

DEALING WITH VARIATION IN SPACE AND TIME: THE CHALLENGE FOR A FORWARD-LOOKING APPROACH TO PRECISION AGRICULTURE

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ABSTRACT

Implementation of precision agriculture (PA) practices anywhere in the world has several dimensions. First, strategic decisions have to be made, followed by tactical and operational decisions, each of them reflecting local conditions and opportunities. Two case studies will be presented in which PA practices are used under operational conditions to the full satisfaction of farmers involved. This introductory paper serves to introduce five papers of our research group. One case study is on a modern arable farm in the Netherlands found on prime agricultural land and the other on a banana farm (finca) in Costa Rica. Real-time forward-looking simulation modeling of crop growth is applied in the Netherlands to fine-tune nitrogen applications in space and time, using management units based on soil data. Remote sensing data are used to improve model calculations, while meta-models are proposed to make modeling results more accessible. Instead of using specific management for each management unit, also on-the-go management has been explored for liming. In Costa Rica soil maps are used to stratify measured yield data, allowing distinction of poorly producing areas within a given area occupied by a given soil type. This allows focussed research on factors inhibiting production. We conclude that PA is ready to be applied as it presents the opportunity to make production processes more efficient while reducing unfavorable environmental side effects of production to acceptable levels.

Keywords: precision agriculture, strategic-tactical-operational decisions, case studies, management track.

INTRODUCTION

This paper serves as a general introduction to five papers in this session presenting results of studies on precision agriculture, conducted by researchers in the laboratory of Soil Science and Geology of Wageningen University. The objective is to put these papers into a general context, illustrate the underlying concepts and discuss possible future developments.

All studies in the Netherlands were made on a modern farm on prime agricultural land and field work as well as all ensuing studies were made in close consultation with the owners of the farm, the two brothers van Bergeijk. Research on management of natural resources in post-modern society should be participatory in character, involving stakeholders. Even though this principle is widely accepted on paper, there are still considerable problems when realizing this lofty goal. Too many times, researchers still follow their own intuition when planning and executing research and they are still genuinely surprised when they find out in the end that their work is not being used. Still, the problem is more complicated than appears at first sight. Researchers may find that they are not taken seriously when they bend over backwards as they listen to stakeholders describing their problems, while not making clear what they have to offer. The key-word here is: 'trust', which is based on the conviction of the researcher that he can do a much better job when he listens seriously to stakeholders, while the latter have the feeling that they are taken seriously and that their concerns are expressed in the research being done even when it means that some of their ideas turn out to be irrelevant. Building trust takes time. It took at least a year or more before we reached this stage in our work at the van Bergeijk farm and we are most grateful for the way our cooperation has now found its form. The same can be said about the second study on precision agriculture that was made on the Rebusca banana farm in Costa Rica where our partner was Mr Orlich, who had a clear vision about his management problems and also proved to be an excellent partner in research. We foresee generation of some scientific papers with our stakeholders as co-authors, illustrating their essential role in formulating and executing research.

Precision agriculture implies more than using a yield-monitoring harvester equipped with GPS. It represents a new way of farming based on the introduction of information and communication technology (ICT) (*e.g.*, National Research Council, 1997). There is a clear parallel here with many other fields of research or activities in society, which have been and still are fundamentally transformed by the introduction of ICT. Application of ICT allows farmers for the first time to guide their management on the basis of up-to-date information about crop and soil conditions day by day during the growing season allowing fine-tuning of management measures to the extent that their objectives are met in a more efficient manner than when using conventional procedures. We are convinced that within a decade, even in Europe, techniques of precision agriculture will have found their undisputed place within agriculture. Delays in implementation at this time, due to poor economic conditions for farming, are temporary and should encourage researchers to vigorously continue to develop comprehensive and operational systems. The methodology and principals involved are universal in character. We therefore not only discuss Dutch but also Costa Rican conditions.

In this introductory paper we will first discuss the type of decisions that farmers have to make before they start with precision agriculture. These decisions are strategic, tactical and operational in character (*e.g.*, Bouma *et al.*, 1999a). Next, operational practices will be discussed on the basis of management tracks as suggested by Bouma (1997). The five following papers will be discussed in this particular context, focussing on work on the Van Bergeijk farm in the Netherlands and the Rebusca Finca (farm) in Costa Rica.

