1. Introduction

"Precision Farming" becomes an important topic in agriculture. World-wide this "key word" caused enormous research activities. Many technical disciplines take part in the scientific work and in the realization. Nevertheless a constant systematics and a "state of the art" does not exist actually. Therefore in the following article an attempt is made from the view of the agricultural engineering, in order to work out especially the site-specific fertilization.

2. Basic technology GPS

Precision Farming is inseparably connected with GPS (global positioning system). In reality however the beginnings already lay very early, because each farmer operates with Precision Farming, if he manages his fields himselfe and knows the local conditions and react to the local conditions.

However the number of these farmers is steadily declining in the high-industrialized countries. The grain harvest set first standards for it. Today probably more than 70 % of the area with cereals are harvested by contractors or machinery rings country wide. The contract use of self-propelled forage choppers in the silo maize harvest is even higher. The same machines take over more and more the salvage of the grass silage. Even more the trend is unmistakable seen to the large self-propelled six-row sugar beet harvester. A similar development appears for self-propelled harvest techniques with the industrial potato.

criterion of this technique is:

- the complete work is removed from the farm
- seasonal workers with often small linkage to agriculture take over the operation of the technique
- beside from the work completion the local information about success or failure of all preceding work from the farm disappears at the same time
- the obligation to homogeneous handling of the areas is irrevocable, if new technologies do not eliminate the information loss and intelligent application techniques enable the reaction to local conditions.

To that extent GPS gets to a central meaning. It supplies

- place and time always and everywhere
- is usable free of charge
- operates without relation to the weather and daytime
- is subject to the miniaturization
- becomes ever cheaper by high numbers of units produced world-wide
achieves in the differential operation the necessary accuracy (Tab. 1) for agricultural application, although the vehicle guidance and the device guidance thereby are aimed at in the future ("tool guidance") economically are not yet realizable.

Table 1: Requirements of the positioning accuracies in agriculture

<table>
<thead>
<tr>
<th>Required Accuracy</th>
<th>Task</th>
<th>Example</th>
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<tbody>
<tr>
<td>± 10 m</td>
<td>navigation</td>
<td>targeting of fields (machinery ring, contractor)</td>
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<tr>
<td></td>
<td></td>
<td>targeting of storage area (forestry)</td>
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<tr>
<td>± 1 m</td>
<td>job execution information</td>
<td>local field operations with</td>
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<td></td>
<td>documentation</td>
<td>yield monitoring</td>
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<td>fertilizing</td>
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<td>plant protection</td>
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<td></td>
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<td>soil sampling</td>
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<tr>
<td></td>
<td></td>
<td>action in protected areas</td>
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<tr>
<td></td>
<td></td>
<td>automated data acquisition</td>
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<tr>
<td>± 10 cm</td>
<td>vehicle guidance</td>
<td>gap and overlay control (fertilizing, spraying)</td>
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<tr>
<td></td>
<td></td>
<td>grain combining</td>
</tr>
<tr>
<td>± 1 cm</td>
<td>implement (tool) guidance</td>
<td>mechanical weed control</td>
</tr>
</tbody>
</table>

Systematically regarded GPS enables different use in agriculture. It can be assigned in the big sectors of position detection and the navigation (fig. 1).

Figure 1: Use of the GPS in agriculture
Each area of use is characterised by constant requirements.

2.1 Documentation

Basicly only GPS technique with position service and time service is used. Resulting from both services characteristic values for

- points in time
- total time and section times
- total travel lengths and section distances
- speeds

are calculated.

In connection with one or more sensors in machines and implements it will be possible to document

- transported quantities
- total expenditure and local expenditure
- total yield and local yield.

All documented data can be visualized with the local and the time information and can be shown flow-referred.

2.2 Local guidance

Actors are added to the sensors. From stored (georeferenced) information and/or from sensor data reactions are forced by actors in the form of:

- information to the driver for necessary actions
- site-specific application of seeds, fertilizer and plant protection agents
- safety-relevant measures for technique and environment up to the "emergency stop" of the used technique

2.3 Vehicle guidance

The vehicle guidance addresses the vehicle at itself and may be understood as driver discharge or as back-up for other non agricultural persons. Executive functions can be used to:

- punctual target guidance
- parallel swathing by farm works, which directly follows past vehicle passes
- guidance along stored guidance lines from preceding, finished measures

2.4 Fleet management

Time-adjusted monitoring, leading and assigning several equal units or several different units operating on the same object becomes more and more important. Fleet management is necessary for

- interaction of application-, harvesting- and transport units by a steady alignment of positions, quantities, average driving speeds and single quantity units.
the synchronisation with temporal disalignment of manned leading vehicles and unmanned satellite vehicles (drones)
the monitoring and guidance of unmanned vehicles, like not yet available field robots.

