Development of a GIS-based management system for precision agriculture

- Perspectives to increase the efficiency of farming and enhance its environmental benefits with spatial-data handling and knowledge-engineering: concept and results from the interdisciplinary work of the joint research project pre agro in Germany -

Andreas Jarfe, Armin Werner
Zentrum für Agrarlandschafts- und Landnutzungsforschung (ZALF) e.V.,
Center for Agricultural Landscape and Land Use Research,
Department of Land Use Systems and Landscape Ecology,
Eberswalder Strasse 84, D-15374 Müncheberg, Germany, E-mail: *ajarfe@zalf.de*

ABSTRACT: In agriculture, even small-scale variations in site-quality can lead to great differences in crop yield and product quality. Today, it is technically possible to detect and take such small-scale differences into consideration for crop management and handle them with the technology of *precision agriculture*. However, yet there is a lack of general valid crop management guidelines which use site related information of fields and can easily be applied by any farmer. Such rules are now being developed in a field-based research project on different farms in Germany. The rules shall permit the farmer to optimally adjust his cropping measures to the respective sub-units (management zones) in a field. For this purpose spatial data of site characterisation and of the crop stand situation are required. In the project they are being gathered from various areas representative for arable crop production in Germany. In addition to the site characterisation also ecologically sensitive areas of the fields are defined and included in the database. This shall help to achieve more environmental compatibility when applying proper cultivation techniques. The rules are compiled as management guidelines and translated into software modules. These modules are tested with respect to their agronomic, ecological and economic efficiency under practical conditions. A first decision support system based on ArcView for calculating site specific and agronomic optimal sowing rates within fields of winter wheat is developed using if-then rules. These rules are based on information from crop experiments as well as from expert knowledge.

KEY WORDS: *precision agriculture, heterogeneous fields, site quality differences, crop production, decision support system (DSS), management guidelines, global positioning system (GPS), geographic information systems (GIS)*

Introduction and problem definition

The properties and qualities of agricultural soils and their relative position within the relief differ considerably even within small areas of arable fields. This variation of local site quality results in non-homogeneous crop stands and thereby influences the crop yields. These locally varying site properties are additionally influenced by cultivation-driven impacts such as compaction, erosion or crop management errors.

In the current agricultural practices, such site differences are not taken into consideration usually. Farmers adjust soil tillage, sowing rate, fertilisation and plant protection to the average site quality of their fields. As a result, on subparts of the fields that have high yield potentials, this potential is not exploited whereas areas of low fertility are over-fertilised.

The technical development of satellite navigation within the last few years provides a tool for regarding the variation within fields during cultivation. Under practical conditions, the Global Positioning System (GPS) which delivers location co-ordinates is coupled with geographic information systems (GIS), which deliver data and rules for decision making. The cultivation steps are transmitted as geo-referenced application maps to a computer on board of the tractor. According to the intended local management for the respective site within the field, the computer controls the cultivation equipment mainly in driving the spatial quantity of seeds, fertiliser, pesticides, or the intensity of soil tillage.

To establish the technology of precision agriculture as a common practice, there is need to develop transferable guidelines and principles for decision making in that crop management. This requires both attention to the specificity of crop production techniques and for fitting these measures into the whole crop production (i.e. crop rotation) of that field. High economic efficiency and ecological benefits are ensured nowadays only by integrated crop production techniques. Therefore, precision agriculture can significantly increase economic and also ecological efficiency of crop management.

Objectives

The project's challenge lies in identifying the geological, geographical, climatic and agronomic interactions that are driving crop yields and in applying guidelines for developing cultivation measures in heterogeneous fields. With this goal in mind, recommendations for precision agriculture will be developed under practical farming conditions. Attention is given to the concept that the individual steps such as soil tillage, establishing the crop, fertilisation and plant protection should not be done separately but in interaction. Such an approach is a prerequisite for integrated farming.

