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INTERDISCIPLINARY RESEARCH FOR PRECISION AGRICULTURE PREAGRO: THE GERMAN JOINT PROJECT FOR AN INTEGRATED MANAGEMENT SYSTEM

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Abstract

Since January 1999, site-specific crop production has been studied throughout Germany in a BMBF-funded joint research project, "Management system for precision agriculture to increase the efficiency of farming and promote its environmental compatibility". The central goal is to exploit the arable land more economically according to the principles of good agricultural practice and at the same time to cultivate it in a more environmentally responsible manner.

With 22 sub-programs operated by 13 research institutions, 2 service companies, 2 software companies and 16 farms, Preagro (www.preagro.de) is developing the base for decision support systems for crop management in precision agriculture. At eight regions across Germany, the available and necessary data are analysed for their possibility to be used in determining the appropriate cropping measurements for sub-units within fields. Algorithms and rules for this crop management are developed and will be provided as software modules to be implemented in any farm software for precision agriculture. Different methods to identify and describe conditions of site or crop stand are compared. New methods in soil survey, remote sensing or optical sensor systems at the fertiliser spreader are developed or tested. The algorithms and rules to manage the crop site-specifically are derived from agronomic knowledge and actual experiments. The rules are developed for managing crops spatially variable with soil tillage (chisel ploughing), sowing density, fertilisation (N, P, K, lime), growth regulators and herbicides. Prototypes of the algorithms are applied on the test farms and will be validated for accuracy as well as the economical and ecological effects. The economical effects of managing crops site-specifically are determined especially for winter wheat and compared with adjacent fields which are managed uniformly. The impact of site-specific management onto vertical and regional flow of nitrate in the soil is also studied.

The opportunities to adopt environmental requirements to site-specific crop management are analysed for local objectives of nature conservation. The way to integrate these tasks is a cross-program linking multi-disciplinary research with industry and stakeholders from the public and the private sector (as farm managers, local governmental agencies, consulting companies, mechanical and software engineers) towards an interdisciplinary and comprehensive outcome.

Introduction

In Europe, precision agriculture could become a common technology in the next ten years. Well Managed farming enterprises will use this technology to strengthen their internal information flows, to enhance their management procedures and also to increase the economic effectiveness of arable crop production. The technology allows the adjustment of crop management according to site-specific yield potential of crops across a field. The yield potential depends on site conditions and is variable within most fields and landscapes. This heterogeneity can hardly be handled by the farmer at present. A production technology, that can supply exact position information, store and retrieve local application information will provide new opportunities in crop management and can support the integration of environmental quality requirements into crop production. The new technology will therefore make it possible to regard much better the different environmental sensitivities and potentials within plots and landscape.

The properties and qualities of agricultural soils differ considerably even within a small area. For example, in moraine landscapes, alluvial areas or low mountain ranges, great differences can be found within a few metres. These locally varying site properties are additionally influenced, to varying extents, both by natural features such as hollows, slopes or ridges, as well as by cultivation-related impacts such as compaction or erosion. In current agricultural practice these site differences are not considered (Fig. 1).

Figure 1: Aerial view of the heterogeneity of a cropping area typical for the eastern German landscapes

Farmers adjust soil tillage, sowing, fertilisation and plant protection to an average site quality of a field. As a consequence, on plots with a high yield potential this potential is not exploited, whereas areas of low fertility are over-fertilised. In such cases precision agriculture can significantly increase economical and ecological efficiency. To realise a comprehensive management system for precision farming, a complex of problems can be emphasised:

- The heterogeneity of natural resources at the sub-field level
  Apply soil coring, geophysical mapping, remote sensing of soil characteristics and crop response
- The heterogeneity of climate at regional scale
  Apply crop growth modelling with a focus on weather dynamics and varieties
- The lack of integration of expertise from multiple disciplines and technologies
  Apply knowledge transfer not only from research to industry and farms but also to establish a platform for direct communication between all the sectors of the agribusiness concerned in site-specific management and resolving trans-sectoral problems from research to development and operationalisation and from isolated solutions to standardisation in mechanical and software interfaces
- The lack of interdisciplinary research
  Therefore, the German Ministry of Education and Research (BMBF) decided to fund the Preagro project as a joint project of farm managers, mechanical and software engineers, scientists from research organisations and universities giving a multi-disciplinary input from soil and crop sciences, remote sensing and image processing, GIS, geophysics, economics, biology and environmental sciences, geomatics and others.

Vision and Objectives

The concept of sustainability requires that farm management seeks continued economic success in such a way as to preserve its fundamental base of natural resources and to avoid any adverse effects on the surrounding environment. The vision for a sustainable agriculture in future is:

"Profitable crop management enhancing the quality of the natural resource base, and meeting the environmental expectations of an informed community"

The role of the Preagro project is to add value to industry research and practice, by facilitating collaborative, multi-disciplinary approaches that enhance sustainable crop production. In so doing, Preagro has a strategic and an operational focus which addresses all three aspects of sustainability in agricultural practices and systems that maintain or enhance:

- the economic viability of crop production
- the natural resource base upon which agriculture directly depends (e.g. soil & water)
- other ecosystems which are influenced by agricultural activities.

Preagro is intended to show the value of excellent collaborative, multi-party research integrating industry parties and farmers with on-farm experiments. The project will deliver robust and independent information and advice that is used to underpin policy development and that influences perceptions of the industry and community. There are five key result areas identified for the Preagro project:

- **Environmental Impact:** Match the environmental management practices of farmers with expectations of an informed community.
- **Managing Natural Resources used in crop production systems:** Maintain or enhance productive capacity of soil and water resources used by crop management.
- **Enhance profitability:** Enhance the profitability and international competitiveness of crop production in Germany.
- **Education and Training:** A pool of people trained in disciplines required for a sustainable sugar industry. Enhanced industry and community awareness of sustainability.
- **Attitudes and Perceptions:** Crop growing sector acknowledged as sustainable. Preagro seen to be an integral part of changing perceptions of growers and community.
- **Synergy from Collaboration:** Research targeted to meet growers and community needs. Enthusiastic commitment of Preagro parties. Effective and transparent management systems. Value-adding role capitalising on synergies.

