# 1 GIS in Agriculture

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**Abstract Start**

Abstract

Since the beginning of the 1990s, modern agriculture and farming has changed dramatically. Agriculture has become a high-tech industry. With the possibility for locating agricultural machinery in the field using satellite positioning technologies (Global Navigation Satellite Systems, GNSS) and the increasing availability of geographic information in digital form and in increasing quality, farmers are now able to measure the spatial and temporal variability in soil, vegetation, relief, etc. within a field and to modify their operations to react to this. Farmers keep electronic field records and farm diaries, which they are able to use on-site with mobile electronic devices in order to enter or retrieve information. Agricultural machinery is also being continuously developed, since due to the in-field heterogeneity many different operations (from yield mapping to plant protection) are performed on-site and logged so that they may be later evaluated by computer. Due to legal regulations (IACS, cross-compliance, traceability, quality management, etc.), GIS (and GeoWeb services) and information-driven crop production are becoming common tools in agriculture, which must be integrated into usual farm practices.

**Abstract Stop**

# 2 Abbreviations

3-D
three-dimensional
ALKIS
Amtliches Liegenschaftskataster-Informationssystem, Authoritative Real Estate Cadastre Information System
ATKIS
Amtliches Topographisch-Kartographisches Informationssystem, Authoritative Topographic and Cartographic Information System
BIS
Bodeninformationssystem, soil information systems
DGK 5
Deutsche Grundkarte, German Topographic Basemap
DLM
Digital Landscape Model
DOP 20/40
Digital Orthophoto 20cm/40cm
DTK 10/25/50/100/250
Digitale Topographische Karte, Digital Topographic Map (in various scales)

| | |
|---|---|
| DTM 1/2/5/25/50 | Digital terrain model (in various ground resolutions) |
| ECa | apparent electrical conductivity |
| FMIS | farm management information system |
| GI | geographic information |
| GIS | Geographic Information System |
| GLONASS | Globalnaya Navigatsionnaya Sputnikovaya Sistema |
| GML | Geography Markup Language |
| GNSS | Global Navigation Satellite System |
| GPS | Global Positioning System |
| IACS | EU Integrated Administration and Control System |
| IoT | Internet of Things |
| ISO | International Organization for Standardization |
| IT | information technology |
| JD | Julian date |
| LAI | leaf area index |
| LIDAR | light detection and ranging, Laser Scanning |
| LPIS | Land Parcel Information System |
| MZ | management zone |
| NDVI | normalized difference vegetation index |
| NIR | Near Infrared |
| OGC | Open Geospatial Consortium |
| PC | Personal Computer |
| RFID | Radio Frequency Identification |
| RTK | Real Time Kinematic |
| SAPOS | Satellitenpositionierungsdienst (German Satellite Positioning Service) |
| SDI | spatial data infrastructure |
| TCM | terrain compensation module |
| TIN | |

Triangular Irregular Network

UAV / UAS
: unmanned aerial vehicle / unmanned aircraft system (commonly known as drones)

VRT
: variable rate technology

WMS
: Web Map Service

WFS
: Web Feature Service

WPS
: Web Processing Service

XML
: Extensible Markup Language

## 2.1 Motivation

Maps have been used for many years in agriculture, for instance, cadastral maps (Chap. 19) for the sale or leasing of farmland, or soil maps to better understand the properties of the land. These were combined with the local knowledge of the farmer and the available agricultural machinery to make field management decisions. Due to the limited amount of mapped detail and technical capabilities, decisions were invariably made at the level of whole field plots.

Since the start of the 1990s, modern land management has changed dramatically. Agriculture has become a high-technology industry. With the capability for locating agricultural machinery in the field using satellite positioning technologies (Chaps. 8 and 9; global navigation satellite systems, GNSS) and the increasing availability of geographic information in digital form and in increasing quality, farmers are now able to measure the spatial and temporal variability in soil, vegetation, relief, etc. within a field and to modify their operations to react to this. Farmers keep electronic field records and farm diaries, which they are able to use on-site via smartphones or tablets to enter or retrieve information [1, 2].

Agricultural machinery is also being continuously developed, since due to in-field heterogeneity many different operations (from yield mapping to plant protection) are performed on-site and logged so that they may be evaluated later by computer. This topic will be investigated further in Sect. 24.4. Machinery is now adorned with a plethora of application devices and onboard computers, which are now becoming standardized with the introduction of the so-called ISOBUS standard (ISO 11783). Similar to the interoperability initiatives in the geographical information (GI) community, this standardization aims to support common, lossless, continuous use of the large quantity of available data along the whole agricultural value chain.

In the European Union (EU), agriculture is tightly legally regulated, but also state supported. Applications for subsidies have, for a number of years, been performed digitally, and since 2005 directly on the basis of spatial information. This has led to the fact that, in the EU countries, agricultural parcels are fully digitized in geographical information systems (GIS), which will be further discussed in Sect. 24.3. Such regulations, and the volume of requirements with which a farmer is confronted, lead to information-driven agriculture. This requires the cooperation of all actors (farmers, various contractors, machinery syndicates, seed producers, and buyers from traders through to consumers) along the whole value-added chain and a continuous information flow and decision process.

A multitude of providers of specific geoinformation (e.g., official bodies, geoinformation brokers) are available to farmers; there are also increasing numbers of information- and decision-support systems for agriculture.

With these few examples, the driving forces and the increased pressure for GIS use in agriculture at a high technical level are indicated. When the use of GIS in agriculture is discussed here, this must be taken in the context of the many agricultural systems, the different political and social structures, the varying surrounding conditions, and the extremely variable farm sizes in different parts of the world. This is illustrated by the example of farm sizes in two European countries: the average farm size in Switzerland is around 14 ha, mainly in smallholdings. In Germany the average size is around 45 ha with an extreme north–south and east–west differentiation. For instance, in Mecklenburg-Vorpommern, the average farm site is around 250 ha and some agricultural concerns manage farms larger than 1000 ha.

From this, we can say in advance that most of the statements in this section are related to parts of the *developed* world, in which high-technology agriculture has been adopted and where the use of GIS has become a general matter of course.

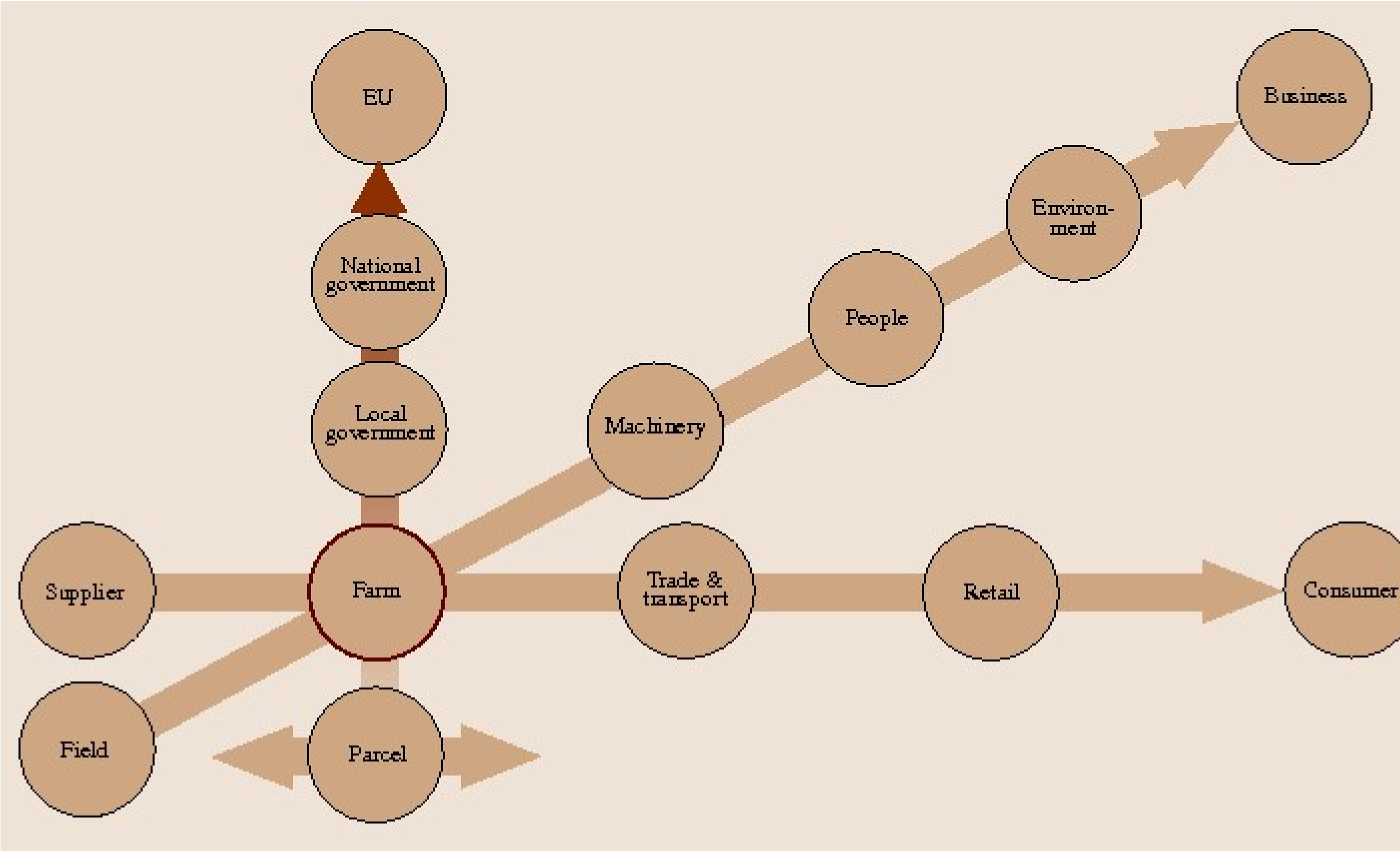
The spatial dimension of agriculture is easily identified: cropland, pastures, plantations, and grazing land define the rural landscape in large parts of the world. The overall effects of local and regional environmental conditions on agriculture are also superficially easy to identify, with patterns of agricultural land use dependent on soil type, climatic conditions, availability of water, etc., and thus differing across different regions of the globe. Potential uses of GI technologies in agriculture are also readily apparent. On the one hand, the basic information related to agricultural parcels such as usage type, yield, and records of operations such as plowing and fertilization have an inherent spatial (and usually also temporal) reference. On the other hand, analysis of site-specific conditions and the reaction of crops and animals to these may assist the farmer in more efficient agriculture. At a national and regional level, this is already practiced, e.g., in the production of recommended varieties and fertilization recommendations, but it may also be used at a part-field level to optimize use of resources within individual crop stands.

Currently there is a vast range of products for agriculture: machinery producers (Full-Liner, Komatsu) and company consortiums offer complete agricultural software solutions, which also include a GIS module, e.g., AGRO-NET, AgroOffice, JD-Office, Helm, etc. Many small (GIS) vendors concentrate on regional markets with proprietary solutions and special services for farmers, e.g., as information technology (IT) vendors and contractors or as value-added resellers of geographic base data. There is also an increasing trend towards expert systems and specialized web-based applications with GIS functionality (ISIP, Yara Sensor Office, Pro-Plant expert, etc.). However, most of the development of agricultural software solutions is driven by vendors and authorities and has let to non or only partly standardized products and services.

## 2.2 Spatial Data in Agriculture

Spatial data related to agriculture may be collected on the farm or provided by external agencies, and farmers must often provide spatially referenced data to a range of third parties, in administration, in agricultural support services, and in the value-added chain. Three dimensions of agriculture are therefore often postulated (**Fig. 1**), representing different chains through which spatially referenced agricultural data may be exchanged.

**Fig. 1 The three dimensions of agricultural data (after [3])**



The use of geographic information in agriculture will be considered here in three categories:

1. GI as a reference system for management of data relating to farms and fields
2. GI as a supporting tool for performing field operations (e.g., driver guidance and autosteering)
3. GI as a source of information for making and implementing agronomic decisions (site-specific or information-driven farming)

Both the second and third of these categories may be grouped together under the umbrella term *precision agriculture* (Sect. 24.4). However, many of these aspects rely on a common data basis and so we will first consider some of the common data sources for geodata in agriculture.

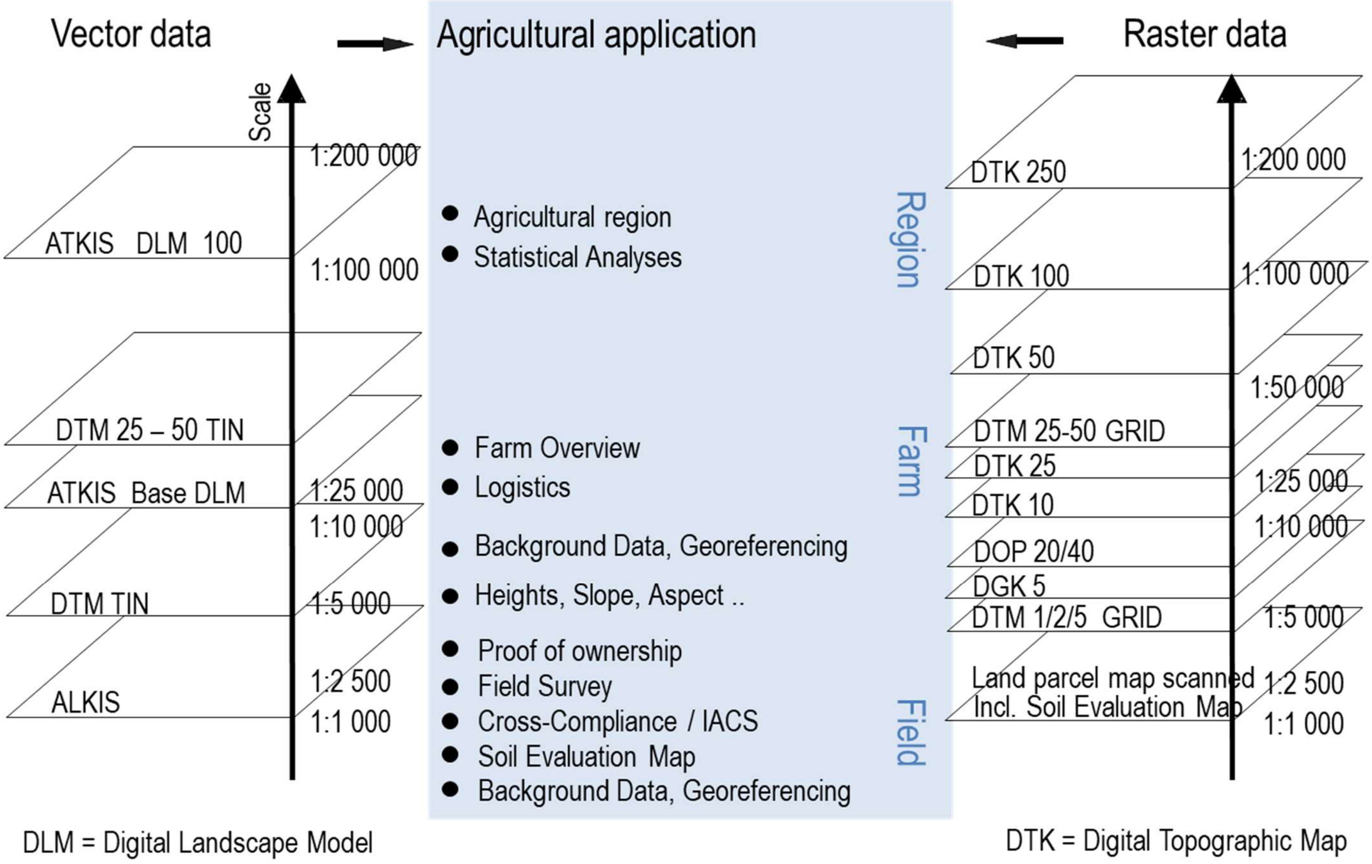
### 2.2.1 Data Sources

The data sources, information processing, and decision processes in precision agriculture have been the focus of recent and ongoing research [4, 5]. One key factor in the choice of data sources is the availability of data; e.g., in some countries, such as Germany, nationwide datasets of soil type are available and form a basis for identifying heterogeneity. We will therefore concentrate on the available data, based initially on that which is commonly available in Germany. Comparable data are available in most other developed countries.