Information on site characteristics (soil, micro-clima, relief etc.), crop stands and site dependent ecological sensitivities are gathered by various methods such as direct measurements, remote sensing and simulation models. This also involves identifying suitable methods for indirect measures (´surrogates´) and thus minimising the effort currently invested in site analysis and characterisation. The resulting spatial data will be entered, administered and further processed in appropriate geographic information systems (GIS). The cultivation guidelines can then be derived on the basis of this information. These guidelines should be generally valid for the relevant crop production sites in Germany and can be implemented as open software modules into commercial products of precision agriculture.

In this respect, the following steps in research and development are necessary:

- Identification, description and delineation of the various site characteristics.
- Determination of spatially distributed crop yield potentials and ecological sensitivities.
- Developing IT-systems for systematic management of the resulting data and information.
- Development of algorithms and rules for appropriate determination of the cultivation practices according to the proper crop management principles as well as to economic and ecological criteria.
- Analysing the impact of site specific crop management onto economic variables of the farms.
- Analysing the impact of site specific crop management onto goals of environmental protection or nature conservation.
- Adopting cropping measures to integrate goals of environmental protection and nature conservation.
- Integration of the algorithms and data into generally available management systems for precision agriculture.
- Supporting the development of specific crop management equipment to serve in precision agriculture.

Structure of the research and development (R+D-)project

The above steps are accomplished in the project *pre agro* by seventeen institutions from science, industry and service companies. They work for four years on 22 subparts of the project which are of scientific, technical and practical nature. These subparts rely in an integrative way on each other. Practical experiments are an essential component of the project. Therefore from the beginning of the project, sixteen representative farms, three private contractors and a machine co-operative have been integrated in the project in order to achieve practical application of the scientific results. The selected farms represent different climatic and geographical conditions of arable crop production in German (see fig. 1). The guidelines and modules for computer assisted precision agriculture will be developed and tested on these farms.

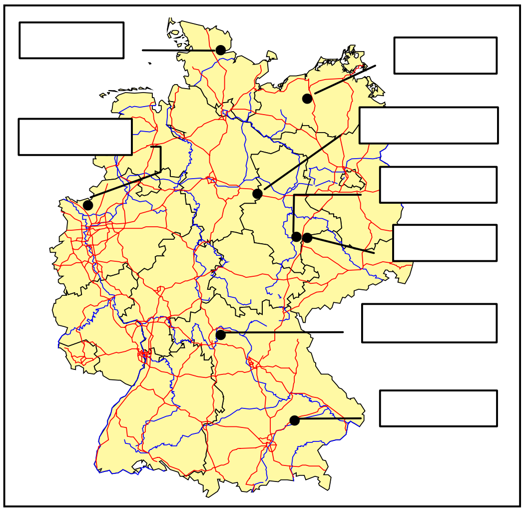


Figure 1: *Locations of the farms within Germany, that co-operate with the joint research project pre agro*

Expected results

The following results are expected at the end of the project:

- Preliminary crop management rules and algorithms are derived for site applying in specific soil cultivation, sowing, nitrogen fertilising, P-, K-fertilising, liming, use of pesticides and of plant growth regulators.
- Substantially required data for site specific crop management are defined as a minimum data set.
- Software products (modules) for integrative data analysis and for decision support in precision agriculture are developed and tested.
- The potential to enhance environmental benefits of crop production by use of precision agriculture are described and concepts to determine these effects under farming conditions are developed.
- The economic profitability of site specific crop production is analysed under different geographical locations, farm structures and management options.

First project results

Goal of the joint R+D-project *pre agro* is to compile the management principles for heterogeneous crop stands into an integrative system of site-specific crop management as the fundamental information-technology of precision agriculture. With the basic crop management plan and estimations of the yield potential by using computer models for every management unit in the field, a flexible planning procedure will take place (fig. 2). For this *pre agro* will produce at least modules for decision support systems to calculate the site specific sowing rate, nitrogen fertilisation rate and rate of growth regulators within the heterogeneous fields of small grains (especially winter wheat). When applying these decision support systems on the very specific spatial situation, the user will get an application map (fig. 2). A first decision support system for a spatially differentiated sowing is already implemented in a GIS-System.