Structure

The Preagro headquarters is located at the Müncheberg campus of the Centre for Agricultural Landscape and Land Use Research (ZALF). The project is an unincorporated joint venture comprising 17 parties representing the mechanical and software engineering sectors of the agro-industry, consulting companies, research organisations, universities and public research funding support. At 8 regions (Fig. 2), farm managers of 16 properties, service companies and machinery co-operatives are participating in the joint project. While they are located across Germany the approximately 55 professional staff (full and part time) and 15 post-graduate students linked to the Preagro project are working in collaboration across a range of disciplines toward delivering outcomes that will promote a profitable and environmentally responsible crop management.

- ***The Participating Parties:*** The Growing Sector with 16 farm properties at 8 locations; The Public R&D Sector with 5 Universities, 3 public sector research agencies; The Private Sector with 4 companies from consulting, the mechanical and software engineering, The Public R&D Funding Sector with the German Ministry of Education and Research (BMBF) and the Projektträger (BEO)
- ***Head Office and General Meeting:*** The Head Office located at the ZALF and is managing all daily activities, financial issues, public relations, preparing and hosting meetings, etc. The General Meeting is the decision-making body of the project. All sub-project and activity managers are entitled to vote.
- ***Management Committee:*** The Management Committee comprises the Project Leader and two elected representatives, who represent the public sector organisations or look after the private sector companies. The committee meets every 2-3 months to review the management of research and technology transfer and also provides advice to the Project Leader regarding the operations of the Project.

- ***Co-operative Working Groups:*** To enhance multi-discipline activities, Preagro has Co-operative Working Groups for the key result areas. The groups identify and set priorities for options for synergetic work and provide input into all ongoing activities. Usually, each group meets twice a year. Attendance at annual program planning and review meetings is also encouraged.
- ***Farm manager committee:*** The growers committee is a cross-program in order to provide a formal mechanism for direct stakeholder input at an operational level. Growers, technical staff as well as staff from the R&D activities and the Head Office are meeting twice annually.
- ***Advisory Committee:*** The Advisory Committee meets on a six-monthly basis and is the primary structure to ensure that Preagro's R&D reflects stakeholder needs. It draws together representatives from the industry, local government and public sector agencies. It encourages and enables a free exchange of dialogue which culminates in recommendations on strategic policy directions of the project, assessing Preagro's research priorities, advising on resource allocation, and identifying emerging issues of importance to the project.

Locations

At 8 regions across Germany (Fig. 2) and on 16 farm properties, the project established on-farm experiments, researching, testing and validating the developing management systems. Researching the economical and ecological effects. Reviewing management priorities. Educating farm managers and technical staff.

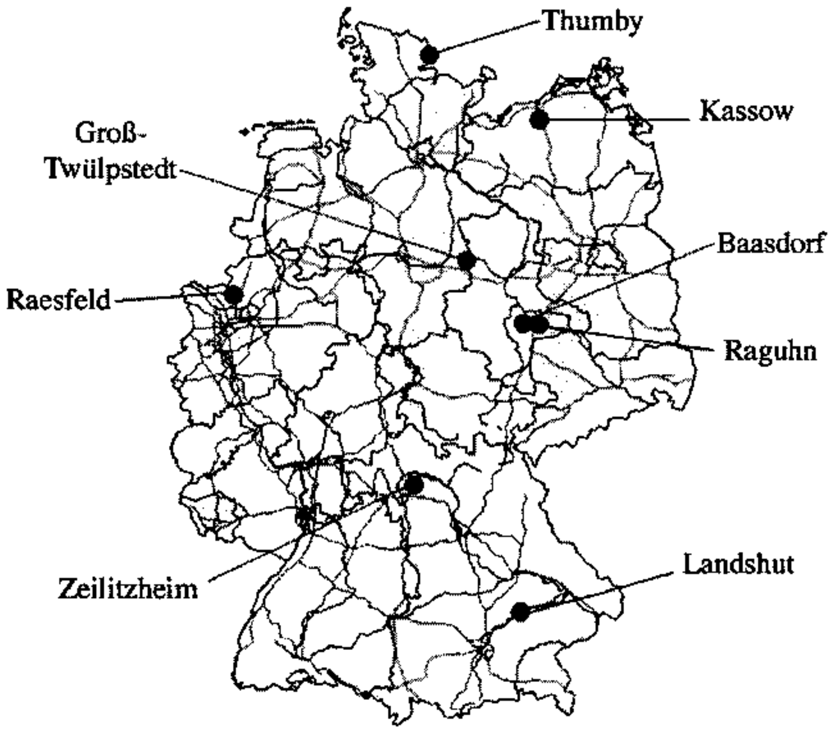

Figure 2: Locations of the project farms across Germany

Research and Development

Preagro's research and development activities are grouped into four research programs:

- **Natural Resource Program** -- Inventory and Monitoring
- **Management System Program** -- Information Processing and Software
- **Effect Analysis Program** -- Economy and Ecology
- Application Program -- on-farm testing, training and education

All programs are cross-linked for integrative and interdisciplinary work. Together the programs address the principal elements required for sustainable agriculture and its dissemination:

- ***Protecting the Environment***
  Goal: To identify, develop and promote environmentally sustainable land, fertiliser, pesticide, and catchment management practices.
- ***Sustaining Soil and Water Resources***
  Goals: To enhance productive and sustainable use of soil and water resources by assessing potential resource constraints and developing and promoting more effective management technologies. To develop spatially referenced inventories of soil, water and climate resources for crop production.
- ***Enhancing Productivity***
  Goals: To improve the profitability of cropping through the development and adoption of management practices that enhance productivity and sustainability in the different production regions. Improving on-farm profitability, with minimal environmental impact, through better management of pesticides, fertilisers and other resources as well as through minimising working time and energy consumption.
- ***Technology Transfer:*** All staff and students in the project have a technology transfer role. A mix of operational techniques is employed to maximise and expedite the uptake of research outputs by stakeholders.
  Goal: To provide growers and advisors with research results; to facilitate their adoption; and to enhance the practicans knowledge base and ability to make informed decisions which contribute to sustainable and profitable crop production.

Natural Resource Program

Heterogeneity at sub-field scale on agricultural land is caused mainly by the composition and interactions of soils and terrain shape with water and nutrients. Crops are responding to the natural resources, the crop management activities and weather dynamics. Preagro's activities related to natural resources are subdivided into two areas:

- ***Mapping and Inventory*** of natural resources using GPS, GIS, classical soil mapping, soil water measurements, geophysical mapping, terrain analysis, remote sensing and image processing, spatial modelling and geo-statistics
- ***Monitoring and Documentation*** of the crop response to natural resources and management activities using remote sensing and image processing, ground measures of morphological and physiological crop stand conditions and yield mapping

The goal of the Natural Resource Program is to establish and develop methodologies to identify and map the limiting resources for crop yield and to assess the yield potential.

