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Farm management information systems: Current situation and future perspectives

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ABSTRACT

Farm Management Information Systems (FMIS) in agriculture have evolved from simple farm recordkeeping into sophisticated and complex systems to support production management. The purpose of current FMIS is to meet the increased demands to reduce production costs, comply with agricultural standards, and maintain high product quality and safety. This paper presents current advancements in the functionality of academic and commercial FMIS. The study focuses on open-field crop production and centeres on farm managers as the primary users and decision makers. Core system architectures and application domains, adoption and profitability, and FMIS solutions for precision agriculture as the most information-intensive application area were analyzed. Our review of commercial solutions involved the analysis of 141 international software packages, categorized into 11 functions. Cluster analysis was used to group current commercial FMIS as well as examine possible avenues for further development. Academic FMIS involved more sophisticated systems covering compliance to standards applications, automated data capture as well as interoperability between different software packages. Conversely, commercial FMIS applications targeted everyday farm office tasks related to budgeting and finance, such as recordkeeping, machinery management, and documentation, with emerging trends showing new functions related to traceability, quality assurance and sales.

1. Introduction

The rapid technological developments during the last few years have introduced radical changes in the working environment in the agricultural sector. Agriculture has entered a new era in which the key to success is access to timely information and elaborated decision making. The up-to-date and skilled farm manager has to choose between various production options utilizing the latest advancements in research and technology. Decision making is an important aspect in farm management and has been studied by numerous authors (e.g. Sørensen, 1999; Fountas et al., 2006; Magne et al., 2010). Gladwin (1989) argued that the key point in decision making for farmers is to understand why farmers act as they do, using their tacit knowledge. Such an understanding will help researchers provide farmers with supporting tools and knowledge to enhance decision making at specific stages of their production process.

The basis for enhanced decision making is availability of timely, high-quality data. However, the current situation in European farming is that most data and information sources are fragmented, dispersed, difficult, and time-consuming to use. This indicates that the full potential of such data and information are not being fully exploited. The integration of spatial and temporal historical data, real-time farm data, knowledge sources, statutory compliance, health and safety guidelines, environmental guidelines, economic models, and so forth, into a coherent management information system is expected to remedy this situation.

Management Information Systems (MIS) solutions in agriculture have evolved from simple farm recordkeeping systems to

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large, comprehensive Farm Management Information Systems (FMIS) in response to the need for communication and data transfer between databases, and to meet the requirements of different stakeholders. Boehlje and Eidman (1984) defined FMIS as electronic tools for data collection and processing with the goal of providing information of potential value in making management decisions. Lewis (1998) noted that an FMIS exists when main decision makers use information provided by a farm record system to support their business decision making. Sørensen et al. (2010a) defined an FMIS as a planned system for collecting, processing, storing, and disseminating data in the form needed to carry out a farm's operations and functions. Essential FMIS components include specific farmer-oriented designs, dedicated user interfaces, automated data processing functions, expert knowledge and user preferences, standardized data communication and scalability; all provided at affordable price to farmers (Murakami et al., 2007). To improve functionality, various management systems, database network structures, and software architectures have been proposed by a number of researchers. In practice, FMIS have increased in sophistication through the integration of new technologies, such as web-based applications and applications for smart phones and tables (Nikkilä et al., 2010).

A key question is whether commercial FMIS are and have been able to capture the functionalities developed in academic research; an indication of the level of transferral and uptake between research and commercialization. Another question is whether the increased demands from data intensive Precision Agriculture (PA) is being met by current development trends in terms of matching design, functionalities, etc. The answer to these questions will provide pivotal guidelines for future research development as well as provide knowledge on possible redirections for software vendors.

The aim of this study was therefore to evaluate current FMIS designs and solutions available for farm businesses from both academic and commercial points of view in order to extract future needs and correspondence with current developments, both in terms of research development and commercialization. The academic perspective covers the more advanced FMIS designs integrating the newest advances in information technology where systems are supposed to set the trend for future FMIS but not yet fully implemented. The commercial perspective cover the FMIS currently implemented and in commercial. This article is organized into three sections. The first section presents the methodological approach for the selection of the agricultural domain, the procedure adopted to select the relevant scholarly contributions to FMIS development, the procedure adopted for the identification of commercial FMIS and the subsequent clustering procedure. The second section presents a targeted review of academic FMIS concepts and solutions, covering FMIS development and architecture, FMIS for PA, FMIS adoption and profitability, and, finally, FMIS development trends. The last section presents commercial FMIS, showing a possible division in groups created through a two-step clustering analysis focusing on functions currently offered.