TYPES OF MANAGEMENT DECISIONS

Strategic Decisions

A decision to incorporate precision-agricultural practices into farm management involves quite a few considerations by the farmer. It is a decision that has lasting implications and must therefore be considered a strategic decision with an impact of decades to come. Research should provide systematic information to farmers to allow rational decision making, while, of course, any decision made in the end is his own decision. A number of considerations have to be taken into account:

1. Is it economically attractive? Costs involved have to be balanced against additional income. Costs relate to making a soil data-base and acquire specific equipment. Is this available through local contractors or not? What are the savings, when comparing current management practices (which vary widely among different farmers) with precision management? Is it likely that prices of crops will be higher when management has been fine-tuned and is well documented or will it make no difference? Obviously, answers to these questions will strongly depend on local conditions. Some farmers have a greater desire to be a pioneer than others! The Costa Rica case (Stoorvogel and Orlich, 2000) present a special strategic aspect: by using this approach planting of new banana trees can be made much more effective when it is done in areas where it is really needed. This is economically quite attractive.
2. Is it helpful in meeting ever increasing environmental demands by environmental laws? Clearly, this question will be answered differently in different countries as environmental laws vary considerably. The hidden feature of precision agricultural is the win-win situation of lower costs, higher and better quality yields and lower emissions to the environment. Is this realistic in the local context?
3. Are soil patterns on the farm heterogeneous, even in single fields? If so, site specific management is more justified than when soil patterns are quite homogeneous. There is a limit, though. Uniform management is again attractive in highly heterogeneous circumstances where it is impossible to defined relatively homogeneous sub-areas within a field. In addition, the time element becomes increasingly important. Management at the right time is under many conditions as important or more important than management at the right place (Van Alphen, 2000).
4. Does working with high-tech technology appeal to the farmer or is it experienced as an alien concept? This is an irrational but very important point. The input of farmers in the development of systems for precision agriculture is

essentials (Van Alphen, 2000; Stoorvogel and Orlich, 2000): realistic systems can only materialize through a joint learning process. Farmers should be willing to spend time on this: data management and interpretation can only be achieved when farmers are really interested. Besides, technology is by many associated with modern intensive production-agriculture which is, in turn, associated with environmental misery and poor product quality. I, however, believe in a high-tech ecological or organic agriculture because this way the demands from mother earth can be best met. Different ideological approaches to agriculture, such as the organic one, the biological-dynamic one and the high-tech industrial approach, can all be served very well by precision practices (e.g., Droogers and Bouma, 1997) studying nitrogen dynamics at the oldest biodynamic farm in the Netherlands). Also, mixed farming systems, including grazing by cows, can benefit from precision practices (e.g., Hack ten Broeke and van der Putten, 1997).

Research has a clear job ahead in providing objective information to allow rational choices to be made. This is so far rather neglected as emphasis in studies on precision agriculture is usually put on operational aspects.

Tactical Decisions

Once the decision has been made to start with precision agriculture, some medium term decisions have to be made for periods of, say, five years. Which crop rotations to choose? Which machines are bought and which ones are rented? This decision also depends (in future) on the method applied in dealing with spatial variability: "on-the-go" precision management using proximal sensing or non-continuous precision management with pre-defined management units. At this point in time, the use of proximal sensing is not yet possible with the possible exception of using electromagnetic induction (EMI) (Walvoort *et al.*, 2000) but this can and probably will change in future, as proximal sensing is very attractive in principle. Other tactical decisions relate to: which types of soil tillage are foreseen, how does this fit within the practices for precision agriculture and which equipment will be needed? How is the drainage situation? Should this be improved by tile drainage or other means? Other issues may come up as well before operational procedures can come into effect.

Operational Decisions

In discussing operational management decisions, we use the management track (Bouma, 1997) which defines a yearly calendar with the times when certain management practices are recommended (Figure 1 for the Dutch case study). These times are quite different in different years. Operational decisions are approached in a forward-looking manner because this is the way the farmer faces the future. Many studies on precision agriculture report on studies that were done in past growing seasons. Though valuable, they do not address the real questions by a farmer who is faced with a growing season of unknown characteristics. We will discuss and summarize steps during the growing season in the following sections, making reference to the five papers in this session.