Within this systematics GPS thereby is needed for the acquisition of information and for its realization. For the production information cycles (fig. 2) can be derived, which lead in form of Precision Farming to site specific application and which deals with the heterogeneity found in the fields.

Figure 2: The information cycle of Precision Farming

Aligned to the fertilization during the vegetation the following technical measures with the information management in the center and the services over that become necessary (fig. 3)
3. Yield detection as starting point of Precision Farming

Farming serves the achievement of a yield. Yield increase and yield stability are essentially achieved and guaranteed in Europe by means of fertilization. Thus yield and fertilization are connected inseparably together. Therefore Precision Farming addresses in first development these two sizes and turns first to the income size "yield" with its local development.

3.1 Yield detection systems

Five subsystems are required for local yield detection (fig. 4).
Problems occur concerning the cut width registration at the combine harvester. Postprocessing of the recorded raw data can create a limited remedy.

For yield measurement various sensors are available (fig. 5).
They are characterized by two types of error:

- individual weights of grain in the tank can be determined with an error of approximately 5 - 7 % (2s-range)
- the deviation of the determined total harvest quantity depend on the calibration. This error can be eliminated, if the raw data are stored and post-calibrated by counter weighing the yield.

First attempts of systems for yield detection in forage choppers, sugar beet harvesters, potato harvesters, forage wagon and big balers are in development, or in first tests on farms.

3.2 Yield mapping and yield patterns stability

So far the yield mapping is unsatisfactorily solved. It is effected via firm-specific software according to undocumented analysis algorithms. Standards for statistically secured admissible and meaningful yield class widths are missing just like for the optimal patterns differentiation by ranges in contour graphics or by expressive grid sizes.

First analyses of the stability of yield patterns over time series increase the prediction security with an increasing number of successive years. Correlations based on grid maps initiate coefficients of determination ($r^2$) between two harvest years between 0.3 and 0.6. If three successive years are regarded, then in the multiple view the coefficients of determination rise to approximately 0.7 - 0.8. Yield patterns of grain crops seem to be very stable. For potatoes however stronger deviations are seen or developments directly moving in opposite directions are noticeable.

4. Soil sampling and/or soil analysis

Whereas the local yield detection documents the total withdrawal of the harvest of a field and the withdrawal on site specific parts of the fields, soil sampling after harvest determines the nutrient supply in the soil for the next crop.

4.1 Sample problems

Thus both variables regarding the production of the current crop are data from the past. Their value is limited, if the temporal distance between the determination of both values gets large and if in this time interval strongly changing conditions will be found (temperature, water conditions by precipitation and inflow or run-off in the soil.

Further the different density of spatial data is a problem. Yield measurements are made with the usual position determination frequency of GPS receivers every 1s or 2s or with average operating speeds of approximately 3 m/s in the distance of 3 - 5 m (multiplied by the working width of approximately 5 m results in yield measured values for incase each 25 - 30 m² harvest area).
However soil samples are collected from cost reasons after country-wide common standards with approximately 15 cores per hectare as mixed samples. Both informations are therefore not or only limited comparable. Ways out of this situation are:
- grid sampling for part-fields between 1 and 3 hectare
- sample relocation in zones of similar yield levels according to yield mapping
- geo-referenced single specimen analysis
- time series analyses on defined sample points with GPS navigation within areas of 1 m²

They can deliver solutions regarding the temporally stabil basic nutrients P and K. For the N-supply they are however unsatisfactory, because additionally temperature and water content in soil and plant overlay the availability and the attainable effect there.

4.2 Geo-referenced sample technique

Soil sample technique uses GPS for several functions to
- area measuring after driving around for the definition of the necessary number of soil sample points
- determination of the positions of the soil sample points and navigation to the points
- accurate position determination at the core point during the sample drawing with integrated indication assistance for the forwarding in the investigation labor and the later integration of the results of analysis into a geo-referenced data record

In all cases geo-referencing serves for the creation of nutrient supply cards as overlay for the withdrawal cards. Both enable together the balancing, which is obligatory prescribed according to the fertilizer regulation for larger operations in field specific form.

5. Site specific application techniques

In agriculture electronics was introduced first in plant production with the application techniques. Industry and practice showed thereby demonstratively and proved that "high tech" is necessary and can and must be used meaningfully and environmental saving in particular for more accurate dosage by means of production. Today the fertilization in Precision Farming is seen in three different methodical approaches (fig. 6).
5.1 Mapping approach

Almost all past work and the realized installations refer to this approach. Initial values are the local balance sizes yield and nutrient supply in the soil. They are brought in agreement with the yield target and find their realization in application cards.

