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25 years Precision Agriculture in Germany – a retrospective

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Abstract.

It all started with the availability of Global Positioning Systems for civil services in 1988. In the same year variable rate applications of fertilizers were demonstrated in northern Germany and Denmark, which were globally the first of their kind and introduced a new era of agricultural production. The idea of Computer Aided Farming (CAF) was born. Only one year later the first yield maps were established. In 1992 at the Soil Specific Crop Management Workshop in Bloomington, Minnesota which later on signed with International Conference on Precision Agriculture the very first scientific presentation of a GPS assisted site-specific nutrient management was presented by the German pioneers. Since then the specialists developed for example innovative strategies for efficient soil and crop sampling, algorithms for the variable rate application of mineral and organic fertilizers providing a balanced nutrient input, and stationary remote sensing devices for the continuous surveillance of crops and soils. Though the tools are ready, the implementation of PA technologies has been only marginal. The reasons are complex data handling, weak system integration between manufacturers and an insufficiently high economic return of the investment which might change with full automation in agriculture.

Keywords.
Balanced fertilization, Local Resource Management (LRM), LOcal Ressource Information System (LORIS), yield mapping; Low Altitude Stationary Surveillance Instrumental Equipment (LASSIE): Remote Sensing

From Dead Reckoning to Global Positioning System (GPS)

In history innovative developments and inventions for originally military purposes have found new fields of application in agriculture. For instance the rapid growth of chemical plant protection after World War I was based on the chemical know-how for the production of poison gases for trench warfare (Schilthuis 1994). In 1988, the first devices of a Global Positioning System (GPS) became available for civil scopes. However, the cost-performance ratio was extremely poor for a device that cost 20,000 € at the time being (Fig. 1). The reasons are that the number of satellites was strictly limited so that the signal was easily lost in hilly, forested terrain. The accuracy was marginal with ±50 meter at best. It deteriorated completely when the military switched on the “selected availability” code for security purposes. Despite these shortcomings the GPS technology was a breakthrough for navigation and positioning in the field. Meanwhile the Global Navigation Satellite System (GNSS) is employed for positioning and navigation on earth and in space. The price for high sensitivity GPS chips with precision in the cm range for auto-navigation, mobile phones and handheld GPS receivers is currently less than 10,000 €.

Prior to GPS positioning, variable rate input of agrochemicals depended on dead reckoning for example by employing the tramline system in combination with ordinance survey maps and topographical surveying in the field (Haneklaus et al. 1997). This approach was labor-intensive, worked, however, satisfactory in flatland areas. In hilly terrain the system failed because of the slip of the machinery.

Fig 1. First GPS system and bord computer employed in agriculture in Germany

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Computer Aided Farming (CAF), Local Resource Management (LRM), Precision Agriculture (PA)

In the 1980s computer aided technology boomed and since then speed of data processing and storage capacities multiplied continuously while the price level decreased at the same pace. The spatial variability of soil and crop features has been studied from field to regional scale in northern Germany (Knoop et al. 1985, Lamp and Schnug 1987, Schnug et al. 1989). The geo-statistical analysis of soil and crop data took days to perform at that time. First digital agro resource maps were created and a modular concept, Computer Aided Farming (CAF), developed in order to transform spatial information for instance into fertilizer application maps (Lamp and Schnug 1987, Schnug et al. 1990). In July 1989 the first public demonstration of variable rate application of the herbicide phenmedipham in dependence on the small-scale variation of the soil organic matter content was demonstrated in Birkenmoor, northern Germany (YouTube 1989). The next television broadcasts followed in 1991 in Northumbria, UK (YouTube 1991a and b) and 1993 and 1995 in northern Germany (YouTube 1993 and 1995), which presented the principles of online yield mapping and variable rate (VR) applications. Local Resource Management (LRM) was the consequent further development of CAF (Schnug et al. 1993) (Fig. 2). LRM addresses the small-scale variability of soil and crop features and consequently translates this knowledge into VR applications. LRM combines traditional methods of field and laboratory soil science with geo-statistics, data management and interpretation by GIS (Geographical Information Systems specifically developed for agricultural purposes such as the LOcal Resource Information System (LORIS™)) together with GPS positioning and navigation). The technical part of LRM, namely the use of GPS, GIS and VR application technology in agriculture are integrated under the term Precision Agriculture (PA) (Haneklaus et al. 1997).