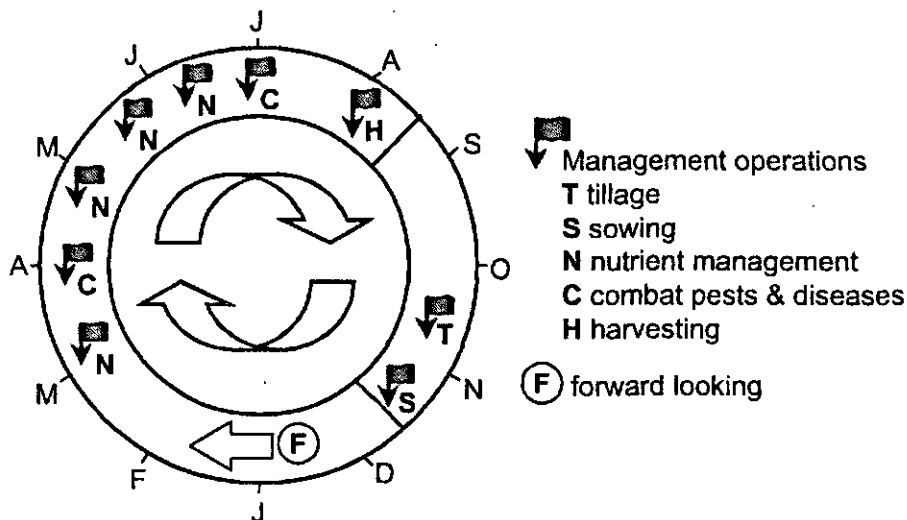


Fig. 1. Example of a management track for winter wheat.

BASIC ELEMENTS OF OPERATIONAL MANAGEMENT

Management Units

A basic question to be raised here relates to the minimum size of the spatial units being considered in precision agriculture. This minimum size should be a function of the technology being used. We do not aim for units that are only a few square meters in size, even though this could be defended by only considering soil variability aspects. Operational aspects will generally require larger units for management practices. Van Alphen (2000) discusses the manner in which management units are derived by simulation from the soil database in the Dutch study. Management units do not constitute a soil map, as they have a functional character, which is defined in quantitative terms by simulation modeling balancing production and environmental aspects. This is in line with one of the major research lines in our Department, trying to “translate” the soil map, based on pedogenic principles, into a functional map (Wosten *et al.*, 1985; Breeuwsma *et al.*, 1986). The management units are the basis for precision management: calculations for the units are based on calculations for representative profiles within the units. The approach in the Costa Rica study is different (Stoorvogel and Orlich, 2000). Here, units from the soil map are used to stratify crop production figures in order to single out areas where production lags behind as compared to similar soil units elsewhere on the farm. Next, reasons for the production lag are explored and management is modified and improved accordingly.

Elsewhere, management units are derived by comparing yield patterns as derived by on-the-go harvesting over a number of years. Thus, significant differences within fields are likely to show up but the reasons for differences observed may vary considerably among different years and may have little to do with soil or crop conditions open to management, while important environmental

effects such as leaching of nitrate or biocides are not shown. Still, measured yield patterns should be compared with patterns defined by management units to improve definition of the latter.

Simulation Modeling

Simulation modeling of crop growth and the associated fluxes of nitrates play a key role in the Dutch study (Van Alphen, 2000). By making daily simulations using real-time weather data, expected moments of N-stress can be predicted before adverse effects occur. Alternative procedures are difficult to define. Of the possible proximal sensing techniques, only crops can crop-canopy reflection measurements could serve a function, but they will show deficiencies when they occur and that is too late. Moreover, complicated labor-intensive fieldwork is needed here and this does not fit in an operational procedure. Much more attractive is the procedure described here by Booltink and Epinat (2000) where remote sensing data is used to improve model simulations by occasional input of crop coefficients. Booltink *et al.* (2000) add a second approach to modeling in defining a meta-model which summarizes results of several years of simulation for different management units and for fields. Such results are easier to use than real-time simulations.

Conditions in Costa Rica are different because simulation of banana growth is not yet possible. Yields were therefore directly measured and associated with certain soil units, allowing definition of areas where growth was unusually low. As is clearly pointed out by Stoorvogel and Orlich (2000), growth patterns of a banana tree are quite different from patterns of a wheat crop. This calls for different approaches as is indicated in the papers.

