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Methods and procedures for automatic collection and management of data acquired from on-the-go sensors with application to on-the-go soil sensors

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Abstract

Sensors for on-the-go collection of data on soil and crop have become essential for successful implementation of precision agriculture. This paper analyses the potentials and develops general procedures for on-the-go data acquisition of soil sensors. The methods and procedures used to manage data with respect to a farm management information system (FMIS) are described. The current data communication standard for tractors and machinery in agriculture is ISO 11783, which is rather well established and has gained market acceptance. However, there are a significant number of non-ISO 11783 compliant sensors in practice. Thus, two concepts are proposed. The first concept is on-the-go data collection based on ISO 11783, which mostly covers data on parameters related to tractor and machine performance, e.g. speed, draught, fuel consumption, etc. Process data from sensors with Control Area Network (CAN) interfaces is converted into ISO 11783 XML and then imported into relational database at FMIS using RelaXML tool. There is also the export function from database to task controller (TC) to provide task management, as described in ISO 11783:10. The second concept is on-the-go data collection with non-ISO 11783 sensors. This data is likely to be recorded in many formats, which require an import service. An import service is based on

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local or public sharing or semantic mapping outputting a common format for FMIS (e.g. AgroXML). Import is best performed as close to the generation of sensor data as possible to maximise the availability of metadata. A case study of sensor based variable rate fertilisation (VRF) has been undertaken focussing on German fertilisation rules.

Keywords: On-the-go soil sensors, FMIS, ISO 11783, data management

1. Introduction

In contemporary farm management significantly large amounts of electronic data are available for decision making. Smooth and efficient streaming and management of this data has a key role in effective utilisation. The insufficiency of user (farmer) friendliness has been the reason for slow and non-uptake of precision agriculture technologies for years (Dobermann et al. 2004; Kitchen 2008; Lamb et al. 2008). The features of the information-to-action decision process have to be the following according to Kitchen (2008): (1) *in situ* sensor-based; (2) automated for real-time or near real-time computer processing into decisions; (3) packaged so that sensing and processing of information are part of the equipment used to accomplish the required management action; and (4) transparent to the operator/manager for decision confirmation. Nash et al. 2011 have pointed out that the lack of availability of required data in digital form is an impediment to realise the potential of automated compliance assessment with common agricultural management standards.Sørensen et al. (2010) have derived a conceptual model for the farm management information system (FMIS) which contains an automated monitoring system of data collection and processing. The concept of service oriented architecture has been employed in several researches (Murakami et al., 2007; Nash et al., 2009; Wolfert et al., 2010) for data management in precision agriculture. Describing within field variability, including spatial and temporal is the most important requirement for successful implementation of precision agriculture (Srinivasan, 2006). Conventional description of within field spatial variability usually involves manual sampling, sample pre-treatment, laboratory chemical and physical analyses and mapping. This procedure is very expensive, time consuming and provides only few scattered number of readings (e.g. 1 sample per ha for soil analysis) (Kitchen 2008). Therefore, fast, cost effective and environment friendly methods for the collection of data on within field variability are required, which can be achieved with on-the-go sensors of soil and crops.

On-the-go sensors refer to those sensing technologies used to collect data while moving across a landscape. An on-the-go sensor to measure key soil properties based on visible and near infrared (vis-NIR) spectroscopy is an example (Mouazen et al., 2007). A key benefit of such on-the-go sensors is mapping the spatial variation in soil and crop at field/subfield scale as a valuable input for decision support. Whilst on-the-go instruments now exist to measure essential parameters on soil (Adamchuk et al., 2004) and crops (Lee et al., 2010), challenges remain in integrating these data into the FIMS in an efficient manner. These challenges stem from the fact that on-the-go collected data are with different formats e.g. images, spreadsheet xls, xlsx, proprietary binary, csv, etc. The potential benefit of a fully integrated FMIS containing updated and accurate soil data allows a farmer to improve the planning of their activities and inputs to achieve management aims. This may decrease the overall environmental impact by achieving lower inputs of energy, fertiliser, seed etc or enhancing profitability by increasing yield, gross margin, etc. It also allows direct reporting of the current state of a vital national or regional resource (soil) without introducing excessive administrative burden on the farmers and growers at the root of the information chain.

