Farm Management Scene: This image provides a variety of patterns such as harvesting in progress (upper left), field not harvested (upper center and lower right), fields that have been harvested (upper right and west side), and fields harvest and fall tillage has begun (lower center). Unusual shaped areas within a field are locations where the crop has been drown out during early spring rains.*

Using Remote Sensing Images as a Layer within a Farm GIS

Assume that you have a soil map, topographic map and an aerial photography of a cropland field and you want to bring them together. These three datasets - 2 maps and a photograph are called data layers or data planes. Further, let's assume that you have a database with the soil map containing soil test information. The software used to bring these datasets together along with its database so individuals can interact information between them is called a geographic information system (GIS). One would have to do some data formatting and preparation to effectively use a GIS with this dataset. The soil map would need to be drawn on ortho photography (photos that has been geometrically corrected so that there's no distortion from one side of the image to another. Then it would need to be digitized (made electronic) to prepare for a GIS. The U.S. Geological Survey is in the process of digitizing all current topographic maps and hopefully one could purchase a CD containing a digitized and corrected version of the topo map. The aerial photograph would need to be scanned where one would place a set of uniform dots over the photo and would record the location and grayscale response for each dot. After taking all of these steps, it is necessary to register the maps with the photo image so that it is possible to combine information from each data layer for a given specific location.

Temporal Data Layers

If one has more then one date of remotely sensed images or photographs, chances are that one will want to compare one date with the other to determine change, whether this is in vegetative cover, locations of anomalies or other features. This type of comparison is also done with a GIS. It may be that after some patterns of change are seen that one would want to compare it with a soil map to determine if the soils had an influence on the change.

Soil Maps

For many producers, especially those involved with Site Specific Farming, existing soil maps do not contain enough detail. Research is being conducted to determine if remotely sensed images taken of a field when it is in bare soil condition can assist in providing a basis for making a more detailed map. Additionally, one could use the images for the guiding of directed soil sampling. Combining the images, existing soil map and the terrain map are very useful in arriving at soil management zones (smaller areas of the field that can be managed separately). A producer might consider using a laser or similar equipment for constructing a more detailed elevation map such as a 1- to 3-foot contour interval, which would be extremely helpful for studying drainage patterns within a field.

Yield Monitor Images

Another important dataset useful in GIS studies of fields are the yield monitor maps. The yield maps need to be processed corrected, as there is distortion due to the speed of the combine, rpm of the combine, density of the crop and other similar factors. Yield maps provide an image that combines all the influences that soil, weather, management, pests and other factors had on the crop yield during the growing season. Combining this image with other maps must be done carefully as errors are multiple in nature. Remote sensed images taken within one month of harvest are extremely useful in assessing yield variation.

Making Remote Sensing Work for My Management System

One needs to learn what to expect from remote sensing images. The images alone will not identify the problems that might be occurring within a field, the information needs to be interpreted by the crop consultant or whomever is working with the farmer. With experience, the farmer will be able to do his or her own interpretation. The use of the images for making management decisions will also come with experience. The bare soil image a field may be valuable for many years. They will show the variation of soil patterns, but are not a substitute for USDA soil maps. Images taken during the time of vigorous crop growth are helpful to show where the crop is best and where there are weak spots.

These are times when a farmer can possibly make adjustments such as apply a pesticide or add additional nitrogen. Later, when the crop is too tall for equipment to pass through the field is not the time to take a lot of images unless one is using an irrigation system. The information that one obtains may be helpful for next year's crop but will likely not help for this year. Exceptions are for aerial applications of pesticides or for irrigation applications where one can use the images to guide better applications. Many farmers have found that images taken over fields that were recently acquired are extremely helpful in locating areas that need corrections.

Obtaining Help

There are currently only a limited number of people who can provide proper assistance. This is due to the lack of training that many ag professionals have had with remote sensing. People who are trained may be found at independent crop consultants, cooperatives, fertilizer companies, and commercial companies specializing in this information area. Some assistance can be obtained from Land Grant University personnel for specifics as well as through their webpages for general information. Other sources of information can be obtained at conferences such as InfoAg, Spatial Information for Agriculture, and International Precision Farming, (which have sessions on remote sensing) as well as university field days, workshops, farm magazines and journals.

Making Money with Remote Sensing Information

Since the development of remote sensing nearly 60 years ago, there have been many applications in agriculture. Some have demonstrated excellent utility while others have not been nearly as successful for resource management applications (Reising et al., 1989). Profit margins for individual farmers are typically slim; therefore farmers are likely to take seriously any technology advances that will help increase those margins. But, adoption will be slow without good economic verification of profit or time management. The use of remote sensing data have been most economically sound for the high-value crops where the risks are greater per unit area of production than for the lower value crops of the Midwest where weather effects are the greatest variable and not manageable (Johannsen et al., 1999). For the Midwest, variable-rate applications of lime have proven quite economical for producers and are being widely accepted. There have been significant advancements in scientific understanding of the spectral properties of crops and technical capability for acquiring and processing multispectral data. The future looks excellent for further progress. The temporal profile techniques are extremely efficient and offer the potential for substantial gains in accuracy and cost effectiveness over earlier Landsat crop estimation methods (Bauer, 1985).

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REFERENCE

VARIABLE-RATE TECHNOLOGIES

By Case Medlin, Stephen Hawkins, Keith Morris, Sam Parsons

Equipment Additions for Reaping the Most from the Technology

This section is devoted to the typical equipment additions/alterations that are customary for variable-rate technology (VRT) applications.

Depending on the applicator's specific needs, some of the equipment changes that will be discussed in this section are purely optional, while others are mandatory if the user is to reap the most from VRT (Figure 1).

Figure 1. Several equipment additions are needed for most VRT applications while some equipment additions may be optional.

A global positioning system (GPS) is usually needed for most VRT equipment. GPS is needed to constantly monitor the equipment's exact field location and continually update the on-board computer. This is necessary when application rate is being changed with a predetermined application map, and when "as-applied" data is being collected. Relatively inexpensive GPS units (less than $800) can estimate their position on the Earth to within 50-100 yards. However, many production parameters (soil properties, weed populations, etc.) in a field can easily change every few feet. Thus, VRT applications made with this level of accuracy are not providing the maximum benefit from the technology and may be more detrimental than beneficial. However, linking a differential correction unit to the GPS unit can increase its accuracy down to 3 feet or less. This increases the application accuracy and is a vital link in reaping the maximum benefit from the technology. This equipment is also used for yield monitoring operations. See the Global Positioning Systems section for more information concerning GPS and differential correction.

Another component in VRT application is a controller that integrates the application map data, GPS data, and equipment operation to vary inputs. Many of these units can be used in application mode and also to collect data during harvest.

Close monitoring of equipment speed is extremely important as well. The readings from transmission-driven speedometers that come standard in tractors, combines, sprayers, etc., are not highly accurate. When properly calibrated, radar-based speedometers are extremely accurate. Since they use radar to measure ground speed, tire slippage due to wet soil conditions or tillage load and topography changes do not impact the accuracy of its measurement.

With liquid products, a flow sensor is needed to compute the quantity of material being applied over a given area as the application equipment moves across the field. Most liquid applicators can be easily modified to accommodate a flow sensor. Applicators that have been successfully modified include broadcast pesticide/fertilizer sprayers, anhydrous ammonia applicators, direct injection pesticide applicators, and liquid manure spreaders (Figure 2).

Figure 2. *Most of the VRT equipment can be transferred between different applicators. For example, a global positioning system used during a pesticide application may also be used during the fertilizer application.*

Liquid products that have been successfully applied with VRT equipment include urea ammonium nitrate (UAN), anhydrous ammonia, pesticides, or effluent. Typically, the N-P-K concentration of effluent is extremely non-uniform both within a load and between loads. Thus, variable-rate effluent applications based on N-P-K content are considerably more difficult than using commercial fertilizer due to the intense sampling needed to monitor its nutrient values.

In the case of anhydrous ammonia, a cooling system along with a flow sensor is needed. Currently, a flow sensor for measuring a liquid-gas combination is not available; therefore, a cooling system is essential to keep the anhydrous ammonia in a liquid form until it passes through the flow sensor, which monitors the output.

VRT applications of single and multiple pesticide products are also being made. Currently marketed sprayers have direct injection systems that inject small quantities of the concentrated herbicide into the spray carrier liquid (Figure 3).

Figure 3. *Site-specific herbicide applicators often carry only water in their bulk tank, such as the 1000 gallon tank on this sprayer. The concentrated herbicide is then pumped into a mixing manifold where it is diluted with the water to achieve the proper rate before entering the spray boom. (photo provided by Aventis CropSciences)*

The rate of application could be automatic (based on an application map) or manually controlled by the driver. Advantages of this system are:

(1) Little cleanup required since the bulk spray tank generally contains only water,
(2) Virtually no herbicide waste since the product is being metered directly out of the spray jug, and
(3) Optimum weed control since herbicide selection would be based on weed species and size.

Variable-rate applications can also be achieved with multiple spray nozzles where all nozzles spray the same herbicide solution, either at the same or different volumes (Figure 4).

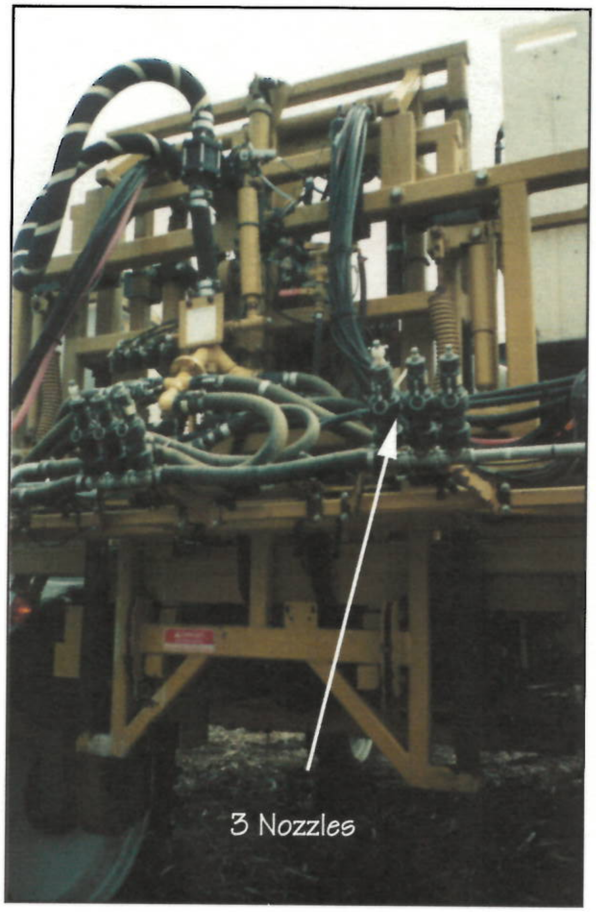

Figure 4. *Some commercially available applicators are equipped with multiple nozzle systems. Generally, the nozzle selection is based on flow rate. This applicator is capable of changing flow from 5 to 10 to 15 gallons per acre while moving through the field. (photo provided by Aventis CropSciences)*

The limitations of this system are:

(1) Application volume restrictions of some herbicides, and
(2) The maintenance cost of the additional spray nozzles and controls.

Some dry product applicators use precalibrated metering units to adjust rate while others use a weight sensor to monitor and adjust the product's flow rate in a similar manner as the liquid flow sensor. These weight sensors and metering units can be thought of as typical flow rate adjustments that have been linked to an automatic controller that changes the flow rate settings based on the applicator's changing field location. Dry products that are being successfully applied with VRT equipment include dry fertilizers, lime, and manure/sludge. However, the same uniformity concerns surrounding VRT effluent applications also exist with manure/sludge applications. Thus, to achieve accurate VRT applications of sewage sludge, the operator must be willing to closely monitor its nutritional value.

Many of the granular or pelletized products such as PEL-lime have been successfully applied with variable-rate air delivery systems. The advantages of these systems are:

(1) More control over the application pattern, and
(2) PEL-lime is generally a more uniform product than ag-lime in terms of acid neutralizing value.

The disadvantage of using PEL-lime is it's cost. The alternative is using ag-lime applied with a spinner spreader. Disadvantages of a spinner spreader system are:

(1) Lack of uniformity of ag-lime among batches and among quarries,

(2) The need to calibrate each application load relative to its acid neutralizing value, and

(3) As rates change across a field, spinner spreaders may not be able to change rate settings as rapidly as desired or maintain the desired pattern or spread width.

For these reasons, PEL-lime typically has better uniformity through the product and, although it costs more, can be affordable when basing application amounts on acid neutralizing values once a baseline pH has been achieved.

Equipment Modifications for Making Variable-Rate Technology (VRT)

Equipment modifications needed for a VRT system, depends on the product(s) to be varied and the method used to measure the production property in the field. For example, spot-spraying weeds based on a driver sighting weed patches and turning a controller on or off, may require few modifications.

However, VRT fertilizer applications based on (1) an application map constructed from sampled soil properties or on-the-go sensing equipment and (2) a system capable of changing rate independent of the operator, may require several modifications (Figure 5 & 6). For field sprayers that already use a monitor-controller, however, equipment modifications may be minimal.

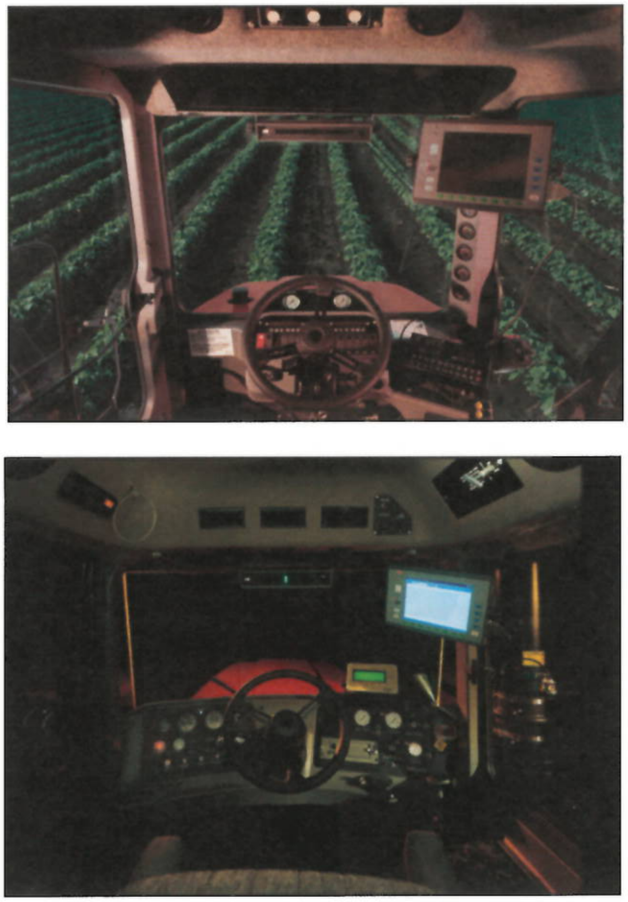

Figure 5*. AIM Navigation System: a) in the cab of a SPX 4260 sprayer, and b) in the cab of a Titan floater. (photos provided by CNH Precision Farming Global Product Line)*

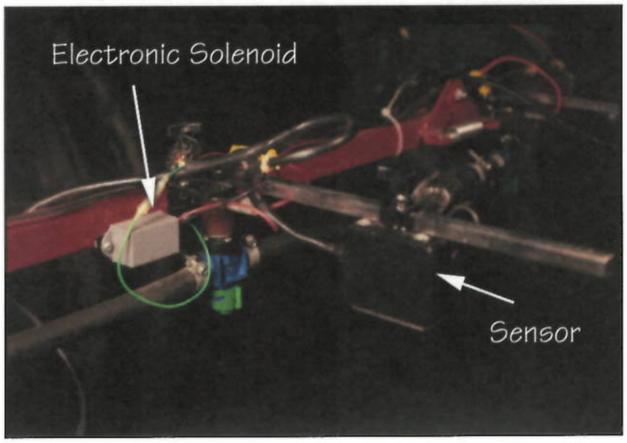

Figure 6*. Some recently developed weed sensors are capable of detecting green plant material, then as the weed passes under the nozzle, an electronically controlled solenoid valve opens, to spray the weed. The down-side of these systems is the inability to distinguish between crops and weeds. (photo provided by Dr. Tom Jordan, Purdue University)*

For seeding equipment and fertilizer applicators with a traditional ground-driven system, the first modification one can anticipate is changing to a hydraulically driven system (Figure 7 & 8). This modification allows a product rate change without altering the ground speed of the equipment. As the equipment moves across the field, the GPS communicates to the on-board computer the exact field location of the applicator unit relative to the predetermined application map (Figure 9). The hydraulically driven system can then automatically vary the application rate if needed.

