Site-Specific Crop Management - A System Approach.

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ABSTRACT.

Today, site-specific crop management (SSCM) is a reality. But most components or equipment for SSCM are not integrated in a common system. A system approach is used to integrate these components and develop on this basis a yield map expert system and a comprehensive decision support system for SSCM. An example of the structure of an integrated system and some needed equipment are given.

INTRODUCTION.

Site-specific crop management (SSCM) refers to a rapidly developing agricultural system that promotes variable agricultural management practices within a field according to site conditions. This is a new multidisciplinary concept based on a systems approach to problem solving.

A proposed definition of SSCM is: an information and technology based agricultural management system to identify, analyze and manage site soil spatial and temporal variability within fields for optimum profitability, sustainability, and protection of the environment (Robert et al, 1995.).

Scientists from universities, research institutions, private and public sectors research groups are working in many aspects of SSCM: yield monitoring and mapping; soil resource variability; managing variability; engineering technology; profitability; environment; and technology transfer.

Some farm equipment necessary for SSCM has been developed. Examples are: variable rate seed planters; pesticide and fertilizer applicators; irrigation systems; yield monitors; and mapping software packages. Other equipment for SSCM is in various stages of development: automated soil samplers (McGrath and Skotnikov, 1996), work station for soil analysis (McGrath and Skotnikov, 1996), applicators and tenders with variable size compartments (Skotnikov and McGrath, 1995), residue monitors (Skotnikov and McGrath, 1994), and cultivators.

Most of this equipment has not been combined into a comprehensive farm system. Typically, farm implements have their own “smart box” processor or “multifunction computer” with a dedicated software package. Computer programs for tillage, seed planting, and applying chemical and fertilizer, are still in various stages of development and usually accomplished by different companies. Presently, the scientific base for the development of efficient computer programs is not elaborated and common procedures for collecting the initial information and its processing is not existent. There is a number of software-based expert systems, or decision support systems (DSS), for conventional agriculture and natural resource management (Yakowitz et al, 1993). All these systems address a specific problem or specific parameter rather than the whole agricultural system. Therefore, farmers find them expensive and difficult to use (Degnan, 1996).

Our goal is to develop a system approach integrating machinery, software, and a comprehensive agricultural management DSS, making them more relevant, useful and affordable.

DISCUSSION.

Integrated equipment and software system.

The analysis of the existing status of SSCM suggests the following preliminary remarks:

- there is a need for a specialized agricultural computer with external I/0 board and with a set of sensors and relay interface;
- it is necessary to develop an integrated DSS including modules for data base creation; mapping; geostatistical, statistical and economical analyses; soil sampling; seed planting; fertilizer and chemical application; and yield map interpretation.

A configuration or structure of an integrated system for SSCM is presented in Fig. 1.