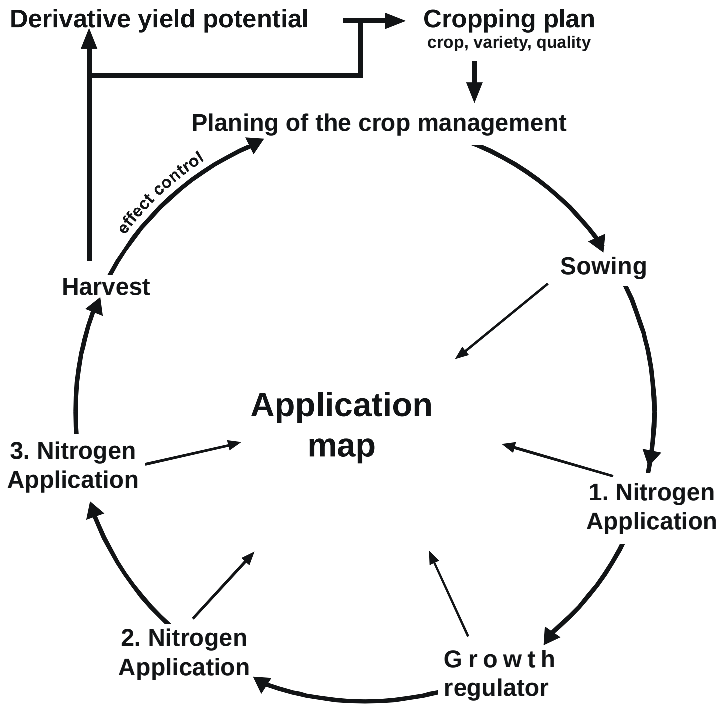


Figure 2: *General concept of crop management in the joint R+D-project pre agro*

Decision support system for spatially differentiated sowing of winter wheat

Yield is a function of crop, variety, sowing date, sowing rate, cropping practice, production objective, effects from previous crop, soil, weather, management strategy, the farmer's skill and other variables. All these parameters influence the potential yield of the crop. Therefore it was necessary to develop a management system in that all these parameters were considered. In a first version for the differentiation of the sowing rate only site related influences (soil and weather) were considered for the calculation of the potential yield. Future versions of this program will also consider relief parameters and other information. In the first version of the pre agro sowing rate calculator the application map is derived by:

1. Calculating the estimated yield potential of previously discriminated sub units in the field ('management units').
2. By estimating the attainable single ear yield (result of multiplying grain number per ear and thousand kernel weight), the number of grain bearing heads (ears) per unit area can be calculated from the potential yield.
3. The necessary number of plants at harvest time is the result of dividing the number of ears per unit area by the number of ears for each plant. This usually corresponds to the number of plants in spring per unit area ($1/m^2$).
4. The next step is to calculate the loss of plants during winter, especially the winter kill of varieties with less cold resistance. In this case the topography has a big influence to such a plant loss during winter.
5. By considering the emergence rate and the proven germination ability of the seed lot, the number of grains which have to be sown can be calculated.

This calculation method for the determination the spatially differentiated sowing rate is described in principle with the following table. For the implementation of these rules with generic software modules it was necessary to describe in a mathematical way the estimations of the single ear yield, the number of harvest-effective grain bearing heads, the number of tillers, relative plant loss due to winter-kill and emergence rate. For each value a separate function is applied.