This paper aims to discuss methods and procedures to automatically collect and manage data (soil is taken as an example) on farms with respect to the FMIS. It will consider how sensors fully integrated with a workflow based on ISO 11783 may be used alongside more technically direct systems not linked to any specific standard.

2. Market survey

Technical systems must be seen as relevant to the market so they are bought and used in practice. The market uptake of on-farm automated recording systems has been investigated by Gasparin (2009) by conducting face-to-face semi structured interviews with 27 arable farmers. Although the specific objective of this investigation was related to agrochemical traceability subject-matter, many of the points analysed are generic to on-farm recording systems, data storage and management, and automation of these tasks. The results of Gasparin (2009) particularly relevant to the current subject were as follows:

- Main benefits of an automated recording system were: saving time in the office for data management, improved accuracy of field operations, improvement of stock control of input products, and avoidance of human errors.
- Concerns were about time spent on the field where the total time spent on the usage of automated recording system should not be more than that spent on conventional methods.
- Full integration with the existing farm software, enabling the farmers to work in their accustomed software environment.
- Sensitivity of data disclosure, i.e. giving out raw information to those who are not familiar with the context of the data (distinctive features of the agricultural task) which could lead to misinterpretation.

- Due to sensitivity of data disclosure the marketing of automated recording systems should be directed towards the farmers benefits, and not as a tool, which helps to provide compliance with legislation.

A key practical concern of users, as highlighted by Gasparin (2009) is the potential for on-the-go data gathering to increase task time through administrative overhead. To set this in context, the data flow on-farm can be considered a sequential process:

1. Gathering data
2. Data analysis – from data to information
3. Decision making from information

The current perception of distribution of effort through this process was gauged using a simple survey of farmers participating in the EU FP7 FutureFarm programme. Seven commercial operators of a range of farm size from three countries (UK, Denmark and Czech Republic) responded, and their perceived breakdown of time is shown in Figure 1. The individuals are generally interested in technology but were not selected on this basis.

This survey shows that farmers believe they already spend more time on gathering information (*mean = 49%)* than on data analysis (*mean = 16%*) or specific decision making (*mean =35%*). The data gathering phase is therefore a critical phase and any data transfer from on-the-go sensors must not increase time and effort. If possible, automation and standards should reduce the time required. Any improvement here may be highly visible (and desirable to drive adoption) by the users. Achieving reduction while handling overall higher data volume requires effective, robust standards which allow direct interoperability between all sensor systems, vehicle systems and FMIS. The point is supported by a market requirement analysis (Gasparin 2009 and Peets 2009), which recommended that:

- There should be one central database to hold detailed field records.
- There is a need for a common data exchange standard.
- Detailed field records have to be accessible by the customers in the food chain if required.
- A series of stakeholder consultations in that study established that the records may be allowed to be edited later to correct both technical and human mistakes.
- There is also an issue that raw field data (e.g. headlands, interruptions) may be misinterpreted when out of context.

These issues mean that the authorisation, responsibility, extent, and procedure of edits have to be identified and well defined. The underlying technology must support these requirements.

3. Concepts of data collection and management

3.1. Outline

The purpose of on-the-go data collection is to populate the FMIS with high quality information at minimal cost to the user. The FMIS must then derive value from the records it stores. User costs are primarily related to the time taken to operate the process and handle any generated exceptions (retries, correction of errors etc). Therefore once functional operation is achieved the key focus of any system should be on robustness to operate reliably every time without manual intervention and recover automatically or work around should errors occur. With the current level of adoption, a realistic implementation of on-the-go sensing includes data recorded using systems compliant with ISO 11783 and other systems not fully integrated with the standard methods of operation. Data processing functions may be performed at a local level (handheld PC, in-cab terminal, FMIS) or via the use of remotely accessed network services. Generally, we believe the focus should be on the function that is required prior to the selection of the optimum location for the processing system.