2. Methodological approach

2.1. Selection of scholarly contributions to FMIS development

The methodology for the academic FIMS review has a principle of using selective keywords for the search in international academic databases. The specific keywords were: (i) farm management information system, (ii) farm software, (iii) decision support systems for agriculture, and (iv) information management in agriculture, and combinations of the formers.

2.2. Identification of commercial FMIS applications

The FMIS market is very large covering many cropping systems and the research was targeted according to two specific selection criteria. The first criterion narrowed the research to only cover crop production and, more specifically, open-field crops, since available solutions for greenhouses involve a very different concept incorporating many control algorithms. The second criterion targeted only solutions that identify the farm manager as the main user related to field operations and does not cover solutions related to Enterprise Resource Planning (ERP) operations.

The selected FMIS were focused on crop production and were centered on the farm manager as the primary user. Initially, to find relevant commercial applications, international FMIS vendors using English as the main language were selected. This allowed collecting data from United Kingdom, United States, Canada and Australia, as well as from other global software houses which provide their applications in English and have an English-based website. Then, the research encompassed also FMIS as representative of the larger European agricultural software market, made of mid and small companies which require applications in their native language. Therefore we collected data about products provided in French, German and Italian, because at least one of the authors has a good command over these languages (Table 1). The data were retrieved through a structured approach: First, we ran a web search in the country-specific languages using different keywords (e.g. farm management, farm software, agricultural management) to create an initial group of applications; secondly, we checked web portals dedicated to farmers; and finally, we validated our group of applications with the top three farmer unions in each country. The information retrieved from the software developers was analyzed using software demo versions when available. In 22 cases, the information provided from the website about the functions was ambiguous. Therefore, phone calls were made to the software vendors to collect the necessary information from a sale representative or technician. In total, 141 commercial FMIS from 75 different software vendors were analyzed according to services they offer to their respective users. The selected software applications were computer based (i.e. enabling farmers to organize work from the farm office) and supported web-based and mobile applications.

A total of 11 generic functions were determined as the main functions or services that commercial FMIS offer farm managers (Table 2). The identification of these functions was mainly based on the guidelines provided by Robbemond and Kruize (2011) and Kruize et al. (2013), analysing the different applications and functions that commercial applications offer, together with data exchange protocols. Additionally, the identification of these 11

Table 1
FMIS functions included in the commercial software.

Countries	Number of commercial solutions	Number of vendors
Europe	**61**	**31**
France[a]	10	6
Germany[b]	16	4
Italy[c]	16	10
United Kingdom	**19**	**11**
North America	67	38
United States	63	34
Canada	4	4
Australia	**13**	**6**
Total	**141**	**75**

[a] In French.
[b] In German.
[c] In Italian.

Table 2
Countries of origin for the commercial farm management information systems.

Function title	Function description
Field operations management	Includes the recording of farm activities. This function also helps the farmer to optimize crop production by planning future activities and observing the actual execution of planned tasks. Furthermore, preventive measures may be initiated based on the monitored data
Best practice (including yield estimation)	Includes production tasks and methods related to applying best practices according to agricultural standards (e.g. organic standards, integrated crop management requirements). A yield estimate is feasible through the comparison of actual demands and alternative possibilities, given hypothetical scenarios of best practices
Finance	Includes the estimation of the cost of every farm activity, input–outputs calculations, labour requirements, and so on, per unit area. Projected and actual costs are also compared and input into the final evaluation of the farm's economic viability
Inventory	Includes the monitoring and management of all production materials, equipment, chemicals, fertilizers, and seeding and planting materials. The quantities are adjusted according to the farmer's plans and customer orders. A traceability record is also an important feature of this function
Traceability	Includes crop recall, using an ID labeling system to control the produce of each production section. Traceability records related to the use of materials, employees, and equipment can be easily archived for rapid recall.
Reporting	Generally includes the creation of farming reports, such as planning and management, work progress, work sheets and instructions, orders purchases cost reporting, and plant information
Site specific	Includes the mapping of the features of the field. The analysis of the collected data can be used as a guide for applying inputs with variable rates. The goal of this function is to reduce or optimize input and increase output
Sales	Includes the management of orders, the packing management and accounting systems, and the transfer of expenses between enterprises, charges for services, and the costing system for labour, supplies, and equipment charge-outs
Machinery Management	Includes the details of equipment usage, the average cost per work-hour or per unit area. It also includes fleet management and logistics
Human resource management	Includes employee management, including, for example, the availability of employees in time and space. The goal is the rapid, structured handling of issues concerning employees, such as work times, payment, qualifications, training, performance, and expertise
Quality assurance	Includes process monitoring and the production evaluation according to current legislative standards

generic functions was complemented by recommendations of Abt et al. (2006) that agricultural software should include production planning, production process integration, performance management, quality and environmental resource management, as well as sale orders and contract management. Each software application was analyzed to define, which of the 11 functions it supports.