The development of more sophisticated and robust methodologies will enable the integration of different data sources and will deliver more robust and precise information about site specific natural resources. The procedures of the natural resource program are monitored with regard to operational use for site-specific management.

Soil Sampling

The development of a practical methodology for recording and evaluating standardised soil characteristics has been tested. The soil samples were described with a standardised soil coding system. Sample plans were drawn up beforehand with the previous knowledge of farmers and broad maps from German geological services. The test farms are representing a cross-section of Germany's soil regions which are important for crop production. It has been recognised that the distances between soil samples has to be less than 50 m to record suitable data sets for direct interpolation routines and to derive soil maps. Therefore, spatial data are necessary for the up-scaling of sampled soil cores. This is the only way to enable a cost efficient methodology for soil mapping at farm scale to be realised. Geo-electrical and optical remote sensing are the techniques that were applied.

Geo-electrical Sensing

A robust and quick technique for mapping soil characteristics has been developed. The principle of measurement is based on the recording of apparent conductivity of the soil, which essentially depends on the soil texture and the water content. The procedure enables a measurement performance of up to 150 ha per day, depending on the size of the mapped area. All 3000 ha of test fields have been mapped in this way. The ECa measurement values were recorded with a resolution of 5 m x 20 m, i.e. with 100 sample points per hectare (Fig. 3).

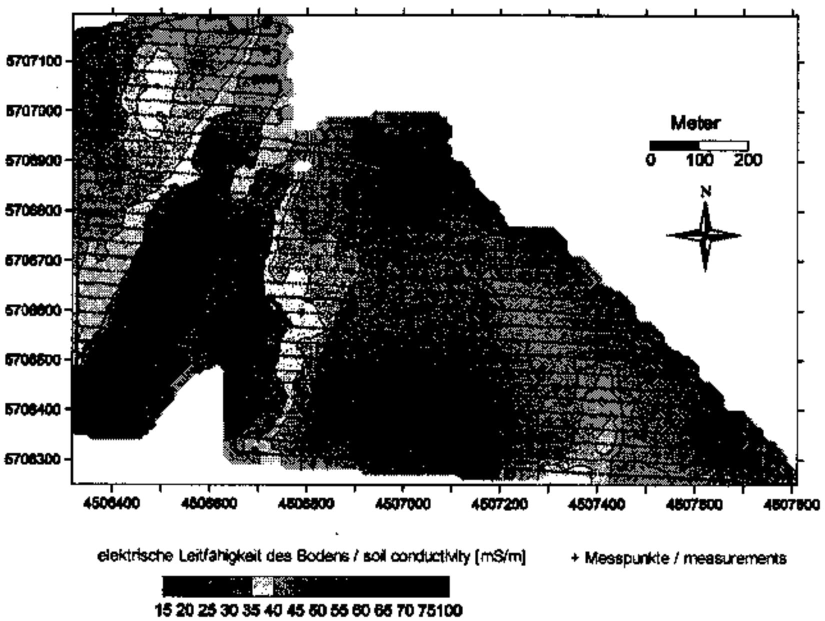

Figure 3: Map of the apparent electrical conductivity measured with Geonics EM38 instrument

The recorded values of the apparent electrical conductivity (ECa) were compared with a number of other information sources (soil characteristics, yield maps, spectral information from remote sensing images). Measurements at different times showed comparable pattern of electrical conductivity beyond the time. The ECa measurement method has already been proved to be a quick and practicable method for recording soil differences.

Terrain Analysis

By identifying potential dry and wet spots from digital terrain models (DTM, diagram 2), terrain information can be integrated in the process of generating application maps. The Topographic Wetness Index (TWI), for the representation of wet and potential dry and eroded conditions. The TWI is calculated from specific catchment area and local slope gradient. Both initial parameters are derived from a DTM. TWI extremes are indicators for optimal supplied areas and waterlogging in depressions respectively, and potential dry areas on shoulders of summits. The TWI can be combined with other data such as the map of the (apparent) electrical conductivity (ECa) or aerial photographs. The TWI represents one of several levels, which are included in the calculation of tillage depth, seeding amounts and N fertilisers. Peculiarities in terrain, which should be taken into account in farming, are also explained. For example, if the TWI shows a terrain-caused wet spot which is not recognised by other data levels (ECa and aerial photographs), it may indicate a change in soil type – a suitable place for cost-efficient directed soil sampling. Compare the patterns between the figures 4 and 5.

Figure 4:
Aerial image of soil surface overlayed with contour lines of the digital terrain model

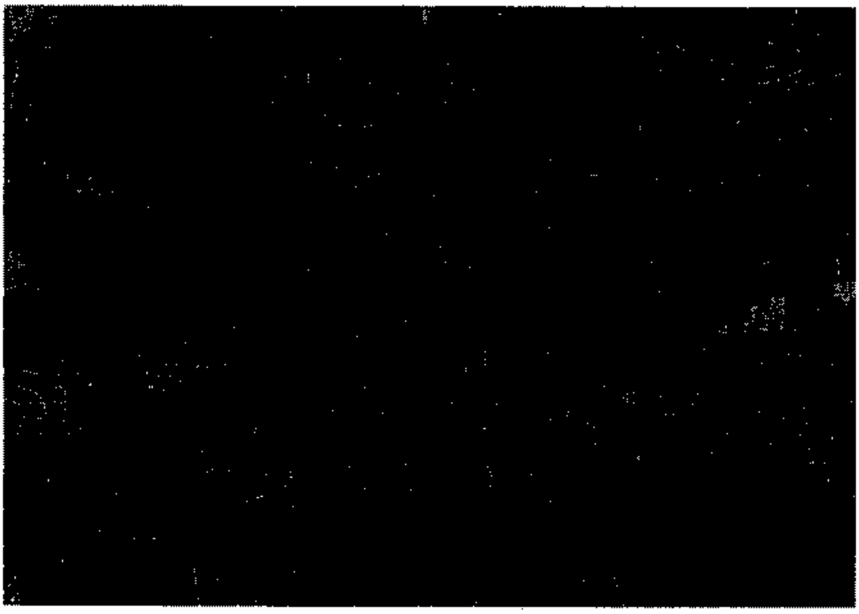

Figure 5: Map of the Topographic Wetness Index (TWI) overlayed with contour lines of the digital terrain model