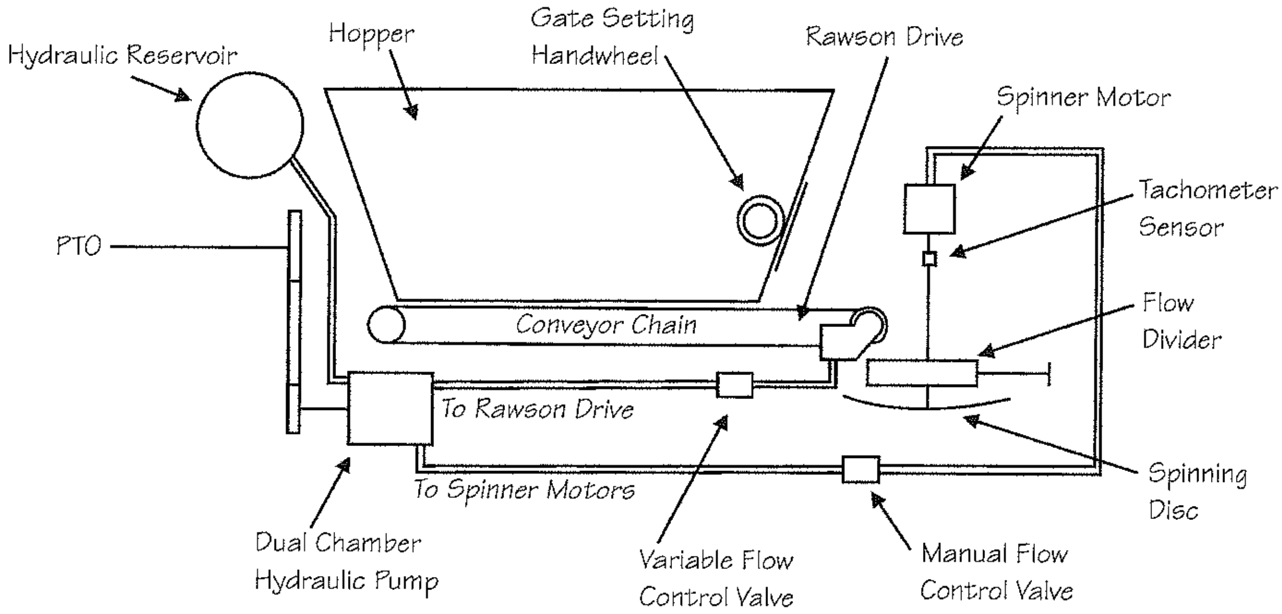

Figure 7. VRT applications are controlled by hydraulic motors on this spinner spreader which vary the rate based on the field location. Traditionally the rate would have been controlled by the flow gate and a ground-drive to the conveyor chain.

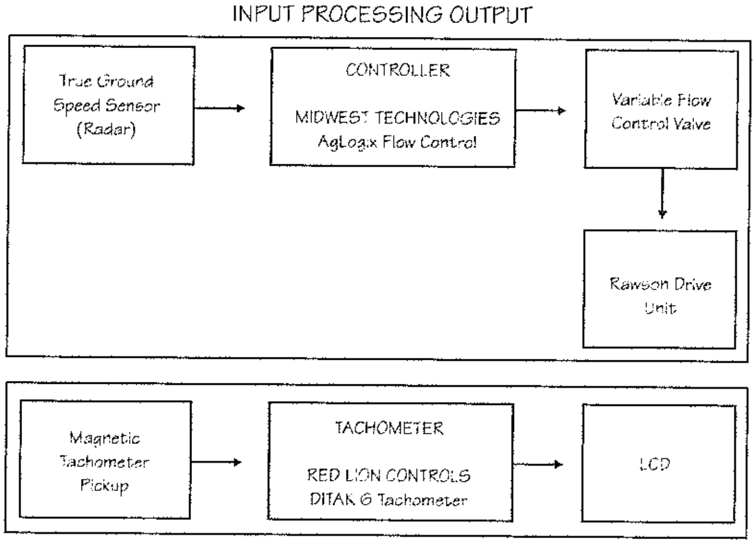

Figure 8. The hydraulically driven system is not complete without a ground-speed sensor since rate is still dependent on area covered in a specified time.

Properties Used to Generate Application Maps

VRT lime and fertilizer applications can be based on field maps. Maps can be derived from many sources, but most are based on soil properties that have been intensively grid sampled in the field (Figure 9).

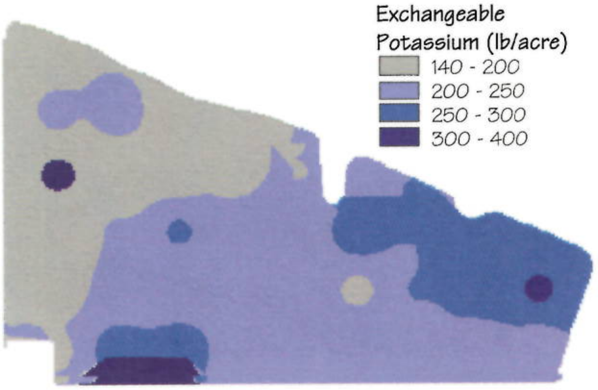

Figure 9*. Prescription maps of soil amendments can be uploaded into an onboard computer for application. As the applicator moves across the field, flow-rate controllers adjust the rate as needed. (map provided by Michael Cox, Mississippi State University)*

Generally, intensive soil grid sampling of soil properties is the most reliable method for determining the variability associated with soil texture, organic matter, pH, and nutrient content. However, some VRT seed, lime and fertilizer applications are based on historical data maps such as the Natural Resources Conservation Service Soil Surveys or the United States Geological Survey (USGS) topographical maps (Figure 10).

Many other sources of data can be used to construct VRT application maps. Yield maps are critical for understanding the complexity of initial within-field variability and the potential effectiveness of VRT applications used to address the variability. Remotely sensed images of crop foliage reflectance and/or soil reflectance can be used to locate nutrient-deficient areas, areas with drainage problems, weedy areas, etc. Soil electrical conductivity (EC) data can be used to indicate soil texture variability and the depth to a root-limiting layer. Manually generated data such as marking weed patches with a yield monitor at harvest, scouting for weeds, drainage problems, fertility problems, or pest problems with a GPS during the cropping season, or creating set-back boundaries with a GPS during the winter months can also be extremely valuable and the basis for VRT applications.

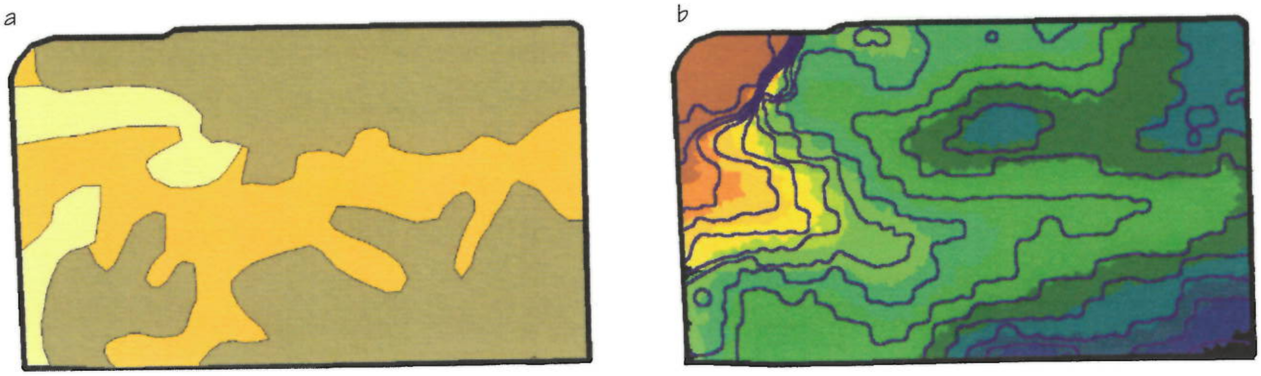

Figure 10*. Often VRT decisions are made based on (a) soil survey maps or (b) topographical maps. Although similar in some cases, these properties may not convey the major variability in any given field. Careful consideration should be given to the source of information, it's resolution, and other factors in the field influencing the parameter. (maps provided by Robert Nielsen)*

Sensor-Based VRT

In addition to map-based VRT, some sensor-based VRT units are also available or being developed. This technology typically involves (1) sensors mounted on the equipment that collects data about a specific property, (2) a computer system for rapid processing of the data, and (3) a delivery mechanism capable of varying the rate of the product being applied. These "real-time" VRT systems are capable of collecting information, processing the information, and delivering a product within a fraction of a second. One real-time VRT system that is commercially available uses an EC-type soil sensor to automatically vary nitrogen application. Other systems that are currently being developed have optical units capable of sensing changes in soil organic matter content and reflectance variability within and between species of plants (Figure 11).

VRT Seeding

VRT seeding can be done with corn planters, grain drills and air seeders. The desired rates can be determined using previous yield data and/or soil productivity estimates. Crops that accommodate a wide range of seeding rates, such as small grains or soybeans, may not respond to variable seeding. Studies have shown that variable-rate seeding of corn can be profitable when a field has a wide range of yield potentials. In particular, evidence suggests that variable-rate seeding is profitable when the low yield parts of the field have a yield potential under 100 bu/acre (Lowenberg-DeBoer, 1998). When yield potential differs widely within a field, yields can sometimes be increased by using higher plant populations in the high yield potential areas. Variable seeding rates can be linked with other input applications to match yield potential to inputs.

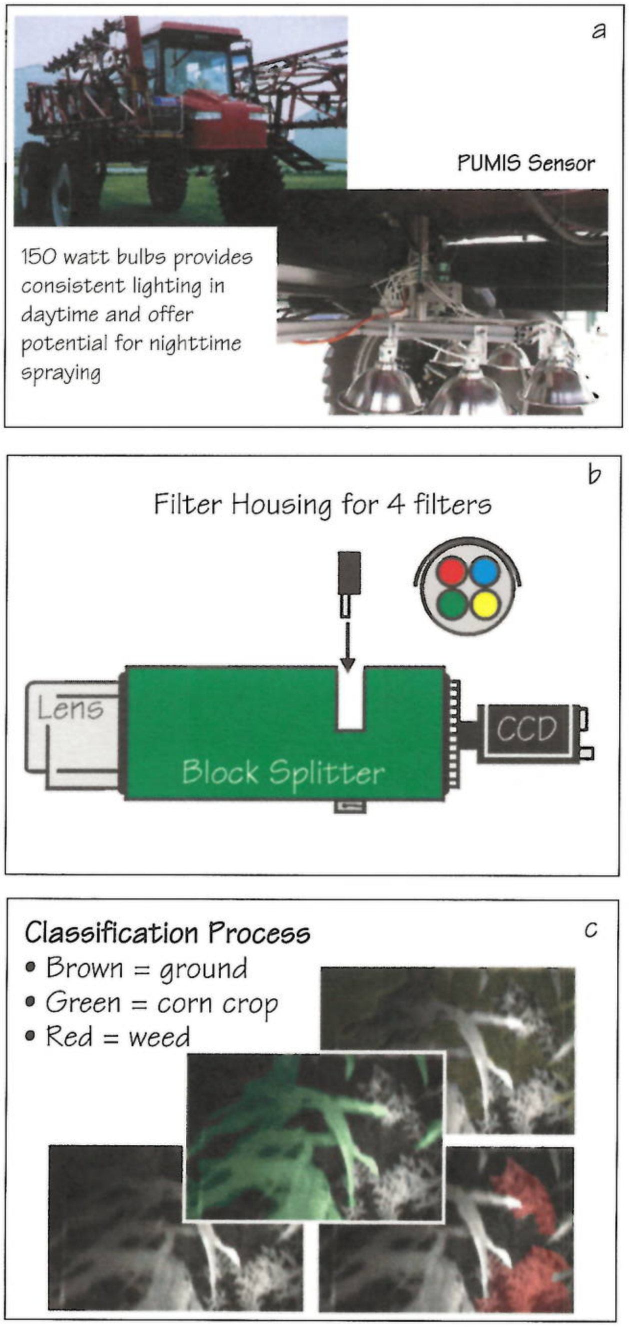

***Figure 11**. The Purdue University Multipurpose Imaging System (PUMIS) (a) is equipped with a tunable filter (b) to allow the simultaneous capture of reflectance from four predetermined wavelengths ranging from 500 nm to 1000 nm. Although this system is currently in the developmental stage, one day it may be used to differentiate among weed species and the crop (c). Then the appropriate herbicide could be applied for each weed infestation. (photos provided by John Brost, Nic Radford, Leonard Lobo, Gaines Miles, and Okan Ersoy)*

Calibrating VRT Equipment

Calibration of all equipment is critical, whether VRT or not. There are four important things to consider when calibrating VRT equipment:

(1) Field or bulk rate calibration,
(2) Uniformity across the swath,
(3) Uniformity of application across rate changes, and
(4) Response time required for rate changes.

All of these factors can impact the actual amount of material that is applied relative to the amount suggested by the application map.

Bulk calibration should be completed well before going to the field. Most applicators can be calibrated setting still. For dry fertilizer or lime this can be done by activating the hopper feeding mechanism and bypassing the spinners or air delivery mechanism. Carrier rate for sprayer can be checked using water and calibration collection cups.

Dry material (i.e. fertilizer, lime, etc.) can be dropped on a hard surface and collected for reuse. Although effective, calibrating across a field does not allow reuse of the material (Figure 12).

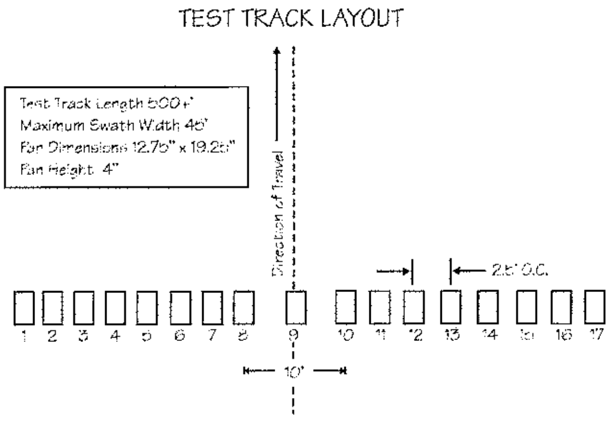

Figure 12. Dry fertilizer spinner spreaders can be calibrated more accurately in the field. Calibrating this equipment on-the-go allows checking of application rate per acre as well as rate across the swath.

