Precision farming — the environmental challenge

Hermann Auernhammer

_Institut für Landtechnik, D-85350, Freising-Weihenstephan, Germany_

Abstract

Precision farming makes use of information technologies in agriculture. With the satellite positioning system and electronic communication standards, position and time may be integrated into all procedures connected to farming. Today, precision farming is primarily geared towards site-specific application of fertilisers with the resulting cost advantages being quite small. Thus, precision farming will likely gain in importance only when viable additional benefits, such as reduced environmental burdens and increased flow of information, are recognised and evaluated and become part of the reward itself. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

At the close of the 20th century, ‘precision farming’ has evolved into a current research topic all over the world. Today, most agricultural disciplines participate in this effort, encouraging progress in agricultural technology, which originally supplied the impetus through the integration of information technology into tractors, machines and implements.

Interestingly enough, however, ‘precision farming’ is almost always associated with site-specific fertilisation. Expectations of farmers using the new technology are usually twofold — a decrease in fertiliser required for the same yield and/or higher yields with the use of the same amounts of fertiliser. Plant protection is secondary. Recently, there have also been demands for site-specific seeding.
Yet, does ‘precision farming’ not really go beyond such concerns? Does it not mean extensive changes in every aspect of land cultivation, inside and outside, as well as with respect to tillage and livestock breeding? And, finally, does this approach not also influence forestry and horticulture? In other words, is it not rather the case that precision farming is the point of departure for a revised use of available land per se, a framework in which operation and herd sizes, wooded lots or horticultural acreages take second place to the central concerns of the environment, its variability and heterogeneity?

2. GPS as a supplier of position and time

At the end of the 1980s, the ‘global positioning systems’ (GPS), NAVSTAR-GPS and GLONASS, introduced a new era. For the military, positioning and time became available at any time and place. Both kinds of information could also be used for civilian purposes, even if the accuracy obtained was somewhat diminished.

Today, civilian users of GPS may well be in the majority, when viewed worldwide. In North America and Europe, reference services provide positional accuracy of 1–5 m on-the-go. More advanced devices even reach decimetre accuracy, allowing for exact navigation or even automated navigation of vehicles. After switching SA off on May 2, 2000, NAVSTAR-GPS will fulfil positioning without differential services. Another improvement will be available with the transition of GPS to the next satellite generation and the European satellite navigation system Galileo which is likely to be implemented. Therefore, GPS is, and in the future will also be, a ‘technology available to everyone’. In agriculture, the possibilities for application will be seen in positioning and navigation (Fig. 1).

3. LBS and ISO 11783 for electronic communication

In Germany, the development and establishment of satellite-supported positioning and navigation happened almost simultaneously with the evolution of a standardised electronic communication system for agricultural purposes. After an 11-year standardisation effort, the ‘Landwirtschaftliches BUS-System’ (LBS) is now available to farmers in a large number of actual devices and implements. This allows for communication between tractors, implements and farm management systems geared towards the needs of European agriculture and its small-scale operations (Fig. 2).

At the same time, LBS functions as a basis for the international standards organisation (ISO) 11783 standardisation procedure. Here, with LBS and ISO data structures largely identical, direct integration of the tractor has been achieved, also taking into account larger tractor-implement units in North America and some parts of Europe. Both systems may be operated within one communication network. With identical physical components and data structure as well as an identically structured virtual terminal, software updates from LBS to ISO cause few problems.
4. Precision farming today

With GPS and LBS (ISO 11783), both essential technologies for precision farming are now available. In response to demand, two different implementation strategies for fertilisation are now in use (Fig. 3).

4.1. The mapping approach

The mapping approach is based on historical data about yield distribution and availability of plant nutrients in the soil. Both pieces of information can be established in practice enough accurately.

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**Fig. 1. GPS in agriculture.**

**Fig. 2. The ‘Landwirtschaftliches BUS-System (LBS)’ according to DIN 9684/2–5.**
4.1.1. Yield measurements in the combine harvester

Yield measurements in the combine harvester are state of the art technology. The mean error (calibration error) is less than 1%, the distribution of data for individual grain elevator loads shows a standard deviation of 3%. Under laboratory conditions, more significant differences in precision were found between different measuring principles, depending on the type of grain, flow capacity and gradient of the machine.

4.1.2. Soil sampling

For soil sampling, certain standard procedures have evolved.

Mixed sample for large sites taken from mapped positions (map unit size = 1 ha, field size defined by driving around the field, mathematical map defined with an on-board computer, target navigation, taking of individual samples around sampling position for one mixed sample per designated map position).

Mixed samples from yield zones with site yield history (sampling positions limited to three (maximum five) yield zones, mathematical sample positioning with the PC, relative assignment of sampling chart by means of driving around the field, target navigation, taking of individual samples around sampling position for one mixed sample per designated yield zone).

Geo-referenced individual samples with yield information missing (limited to certain sampling sites, field size determined by driving around the field, minimum number of sampling positions mathematically defined, target navigation, individ-
ual samples taken with geo-referencing — possibly as a mixed sample around sampling position).
Permanent navigational sampling positions for basic fertilisation in closed ‘precision farming’ systems with fertilisation to nutrient removal (one-time definition of permanent sampling positions, relative assignment of sampling chart by means of driving around the field, target navigation, individual samples taken with geo-positioning).