#### 2.2.1.1 Basic Geodata from Administrative Surveys

In Germany, the survey and cadastre administrations produce so-called geo base data for business and government. According to their legal commission, these are produced nationwide, currently provided via standardized OGC web services, and as far as possible consistent across the total area of the federal republic. Their relevance for agricultural applications is shown in Fig. 2. For the management of leaseholds and other farmed land, property rights from the cadastral system are very relevant and are also required for the EU Integrated Administration and Control System (IACS (Sect. 24.3)). Currently an integrated model of the former real estate map (the parcels, their geometry and usage) and the real estate book (the ownership and rights) into the new Authoritative Real Estate Cadastre Information System (called *Amtliches Liegenschaftskataster-Informationssystem*, ALKIS) is available all over Germany. Topographic maps – as part of the existing Authoritative Topographic and Cartographic Information System (called *Amtliches Topographisch-Kartographisches Informationssystem*, ATKIS) – are often used only as background information for farm overviews, although, e.g., the road infrastructure may be used for fleet management. Administrative boundaries are mainly of relevance for regional and national agricultural statistics.

**Fig. 2 Geo base data and their applications in agriculture** (after [6])



Digital terrain models (DTM) represent the relief of a landscape in digital form. In Germany they are available in different resolutions (from 1 to 50m grid size) and quality (from dm to some m height accuracy). As the main determining factor for radiation and water balances, the relief controls soil development, the rate of runoff and leaching, material transport, and microclimates, and plays a central role in site-specific differences in agriculture. The DTM may be used for spatial and temporal predictions of the properties of the crop stand and its growth. It may be straightforwardly interpreted, is easily managed by computer, and has relatively high data stability. The relief has influences on the local climate (e.g., differences in sun exposure and cold air flow), lateral material transport, movement of surface water, and abrasion and accumulation of matter. DTM in combination with the official soil evaluation are also of particular relevance – especially in relation to soil management. Soil formation processes and yield differences are strongly correlated with the relief. From the DTM it is also possible to deduce whether particular machines may be used due to slope angle, and differences in machine performance (dampness, soil compaction) may be interpreted. Currently there is a trend towards capture of terrain models using digital photogrammetry and/or airborne laser scanning, which may produce data with more details and higher accuracy.

*Soil evaluation* is based on a Germany-wide method for description of soils. The original data of the earlier *Reichsbodenschätzung* are held in the field evaluation books (*Feldschätzbüchern*) of the fiscal authorities. They are available as an extra layer for the cadastral maps at a scale of 1:2000 to 1:5000, and are often digitized and prepared for GIS use. In some federal states the information is provided as a free WMS-Service. These maps show the spatial extent of the soil number (*Bodenzahl*, a measure of estimated agricultural productivity), the main soil type, the soil condition, and the geological background. A further dataset is a description of bore holes, at which soil type, humus content, hydromorphology, and lime content are recorded in two to four layers. Where newer soil mapping is not available, these datasets still represent a good information basis for tillage, sowing, and base fertilization [7].

#### 2.2.1.2 Specialist Administrative Geodata

Today, nearly all information related to the landscape is represented in map form. Similar to the governmental cadastral and survey agencies, other state bodies are also tending to deliver information derived from the analogue map materials in digital form.

This is for instance the case for the soil, geological, and geomorphological map series, which are gathered and maintained by the state geoscientific agencies nationwide in the so-called soil information systems (*Bodeninformationssystem*, BIS) as a comprehensive and systematic soil inventory. As well as soil science data, the BIS includes data on the geological composition of the Earth’s upper crust alongside information on hydrogeology, resilience, engineering geology, and geochemistry. They contain descriptions of the local distribution of soil types and their properties such as soil structure, humus content, pH value, soil density, parent material, and upper-layer water balance. Soil mapping includes selective sampling through drilling and/or on the basis of test pits as well as the spatial extents of regions with identical soil properties or, depending on scale, similar properties. Usually the pedosphere is sampled to a depth of 2 m under the surface. Mapping on the basis of probes may, as well as soil type, also show the soil capacity or the erosion risk. The data are represented as probe descriptions, analyses, and thematic maps at various scales. Most of them are made available via standardized web services.

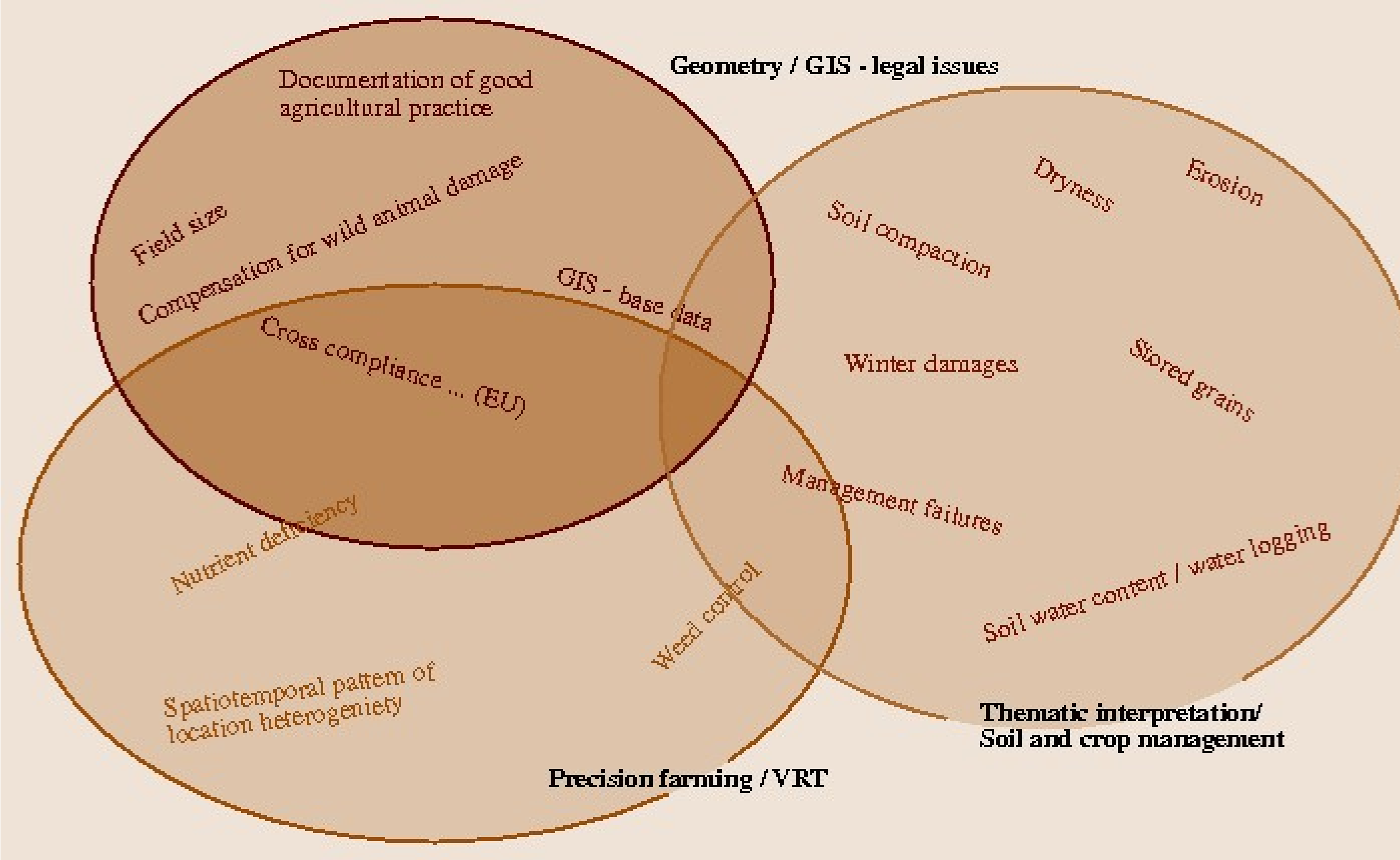
Within the EU-wide Integrated Administration and Control System (IACS (Sect. 24.3)) for the monitoring and implementation of a consistent agricultural policy in the EU member states, the state agricultural agencies now hold contiguous parcel maps of all agricultural land. These are held digitally and are usually available via web services (e.g., in Rhineland-Palatinate at http://www.geoportal.rlp.de/ or in Bavaria at www.geoportal.bayern.de/. IACS is used for calculating subsidy payments to farmers and controls whether the correct crop type was grown and whether the stated extent was correct. The basic unit for the so-called multiple application is the field plot or physical field block.

### 2.2.2 Remote Sensing

The use of remote sensing data has a long tradition in agriculture [8]. Both satellite-mounted and aerial sensors are used as well as sensors mounted on agricultural machinery. While satellite remote sensing is mainly used in the national and international range, e.g., for prediction of droughts, remote sensing data is also used at the farm level, e.g., for the determination of parcel sizes for EU subsidy payments and as base data in precision farming. The potential of remote-sensing data for farm-level plant production is great, as shown in Fig. 3.

**Fig. 3 Potential applications of remote sensing in plant production (VRT = variable rate**

**technology)**



As this figure makes clear, remote-sensing information can be used not only for precision farming in the narrow sense but also as a basis for the interpretation, together with advisors and experts, required to answer many questions regarding soil and crop management. However, this information is required in near real time and where possible in all weather conditions. Therefore, the use of specialized aerial photography missions or the use of drones or unmanned aerial vehicles (UAVs) is necessary. The use of tractors with special sensors (nitrogen sensor, Crop-Circle, CropSpec, NIRS-sensors) to measure the variability of water and nitrogen content and some other parameters has proved to be helpful for certain applications.

## 2.2.3 Internal Farm Geoinformation

### 2.2.3.1 Parcel Measurements

One fundamental spatial dataset required for use of GI in agriculture is the exact boundary of each field and/or crop stand. Even where digital cadastral or topographic mapping is available to the farmer, it is usually necessary to capture the boundaries, as they may not match land parcel boundaries or the features shown on a topographic map. The accuracy requirements for boundary measurement are defined by law for some purposes, e.g., IACS (Sect. 24.3). Although in some cases the boundaries may be captured using traditional survey methods, two common methods are capture using GNSS, for which the boundary of each field is simply traversed with a high-accuracy GNSS receiver (real time kinematic, RTK), or manual tracing from precise orthophotos, produced by aerial imagery or UAV imagery. In both of these cases, it is possible to capture new boundaries, e.g., where an existing field is planted with two different crops, creating two new crop stand boundaries, with relatively low cost, high precision and good actuality.

### 2.2.3.2 High-Precision DTM

As an alternative to the official DTMs from the state survey agencies, it is also possible to produce a *high-precision DTM* using DGNSS (differential GNSS), either using existing farm equipment such as may be used as the basis for parallel driving systems (in *GNSS Guidance and Autosteer Systems*) or as a service provided by a contractor [7, 9]. Such a survey is completed using two high-quality GNSS receivers with an accuracy of ± 2–5 cm. With one receiver at a known point (Chap. 8) or using a reference signal, e.g., from a satellite positioning service (e.g., StarFIRE, SAPOS (German satellite positioning service)), the majority of error sources may be corrected directly in the field (RTK mode) with height accuracy of 10–15 cm [10]. The height of the terrain is collected during field operations, and this may be combined with other data collection, e.g., EM38, or during normal operations in the drive lanes.

#### 2.2.3.3 On-Site Collection

*Soil samples* are, as a rule, collected every 6 years (minimum legal requirement of one sample per 5 ha every 6 years) in order to determine soil texture, nutrient content (Ka, P, Mg, etc.), pH, humus content, cation exchange capacity, etc. For planning of sample locations there are two approaches: raster sampling and directed sampling. Raster sampling is the standard for precision farming, whereas directed sampling is an interesting alternative where there is already good knowledge of the crop stand. In raster sampling, 20–40 individual samples are combined into a mixed sample, either around a single point, along a diagonal or in a zigzag pattern. From the chemical analysis, farm soil maps and management zones may be generated to form part of the decision process for agronomic applications.

An alternative approach has been presented by Peets et al. (2012) with the use of on-the-go sensors for the collection of soil properties [S. Peets, A.M. Mouazen, K. Blackburn, B. Kuang, J. Wiebensohn: Methods and procedures for automatic collection and management of data acquired from on-the-go sensors with application to on-the-go soil sensors. Computers and Electronics in Agriculture 81 (0), 104–112. doi:10.1016/j.compag.2011.11.011(2012)44]. This approach uses mobile VIS-NIR spectroscopy in the field to measure soil spectra in a high resolution. The measured values are then compared with properties of soil samples to establish a typical soil model which can then be used to predict soil properties from VIS-NIR spectra data. The number of measurements increases significantly (comparable with other GNSS-based field operations) and could serve as a source for precise soil fertilization and liming operations.

During the crop growth season, plant ratings and field measurements are performed, usually supported by GNSS. These may be used, e.g., for calculation of crop density, derivation of total biomass, or for mapping of weed distribution, which are in turn used as the basis for decisions for agricultural operations. Farmers may also perform their own field trials (parcel-based on-farm experiments), which will also be mapped and contribute to the sum of farm-internal data for management of crop production.

### 2.2.4 Other Data

Further spatially referenced datasets are also used in agriculture. One example is weather data, which may on the one hand be obtained from national meteorological agencies or on the other hand be provided by on-farm or regional weather stations serving the agricultural community. The record of past conditions and forecast future conditions play an important role in decision making, e.g., spraying operations may be forbidden or not possible during rain or high winds, and many operations are not possible while the soil is frozen. In areas with limited water availability, decisions on irrigation and other inputs where the uptake is dependent on sufficient available water, the need for locally generated rainfall records and forecasts are also immediately apparent.

## 2.3 Integrated Administration and Control System

### 2.3.1 Integrated Administration and Control System

The Integrated Administration and Control System (IACS) was introduced in 1992 by EU Council Regulation 3508/92. The aim of this system is more effective administration of financial aid payments to farmers, and to more easily prevent fraud by allowing cross-checking. This legislation required each member state of the EU to set up a computerized database system comprising an alphanumeric identification system for agricultural parcels based on land registry maps and documents, other cartographic references, or of aerial photographs or satellite pictures, or other equivalent supporting references, or on the basis of more than one of these elements.

Although the requirement was specified to identify agricultural parcels, particularly with respect to support schemes linked to surface area, no requirements were specified with regard to storage and management of spatial data. However, due to the use of GI-based systems in all member states and the increasingly widespread availability of GI systems and data, this regulation was amended in 2000 by EU Council Regulation 1593/2000 to mandate explicitly the use of GIS for identification of agricultural parcels, specifying that accuracy should be guaranteed equivalent to 1:10000 topographic mapping.

Furthermore, "… Member States shall simplify the application process by distributing pre-printed forms based on the areas determined in the previous year and supplying graphical material … indicating the location of those areas".

The original legislation has been frequently modified by many further EU Council Regulations, but the requirement for all EU member states to maintain a GIS database of agricultural parcels, and to make available extracts of this data for farmers, has remained constant. This legislation has therefore created one of the largest GIS projects in the EU.