Technical solutions pursue three conversion strategies:

- electronics which is so far used in the application technique of the operation is extended by GPS. For the transfer between management and mobile electronics the medium smart card or PCMCIA card is furthermore used.

- manufacturers develop integrated, but firm-specific solutions including new communication technologies. Not in production contained techniques are bought by efficient medium-size manufacturers and are company specific integrated.

- specialists on the fertilization sector open their technique for all manufacturers and users by utilizing standardized, universal communication technique based on the "agricultural BUS system (LBS)".

The application is realized with centrifugal or air spreaders. Different nutrients can be specifically mixed and applied by multiple bin systems on-the-go or a limitation on two nutrients is realized using simultaneously two times available application technique.

Local application is exclusively operated according to grids. These are aligned usually at the north/south direction and deviate thereby in many cases substantially from the driving lanes. Transitions between the raster specifications are smoothed partly with special control.
programs. Available section specific controls can be used automatically for spreading non rectangular fields with the help of GPS.

This approach is used in particular for the supply of basic nutrients and trace elements. Also the first N-fertilization is to be included, in order to give a site-specific start application.

5.2 Real-time sensor approach

Due to the not directly foreseeable weather process the N-top-fertilizing can be derived only insufficiently from Mapping data of the preceding vegetation. Therefore particularly for the N-fertilization it is tried to determine the current plant growth with on-line sensor technology and to make the necessary N-dosage under real-time conditions. Two approaches are pursued in present:

- measuring of the chlorophyll content as control value which is strongly correlating to the N-content in the plant. The calibration is effected via comparative measurement at single plants and company-specific defined supplying values. The used control software calculates the chlorophyll content and fertilizes with regard to the defined yield target less developed plants. Generally this approach therefore results in more uniform fields. At present no dosing limitations dedicated to geographical allocations in the system are contained.

- recording of the plant growth with the measurement of the plant resistance at a pendulum attached at the tractor front. Comparative measurements showed that the resistance supplies an useful correlation to current plant growth. Realizations in practice were made only in test attempts.

The development of these systems almost exclusively takes place in Europe with emphasis in Germany. It is a response on the Central European production conditions on high yield level under predominantly humid conditions with locally different conditions concerning precipitation and temperature. The integration of mapping data, which is missing actually confines however the application type one and excludes the environmental exculpatory component in a such system to a large extent.

5.3 Real-time sensor approach with map overlay

With increasing meaning of an environmental friendly production the mapping approach has to be integrated therefore as an overlay in the sensor approach and has to be amended by an additional control value. Necessary are:

- target sizes for the optimal N-supply of plant types and planting places according to growth curves and yield level as pre-set value for the necessary cybernetics
- the on-line detection of current plant growth for the adjustment of the plant-specific regular target size to the field specific conditions
- a site specific delimitation according to yield mapping of several years for the proof avoidance of over fertilizing in less efficient places within the field (characterization of the field section)
the additional detection of the water situation stop in plant and soil as in the long run
determining control variable for the effectiveness of a possible N-fertilization in connection
with an on-line N analysis of the available soil nitrogen.

6. "Information System Spatially Variable Management Duernast (IKB-Duernast)"

Accurately these objectives are intended by the DFG research group "Information System
Spatially Variable Management Duernast (IKB-Duernast)", which is settled at Weihenstephan
(fig. 7).

Figure 7: Structure of the research group "Information System Spatially Variable
Management Duernast (IKB-Duernast)"

Five institutes of the Technical University of Munich are cooperating, in order to compile the
necessary bases for the shown N-fertilizing system. These is:

The institute for agricultural engineering (TUM) with two subprojects:
SP 1 tries to develop standardized yield mapping algorithms using local yield data of almost
10 years. The special attention in this project is based on the analytic entry of possible errors
during the acquisition of information (site detection, yield measurement, moisture test and
others) and their consideration with the definition:

- more meaningfully and significantly different yield levels in the field
- homogeneous grid sizes or admissible ranges of iso-yield areas in contour graphics

Thereby analyses for yield stability should follow, in order to be able to derive a weight of the
limiting effect in the intended nitrogen-fertilization system.
SP 2 would like to complete the present site specific vehicle and work time data acquisition in the production process and to transfer on all those machines and implements, which are not explicitly equipped with electronics for the necessary site-specific application. In particular the soil tilling machines should be included (to this acquisition of information), in order to enter site specific parameters with these machines to register the regarding power demand, operating depth, etc. and have them be recognized for the strategic decisions of a on-line nitrogen fertilization system. In addition the requirements for the automated and continuous data acquisition should be created, which represent the base for cost accountings and operational evaluations.