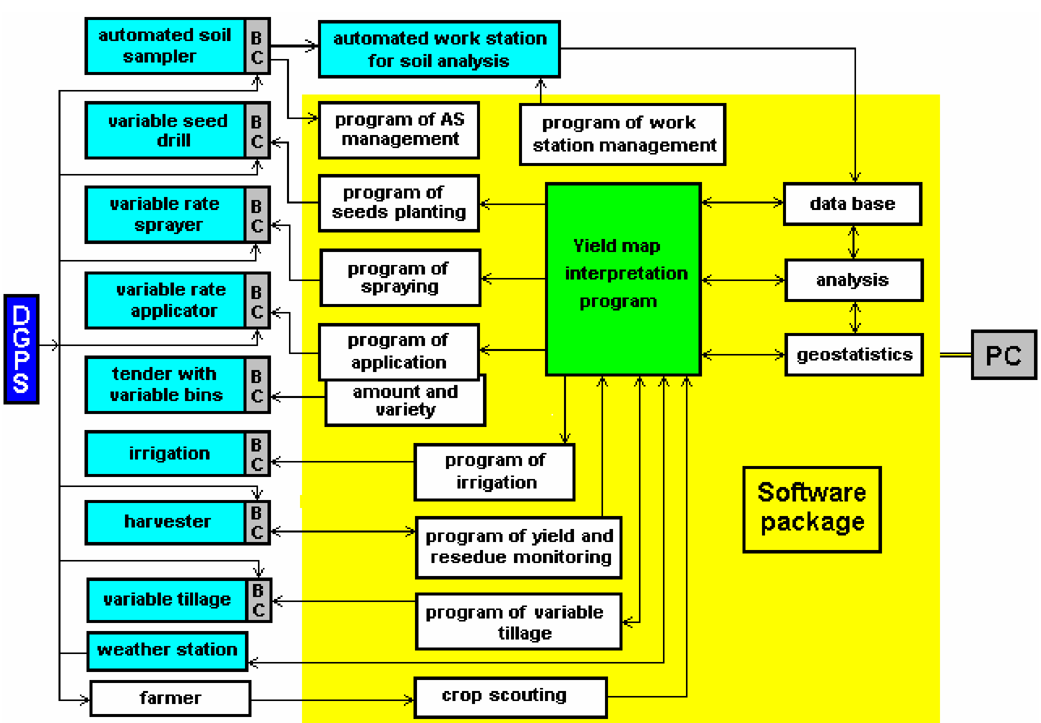

Fig. 1. The integrated structure for a SSCM equipment and software system.

All equipment listed in Fig. 1 require an automated system. Any automated system consists of sensors, data acquisition board, processor or "smart box", positioning system (GPS), relay interface and actuators. A portable rugged computer with I/O board (BC on Fig. 1), a set of sensors, and relay interface could eliminate the need for different systems. The same computer would be used for all farm equipment and would eliminate the need for specialized processors. Sensors and electric valves already installed on the equipment would be used. For example, to activate the automated system on a seed drill, the multifunction computer will be transferred from a sprayer or harvester, the I/0 board will be connected with corresponding sensors, and the relay interface with electric valves. The software of sensors recognition and seed planting management will be inputted using a diskette or PC card. The use of the multi-function computer would significantly reduce the cost of equipment involved in SSCM, simplify the upgrading of automated systems, and improve their compatibility. It could also help to collect, store and process data for further management.

In addition to the multifunction computer, some farm equipment needs to be developed or modify to complement the system approach:

- automated soil sampler and work station for soil samples analysis. Such equipment will significantly reduce the cost of soil sampling and analysis, facilitate the development of the soil geographic data base, and develop a strategy for soil sampling based on previous data (McGrath and Skotnikov, 1996).
- equipment for variable rate of fertilizer application (VRA) and tenders have a significant disadvantage - a constant size of compartments or bins for applying components. This reduces the productivity and increases the cost of operation significantly. When one of the compartments is empty, the whole unit has to stop for a refill. To improve the performance and productivity of equipment for applying fertilizers it is necessary to have changeable size of compartments on VRA and supplying tender. A possible technical solution is presented in Skotnikov and McGrath, 1995. The design is also suitable for seed drills.
- yield monitor systems do not measure the amount of residue and the transport delay of threshed grain is considered constant. But the transport delay varies due to variable grain moisture, ratio of straw and grain, slope of terrain, combine adjustments, and harvester load (kg/sec). The straw-grain ratio depends on the cutting height and width. The width may vary due to driving inaccuracy, adding an additional error. All these factors may give an error in yield estimation for a particular area up to 35 %. Residue monitoring should aid develop a better model of soil moisture and nutrients cycling. Some technical solutions for improving yield and residue monitoring are suggested in Skotnikov and McGrath, 1994.

Another essential need of SSCM is an integrated DSS. It must be a reliable, self teaching, easy-to-use system combined with expert assessments and statistical models. It is practically impossible to develop an optimum agricultural management system based on a few operations or parameters. The whole system of crop production and many related factors must be considered.

Our hypothesis is that the knowledge of initial soil spatial conditions of the field, crop management practices, work quality of equipment, weather during the growing season, and the final crop yield, will explain reductions in yield and give the elements to optimize them in the future. A statistical model of yield crop dependencies on different parameters and programs for input applications can be developed.

