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PRESCRIPTION FARMING BASED ON SOIL PROPERTY SENSORS

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Introduction

Prescription farming as used in the context of this paper will be defined thusly: The site specific management of variable cropping inputs so as to achieve maximal economic return while minimizing degradation of the environment. Obviously many factors must be integrated into a management plan to achieve such a worthwhile goal. Proper equipment, skills, management ability, and timing are all crucially important. Perhaps the most important factor, and the one which is the most limiting currently, is the ability to collect and organize detailed information about the site in question.

It is not always clear how today's traditional farming methods can make the leap to prescription farming. As a case in point, consider the prescription application of a soil-applied herbicide. Often a number of factors must be taken into account just in the selection of the proper herbicide for a field; among these are the crop to be grown, weeds known to be present, probable future cropping rotations, equipment, and time available for application. Once these rather basic parameters are known, the farm manager must consider such subjective data as potential level of weed pressure, soil variation within a field, and potential risks associated with excessively wet or dry seasons. Once candidate chemicals are identified, the manager must select the one with the best cost/benefit ratio with the realization that tradeoffs must often be made and that seldom will perfect results be achieved.

Obviously, long before the farm manager goes through the chemical selection process, other decisions have already limited the available choices. Chemical companies have carefully screened and tested the available compounds for weed control spectrum, crop tolerance, human and animal toxicity, environmental persistence and a host of other pertinent factors. Federal and state regulatory agencies have reviewed data and issued clearances. Sales and marketing departments have decided on niches to target for the chemical. Finally, labels are written which delineate proper usage of the material, often with several provisions and exceptions listed.

Using the information previously described, the farm manager or custom applicator chooses a chemical and multiplies the total number of acres to be treated by a representative number of pounds or gallons of the material recommended per acre and orders the resulting amount of material to be applied. This is then mixed in large containers with a carrier (such as water) or
put into bulk tanks and applied as uniformly as possible to the land. The concept which is often stressed to applicators is that of uniformity. In fact, the quality of chemical application is commonly based upon two factors: accuracy and uniformity.

Prescription farming, by its very nature, will continue to stress accuracy as an important goal, but will often require that chemical application be very non-uniform. This poses several problems to the whole infrastructure of chemical application. A system that has been based on maintaining uniform chemical application must be converted to one which intentionally varies rates. In many cases, incremental changes in the system may not be possible. Equipment, management skills, application recommendations, and knowledge about all factors of the land and crops will need to improve significantly.

The bulk of this paper deals with the equipment that will be needed in prescription farming systems. It would, however, be incomplete if the other factors: management skills, application recommendations, and knowledge about soil and plants were not discussed.

The major impact of prescription farming on management skill will be in the area of operating computers and microprocessor-based control systems. Although these systems will, in many cases, be easy to program and have some self-diagnostic features, they will be "new and different" and will require an investment of time to learn how to operate. Also, since no such system is infallible, the operator will be responsible for judging the validity of computer output or control system output. Many of the control algorithms and functions may become so complex that a numerical check may be impractical, but it will be imperative that the operator know reasonable and probable ranges for output values.

A major benefit of prescription application systems will be that once they are properly programmed and calibrated, they will eliminate many of the sources of error which currently result in both over-application and under application of inputs. Therefore, while they will require more initial preparation before a manager can become proficient in their use, prescription application systems will ultimately pay dividends both in improved spatial placement of inputs and improved accuracy of application.

Application recommendations for agricultural chemicals will need to change from current label formats. For example, soil-applied chemicals are often labeled for specific rates or ranges of rates based on soil properties. Some chemicals have rate ranges for both soil organic matter content and soil texture; typically, these are shown in tabular format with two or three organic matter ranges and three or four soil texture classifications. Often, each of the rate recommendations is expressed as a range which may vary up to 50% for each organic matter/textural combination. These types of recommendations result in the need for substantial compromises by the farmer. Fields in the U.S. Corn Belt often have combinations of soil texture and organic matter which match over half of the categories in the rate recommendation table. In practice, it is common for the farmer to choose the rate for the most absorptive soil in the field;
thereby assuring adequate control of weeds. This results in over-application on the rest of the field. Alternatively, the farmer may select a herbicide application rate for the most prevalent soil texture and organic matter in the field. This can potentially result in inadequate weed control in some areas and over application in others. The over-applied material may, in many cases, be moved into the groundwater since it is not bound up in the soil. Obviously, there is an economic cost to the farmer in addition to the environmental pollution.