Application uniformity of dry materials may vary dramatically with rate changes in the field. As the flow rate of material changes, uniformity of the spreading pattern can change. Although less of a problem with air spreaders, spinner spreaders can exhibit changes in pattern width and uniformity.

The response time required to successfully change the rate is a calibration issue specific to each piece of equipment. Some control systems for map-based VRT have "look-ahead" features that allow them to change rates closer to the desired location rather than having a lag phase of several seconds before the rate change actually occurs. Perhaps the control system with the shortest lag phase is the on/off control system. Depending on the equipment, there still may be lag-time associated with final mixing of the product and any inherent error that is associated with all equipment.

As-applied Verification

Some VRT systems are designed to produce a record of application details. The verification of application gives the operator and the producer a record of inputs, location, and date. This ability can be used to document the application of inputs and effluent for future reference or to settle potential disputes over alleged misapplication. Planned application can be re-recorded from the controller and should be identical to the application map. True as-applied maps reflect the reading from the flow meter or load sensors of material moving through an application device.

Further Information

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THE BASICS OF GEOGRAPHIC INFORMATION SYSTEMS

By R. Mack Strickland, Sam Parsons

An Introduction to GIS

Timely decisions - they are key to so many major and minor success stories in today's agriculture. But volumes of text and cyber information tend to overwhelm and over-tax producers' time constraints. What is really needed? A sharp producer answers: access and analysis - innovative ways to access accurate, current information and the ability to analyze it.

A Geographic Information System (GIS) provides producers with such a tool. GIS is computer software that can collect, sort, map, graph, store, analyze and otherwise shuffle data pertinent to the producer's operation. GIS supports producers through processing *spatially referenced data* which allows them to address, plan and manage agricultural cropland. A GIS can help solve problems by combining computer hardware, software and procedures with both existing and producer supplied information.

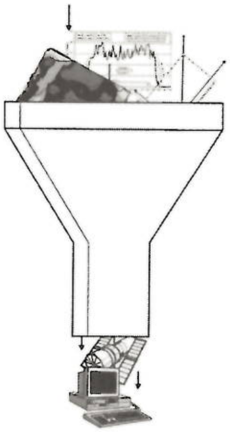

Figure 1. Clearly defining GIS means first breaking down some of its components. GIS collects, stores, retrieves, analyzes and displays spatially referenced data. Data is a collection of attributes (numeric, alphanumeric, figures, pictures, etc.) about entities (things, events, activities). Information is the organization of data such that it is valuable for analysis, evaluation, and decision-making. Information systems are the means to transform data into information. Information systems are used in planning and managing resources.

Many Sources - Many Uses

Every day, every producer faces dozens of decisions in running their businesses - particularly since that business is tied to the uncertainty of the weather, markets, disease, weeds, insects and countless other variables. Making sound business decisions depends on the accuracy of information collected, then process to determine a best course of action.

A GIS for crop production is a tool that helps producers utilize information from various sources. Producers input the information and the GIS makes it useful to them. A GIS for crop production requires information from many sources including yield maps from previous years, soil survey information, aerial photography, satellite imagery, and field scouting data. That data is shown spatially (geo-referenced) on top of a base map of the field. For example, one basic map might show the outline of the field with areas that cannot be planted. Layers combine to provide accurate analysis of crop health and maturity at each given point in the field.

GIS allows a producer to relate information about many different cropping factors, such as temperature, rainfall, insect and weed problems, seed varieties, and planting populations to a particular field location based on criteria he or she selects. The system brings all types of data together based on geographic and location components of the data. This makes relationships between the data more apparent and more valuable.

A Reference Point - Getting One's Bearings

The primary requirement for GIS source data is known geographic locations. Without precise locations, the information might be meaningless. Locations are given names. They may be noted by x, y, z coordinates indicating longitude, latitude and elevation, respectively.

Those variables, or various conditions across a field, can be stored and mapped in a GIS. The system makes this information usable. It converts existing geo-referenced digital information, which may not be in a map form, into recognizable and useful maps.

For example, say there has been a hailstorm or a drought and a farmer needs to determine how much vegetative cover is out in a certain field to help get a handle on predicting yield. Digital satellite images can be analyzed to produce a map-like layer of digital information about that vegetative cover. Producers using GPS also can convert fertilizer or chemical application data into a map. That can provide an additional information layer in GIS.

There are conversion issues with map information in GIS. Some information might need to be re-configured to work with information gathered from other maps or sources. Providers of existing geographic maps use different scales. GIS systems reconcile these differences and develop a common scale. For example, a field varying in topography appears distorted when displayed on a flat surface. GIS corrects the distortion, which may be temporary for display, or permanent for analysis.

GIS vs. Mapping Software

The terms "GIS" and "mapping software" often are used interchangeable. That is incorrect. These terms refer to different processes. Mapping software is used to make maps. GIS can perform analysis in addition to making maps, graphs, charts, etc., as indicated earlier in this section. Perhaps it is a map that is needed for a field. Or, perhaps what's required is a graph detailing various conditions. The best tool for a given situation depends on how the producer wants to use the information.

What GIS Can Do

GIS can emphasize spatial relationships among objects being mapped. For instance, mapping software may display a tile line as a simple line, while a GIS may recognize that the tile line passes through a wet area of the field, or lies in the field's lowest elevation. GIS lends richness to basic data.

GIS provides a graphic image of data that makes relationships between factors more apparent. These systems provide more than maps. Graphic display techniques available in a GIS make relationships between different factors visible, allowing a producer to see information as never before.

The list is long regarding other GIS abilities. GIS is capable of using information from many sources, performing complex spatial queries and data analysis, and establishing spatial relationships. GIS software can show relationships between field location and key information such as yield levels, soil types and fertility regime. The system also can relate new geographical information to original data by integrating data layers and showing the information in different ways and from different perspectives. This feature allows GIS data to be cumulative, or gathered and analyzed throughout the years.

What Mapping Can Do

Typically, mapping software is limited to maps. Mapping software not based on a GIS typically allows the user to overlay a yield map with another layer (Figure 2). This software allows producers to easily overlay two maps, such as yield data and soil type. However, the mapping software would not be able to highlight areas on the yield and soil type map with specific characteristics. A producer must visually relate the data.

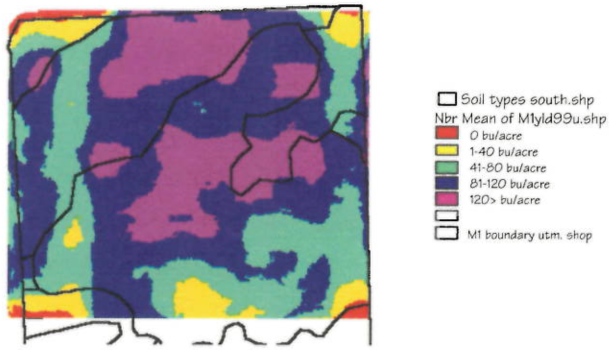

Figure 2*. Sample of what mapping software can do.*

Mapping software is especially good for displaying data for variables that do not fluctuate from season to season, such as organic matter, soil texture, soil type, and to a certain extent phosphorus and potassium levels. The data then can be converted to a form compatible with a variable-rate applicator. Mapping software working in conjunction with a GPS unit can control the amount of chemical or fertilizer applied at predetermined locations as the applicator moves through the field.

How GIS Works

GIS is not an automated decision-making system. It is, however, a tool to query, analyze, and map data - which can support that decision-making process. And, like fuel for a tractor, GIS requires data.

A GIS can be used to combine both vector-based digital data captured as points, lines (a series of point coordinates), or areas (closed shapes bounded by lines) and raster-based data files consisting of rows of uniform cells coded according to data values (e.g. soil sampled using a grid). These are combined, along with attributes (supporting information), to greatly expand the power and utility of a GIS.

If data are not already in a computer compatible digital format, several methods can be used to capture the information. Maps can be digitized, or hand-traced with a computer mouse, to collect the coordinates or features. This method requires a special mouse and software.

Electronic scanning devices also can be used to convert map lines and points into a digital format. Several graphic formats are available. Consult the software manual to ensure graphic format compatibility when scanning a map.

Capturing data usually is the most time-consuming component of using GIS. The identity of map objects must be specified with their spatial relationships. Editing electronically captured information also might be difficult. Scanners do not distinguish between a blemish on a map and the desired data, and record the blemish just as faithfully as other map features. A crease in a map might connect two tile lines when they do not connect at all. GIS software programs typically provide the ability to manipulate spatial data and weed out unnecessary and erroneous data.

GIS provides both simple point-and-click query capabilities and sophisticated analysis tools to provide timely information. Querying the data allows the producer to select variables for comparison. Additional analysis tools include the ability to perform spreadsheet and database tasks, query (look at relationships between specific locations within the field) and analyze spatially related layers of information, and statistically describe what is occurring.

GIS technology really sets itself apart from basic mapping software when used to analyze geographic data to look for patterns and trends, and to undertake "what if" scenarios.

Developing Information Databases

Data represent the most important components of GIS or mapping software. The first step in setting up a GIS is to identify the data most useful to that specific farm. Producers unfamiliar with map data first should consider carefully how the data will be used.

GIS makes it possible to analyze information difficult to associate through other means, or to compare data overwhelming to process manually. A GIS uses combinations of mapping variables to build and analyze new variables. Using GIS technology and chemical application information, it is possible to simulate the amount of chemical that might drift onto a neighbor's field. Wind data, droplet characteristics, nozzle information, and crop type might be used to predict the amount of crop damage. Mapping software has more limited data management, spatial analysis and customization capabilities.

Data Storage Options

GIS offers several data storage options. For small mapping projects it may be sufficient to store the information as simple "comma-delimited" ASCII "text" format files. ASCII (American Standard Code for Information Interchange) stores data (as numbers or text) in rows with a comma between data values. These uses also might justify the use of mapping software as opposed to GIS. However, when large data volumes are involved, a database management system (DBMS) is the best solution for storing, organizing, and managing data. A DBMS is computer software for managing large amounts of data in tabular form (e.g., telephone directory). To use a DBMS that is separate from the GIS, the file must contain spatial data that relates its stored data (e.g. soil type, pH, % o.m.) to specific locations in the field. These programs do not have the analytic and visualization tools common to a GIS.

GIS,DBMS, and mapping software programs contain, or generate, large amounts of data. If an individual is storing everything on their hard disk, they will run out of space very quickly. Besides the lack of space on the hard disk, one of the most important factors a person using a computer should consider is the potential loss of information that occurs in something happens to the computer system. Therefore, all data should be backed up in some way. Today that should be accomplished through the use of a second hard drive, Zip drive, CD-ROM writer, or tape back-up system. The size of files today, especially those containing graphics, make it impractical to use 3.5" disks for backup.

There are many different types of DBMS, including the most common - relational databases and linear databases. Relational design is the most useful DBMS for a GIS. A relational DBMS stores data as a collection of tables with common fields (information about one characteristic that is common to all records in the database) in different tables that are used to link them together. So if a variable for a data line is changed in one table, that change is made in all tables. This type of format provides a lot of flexibility and is the most widely used type of DBMS for GIS data storage.

Linear databases do not allow for the same kind of relations among variables. Changing a variable in one table will not change that same variable in the other tables. Linear databases can be useful for some applications. Consult with the software vendor about the database most appropriate uses.

Potential Sources of Error in a GIS

GIS software is very powerful, but inexperienced users can generate misleading results. As with any data entry project, extra care must be taken when entering data, or when importing it from various sources. The person entering the data should have some knowledge of the field itself. This usually prevents data entry errors.

Importing data from various sources can present several challenges. If data fields (column headings) have different names, data may not align in the correct data field. There are many different ways to format data, and one should be somewhat familiar with the format of the data being imported. Usually, consulting the software's user guide will provide a quick fix to any incompatibility issues. Also consider how clean the data is. The data provider may have had data entry errors. Consider the credibility of the source the information is coming from.

Keep viruses in mind. Downloading information from online sources or copying it from disks presents the opportunity for a virus to attach itself to the computer. Invest in reliable virus detection software.

Another error source is lack of knowledge of the field itself. If someone not working in the field on a daily basis generates maps, they not only need to have knowledge of the process, but they also need to have knowledge of the field. Otherwise, data may not be accurately interpreted. The farmer has knowledge of the field and needs to provide that information to the individual generating the maps so they accurately reflect what is occurring.

It is very important to understand the following factors before GIS data is incorporated into a management plan:

1. How was the data collected?
2. How accurate is the data?
3. What was the intended purpose of the data?
4. What do the attributes mean?
5. Who collected or compiled the data?

Effective GIS Can Make Money

Improved yields, lower production costs, improved crop quality, and more accurate yield forecasting - these can be some benefits of effectively implemented GIS-related technologies. Given accurate and appropriate input data, GIS can allow an analysis of cause and effect based on many factors. It can provide a producer with the ability to appropriately manage every field operation at each location in the field. Taken a step further, it can provide the information necessary to precisely micro-manage every step of the farming process if economically advantageous.

An Investment in Time

Software cost and program complexity become issues when deciding between mapping software and GIS. A GIS will cost more than typical mapping software, but the real cost comes in the amount of time required to learn how to use GIS software as opposed to mapping software. A GIS requires specialized training and continual use of the program to be able to generate the desired maps. Being able to use the program to its full benefits requires time and patience. GIS technology is of limited value without a trained person to manage the system and develop problem-specific applications.

Companies selling mapping software based on a GIS typically market it to crop consultants due to the steep learning curve, cost and continuous practice. Another factor to consider when deciding between mapping software or a GIS is having the required technical know-how, equipment and software to convert soil maps and other data sets to the required format for use in the GIS.

There are many levels of sophistication, hardware and software available so that no producer will feel left behind by technology. Being able to map field data and conditions provides another layer of information to help answer difficult questions involved in growing a crop.

Can a producer afford the costs associated with using mapping software, regardless of whether it is GIS-based or not? Professionals currently charge from $2 to $10 per acre to generate soil nutrient and yield maps. Further analysis may cost more or may not be available from a particular service provider. However, the better question might be, "can a producer afford not to use mapping software to aide the decision-making process?" A GIS provides the power to create maps, integrate information, visualize scenarios, solve complicated problems, present powerful ideas, and develop effective solutions like never before.

Summary

Data is a collection of attributes (numeric, alphanumeric, figures, pictures, etc.) about entities (things, events, activities). Information is the organization of data such that it is valuable for analysis, evaluation, and decision-making. Information systems are the means to transform data into information. Information systems are used in planning and managing resources.

GIS is a computer-based system that allows the user to question and manipulate various layers of spatial data. The system is designed to help answer questions and explore relationships. The data represents real-world entities (fields, trees, waterways, etc., to world scale) including both spatial (geo-referenced) and quantitative attributes of these entities. A GIS is not an automated decision-making system, but rather a management tool to query, analyze, and visually display data in support of the decision-making process.

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REFERENCE

ON-FARM RESEARCH

By Sylvie Brouder, Robert Nielsen

One of the most common complaints about adopting recommendations from university or commercial research is that the conditions of an experiment were too different from those on a "real farm" or on one's own farm. Farmers may not be convinced that they will see the same beneficial results when they invest in the recommended changes in management on their whole farm because their operation differs in certain key ways. The goal of conducting on-farm trials is to convince oneself that some alternative management practice will improve long-term profitability.