2.3. Clustering procedure

As each software house offers different products that can be combined in a single integrated solution, our analysis targeted functions covered by complete software solutions and a clustering analysis was carried out on these complete solutions. After collapsing the initial group of 141 FMIS into 73 complete solutions, a clustering algorithm was selected with the aim of maximizing the difference between clusters and thereby to clarify the subsequent characterization. Clustering methods are a family of multivariate data analysis techniques that can identify groups of objects that are similar but different from objects in other groups (Hair et al., 2010). Although hierarchical clustering is one of the most common methods, it has limitations in terms of categorical and binary data. Therefore, a two-step clustering approach was adopted to overcome the limitations of hierarchical clustering (Norušis, 2011). The first step involved scanning the data and defining pre-clusters, where every record was determined to belong either to an existing pre-cluster or to a new pre-cluster (Zhang et al., 1996). In the second step, the pre-clusters created in the first step were grouped into a preferred number of clusters. Since two-step clustering is influenced by the order of data, multiple tests were conducted to determine the optimal number of clusters and to check possible changes in the assignment of FMIS to clusters. For the analysis, the SPSS (IBM USA) statistical package was used.

The best results were obtained with four clusters. The validity of these four clusters was tested for changes in cluster assignments as suggested by Hair et al. (2010). The two-step clustering results were compared with the outcomes of a classical hierarchical method, in which the selection of the combination of the 'distance measure' with the 'linkage method' has a significant impact on the clustering results. The former is the criterion for determining the distance between cases; the latter is the criterion for determining which clusters are merged at successive steps. Since many selections were possible, different tests were conducted to select the distance measure and linkage method able to maximize the difference between clusters, allowing for a clear interpretation of results.

The binary squared Euclidean distance, in combination with Ward's method, was selected. The cluster assignments derived from the two different methods were cross-tabulated and less than 17% of the stipulated records were shown to change cluster assignment, which was considered a stable solution according to Hair et al. (2010). Finally, special attention was devoted to profiling the final solution. We conducted a clustering interpretation phase, as suggested by Hair et al. (2010), focusing on the agricultural practice. The outcome of the results were evaluated twice, involving a defined meaningful interpretation of the results as well as assigning names to clusters and commenting on the functions covered by each of them in comparison with the others.

3. Academic FMIS concepts and solutions

3.1. FMIS development and architecture

The first FMIS was introduced in the 1970s with applications targeting recordkeeping and operations planning (Blackie, 1976; Thompson, 1976). Canfarm was one of the first applications used by Canadian farmers in 1978, when 10,000 farmers adopted it for recordkeeping and 4000 for planning (Thompson, 1976). Kok and Gauthier (1986) then presented a FMIS with incorporated decision support algorithms in recordkeeping and planning and consisting of four major components: the processing of permanent data that seldom change, annual data linked to particular cropping seasons, daily data representing daily farm operations, and inventory data related to farm stocks and suppliers. This type of design and architecture is still common in many current commercial applications. The first application to combine decision support tools with recordkeeping and planning was the CALEX system in California, USA, covering irrigation, pest management, and fertilization applications (Plant, 1989).

The majority of the FMIS and decision support systems (DSSs) described in the scientific literature are based on simulation models or targeted optimization models and methods (Lilbourne et al., 1998; Attonaty et al., 1999; Thomson and Willoughby, 2004; Sahu and Raheman, 2008; Sante-Riveira et al., 2008; Papadopoulos et al., 2011). They are very often based on probabilistic methods (Kamran and DePuy, 2011), including methodologies such as linear programming (Sante-Riveira et al., 2008), dynamic programming (Parsons et al., 2009), rule-based management (Shaffer and Brodahl, 1998), decision trees (Cohen et al., 2008), eExpert heuristics (Trépos et al., 2012), fuzzy optimization (Papadopoulos et al., 2011), generic algorithms (Hameed et al., 2012), and smart elements (Lilburne et al., 1998) to model, solve, and generate optimal strategies.