3.2. Specification of on-the-go sensor data

On-the-go collected data includes information about crop yield (Maertens et al., 2004), crop cover and NDVI (Reyniers et al., 2004), soil chemical and physical properties including moisture content, total nitrogen, organic carbon, pH (Mouazen et al., 2005; Mouazen et al, 2007). Data can be distinguished by the form of transfer into FMIS as conventional, ISO 11783 XML data, and non-ISO 11783 data. Conventional methods of transferring field data into an electronic FMIS can be classified as paper records taken in the field, human memory, collective memory, and physical records and deduction. Paper records can be designed to be very simple and quick, and if carefully filled complete. Human memory is quicker but prone to errors and much less predictable. Next worse is using collective memory – asking others associated with a task if it is not directly being entered by the operator. That is much slower and links in with a second person memory process to update then to transfer the data onto the system. Finally, the slowest and least desirable, but not unusual is the use of physical records and logical deduction (e.g. the number of empty spray cans and locating them) to work out afterwards what was done.

Paper records are usually transferred into FMIS by manual data entry through an on screen data input form, entering into spreadsheet or as scanned images of paper records (e.g. jpeg, tiff, pdf), possibly combined with optical character recognition processes.

Current data communication standard for tractors and machinery in agriculture is ISO 11783, which is rather well established and has gained market acceptance and has been adopted by many agricultural machinery manufacturers (e.g. AGCO, John Deere, Claas, Kverneland). Compatibility with ISO 11783:10 XML data transfer standard allows achieving full benefits. The identifiers for the data elements that are used in the process data message are specified in the Data Dictionary (ISO 11783:11 online data base, http://www.isobus.net/isobus_E/). The database is open for requests of new data elements.

Most of the on-the-go sensors are non-ISO 11783. Data from these sensors are available in a variety of formats (e.g. general XML, spreadsheet xls, xlsx etc, proprietary binary, csv) depending on the manufacturer. The manufacturers provide software to gather and analyse the data in FMIS. The data can be transferred from the field sensors also to brand specific database such as WebTrack by Patchwork, Fieldclimate by Pessl Instruments and AGCOMMAND by AGCO.

3.3. ISO 11783 task management

Data transfer from an on-the-go-sensor must be located within the overall framework of management of in-field tasks. Task management, communication between task controller and electronic control units, and data transfer between FMIS and mobile implement control system (MICS) are defined in ISO 11783:10 (ISO 2009). FMIS is the information processing infrastructure comprising of hardware and management software. MICS refers to devices that are coupled by ISO 11783 network. A task controller is the primary electronic control unit (ECU) on the MICS responsible for sending, receiving and logging of process data. It has links with FMIS and electronic control units of implements. The central atomic data management unit that comprises the agricultural resources, products and operations is called task. Tasks can be generated on the FMIS and MICS. In ISO 11783-1 (ISO 2007) task is defined as an execution of work on one field for one farm. A maximum of one task can be active concurrently on a single task controller. The main objectives of the task management are the management of farm resources and field activities (ISO 11783-10:2009). Data transfer between FMIS and MICS is bidirectional: planned task is sent to the MICS and resulting logged data back to the FMIS (Figure 2). The planning data is converted into a standard XML format and transferred to task controller on a tractor through wireless link or on a memory card. Task controller sends messages to implements according to the planned task file and logs data values recorded from a particular processing operation. The collected data is sent back to the farm computer and converted into an appropriate format. Finally the completed task data is converted into desired format for further usage or storage.

The ISO 11783 task file is based on the Extensible Markup Language (XML) where the elements represent the real world objects. The main task file contains the root element ISO_11783_TaskData, coding data, and a number of tasks. Inside the main file, there can be references to sub task files, which may each contain a single XML element. During the execution of tasks the files are modified and binary data appended by MICS.