To conduct a successful on-farm trial, farmers need to follow the systematic approach that is common to all research projects (Table 1). This "scientific method" involves the following four steps:

1. Developing a question or *hypothesis.*
2. Planning an experiment or "trial" to objectively test the question.
3. Careful observation and collection of data from the experiment.
4. Interpretation of experimental results to answer the question.

***Table 1**. The Guiding Principles for conducting on-farm trials.*

1. Keep it simple ~ Yes/No question, one at a time

2. Design it right ~ Replicate, randomize, request help

3. Record everything ~ Planning, planting, in-season happenings, harvest notes.

4. Use statistics ~ Don't trust your "eye"

5. Be objective ~ Consider the cost of being wrong

In this chapter key "guiding principles" for successfully conducting an on-farm trial are presented.

What kind of questions should the farmer try to answer with on-farm research?

It is critical to understand that not all questions are easily answered by conducting one's own field trials. The principle reasons are that all trials require time, energy and money. The more complex questions require more of these resources. At some point this will come at the expense of regular farm operations.

The best questions to address with one's own on-farm trial are simple ones where the expected result is only *one* of *two* outcomes. Examples of good questions to address include:

- Selecting between two hybrids or varieties,
- Selecting between two herbicides (product A vs. product B) or two weed management strategies (product A vs. no product),
- Selecting between two fertility management practices such as pre-plant vs. sidedress N application,
- Deciding whether to use a specific seed treatment, and
- Deciding whether to use a "non-traditional" product.

In addition to keeping it simple by asking primarily yes or no questions, another guiding principle for conducting on-farm trials is to attempt to answer only one question at a time. Farmers should plan, conduct and interpret separate field trials for each of their questions and not try to cut corners by combining experiments. In other words, avoid testing hybrids A and B with and without herbicides C and D. That situation doubles the number of treatments one needs to compare and interactions between "factors" (in this case varieties and herbicide) may make it difficult to see the main effect of changing variety or changing herbicide.

Other examples of questions that are more difficult to address successfully with an on-farm trial include input rate trials such as fertilizer or pesticides and population studies. With the increasing availability of VR application equipment producers have become interested in developing their own "yield response curves." Realistically, however, it is probably overly ambitious to expect that an individual farmer will be able to develop his/her own yield response curves to fertilizer and lime. Response curves require multiple years of data to accurately develop, even longer when the input has residual value. This requires rigorously adhering to the same research plan regardless of expense and convenience, and this is typically more of a financial investment and a sacrifice in convenience than a commercial farm can afford to make. Multiple "treatment" trials will inevitably require statistical techniques to interpret.

Why do treatments have to be replicated?

This question brings us to the three R's of conducting the successful on-farm trial: **R**eplicate, **R**andomize, and **R**equest help. Many farmers ask why a simple side-by-side comparison is not good enough. After all, in most cases the objective is just to get a better idea of how something works and not prove it beyond all reasonable doubt for the whole agricultural community. However, to meaningfully answer questions farmers will have to replicate, randomize and probably request help.

Replication

Replication allows the farmer to be sure that the result represents a response to his/her "treatment" and that the farmer is not just looking at the random variation that naturally occurs across the field. Figure 1A shows a side-by-side comparison of two treatments ("A" and "B")

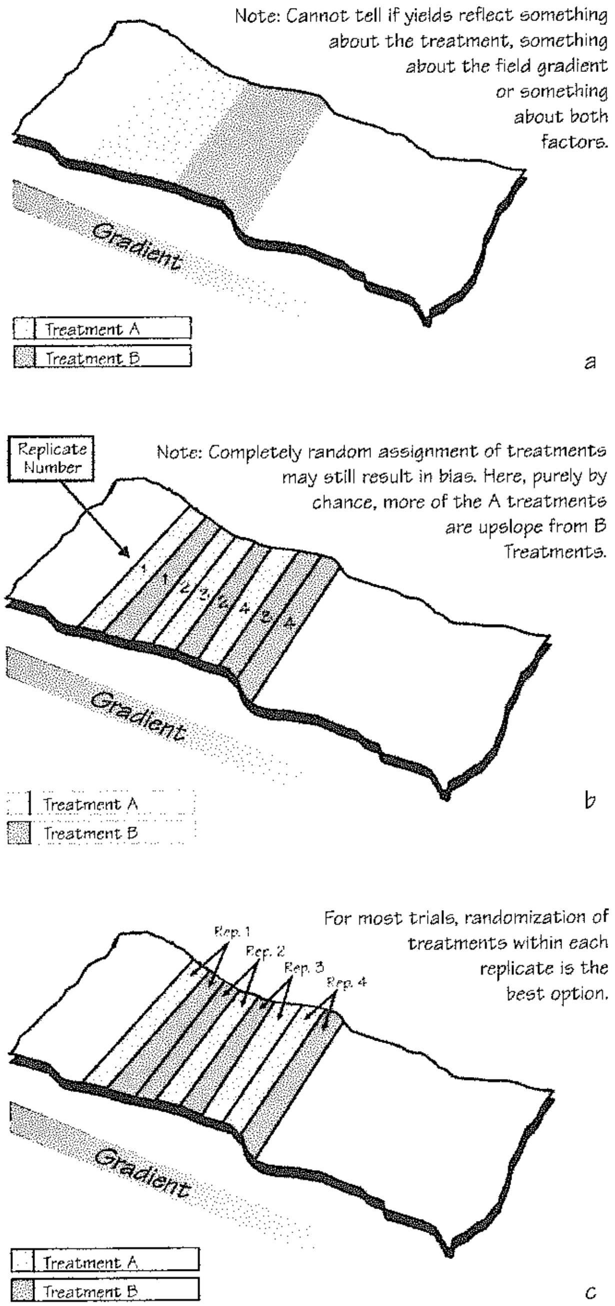


Figure 1 a. Side-by-side comparison: no replication. b. Completely randomized design w/4 replicates. c. Randomized block design w/ 4 replicates.

conducted in a sloping field. We might expect yields to increase with decreasing elevation due to increased depth of topsoil and/or improved water and nutrient availability. Because treatment A is upslope from B, one will not be able to tell if the yields measured in these two treatment areas reflect treatment effects or the effects of position in the landscape. Having more than one comparison will also give the farmer a much better idea of the true size of the effect of the "treatment." In other words, if one treatment really does increase yield, how much of an increase can be expected? Without this information on the size of the response to the treatment, an evaluation of profitability can not be made.

Using two replicates is better than not replicating at all, but it is generally insufficient to produce reliable information. This becomes obvious when considering a trial where the results from the two replicates give completely different answers. For example, in the first replicate one treatment yields 15 bu/acre more than the other, but in the second replicate the yields of the two treatments are identical. Which result should be believed? Three replicates are usually sufficient but four or more is optimal. The smaller the expected difference between treatments, the more replicates the farmer needs to have. A farmer may need six or more replicates to identify real changes in yield that are on the order of only a few bu/acre.

Randomization

Randomization of treatments within a replicate is necessary for the same basic reasons as replication. Randomization ensures that each treatment will have the same chance of being affected by a spatial differences slope (known or unknown) in the experimental site.

Figure 1B shows the field layout for a trial to compare treatments A and B. There are four replicates of each treatment and the eight treatment plots have been randomly assigned to the eight strips in the field. Note that the completely random assignment of treatments to plots has still resulted in some of the same bias that comes with the side-by-side comparison given in Figure 1A. Purely by chance, more of the A treatments have been assigned plots on the upper part of the slope. There is still a risk that treatment effects will not be distinguishable from topographic effects.

For most agricultural trials it is best to use a design that randomizes treatments within a replicate. If the farmer has complete replicates of all treatments at each location in the slope, then some of the effects of field variability can be removed by looking at the relative performance of treatments within a more uniform area of the field. However, one still must randomize the assignment of A and B within a replicate. If treatments are always placed in the same order, then farmers again may not be able to tell if the effect seen in terms of yield is from the treatment or from the fact that one treatment is always downslope from the other in the replicate. Randomization within replication as shown in Figure 1C. gives the farmer the best chance of being able to distinguish between treatment effects and effects produced by field variability.

Request Help

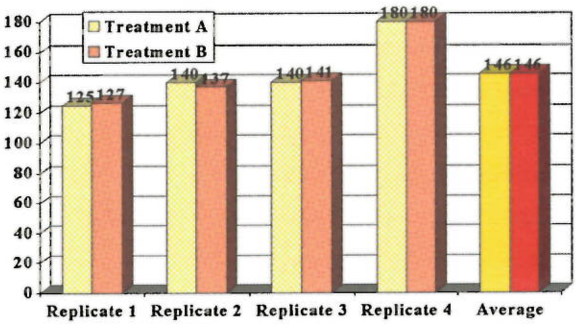
Designing a good experiment to test a hypothesis is not easy to do. Selecting an optimal field and location within a field requires skill. There are many things a farmer may wish to consider including soil types, drainage patterns, soil tillage/compaction, fertility and pH patterns, historical patterns of weed and insect infestation and carryover of chemicals. If the trial is not appropriately replicated and treatments randomized within replicate, results may be hopelessly confused by other factors and one will not be able to successfully interpret results. It is a good idea to *request help* in the planning stage and not wait until the interpretation stage to seek expert advice. Never think that you can bend the "garbage-in garbage-out" rule. Statistical expertise cannot save a poorly designed trial.

When are statistics needed?

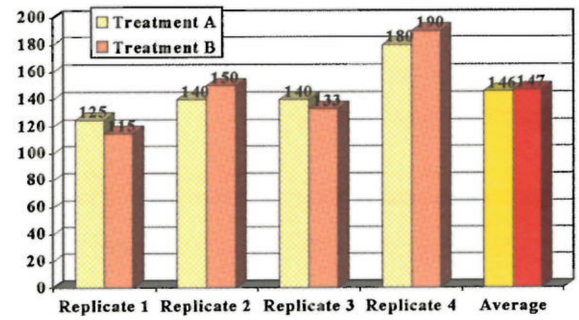
Statistics are the basis for objective evaluation of results. Most farmers recognize the value of performing a statistical analysis on their data but often do not have the advanced mathematical background to do this step on their own. The question is, given a significant investment in developing an original hypothesis or question and performing the trial, how does one determine if statistical analysis is needed to interpret the data? The following examples will test a farmer's ability to identify real (often called "significant") effects of a treatment without statistics. These examples provide farmers some guidance on when *not to rely on "eyeballing" the data.*

Use the experimental design given in Figure 1C to compare corn yields from fertility treatment A (the standard practice) to yields from fertility treatment B (the "new" practice). Figure 2 gives three situations (Cases) in which statistics to interpret the results with confidence are clearly not needed. In Case 1, the performance of A and B are almost identical within each replicate and the average yields are the same (146 bu/acre). In Case 2, there is again no increase in average yield of the trial. However, in replicates 2 and 4, B out-yields A by an average of 5 bu/acre but the reverse is true in replicates 1 and 3. The variability likely reflects random field conditions. In these two cases, there is no advantage of one treatment over the other.

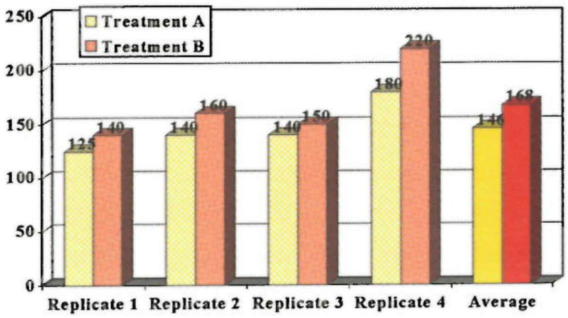
In Case 3, treatment B always has higher yields than treatment A and since the experimental design was sound (replication and randomization within each replicate), one can be highly confident that the yield increase is a direct effect of treatment B and not the result of a slope across the field. A statistical analysis is not likely to increase a farmer's confidence in his/her interpretation in any of these three situations.



Case 1: No difference in yields.



Case 2: No difference in average yields but replicates vary.

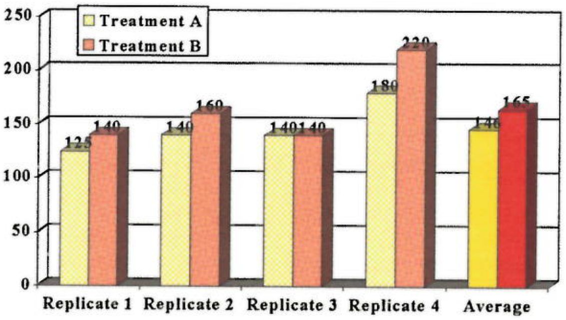


Case 3: Treatment B out-yields Treatment A in every replicate.

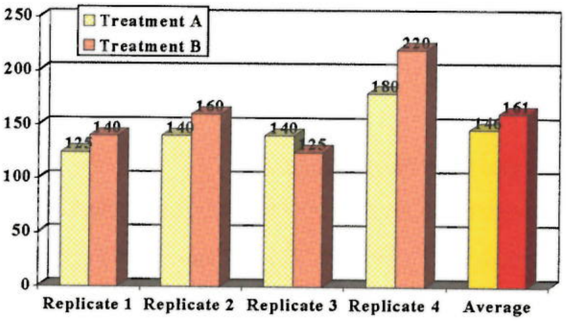
***Figure 2.** Three cases where statistics are not needed to interpret the results from a 2 treatment trial with 4 replicates.*

Another good rule of thumb for deciding when to invest in a statistical analysis relates to the size of differences. In general it is wise to pay less attention to small yield differences. For corn, average and within replicate yield differences of 5 bu/acre or less are probably not meaningful, if for no other reason than that the yield monitor or weigh wagon is probably not this sensitive. For soybeans, a 2 bu/acre difference may be below detection limits.

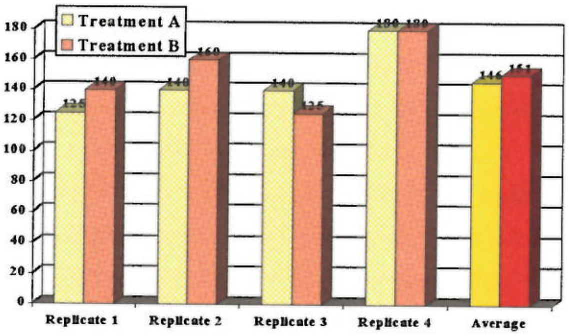
In the next three cases, the effect of treatment B may be less obvious (Figure 3). In Case 4, three replicates show an increase in yield for the B treatment but one replicate shows no treatment effect on yield (replicate 3). A similar case is when three replicates show an increase for treatment B but one replicate (replicate 3) shows a decrease in yield (Case 5).



Case 4: Treatment B yields more than Treatment A in 3 replicates but yields are the same in one replicate.



Case 5: Treatment B out-yields A in 3 replicates but A out-yields B in 1 replicate.



Case 6: Results in individual replicates are mixed but Treatment B averages 5 bu/acre more than treatment A.

Figure 3*. Three cases where statistics are most likely needed to correctly interpret the results from a 2 treatment trial with 4 replicates.*

Finally, what if treatment B increases yields in two replicates, has no effect on yield in one replicate, and decreases yields in the fourth replicate (Case 6)? Most farmers would feel fairly confident that the average yield increase with treatment B observed in the (Case 4) (average increase of 19 bu/acre) is real. Practice B really is "significantly" better that practice A. In the second and third situations, (Case 5 & 6) the average yield for all replicates still increases for treatment B when compared to A (15 and 5 bu/acre, respectively), but is it "real" or a reflection of natural variability? Statistics are needed to characterize the *probability* that the yield difference is a real treatment effect.