Crop yield will be the main criterion for the comparison of different crop growth technologies, the selection of managerial decisions, and the development of programs for input application. Maximum profit will be the main managerial criteria but potential environmental impact will be a limiting factor in the development of programs for fertilizer and chemical applications.

The base unit will be a set of software developed for the farm-based computer electronically linked to a WEB site with a common data base for the SSCM decisions support system. The software package should include modules for data base creation; mapping; geostatistical, statistical and economic analyses; soil sampling; seed planting; fertilizer and chemical applications; irrigation; and yield map interpretation. We will only consider the development of a yield map interpretation expert system.

Development of a yield map expert system.

The first step is to create a data base connected to a GIS and choose parameters which influence yield. The expert system output will be more accurate and precise when a greater number of parameters is available. All parameters must be referenced to a field map.

The initial set of parameters deals with field characteristics (Fig. 2).

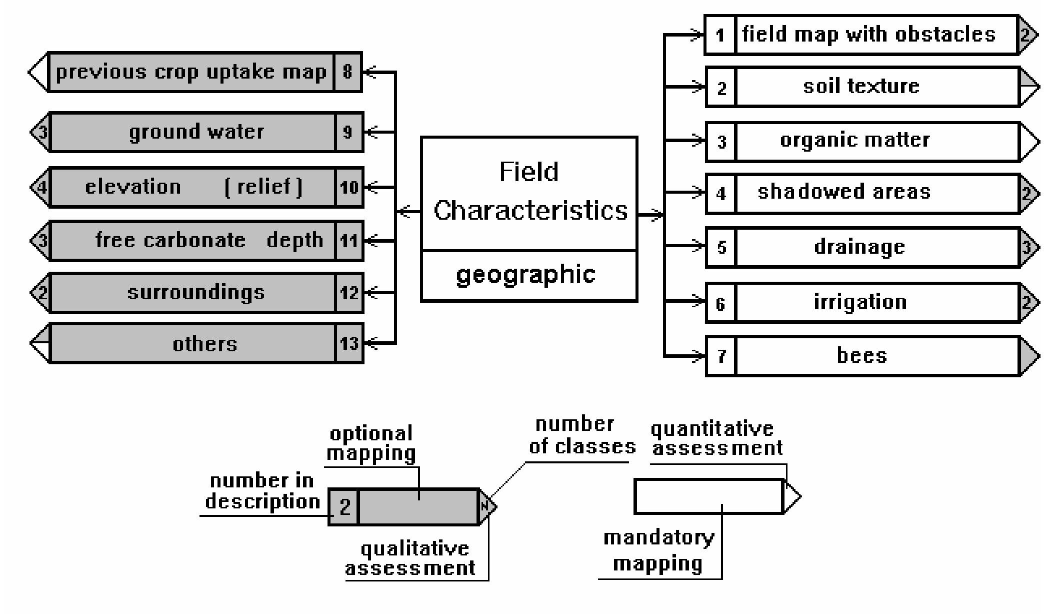

Fig. 2. Field characteristics

Characteristics involved in the analysis consist of two groups: mandatory (white) and optional (gray). Some of them are quantitatively assessed (white triangle), while other are qualitative (gray triangle). The qualitative assessment has several differentiating classes for a particular parameter. For example, for two classes (irrigation) it can be yes or no; for three (carbonates) - low, medium, high; and for four (relief) - shoulder, backslope, footslope, and toeslope. For some crops, alfalfa for seed production for example, the presence of bees is important. In this case, it is necessary to include this information in the data base.

The second set of parameters is soil analysis (Fig. 3). This set of data has mandatory and optional geographic parameters.