### 2.3.2 Land Parcel Identification System

This GIS component of the IACS [11] is known as the Land Parcel Information System (LPIS). As is normal for EU regulations, each member state may decide how this is implemented, as long as it meets the minimum requirements laid down by the EU. Two key spatial features are defined: the agricultural parcel (also known as the production unit) and the reference parcel (the production block). The reference parcel is defined in EC Regulation 796/2004 as "… a geographically delimited area retaining a unique identification as registered in the GIS …", whereas the agricultural parcel is defined in EC Regulation 972/2007 as "… a continuous area of land on which a single crop group is cultivated by a single farmer; however, where a separate declaration of the use of an area within a crop group is required in the context of this Regulation, that specific use shall further limit the agricultural parcel". However, "… the identification system for agricultural parcels … shall operate at reference parcel level such as cadastral parcel, or production block which shall ensure unique identification of each reference parcel" (EC Regulation 796/2004).

The reference parcel may therefore be semipermanent, which is indicated by the expected features to be used as physical block boundaries [12]:

…

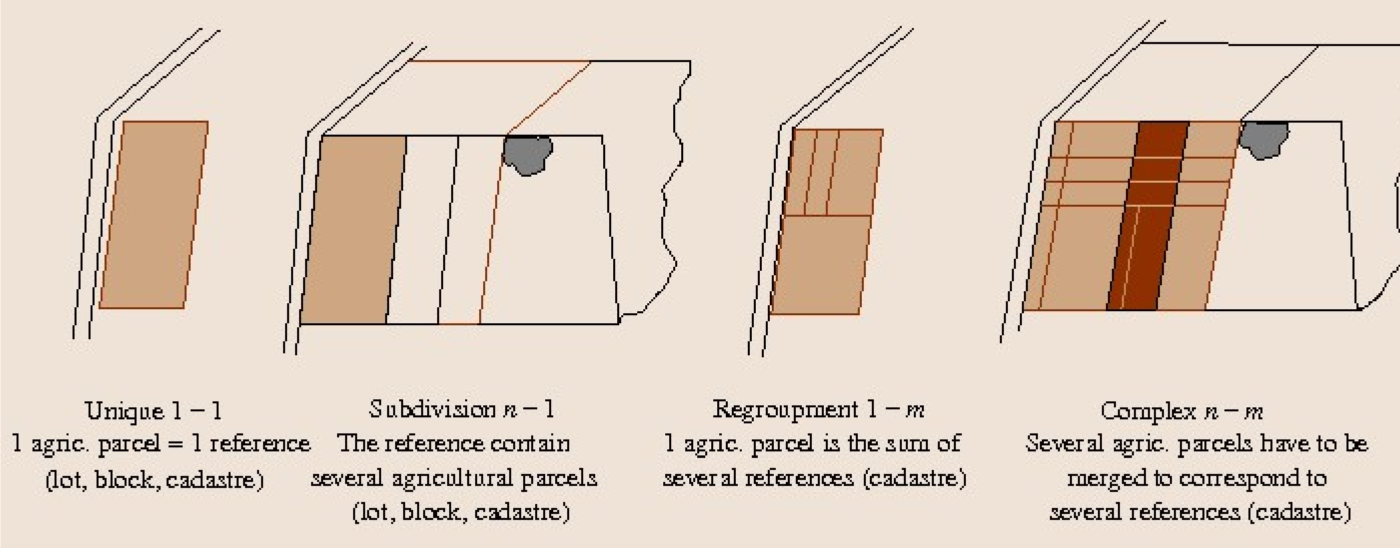
Infrastructure (roads, railways, water channels, etc.)

Farm tracks and other limits between land cover types that are considered mostly permanent (streams, vineyard, orchard/olive grove limits, woodland borders, etc.)

Limits between parcels of the same cover type that can be considered permanent (fence-lines, hedge-rows, etc.).

However, not all member states use physical blocks as reference parcels: the agricultural parcels themselves, farmer blocks (defined as a piece of land cultivated by one farmer with one or more crops), and cadastral parcels are also used, although as noted by *Léo* and *Lemoine*, "… cadastral maps may be at a large scale and recorded at a high precision, their information is related to land ownership and not to the real agricultural parcels …". Various possible relationships are therefore possible between reference parcels and agricultural parcels (Fig. 4).

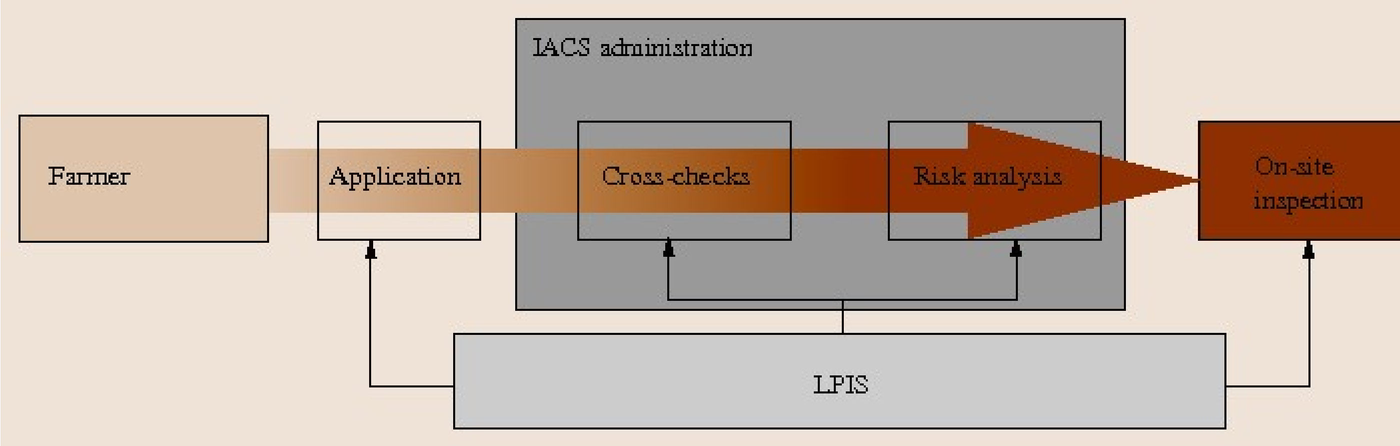
**Fig. 4 Relationships between agricultural and reference parcels (after [12])**



In the 16 federal states within Germany, 13 different solutions are used, being different combinations of parcel identification systems (lot, block), different spatial reference systems, different subsidy application processes (online/offline), and different on-site controls, which makes the use of digital data for national agricultural services difficult.

The farmer makes the subsidy application at the agricultural agency, for which the LPIS is used for the unique spatial identification of eligible parcels in the EU. In the ideal case, the complete subsidy application including spatial aspects may be completed online. For this, some federal states make Internet-capable viewers with basic GIS functionality available to farmers such that, based on the geo base data (orthophotos/cadastral parcels) from the regional survey agencies, the farmer can see the fields and parcels belonging to the farm and select those to be included in the subsidy application, or modify existing parcels where changes are needed (Fig. 24.5).

**Fig. 5 LPIS workflow**



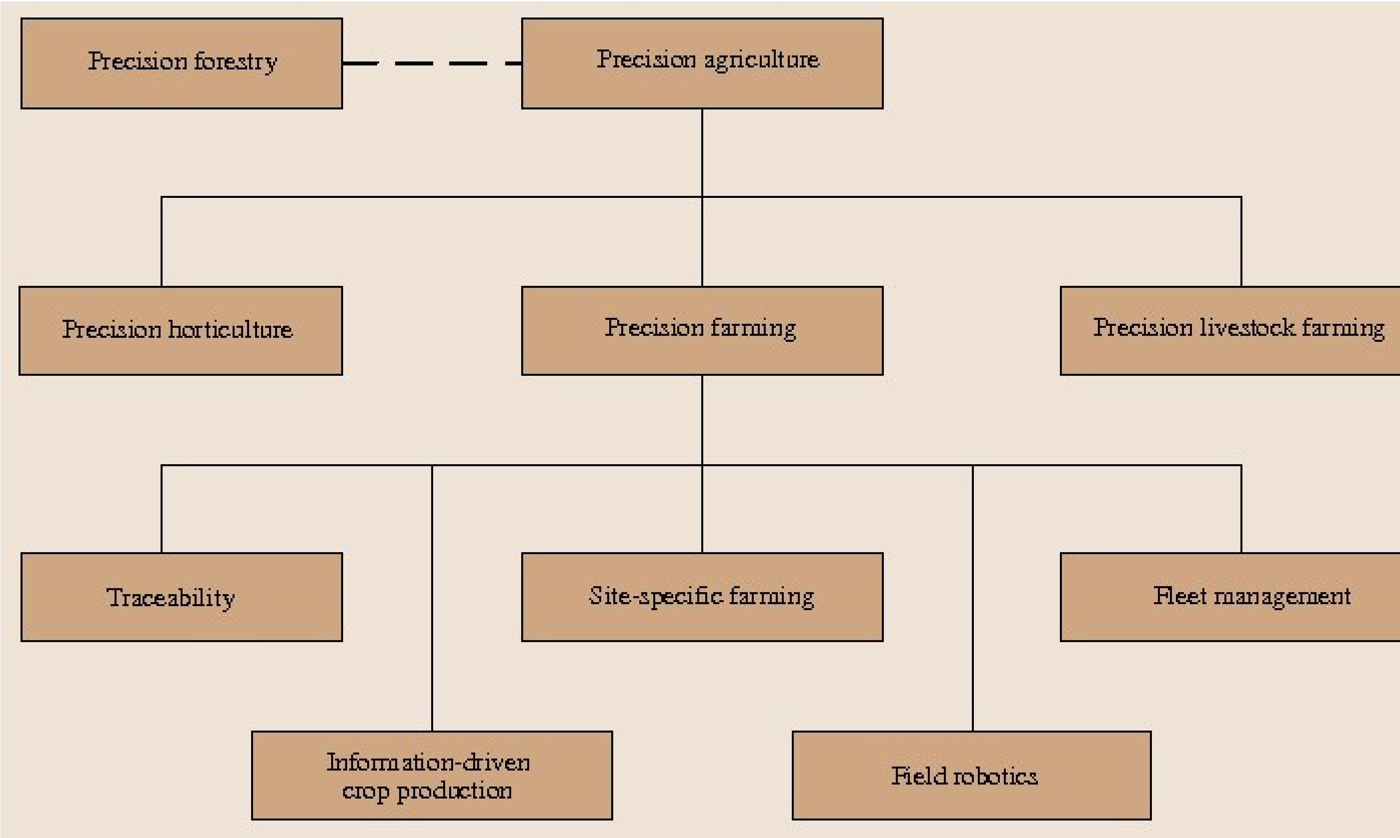
## 2.4 Precision Agriculture

### 2.4.1 Precision as the Basis for Modern Agriculture

Many of the fields around the world are heterogeneous. They have small-scale differences which result from the influence and effects of variabilities in soil, relief, human, and management factors as well as due to the location of the field in relation to other landscape features. These site-specific differences impact on the plants which are grown, resulting in inhomogeneous crop stands and differences in yield [13]. Using modern technology, such small-scale differences can be taken into account during management and application processes.

Such site-specific, information-driven crop production is usually referred to as *precision agriculture* [13], [51] or *precision farming*, although the exact definition of this term is not universally agreed. Similarly *precision livestock farming* refers to the use of sensors and geoinformation for animal production. In neighboring disciplines terms such as precision horticulture, precision forestry, etc. are used (Fig. 24.6).

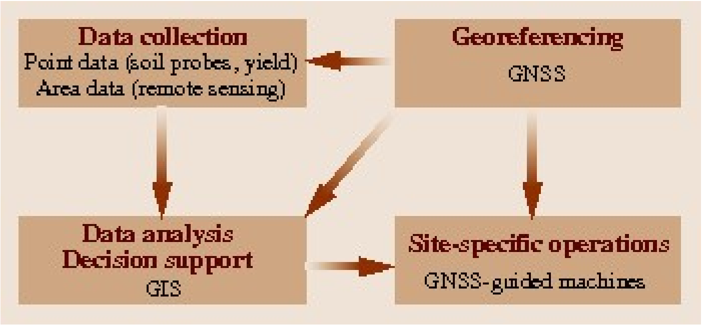
**Fig. 6 Classification of *precision* technologies in precision agriculture**



Although applications of GI for extensive livestock farming are also under development, particularly use of GNSS for monitoring animal movements and behavior [14, 15] and virtual fencing [16], the use of GI in the arable farming sector, particularly extensive crop production, e.g., for cereals such as winter wheat, is more widespread and is the primary focus of this section.

Precision farming encapsulates the adaptation of agronomic activities to the variability of the site-specific and crop parameters, which are measured using satellite navigation systems (GNSS, [17]) and combined and calculated in GIS [18]. From this, site-specific agricultural applications and operations may be derived, which are then applied with the help of integrated sensor technologies on agricultural machinery. This can assist the farmer in reducing the quantity of agrochemicals applied, increasing yield reliability and leading towards more sustainable and environmentally friendly agriculture. It has been shown that the greatest potential for these techniques in both economic and ecological terms lies in areas with heterogeneous conditions and large-scale production. It is possible to perform site-specific operations in all field operations, from tillage through sowing to fertilization and plant protection [7]. These spatial technologies are leading to a paradigm change in crop production: whereas previously a crop stand was the smallest unit of crop production, now new spatial technologies allow specific management of subareas within a crop stand.

**Fig. 7 Spatial components of precision farming technologies**



### 2.4.2 Spatial Technologies

The enabling technology for precision agriculture are global navigation satellite systems (GNSS) such as the US NAVSTAR-GPS, the Russian GLONASS, the European GALILEO or the Chinese Beidou/Compass. GNSS receivers are mounted on the tractor, combine harvester or other field implement. As well as this, precision farming requires a large amount of high-resolution spatial and temporal data, which must be processed in GIS and applied using the available agricultural machinery.

Usually, DGNSS or RTK-GNSS are used to allow collection of data or application of agricultural chemicals with submeter accuracy. This is combined with agricultural machinery allowing, for applications of fertilizers or plant protection products, exact and variable dosage or onboard sensors continuously measuring yield volume and other parameters. The development of crop growth models and the use of data about the conditions in the field such as soil type, relief, and climate allow optimum inputs to ensure maximum yield or minimum environmental impact to be determined.

The various possible uses for GNSS in agriculture cannot however all be realized with a single GNSS solution. In particular regarding the required accuracy (Table 24.1), many different receivers from integrated low-cost devices through to expensive precision receivers must be used.