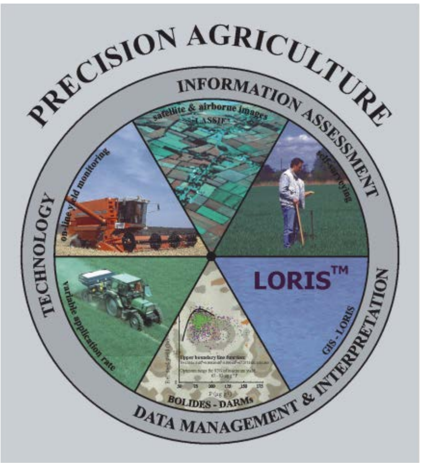

Fig 2. The modular principle of Local Resource Management (LRM) (Lilienthal et al. 2004a)

In the presented retrospect main emphasis has been put on advances in PA in Germany with view to data acquisition, interpretation and conversion into options for actions.

Geocoded Sampling and Mapping

Geocoded sampling is a major prerequisite in PA and ground truthing is essential if spectral images are used for decision making.

Grid sampling is usually performed in scientific studies rather than on production fields. Here, sampling efforts need to be reduced efficiently without losing spatial information. The pivotal point is that sampling locations represent the entire range of variation within one field. Images from remote sensing and yield maps proved to be suitable to identify equifertiles, zones of similar crop productivity as a basis for directed sampling (Haneklaus et al. 2000). Based on sampling locations chosen for directed sampling the sampling number is further reduced to so-called monitor pedo cells. These mirror permanent control plots which reflect temporal changes in zones of same crop productivity and thus provide information about causal factors inducing differences in crop performance (Haneklaus et al. 2000). Another advantage of monitor pedo cells is that spatial correlations are perpetuated.

The first digital agro resource maps in black and white based on GPS positioning were yield maps (Haneklaus et al. 1991). The effect of such maps on farmers back then can be compared to food porn nowadays (Anonymous 2016). As is quality the critical parameter for food it is the quality of the yield data for PA. Haneklaus et al. (2001) showed that the processing of raw yield data is necessary and needs to comply with defined routines in order to extract valid figures. Yield maps based on automatic corrections which cannot be followed up by the customer have to be seen critical. Yet other essential points with regard to yield mapping proved to be calibration with weighing counts and grain moisture content, respectively (Haneklaus et al. 2001).

LORIS™ (Local Resource Information System) was the first GIS software which was designed to manage geo-referenced agricultural data (Schnug und Junge 1994; Schroeder et al. 1997). In LORIS™ data from different sources, for example GIS files, point/polygon data from GPS systems and digitizers and yield maps can be imported. Gridded data are stored and can be computed mathematically without constraints according to customer algorithms for producing digital agro resource maps. These algorithms are stored in a so-called prescription library. For example, universal algorithms for the application of straight and compound mineral fertilizers, and manure have been developed which assure a balanced input of nutrients either within one year, or within one crop rotation (Haneklaus and Schnug 2006; Haneklaus et al. 2016). Operation maps can be exported in different file formats (Schroeder et al. 1997).

The term site in site-specific nutrient management may be chosen for different fields (Dobermann and White, 1999) or independent management zones. A management zone was defined by Doerge (1998) as "a portion of a field that expresses a homogenous combination of yield limiting factors for which a single rate of a specific crop input is appropriate". The question, whether VR fertilization should preferably operate in a continuous context or in discrete management zones is still open. However, Thrikawala et al. (1998) expect an increase of the fertilizer utilization efficiency with decreasing management unit sizes and increase in spatial variability. Besides this the scale of temporal variation, its impact on crop yield in the ranking with other growth factors, the bandwidth of the optimum nutrient range, the response in terms of yield and the scale of variation of the input are other important criteria. In other words, if the spatial and temporal variation of the nutrient is high, and the optimum range only small, yield fluctuations need to be faced when the nutrient supply is slightly below or above the optimum and if crop performance is primarily dependent on a sufficient supply of this nutrient, a continuous mode is supposedly preferable for matching the site-specific nutrient demand.

On-site experimentation

PA technology enables farmers to set up their own experimentation for a truly site-specific management (Fig. 2). Here, it is possible to determine yield limiting factors, optimum nutrient ranges in soils and plants, the site-specific yield potential, temporal changes in the nutrient supply and the crop-specific nutrient demand, and to quantify the yield response of agro-technical measures (Haneklaus and Schnug 2006).