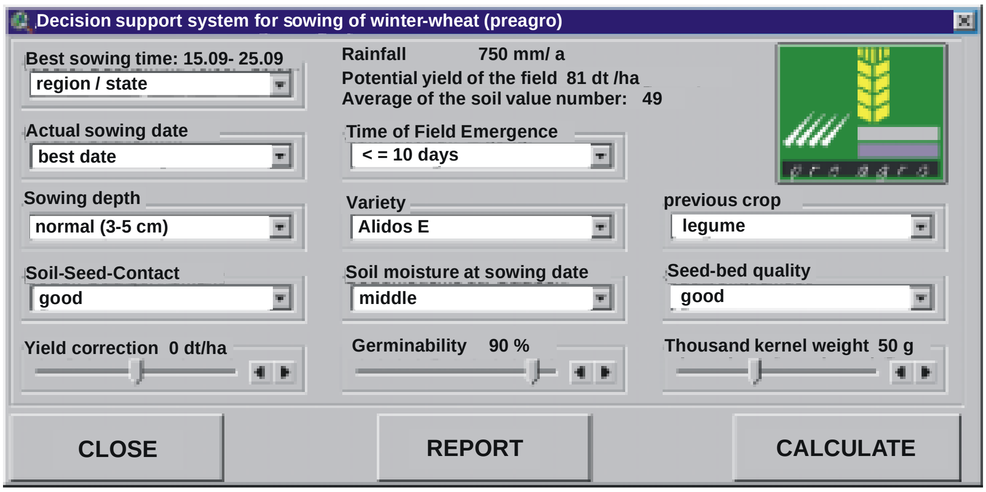
Table 1: *Example of a table-function to calculate the site-specific sowing rate (winter-barley, site in North-East Germany)*

	Index of land quality < 30				**Index of land quality 30 - 39**				**Index of land quality 40 - 45**				**Index of land quality > 45**			
Position	normal	crest	lower	slope	normal	crest	lower	slope	normal	crest	lower	slope	normal	crest	lower	Slope
estimated yield (dt/ha)	30				45/50				55/60				65/70			
Ear density (per m²)	350				475				575				650			
heads / plant	1.2				1.9				2.9				2.9			
Plant density in spring (per m²)	300				250				200				225			
loss of plants during winter (%)	10	30	30	20	10	25	25	15	10	20	25	10	10	15	25	10
plants in fall (per m²)	330	390	390	360	275	310	310	290	220	240	250	220	245	260	280	245
seedlings (per m²)	335	400	400	370	280	315	315	295	225	245	255	225	250	265	285	250
Emergence rate (%)	95	75	90	95	90	85	90	95	90	80	90	95	90	75	90	95
sowing rate (seeds per m²)	355	500	440	375	310	360	345	310	250	295	280	250	275	325	310	260

All site information is are taken from the databases of the GIS-System, containing soil maps as well as in future the digital elevation model. Some additional information must be indicated by the user (see figure 3). As a result of calculating the sowing rates of the management units, the system produces an application map for using it in the tractor of the precision agriculture equipment. The user always has the opportunity to change suggested decisions (e.g. changing correction values for the yield estimation based on local experiences).

The module is programmed with the script-language: ArcView-Avenue and can be incorporated easily into ArcView or related products as an extension. Currently work is underway to incorporate the influence of topography onto the optimal sowing rate into this decision support module. Later there will be modules for soil cultivation, fertilisation and spraying of pesticides and plant growth regulators with comparable concepts and design.

Figure 3: *Screen capture of the pre agro decision support system for calculating site specific sowing rates in precision agriculture*



Acknowledgements

Further information to the joint R+D-project *pre agro* can be assessed through: www.preagro.de .

This work was funded through the German Ministry of Education and Research (Bonn) within the joint research project *pre agro* (Management system for site specific crop production, grant no: 0339740). The activities of the research centre ZALF in Müncheberg are made possible through basic funding by the state ministry of agriculture, environment and spatial planning of Brandenburg (Potsdam) and by the German federal ministry of food, agriculture and forestry (Bonn).

The work for this paper was shared by the authors as follows: Jarfe 70%, Werner 30%.