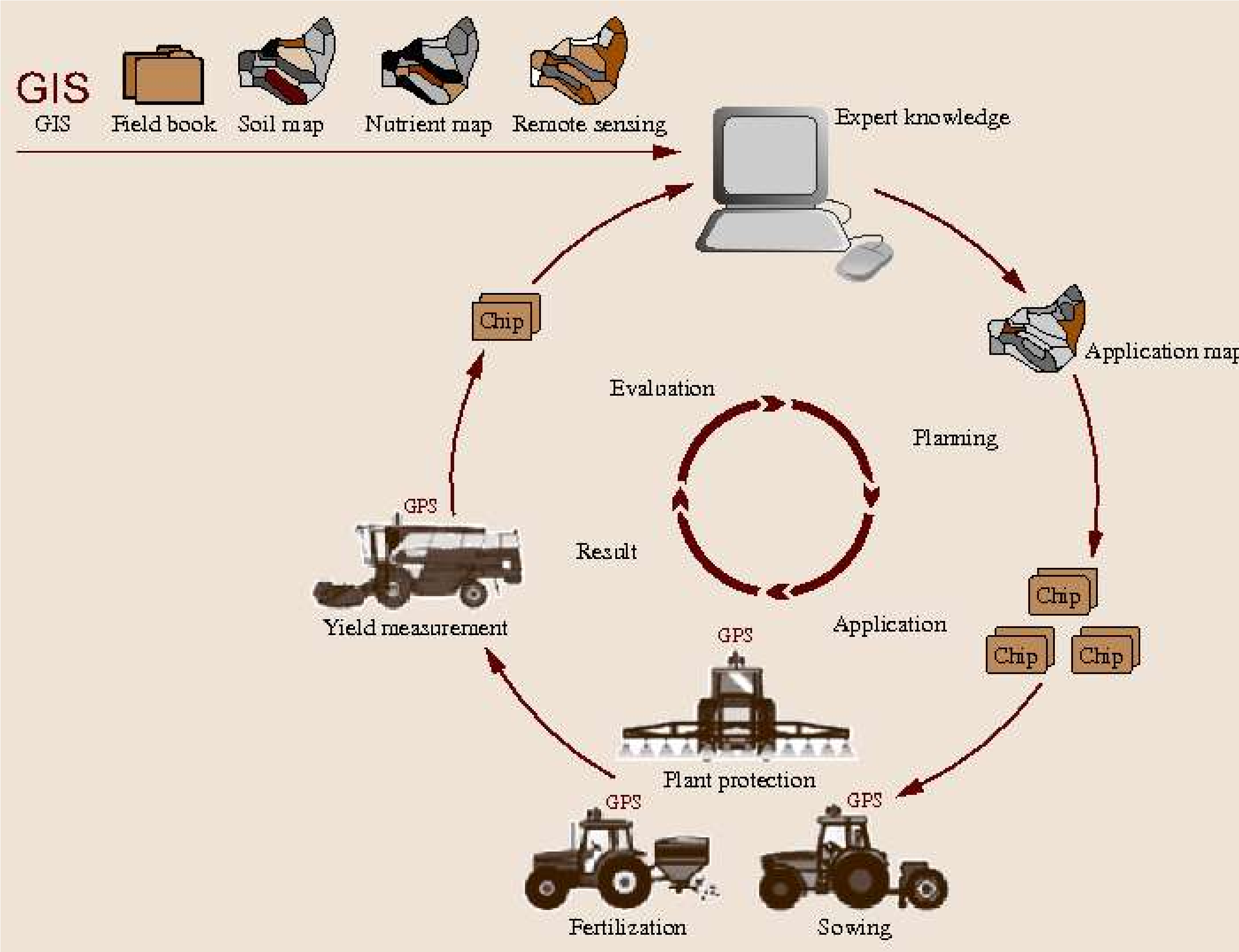
**Table 24.1** GNSS accuracy required for agricultural applications

| **Applications** | **Required accuracy (m)** |
|---|---|
| Navigation, fleet management, documentation | <5–10 |
| Yield mapping, soil mapping, observation recording, area measurement for subsidy applications | ≈ 1 |
| Parallel driving assistance, terrain modeling | <0.30 |
| Autosteering | 0.02–0.30 |
| Field robotics | 0.05 |
| Variable rate technology | < 1 |

### 2.4.3 Precision Farming

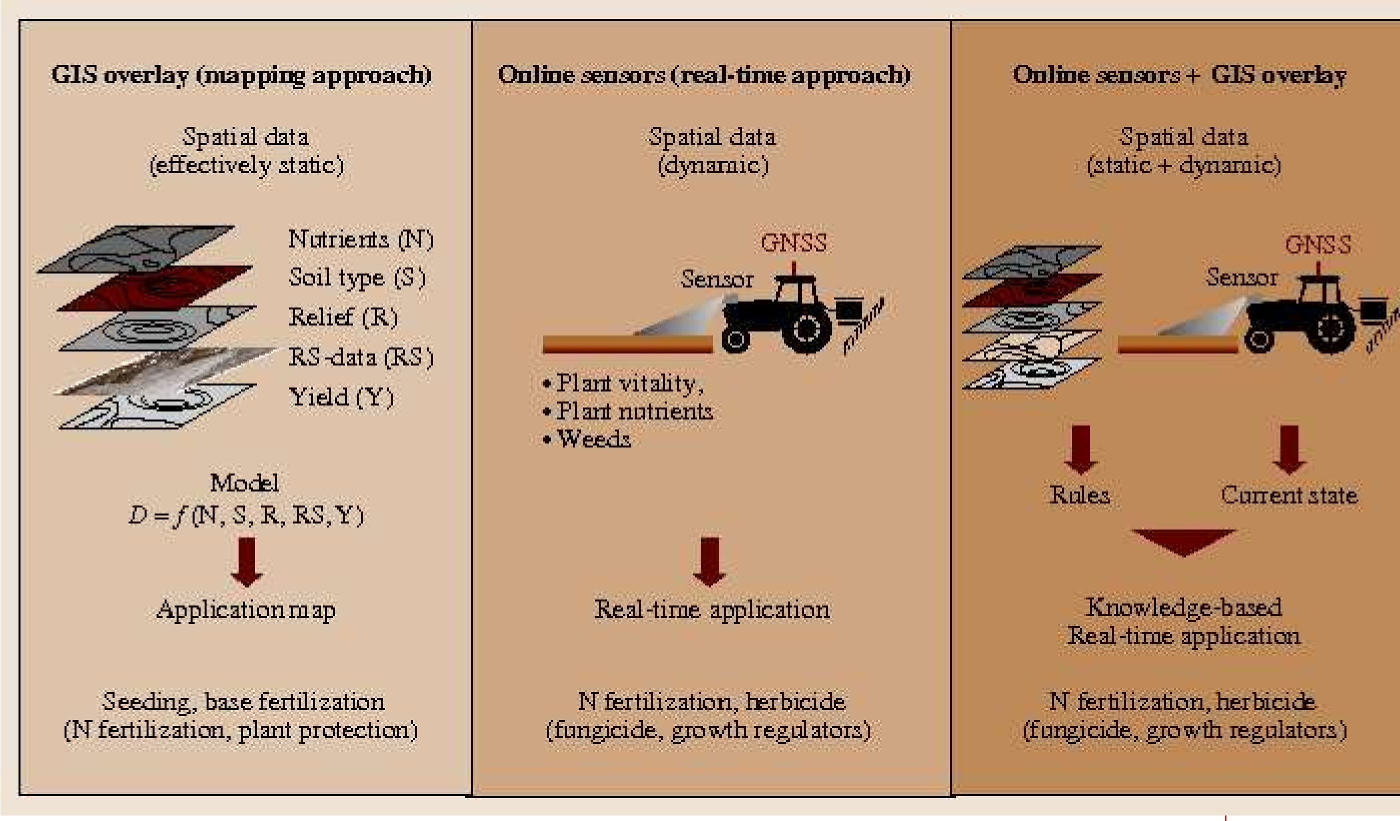
As the basis for the further explanation, the precision farming cycle is presented in Fig. 24.8. A variety of agricultural operations are performed during the crop growth period. This starts with tillage, followed by sowing. During the growth of the plants, fertilization is necessary and spraying to combat plant diseases and weeds. As the result of the process, the harvest is collected. Today many of these operations are performed using machinery which is equipped with sensors which in combination with GNSS can map the spatially differentiated application of seed, fertilizer, and crop production products as well as the resulting harvest yield. In order to plan and perform the individual site-specific operations correctly, further data are required, which must all be analyzed in a GIS or farm management information system (FMIS) [47].

**Fig. 8 The precision farming cycle (after [19])**



Precision farming can be applied in many different ways (Fig. 24.9). Using the GIS overlay method, a generally static process, the multitude of spatial data are processed using models in order to generate application maps. These are then used to control the field operations such as sowing, fertilization, and crop protection, and the driver can, usually with only a few button presses on the onboard computer, apply more or less or halt the operation. The actual quantities applied are registered and saved on the farm as an as-applied map.

Fig. 9 Different precision farming strategies for site-specific applications



In the online-sensor method – a dynamic method – sensors are mounted on the agricultural machinery to directly sense crop stand characteristics, which are then processed by the onboard computer. The application is then instantly adjusted. This is applied, e.g., for nitrogen fertilization with the Yara N-Sensor as well as for the application of herbicides and fungicides and for growth regulators.

Both online and overlay methods can be used in a hybrid approach. In this, information processing before the operation generates an application map, which is then modified using online sensors and a rule-base. Hybrid methods may also be used in N-fertilization and herbicide, pesticide, and growth regulator applications.

GNSS provides one of the foundations for site-specific agricultural management, with which spatially referenced data may be generated and made available in a GIS for analysis. However, a multitude of further information is required in order to implement precision farming technologies across all areas of farm operations. Compared with traditional agriculture, the volume of geoinformation which is used, and the number of tools which are required to manage this, are significantly increased in precision farming [6].

#### 2.4.3.1 Soil Heterogeneity

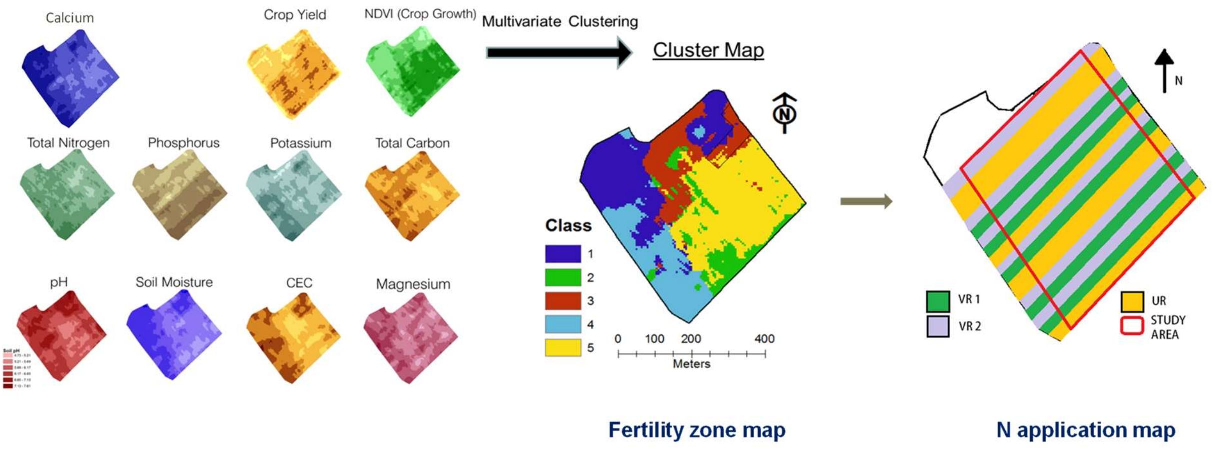
There are various methods available for measuring soil heterogeneity. For deriving the apparent electrical conductivity (ECa) of soil for agriculture, the contactless close-range remote sensing method EM38 (Earth conductivity meter) has established itself as a relatively robust and performant method [7]. The apparent electrical conductivity of agricultural soils is strongly related to the clay content, but also influenced by the moisture and soil content of the soil suspension. In order to estimate the average clay content of the soil, simultaneous soil core sampling is necessary (in particular to measure soil type and moisture). The probes are used to calibrate the measured values in zones of equal apparent electrical conductivity. Measurement of ECa is performed using a sledge towed behind a vehicle. The sensors react very sensitively to metallic objects and underground high-voltage cables.

For site-specific management, usually *raster soil sampling* is used to measure parameters such as soil texture, nutrient content (Ka, P, Mg, etc.), pH, humus content, and cation exchange capacity. The soil samples are analyzed in a laboratory, and the values may be used as inputs to decision-support algorithms. Raster sampling can be used for identification and separation of management zones. This is, however, only sensible in combination with other data (aerial imagery, ECa maps, yield maps, etc.), and knowledge of the field/farm and/or the region are also required. The soil sampling density should be below the desired size of management zones. A higher sampling density is required in areas in which a high variability is expected, and a lower density where low variability is expected. The crop stand is separated into zones, which will be uniformly sampled. Ideal are predefined yield or management zones. The shape and size of the zones is determined by the variability and the required operating precision as well as practical and financial considerations. The sampling of the crop stand should concentrate on representative areas within each zone. Transitional regions and anomalies with each zone should also be considered.

*Digital farm soil maps* represent an important instrument in precision farming for collection, management, and analysis of soil properties, function, and nutrients, with the assistance of GIS. The different soil and nutrient data are the input parameters for the part-field operations performed [7]. These data may be quickly and efficiently collected through use of a *SoilRover* vehicle, collecting and analyzing probes from 1.5–3 m depth, the results of which may be directly entered into a database system and evaluated automatically. In order to minimize the number of probes, further soil sensors such as ECa measurements using EM38 [52] may be applied, spectrophotometric data (humus quantity of the topsoil), digital photos collected, and soil resistance (compactedness) measured. The sensor data may be prepared in a field laboratory and combined and analyzed with additional existing information (relief, remote sensing, soil estimation, yield) in GIS. For the data values which are to be generated, differing weightings may be used in a modeling process. Digital farm soil maps are not only product maps but also a complete soil information system for collection and analysis of soil data in precision farming [20].

High resolution appoaches as the measurement of soil properties with VIS-NIR spectroscopy in the field [44] also require additional support for data collection and management as presented by Peets et al. (2012) [52]. Another aspect is the quality of the predicted properties, which can be improved by the utilization of suitable models. A machine learning based prediction of precise soil maps to improve the results of VIS-NIR spectroscopy measured with on-the-go sensors has been introduced by Morellos et al. (2016) [48](Fig. 24.10).

**Fig. 10 Soil nutrients derived from a VIS-NIR spectroscopy sensor**



### 2.4.3.2 Yield Mapping

Most farmers who already practice precision agriculture or are planning to introduce it start with yield mapping [21]. Almost every new combine is equipped with GNSS and a yield monitoring system. Consequently the availability of multiyear yield maps as a basis for delineation of management zones is useful. Accurate yield maps depict the influences of site, climate, and management factors on yield formation for a specific year. Multiyear yield maps may contain valuable information about site-specific yield variability.

In order to produce a yield map which accurately represents yield, some processing is required. Data is collected as a georeferenced time series based on a flow sensor mounted at a point in the harvester mechanism. Typically the series will also include points measured while the harvester is turning in the so-called *headlands* and thus not harvesting, as well as some unreliable measurements, as well as large random variation due to measurement errors. Furthermore, the measurement points are not distributed evenly across the field but represent an average yield across the strip harvested from each drive line. The speed of the harvester and overlap between the harvest strips will also affect the measured values [23].

In an initial step, the individual point measurements must therefore be filtered to remove outliers and adjusted to account for overlap (Chap. 2), [21]. The point values must then be smoothed and interpolated (e.g., using Kriging or inverse distance weighting [18, 22]) to produce a yield surface for the field. Once this surface is generated, it must be interpreted in order to make management decisions for subsequent crop cycles. *Blackmore* et al. [25] have shown that spatial yield trends do not remain stable through time due to the complex interplay between many factors (e.g., soil, crop type, and prevailing meteorological conditions during the crop cycle), and that fields should instead be managed based on the conditions and variability measured in each given year rather than based on historical yield data. Despite its initial promise, the use of yield maps is therefore regarded as problematic in practice as a basis for decision-making [21], and soil maps are often preferred [26].

### 2.4.3.3 Terrain Modeling

Relief influences the process of soil formation, water balance, microclimates, and thus the yield capacity of the soil to a large degree. The consideration of relief in site-specific management through use of digital terrain models is therefore an important method, particularly as it is based on easily gathered base data with wide application potential for precision farming.

Nowadays national and regional DTMs are available. In general, raster size of 5 m with height accuracy of <0.1 m is required for most agricultural purposes; consistent and high-quality collection and interpolation methods are fundamental [27]. In Germany the DTM 1 (1 m grid size) and DTM 2 (2 m grid size), being derived from airborne laser scanning (light detection and ranging, LIDAR; Chap. 9) and producing a high point density and very good height accuracy of 10–15 cm, fulfill these requirements.