Communication between FMIS and MICS is based on standardised XML data transfer files, Figure 3. The task controller interface driver is responsible for sending task data to the task controller in proprietary or XML format. The task controller converts data from the transferred task file into process data messages, which contain commands and values to control the relevant implement ECUs on ISO 11783 network.

3.4. ISO 11783 sensor data

A prototype implementation of agricultural process-data service has been proposed by Steinberger et al. (2009). It is based on data recording in ISO11783 environment, transfer of ISO 11783 XML data to the web-server for analysis and storage, and aggregation of AgroXML data to the jobs at FMIS. However, the solution proposed by Iftikhar and Pedersen (2011) for the exchange of sensor data with FMIS was adopted. The main features of this approach are: asynchronous bi-directional data exchange, high-level specification without the need of hand-coding, user-friendly graphical user interface, standardisation and open source technologies. They use platform independent tool RelaXML (Knudsen & Thomsen, 2004) to transfer data between relational database and XML. The work by Iftikhar and Pedersen (2011) is part of the Danish LandIT project (data integration of farming devices and farming systems). Following the methodology of Iftikhar and Pedersen (2011) the solution works in the following way (Figure 4). The database is an integrated database able to store low level sensor readings. It's structure is based on the ISO 11783:10 standard For example, for datalogging the following four tables are required: task as the core element, time (includes position), ProcessDataVariable and DataLogValue. Data export and import is carried out by RelaXML tool, which uses options, concept and structure definition files to perform XML-based export and import of data (Knudsen and Thomsen, 2006). An options XML file used for specifying user and site specific settings is needed for both export and import. A concept XML file defining what data to export by creating relations between parent and child elements is needed for export. Additionally, a structure definition file defining the structure of the generated XML file is needed for export.

4. Non-ISO 11783 data collection and management

4.1. Non-ISO 11783 sensor data

Non-ISO data is likely to be recorded in many formats, and this has been one key challenge in the adoption of technology in agriculture for many years. Ultimately, all FMIS and other processing systems are being designed to use agroXML, as an interchange standard.– agroXML is foreseeably going to become widely adopted in agricultural sector (Bareth & Doluschitz, 2010). Therefore, our aim is to complete relevant records in this format from the original data. This import process must combine the contents of the data file with other metadata not present in all formats. It may also include a distillation phase where meaningful data is separated from irrelevant machine specific data (e.g. combination of multiple individual load cells into a single specific soil resistance or processing raw TIFF images into NDVI values). The import process is best performed as close to the generation of that record as possible, in real-time or near real-time as suggested by Kitchen (2008), (Figure 5). This maximises availability of metadata, which is increasingly lost the longer the data is held in incompatible formats. Specifically, in order of preference:

1. Where possible, any producer of a third party file should be upgraded to include agroXML output directly.
2. A second choice is to provide a format exporter which is incorporated in the workflow to be used by the original operator –integrated with the end of day or data transfer process.
3. A next choice is to include the function as an import filter at the time data is taken into a farm-office system.
4. Last choice is that the data is encapsulated in a raw format and incorporated later.

Automated unification will take place through a common data dictionary (semantics), an ontology based approach, as demonstrated by Nash et al. (2011 & 2010a). It should also be possible to provide each translator with a manual interface to allow definition of the sematic mapping for the first import between systems. This mapping should be storable in the destination device to allow future translations to be entirely automated. Although a large number of potential sources of data exist, the single target format of agroXML reduces the number of translation maps which must be made.