It is not the objective of this handbook to teach how to perform the statistical analysis. However, if a farmer is going to conduct an on-farm trial, he/she needs to understand how the element of chance can interfere with a carefully planned trial and what it means for a treatment effect to be "significant." After all, an objective of an on-farm trial is to be able to explain what happened, and to have an understanding of the likelihood that it will happen again in the future. Chance is the "un-designed" or unplanned happening of something and it is a concept that most producers understand well. In a field trial, chance variations due to unplanned or unforeseen events such as flooding or pest damage will inevitably make results vary within and between replicates. When this unplanned variability becomes great enough that one cannot or should not try to "eyeball" the data, a statistical analysis will give the ***probability*** *that an alternative treatment* ***is not different*** *from the original treatment.* (See Table 3 at the end of this section to test the reliability of "eyeball" interpretations.)

Table 2. Understanding the probability.

Probability	"odds" (chances are...)	Interpretation
less then 1%	less than 1 in a hundred	"Highly significant"
5%	1 in 20	"significant": most researchers are comfortable with a 1 in 20 chance of being wrong
10%	1 in 10	Not significant to most university researchers but may be good enough for you. Consider the cost of being wrong.
25%	1 in 4	The chances of being wrong are pretty high. Changes should not be implemented unless there is virtually no cost to being wrong.
50% or more	1 in 2	A flip of the coin will give you the same ability to predict what will happen if you do this trial again.

What are the "odds"?

A key concept to understand when conducting a field trial is that the question will never be answered with 100% certainty. Even in the situation described by Case 3 (Figure 2) where treatment B out-yielded treatment A in every replicate, there is still a possibility that this is the result of some unknown factor unrelated to the treatments. Statistical analysis gives this probability at about 5%. In other words, there is a 1 in 20 chance that B is really no different than A. A probability of less than 5% is usually small enough that we are quite confident that the difference is real or a "significant" effect of treatment B. If we happened to get the exact same results when repeating the experiment in another year or in another field in the same year, the odds that A and B are really no different drops to less than 1 chance in 1000.

The probabilities that A and B are not different are much higher in Cases 4, 5 and 6. In Case 4, the probability is slightly greater than 10% (a 1 in 10 chance). In case five, treatment B still has a sizeable apparent average yield advantage of 15 bu/acre, but there is a 28% probability that these treatments are not different (greater than 1 in 4 chance). Finally, in Case 6, the probability is 57% (greater than the even odds for predicting the outcome of the flip of a coin) that the B treatment does not change yields even though, on average, B yielded 5 bu/acre more than A.

What odds are "significant"?

The probability level at which a treatment effect is considered to be "significant" is arbitrary. If the probability level is 5% or less that the differences in yields could have occurred by chance alone, then most university researchers will say that the average yields are "significantly different." However, there is nothing magic about the 5% level of significance other than that most researchers are comfortable with having a less than a 1 in 20 chance of making an incorrect conclusion. Selecting a meaningful breakpoint for separating significant from non-significant differences for an on-farm trial should realistically be based on more than just the statistical analysis. In the final analysis one should view results (including the statistical analysis) in the light of what is already known and in consideration of the consequences of being wrong.

Table 3. In each case average yields in Treatment B are greater than A. Test your statistical IQ by figuring the odds that the Treatment B cases are really no different than Treatment A. In cases 6-10 look at only the first 3 replicates of Treatment A.(see end of section for answers)

Replicate	Treatment A	Treatment B									
		Case 1	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**	**Case 7**	**Case 8**	**Case 9**	**Case 10**
1	125	125	120	128	122	120	125	135	122	130	118
2	140	160	150	142	143	170	142	153	188	138	150
3	140	140	135	143	140	165	160	141	139	188	155
4	180	190	195	185	220	175	no#	no#	no#	no#	no#
Mean: all	146	154	150	150	156	158					
Mean: reps 1-3 only	135						142	143	150	152	141
Estimate the "odds"											

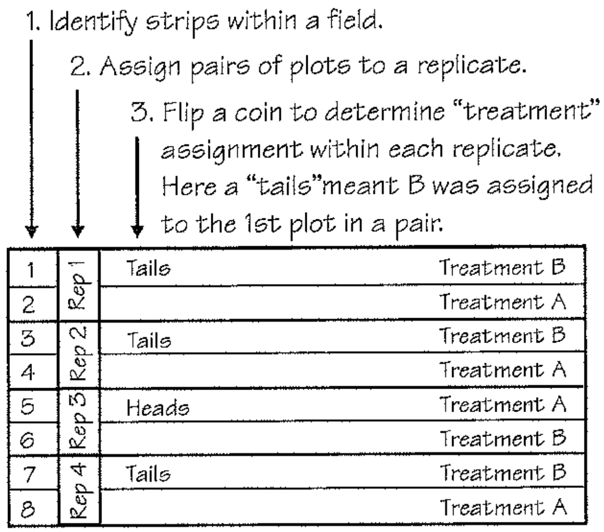
In many cases, the motivation to conduct one's own on-farm trial will have come from reviewing the research results of others which were not found to be convincing. For example, consider commercial research results indicating treatment B increases yields 10 bu/acre when compared to A. A farmer then conducts his/her own experiments and achieves results similar to case 4 with a yield increase of 19 bu/acre for treatment B but the odds of approximately 1 in 10 (10% probability) that this increase resulted from chance variation alone. Since the farmer's results are generally in line with those earlier results, he/she can feel quite confident that treatment B is a better practice that works for them. Especially if the cost of switching from B to A is relatively minor. If, however, the cost is high, the potential increase in profitability is low and/or the results are not in line with those of earlier studies one may wish to adhere to the more conservative definition of significance used by university researchers. Alternatively, the farmer may want to further test the conclusions by conducting another trial.

Simple on-farm research designs for use with yield monitors

There are several possibilities for conducting simple on-farm research designs to use with yield monitors. The two designs discussed here are the strip plot design and the split-planter design.

Strip Plot Design

The strip plot design is probably the most common design used with yield monitors. In this design, the treatment runs in the same direction across the field as planting and harvesting. Figures 4 and 5 give examples of strip plot trials for comparing 2 and 3 treatments, respectively. The width of the strip should be multiples of the width of the combine head. Although combine mounted yield monitors allow a farmer to punch in the width of the pass, planning on harvesting less than a full pass is inefficient and introduces one more point for potential operator mistake. The width of the strip should also account for the width of the piece of equipment that will apply the treatment. This design can be used to compare fertility programs, weed and pest control programs as well as hybrids.



1. Identify strips within a field.
2. Assign pairs of plots to a replicate.
3. Flip a coin to determine "treatment" assignment within each replicate. Here a "tails" meant B was assigned to the 1st plot in a pair.

1	Rep 1	Tails	Treatment B
2			Treatment A
3	Rep 2	Tails	Treatment B
4			Treatment A
5	Rep 3	Heads	Treatment A
6			Treatment B
7	Rep 4	Tails	Treatment B
8			Treatment A

Figure 4. Design for an on-farm trial comparing 2 treatments using 4 replicates. Treatments are randomized within each replicate.

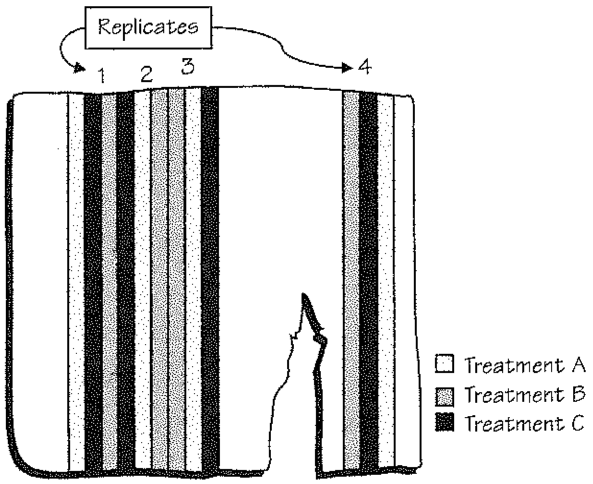


Figure 5. Design for an on -farm trial comparing 3 treatments using 4 replicates. Treatments are randomized within each replicate, and replicates are located so as to avoid known areas of extreme variability.

It is best to have the treatment run the full length of the field so that adjustments are not needed part way through a trip across the field. The length of the test plot should be a minimum of about 350 feet. This will allow end rows to be removed and will ensure that the combine can maintain the constant speed required by the yield monitor for the majority of the pass.

Note that in both examples, the sequence of treatments has been randomized within each replicate. Randomization can be accomplished by flipping a coin for two treatments or by drawing numbers out of a hat for trials with more than two treatments. Also note that replicates do not have to be next to each other in space but they do have to have one strip of each treatment. This allows the farmer to work around problem areas in a field where the expectation of chance variation is just too high.

Split-Planter Design

If the combine header width is equal to the planter width or is exactly one half of the planter width, this design is very simple to implement (Figure 6). This design can be used if the objective is the comparison of two hybrids. It can also be used to compare two agronomic practices conducted at planting including the comparison of two seed treatments, two seeding rates or planting with and without starter fertilizer.

One half of the planter is filled with one hybrid, one batch of treated seed, or is set up to deliver one rate of seed or starter fertilizer and the other half is set up to deliver the comparison "treatment." Assuming a farmer plants back and forth across the field, the result will be multiple, side-by-side replicates. Figure 6 shows the map for a two-hybrid comparison. With the exception of the outside rows each hybrid plot will end up with the number of rows of a full planter pass. If the combine is one half the planter width, a harvest pass in each direction for each treatment plot results. This will eliminate yield monitor calibration problems caused by the direction of travel, particularly in sloping fields. If the planter width and harvester width are equal, be sure the planter marker is set correctly and the planter operator drives correctly. Otherwise, extra ear loss during harvest may occur due to the "varying row width" between the adjacent planter passes.

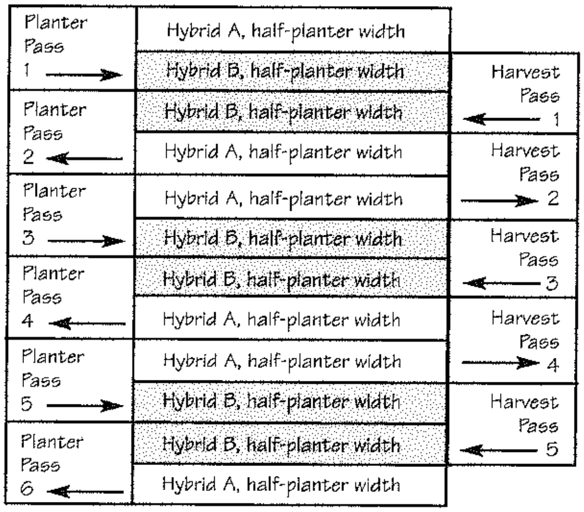


Figure 6. *Design for an on-farm trial using the "split-planter" approach. This layout shows the equipment passes when planter and combine widths are the same.*

The split-planter approach does not permit randomization of treatments within a replicate. The approach that has most often been used to analyze these data has been to use advanced statistical techniques to draw separate yield maps for each hybrid or treatment. This involves estimating yields in each strip where the hybrid was not planted using the neighboring strips where the hybrid was planted. Analysis of the relative performance at any given location is then based on the comparison of a measured yield with a virtual yield.

Regardless of which design is selected, farmers will need to designate "loads" on the yield monitor. Providing the combine operator with a detailed map and using visual marks in the field will also help insure that harvest passes are correctly identified. Backing up yield monitor measurements with a calibrated weigh wagon or certified scale is recommended to ensure high quality data.

Additional Tips: Simple do's and don'ts for quality assurance and control.

What follows is a simple list of do's and don'ts, each with a short explanation, for quality assurance and control in on-farm trials.

DO:

1. Be aware that one may have to sacrifice yield/profit to prove a point. For example, in a rate study one will need to have rates that are above and below what is suspected to be optimal.
2. Treat all plots alike. For example, run knives through "zero" N rate plots or run equipment through a plot without doing an application so that equipment is not part of the "treatment" effect.
3. Be aware of "confounding" factors. For example, when changing row width one will also need to change planter transmission setting if the objective is a row-width and not a population study. Plan and think ahead of time to eliminate other factors that could affect yields.
4. Be aware of the consequences of one's own choices. The strips should be narrow enough to minimize variability within a set of comparisons but still wide enough to accommodate the equipment (harvesting vs planting, boom width, etc.).
5. Increase the power of the study by getting others to conduct the same trial on their own farm and/or conducting the same trial for more than one year.
6. Write everything down and take the time to document all field notes. Keep all written records.

7. Carefully review written notes when yields are in hand so that results that involve errors in field operations or excessive, unplanned variability can be removed. For example, remove plots that had severe yield loss from early season drainage problems.
8. Check and double-check everything. When possible, personally conduct the checks. This includes everything from plot plans to yield monitor calibration.

DON'T:

1. Bother with a trial if it will not be checked all season long.
2. Don't, assume that eyeball estimation of results will be accurate most of the time.
3. Bother with a trial if the farmers think he/she already "knows" what will happen. Being "biased" towards one result will tend to make the farmer less objective in planning, collecting and analyzing the data and more inclined to cut corners.
4. Disregard the findings of others (university or commercial) research. On-farm research should be viewed as complementing other information but it does not replace it. One simply cannot afford the degree of control and investment of time in collection and analysis of data that characterizes the long-term field research programs of university or industry specialists.

(Key to guessing the odds in Table 3: Case 1: 1 in 4 (P=22%); Case 2: 1 in 2 (P=52%); Case 3: 1 in 100 (P=1%); Case 4: 4 in 10 (P=39%); Case 5: 1 in 3 (P=32%); Case 6: 4 in 10 (P=37%); Case 7: 1 in 8 (P=16%); Case 8: 1 in 2 (P=50%); Case 9: 4 in 10 (P=40%), and Case10: 1 in 2 (P=46%).)

H
REFERENCE

MANURE MANAGEMENT IN PRECISION AGRICULTURE

By Keith Morris, Stephen Hawkins, Dan Ess, Sam Parsons

Challenges to Precise Applicator

The goal for precision agriculture is the same as for any good management practice: the farmer must optimize inputs to produce the maximum return on investment and still be environmentally friendly. The increased use of fertilizer, pesticides, and seeds, as well as the environmental impact of agriculture in general, has caused many farmers, researchers, and government agencies to ask whether more precise application of these inputs is possible and if this technology can provide such precision.

One important technical aspect in the progression of precision farming concepts is the development of the hardware and software necessary to control material application. Another major developmental challenge is establishing methods for determining how much material to apply if given a specific condition. Animal manure is a heterogeneous material and this makes characterization extremely difficult. From a practical standpoint, total nutrient content is the only readily available test for animal manures.

Characterization of Animal Waste

The nutrient content of manure can be characterize by storage method or the size and type of animal (i.e. dairy cattle vs. swine, farrow vs. finish). In swine production, the primary methods of storing manure are liquid pit or lagoon. In the liquid pit system of mixed types, the approximate phosphorus (P) content can be as much as 36 lbs. per 1000 gallons; whereas, in a lagoon storage system the total P can be as low as 5 lbs. per 1000 gallons.

Another example of nutrient variation can be observed when comparing different animal types even within a species. Table 1 shows the approximate nutrient content of swine manure produced by different operations.

Table 1. Average Nutrient Content of Liquid (Pit) Swine Manure (lbs/1000 gals).