Remote Sensing of Soil Characteristics

Procedures for deriving soil characteristics from multi-spectral remote sensing data are under development. The goal is to gain remote sensing-supported methods for plotting soil attribute maps at sub-field level. Two approaches are at the focus of attention:

- Detection and quantification of topsoil characteristics and attributes for the use of site-specific applications, such as tillage, sowing, seedbed preparation, fertiliser and herbicide application
- Derivation of the plant-available soil water storage capacity, as a planning basis for all site-specific measures

Remote Sensing of Topsoils

Topsoil characteristics play an important role in correctly adapting site-specific tillage, seedbed preparation, sowing, fertiliser and plant protection applications. Important topsoil characteristics are aggregation and erodibility, as well as temperature and water balance. These are essentially determined by the humus content and form, as well as the soil type. Based on Australia's hyperspectral scanner, called HyMap (Integrated Spectronics, Sydney), it was possible to quantify the organic carbon content and humus quality, the clay content and iron oxides with close regressions. This procedure is actually under validation. Detailed maps of topsoil characteristics (Fig. 6) can now support the delineation of management units for seed bed preparation, tillage, sowing, fertiliser and herbicide application.

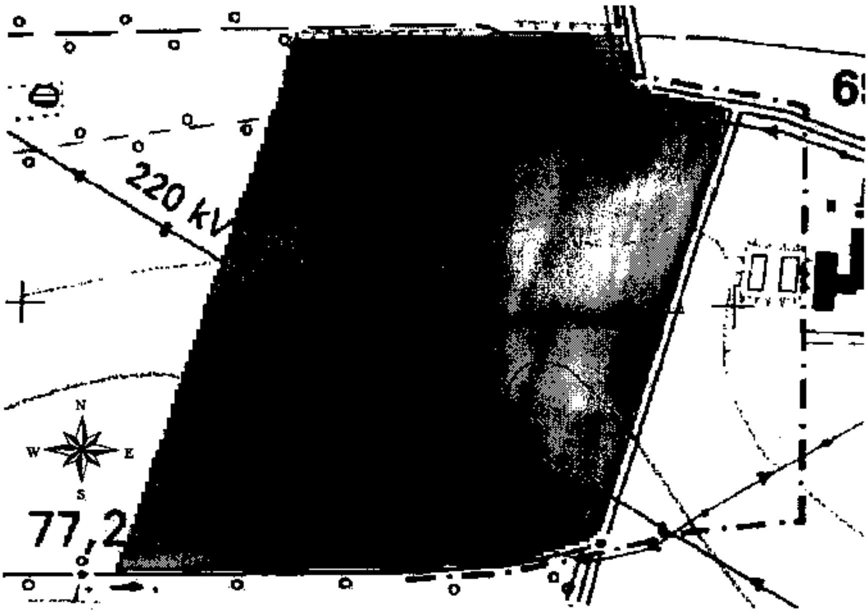

Figure 6: Topsoil map of the humus content ranging from 0.75 % (light brown) to 4.2 % (Dark brown) of the plot "Finkenherd", Baasdorf region

Remote Sensing of Available Soil Water Capacity

The main task when applying remote sensing for soil characteristics is to derive the plant available soil water storage capacity as a central parameter of soil productivity and therefore of the site-specific yield potential. Figure 7 shows a map like this for the "Finkenherd" field in the Baasdorf region.

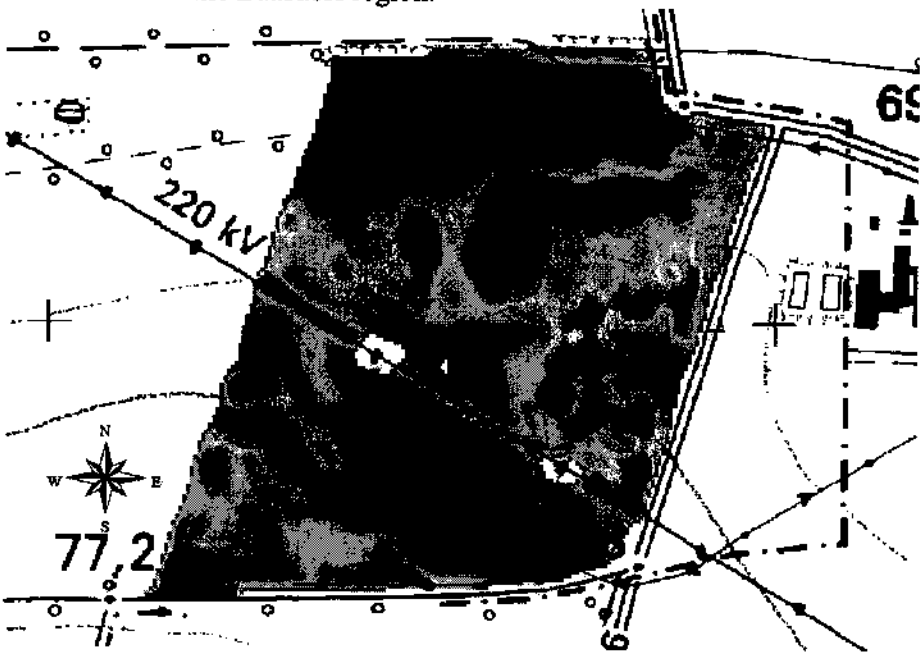

Figure 7: Map of plant available water capacity of the root zone as it varies across the reference field "Finkenherd", Baasdorf region (<50 mm = dark red to >250 mm = dark blue)

These maps can therefore form the central basis for planning site-specific management decisions in the future. Likewise they form the basis for site-specific yield prognosis. With the processing algorithms developed, soil differences are quantitatively derived from the spectral data. Such maps can be processed with a high degree of accuracy for fields in regions with a negative water balance during the vegetation period. The algorithm also takes the effects of ground water influence and lateral extra water into account.