One of the most effective PA applications is VR liming. The optimum soil pH is a compromise between plant availability of micro-nutrients and soil structure. The optimum range of pH values for achieving maximum yield was determined employing BOLIDES (Boundary Line Development System) (Fig. 3). Following the BOLIDES approach, the pH values were plotted against the relative grain yield data from three consecutive years. The upper boundary line function lies on the upper edge of the body of the data and describes the relationship between pH and grain yield, if no other growth factor is yield limiting. For the field investigated this means that in the range between pH 6.1 and 6.4 highest yields can be expected (Fig. 3). Different pH optima in dependence on the variation of the clay content were not observed. The lime requirement has been determined *in situ* by establishing a buffer curve.

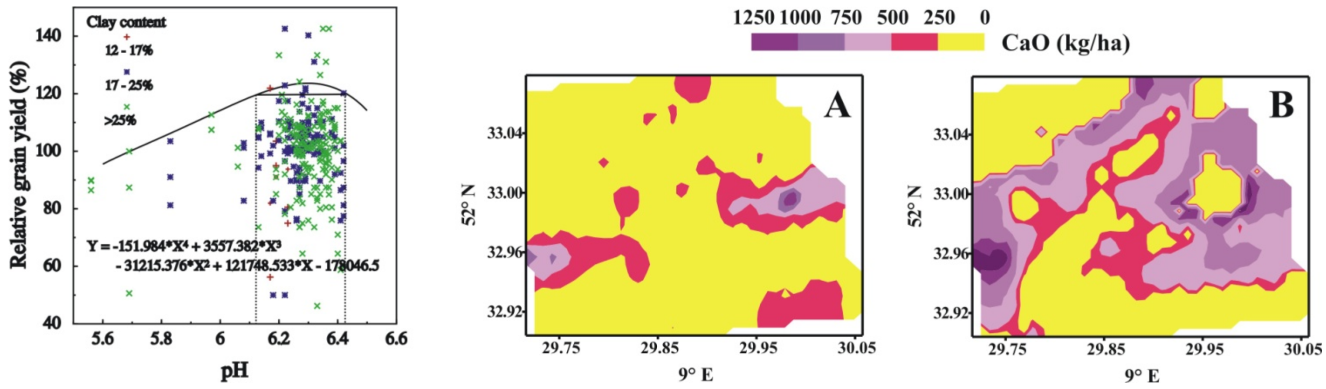

Fig 3. Left: Assessment of the optimum range (6.1 - 6.4) of pH values in the top soil (n=312) of a field in Mariensee, northern Germany by BOLIDES; Right: Lime application maps A) based on the determination of optimum pH range by BOLIDES and B) based on the general recommendation for optimum pH values in relation to the spatial variation of the clay content [the lime requirement was calculated on basis of the buffer curves (Haneklaus and Schnug 2000)

A uniform application rate of lime based on average pH and soil texture would have yielded a lime dose of 440 kg/ha CaO while the mean VR application rate of lime was only 252 kg/ha when based on general liming recommendations and even lower with 201 kg/ha when based on BOLIDES. Uniform application rates would have caused 343% higher costs compared to VR application based on BOLIDES (Haneklaus and Schnug 2000). VR liming is one of the few profitable fertilizer applications. In case of all other nutrients VR fertilizer applications will only result in savings if the supply is higher than the optimum. On livestock farms, regularly the disposal of farmyard manure rather than the demand-driven application of nutrients is prevailing (Haneklaus et al. 2016). VR application of manure conveys a lot of gain for a truly sustainable phosphorus (P) use that reduces environmental burdens from P losses to water bodies, but it will yield extra costs for the farmers who need to find alternative ways of utilization (Haneklaus et al. 2016).

Remote Sensing

When the first aerial photographs were taken at the beginning of the 20th century (Loeffler 1994), the potential benefits of remote sensing for agricultural purposes were already obvious.

Important differential diagnostic criteria for identifying the true cause of visible symptoms of plants are spatial patterns and coincidences with soil characteristics which require real-time surveillance of crops. During the vegetation period for instance, the spatial pattern of signatures of flowering oilseed rape or ripening barley reflect dynamic information about the spatial variation of the soil water regime. Additionally, the progression of disease and pest development can be tracked if time sequences of less than three days are available. Any time, real-time and cost-effective remote sensing is the ultimate expectation for agricultural purposes. LASSIE (Low Altitude Stationary Surveillance Instrumental Equipment) enables the continuous recording of real-time images of crop and soil surfaces which are automatically rectified and geo-referenced in a GIS (Fig. 4; Lilienthal et al. 2004b). Such data processing has been laborious 15 years ago, while meanwhile software is available which performs the required conversions automatically (Agisoft 2016).Changes in crop performance become easily identifiable with LASSIE and causes can be identified by an accompanying directed ground truth. The results of soil/crop analysis can then be more or less instantly transferred into variable rate management on the fields.