FOLLOWING THE MANAGEMENT TRACK

Tillage

Tillage is an important part of soil management in the Netherlands as it has a major effect on soil structure, which, in turn, determines fluxes and crop uptake of water and nutrients. Of course, moisture retention and hydraulic conductivity data express these processes but within a given soil, soil structure can differ considerably due to different types of tillage and soil traffic and this is not always properly expressed by hydraulic data from standard tables or equations, as used by Van Alphen (2000). Bouma and Droogers (1999) compared different methods for determining hydraulic characteristics in the same soil type, but for different types of management (conventional arable farming, biodynamic farming and grassland) and they found considerable differences, certainly when soils were compacted due to tillage and traffic at wet conditions. Whether tillage practices should also be part of standard precision farming remains to be seen but soil scientists are advised to pay more attention to soil structure in a pro-active manner. For any soil, they should define optimal structures that allow adequate infiltration and retention of water and extensive, deep rooting patterns that make the soil solution completely accessible. (*e.g.*, Bouma *et al.*, 1999b). Once defined, tillage and other forms of soil management should be focussed on achieving such

soil structures and precision techniques can certainly play a role there. In the studies reported in this session, soil structure and tillage are not discussed.

Fertilization

Van Alphen (2000) shows how real-time simulation modeling can result in early identification of moments that soil supply of nitrogen will be critically low. This information is used to optimize the timing of consecutive split fertilization applications. Simulations and field measurements agreed quite well. The question as to how much N should be applied each time is an interesting one. After a standard base fertilization in spring, up to three additional split N fertilizations are applied in winter wheat. Fertilizer rates are determined through exploratory or forward-looking simulations, which calculate the amount of N fertilizer required under 'average' conditions during the remainder of the growing season. Under Dutch conditions, the N content at the end of the growing season is important because nitrate leaching mainly occurs during wintertime when there is a precipitation surplus. A maximum residual N content of approximately 40 kg N ha⁻¹ is indicated as a threshold value (Verhagen and Bouma, 1997) and in estimating the last N application, this content should be taken into account, as Van Alphen has done. A meta-model was developed by Booltink *et al.* (2000) to summarize data obtained by simulation with the objective to make simulation results more accessible. However, errors involved are still relatively high.

Fertilization in the Costa Rica study was considered for the separate management units and expert knowledge is needed to obtain dose-effect relations. Some experiments are in progress now to derive more specific relations between fertilization rates for banana's and their growth.

Liming, as discussed by Walvoort *et al.* (2000) for the Dutch case study, can, in principle, use a proximal method because the pH value can be measured by sensors and liming rates can be adjusted accordingly. In this manner, management units do not have a function and liming can proceed on-the-go, the more so since it will be done either before or after the growing season. The prototype system he has developed has not been tested yet under field conditions.

Irrigation

No studies on irrigation were made but the work of Van Alphen (2000) clearly indicates the potential for precision irrigation, because the soil water status and the water demand of the crop are calculated by the model on a daily basis. This aspect is not only significant for many semi-arid areas in the world but also for moderate climates where precipitation deficits may occur in summer and where good water becomes more scarce, requiring increases in water-use efficiencies.

Crop protection

Use of agro-chemicals or integrated pest management techniques for crop protection are very important for our modern production systems. Biological products do not allow use of agro-chemicals and concern about pollution of

ground- and surface waters by a wide variety of biocides is widespread. Although not reported here in the studies, work is in progress to characterize these problems. Rather than perform unacceptable dose-effect field experiments, work is done for representative soils in the various management units, exposing them in column experiments to a wide range of applications of different biocides. Thus, critical thresholds for application rates can be defined taking into account travel times of biocides and the corresponding degradation. Simulation models are used to generalize results, as has been well demonstrated for Costa Rican conditions (Stoorvogel *et al.*, 1997). Work along the same lines for the Dutch study is in progress.

The application in the context of precision agriculture can consist of blacklisting application of those biocides that are likely to penetrate certain management units under prevailing flow conditions in the field and by suggesting alternative chemicals.

CONCLUSION

The technical development of operational systems for precision agriculture has reached a stage that the systems can be applied under practical conditions. Researchers, in close interaction with farmers, have a responsibility now to "package" their information in a form allowing farmers and decision-makers to make strategic decisions as to using the system. The more efficient use of natural resources, the associated documentation of leaching rates of agro-chemicals in relation to environmental regulations and claims for higher and more consistent product quality are likely to carry more weight than lower costs that could be associated with applying precision agriculture. Of particular concern is the need to de-diabolize use of technology in modern agriculture. Precision agriculture is an essential tool to develop ecologically more friendly types of agriculture and is, therefore, also an ideal tool in organic farming.

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