Since agriculture as a biological production system is characterized by a high degree of uncertainty, a deterministic FMIS model as a backbone cannot fully capture the probabilistic nature inherent in agricultural production systems. However, few FMIS deal with uncertainty in farm management problems (Engel et al., 2003; Bange et al., 2004; Harwood et al., 2010), while most revert to solely deterministic aspects (Thomson and Willoughby, 2004; Sahu and Raheman, 2008; Papadopoulos et al., 2011). In this regard, uncertainty assessment is the least well understood and implemented capability of farm management and DSSs. Future FMIS should provide the farm operator/manager with information about resources across the farm and the potential impacts of management decisions on those resources.

To improve FMIS functionality, a number of software architectures and designs have been introduced with increased level of sophistication, using, for instance, web-based applications or other emerging technologies in agricultural production (e.g., PA, automated data transfer). Farm management systems implemented with web-based services facilitate collaborative research over the Internet by connecting geographically dispersed teams (Schweik et al., 2005) such as farmers and crop advisors or customizing end-user data for analysis or presentation purposes (Chaudhary et al., 2004). Additionally, web services facilitate the use of standard language for data exchange between systems and services based on Extensible Markup Language (XML) and a service bus as message-oriented middleware for the connection of web services (Murakami et al., 2007).

Finally, holistic FMIS have been recently presented to capture all data flows from the various actors linked with FMIS. According to Sørensen et al. (2010a), an FMIS is needed to advise managers of formal instructions, recommended guidelines, and documentation requirements for various decision making processes. For these purposes, the architecture must consider the farmer the central decision maker with regard to planning, controlling, and operating a crop production system and outlining how the operational field data need to be collected and transformed in an automated way. To cover all activities ranging from planning to execution and evaluation activities, a reference architecture design has been presented (Sørensen et al., 2010b), identifying the actors involved, their roles, and the communication specifics related to decisions and control processes. The knowledge content of the decision processes and the data embedded in the information entities has also been documented (Sørensen et al., 2011). While most of the recent holistic FMIS architectures have focused on the farm manager as a focal point, a FMIS architecture based on the collaboration and automated acquisition of operational farm data between farmers, governmental organizations, service providers, and machinery manufacturers in the agrifood production chain has been presented (Teye, 2011). In summary, the design of new FMIS requires a user-centric approach to serve specific farm operations strategies while simultaneously maintaining their ability to be integrated in a holistic managerial scheme with the farm manager at the center of the system.

3.2. FMIS for precision agriculture

Early FMIS operated largely in a non-spatial realm, using computer simulation models to project current conditions onto alternative future scenarios (Lilburne et al., 1998; Attonaty et al., 1999; Jensen et al., 2000). In that context, precision and accuracy proved insufficient, requiring the development of spatial management features (Thorp et al., 2008; Cohen et al., 2008; Cardín-Pedrosa and Alvarez-López, 2012). The advent of PA information technologies and electronic communication along with the development of more accurate Global Positioning Systems (GPS) at reasonable costs have enabled farmers to acquire large amounts of data to be used effectively in site-specific crop management (Stafford, 2000; Tozer, 2009). This has created the need to design and develop dedicated FMIS to cope with this increased amount of data generated by applying PA in field production. Fig. 1 conceptually outlines the spatial management of field operations involving the acquisition of spatial and temporal data and the subsequent processing and inference within the realm of an FMIS for final decision support within the operations management and activity documentation aimed at external stakeholders.

This development aimed to support decision processes with inherent spatial requirements. The employed methods include dynamic spatial links that allow the simulation at one location to impact other locations at each time step. This functionality is essential for whole farm simulations, because individual parts of a farm often share or transfer resources. Additionally, whole farm simulation models are expected to facilitate PA by targeting conservation measures that provide environmental benefits (Berry et al., 2003). To organize the increasing data generated by PA applications, Fountas et al. (2006) defined the information flows involved with decision making in PA and Nikkila et al. (2010) defined the requirements for the architecture of a FMIS for PA. Compared to a traditional FMIS, such an architecture is more focused on the digital transfer of data and storing, managing, and handling geographic information systems data since most of the calculated data originate from external sources. The formulation of operational plans and the ability to manage several transformations of the acquired data to achieve interoperability with all relevant systems and services are also required by an FMIS targeting PA. In this regard, Nash et al. (2009a) analyzed the data flows within PA operations. The basic idea was to capture the data flows at different planning levels that take place in crop production system and to represent explicitly the domain knowledge in terms of entities and their relationships.