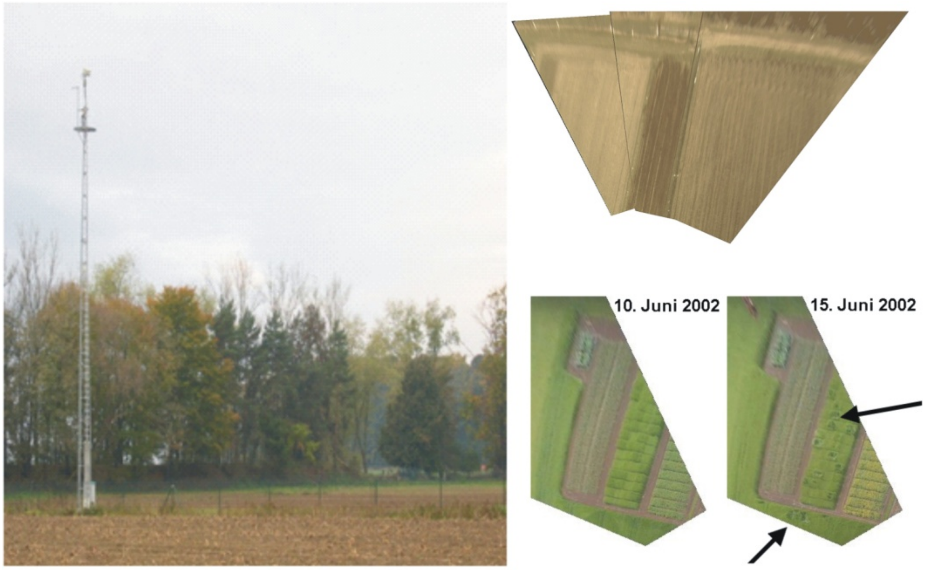

Fig 4. Principle of LASSIE (Left: pole with 360° rotating digital camera with flexible tilt; Right, top: conversion of aligned, oblique images into a geocoded pseudo-nadir image; Right, bottom: dynamic mapping (Lilienthal et al. 2004b))

VR application of N is popular among farmers. Various ground-based sensors are employed to estimate the N demand and adapt N rates accordingly. Among all nutrients N has the strongest effect on the chlorophyll content of plants and reflectance spectra are used to determine NDVI and red edge, which are set in relation to the chlorophyll content or N status. Thus the causal chain: green color of plants – chlorophyll content – protein content – total N content – N status of plants has been extended by N supply of plants from the soil, ignoring basic knowledge of natural science. The first two assumptions are valid under *ceteris paribus* conditions as there are many more factors affecting the green color of plants and chlorophyll content than just N, as for instance deficiency of other nutrients such as S, K, Mg, Mn, Zn and Cu, genetic dispositions, pests and diseases, drought, water logging, soil compactions and other physiological disorders. Images of the vegetated soil reveal different patterns in the field, but causal factors are unknown so that a ground truth is inevitable. The same applies to low-cost hyperspectral spectrometers which permit pseudo-imaging with the Penta-Spek system in order to assess spatial variation of crop parameters such as N status, LAI, grain protein content and yield. Bottom line is that no matter how sophisticated sensor technology might be, validation of data must be obligatory for producing precise and reliable results.

Conclusion

The future of PA is difficult to predict as the retrospective has shown. Local knowledge and field inspection are inevitable as are advanced computing skills. PA technology could really make a difference to reducing diffuse nutrient losses and to apply limited resources such as P in a sustainable manner. Though the advantages are obvious and intrinsic, implementation is unsatisfactory. Even if nutrient budgets for a farm within one crop rotation are obligatory as in Denmark and associated with losses in yield and quality of the harvested crops (Knudsen and Schnug 2016), this has not pushed acceptance of PA to compensate nutrient deficits by adjusting rates to spatial variation of soil fertility parameters. The key problems are poor earnings by the investment, time expenditure, and biological, mathematical and technical know-how. The saving of labour costs by replacement of operators with autonomous vehicles and tractors might improve the economic situation. However, history of PA has like any cutting-edge development its embarrassing moments when individuals plagiarize ideas shared previously with the science community (US 7050910, 2006). New technologies need genuine pioneers, no copycats!

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