As a method for collecting a DTM at the crop-stand level, parallel drive systems (in *GNSS Guidance and Autosteer Systems*) may be used, having an integrated RTK GNSS receiver which may be able to deliver height measurements with accuracy of 5–10 cm. However, due to the suboptimal geometry of the point distribution (measurement points at small intervals along driving lanes and with 18–24 m between lanes), measurements must be interpolated with complex algorithms such as Kriging in order to reduce errors in interpretation between driving lanes [10].

Therefore, both GNSS and laser scanning provide a basis for delivery of high-quality DTMs at scales relevant for agriculture. Analysis of the terrain model is performed using special software and delivers basic information such as slope, exposition, curvature, and inflow area as well as special relief parameters. Following interpolation of the gathered data into a continuous digital terrain model, various index algorithms may be applied in GIS [27, 28]. The topographic wetness index $\mathrm{TWI} = \ln(A_s / \tan \alpha)$ ($A_s$ = specific upstream area of a point, i.e., the area from which it is calculated that water will flow through that point, $\tan \alpha$ = local slope) describes how strongly an area is affected by inflow and outflow of water and enables identification of moist and dry areas based on the combination of specific upstream area $A_s$ and slope $\alpha$. This takes into account that water runs off more steeply sloping areas faster. The result is the potential pattern of soil moisture after precipitation and the run-off lines along which the movement of water and material will occur. The TWI usually has a strong correlation with soil moisture values obtained by remote sensing or EM38 measurements [27].

A variation on the TWI is the stream power index, which describes the potential abrasive power of the water for every cell in the DTM and therefore predicts the patterns of erosion. Such secondary relief parameters are usually based on a combination of basic parameters and empirical or process-oriented formulae. Many equations deliver only potential patterns representing the contribution of the relief in determining the observed process and therefore relative values, which may be combined with other spatial data in order to explain patterns of crop stand heterogeneity [27].

For the calculation of the general soil erosion formula after *Wischmeier* and *Smith*, the length slope factor $(A_s/22.13)^{0.6}(\sin \beta/0.0896)^{1.3}$ is important.

Using a GIS, the relief parameters may be compared with soil, climatic or yield parameters and further investigated [27]. Relief-based increases or reductions may be considered during the creation of nearly all application maps.

### 2.4.3.4 Remote Sensing

A fundamental requirement for successful precision farming is that the heterogeneity of the soil and of the crop status must be measured in order for consideration during the decision-making process. Remote sensing is ideal for this (Chap. 9), as with a bird's-eye view, farmers can get continuous detailed information about their crop stands and then apply their knowledge in order to react to this. Remote sensing is an indirect method, which, depending on the timing of the data capture, delivers information on differences within a crop stand. These differences may be caused by many factors, such as heterogeneity of the soil, the crop, the nutrient supply, the exposition, the management, etc.

The many possible causes for spectral differences significantly hinder the application of remote sensing, since plants may react to different stress factors (e.g., nutrient deficiency, water deficiency, plant diseases) in – from a spectral point of view – very similar ways.

Additionally, the exact time of data capture plays a central role. On the one hand, the reflective properties of the vegetation and the soil, as well as the architecture of the crop stand, change continuously. On the other hand, changes in reflection may be reliably correlated with the desired biophysical characteristics, e.g., leaf area index (LAI), biomass, chlorophyll content, etc. Many common indices, e.g., normalized difference vegetation index (NDVI) reach saturation with increasing leaf area and therefore cannot be used for further differentiation.

Remote sensing data are snapshots of plant development with a limited half-life value. Therefore, it is of utmost importance to obtain the information at the most appropriate development stage of the crop.

Remote sensing for precision farming is performed using many different methods from various sensor platforms. The wide range of sensor platforms, which range from satellites through to tractor-based systems, all have various weaknesses and strengths regarding availability, ground resolution, etc. In the overview presented in Table 24.2, the different sensor platforms and their main uses are described and compared.

**Table 24.2** Comparison of various remote-sensing sensor platforms for precision farming applications

| | **Terrestrial** | **UAS / Airborne** | **Satellite** |
|---|---|---|---|
| Platform (sensor) | Tractor (N sensor / green seeker / CropSpec / VIS-NIR / laserfluorescence) | Rotary and fixed wing UAS | Sentinel 2a/b / Landsat 8/ Planet labs / Landmapper |
| Application area (strengths and | Operational support (N fertilization, | Operational support (Crop | Operational support / base data (culture type, yield |

| | **Terrestrial** | **UAS / Airborne** | **Satellite** |
|---|---|---|---|
| main use of sensors) | fungicide etc.) | height, N fertilization, fungicide etc.) | potentials, time series analysis, hail / damage mapping) |
| Information requirement | Real time | Near real time / short term | Short term / strategic |
| Regionality | Crop stand | Single crops / crop stand | Crop stand / regional |
| Weather independence | +++ | +++ | + / ++ |
| Turnaround time | Instant to 48 h | 1 h to 48 h | 12 h to 5 days |
| Spectral resolution | Selected narrow spectral range (10–20 nm), active sensors | RGB, Multispectral, (Hyperspectral) | Broad spectral bands (50–200 nm) |
| Atmospheric effects/ correction requirements | Low / low | Low / medium | High / medium |
| Geocoding workload | Low | High | low |
| Price (crop stand) | + | + | + |
| Price (region) | +++ | +++ | + |
| Spectral calibration | +++ | ++ | +++ |
| Analysis (derivation of end-products) | Automatic / farmer | Farmer / expert | Automatic / expert |

From the farmer's point of view, particularly *terrestrial tractor-based sensors* are interesting, as these can deliver weather-independent on-the-go spectral information for agricultural operations and therefore generate a direct benefit for precision farming.

In order to measure plant vitality, in particular with a view towards nitrogen delivery, many tractor-based systems have been developed in recent years, which are based on differing optical or mechanical techniques:

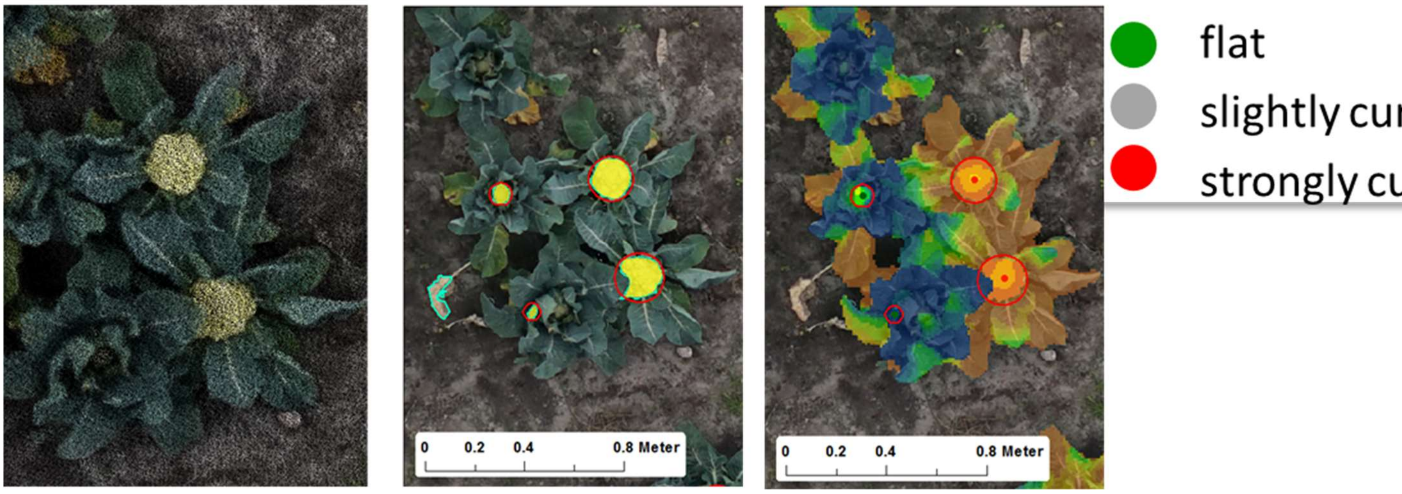
1. The *Yara N-Sensor* measures the reflective properties of plants under different viewing angles in the visible and near-infrared (NIR) spectrum in the vicinity of the tractor. Based on a large experimental data base and in field calibration, N-fertilisation recommendations are instantaneously available.
2. The crop circle and other scanners such as ISARIA or CropScan provide an active light source, which is kept close to the crop stand. The registered reflection at selected wavelength is independent of the weather conditions. Calibration and N-fertilisations rated must be determined by the farmer.

The use of *unmanned aerial systems (UAS)* has recently become a focal point for research [28], because these systems are able to gather up-to-date remote-sensing data for small areas, independently from the weather conditions. Depending on the camera used and the flight height over the terrain, UAS images can observe crops at the so-called leaf level or the canopy level. Images taken at only a few meters over the ground at the leaf level provide answers to weed detection and crop deseases etc., whereas common canopy level applications are devoted to fertilization and water stress.

UAS generally fly at lows altitudes, typically acquiring many images in a systematic manner. With recent developments in computer vision and digital photogrammetry images are mosaicked automatically together to produce a continuous orthoimage of the field or farm of interest. Fixed-wing UAS can cover larger areas, because they generally have longer flight time than multicopters. Common cameras used on UAVs range from inexpensive digital cameras that provide RGB-information to expensive multispectral cameras that provide narrowband reflectance in the blue, green, red, red edge, and NIR regions of the spectrum. Despite promising options for the determination of crop diseases, N-status etc., the use of miniaturized hyperspectral cameras is currently restricted to research projects due to the complexity of the data analysis and sensor price [31].

Promising results have been obtained using UAV-based remote sensing for estimating crop LAI, biomass, nitrogen status, water stress, weed infestation, yield, and grain protein content. Photogrammetric image processing of UAS data delivers highly accurate 3D point clouds and digital surface models with centimeter accuracy. By substracting digital surface models of the crops with a reference terrain model of the bare soil, crop height can be determined with high accuracy [30]. Furthermore additional and specific crop parameters can be derived using image analysis tools. As an example, the ortho images of a mature cauliflower head can be separated from the rest of the crop by its white color. With a raster to vector conversion, the diameter of the approximately round head is available with an accuracy of a few millimeters. Comsumers prefer curved heads. This parameter is derived from the ratio of the crop height from the center of the head versus the edge of the cauliflower head (Fig. 24.11).

**Fig. 11 3D-Point cloud of cauliflower at leaf level, derived from UAS images, taken at an altitude of 20 m above ground, and derived agromarketing relevant parameters (diameter, curvature)**



*Spaceborne sensors* cover large areas and, with fully automated processing procedures, allow the capture of information at little to reasonable cost. In order to obtain quantitative information about the Earth's surface and to make optical remote-sensing data capable of being spatially and temporally compared, it is necessary to correct for the influences of the Earth's atmosphere. Following atmospheric correction, bio- and geophysical parameters such as leaf area index, proportion of photosynthetically active radiation, etc. may be derived and modeled. In recent years, two hardware developments boosted the market for spaceborne remote sensing for agricultural purposes.

1. The European Union lauched Sentinel 2a/2b satellites in 2015 and 2017. These satellites provide free multispectral data at 10 – 20 m resolutions with a repetition rate of 5 days.
2. Private companies such as Planet Labs launched a huge swarm of approx. 150 small earth observation satellites allowing for a daily coverage of the whole earth. Astro Digital will follow with another 30 satellites in the next years.

With the high number of satellites being available, a daily coverage with high-resolution data with GSD of less than 4 m is possible. In turn, a more or less continuous monitoring of the crop growth at the field level is possible. Site-specific forecasts of the needs of the crops in terms of nutrients, crop protection and water is a key for further savings and higher yields. For better forecasts, a combination of current remote-sensing data with crop growth models is object of many worldwide research activities.

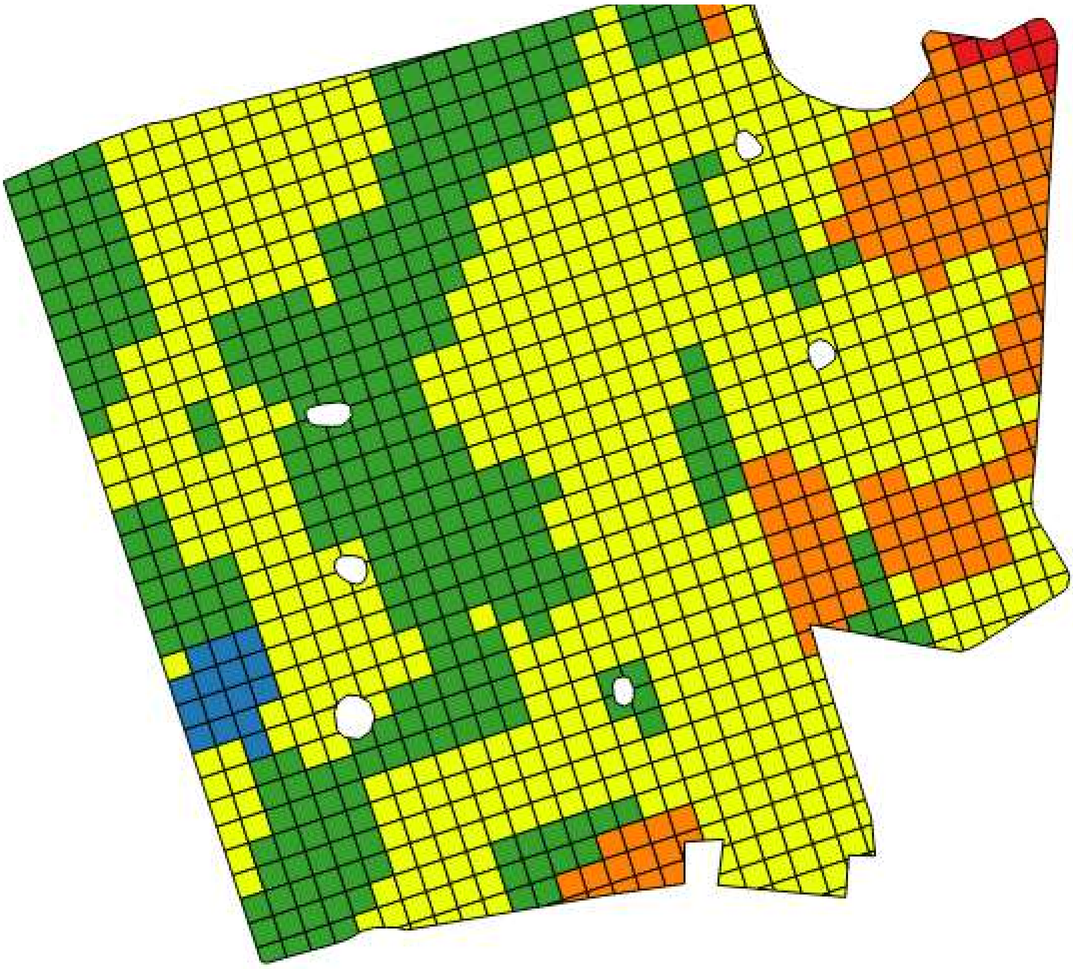
### 2.4.3.5 Management Zones

Because influences and interdependencies of factors determining site-specific yield are complex and not always understood, straightforward approaches for the delineation of zones with similar yield potential, and which can therefore be similarly managed, are a tool for simple and effective precision agriculture. Up to now many approaches for the delineation of management zones (MZ) have been discussed. *Whelan* and *McBratney* [32] categorize approaches into five groups:

1. Hand-drawn polygons based on yield maps or imagery
2. Classification of remotely sensed data
3. Identification of yield stability patterns across seasons at fixed monitoring points
4. Fuzzy multivariate cluster analysis using seasonal yield maps
5. Morphological filters or buffering

Once management zones have been delineated, they may form the basis of decision-making for one or multiple field operations, depending on the data sources used and the interpretation of the zones (Fig. 24.12). The management zones here have a size of 30 meter by 30 meter according to the standard working width used in the farm and are aligned to the standard driving direction. The example shows 5 different classes ranging from poor soil fertility (red, orange), medium soil fertility (yellow, green) to high soil fertility (blue).