In addition to data generated from PA operations, a number of FMIS have recently been developed related to machinery management in an attempt to accommodate the increasing amount of data generated by tractors. These data are being made available through the standard ISOBUS protocol for tractors and implements. Steinberger et al. (2009), considering the difficulties of data acquisition in agriculture caused by the lack of compatibility between hardware and software, developed a prototype implementation of an agricultural process. Specifically, agricultural process data acquired from the ISOBUS were sent to a server for further analysis and subsequent task formulation. To resolve compatibility problems between the devices, Nash et al. (2009b) suggested the creation of geospatial web services. Recently web-based applications for farm machinery have been proposed with real-time data acquisition to capture both the sub-field spatial variability within field operations as well as communication with autonomous mobile vehicles (Tsiropoulos et al., 2013a,b). In summary, FMIS should integrate PA activities into a holistic system incorporating crop, soil and climatic information to allow locally based planning and management at the sub-field scale.

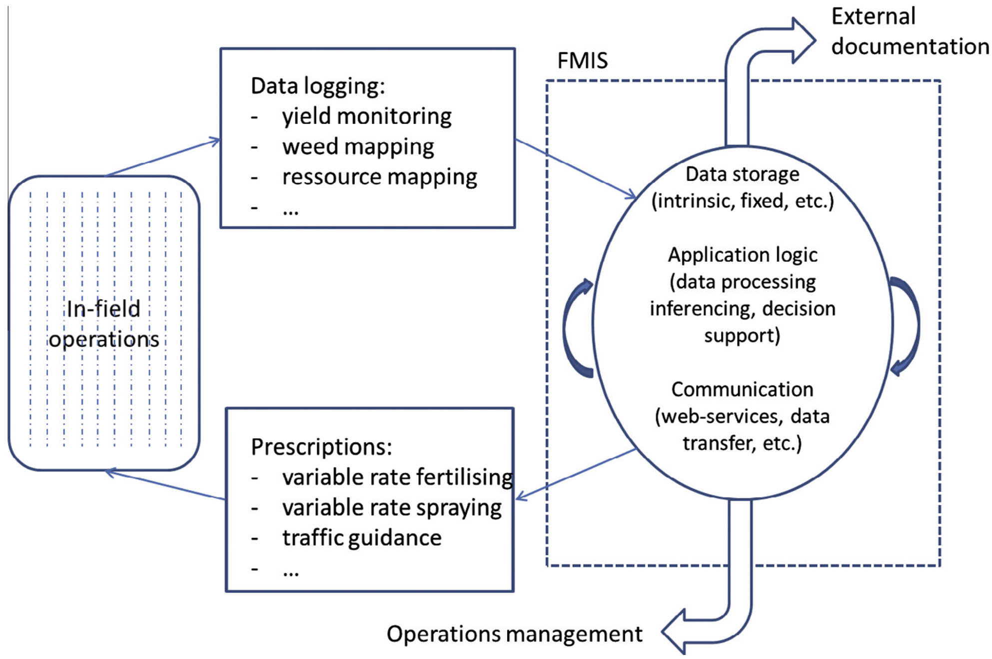

Fig. 1. Conceptual outline of precision agriculture FMIS.

3.3. FMIS adoption and profitability

In addition to the actual physical development of FMIS and the early introduction of computers on farms, user requirements and adoption studies for FMIS were also initiated. Sonka (1985) argued that the change from rigid and inflexible management strategies to the flexible and adaptable management of the information age will significantly enhance the potential contribution of farm computers and systems. Doluschitz and Schmisseur (1988) predicted that DSSs and expert systems in agriculture as integrated parts of an FMIS would have a vast influence in resolving the analytical shortcomings of the end user (farmer) by transforming raw data through analysis and expert interpretation into useful information and finally knowledge for decision making. On the other hand, Ohlmer (1991) stated that farmers tend to use FMIS to execute similar management tasks and for knowledge generation as previously supported by external service organizations or advisors, indicating that the farm management methods in the computer software systems introduced at that time were not sufficiently mature. Therefore, FMIS adoption relies not only on pure technical aspects, but also, to a high degree, on the human or usability aspects of information system implementation (Mackrell et al., 2009).