The experience of other industries suggests such mappings can be productively shared in a community (e.g. CDDB for mapping CD tracks to catalogue data). This type of collaborative sharing of community developed input mappings is most effectively performed where systems are connected to the wider internet. The location of such functions is discussed further below. FMIS providers may offer a curatorial service, combining user provided import filters into a centrally validated update package which is distributed to their users. Alternatively entirely online services may be provided. As currently found in the industry, it is suggested that import processes are likely to remain to some extent manufacturer specific or based on de-facto industry standards. There is however the opportunity for third parties to produce translation layers for incorporation in machine controllers or FMIS PC environments where original manufacturers are unwilling or unable to provide a solution.

4.2. System Structure

Entities of the system, shown in Figure 5 are sensors, tractor, MICS, TC, FMIS, central store (e.g. national level servers) and clients (farmers). Data processing may be undertaken at each entity, either locally or with the aid of network (internet) connected centralised systems or servers. Any farm-office system, if it is a single piece of hardware or a more complex local-area-network of servers and clients is considered as a conceptual FMIS. Independent server processing has advantages and disadvantages. From an information perspective particular advantages are:

- Combination / aggregation of data with other sources not available at a local level, either because of technical limitations (e.g. large maps on handhelds) or administrative / license restrictions (e.g. access to national non-farm data).
- Provision of independent third party function – certification to a standard or certification of holding a record at a particular time (e.g. solicitor registered letters).
- Tracking of processes – generation of non-compliance data.
- Multiple access of single data store – public or limited user group.
- Operation of community supplied import routines, where FMIS suppliers are unable or unwilling to provide software update packages, import and translation can be supported as a community developed function where data is submitted, translated on-server and immediately returned as agroXML for import to the FMIS. Such processes do introduce data integrity/process assurance issues which must be addressed.

From a technical perspective the advantages are:

- Centrally maintained hardware/software (high and managed availability)
- Ensure a common process (code path) applied to all data entered in subsequent systems.
- Unattended, therefore cost per transaction is many orders lower than any process that involves a human operator.
- Potentially much greater processing power or storage available than on local systems.
- Access to wide community input at low cost – following a wiki model of widely sourced collaboration.

With current technology, server processing may be invoked at any stage of the system, from field operation onwards. The cost of accessing networks is however usually considerably reduced at the stage of the FMIS, which is office based and has access to relatively low cost higher bandwidth links compared with earlier parts of the chain. It is acknowledged that rural access to broadband remains difficult in some areas, however the absolute quantity of data exchange required is low compared to consumer data (video, music) and highly suitable for unattended batch transfer over slow links from the FMIS (overnight etc).

4.3. Data from sensors

Raw sensor data is not usually taken as an input to this system, as some level of processing and storage is required, even if only to calibrated engineering units. Where smart-sensors are used they should ideally be collected according to ISO 11783:10, however if this is not the case they should be considered as a general import as per the machine controllers described below. An important function in management of sensor systems is in holding and tracking calibration and setup data to verify data from source. This is likely to be performed at a higher level e.g. FMIS, although it requires item tracking identification to machine or sensor level. Such source identifiers must be passed with data.

4.4. MICS

Machine controllers usually have significant processing, display and user interface capabilities. Their software can often be updated and such activities can form part of existing machine regular maintenance. By this route existing systems may be upgraded to produce agroXML directly as per the order of preference above. Where technical limitations exist (e.g. memory or display sizes), it may be possible to introduce required additional data fields to binary formats at the MICS level for later extraction.

4.5. FMIS

FMIS accepts ISO 11783:10 XML, agroXML and proprietary formats. The FMIS may be useful to make use of server processing for particular functions (such as wide area geographical or statistical data), but retains the essential local database requirement. The proposed workflow of utilising the soil data for rules checking is shown in Figures 6 & 7, as found in literature.

There is a tendency for all data import and translation functions to be focussed at the beginning of the FMIS. This is technically logical (access to PC computing power, network resources, and office environment for data entry), however, time spent here is highly visible to the user and to farm management. New import functions to generate agroXML for example will be perceived as additional time consuming work. Every effort must be made to integrate import processes and provide user-appropriate interfaces (e.g. selection of a machinery manufacturer rather than controller manufacturer). The use of community contributed import functions should be on a "specify once, use automatically without further prompting" basis as discussed above.