**Fig. 12 Management zones**

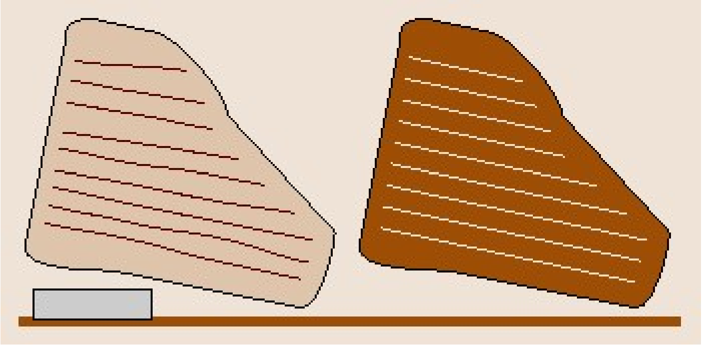


### 2.4.3.6 GNSS Guidance and Autosteer Systems

GNSS guidance and autosteer systems assist drivers to keep to the desired driving lines during field operations (Fig. 24.13). This leads to a reduction in the overlap of the area being worked, thus reducing the amount of agrichemicals applied and a reduction in the area affected by compaction from the vehicle's tires. Further economic benefits are gained from a higher average driving speed, reduced fuel consumption, less driver fatigue, and reduced driver and equipment working hours [34]. The results show that there are significant reductions in operational costs varying from 9 to 20%, depending on the specific machinery and field configurations. Such results show the considerable potential of advanced route planning designs and further optimization measures [34].

Usually, driving lines will be parallel, but some systems also allow contour driving or other functions.

Fig. 13 Typical driving lines without and with a parallel driving system (schematic)



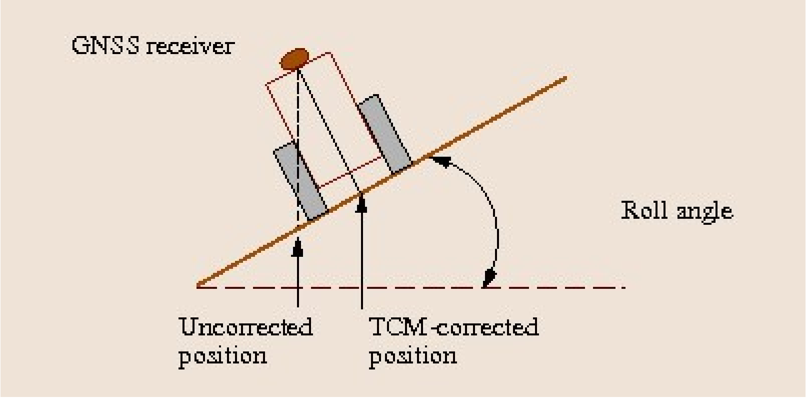
Three different levels of assistance exist: GNSS guidance, steering assistance, and autosteer. GNSS guidance gives the driver a visual indication of whether the correct course is being held using so-called lightbars. Steering assistance physically assists the driver in holding the line once the correct path has been entered, usually through hydraulic connection to the steering wheel or a motor with a friction roller on the steering wheel itself. Autosteer is fully integrated into the vehicle and almost completely automates steering. Table 24.3 gives an overview of the different systems and their application areas.

**Table 24.3** Overview of the accuracy and applications of different driver assistance systems. (Source [33])

| | **Driver guidance** | **Steering assistance** | **Autosteer** |
|---|---|---|---|
| Accuracy | ca. 30 cm with DGNSS | 30–5 cm with Omnistar HP, or StarFIRE SF1 | Up to ca. 2 cm with RTK |
| Applications | Lime Organic fertilizers Tillage | As for guidance, also harvest and potentially sowing | As for steering assistance, plus sowing |
| Driver relief | Low | High | High |
| Steering | Manual | Automatic | Automatic |
| Price (net) | From 1800 € up to ca. 7500 € | From 9000 € up to ca. 19000 € | From 8500 € (DGNSS) up to ca. 40000 € (RTK) |

In order to improve the accuracy of parallel driving in undulating terrain, and to compensate for the shift in horizontal position of the roof-mounted GNSS antenna due to vehicle roll on slopes, a so-called terrain compensation module (TCM) may be used. This projects the position measured by the receiver to the true ground position of the center of the tractor using a gyroscope system (Fig. 24.14). The use of a TCM also allows direct comparison of the positions and heights measured using onboard systems with those in external DTMs.

Fig. 14 Functionality of a terrain compensation module (TCM)



### 2.4.4 Information-Driven Plant Production

In order to produce a complete document of the production and quality of agricultural products, including all operations performed and all materials used along the complete value-added chain, agriculture is turning towards *information-driven plant production*. The information is not only used for operational planning in precision farming but also offers the opportunity to deliver appropriate information for quality management and controlling along the entire agricultural process chain, e.g., in order to derive process and product indicators. The information may also be used for certification and product liability towards processors and traders. The resulting financial benefits of information-driven plant production result from greater efficiency due to:

- A complete quality-oriented production system
- More transparency in machine use on large farms, machinery syndicates and contractors, and automated contracting
- New performance- and person-related billing procedures
- Automated gathering of all crop-stand-relevant management data in a single file
- Complete documentation, e.g., in order to fulfill the requirements of EU Regulation 178/2002 related to continuous documentation on the production and quality of agricultural goods (traceability), including all required operations and applied products
- Better internal auditing through (partial) crop-stand-specific balances
- Last but not least, simplification for the farmer of subsidy applications and the many other communications with the outside world

Additionally, ecological benefits are achieved, such as effective integration and documentation of environmental protection goals from water and contract nature protection schemes where farmers are paid for conservation of nature, e.g., part-field-specific documentation of appropriate use of fertilization and crop protection agents (e.g. optimization of nitrogen efficiency and minimization of applied nitrogen), documentation of additional expenditure for water protection for cross-compliance, and organic fertilization (slurry application plans). Farmers increase their chances of certification or of selling their products to particular markets by meeting particular quality requirements.

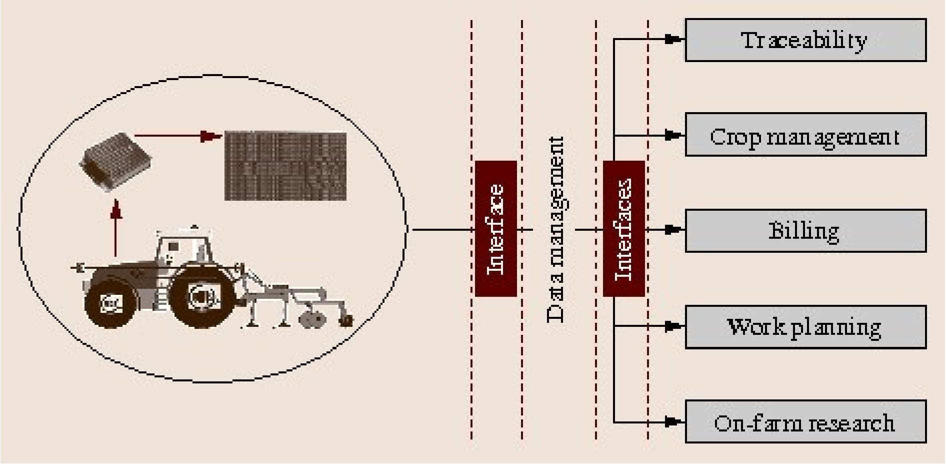
In particular, two aspects will be presented here, namely how data are captured on agricultural machinery and transferred for further use on-farm, and how on-farm processing of data may change due to the influence of the spatial data infrastructures which are currently being constructed.

#### 2.4.4.1 Information Gathering on Agricultural Machinery

Agricultural machinery is one of the most important information sources for collection of in-field data (Fig. 24.15). Through measuring the site-specific yield during harvesting, the effects of agronomic decisions may be analyzed, and through recording the exact quantities of fertilizer and plant production products applied, the requirements of environmental protection and traceability may be met. Furthermore, the performance of agricultural machinery may also be assessed through recording fuel consumption, motor speed, etc., and this information may even be transmitted and analyzed in real-time with telematics systems to prevent expensive and time-consuming equipment failures.

**Fig. 15 Logging and documentation of all information georeferenced during the application,**

**followed by transfer to agricultural software to support various tasks**

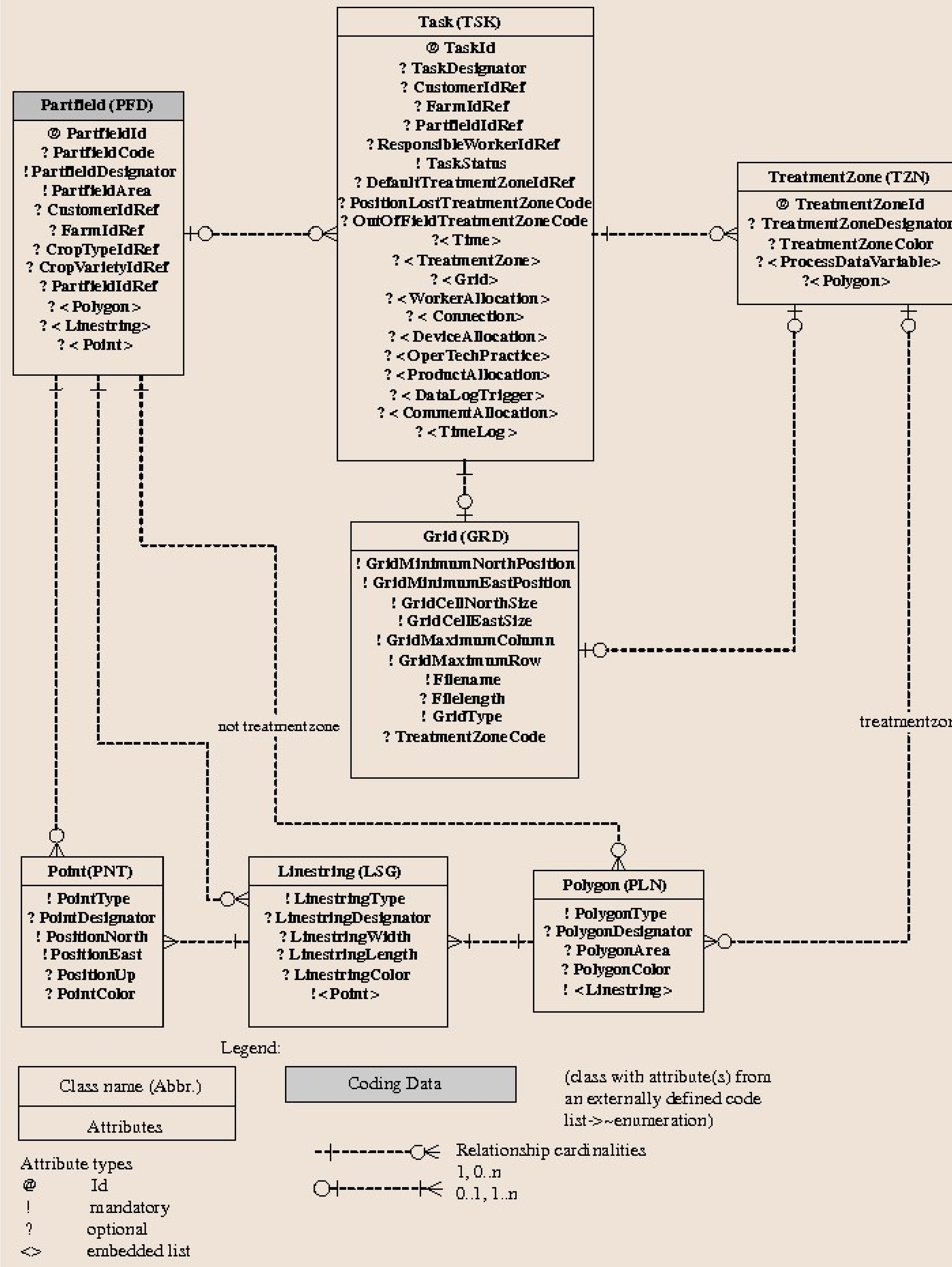


For useful analysis of much of this data, it is essential that it is georeferenced, and it is desirable that all data be logged and simultaneously georeferenced by a central system. If problems of proprietary lock-in where all equipment must be supplied from a single vendor are to be avoided then this requires that all devices attached to the vehicle can be connected and communicate in a standardized manner, requiring both hardware and communications/software standards. Examples for relevant standards are NMEA2000 for GNSS technology and the ISO 11783 series (ISOBUS) for agricultural machinery communication.

ISOBUS is based on the principle of a task controller which forms the hub of the onboard system. This task controller communicates with all onboard devices, including positioning receivers, over a bus system. Within the onboard system, each device (e.g., a sprayer head) is located at a known three-dimensional (3-D) position in a local platform-centric coordinate system. Using the measured real-world position and heading information of the platform (e.g., the tractor), the real-world position of each individual device can be determined. A preprepared application map can thus be implemented and/or spatially referenced data recorded. The transfer of data between the task controller and the farm software is performed using an extensible markup language (XML) file format. Within this format, spatially referenced data may be encoded using either a simple vector- or a grid-based model (Fig. 24.13). It has to be stated, that a lot of current ISOBUS implementations on the machinery only support the grid-based model of application maps. This model is not suitable for field operations with high precision requirements, e.g. the application of plant protection products in the neighbourhood of sensitive areas. Therefore it would be desirable to have more implementations of the ISOXML vector-based model, which would also improve the interaction with vector-based services of Spatial Data Infrastructures (see 2.4.4.2).

Information-gathering on agricultural machinery as a whole is an on-the-go process without much interaction of the operator. The new challenge is to make this huge amount of information count for farmers and consumers.