Kuhlmann and Brodersen (2001) argued that commercial software products have reached a level of sophistication involving complex algorithms that can address demanding planning problems. However, such complex systems present a challenge in terms of acceptability and usability, making farmers revert to use of ad hoc calculations using, for example, standard spreadsheet software. The authors noted that, with the advent of new technologies such as PA, the amount of data collected is too large to be managed by simple spreadsheet software making the case for the wider adoption of more sophisticated FMIS for crop production. A recent farmers' adoption study by Lawson et al. (2011) pointed out the benefits of introducing advanced FMIS in relation to budgeting procedures, field planning, and paperwork for subsidy applications and public authorities. The study compared FMIS adoption between northern and southern European Union (EU) countries and found that Northern European farmers are inclined to spend more time working with computers than their Southern colleagues, probably due to the more developed and more business-oriented types of farms that exist in Northern Europe.

A key point in FMIS development and adoption is the profitability of the system (Verstegen et al., 1995). Profitability indicators are important not only to the farmers who consider software investments but also to the developers who design and market FMIS. The benefits of a FMIS extend from the value of the improved decision making, which, however, is often difficult to quantify. For example, the benefit of using an FMIS could depend on the level of the user's experience. As a special case, Lewis (1998) noted that younger farmers with a relative lack of farming experience can particularly benefit from using an FMIS. Moreover, Steffe (2000) argued that the cost to design and set up an information system is relatively high, stressing the need for the design of a dynamic and adaptable model to meet both current and future demands. In addition, Steffe (2000) pointed out that the benefits of integrating PA data into a general FMIS would automatically generate documentation data, reducing management task time, while it would provide better management quality for supplying regulatory bodies with precise site-specific information that is otherwise not available.

In conclusion, the interaction between FMIS developers and end users (farm manager and employees) should be enhanced. The interplay between the developers and end users should be favoured by institutional actors such as universities and other organizations, which could act as facilitators, providing training to farmers and feedback to developers. Future FMIS implementation should require a minimal level of operational training and must clearly show immediate benefits of its use. Improving transparency for the operator/manager by providing a user-friendly interface can be a first step. Self-learning and the cognition of the farm operator/manager are essential to accelerate the learning process.

3.4. FMIS development trends

The FMIS field is developing rapidly to produce new and useful tools for the agricultural community to meet market demands. A recent study by Wageningen University, aimed at presenting the current situation of FMIS and the use of data standards, provided an overview of all the functionalities used and data standards offered by applications in the market through the creation of a reference model (Robbemond and Kruize, 2011; Kruize et al., 2013). Key points included the importance of a common data exchange between the FMIS and external actors, such as agricultural input suppliers, processors, data providers, and governmental offices.

Moreover, wide use of the Internet has presented new possibilities and challenges, namely, to fulfil the increasing needs of farmers and agricultural advisers for time-critical, up-to-date, and precise information as part of farm management. Web applications support data collection from distributed sources and integrate the results into personalised web graphical user interfaces with embedded graphics, expert interpretations, and links (Jensen et al., 2000; Engel et al., 2003; Thomson and Willoughby, 2004; Plénet et al., 2009). In addition, recent developments in computer technology along with advances in the hardware and software capabilities of mobile phones providing wireless Internet access have enabled real-time data recording and fueled the interest for 'on the go' information in the field (Hearn and Bange, 2002; Karetsos et al., 2007; Kitchen, 2008; Peets et al., 2012). Web applications have proven to be a very powerful tool, particularly for less experienced users. Recent designs and prototypes using cloud computing and the future internet generic enablers for inclusion in FMIS have recently been proposed by Kaloxylos et al. (2012, 2014).

Key points from the academic analysis include that FMIS architectures have been proposed to cover a range of farm activities and functions. The focus has been on the farm manager as the main decision maker and main actor. FMIS is trying to cover very complex systems with all possible interrelationships of data gathering on the farm, revealing the need for more holistic approaches. In this complex setting, establishing industry-wide data exchange protocols becomes pivotal in facilitating integration between different FMIS modules that handle specific tasks. Although some have pursued this goal (e.g. the creation of the ISOBUS protocol), the level of integration still remains inadequate. The development of standards for data exchange should be coupled with current definition of FMIS architectures to improve transparency for the operator/manager by providing not only user-friendly interfaces, but also reliable data structures and data manipulation procedures.

A general understanding of FMIS evolution and the current development level of commercial solutions is still lacking. Therefore, to provide an overview on how research in this field has been implemented in practice, the second part of this study tries to decompose the current functions provided by commercial FMIS and identifies potential improvements.