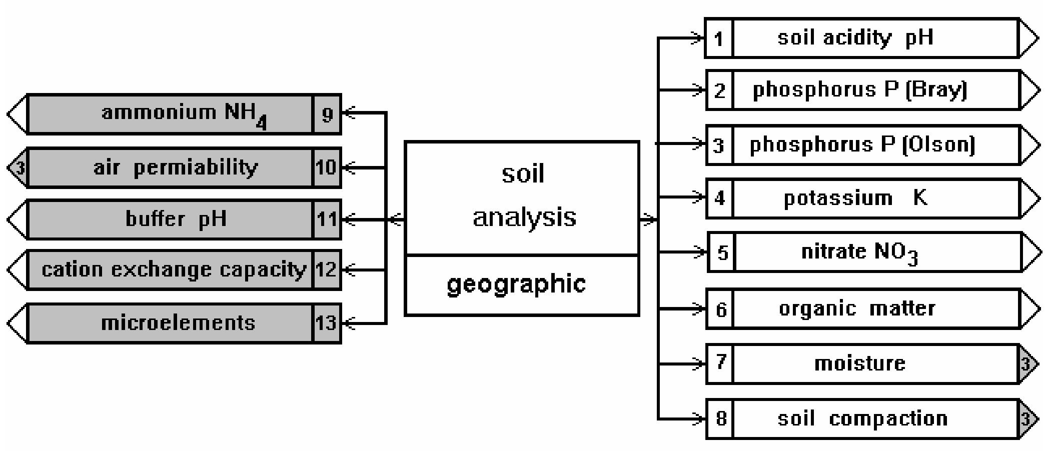

Fig. 3. Soil analysis

The next set of parameters relates to a field management (Fig. 4).

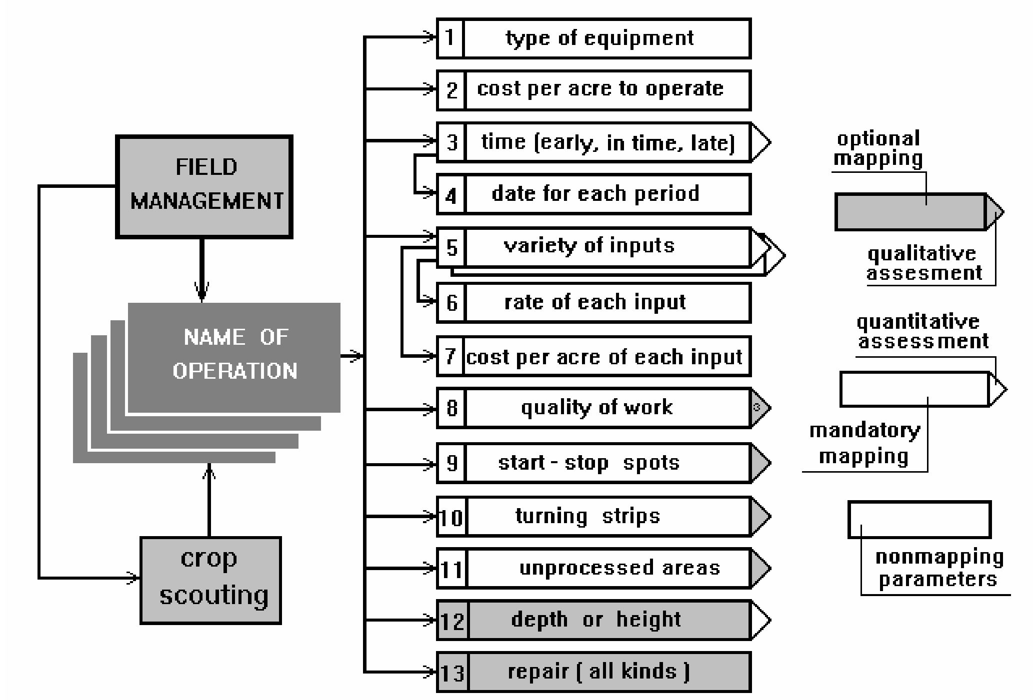

Fig. 4. Field management.

It contains information about all operations to produce a crop and results of crop scouting.

First, the type of operation is specify. Then, a corresponding time period is selected: “early”, “in time”, and “late”. A date for that period is required. Next, the input for every operation is defined. For example, for planting, it is: crop variety (or varieties), type, and date; for chemical application it is: type of chemical, equipment, and date; and for tillage: type of tillage, depth, and date.
Start and stop events and turning strips are indicated. The quality of all applications in these areas is usually lower due to overdose or underdose of materials. Obstacles are indicated because these areas are poorly processed and will be excluded from the yield map analysis. Otherwise, they could be analyzed as potential zones for yield increase. All locations of equipment malfunction are recorded. They are important to explain some very contrasting yield variability.