**Fig. 16 Extract of ISOBUS XML elements relationship diagram showing spatial data components (after ISO 11783-10, annex C)** ◂


Task (TSK)
@ TaskId
? TaskDesignator
? CustomerIdRef
? FarmIdRef
? PartfieldIdRef
? ResponsibleWorkerIdRef
! TaskStatus
? DefaultTreatmentZoneIdRef
? PositionLostTreatmentZoneCode
? OutOfFieldTreatmentZoneCode
?< Time >
? < TreatmentZone >
? < Grid>
? < WorkerAllocation >
? < Connection>
? < DeviceAllocation >
? <OperTechPractice>
? <ProductAllocation>
? < DataLogTrigger >
? < CommentAllocation >
? < TimeLog >
Partfield (PFD)
@ PartfieldId
? PartfieldCode
! PartfieldDesignator
! PartfieldArea
? CustomerIdRef
? FarmIdRef
? CropTypeIdRef
? CropVarietyIdRef
? PartfieldIdRef
? < Polygon >
? < Linestring>
? < Point >
TreatmentZone (TZN)
@ TreatmentZoneId
? TreatmentZoneDesignator
? TreatmentZoneColor
? < ProcessDataVariable>
?< Polygon>
Grid (GRD)
! GridMinimumNorthPosition
! GridMinimumEastPosition
! GridCellNorthSize
! GridCellEastSize
! GridMaximumColumn
! GridMaximumRow
! Filename
? Filelength
! GridType
? TreatmentZoneCode
not treatmentzone
treatmentzon
Point(PNT)
! PointType
? PointDesignator
! PositionNorth
! PositionEast
? PositionUp
? PointColor
Linestring (LSG)
! LinestringType
? LinestringDesignator
? LinestringWidth
? LinestringLength
? LinestringColor
! < Point >
Polygon (PLN)
! PolygonType
? PolygonDesignator
? PolygonArea
? PolygonColor
! < Linestring >
Legend:
Class name (Abbr.)
Attributes
Coding Data
(class with attribute(s) from
an externally defined code
list->~enumeration)
Relationship cardinalities
1, 0..n
0..1, 1..n
Attribute types
@ Id
! mandatory
? optional
<> embedded list

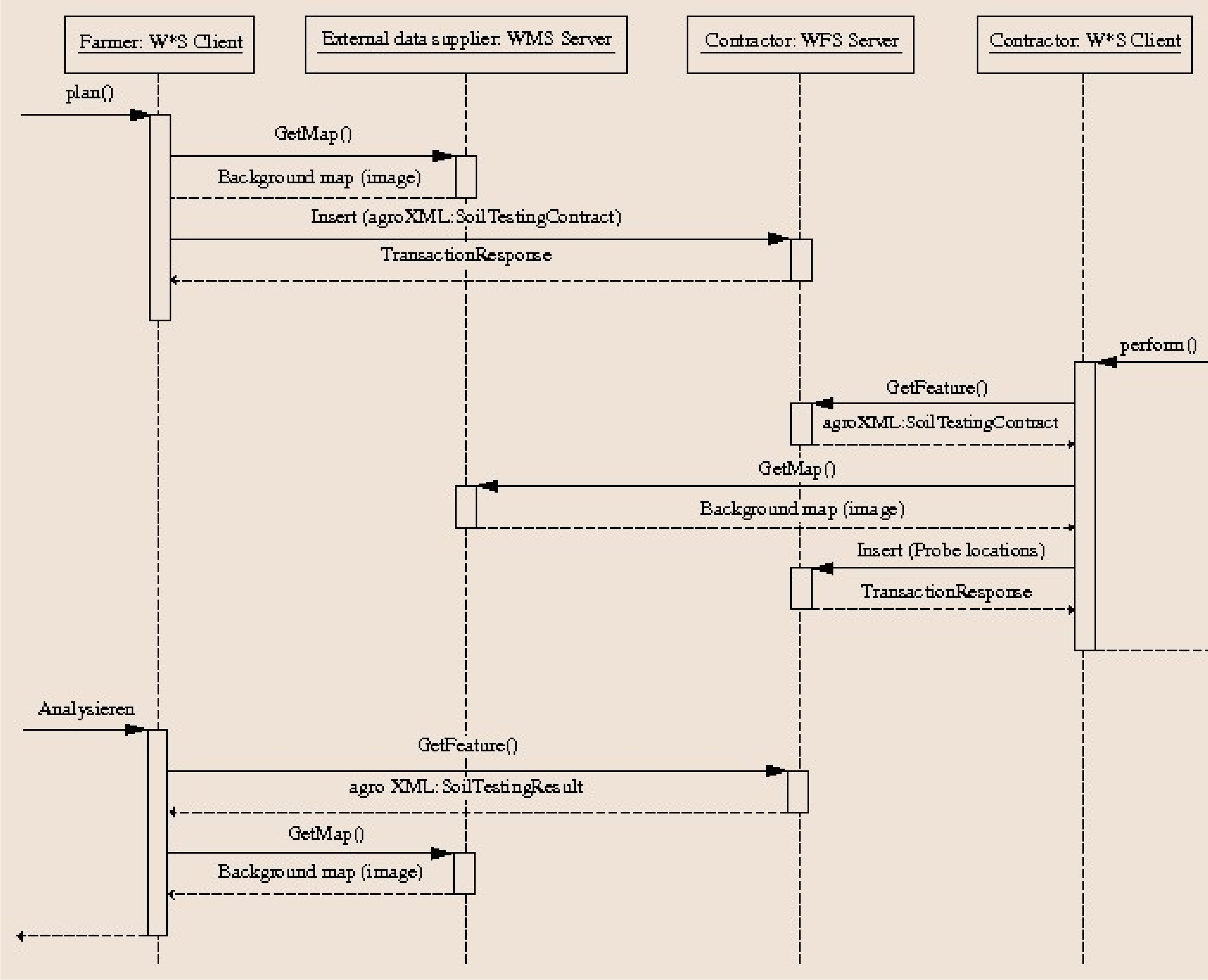
#### 2.4.4.2 Spatial Data Infrastructure for Agriculture

Geodata are increasingly being made available in digital form over the Internet, not only to stationary desktop personal computers (PCs) but also to mobile devices. With the construction of *spatial data infrastructures* (SDI), which are based on international standards and allow interoperable use of geoinformation at every place and time, work processes in agriculture are also changing. Since *Nash* et al. [36] modeled and developed various SDI-based scenarios for precision farming only a few implementation trials have been done. It has to be stated, that there is a lack of adoption of SDI-technologies in agriculture. Even a major use case like the spatial application for subsidies in the EU has not been implemented using a standardized SDI. The offered software clients from most authorities and FMIS vendors are not or only partly SDI-ready, but offer web services in a proprietary way. The most common usage of SDI in agriculture is the usage of satellite or parcel images as background maps via WMS. These use cases are easy to implement and are not that complex than those proposed by Nash et al. [36]. However, there is an apparent need for farmers to benefit from the advantages of an SDI in agriculture. Beside the technical issues there seem to be an organizational barrier among the included parties.

On the technical side it can be stated, that non-complex scenarios are straightforward to implement with OGC web services. The underlying information of an SDI is already available in most organizations and has to be prepared for the usage within an SDI. Once captured and made available via a web-service interface, the data may be used in many different processes, particularly when these are implemented in the context of web services [7].

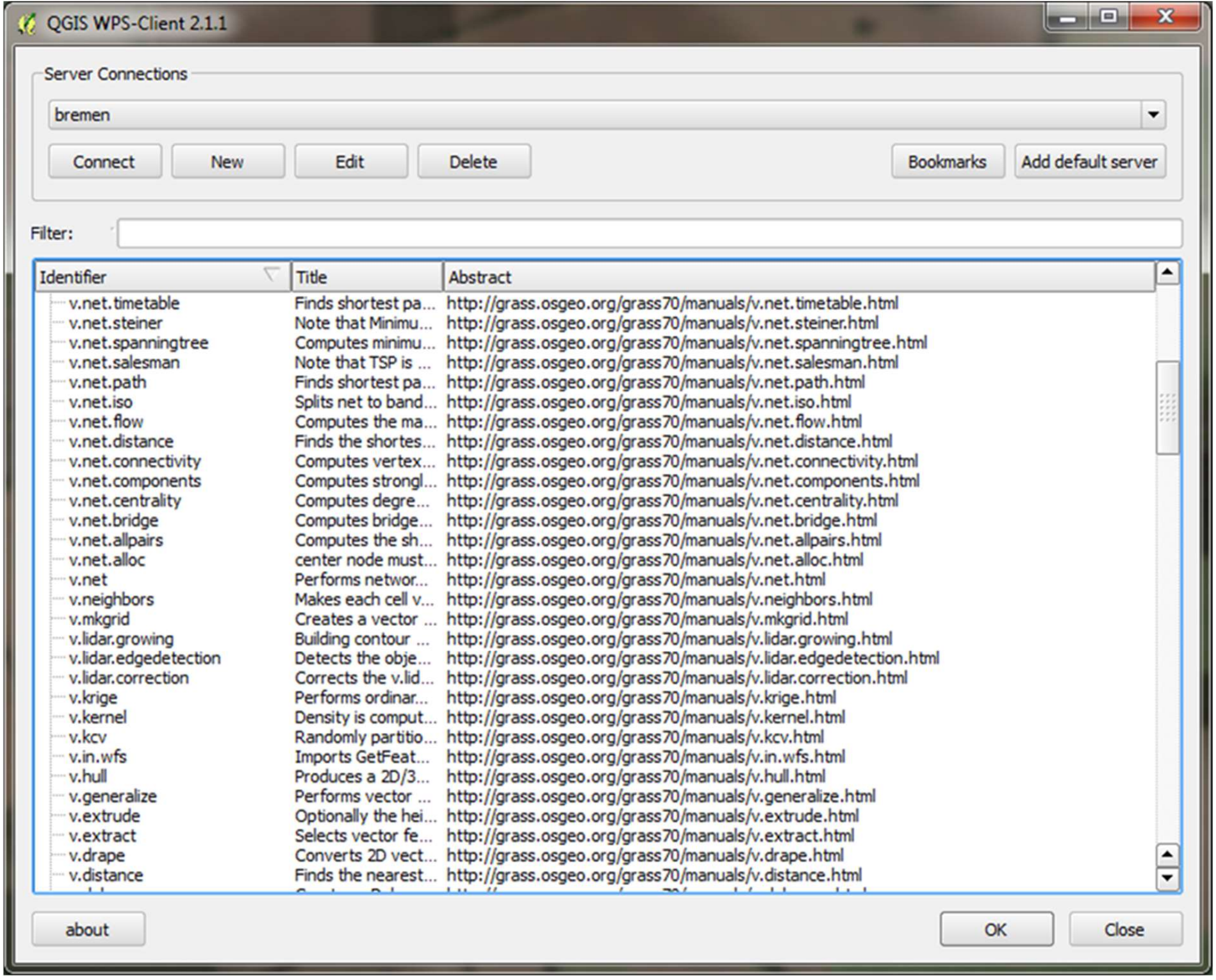
Figure 24.17 shows a sequence diagram for soil sampling and testing, showing how the required information flows may be implemented using a modern spatial data infrastructure. Farmers periodically perform soil testing on their fields, or employ a contractor to perform the testing, on the basis of which site-specific plans for tillage, sowing or fertilization will be made. In order to define the probe locations, existing geodata such as soil maps or geological maps from government geological surveys and topographic and cadastral maps from governmental cadastral and survey agencies as external data providers are used. The samples taken are analyzed by a laboratory in an agricultural research and testing agency. The results of the analysis are communicated to the farmer, or the contractor, who then produces, e.g., a soil nutrient map.

**Fig. 17 Sequence diagram for soil testing with data transfers implemented using OGC interfaces and agriculture-specific data formats**



One example presented by *Nash* et al. [5] is the calculation of the required nitrogen fertilization using Open Geospatial Consortium (OGC) Web Processing Service (WPS) interfaces and an opaque service chain. The total required nitrogen content may be estimated in a simple form by subtracting the available soil mineral nitrogen content from the amount of nitrogen contained in the previously harvested crop. The yield data may in future be collected by a harvest contractor and uploaded to an agricultural data warehouse, from which the data may be retrieved via a specialized OGC Web Feature Service (WFS) interface as part of an agricultural process data service [2].
Figure 18 shows the provision of existing GIS processing algorithms (QGIS) remotely via WPS in WPS-aware client software.

**Fig. 18 QGIS-WPS-Client with a selection list of WPS processes**



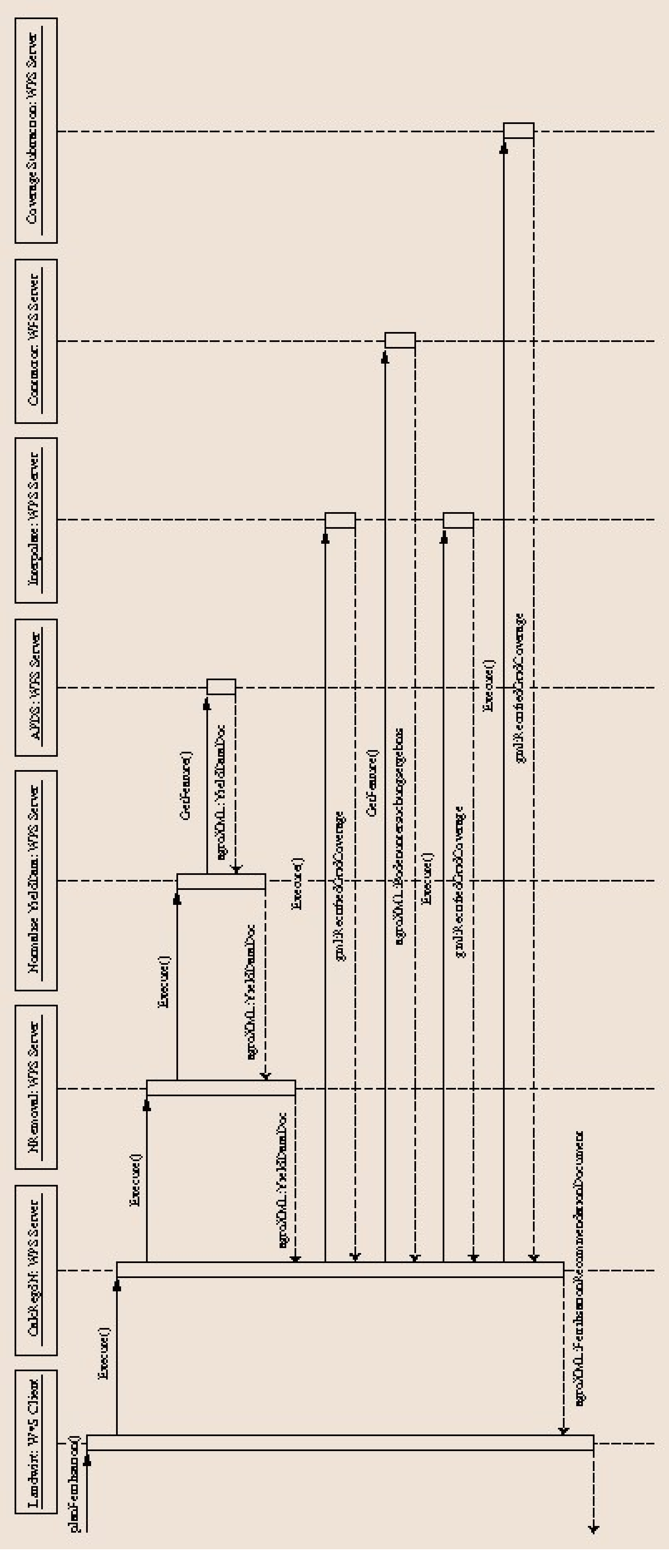
Server Connections: bremen

Filter:

| Identifier | Title | Abstract |
|---|---|---|
| v.net.timetable | Finds shortest pa... | http://grass.osgeo.org/grass70/manuals/v.net.timetable.html |
| v.net.steiner | Note that Minimu... | http://grass.osgeo.org/grass70/manuals/v.net.steiner.html |
| v.net.spanningtree | Computes minimu... | http://grass.osgeo.org/grass70/manuals/v.net.spanningtree.html |
| v.net.salesman | Note that TSP is ... | http://grass.osgeo.org/grass70/manuals/v.net.salesman.html |
| v.net.path | Finds shortest pa... | http://grass.osgeo.org/grass70/manuals/v.net.path.html |
| v.net.iso | Splits net to band... | http://grass.osgeo.org/grass70/manuals/v.net.iso.html |
| v.net.flow | Computes the ma... | http://grass.osgeo.org/grass70/manuals/v.net.flow.html |
| v.net.distance | Finds the shortes... | http://grass.osgeo.org/grass70/manuals/v.net.distance.html |
| v.net.connectivity | Computes vertex... | http://grass.osgeo.org/grass70/manuals/v.net.connectivity.html |
| v.net.components | Computes strongl... | http://grass.osgeo.org/grass70/manuals/v.net.components.html |
| v.net.centrality | Computes degre... | http://grass.osgeo.org/grass70/manuals/v.net.centrality.html |
| v.net.bridge | Computes bridge... | http://grass.osgeo.org/grass70/manuals/v.net.bridge.html |
| v.net.allpairs | Computes the sh... | http://grass.osgeo.org/grass70/manuals/v.net.allpairs.html |
| v.net.alloc | center node must... | http://grass.osgeo.org/grass70/manuals/v.net.alloc.html |
| v.net | Performs networ... | http://grass.osgeo.org/grass70/manuals/v.net.html |
| v.neighbors | Makes each cell v... | http://grass.osgeo.org/grass70/manuals/v.neighbors.html |
| v.mkgrid | Creates a vector ... | http://grass.osgeo.org/grass70/manuals/v.mkgrid.html |
| v.lidar.growing | Building contour ... | http://grass.osgeo.org/grass70/manuals/v.lidar.growing.html |
| v.lidar.edgedetection | Detects the obje... | http://grass.osgeo.org/grass70/manuals/v.lidar.edgedetection.html |
| v.lidar.correction | Corrects the v.lid... | http://grass.osgeo.org/grass70/manuals/v.lidar.correction.html |
| v.krige | Performs ordinar... | http://grass.osgeo.org/grass70/manuals/v.krige.html |
| v.kernel | Density is comput... | http://grass.osgeo.org/grass70/manuals/v.kernel.html |
| v.kcv | Randomly partitio... | http://grass.osgeo.org/grass70/manuals/v.kcv.html |
| v.in.wfs | Imports GetFeat... | http://grass.osgeo.org/grass70/manuals/v.in.wfs.html |
| v.hull | Produces a 2D/3... | http://grass.osgeo.org/grass70/manuals/v.hull.html |
| v.generalize | Performs vector ... | http://grass.osgeo.org/grass70/manuals/v.generalize.html |
| v.extrude | Optionally the hei... | http://grass.osgeo.org/grass70/manuals/v.extrude.html |
| v.extract | Selects vector fe... | http://grass.osgeo.org/grass70/manuals/v.extract.html |
| v.drape | Converts 2D vect... | http://grass.osgeo.org/grass70/manuals/v.drape.html |
| v.distance | Finds the nearest... | http://grass.osgeo.org/grass70/manuals/v.distance.html |

Starting from non-complex scenarios there are lots of use cases which are very helpful for farmers, service contractors and authorities when they are delivered within an SDI. Figure 19 shows how the required data processing may be implemented. In this scenario, the farmer does not have to store or manage any spatial data or perform any local processing locally. Given that problems related to data handling are frequently reported as being a reason for low uptake of precision farming [37, 38], the introduction of such a service-oriented architecture may be one means to increase acceptance of information-driven agriculture whilst also allowing access to powerful processing algorithms via mobile devices (e.g., from smartphone in the field for on-the-spot decision-making) and to new scientific results, as improved models may be incorporated by simply swapping alternative services into the background chain whilst the interface remains unchanged.