4. Targeted review of commercial FMIS applications

4.1. Review of commercial FMIS applications

Fig. 2 illustrates the distribution of the 11 defined FMIS functions indicating how frequently these functions are appear in the studied vendor applications and which functions are most useful to the farmers. The functions most frequently found in the software applications included field operations management (63%), reporting (57%), finance (45%), site-specific management (40%), inventory management (38%), machinery management (28%), and human resource management (25%). Additionally, less frequently used functions included traceability (19%), quality assurance (19%), sales (18%), and best practices (16%). It is evident that functions that support operations and finance management of farm enterprises are used more frequently, together with reporting, as an integral element of the FMIS. The high rate of site-specific functions, however, reveals the vendors' understanding that PA techniques pertaining to the rational use of inputs to both reduce production costs and support environmental protection will eventually be part of mainstream agriculture. The analysis clearly demonstrated that traceability is still in its infancy in commercial FMIS, as well as best practice functions, which are directly related to food quality and could be used to differentiate and enhance the value of farm products, as well as improve competitiveness (Canavari et al., 2010). Moreover, sales components within FMIS for farmers are still very scarce, since usually farmers do not selling directly to end users. However, one of the strategies of the EU Directorate-General for Agriculture and Rural Development through the new Common Agricultural Policy is to facilitate direct sales between farmers and consumers and therefore more FMIS solutions in this domain may be introduced in coming years.

Finally, the analysis showed that, regarding the prevailing platforms, 75% of applications are computer based, with 10% of which are only operating on mobile applications (tablets and smartphones), 9% are web-based applications, and 6% are both mobile and web-based applications (Fig. 3). This indicates that most FMIS applications are standalone computer software applications that do not require Internet access. The very limited introduction of web-based applications in commercial FMIS is presumably due to the fact that farm managers are used to having sole access to the data. Additional, the limited introduction of mobile applications could be explained by limited wireless data access in urban farm areas. This reasoning was supported by a survey of Danish and US Corn Belt farmers findings (Fountas et al., 2005), where indications were that 81% of the Danish and 78% of the US respondents preferred to store the data themselves. Moreover, 88% of the US respondents preferred not to store the data in a shared Internet-based database explaining the reluctance of software vendors to push in this direction, which further emphasize the importance of farm data ownership. Nevertheless, the introduction of tablets and smartphones is expected to increase dramatically in the near future. In general, no sustained relation between available functions and type of hardware platform was found.

4.2. Clustering analysis

The cluster analysis outlined a solution with four-clusters, in which the complete solutions from software houses are grouped according to the coverage provided to the functions. In other words, the clustering procedure grouped in the same cluster the systems which largely support the same set of functions. The spider diagrams of Fig. 4 show the results of the clustering analysis: each single diagram presents the coverage of functions by the systems grouped in that cluster.

Showing the percentage of solutions in each cluster which have a particular function, Fig. 5 presents the same information, but in relative terms, making possible comparisons between clusters.

Cluster 1 was called *basic systems* and groups 15 FMIS (21%) devoted to a limited set of functions, especially finance and reporting. These functions constitute the core of the FMIS and mainly support traditional farm management, without giving any support to specific activities.

Cluster 2 collects *sales-oriented systems* and comprises 13 FMIS (29%), including all sales and marketing, inventory management, and finance functions. These systems cover the product management of a company but, surprisingly, the majority of them also include functions for human resource management. This extension could be related to the necessity of providing a full product, which requires the inclusion of the costing of human labour.

Cluster 3 refers to 21 *site-specific systems* (18%), comprising a homogeneous group of systems designed for site-specific purposes