During the entire growing season, weather data (Fig. 5) such as daily temperature, growing

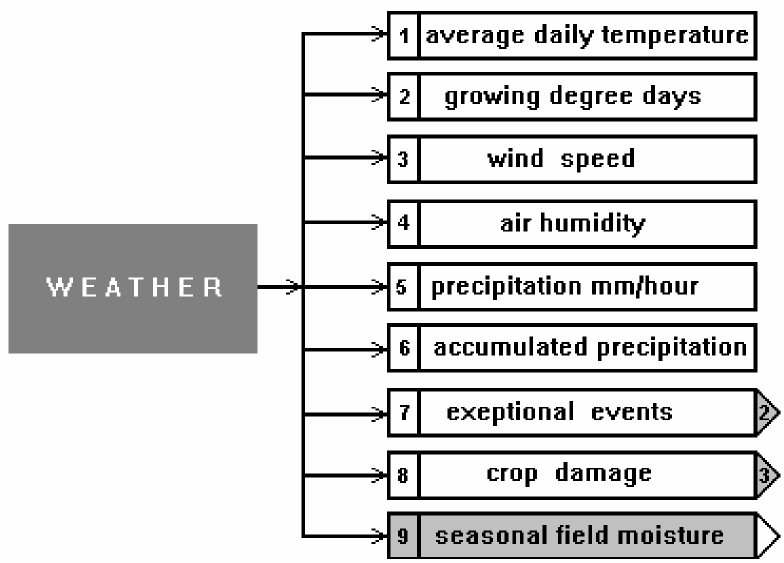

Fig. 5. Weather monitoring.

degree days, precipitation, wind speed, and exceptional events should be recorded. Weather data will help explain the influence of temperature and precipitation during different growing periods, and help develop soil moisture models.

Special field characteristics or events such as wash outs, standing water spots, and chemical spills need to be recorded.

The set of parameters for yield monitoring is shown in Figure 6.

Before harvest, the field should be surveyed for apparent causes of yield reduction. After harvest a yield map is created and saved in the farm GIS.

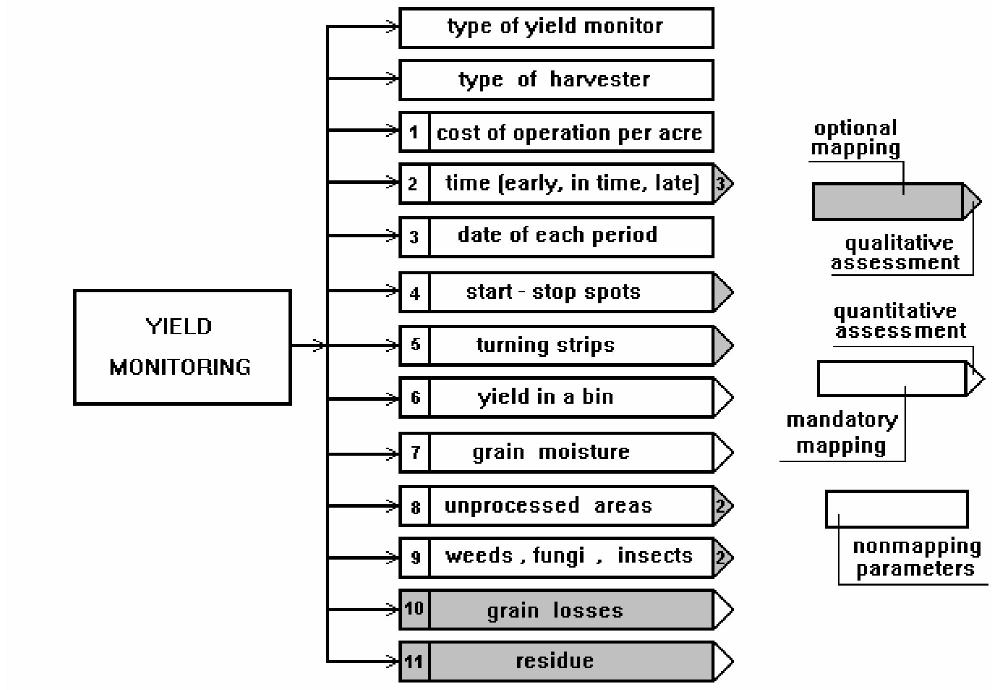

Fig. 6. Yield monitoring.