Crop Monitoring using Remote Sensing

The crop monitoring activities are aimed:

- To document canopy changes across the fields applying time series of images using low-cost video and digital camera systems.
- To detect online the actual situations of nitrogen availability using the N-Sensor technology of Norsk-Hydro.
- To detect crop canopy stress using multispectral airborne scanners
- To quantify the crop stand conditions for yield forecast using low-cost systems as well as sophisticated multispectral scanners

Repeated aerial surveys are necessary to record different plant canopy development stages. By calculating vegetation indices from NIR and visible light (RGB), the distribution of the photosynthetically active biomass within a field can be determined. Since the canopy is not static, but subject to rather dynamic processes, the purpose of remote sensing is to record and compile the impact of natural or human induced intervention through change analysis. To assess and validate possible inter-annual senescence patterns from two different years of plot data, the field "Finkenherd" in Baasdorf was analysed. An aerial survey was conducted in 1999 at the time of maize senescence (Fig. 8). In 2000 the NIR senescence pattern of winter wheat was recorded. The results showed that the senescence processes of winter wheat in 2000 and the senescence of maize the previous year had a high statistically significant correlation. A deviation analysis was made by computing a relative differential image, in order to find out the zones of comparable senescence processes between both years.

One of the objectives using multi-spectral remote sensing is to localise and quantify site-specific stress phenomena and management effects. For this, different kinds of vegetation indices are calculated from spectral data. Traditional indices, such as the "Normalised Differential Vegetation Index (NDVI)," are only of limited use in quantitatively discriminating differences in medium to low stressed canopies. Research work has shown that very good differentiation can be achieved in the area of low stress effects by using emissive spectral response. In this way stress situations can be detected earlier, in comparison to the NDVI, which can only document stress which is already apparent. The further development of biophysical models is now an important task for the future.

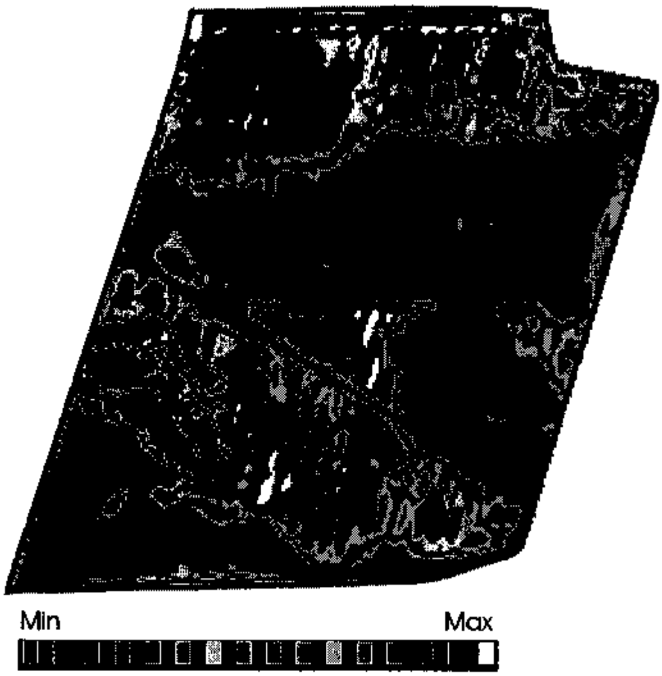

Figure 8: Differences of NIR signal backscattered from maize canopy during development stages of senescence, "Finkenherd" plot, Baasdorf region

Management System Program

Overview

Management guidelines and software components are in development under the management system program for site-specific crop management, with differential actions of tillage, seed density, basic fertilising (N, P, K, calcium), N-fertilising and plant protection. The essential task is the integration of the algorithms which are calculated into a management system. The conversion into a software module, which clearly makes site-specific management easier for the user is carried out by the collaborating software engineers.

Tillage Guidelines

The "tillage and cultivation" activity broke new ground by tackling site-specific tillage. Tillage, which is optimised for the site-specific soil attributes, should reduce costs by minimising the use of energy and working time, as well as prevent soil compaction and soil erosion. At the beginning, a tool was built which was the first of its kind in the world. This tool can switch over to a varied tillage depth during operation. The prototype, a 3 m wide combination of a highly-variable pre-loosening tool, a gyratory cultivator and a V ring roller was produced in co-operation with mechanical engineers of "Amazone Factory". Meanwhile a second prototype, a drawn tillage tool with a width of 6 m is being tested (Fig. 9). Four stroke cylinders provide the cultivator with a variable depth for the chisel-loosening share up to a maximum of 25 cm.

Figure 9: Prototype of a site-specific soil tillage tool

The instructions for site-specific tillage state that soil needs to be loosened when unfavourable growth conditions for plant roots predominate. This is often the case on sandy soils with a tendency to compaction, soils with coarse aggregation or water-affected soils e.g. gleyic soils. The algorithm developed considers different information levels for the derivation of site-specific tillage depth:

- Regulation value: Tillage depth of passive tillage (8-25 cm)
- Input values: Soil texture, Organic matter, Terrain position, Water balance, Drainage site, Environmental quality targets

Site-specific tillage was tested with the first prototype on two plots. The sites moved up in the 2nd, 3rd and 4th experiment year will, as scheduled, be tilled for one year. It is currently being monitored as to what extent the algorithm for changing working depths enable improvements by including further information sources. It is planned to include terrain modelling as well as aerial photographs. The energy measurements underway will be continued and expanded.

Seeding guidelines

The hypothesis is that on heterogeneous fields with varying degrees of yield potential, an adapted seed density performs far better than uniform seeding. An algorithm was worked out for winter wheat:

- Regulation value: Seeding mass (90-200 kg·ha-1)
- Input levels:
    - Yield potential: soil fertility index, annual mean precipitation, soil texture, soil type, soil water capacity
    - Site information: geographic region, terrain position and shape, Humus content, stone content, structure, texture of topsoil
    - Cultivation data / Seed bed condition: variety (variety type, quality, characteristics), expected plant losses in winter, Preliminary crop group, plant

emergence rate, Seed (seed capability), Seed bed values according to site, Seed date, Soil moisture at seed time

Experience and local knowledge of growers and information about the cultivation planning and seed conditions is decisive for the estimation of the expected yield of the individual sites. These will be retrieved by the software model user interface. A first version of the algorithm based on the seeding module was tested in 1999 and 2000 on 33 wheat plots in different regions of Germany. For this, 118 polygons of various seed mass were derived. The available monitoring results indicate that site-specific seeding for targeted yield can be realised in principle and the management of crop stands with adapted plant densities can be established. Essentially, better initial conditions will be created for the site-specific spread of nitrogen fertiliser and growth regulators. The task for the future is to develop an extended algorithm as a basis for decision aid systems for integrating (sequence and interactions) the cultivation sub-systems of tillage, seeding and fertilising. At the same time, the practice use and monitoring of the seeding algorithm continues.