4.6. Central services

As well as specific processing functions called as required from the FMIS (e.g. map images, import functions) central services can provide data storage and backup for a FMIS. Any storage should be divided into two parts: farmer centric and customer centric. Both would be based on input and output of agroXM, irrespective of any internal database format.

Splitting the database addresses the privacy concerns farmers may have when exposing raw data. Generally the farmer centric data is kept private to the farm, whereas customer centric data is "reported" to the wider industry. This may be linked to the physical export of product from a farm triggering the production of a data record in the customer centric side from the farm centric side. Then the functionalities of these two stores can be developed independently depending on the requirements of farmers and customers respectively.

4.7. Clients/farmers

Site specific tasks under clients are site specific tillage, fertilisation including NPK and organic fertilisation, lime application, manure injection, irrigation and agrochemical application. A case study of variable rate fertilisation was discussed in detail in Peets, et al. (2011), as part of deliverable 7.6 of FutureFarm EU FP7 project.

5. Case study of variable rate fertilisation

A specific example of how the concepts presented above can be used in practice relates to the collection of on-the-go soil data and how this can be incorporated and interpreted within the FMIS into a real VR application. This case study will consider such a process, specifically as applied to variable rate fertilisation (VRF), which has been chosen as an example. This choice stems from the fact that the vis-NIR on-line sensor has the potential to provide direct benefits to the farmers when adopted for VRF, although limited data is available so far. This is in-line with the assertion in section 2 about the marketing of automated recording systems. A recent study reported a successful sensor-based VRA of P2O5 based on on-the-go measurement of extractable P, achieving an increase in kernel maize yield of 334 kg/ha due to VRA, as compared to uniform application of P2O5 (Maleki et al., 2008). In this study, it was found that the average phosphate applied on plots was 28.75 kg/ha, which was 1.25 kg/ha less than the uniform rate fertilisation (30 kg/ha), recommended according to the standard soil test (1 sample per ha). The overall profit was about €30 per ha, by only applying variable rate P_2O_5..

Different European countries obey different rules for VRF, which need to be unified in one set of rules across the continent. Therefore, we will focus, in this case study, on the German fertilisation rules only. These rules have to be integrated into the FMIS as shown in Fig. (8). They are set for the determination of available soil nutrient amounts in soil, which is a requirement before application of significant nutrient amounts. Among others the following most relevant rules are considered (http:// test.futurefarm.eu):

- **Rule 3.1.** Determination of fertilisation need by crop is required before application of significant nutrient amounts. Requirements for conservation of site-specific soil fertility have to be considered additionally. The determination of fertilisation need has to guarantee a balance between foreseeable nutrient demand and nutrient supply.
- **Rule 3.2**: This rule concretizes how the determination of fertilisation need has to be done. For every field or production unit the farmer should consider site-specific nutrient demand (earning, quality), soil fertility (nutrients from previous crop and organic fertilisers, soil lime content (pH) and organic matter content, other nutrient supplies (irrigation) and cultivation conditions.
- **Rule 3.3**: Determination of available soil nutrient amounts is required before application of significant nutrient amounts. The vis-NIR on-line sensor is used to collect the required data.
- **Rule 3.4**: Fertiliser application time and amount have to be chosen so that available nutrients correspond to crops nutrient need.
- **Rule 4.3**: The maximum allowable amount of nitrogen from farm fertilisers of animal source is 170 kg per hectare and year (average of all used agricultural areas of the farm).

- **Rule 4.4**: This is a exception from German Duengeverordnung rule 4.3. The maximum amount of nitrogen from farm fertilisers of animal source is 230 kg per hectare and year on grassland and field grass (average of grassland and field grass areas of the farm).
- **Rule 8.1**: Applied mineral fertilisers must comply to German Duengemittelverordnung or Regulation No. 2003/2003 of the European Parliament and the Council regarding a type of fertiliser. Applied farm fertilisers, soil helper, culture substrates and plant helpers must comply to German Duengemittelverordnung regarding the composition and declaration of ingredients.