Yield decision support system.

The first step of the analysis excludes all areas of possible yield reductions due to exceptional factors (improper equipment work, unprocessed strips, yield damage, etc.). The next step analyzes the remaining field grids of the yield map and selects grids with the highest yield to create a table in which a column represents a grouping of grids with a corresponding set of parameters.

Each selected grid is analyzed through the parameter layers. If a grid area is attended by more than 50% under a certain parameter (color), the whole grid area is defined by this class (color). Then, grids with corresponding classes of parameters are summarized in a new table (Table 1) consisting of several groups (columns) of parameters that support the highest yield.

Table 1.

Parameter	Yield 0.8-1.0 kg/m^2			
Percentage, %	15	45	20	20
Organic matter, %	1.5-2	2.1-2.5	2.6-3.0	3.1-3.5
pH	5.5	6.5	7	7.5
Soil phosphorus, mg/kg	70-100	101-130	131-160	161-200
Soil potassium, mg/kg	25	15	15	5
....	....	....	....	....
Time of planting	early	in time	in time	late
Quality of planting	good	good	good	excellent
N applied, g/m^2	50	100	50	50
....	......	......	......	....
Total expenditure, $/acre	1100	1115	1008	1005

Table 1. The distribution table of parameters influencing the crop yield.

The row “Percentage” of the table shows the percentage of highest yield grids with a certain set of parameter classes.

The flow chart of a yield map interpretation module is presented in Fig. 7.