This information allows for a one-time decision regarding phosphorus and potassium requirements for future vegetation. It also facilitates an estimate of the most suitable plant density subject to yield and soil specifics. This approach is useful for production under certain conditions, at stable weather conditions within the vegetation period, with a known deficit in the availability of nutrients phosphorus and potassium, and ignoring nitrogen top fertilisation for high yields.

4.2. Sensor approach

Historical data are not enough if high yields are based on nitrogen fertilisation, livestock breeding ensures adequate nutrient supply with P and K, and the weather is subject to great changes.

For such conditions, the sensor approach monitors actual growth conditions over time. To do this, plant chlorophyll reflectance is a very useful measurement because it correlates closely with nitrogen content of the plant and with resulting plant mass. At the same time, reflectance in the near infrared area is distinguishable easily from surrounding plant matter and soil. In combination with type-specific growth functions for individual plants, growth deficits may be detected and remedied by real-time application of nitrogen-fertilisers. Several studies have illustrated the efficiency of this approach, showing overall yield increases and more uniform yield distributions.

4.3. Plant protection

For site-specific plant protection measures, mapping and sensor approaches have been developed in close analogy to fertilisation (Fig. 4). However, in practice, both approaches have been put to very limited use. The reasons are several. First, manual mapping is extremely labour-intensive as very limited technical support is available. Second, the accuracy of remote data collection is still unsatisfactory. It is not yet possible to analyse and interpret information thus obtained, automatically, or not with acceptable precision.

Third, sensor approaches that collect data about spacing do not allow for plant-specific application. Fourth, image analysis approaches are still thwarted by extensive computation requirements in order to apply them to advanced direct injection systems.
5. Precision farming tomorrow

In light of the technical possibilities of information technology that are available, the current use of precision farming must, at best, be called ‘modest’. Apart from economic concerns, three other reasons may be cited which are described below.

5.1. The nitrogen and water problem

With respect to fertilisation, the problems lie in plant-specific application of nitrogen taking into account the soil water available to the plant. Several improvements are needed.

5.1.1. Sensor approach with map overlay

Existing sensor approaches always over fertilise poor growth sites, without taking into account local limitations of soil type and water supply. Such excess additions of nitrogen not tailored to crop needs might lead to ground water contamination. To avoid this, the sensor approach needs to be complemented by additional no-contact sensors for the acquisition of data about water stress in the plants, soil water available to the plants, and nitrogen available in the soil. Moreover, better models, that incorporate N requirements of individual cultures and types of plants, need to be developed, including information about the actual growth patterns of the crop as a whole or in the region (aerial photographs, satellite imagery), and local limitations from mapping information.

Fig. 4. Systematic approaches for site-specific plant protection.
5.1.2. Equal spacing of plants

Whereas in most cases, nitrogen may be applied and tailored to plant requirements without problems and at low cost, the delimiting factor in many regions around the globe is available soil water. Thus, precision farming must pay closer attention to this problem while thoroughly re-evaluating traditional cultivation systems. There is a dire need for an investigation of whether even plant spacing could not use available resources more efficiently, especially with generously spaced row cultures such as corn and soybeans, (Fig. 5). Initial experiments have shown that such approaches result not only in higher yields but also in significantly more efficient soil water and nitrogen uses. Additional improvements might be obtained by site-specific plant density.

5.2. Structural problems

Precision farming today aims at heterogeneities within a crop, attempting to take into account the requirements (and environment). Thus, this agricultural system is geared toward large-scale farming, increasing its existing production advantages (Fig. 6).

Most regions around the globe are dominated by small-scale farming operations. Precision farming, in such regions, must take the reverse approach and create economically and ecologically sound operations by ‘virtual land consolidation’, while keeping ownership structures intact (Fig. 7). Initial analyses of existing ‘transborder farming systems’ show a saving of 15–25% in required headland, 20–30% in required work time, and 100–300 € per ha in costs.
5.3. Improvements in genetic engineering

Along with improvements in plant performance characteristics, genetic engineering in agriculture is aimed mainly at improving resistance to disease. Results affect plant protection, reducing the need for intensive control efforts as in traditional cultivation systems. Significant implications are to be expected in the area of weed control, a leading concern with respect to overall effort and acreages affected. Thus, precision farming will have to meet new challenges found in precise application of minimal chemical amounts, accommodation for chemical bonding to the soil humus, and improving efficiency by integrating chemical applications with available soil water. Furthermore, because genetic engineering advances are expected to be more rapid than other technologies, such as plant identification systems, those latter technologies are likely to become subsumed and lose much of their importance.