Fertilising

Decision rules for site-specific fertilising are the core of a crop management system. Suitable decision models have to be developed incorporating recent research results as well as the proved advise statements of the Public Agricultural Advisory Board (VDLUFA). The algorithms have to be tested on the Preagro project farms. At the same time, environmental and nature conservation goals will be integrated in the new procedures for site-specific control of nutrient supply.

Nitrogen fertilising guidelines

Nitrogen fertilising is the essential core of operative crop management in Germany. Nitrogen fertilising enables adjusted and calculated effects on the crop stand. Different strategies and techniques of N-fertilising are in use: intensive fertilising with up to four application shares, extensive N-fertilising with usually two application shares, injection fertilising or fertilising with ammonium or N-fertiliser with nitrification inhibitors (1 or 2 shares). Each strategy and technique needs a purpose-built decision support. The following approaches are under development for site-specific N-fertiliser control:

- Complex N-balance model: "offline-approach" (Fig. 10)
- Hydro-N-Sensor, coupled with thematic maps (soil characteristics, environmental conservation requirements etc.): "online-approach with map overlay"
- Dynamic soil nitrogen modelling: "offline-approach" with high data demand.

For all three procedures, algorithms for winter wheat, winter barley and winter rape have been calculated and tested on the Preagro project farms. The tests at most of the test sites with heterogeneous soil conditions proved that a homogeneous N-balance can be expected applying the Preagro-N model. The outcome model was slightly adjusted and calibrated according to the results and is now available for transformation into a software module. Up to the end of the project the focus on site-specific N-fertilising will be:

- To use the N-balance model at all project farms in 2002
- To integrate other crops
- To integrate remote sensing for better spatial detection of crop stand variation

- To research on new fertilising techniques to reduce the number of fertiliser shares (e.g. stabilised fertilisers)
- To combine Hydro-N-Sensors with N-balance algorithms
- To use dynamic soil nitrogen models with reduced parameter sets

The Preagro-N balance model for winter wheat

- Regulation values:
  1. N-appl.: max. 70 kg N/ha up to BBCH 30
  2. N-appl.: max. 100 kg N/ha incl. BBCH 31 - 33 (Splitting if N-need > 80 kg N/ha)
  3. N-appl.: A: max. 80 kg N/ha at BBCH 37 - 39 (Splitting depending on current yield expectation and soil moisture) B: max. 60 kg N/ha at BBCH 49 - 51
- Input values:
  General information for management unit: Yield potential, soil type, Terrain (DTM), production target (variety type, quality type), preliminary crop group;
  Application-specific information for 1.application: BBCH-Stage, Nmin, tillering, plant density, weather of spring and winter;
  Application-specific information for 2- and 3. application: BBCH-Stage, plant density, nutritional situation (N-Tester or visual), 2. appl.: Date of cutting, 3. appl.: crop condition and weed occurrence, drought stress, precipitation in Mai.

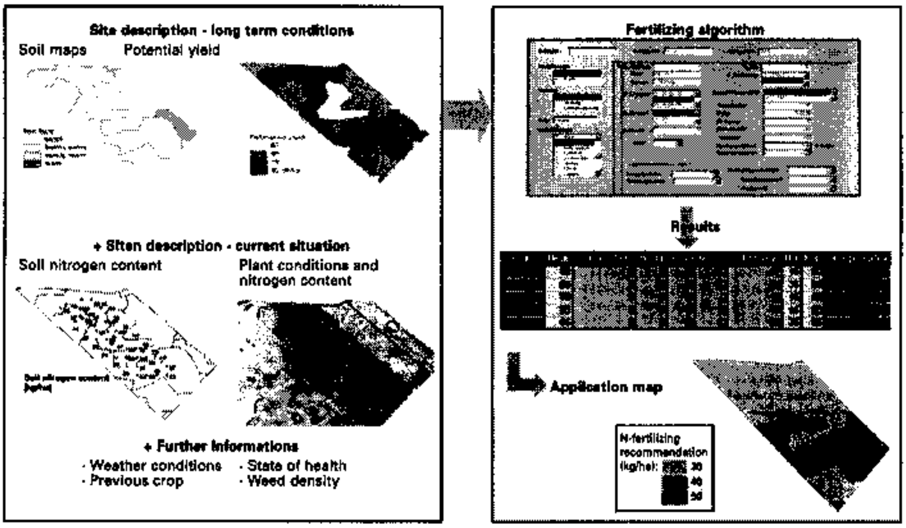

Figure 10: Conception of the N-balance model PREAGRO-N towards site-specific N-fertilising strategies

Basic fertilising guidelines

The calculation of fertilising recommendations for the basic nutrients P, K, Mg and lime is based on the research and recommendation of the VDLUFA and has a research and advice history of about 100 years in Germany. The algorithms developed in the project are at the test stage. The adjustment and calibration onto special farm conditions is on the go. The software is designed to make the calculations easily understood, and to make the algorithms flexible for further development. The VDLUFA Standard methodology has been modified as follows:

- Algorithmic preparation of VDLUFA regulations
- Considering the new limits for content class C (optimum), adjusting other classes
- Development of continuous functions for soil balance fertilisation
- Special consideration of subsoil fertility (nutrient content of subsoil)
- Increased consideration of targets for farm management and environmental protection
- Regional adaptation of site-specific nutrient-yield relations
- Integrating of new data sources (yield and soil maps, terrain models, remote sensing data etc.)
- Software engineering: transparent algorithm with most flexibility to adaptation

The algorithms are crop type independent and can be used across the farm. Currently, the algorithms are implemented as dialogue-driven software. Figure 11 shows the general scheme of the basic fertilising algorithms.