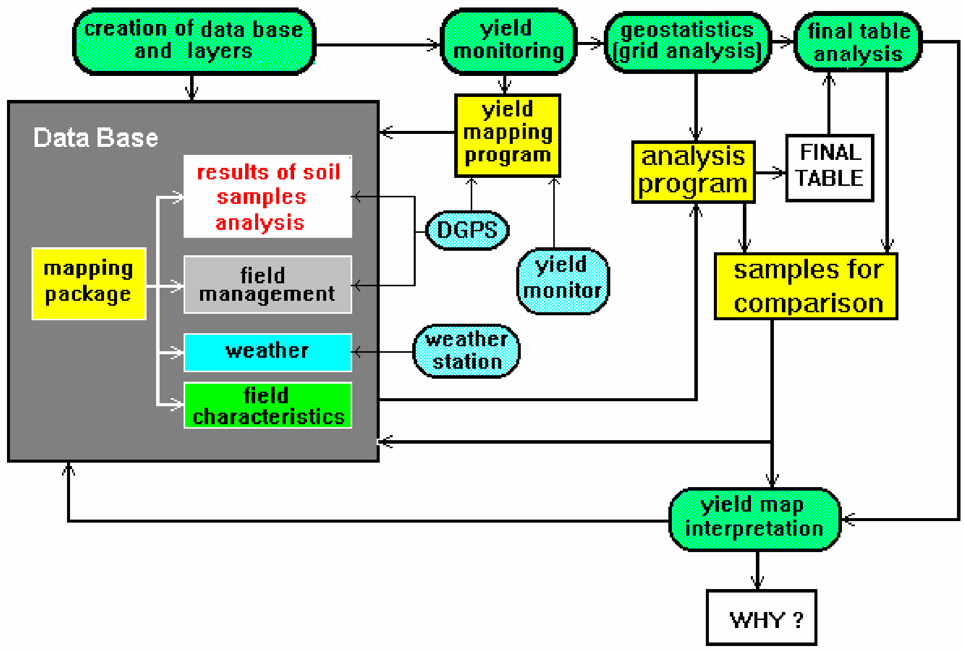

Fig. 7. Flow chart of a yield map interpretation module

The distribution table is analyzed to determine the validity and significance of each row and column. The analysis of the distribution table is a main source for the creation of rules. For example, if the same amount of phosphorus is presented in several yield classes it probably means that phosphorus has no influence on the yield of this particular crop and this parameter can be removed from the table. Another example is that a low yield class with similar or higher level of parameters than for higher yield class may be suspect. There can be several reasons, such as errors of data acquisition (monitor calibration, DGPS, sensors), wrong seed variety, or any other causes (like washouts or standing water spots, birds destroyed seeds, chemical spills, and hoses of seed drill plugged) which were not noted. The user of the expert system should make all necessary explanation of events. After the validation of accumulated data, the final table is prepared and saved in a data base.

A similar procedure is followed for all yield classes.

The groups of parameters (columns) from the final table are compared with the other classes of yields. It can be a direct comparison of each column of lower yield class with every column of higher yield class or comparison according to a key parameter such as pH, soil fertility, microclimate conditions, elevation, or rate of applied fertilizers.

The program indicates causes of yield reduction (WHY block).

By comparing final tables of highest yields from different fields, it is possible to find management practices for increasing yields in other parts of fields. Economical assessments (the total sum of costs per acre for every technological operation connected with chosen yield and related parameters) are incorporated in the final tables. In the final table for highest yield, all present combinations are expected to provide the same average yield. The line "per acre expenditure" for each set of parameters indicates the most economical way to reach this yield. After accumulating sufficient information (sets of different parameters providing certain yields), it will be possible to develop a statistical model of yield and simulate different management techniques. All decisions will be based on real practice. Here are some examples.

Example 1. Previous crop, results of soil samples analyses, average weather conditions and yield goal are known. After entering this data in a computer, several sets of parameters providing similar yields, but different cost per acre of production, can be received. These sets can differ by a field management practices (rate of fertilizers applied, time and methods of their applications, tillage, e.g.). Considering the sets of parameters presented, one may choose the most suitable set of practices for a farm.

Example 2. Certain management decisions and possible resulting yields are considered. Again, the previous crop, results of soil samples analyses, average weather conditions, and proposed management decision are known. After entering these data in the computer, predicted yield (if this took place in a previous practice) can be received. In this simulation it is possible to obtain the resulting yields when changing fertilizer management.

On this basis, it will be also possible to develop programs for soil sampling, irrigation, seed planting, and chemical and fertilizer applications. Alternatively, it will possible to select among various management systems, the crop, desired yield, and level of expenses.

CONCLUSIONS

In order to develop a system approach for SSCM, the following components are needed:

- specialized agricultural computers with external I/0 board and set of sensors and relay interfaces;
- automated soil samplers and work stations for soil sample analysis;
- soil/site-specific agronomics and SSCM equipment for all agricultural practices;
- an integrated decision support system including modules for data base creation; mapping; geostatistical, statistical and economical analyses; soil sampling; seed planting; fertilizer and chemical application; and yield map interpretation;
- new agriservices;
- education and training of specialists for SSCM.

Fig. 1 shows that SSCM is a very complicated agricultural system. It requires new skills and new agricultural services. The more developed parts of the entire system are DGPS and yield monitoring. The availability of a commercial automated soil sampler and work station for soil analysis, in conjunction with SSCM equipment and software packages can be a foundation for creation of new agricultural services.

Already many farmers may have on their farm some SSCM equipment: seed drill, sprayer and spreader, cultivator, irrigator, harvester, weather station and DGPS. Now they need a DSS to help them optimize SSCM. A possible scenario of a farm operation, using a decision support system is the following: the farmer receives recommendations for soil sampling. He enters the soil analysis results, weather monitoring data, scouting data, and equipment data in the farm GIS. He chooses the most suitable management. Then he develops SSCM programs possibly in association with a qualified agribusiness consultant for applying chemicals, fertilizers, seed planting, irrigation, and other practices.

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