Prescription application of fertilizers also shows promise to address economic and environmental concerns. Soil fertility and yield potential may vary significantly across a field. Uniform application of fertilizer results in economic loss at both ends of the spectrum. In areas of lower than average yield potential, the extra fertilizer is not usable by the plants since some other factor (often water-holding capacity) is a limiting factor. Areas with high yield potential, on the other hand, may suffer from a deficit of a major nutrient and thereby reduce a farmer's profit.

True prescription farming will require that application rates of all soil-applied chemicals be specified as a mathematical equation rather than as points or ranges in a table. Just as soil conditions change on a continuum, so should the application rates of the chemicals. A general equation which describes the influence of all measurable variables would be required for each chemical.

Prescription farming can also be applied profitably at planting time. Seeds germinate more rapidly and emerge more uniformly when planted at the best combination of depth and soil moisture content. A planter that could vary planting depth on-the-go based on a soil moisture sensor and an appropriate control algorithm would be especially beneficial to farmers who had significant soil variation in a field.

Another possible enhancement that could eventually be made to planters is the ability to vary seeding rate and change variety based on soil type. This would require a sensing system that could assess soil texture, organic matter content, and moisture content.

The farmer must understand more about soils and plant growth to be successful in the practice of prescription farming. If a formal education is not practical, the farmer may need to rely on expert decision support systems to help make management decisions. A decision support system is a computer program which can answer the farmers’ questions based on the advice of experts. As more and more variables come into the management equation, knowledge may well be more important than time or money in arriving at the best decision.

The ultimate goal of prescription farming is to achieve maximum economic return while minimizing degradation of the environment. In order to verify that this is being accomplished, the farm manager must be able to measure yield. No longer will it be sufficient to simply
calculate average yield. The more accurately yield variations within a field can be measured, the better management decisions will be possible with regard to pesticides, fertilizers, and planting.

Significant work on yield mapping has been done in Belgium by Vansichen and DeBaerdemaeker. It appears that within a few years, on-the-go yield mapping can be reliable and cost effective.

Strategies for Prescription Application

Two strategies can be used to control equipment for prescription planting or application of chemicals. One method is to prepare a map of each field with respect to all variables of interest. These variables might include soil texture, organic matter content, available phosphorus and potassium, soil drainage, soil pH, soil moisture, and yield potential. The second strategy is to use real time soil properties sensors and control algorithms to automatically match planting and chemical application rates to the sensed area. Both methods have their benefits and drawbacks. It is probable that initially the two basic concepts may need to be used together since a lack of appropriate real time sensors will be a limiting factor.

Detailed mapping of fields appears, at first, to be the preferred method for implementing a prescription farming program. Mapping facilitates long-term planning and analysis. It provides an opportunity to make decisions regarding the selection and purchase of seed and chemicals well in advance of their time of use. Mapping makes it possible to control a machine to apply either the best rate, or rates, depending upon the sophistication of the equipment. In other words, on a computerized soil map, the control algorithm should be able to interpret all of the surrounding soil properties and to respond with the best average rate for the soils encountered. Alternatively, if the machine is capable of varying rates along a boom or from unit to unit on a planter, it would be possible to be even more accurate.

The use of maps as a basis for control of prescription farming has several drawbacks. Preparation of an accurate map may be time-consuming and expensive. Manual sampling on a grid will provide information that can be utilized by a computer but the resolution is limited by the grid-point spacing. Maps for some soil properties such as organic matter and yield potential might be prepared from aerial or satellite pictures. These often have less resolution than needed and are dependent on appropriate weather and soil conditions before a suitable map can be generated. Generally, the resolution of maps is limited by the apparatus and method by which the data are collected and by the resolution with which the data can be stored. Mapping often results in having a step function as a control output because of these factors.

Maps are good for collecting data for variables which do not fluctuate from season to season. Variables such as organic matter, soil drainage, and yield potential change slowly, if at all, barring major erosion events. Soil fertility with regard to particular nutrients such as nitrogen, phosphorus, and
potassium, may change from year to year and, therefore may be more expensive to map with a high degree of resolution.