The institute for plant agronomy (TUM) with one subproject.
By this the reference values (calibration curves) for the biomass development are compiled. The examinations concentrate on winter wheat and corn with different variations, in order to address and enter thereby also different growth types and different chlorophyll developments. Nutrient supplying degrees for different yield targets are included into the investigations.

The institute for plant nutrition (TUM) with one subproject and three different methodical approaches for two different questions. Water content in plant and soil is examined with the help of direct and remote sensing. Reflection measurements at defined measuring points are used in the field, in plot trials and in a strip plot trial. The soil water and that soil nitrogen are detected additionally with electromagnetic measuring procedures.

The institute for land use planning and nature protection (LMU).
The subproject tries to enter the plant development with direct and remote sensing methods. Suitable bandwidths within the near and further infrared range are examined. As substantial measured variable the exposure is included into the investigations, in order to be able to derive standardized models thereby.

The institute for operational research (TUM) with two subprojects:
SP 6 creates the common information platform with the design, the structure and the maintenance of a universally usable operational data base. Large attention is put on the necessary interfaces. The transfer to mobile process technique and the return flow coming from it have high priority.

SP 7 compiles a cost accounting system for the operational, field and site specific referred evaluation. To that extent this subproject furnishes already promptly results for and over the information system, which should be developed and the desired on-line nitrogen fertilization.

The necessary farm information system is structured in the subprojects SP 2, SP6 and SP 7 and completed with a unique investment of an electronic communication system by the research station Duernast (managing director Professor Heissenhuber). This includes all mobile units and also the stationary technique (fig. 8).
7. Communication in a Precision Farming system

Precision Farming means communication. Thus the availability of an efficient communication system decides on the acceptance and on the possible introduction. For Europe the starting point was already put in the middle of the 80’s with the "agricultural bus system (LBS)"
It enables communication on standardized base
- between management and mobile technique
- between drivers and implement electronics
- between the implements.

With its performance it fulfills the requirements for the integration of the techniques specified above and at the same time creates independence of the farmer from the manufacturers. Beside that the manufacturer can differ through own electronic devices from the competition and make thus a significant contribution to innovations and to steady progress.

With the present continuation of standardisation efforts on ISO level a connecting system for further developed and refined techniques will be created for the Precision Farming from tomorrow, which can be used global.

8. Conclusions

With the change to larger farm units and an increasing amount of work done by contractors and machinery rings the farmer loses the direct relation to his fields on his farm.

Homogeneous applications of seed, fertilizer and pesticides are the result. Over and less supplied areas lead to less yield and eutrophication with a multiplicity of negative effects at expense and environment. Precision Farming changes this development and enables without losses of machine power the management of large fields according to site-specific conditions.

A prerequisite of use in practice is the application of GPS to the geo-referenced acquisition of information and information conversion. For the fertilization the following classification results:
as entrance technology the local yield detection is available for wide spread use in the combine. For other harvesting machines scientific solutions are compiled and can be integrated after appropriate adjustment into the available machines. The standardized data analysis is not solved, often problems exists during the data communication into non-firm-specific analysis software.

the geo-referenced soil sampling is suitable as tool for the optimized supply of basic nutrients. It is usable for the N-fertilization, where continuous growth and climatic conditions are present over the vegetation season.

not available are scientifically founded strategies from both sources of information for yield-target-oriented site-specific fertilization measures. N-fertilization strategies derived from the mapping approach requires high specialized knowledge for the realization.

sensor-based on-line N-fertilization systems are in the first practical application. Firm-specific aligned control electronics operates for uniform yields and leaves environmental friendly criteria without consideration.

with a sensor approach N-fertilization with map overlay these disadvantage could be eliminated. The research project IKB Duernast, created at longer term, tries to close the gaps for it.

the actual introduction of Precision Farming for the fertilization into practice is however handicapped by the not realized use of the available communication standard LBS. The farmers hesitate therefore rightfully with the entrance into the new technology, particularly since the economical use is monetary modest by low nitrogen prices. In contrast to this the actual performance of the Precision Farming, environmental discharge, is only seizable with difficults, a remuneration of these performances is not in view.

9. Literature


10. Summary

Precision farming has become a main focus of worldwide agricultural research. Mainly "mapping approaches" are investigated. "Real-time" application technology can be seen in first approaches. Solutions for georeferenced documentation, vehicle guidance and fleet-management are discussed. Solutions with standardized communication for a cheap realization on the farm are mentioned only theoretically, although with the Agricultural BUS System LBS a standardized basis technology is available.

The research group "Information System Spatially Variable Management Duernast" IKB-Duernast has the aim to realize the integrated approach of "real-time application with map overlay" based on LBS in a data collection and analysis concept for farms.


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