6. Environmental impact

In light of extensive on-going research activities, development and implementation of precision farming around the globe is rather discouraging. Approximately 10% of the available agricultural land in the US Midwest benefits from yield mapping. In Europe, application of precision agriculture includes well-developed sites in UK, Eastern Germany and Denmark. The implementation of site-specific fertilisation measures, with data obtained from yield mapping, is even less. Site-spe-
Specific plant protection measures are negligible. Naturally, this raises the question of whether precision farming in this form is really needed or if there are important reasons for such restrained use.

6.1. No uniform systems available

Despite the completion of standardisation procedures, there are currently no uniform electronic communication systems available in agriculture. In Europe, LBS is used by a certain number of manufacturers. There are significant problems with respect to implementation caused by a lack of know-how on the manufacturers’ side and by different possible interpretations of the standards. For ISO 11783, the problems will even grow worse because the currently defined rate of data transfer represents an enormous bottleneck for a substantially increased information volume. Improvements in performance can only be obtained via fibre-optic cables which, in turn, lead to additional problems when used for mobile agricultural technology. The situation is aggravated by globalisation, i.e. the reduction of manufacturers to a handful of ‘global players,’ resulting from corporate mergers. For reasons of cost-efficiency, their strategies are likely to favour closed systems allowing them to gain a competitive edge.
6.2. More technology leads to more costs

With the integration of information technology, precision farming requires more and more comprehensive technology, which, while performing better, is also more cost-intensive. However, potential savings are relatively small if operations are already running close to optimal capacity without the technology. In this case, site-specific fertilisation will, at best, lead to a redistribution of the amounts of fertiliser used, and the resulting increase in yields are comparatively modest and may not cover additional costs unless very large sites are involved. Additional costs, therefore, may only be recovered by new management options and reduced environmental impacts, resulting from higher quality information. For these benefits, no nationally or internationally recognised assessment schemes exist.

6.3. Documentation and environmental performance

This leads to the question of whether environmental performance should or must be documented. Precision farming supplies the tools for such a documentation if electronic communication is extended to all machines and equipment. With the implement indicator (IMI), this will be possible at low cost, with LBS and GPS once more being prerequisites. Definitions for data acquisition density, and thus, for the stipulations in the task controller, are required (Fig. 8). The data obtained could be the basis for all kinds of environmental achievements as a geo-referenced documentation of measures taken (a mark of quality in the resulting products) and for public funds designed for environmentally sound agriculture.

![Fig. 8. The IMI for automated documentation of geo-referenced process data.](image)
6.4. New environmental achievements

In this context, precision farming could lead to additional environmental achievements.

6.4.1. Fleet management

Fleet management for the timing of field work and co-ordination of available equipment will result in less traffic (via optimised unloading procedures) and a decrease in the number of trips, more adequate co-ordination of transport vehicles and site-specific accumulation of goods, machinery use in accordance with soil moisture and a decrease in energy costs, and integration of local information about soil conditions and soil type in maximum load control to avoid permanent soil compressions.

6.4.2. Field robots

Field robots will optimise the use of machinery and lead to the decreases in multiple field visitation and overlaps in the application of fertiliser and plant protection agents by means of seamless navigation, improved total work efficiency by the use of manned guiding vehicles and unmanned follow-up units, and a potential reversal of the trend toward ever larger machinery in favour of the development and use of smaller field robots.

7. Conclusions

The precision farming developments of today can provide the technology for the environment friendly agriculture of tomorrow. This can be seen in the areas described here below.

- GPS will supply the required accuracy. Further progress is expected by the improvement of NAVSTAR-GPS and the impending installation of Galileo.
- Through the standardisation within LBS and ISO 11783, mobile electronic communication will be available. Whether this signifies the emergence of open systems for tractor-implement combinations — independent of manufacturers and of manufacturer-specific systems made by the few remaining global agricultural technology providers — remains to be seen.
- Basic fertilisation with the mapping approach is a system that is available already. With fertilisation after removal, intensive sample-taking would become largely redundant.
- With respect to nitrogen fertilisation, the development of online-sensor systems is taking shape. By means of map overlay, site-specific limitations and also excess dosages may be taken into account.
- With respect to plant protection, current manual assessment has proven to be time- and cost-intensive. It remains to be seen whether progress in genetic engineering will point site-specific application towards a new direction.
• Enormous potentials for precision farming may be seen in an overall approach to environmentally sound agriculture. These may only be tapped, however, if the environmental benefits of geo-referenced information are financially rewarded.
• Through the use of geo-referenced information, the potential of fleet management and field robotics can come to fruition.

In this vein, precision farming today is already able to supply the technology required for the environmentally sound agriculture of tomorrow. Huge efforts will be involved in activating its slumbering potentials for the benefit of the environment.

Further Reading

Teil 3: Systemfunktionen, Identifier (DIN 9684–3; 1997–07).
ISO: Tractors, machinery for agriculture and forestry — Serial control and communication data network.
Part 1: General standard for mobile data communication.
Part 2: Physical layer.
Part 3: Data link layer.
Part 4: Network layer.
Part 5: Network management.
Part 6: Virtual terminal.
Part 7: Basic application layer.
Part 8: Power train.
Part 9: Tractor ECU.
Part 10: Process data application layer.
Part 11: Task controller and management information system data interchange.
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