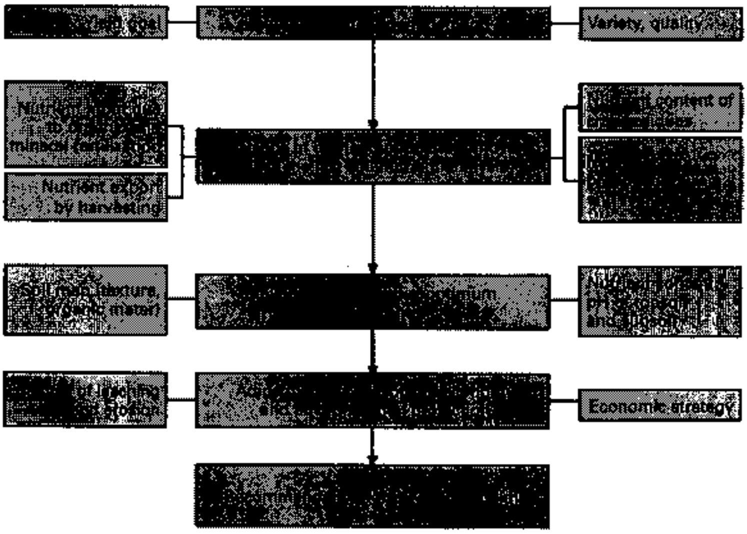

Figure 11: The Preagro fertilising algorithm for base nutrients

Plant Protection Guidelines

Plant protection is always linked to the input of chemical substances into nature. A site-specific application of pesticides on a plot can essentially lead to a reduction in the use of chemicals. Sensors can be used to adapt the quantity of pesticides to the appearance of weeds (herbicides) or plant leaf area (fungicides and growth regulators) in real-time. It will be possible to implement the harmful threshold principle in herbicide applications in a site-specific way. For control purposes, the various expenditure amounts are shown on a site-specific application map. The basis for site-specific quantification of the fungicide and late growth regulation application is the Leaf Area Index (LAI), which should be moistened by spray water (target area). The LAI can be measured online using a pendulum sensor. As a result of the proven correlation between the pendulum angle with the values of the LAI, target area quantification is possible. According to this form of expenditure amount, measuring resources will be saved in poorly developed plant stands.

Application Program

The management system resulting from the collaborative Preagro project will be of assistance to the user in the selection of suitable input data and in the derivation of agronomic measures. Thereby, it will considerably ease the task of carrying out site-specific cultivation. The aim and the concept of the project have, thus, a strongly practical orientation. The rules which have been drawn up and the software modules for site-specific tillage, seeding, fertilising and plant protection are being tested on test farms at 8 locations within Germany. The technology used is being tested and assessed with regard to its suitability in practice and compatibility. The application program will provide the operational and technical data required in order to develop the management system further, as well as the results for the experimental fields. The yield maps, which have been cleared of systematic and random errors, serve as a standard by which to measure the success of the site-specific applications.

Virtual land consolidation

The south German region of Zeilitzheim has been selected as a representative example of regions with a tessellated pattern of land ownership. In Zeilitzheim, each farmer has approximately 37 plots under cultivation with an average size of 0.68 hectares. The high proportion of time spent on moving between the different fields and the small share of time actually spent on the field have negative economical consequences. The resulting farming costs are comparatively high. In principle the traditional methods used for rearranging the order of fields ("land consolidation") is available for improving such a situation. In village communities, however, these plans frequently fail due to the resistance of those businesses, run on a part-time basis, which expect to be put at a disadvantage and see no financial benefits in a new property order. The use of information technology in crop production opens up further options for structural improvements. The use of GPS enables a "virtual land consolidation" when clubbing plots together and creating cross-plot farming (Fig. 12).

Ownership of the fields is still left untouched. However, the cross-plots that are clubbed together can be managed more effectively. To the extent that the owners of the plots and the tenants are willing to co-operate, management requirements can be achieved that are owner-orientated, joint or plot-specific and which can also be altered at short notice. After the first two years, a wealth of knowledge and results are available. The most important of these are shown below:

- Formation of a cross-plot field: The biggest problems came from taking into account the distribution of property on the one hand and the crop rotations required by the businesses taking part on the other. It was only possible to arrive at a joint approach by everyone making concessions. The first cross-plot field brought up some special problems, because sugar beet have additional restrictions due to quotas set by the European Union.
- Size of cross-plot field: Simulations reveal that, with an assumed mean working width of 3 metres and a mean working speed of 8 km/h, increased output of approximately 80% can be achieved in areas of between 7 and 8 hectares.
- Cultivation: There was agreement that the best technology available should be used by the owner of the machine. It was possible to fall back on the specialised knowledge of a farmer involved in the project for the management of the crop. The

harvest was carried out at a supra-business level by combine harvester with attached yield monitor to calculate the yield site-specifically.

Calculation of costs and yields: An economical assessment was carried out on the basis of the data for the first cross-plot field. The additional gross profit for the collaborating farmers was at 150 EUR per hectare for winter wheat and 180 EUR for sugar beets. This is an impressive improvement of profitability for these small farm properties.

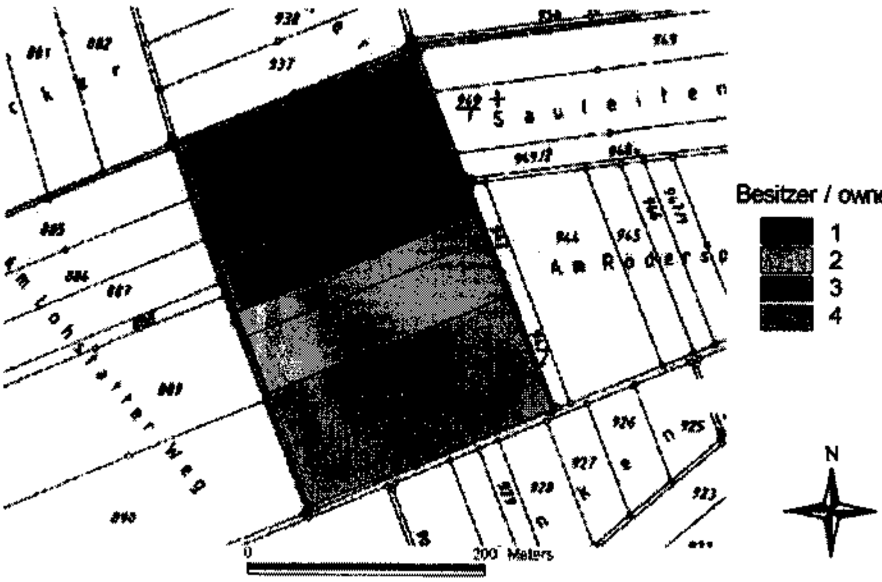

Figure 12: Map of the cross-plot field and the tessellated pattern of ownership at the Zeilitzheim region

Yield Mapping and Error Elimination

Yield mapping is one of the most common applications in precision agriculture. It is well suited to detect the often surprisingly great differences of yield within fields. These spatial patterns are often stable over years, but it is not rare that the patterns change over the years. Therefore, statements can only be made considering the spatial yield structure after applying a multi-year yield mapping. Thus, Preagro does not use yield maps directly to derive agronomic measures. However, yield maps serve as an essential yardstick to assess the success of the site-specific management as applied across the project farms of Preagro.