Type of Operation	Total N Nitrogen		Total P Phosphorus		Total K Potassium	
	Range	Avg.	Range	Avg.	Range	Avg.
Finisher/Grower	4.8-17	10.9	2.9-14	8.5	3.8-13	8.4
Nursery	2.9-14	8.5	0.7-2	1.4	0.7-3	1.9
Farrowing	3.8-13	8.4	3.2-17	10.1	3.2-15	9.1

Disposal and Land Application

Assuming that application starts on the fields closest to the collection facility, the cost of slurry application per acre increases with each additional load because of the increases in fuel and labor requirements. This practice also encourages over-application because as manure is being applied, the "natural tendency" of the operator is to stay as close to the source as possible. Also, changes in equipment operators involved in the distribution as well as ineffective means of demarcation of applied areas (especially with surface application) can result in over-application.

Manure is sometimes applied to land as a means of disposal. It is also used as a means of amending the soil for crop production. Manures, composts, litters and lagoon effluents represent the most common types of animal waste applied to soils. Because most animal wastes are bulky, heterogeneous, relatively low-analysis fertilizer materials, the amount of manure required to supply a crop's nutrient needs can easily be 10 to 100 times the volume of commercial fertilizers needed.

The logistical problems associated with storage, handling, transport, and field application of literally millions of gallons of animal manure each year create significant economic burdens for farmers, even if environmental issues are not considered. Nevertheless, the lack of universal adoption of alternative uses for animal waste materials, such as composting for horticultural markets, incineration as a fuel, or pelletizing and enrichment with mineral fertilizers to encourage wider agricultural uses, has meant that land application is typically the only viable option left for the livestock producer. Unfortunately, the long-term over-application/misapplication of animal wastes to soils can create a number of environmental problems.

Best Management Practices

States are attempting to minimize environmental problems by requiring that producers use Best Management Practices (BMP's). Most BMP's for animal wastes are now based on providing sufficient nitrogen, in a timely manner, to meet a specified crop's nitrogen requirements for a predetermined yield goal. Studies have documented problems with nitrate leaching contaminating groundwater in areas with high animal populations. This problem has been the driving force behind implementation of BMP's. However, a number of emerging environmental issues, such as the fate of trace elements, pesticides, and growth hormones, and the more pressing issue of the eutrophication of surface waters by phosphorus in runoff, have forced the regulatory agencies to re-evaluate the nitrogen-based BMP's for animal waste application.

Applying manure to meet crop N needs usually means over application of P. For example, the N/P ratio of manure in a finisher/grower operation is approximately 1.35/1(see Table 1), whereas the N/P ratio requirement for a 150 bu/acre corn crop is approximately 2.3/1.

Constant manuring of soils creates agronomically excessive accumulations of soil phosphorus. If this situation exist phosphorous finds its way to a body of water sensitive to eutrophication, a potential environmental pollution problem exists. On the contrary, even soils which have had N applied to them in agronomically sufficient quantities for crop needs can experience leaching into groundwater if excessive rainfall or dramatic temperature changes occur.

Although most BMP's today are based on N requirements, an increase in recent algae blooms in rivers and lakes may soon make phosphorus-based regulations a reality. Recent studies in the U.S. indicate that many soils in areas dominated by animal-based agriculture have high or excessive soil phosphorus. P can be mobile in the environment through soil drainage, runoff, and erosion. If soil P levels are very high, leaching can occur.

But some soils are not prone to P loss, and can handle excessive P application with little environmental impact. In these soils, few pathways exist to carry P to nearby ground water.

The most significant problem that arises from phosphorus-based management is the inadequate land base available for manuring on many farms. Consequently, if the potential environmental impacts of high-P soils become the limiting factor for land application, then farmers will be forced to find alternative ways to properly utilize their operations' manure. In areas of high animal concentrations, it is difficult to find large enough acreage with low phosphorus soil test levels to permit a farmer to properly apply manure.

Precision Manure Management

Because of the heterogeneous nature of manure, variable-rate application is, at best, difficult. In lieu of variable-rate application, measurement and documentation of actual land application rates is a significant improvement over current practices. A system that can provide documented manure application has the potential to improve production efficiency and reduce farmer exposure to legal action from inappropriate manure applications.

Development of precision manure management systems must incorporate several distinct components which include:

- Manure analysis to establish nutrient content (NO_3^-, P_2O_5, K_2O, trace elements) either in real-time or rapid, simple on-farm analysis of nutrients.
- Soil sampling to determine pre/post-application soil test levels of nutrients.
- Proper site selection as determined by Best Management Practices (BMP's) and/or regulations.
- In-season plant analysis to select proper side-dressing or late-season manure application rates.
- Appropriate application methods (broadcast vs. injection vs. irrigation).
- Homogenization of manure before application.
- Uniform application.
- Documentation of nutrient content, location, and time of manure application.

Each of these areas must be considered as an integral component of any precision nutrient management program.

Producers, consultants, agribusiness and students must be increasingly cognizant that the environment is a closed system. The inputs they apply do not disappear; they are only redistributed. Environmental consciousness must not be considered a nuisance, but a prerequisite for survival.

REFERENCE

WEATHER INFORMATION FOR SITE-SPECIFIC FARMING

By Monte O'Neal, Jane Frankenberger, Richard Grant

Site-specific agriculture has led to an interest in characterizing every possible variable on a site-specific basis, including weather. Many farmers, recognizing that weather variables such as temperature and rainfall may vary not only from farm to farm, but also from field to field, and even within a field, are purchasing and installing weather monitoring stations on their farms.

However, while it is true that a storm may drop rain on only one side of a highway, or that part of a field can escape a freeze while the other part does not, this kind of small-scale variability may not affect crop yields. Farmers are faced with many decisions when it comes to weather monitoring. How should data be obtained? What collection options are available for farmers? Is weather data even necessary to a farm operation?

Why monitor weather?

Defining an overall purpose behind weather data collection can help avoid a random assortment of gauges with unused options. Curiosity can be an acceptable purpose, but it should accompany a more specific goal.

Think of Goals

One logical goal of collecting weather information is to better interpret yield maps. For instance, yield maps for a particular field may show widely varying yields over the last five years. The farmer knows that fertilization rates and crop varieties varied over the years, and can use the yield map information to interpret the effects of the management decisions on yield. The interpretation may differ, however, if the farmer knows that two of the years were dry and three were wet. With solid data, the weather's influence could be factored out in order to better understand the effect of management practices. Having multiple years of yield maps is useful, in part because weather factors interact with management factors in complex ways.

Figure 1 shows a yield map and a soil map for a Midwestern soybean field in a dry year. Yield varies considerably across the field, ranging from 1 to 94 bu/acre. On the soil map, areas with Pewamo soil (a poorly drained soil in depressions) correspond with the areas of higher yield, and the two Glynwood (well-drained) soil areas correspond with lower yielding areas on the yield map. If this pattern (higher yield in the more poorly-drained soil) reversed in a wet year, weather would clearly have a significant influence on yield patterns.

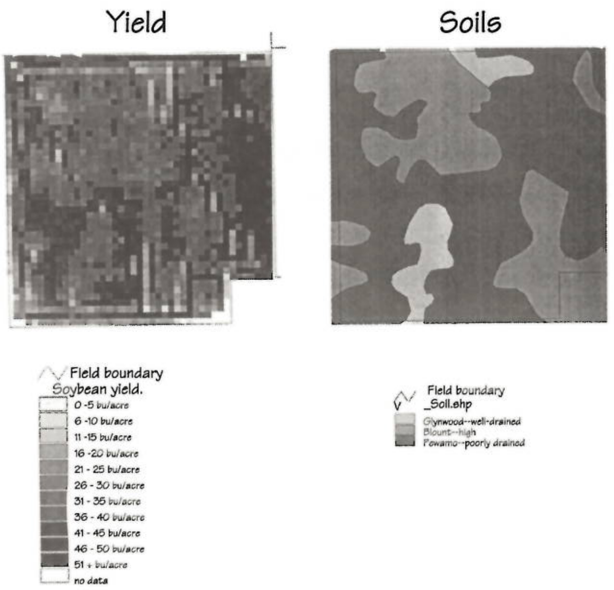


***Figure 1**. Yield map and soil map, dry year.*

Another reason to collect weather information is to use computer crop simulation models, which may require an assortment of weather variables at each site modeled.

Spatial Variability of Weather

Site-specific farming has given producers new insight - providing looks at smaller and smaller areas of the field. However, there is a tendency for producers to overestimate the amount of spatial variability in weather across their farm. Exceptions are easier to remember than the rule.

Weather systems producing rainfall usually are much larger than a single farm. Thunderstorms bring the most spatially variable rainfall, and even they can be miles across. Long-term studies in several locations* found that in flat, non-urban areas, rainfall readings tend to be statistically similar at a distance of 1-2 miles or less. A few days' rainfall difference during thunderstorms rarely affects crop yield over the growing season. In a Purdue University study, researchers recorded rainfall with four rain gauges across a 620-acre farm, for four growing seasons. The resulting rainfall variability averaged less than 0.05" per day. (* see further information section at the end of this chapter)

For air temperature, conditions are even more similar over larger areas. Recent studies show that spacing of air temperature sensors 18 miles apart accounts for 90% of the variability between locations. One air temperature sensor is sufficient for the farm, for counting degree-days or getting data for a model. Wind speed and relative humidity are highly variable at the micro-scale (3 ft. or less), but less so at field scales. The corresponding spacings necessary to measure 90% of spatial variability are 18 miles for relative humidity and solar radiation, and 6 miles for wind. Soil temperature varies with soil color and drainage, and it may be appropriate to place a sensor in one or two areas representative of each clearly visible soil type. The detailed need for information depends on the type of management decisions made.

Finally, multiple years of data are necessary for determining true spatial variability of any weather variable. In one 14-year study of maximum air temperature, the range of spatial correlation between stations (the randomness of spatial patterns) varied widely the first year, was cut to 1/2 by the 5th year of data, and was cut to 1/4 by the 7th year of data. It is tempting, but unwise, to make major decisions based on only two or three years of weather data. Because rainfall is the most spatially varying weather parameter, rain measurement is the focus of the rest of this chapter.

Weather Monitoring -- Early Considerations

Collecting on-farm data is an option farmers may consider. But before thinking about buying new equipment, consider existing sources of weather information. All needed data may be available from nearby weather stations. In that case, producers may not need to make weather measurements themselves. There are countless services providing accurate information. For example:

- The Midwestern Regional Climate Center provides daily weather information, soil moisture estimates, crop yield risk estimates, and river levels. It also offers an on-line subscription service to MICIS (Midwestern Climate Information System).

- The National Climatic Data Center archives daily rainfall and air temperature measured at up to 12,000 stations across the U.S. Recent years are available free over the Internet.

- TV and radio stations and NOAA weather radio all give free forecasts and current weather.

- Several Internet sources provide daily weather data, including NEXRAD precipitation totals from Doppler radar (with resolution as small as 1,000 acres). While Doppler radar can determine rainfall patterns, a farmer should not rely on the absolute amounts of precipitation, which are based on generalized assumptions.

- Specialized agricultural services provide current weather, satellite photos, farm prices, and audio forecasts to subscribers via a special receiver or the Internet. Some agricultural services allow the subscriber to purchase weather data from local networks, collected with research-quality gauges by other farmers in a small area. Some premium services can provide enhanced weather data for an additional fee.

Using data collected by professionals or agencies whose job it is to provide accurate data can be the most efficient, cost-effective, and reliable means of obtaining weather data. When considering an outside supplier, ask for references and a sample of the data or demonstration. If they stand by their work, neither of these requests will be inappropriate.

On-farm data gathering may be more appropriate if there are known discrepancies between the supplier's data and recorded weather on the farm, or if weather irregularities occur within the farm. Anyone considering such data collection, however, should be aware that collecting accurate weather data is time-consuming, expensive, and requires regular maintenance.

Above all, consider in advance how the data will be used. Think about why it is important to know exactly what happens on a very small scale within the farm (rather than a few miles away) and how that information will be useful in management decisions. Assess the financial costs of buying the equipment as well as time required to read and maintain gauges. Decide what type of investment is required to provide the greatest return on investment for a specific situation. The possibilities here range from $25 for a plastic rain gauge to $10,000 for a state of the art weather station. Each can provide valid measurements.

Either option mentioned above has its pro's and con's. Each requires personal involvement. What is right for one operation may not apply to another. Personal knowledge of the farm can lend the advantage of experience to interpreting any collected data. But, if the person responsible for monitoring weather falls ill or fails to understand the purpose, the data could be rendered useless. Meanwhile, automated equipment still cannot substitute for human expertise. Having trained, daily observers can save money and increase accuracy.

Equipment Available

Many choices are available for collecting on-farm weather data. Agricultural equipment manufacturers and dealers are selling more and more types of weather monitoring equipment ranging widely in cost and accuracy.

Combined "all in one" weather stations, consisting of several instruments mounted together and linked to a datalogger, are convenient but should be purchased with caution. If several gauges are mounted on one post, some sensors may interfere with airflow patterns and cause faulty precipitation readings. The equipment is often of inadequate quality for reliable, repeatable measurements. Most of the weather parameters are not highly variable above the crops and at field scales, and are not generally needed for the individual farm. Therefore these systems are not recommended.

Some precipitation gauges are "recording gauges" that output an electrical signal to a datalogger. Others are "non-recording gauges," meaning they must be read manually. Recording gauges allow farmers to collect data infrequently and create computer files. However, the mechanisms, often including moving parts, make them susceptible to problems. Non-recording gauges are easy to use, not as prone to mechanical problems or equipment failure, and are often more portable. Non-recording gauges require human labor and time.

A common instrument setup for manual readings is among the most labor-intensive: a ground-mounted metal 8" non-recording gauge, set in a concrete pad, with someone taking daily readings. Another is the ground-mounted or post-mounted tipping bucket gauge (Figure 2) with computer datalogging capability, combined with a multi-purpose datalogger. Both types of gauges can be highly accurate, if properly sited and leveled—or useless, if not maintained and located properly. The remaining option is the flow-through rain gauge, with less established accuracy. Measuring precipitation in the winter is possible with certain gauges and special equipment, but is difficult and probably not necessary.

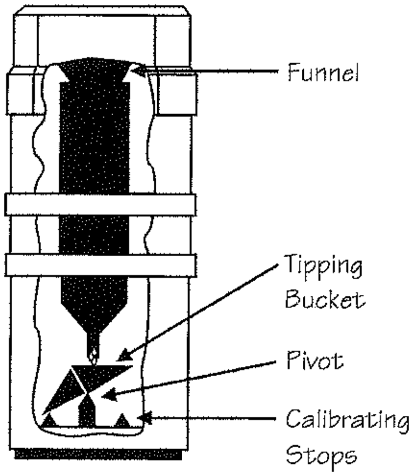


Figure 2. Tipping bucket rain gauge.

The most widely available non-recording gauge for farmers is the plastic or glass cylinder gauge, usually costing $25-60 (cheaper versions less reliable). Water collects in a cylinder with labeled numbers, or is read with a graduated dip-rod. These are accurate and dependable, and can achieve very high accuracy. Strictly cylindrical gauges crack in cold weather; to be durable all year round, gauges should have a slightly wider funnel-like top, so that frost and ice can push upward instead of outward. For reading plastic gauges, etched-in numbers are more durable than those painted on.