Fig. 19 Sequence diagram for N fertilization implemented with OGC services



One notable requirement for SDIs for agriculture is that current agricultural data formats are not based on Geographic Markup Language (GML), and so OGC services must be modified to manage these formats. In this way a specialized SDI for agriculture may be developed.

#### 2.4.4.3 Summary

The preceding paragraphs describe a modern high-technology agricultural system which uses various information sources in order to reach better decisions and therefore produce better products. Naturally there are many practical problems and challenges in implementing such a system, which should be mentioned.

On the technical side, extremely complex systems are produced, which due to a lack of standardization, a large quantity of data, and multiple data exchange requirements, do not always function in union. Metadata are missing, and data security and archiving are as yet mainly unexplored themes. The costs for programs, contractors, and services are still high, and networking with other on-farm software does not always work.

For implementation in crop production, rules and algorithms for decision support and farm-specific functions are often missing. The time required for an individual analysis is immense, and only a small minority of farms have the required IT and GIS knowhow. Functionality and complexity compete with simple usage, meaning that there is a large requirement for training.

## 2.5 GIS in the Farm of Tomorrow

### 2.5.1 Smart Farming

In the last years the term “Smart farming” or “Smart Agriculture” seems to get more prominent. From the perspective of farmers, smart farming should provide added value in the form of decision support or the optimization of processes whenever and wherever needed. Some sources call this a next revolution in agriculture, after plant breeding and genetic engineering, influencing the agricultural world through the combination of ICT solutions, the Internet of Things (IoT), sensors and actuators, geo-positioning systems, big data, unmanned aerial vehicles (UAVs), robotics, etc. Smart farming has the potential to support more productive and sustainable agriculture through a more precise and resource-efficient approach [46]. Accordingly, smart farming is closely linked to those technology areas which we described in this article:

- Management Information System: Systems for collecting, processing, analyzing, storing and communicating data in a form necessary for the execution of processes and functions in agriculture.
- Precision Farming: Managing spatial and temporal variability to increase cost-effectiveness and reduce negative environmental impacts through optimized input. This includes Decision Support Systems (DSS) for overall operations management to optimize revenue while conserving resources. The use of GNSS, drone aerial photography and the latest generation of Sentinel satellite time-series images ensures the creation of high-resolution maps using a variety of factors (e.g., yield, terrain characteristics, topography, humus content, soil moisture, N status).
- Agricultural Automation and Robotics: The process of applying automation, robotics, and artificial intelligence to all levels of agricultural production, taking into account farmbots and farmdrones.

Smart Farming applications not only target conventionally large farms, but also have the potential to support family farms (small scale, specialized crops, rare species conservation) and organic farming. Furthermore, it allows for an accepted and transparent production in the sense of the European consumer. Smart farming also contributes to environmentally sound production, e.g. through efficient water use or optimized inventory management.

### 2.5.2 Trends in Farm Management

Farm Management is currently undergoing many changes, which are driven by many different causes [39]. One common theme is the requirement for farmers to manage and exchange increasing volumes of information, much of which is spatially referenced. This in turn is driving various standardization initiatives in which spatial information and standards from the GI domain are playing a role. In this section, some current research trends relevant to GIScience will be briefly presented.

In many regions, changing economic conditions for farmers are leading to a decrease in small farms as smallholders or tenant farmers transfer their holdings to larger commercial enterprises, leading to an increase in farm sizes and increasing distance between farm managers and the conditions in the fields. Alternatively, small-scale or hobby farmers in a region may cooperate by combining neighboring fields and/or sharing farm machinery in order to reduce the amount of low-yield field border regions and produce economies of scale, perhaps also through use of larger machinery which could not be used in the individual land parcels. A further trend is for use of contractors to perform farm operations such as harvesting, reducing the need for the farmer to invest in specialized machinery.

In all of these cases, spatial information plays a role in the management: in larger farms the lack of detailed local knowledge by the farm manager may mean that interpretation of data such as soil and yield mapping will play a more important role in the decision-making process. Where cooperative management is used, the amount of inputs and the yield from each of the contributing land parcels and thus the profit/loss for each farmer may be calculated based on spatially referenced data collected during field operations. Similarly, the exact region of operation is an important part of the contract information for a contractor, and the data collected during operation may be used to calculate the fee charged.

### 2.5.3 Standardization activities in the agricultural information domain

Until now, standardization in agricultural data transfer has concentrated on communication between field devices, e.g., the *ISOBUS* standards family. Transfer of data between software systems and between organizations has, with the exception of some limited proprietary and/or national-based standards (e.g., DAPLOS, EDI (electronic data exchange)/teelt), remained unstandardized and relied on bilateral agreements. Currently, multiple initiatives are attempting to produce XML-based transfer formats for agricultural information. The spatial properties of agricultural data are covered in these proto-standards to varying degrees, but do not play a leading role. The use of GML, which would offer many advantages [40] including strongly object-oriented modeling, has become more popular through implementations of the European INSPIRE regulations.

During the course of the European project *GeoWebAgri*, the usage of GML and Geo Web Services in the context of precision farming field operations is shown. However, the usage of these technologies in agriculture is not widespread until now and the supporting community is still small.

The preceding activities may fit well for the standardization of specialized tasks within the agricultural domain. For the case of information exchange and integration with other domains (e.g. within the food chain and beyond), the usage of RDF (Resource Description Framework) can be a suitable supplement technology. Particularly for the GISciences the GeoSPARQL[1] language and vocabulary offers the representation and querying of geospatial information in RDF. GeoSPARQL extents the generic RDF query language SPARQL[2] with support for querying geospatial information. Thus there is an opportunity to seemlessly integrate geospatial information with RDF-based information from other domains including the exchange and processing of spatial and

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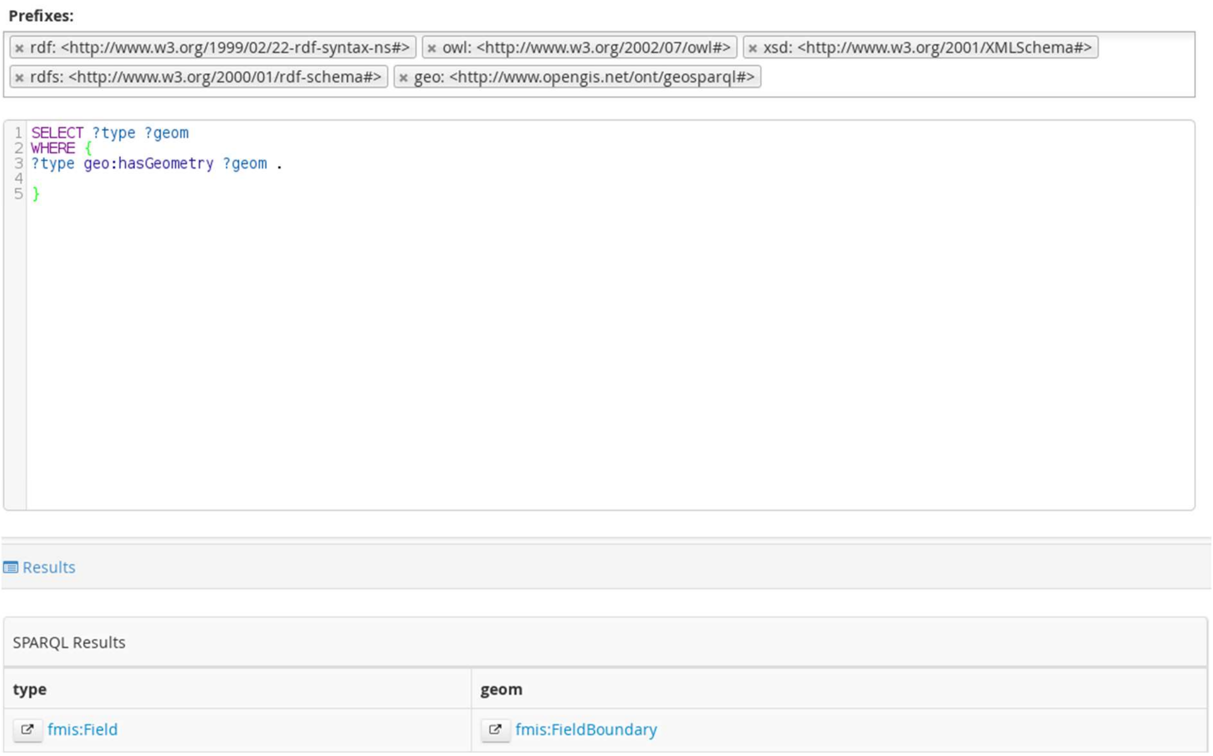
[1] http://www.opengeospatial.org/standards/geosparql

[2] https://www.w3.org/TR/sparql11-overview/

non-spatial rules in a standardized manner (OWL 2[3], SWRL[4], RIF[5]). The introduction of these technologies may lead to a more efficient information exchange along the processing chain and implementations of crop-production standards with less burden for all partners (see 2.5.4). In order to take advantage of RDF-based information the underlying GIS needs to support connections to RDF-databases (aka triple stores) such as Parliament[6] or Stardog[7]. Fig. 24.20 shows the usage of GeoSPARQL to check the presence of a geometry for an agricultural field.

**Fig. 20 Using GeoSPARQL to obtain a field boundary with Stardog**



Prefixes:

- rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
- owl: <http://www.w3.org/2002/07/owl#>
- xsd: <http://www.w3.org/2001/XMLSchema#>
- rdfs: <http://www.w3.org/2000/01/rdf-schema#>
- geo: <http://www.opengis.net/ont/geosparql#>

```
SELECT ?type ?geom
WHERE {
?type geo:hasGeometry ?geom .

}
```

SPARQL Results

| type | geom |
|---|---|
| fmis:Field | fmis:FieldBoundary |

## 2.5.4 Crop-Production Standards and Traceability

Farm management and crop production standards are playing an increasingly important role in farm activities. Legal regulations control which fertilizers may be used, and how and when they may be applied. Crop production standards and associated product labels may be used to enforce good agricultural practice or conformance to a particular production system (e.g., organic farming). Finally, subsidy payments to farmers in the European Union are directly related to compliance with environmental measures through the cross-compliance scheme (Sect. 24.3). Each of these laws, regulations, and standards can be considered to define a set of individual

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[3] https://www.w3.org/TR/owl2-overview/

[4] https://www.w3.org/Submission/SWRL/

[5] https://www.w3.org/TR/rif-overview/

[6] http://parliament.semwebcentral.org

[7] https://www.stardog.com

rules which farmers must respect when planning and performing field operations. Currently, each farmer is likely to have to manually draw up a personalized checklist against which operations are evaluated. This is complicated by regional and local variations in rules, e.g., within nature and water protection areas, which may cover only part of a farm or part of a field, additional rules may be enforced.

Ways in which the process of compliance checking may be automated have already been researched [45]. Using a combination of machine-readable encoding of the actual rules together with metadata describing the regions and farmers to which they apply, creation of a service-oriented architecture is proposed as a means to allow farm software to adapt dynamically to the local situation. However, the evaluation of rules requires large quantities of data, and nontrivial data processing, e.g., evaluating compliance to exclusion zones around water bodies requires the boundaries of these, potentially together with digital terrain models in order to calculate slopes. Where the broader effects of operations must also be considered, e.g., in regulating agricultural run-off, complex models and many geographic datasets may be demanded.

Food safety concerns as well as consumer demand for regional produce and fair trade are leading to increasing requirements on farmers to record all agronomic activities in detail, and for this information to accompany the actual produce through the processing chain so that in the case of contaminated food it may be possible to swiftly trace the exact field of origin of the produce and thereby search this region for potential environmental sources of the contamination. In order to implement such a system efficiently, it is necessary to have standardized data transfer formats and procedures and a mechanism to link the information to the physical product, e.g., through barcodes or radiofrequency identification (RFID) tags which will be propagated along the chain. However, farmers are also concerned about the possibility of *transparent farming* and loss of the private sphere for both themselves and their business. Data protection and security mechanisms are therefore also an important component: all actors must only be able to see the relevant data, and ideally any access will require permission from the data owner.

### 2.5.5 Robotics

Two trends in the automation of extensive farm operations with robots may be observed:

1. Automation of existing large-scale machinery (of which autosteering may be considered a part) such that existing operational techniques may in the future be performed by large automated vehicles with the human operator increasingly becoming an observer
2. Use of fleets of small robots which allow use of new and novel techniques in crop management [41, 42, 43, 50].

In both of these cases, spatial information plays an important part both in planning and in documenting operations: either an exact, spatially referenced plan must be prepared in advance and used to program the robotic operation, or a more general region of operation must be defined within which the robot may operate independently using sensor inputs to control the operation. Particularly in the latter case, it is necessary to document also exactly which operations the robot has performed in the field, including the location of each individual step. In cases where small, energy-limited robots are to be used, resource-aware positioning techniques developed for wireless geosensor networks may be necessary in place of GNSS.

## 2.6 Outlook

Due to legal regulations (IACS, cross-compliance, traceability, quality management, etc.), GIS (and geo web services) and information-driven crop production are becoming normal tools in agriculture, which must be integrated into usual farm practices. It is not realistic to expect farmers to maintain multiple separate information systems, and so the farm GIS must be fully integrated into the typical record-keeping software in use on farms. Data and services provided via the Internet will to some extent reduce the role of the farm GIS in the future. Regional service providers will gradually have an even more important role. Until then, there is much research and development necessary (standards, interoperability, metadata, workflow optimization, etc.), which will maximize automation in the management and processing of agricultural geodata.

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