The yield maps are affected by various errors that do occur during recording and are caused by the sensor system itself. Numerous systems from various manufacturers for measuring yield are in use on the collaborating farms. It is common that yield data from different yield measuring systems are recorded from one field if several combine harvesters are used. Likewise harvesting equipment from various manufacturers will often be used over the years on one field.

Yield data from various yield measuring systems differ considerably (e.g. data file format, information levels, degree of pre-processing). Import filters have been developed for all yield data used in the project. An approach is under development to eliminate data considering the neighbourhood of data points and the position within a harvest strip. At the moment, the yield data is supplied exclusively in the form of grid maps with a grid size of 25 meters (Fig. 13), since the error correction in relation to the point data is still regarded as being inadequate. An accuracy of approximately 1% in relation to an entire potential field of 25 m grid cell size is achieved. Individual point data, on the other hand, can deviate from the true yield by up to 40%.

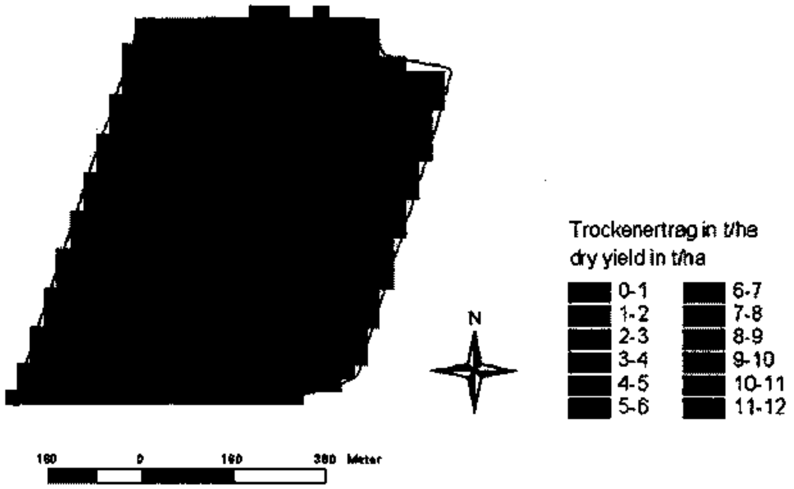

Figure 13: Yield map of the plot "Finkenherd" at Baasdorf in 2000

Farm Support

Farms and contractors were equipped with the technology required for site-specific crop production, as well as advised and supported. The final decision on the purchase of a system was taken by the managers themselves. Thus, throughout the numerous project farming locations there are many different components, in various combinations, from almost all suppliers in the precision agriculture market in use.

Checklist for Precision Agriculture Technologies

General

- compatibility of software and hardware components (LBS or ISO Standard) - reliability of software and electronic components hardware
- simple calibration system, reduction in time required - control sensor equipment for drawing up "as applied" maps - new developments, particularly with regard to plot-specific farming

Software

- comparability of data, standardised filter and interpolation methods - standardised data formats, grid sizes etc. for GIS - universally compatible data formats for all agricultural software

Management

- ensure that people are well informed, establish heterogeneity of plots - formulate realistic expectations. Estimate the required levels of accuracy for the PA technology - co-operation with service providers and consultants - service of firms

Technical Evaluation

Intensive tests regarding the working quality of fertiliser spreaders in combination with common nitrogen fertilisers for variable rate application were conducted. The results of these tests show considerable deviations in the transversal distribution for some spreaders. The majority of the spreader-fertiliser combinations tested showed deviations in transversal distribution between 10 and 15% and thus were tested successfully according to European standards for centrifugal spreaders. The standard requires a deviation less than 15% at constant application rate. An adaptation of the standard taking variable application rate into account has not yet been phrased. Testing revealed the main reasons for the deviations between the planned distribution and the actual distribution of fertiliser. The user can reduce or avoid errors:

- Application rate errors: These can be avoided or reduced by checking the spreader settings regularly and accurately performing calibration
- Positioning errors: High quality DGPS receivers ensure good positioning accuracy
- Longitudinal distribution: Delays in application rate changes caused by long control times was not a problem in the case of the centrifugal spreader tested (tests for full width and forced feeding spreaders are yet to be executed).
- Transversal distribution errors: The form of the transversal spread pattern is the main cause of deviations in the distribution of the fertiliser. The spread pattern is determined by the physical properties of the fertiliser as well as the setting and mechanics of the spreader.

  It is critical that the spreader is set accordingly for each specific fertiliser. The manufacturers' recommendations should be followed in order to find an optimised setting.

  The settings must be checked with the aid of spread patterns and field test kits for each fertiliser, and additionally for different shipments of fertiliser.

  Easy spreader setting adjustment, simple ways of optimisations and good results from independent testing guarantee an all-time good result in spreader distribution. Unfortunately, no general rules of spreader setting adjustment for variable rate fertilisation can be deduced. The influence of the physical properties of fertiliser on the various types of spreaders is too difficult to predict to allow any advice independent of spreader and fertiliser.

Standardisation

The standard of DIN 9684 'LBS' (agricultural interface system) is available for the purpose of achieving uniformity of the signal and control information in the field of instrument technology. In the autumn of 2000, the major suppliers of farm machinery, electronics and software used in German agriculture agreed on a common plan of action. They will use the LBS standard in a slightly adapted form (LBS+) in connection with their equipment and software. This is a step towards further security for suppliers and users with regard to the compatibility of engineering components used for precision agriculture. Agreeing to this variant of the LBS standard allows the manufacturers of tractors and equipment to continue developing electronics for use in the control and monitoring of agricultural equipment. This involves, in particular, the control of application technology in precision agriculture through on-board electronics for tractors and self-propelled equipment. By switching over to the LBS standard it is guaranteed that control and monitoring control systems for agricultural equipment and transmission technology will still fit in future with international standards.

ISO Standard 11783, which is based to a large extent on the German LBS standard, is being worked on at present. It is expected that a definitive version of the ISO standard will be available in the next three to five years. The equipment and electronic systems based on the LBS standard will, furthermore, be kept compatible with one another as well as with the operating systems that might be introduced in the future in accordance with the ISO standard by adapting the software. For the harmonisation of data exchange the standards LBS = DIN 9648 (existing) or ISO 11783 (in preparation) can be a solution. To reduce the number of different control devices and computers that are needed is the main goal. The standardisation of I/O data formats and compatibility between agricultural software products will promise for the future that only one software package will need training, handling and operation.

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