The tipping bucket gauge is also widely used, and can cost from $100 to well over $2,000, with datalogging versions costing $200-280. Water falls through a funnel into a see-saw tipper, which triggers a switch for each 0.01" increment of precipitation. Accuracy is extremely sensitive to balance, and there may be extra "tips" from wind. Cheaply made tippers are hinged on a rod run through two holes; they can wear out in a year. Better, more durable models have bearings. For tipping bucket gauges, recommended orifice size (the opening rain falls into) is 6 to 10 inches in diameter. Gauges smaller than this size catch an unknown percentage of the true precipitation.

More recently available to farmers is the flow-through gauge, which costs around $90-100, with datalogging versions costing $250. Water flows through a funnel and wets a wick at the bottom of the catch area, which drips in 0.01" drops. Underneath the catch area are metal electrodes, which close a circuit after each drop's impact. The drop then exits the gauge. Accuracy and reliability are not yet established. Openings tend to be quite small, and wicks would be expected to wear out more quickly than metal tippers.

Dataloggers

If an automated (tipping bucket) rain gauge is used, a datalogger is needed to store the information. The logger usually is read by downloading to a computer. Some systems use telephone modems, satellite or radio transmission for remote downloading. Dataloggers range widely in price, from less than $100 to more than $1,500. Following are some considerations in purchasing a datalogger.

Dataloggers allowing multiple types of instrument inputs are more expensive than those specific to a rain gauge. However, some rain-gauge-specific dataloggers are too cheaply made for quality control. Strength of the tipping bucket signal may be too weak and inconsistent, causing lost tips, making it difficult to determine which days' rainfall amounts are reliable.

Loggers required to hang outside the gauge can create extra wiring problems and allow water to rust the components, while those placed inside the gauge can require shaking of the gauge every time data is downloaded, making it necessary to re-level each time. Measurements at equal time intervals produce largely empty data files, since rainfall occurs on only a very small percentage of the total hours, while other loggers treat rainfall only as events, which is more efficient. Multiple-use dataloggers usually are free of these problems.

Reliability also varies, ranging from expensive but durable dataloggers that have been used for years in remote locations to cheaper ones that require significant equipment maintenance and data troubleshooting.

Datalogger resolution and data download (transmit) speeds are important items to compare when choosing a system. The higher the resolution, the more accurately the system can measure sensor signals, but higher resolution increases costs. Typically, 12- or 16-bit dataloggers are used. When downloading data, large file sizes can take several minutes or even hours to transmit. Compare the transmit speeds and file storage types: higher speeds with data transmitted in binary format will take less time to download.

The equipment enclosure and protection from severe weather are important considerations. The operating range (temperature, humidity) of the datalogger should also be considered. Since it is usually difficult to find a location far enough away from buildings or other obstructions but within range of AC power, a solar power kit with a rechargeable battery backup is recommended. Some dataloggers available with solar power were originally designed for AC power and may not be fully adaptable for use in remote locations, requiring very quick downloading to avoid draining the battery backup. A mobile data storage unit is often available, which can download data from the logger and transfer it to the farm computer. The most convenient (and most expensive) option is a laptop computer, which can be brought to each gauge to download.

Setting up --Locating, Installing and Calibrating the Instruments

As with many pieces of agricultural equipment, the outcome is only as good as the operator's input. Weather instruments are no exception. Many weather-measuring devices are especially sensitive to proper location, installation and calibration. Improper location, installation and calibration can lead to altered or misleading data readings.

Location, Location, Location

No matter how accurate a sensor may be, it has to be in the right place to give useful readings. The sensor site should be representative of the area to be measured. Instruments should not be placed in depressions or extreme areas if a whole field average is the goal. It is also important to place instruments in a spot where they do not interfere with field operations.

Rain gauges should not sit at the side of a house or on a roof, where air pockets can deflect raindrops up and over the gauge. A good rule of thumb is that the nearest obstruction should be at least twice as far from the gauge as its height above the gauge (excluding telephone poles). Since corn and soybeans can grow taller than the gauge, this means not planting near the gauge. Figure 3 shows proper siting of a rain gauge relative to obstructions.

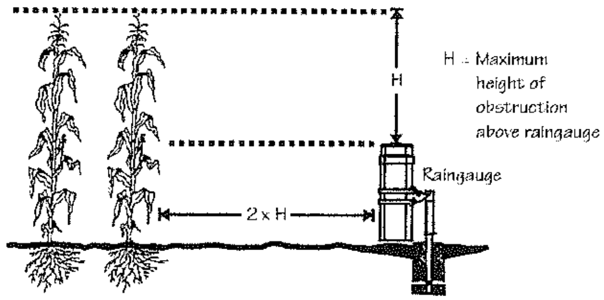


Figure 3. Rain gauge should be located at least twice as far from obstructions as the height of the obstruction above the gauge.

Installation

Manufacturer's instructions describe many of the important considerations for installation. For some of the less expensive rain gauges, manuals may not cover all of the precautions necessary for accurate measurement.

Securing the gauge in concrete is a good idea for ground-mounted gauges (Figure 4a) and required for post-mounted gauges (Figure 4b). The concrete platform must be deep enough to not be affected by frost heaving; otherwise it will have to be re-leveled every year. In high-wind areas, the farmer might want to consider a windshield, of which there are a few standard types available. Ground-mounted gauges should be kept as free from splash as possible. Between the gauge and the cropped area, gravel and grass are good ground covers for absorbing rainfall.

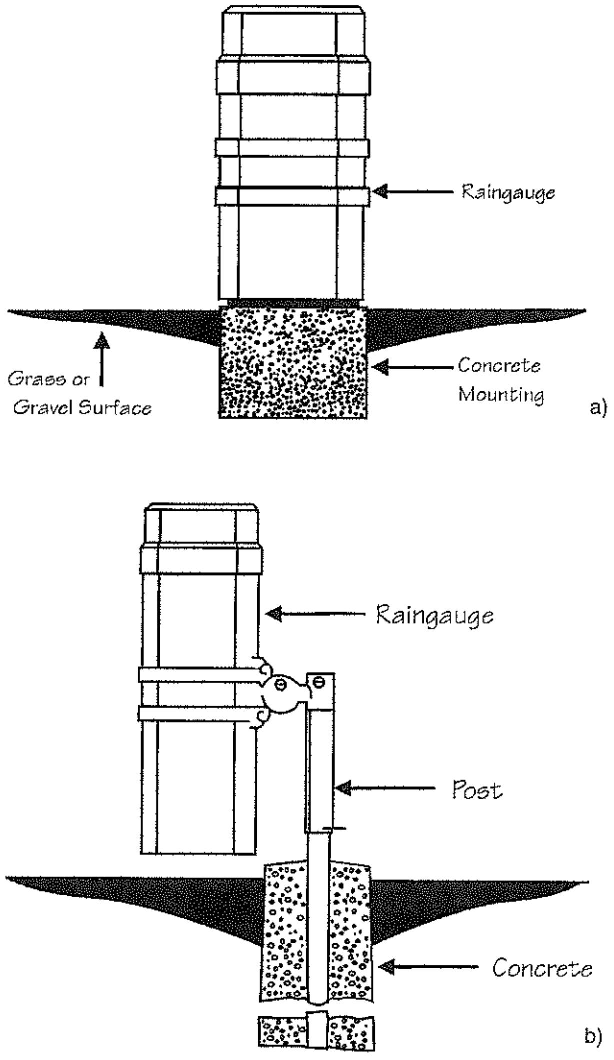


Figure 4.
(a) Ground-mounted gauges should be secured in concrete and surrounded by grass or gravel.
(b) Post-mounted gauges should be secured in concrete to remain level.

It is essential to level the rain gauge. A study by Purdue University found that a tilt of 5° decreased the rainfall recorded by a tipping bucket gauge by 15%. At 10° the reduction was 35%, and at 11° measurements nearly stopped, even if water was poured into the gauge. A bubble level long enough to lie across the gauge top should enable leveling in both perpendicular directions. The gauge lid should be secure before leveling, to avoid the lid being straight while the tipper is tilted.

Since birds often perch on rain gauges, installing a bird perch higher and nearby is often recommended. Mice can also cause major problems by gnawing the wires and building nests in the mechanism of tipping bucket and weighing rain gauges. Inserting steel wool in any holes will prevent mice from establishing themselves in the gauge.

If electronic recording instruments are used, all connections should be tight and secure, and all lights, tippers, and waterproof locks checked before starting to record data. Keeping wires between the gauge and the data logger either entirely exposed to the elements or entirely enclosed in garden hose or other tubing will reduce the risk of severed wires by gnawing mice and other animals. Lightning protection for the data logger and instruments is a wise investment, even if not included in the instrument package. A few days of "test" weather observations can help make sure everything is recording properly.

Calibration

The equipment manual should clearly explain recommended calibration methods. Calibrating a rain gauge is simple. First, drill a hole in the bottom of a bowl or can and hook up the datalogger to the gauge. Next, fill the bowl with a known amount of water and let it drain into the gauge slowly. Check the data on the computer to see how much rain was recorded. A special rain gauge calibrator can be purchased for this purpose, which provides constant flow rates from an upturned water container. The equipment manual should tell how to convert a volume of water to inches of rainfall. For a non-recording rain gauge, simply pouring a known volume of water into the gauge and reading the number of inches is sufficient. Some manuals suggest turning the screws beneath the tipper stops ("calibrating stops" in Figure 2), but this is not recommended because a lower screw causes the tipper to remain on that side more often. Instead, it is best to calculate what the calibration factor is, and simply use it as a multiplication factor for all subsequent measurements, instead of trying to recalibrate the instrument itself.

Collecting Measurements

Graduated cylinders must be read with the top of the liquid at eye level. The reading should always be from the bottom of the meniscus (the curve that the liquid makes inside the tube). A good rule is to go out the same time of day to record or download data, because differences of even a couple of hours can significantly change 24-hour highs and lows. In order to compare farm data with other sources such as National Weather Service data, it is important to observe at the same time as they do; otherwise, the 24-hour totals will not match up.

If precipitation measurements from automated equipment stay at zero for too long, the equipment may not be properly connected to the logger, the gauge may be obstructed or tilted, or the tipper may be loose. If no precipitation appears on the record, and other sources indicate rain fell, then immediately check the gauge, siting, and hookups to avoid lost data. If records show a great deal more rainfall than indicated elsewhere, connections or tape may have been loose, allowing wind to touch the wires together. If a record reveals missing information after the 30th day of the month, the software may be unable to handle 31-day months (some cannot). It is also a good idea to plan how data will be organized into directories, and develop a naming strategy that keeps each station and downloading interval separate and easily identifiable.

Maintenance

Maintenance is essential for accurate data for all gauges. If not maintained, an automated gauge can give bad measurements, leading to a false assessment of the gauge as being unreliable.

Rain gauges should be checked regularly to make sure they are level. To avoid evaporation, particularly with a non-recording rain gauge, oil can be placed in the gauge funnel and chamber in a thin, even layer. Cleaning out the rain gauge during dry periods, using soap and water, helps keep the gauge unobstructed. Buckets or scales should be completely dry before replacing the gauge lid. Every time data is downloaded, foreign objects such as dust, debris, and insects, should be brushed out. Plant material, bird droppings, or other material will accumulate and stop up the gauge if it is not cleaned frequently.

Rain gauges not equipped for year-round recording should come inside for the winter. This is a good time to clean the gauges, remove old datalogger batteries, and inspect moving parts for wear. Outside, a drop cloth or overturned drum over concrete pads, posts, or tower brackets can help prevent damage from the elements. Storage of equipment should be in a place where it will not have weight put on it, and it should be covered over with a protective cloth or plastic.

Lastly, it should be kept in mind that high-quality rain gauges are somewhat delicate. The farmer should be careful when using, cleaning, and installing the equipment, to maintain the gauge as a precision instrument. For instance, if the tipper becomes loose, it would destroy the integrity of the gauge to simply pry open the sides and stick it back in. If in doubt about a repair, it does not hurt to call the manufacturer.

Considerations in Data Collection Weather

Weather has a strong effect on crop growth, but measuring weather data on a farm requires a significant investment in time and effort to properly install and maintain a system. The most useful parameter to measure on the farm is precipitation. Other information can be obtained from existing sources. Equipment is available at a variety of costs and effort needed. With quality equipment, careful siting and installation, and a proper investment of time in wise maintenance and consistent data collection, it is possible to achieve an accurate site-specific database that may have future economic benefit. As scientists more clearly tie together weather and crop yield, having several years of weather data could help farmers interpret yield maps and manage economic inputs.

Further Information

To obtain weather from outside sources instead of measuring on the farm, the following web sites are useful.

Midwestern Regional Climate Center, 2204 Griffith Drive, Champaign, IL 61820, (217) 244-8226 or http://mcc.sws.uiuc.edu/
http://cirrus.sprl.umich.edu/wxnet - WeatherNet (current conditions and forecasts)
http://www.ncdc.noaa.gov/ol/about/ncdcordering.html - National Climatic Data Center (historical data)
http://www.nws.noaa.gov/nwr - NOAA weather radio (current conditions)

The following extension publication provides information about other kinds of (non-automated) weather instruments:

Newman, James E., and Walter L. Stirm. 1982. Farm and Home Weather Instruments. AY-242. Purdue University Cooperative Extension Service. http://www.agcom.purdue.edu/AgCom/Pubs/AYAY-242.html

Two long-range (>20-year) studies in particular are worth noting:

Huff, Floyd A. 1979. Spatial and temporal correlation of precipitation in Illinois. Illinois State Water Survey Circular #141, pp. 1-14. Urbana, Illinois: Illinois Institute of Natural Resources.

McConkey, B. G., W. Nicholaichuk, and H. W. Cutforth. 1990. Small area variability of warm season precipitation in a semiarid climate. Agricultural and Forest Meteorology 49:225-242. [study in Saskatchewan]

Hubbard, K. G. 1994. Spatial variability of daily weather variables in the high plains of the USA. Agricultural and Forest Meteorology 68:29-41.

Camargo, M. B. P., and K. G. Hubbard. 1999. Spatial and temporal variability of daily weather variables in sub-humid and semi-arid areas of the United States high plains. Agricultural and Forest Meteorology 93:141-148.

Roche, M., A. R. Perks, M. Moss, and D. Starosolszky. 1994. Precipitation measurement. In Guide to Hydrological Practices, 5th ed. (World Meteorological Organization; WMO #168; Geneva, Switzerland: WMO), 91-116.

World Meteorological Organization. 1996. Measurement of precipitation. In Guide to Meteorological Instruments and Methods of Observation, 6th ed. (WMO-No. 8; Geneva, Switzerland: WMO), I.6-1 - I.6-15.

Sevruk, B., and V. Nespor. 1994. The effect of dimensions and shape of precipitation gauges on the wind-induced error. In Global Precipitation and Climate Change (M. Desbois and F. Désalmand, eds; Berlin: Springer-Verlag), 231-245.

A GLOSSARY OF TERMS FOR PRECISION FARMING

aerial photography

Photos taken from airplanes to assist growers to determine variations within an area of interest such as a field.

ag consultant

Person trained in agricultural and management sciences to provide information to land owners/managers for a fee related to the farming operation.

ag consultant certification

There are 3 types of certification for ag consultants that are recognized in the U.S.:

1. Certified Crop Advisor (CCA). Administered by the American Society of Agronomy. Requirements include a high school education, 4 years of experience, continuing education credits and testing.
2. Certified Professional Agronomist (CPAg). Administered by the American Society of Agronomy. Requirements include a college education, 4 years of experience, continuing education credits and testing.
3. Certified Professional Crop Consultant (CPCC). Administered by the National Alliance of Independent Crop Consultants. Requirements include a college ag degree, 4 years of experience, continuing education credits and testing.

algorithm

A finite, ordered set of well-defined rules written as a computer program to assist in solving a specific problem.

agriculture anomaly

an agronomic (vegetation or soil) deviation or inconsistency in excess of "normal" variation from what one would expect to observe.

application

A practical use of computer software, an electronic system or a concept.

applications package

Specialized computer programs and their associated documentation developed for practical usage. Ideally, applications packages allow a non-computer specialist to use the computer without learning complex programming languages.

arc

A line described by an ordered sequence of points associated with vector data models. When a node joins two or more arcs and several arcs are linked together in a loop, they form an area or polygon.

archive

The storage of historical records and data. When you have collected a year or two of data from your precision farming applications, you have started your own archive.