One of the major drawbacks encountered thus far in using maps to apply inputs on a prescription basis is the need to know, with substantial accuracy, the location of the equipment in the field. This has been neither easy nor inexpensive to this point and has substantially limited the development of affordable variable rate equipment. Several methods including dead reckoning, microwaves, satellite signals, triangulation, lasers and reflected light have been tried with varying degrees of success. Currently, tradeoffs exist between resolution, cost, and ease of use for these methods. Global Positioning Systems which use satellite signals supplemented by a ground-based reference point seem to offer the best solution in the long run.

Real-time soil property sensors show great potential for serving as the basis for prescription farming. Although only two on-the-go sensors have been reported to date (Farm Journal, 1989; Shonk and Gaultney, 1988), researchers have been developing the basis for other sensors. The most promising feature of real-time sensors is their ability to control prescription farming equipment without the need for extensive data storage and retrieval systems. They can also work independent of knowledge of the location of the machine in the field. This makes a real-time sensor extremely valuable because of its ability to interface with current variable rate systems which respond to an input such as ground speed. Since little, if any, data storage and retrieval is necessary with a real-time sensor, it can provide an analog output signal which allows machine output to change on a continuum rather than as a step function. This more closely matches the variation which occurs in a field.

Real-time sensing has some potential drawbacks. Although a real time sensor may be the best and fastest way to collect data for field mapping, it does not provide any good way to "plan ahead" on the go. In other words, it does not allow a control system to anticipate upcoming changes and to begin adjusting to compensate. A real-time sensor requires that the response time of the sensor and the control system be fairly rapid. Something on the order of two seconds or less is reasonable for agricultural chemical application systems. It is, of course, possible to mount a sensor well ahead of the machine and therefore allow for more computational time. There is a limit, however, to how practical that approach is. A bulk fertilizer spreader truck may operate at field speeds of 25 miles per hour. This means that 37 feet will have passed beneath the truck if the lag time of the system is one second.

**Precision and Accuracy**

Any method which a prescription farming system uses to store knowledge or control chemical application or seeding rate on-the-go must be precise and accurate to an appropriate degree. The more precise one wishes to be, the higher will be the cost and complexity of the system. As an example, consider the three maps in Figure I. All three maps are of the same field and were plotted using data generated by a soil organic matter sensor developed at Purdue University. The top map uses four gray levels to depict the range of organic matter in the field. The center map uses eight gray levels to distinguish the same range of organic matter content. Finally, the bottom map divides the field into
sixteen gray levels. In the top map, each gray level represents a range of approximately one percent organic matter. This results in an average error of approximately one-fourth of one percent organic matter assuming that there is a random distribution of points across the range. Table I indicates some pertinent figures for the three maps. These values assume perfect sensor accuracy, which is not attainable using a sensor that is economically feasible. As shown in the table, with just three levels of precision, a ten-fold range in the magnitude of error results. This means that a level of precision will need to be chosen which reflects the need for accuracy. The map which uses four gray levels might be acceptable for use with a fertilizer spreader where an occasional application error of 25% would not drastically cut yields on either end of the spectrum. On the other hand, application of some herbicides with that level of error could easily result in reduced yields due to either crop injury or weed pressure. In addition to the physiological effects, the economic impact of improper application must be considered.

Summary and Conclusions

Prescription farming will benefit greatly from the development of real-time soil property sensors. Ideally, these sensors will be used on-the-go to control application rates of herbicides, fertilizer, and other soil amendments as well as seeding rates. Sensors will also prove valuable in collecting data for use in field mapping. These data can be combined with other layers of data in geographic information systems to facilitate long-term planning and analyses. The data collected by these sensors could also be used to control application rates of materials providing the position of the equipment is known in a field.

Long-term benefits of prescription farming will be both economic and environmental in nature. The ability to place production inputs precisely where they are needed will lower the unit cost of production. In many cases the total cost of production will drop. Even if production costs don't drop, a higher yield will result because the inputs are more efficiently distributed. Environmentally, a reduction in total inputs will decrease the non-point sources of pollution attributable to agriculture. Even if total inputs are not reduced in all cases, the more appropriate placement of inputs will reduce localized over-application.

The challenge for universities and industry alike will be to develop sensors that are effective and reliable. Prescription farming has potential to improve the efficiency of crop production in both developed and developing countries. It will help to reduce the adverse environmental impact of farming in developed countries and will help spare developing countries the problems associated with misapplication of chemicals.

Bibliography


Table 1. Error as a function of precision

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<th>% Organic Matter</th>
<th>Average Error</th>
<th>Maximum Error</th>
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<td>As a % of 5% OM</td>
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Figure 1: Mapping precision using grey levels