Figure 8 shows the process of VRF, considering the German rules of fertilisation as an example. The on-the-go vis-NIR sensor (Mouazen, 2006) will provide most of the required data on soil, namely, total nitrogen (TN), organic carbon (OC), moisture content, P (Maleki et al., 2008) and pH (Mouazen et al., 2007). The high resolution data of about 2000 readings per ha obtained with the on-the-go sensor will enable carrying out both map-based and sensor-based VRF. However, fertilisation recommendations are strongly dependent on soil, climate, crop and environmental conditions and, not surprisingly, methods to achieve this are called "philosophies" (Build-Up and Maintenance; Basic Cation Saturation, Percent Sufficiency Concept; Hydroponics). However, map-based VRA can build in errors through the use of a positioning system during data acquisition and in the interpolation between discrete observations during creation of application maps (Morgan and Ess, 1997). The sensor-based variable rate application is based only on data collected automatically by on-the-go sensors and models that transfer sensor output into application. The sensor-based VRA are only possible when on-the-go sensors for measurement of soil properties provide accurate data on a specific soil property to enable real time VRA, without the need for data on crop and other ancillary data.

After on-the-go data collection, the non-ISOBUS data will be imported into the FMIS by means of an Import service (Figure 5). The German rules of VRF should be incorporated into FMIS, so that decisions on VRF are made by an external expert or by a future decision support system, taking into consideration these rules. Since available nitrogen is needed for VRF of nitrogen, map-based VRF will be the preference possibility.. The map-based will assist obeying to the German rules of fertilisation mentioned above and fit with the sensor output, which provides measurement of total nitrogen that has to be transformed into available N by accounting for the nitrogen mineralisation rate and using advanced modelling techniques. The data collected on soil (N, C, pH and P) will then be integrated into FMIS as internal sensor data, as shown in Figure 9 (Sørensen et al., 2009).

However, with sensor-based variable rate application all steps adopted during the map-based VRF have to be executed on-the-go, while the fertiliser equipment is running in the field. In this case, farmers will comply with the most German rules of fertilisation available in FMIS (e.g. rules 3.1, 3.2, 3.3, 3.4 and 8.1). However some of these rules (e.g 4.3 and 4.4.) should be considered during the on-the-go VRF. Therefore, a modelling scheme should be considered in order to transfer the on-the-go collected data into fertilisation recommendation dosage (Figure 9). Wireless data communication will allow for this application to be fulfilled. In the modelling stage a threshold of maximum application of N should be considered. This maximum dosage should not exceed the maximum allowable N fertilisation of 170 and 230 kg/ha according to the rules 4.3 and 4.4, respectively. The other German rules listed above are complied prior to the field VRF in case of sensor-based application.

Conclusions

The paper discussed the potential and has introduced general procedures for on-the-go data acquisition of soil sensors. The methods and procedures were used to manage data with respect to farm management information system (FMIS). The following conclusions can be drawn:

- The preferred route for automated collection of on-the-go sensor data is the integration of sensors with ISO 11783 data network. This facilitates the adoption of the common agricultural data exchange standard. A relational database with the structure based on ISO 11783:10 task file is suitable for storage of acquired data. RelaXML tool provides user friendly data export and import between database and TC.
- Non-ISO 11783 compliant sensor data is proposed to be transferred into the FMIS ultimately as agroXML by using an import service based on local or public sharing of semantic mapping. The performance of the import service is the key challenge in management of sensor data.
- There is a significant potential benefit in time-saving from the adoption of standards to ensure robust transfer of in-field data. This may be directly accepted by farmers who already perceive information gathering to be the most time consuming element of field management.

A further work is needed to develop or upgrade the current procedures considered for the integration of on-the-go data, collected with wireless technologies into FMIS.

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