ASCII

(American Standard Code for Information Interchange). A standard coding system used to represent alphanumeric characters within a computer. ASCII files enable the transfer of some data between different computers through the use of a common set of symbols.

aspect

Horizontal direction in which a slope faces (e.g., a SE facing slope has an aspect of 135 degrees).

attribute

A numeric and/or text description of a spatial entity (e.g., address or owner's name for a parcel).

attribute value

A value or property that is a characteristic of a spatial element. For example, a specific symbol or color may represent 150-160 bushels/acre that is a value assigned to that attribute.

base map

The outline of your field with its proper coordinates is your base map. Data collected within the field by your yield monitor will be defined in location by the base map, which is a binary digital map.

baud rate

A measure that describes the speed of the transmission of single digital elements over a communications line. The number indicates how rapidly data could move through your modem or between a computer and a printer.

benchmark

1. Used to define how comparisons are to be made between different computer software or systems according to specific requirements.
2. In surveying, a benchmark is the elevation at a specific point.

bit

An abbreviated term for binary digit, the smallest unit of computer data.

block kriging

A piecewise form of kriging based on grid cells.

buffer

An area defined by the specified length extended around a point, line, or area.

byte

A unit of computer storage of binary data usually comprising eight bits, and equivalent to a character. You will commonly hear computer memory and storage referred to using terms such as Kilobyte (approximately one thousand bytes), Megabyte (approximately one million bytes) and Gigabyte (approximately one billion bytes).

cartography

The art and science of the organization and communication of geographically related information such as a yield image into maps or charts. The term will refer to their construction, from data acquisition to presentation and use.

centroid

The position at the center of a one- or two-dimensional (2D) entity such as a polygon.

choropleth map

A thematic map such as a yield image where quantitative spatial data is depicted through the use of shading or color variations of yield ranges.

computer aided design (CAD)

Software with the capability of performing standard engineering drawings.

computer aided mapping (CAM)

Software with the capability of generating standard mapping functions. In contrast to GIS, it cannot analyze or process a database.

contour

A line connecting a set of points, all of which have the same value. A contour line will show elevations of the same value.

controller

An electronic device used to change product application rates on-the-go, based on user directions or prescription applications maps.

crop scouting

Precise assessments of pest pressure and crop performance that can be tied to a specific location for better interpretation.

cross tabulation

Comparison by location of attribute data in two or more map layers.

customization

A procedure which produces an application or company specific interface and/or database design such as yield mapping software. For example, a customized version of a commercial yield monitor product may include menus that allow one to add individual field numbers and other identifiers into the database.

database

A logical collection of files managed as unit. A GIS database includes data about both the position and the attributes of geographic features.

database management system (DBMS)

A collection of software for organizing the information in a database that might contain routines for data input, verification, storage, retrieval, and combination.

data input

The entry of information into a computer through the use of a keyboard, digitizer, scanner, or even entering data from already existing databases.

data standardization

The process of achieving agreement on common data definitions, representation, and structures to which all data layers must conform.

DEM (Digital Elevation Model)

A digital representation of the elevation of locations on the land surface. A DEM is often used in reference to a set of elevation values representing the elevations at points in a rectangular grid on the Earth's surface. Some definitions expand DEM to include any digital representation of the land surface, including TIMS or digital contours.

differential correction

Correction of the GPS signal to make it more accurate. An uncorrected signal will be accurate to about 50 yards. A corrected signal can be accurate to within 1-5 feet. Correction of a signal is done from a second GPS receiver/transmitter at a known fixed location. The signal is then transmitted to the tractor, combine or other equipment that corrects the proper location through differential processing. There are four common ways to transmit a correction signal from the base station to the farm implement:

1. A dedicated AM transmitter that is located on a U.S Coast Guard tower located near coastal and inland waterways, which has a range of 100-250 miles.
2. A separate, private corporation satellite to send the corrected signal (OmniSTAR, RACAL), which has worldwide coverage.
3. Piggyback the correction signal on a commercial FM radio station frequency (DCI, ACCQPOINT), that has a range of 30-40 miles.
4. WAAS (Wide Angle Augmentation System) developed for the Federal Aviation Administration (FAA) which has U.S. coverage.

digitizer

A table or tablet which has the capability of digitally recording the relative position of a cursor which is moved over the area or line that you want to digitize or record.

DLG (Digital Line Graph)

A U.S. Geological Survey digital map format used to distribute topographical maps in vector form. The digital files contain lists of the coordinate points that describe linear map features.

edit

The process of adding, deleting, and changing data/information on a computer.

expert system

A system designed for solving problems in a particular application area. One can draw an inference from a stored knowledge base that was developed by recording and structuring human expertise through an individual commonly called a knowledge engineer.

extrapolation

A method or technique to extend data or inferences from a known location to another location for which the values are not known.

feature

A geographic component of the earth's surface that has both spatial and attribute data associated with it (e.g., field, well, waterway).

field

1. A set of alphanumeric characters comprising a unit of information.
2. A location in a data record in which a unit of information is stored. For example, in your data base, one of your crops may contain columns of data such as location #, crop type, variety, date of planting, etc. (all of which are fields).
3. A specific location on a person's farm that may be called "Field # 10A."

field prescriptions

Applications of inputs at variable-rates based on data obtained through yield monitors, crop scouting, remote sensing and soil sampling.

geocode

A code associated with a spatial element which describes its location. An example would be a coordinate such as longitude or latitude.

geographic information systems (GIS)

System of computer hardware, software, and procedures designed to support the compiling, storing, retrieving, analyzing and displaying of spatially referenced data for addressing planning and management problems.

georeference system

A coordinate system keeping track of specific points on the Earth's surface. Examples of such a system are the Universal Transverse Mercator system (UTM) and the State Plane Coordinate System.

geostationary satellites

Space vehicles in an orbit that keep them over the same location on the Earth at all times. Satellite-based differential correction signals are broadcast from this type of satellites. Others are maintained by NOAA to provide weather images every 30 minutes of the Earth.

grid

A data structure that uses rectangular units or grid cells arranged in rows and columns to represent an area like a field.

grid mapping

Predetermined locations in a field where soil or plant samples may be obtained for analysis. The test information can be used for assessing fertility needs and determining approximate locations for varying fertilizer and lime applications.

GPS (Global Positioning System)

A network of satellites controlled by the Defense Department that is designed to help ground based units determine their current location in latitude and longitude coordinates. Note that the term "GPS" is frequently used incorrectly to identify Precision Farming. GPS is only one technology that is used in Precision Farming to assist you to return to an exact location to measure fertility, pests and yield.

ground control point

An easily identifiable feature with a known location that is used to give a geographic reference to a point on a yield image.

ground reference data

The field collection of data that is used in the interpretation of information gathered from other sources such as a yield image or a remotely sensed image. Also known as ground truth but the preferred terminology is ground reference.

guided crop scouting

Assessment and recording of crop anomaly and conditions on a site-specific basis using a backpack GPS receiver and hand-held computer. The system allows the user to record growth stage/maturity, plant vigor, presence of disease, weed and insect infestation.

hard disk

A large capacity, mechanical, magnetic, computer storage device that stores your programs and data.

hardware

The various physical components of an information processing system such as a computer, view screen, plotters, and printers.

image classification

Processing techniques which apply quantitative methods to the values in a digital yield or remotely sensed scene to group pixels with similar digital number values into feature classes or categories.

input

An overused term that applies to the process of entering data into a computer. Also used to describe the actual data that are to be entered.

internet

An international network comprised of many possible dispersed local and regional computer networks in which one can share information and resources. Developed originally for military and then academic use, it is now accessible through commercial on-line services to the general public.

kriging (creeging)

An interpolation technique for obtaining statistically unbiased estimates of spatial variation of known points such as surface elevations or yield measurements utilizing a set of control points.

layer

A logical separation of mapped information representing common data (e.g., roads, soils, yields, vegetative cover, and soil tests).

lat/lon

Refers to Latitude and Longitude that specifically describes a position on the earth. Latitude is the north to south position. Longitude is the east to west position. Precise locations are described in degree, minutes and seconds. The lat/lon of Purdue University is 86 degrees, 55 minutes, 05 seconds latitude and 40 degrees, 25 minutes, 50 seconds longitude.

legend

A map section containing explanations of symbols, colors and/or shades that signify various elements and data values on the map. A yield map will contain a listing of yield values and the color denoting a range of yields.

LIS (Land Information System)

A system for describing data about land and its use, ownership and development. LIS refers to all aspects of handling the data such as collection, storing, checking, merging, manipulating, analyzing and displaying.

locational reference

Referencing data collected by yield monitor, sensor or other method and relating it to a specific spatial position.

lookup table

A reference table containing key attribute values that can be linked or related to data usually collected at a specific location. An example would be physical and chemical data relating to a soil-mapping unit.

menu

A list of options displayed by a computer data processing program, from which the user can select an action to be initiated. These choices are usually displayed in the form of alphanumeric text but may be as icons.

merge

To take two or more maps or data sets and combine them together into a single coherent map or data base without redundant information.

metadata

A term used to describe information about data. Metadata usually includes information on data quality, currency, lineage, ownership, and feature classification.

mosaic

Process of assembling GIS database files for adjacent areas into a single file.

network

1. A group of linked computers that are able to share software, data, and various hardware devices such as printers.
2. A geometric or logical arrangement of nodes and interconnecting lines.

noise

Random variations or error in a data set. Also an unwanted sound coming from the combine.

output

The product of a computer process and analysis that may be displayed on a computer screen, or as a printed map or tables of values.

orthophotograph

An aerial photograph that corrects distortion caused by tilt, curvature and ground relief.

pixel

A term used in remote sensing referring to the fundamental unit of data collection which is an abbreviation for "picture element". A pixel is represented in a remotely sensed image as a rectangular cell in an array of data values and contains a data value that represents a measurement of some real-world feature.

point sampling

A method of grid sampling in which a sample is taken in a 10-30 foot radius at the center point of each grid location.

polygon

An area enclosed by a line describing spatial elements, such as a similar yields range, land use or soil type.

precision farming

Using the best available technologies to tailor soil and crop management to fit the specific conditions found within an agricultural field or tract.

raster-to-vector conversion

A process in which one converts an image such as a yield map of grid cells into a data set layer of lines and polygons.

RDBMS (Relational Database Management System)

A database management software system that organizes data into a series of records that are stored in linked tables. This provides the ability to relate different records, fields and tables, and aids data access and data transformation.

registration

A process where one can geometrically align maps or images to allow one to have corresponding cells or features. This allows one to relate information from one image to another, or a map to an image, such as registering a yield image to a soil map to determine if soils are influencing the yield response.

remote sensing

The act of detection and/or identification of an object, series of objects, or landscape without having the sensor in direct contact with the object. The most common forms include color and color infrared aerial photography, satellite imaging and radar sensing.

resolution

A way of detecting variation. In remote sensing, one has spatial resolution (the variation caused by distance separating adjacent pixels), spectral resolution (the variation from the range of spectral responses covered by a wavelength band), and temporal resolution (the variation caused by time over the same location).

satellite constellation

A system of 24 satellites that is owned by the U.S. Department of Defense (DOD) that can determine location to within inches. There are usually at least 4 of these satellites that are in view 24 hours a day. The DOD can intentionally introduce error into the signal during national emergencies. This error called "Selective Availability" would allow an accuracy of approximately 50 yards without differential correction.

scale

The ratio or fraction between the distance on a map, chart, or photograph and the corresponding distance on the ground. A topographic map has a scale of 1:24,000 meaning that 1-inch on the map equals 24,000 inches (2,000 feet) on the ground.

software

The programs, procedures, algorithms (set of rules), and their associated documentation, for a computer system.

spatial data

Data pertaining to the location, shape, and relationship among geographical features.

thematic map

A map related to a topic, theme or subject. These maps emphasize a single topic such as yield, soil type, or land ownership.

topologically integrated geographic encoding and referencing (TIGER) file

The nationwide digital database developed by the U.S. Bureau of the Census. TIGER files contain street addresses and census boundaries with accompanying population statistics.

turn-key system

A reference to hardware and/or software systems meaning that they are ready to be used immediately and are designed, provided at a cost and supported by a commercial group.

UTM (Universal Transverse Mercator)

A commonly used map projection that uses a set of transverse mercator projections for the globe which are divided into 60 zones, each covering 6 degrees longitude. Each zone has an origin of the central meridian and latitude of 0 degrees.

variable-rate technology

Instrumentation such as a variable-rate controller for varying the rates of application of fertilizer, pesticides and seed as one travels across a field.

waveband

A remote sensing term used to describe a contiguous range of wavelengths of electromagnetic energy. Visible wavelengths (seen by the human eye) which range from 400 to 700 nanometers. Near infrared (NIR) wavelengths are at 700 to 2600 nanometers.

yield maps

A representation of crop yields collected on-the-go by a harvester equipped with an instantaneous yield monitor. Each location/site (pixel) in a field is assigned a specific crop yield value.

yield monitoring

Regular intervals where a harvested weight has been obtained along with a GPS reading. A display of the weights every 1-3 seconds is translated to bushels/acre or yield providing a yield map. Moisture of the grain is obtained at the same time.

zoom

To enlarge or decrease the scale of an image that is being displayed. One can "zoom out" of a yield monitor image and enlarge it in a progressive scaling of the entire image or one can "zoom in" decreasing the scale.

z-value

A commonly used reference referring to elevation values. The "z direction" refers to upward direction on a 3-D chart or diagram.

Compiled by Chris J. Johannsen, Professor of Agronomy, Purdue University, johan@purdue.edu

PRECISION FARMING

Profitability

SSMC

Site-Specific Management Center
Purdue University
1150 Lilly Hall, Room 3458, West Lafayette, IN 47907-1150
(765) 494-6134, e-Mail: SSMC@agad.purdue.edu
Internet Site: www.purdue.edu/ssmc

The goal of the Site-Specific Management Center (SSMC) at Purdue University is to help make precision agriculture profitable and practical for farmers. Because no one discipline has all the tools needed to make sense of yield maps and fine tune agronomic practices to fit field variability, 20 Purdue faculty and staff from 4 departments in the School of Agriculture are working together in the SSMC with a focus on crop management. The departments are Agronomy, Agricultural and Biological Engineering, Botany and Plant Pathology, and Agricultural Economics.

Current SSMC activities cover a wide range of precision farming topics, such as soil sensors for pH and potassium, optimal soil sampling patterns, site specific crop response, remote sensing for identification of soil and plant problems, spatial weed control options, site-specific tillage, and statistical analysis of yield monitor data.

The center was created in February 2000 to better coordinate site-specific management research and extension activities at Purdue. It grew out of a group of interested parties that had met monthly on campus since 1994 to discuss developments in precision farming. The center has received seed money from Purdue's Ag Research Programs and Cooperative Extension Service, and support from several agribusiness partners.

SSM - 3

PRECISION FARMING
Profitability

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