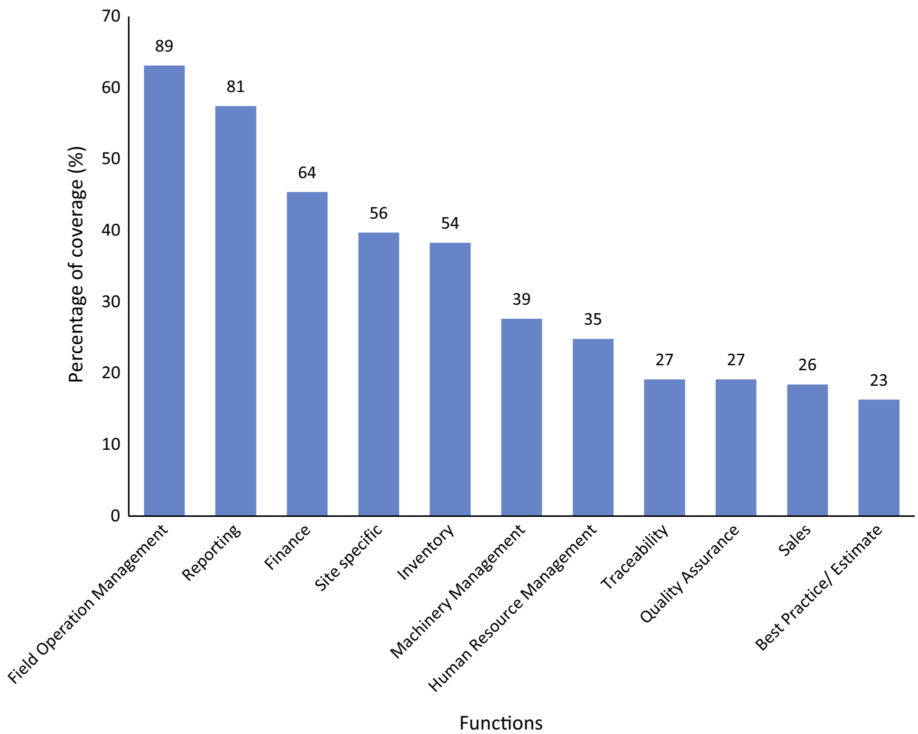

Fig. 2. Distribution of defined functions in the FMIS (numbers indicate the FMIS in each function).

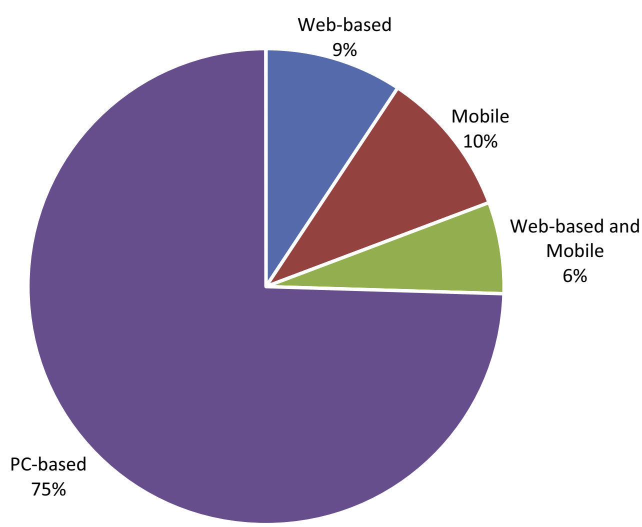

Fig. 3. Prevailing platforms of the studied applications.

(precision agriculture) in addition to functions for field operations management. About 60% of these also offer reporting functions of which more than 30% offer services on mobile platforms. These features are coherent with the site-specific functions, which require direct in-field data collection and operations management.

Cluster 4 comprises 24 FMIS (33%) *complete systems*, which involve the widest range of functions. A number of these functions are also covered by the other three clusters, such as reporting and field operations management. Some other functions, such as inventory management, are offered by only one or two of the other three clusters.

Interestingly, cluster 4 shows the highest percentage of web-based and mobile functions, slightly distancing the other clusters. Moreover, this cluster offers two functions that are weakly supported by the other clusters: quality assurance and best practice estimate functions. Both of these are complex functions requiring the coexistence of multiple other functions: For example, to define best practices, historic data related to inventory, field operations, and machines are needed to compare yearly yields and define possible alternatives. Most of the FMIS in this cluster include a site-specific module, showing that such functionality advances the complement of existing services. Surprisingly, only 20% of the systems in this cluster include a sales module, probably because this function is conveyed by external systems that are not integrated in the FMIS.

The matrix in Fig. 6 presents the four clusters positioned along two dimensions: the support of site-specific activities and the inventory function. We selected these two functions because they require more advanced algorithms and sub-functions to be offered by a FMIS and they pave the way for the development of more complex systems. Inventory management is necessary to support the introduction of still more complex and complementary functions as traceability and quality assurance, while site-specific features enable the use of DSSs with best practice estimation, which are unique functions of cluster 4.

As an overview of the commercial FMIS analysis, a limited presence of functions for traceability, quality assurance, and best practice was observed. This could be explained by the greater degree of complexity in data processing and interpretation of the results in an automated manner. Therefore, these systems need to be considered as an essential area for future development in FMIS. Moreover, future developments should also address the low penetration of FMIS covering sales by holistic systems as in cluster 4, especially since customer relationship management systems are becoming pervasive.

In conclusion, new complete commercial FMIS based on the integration of inventory management and PA (site-specific) functionalities should include traceability, quality assurance, and best practice estimate functions in the immediate future. The integration of customer relationship management systems in the subsequent years will enable the support of sophisticated decision support functionalities.

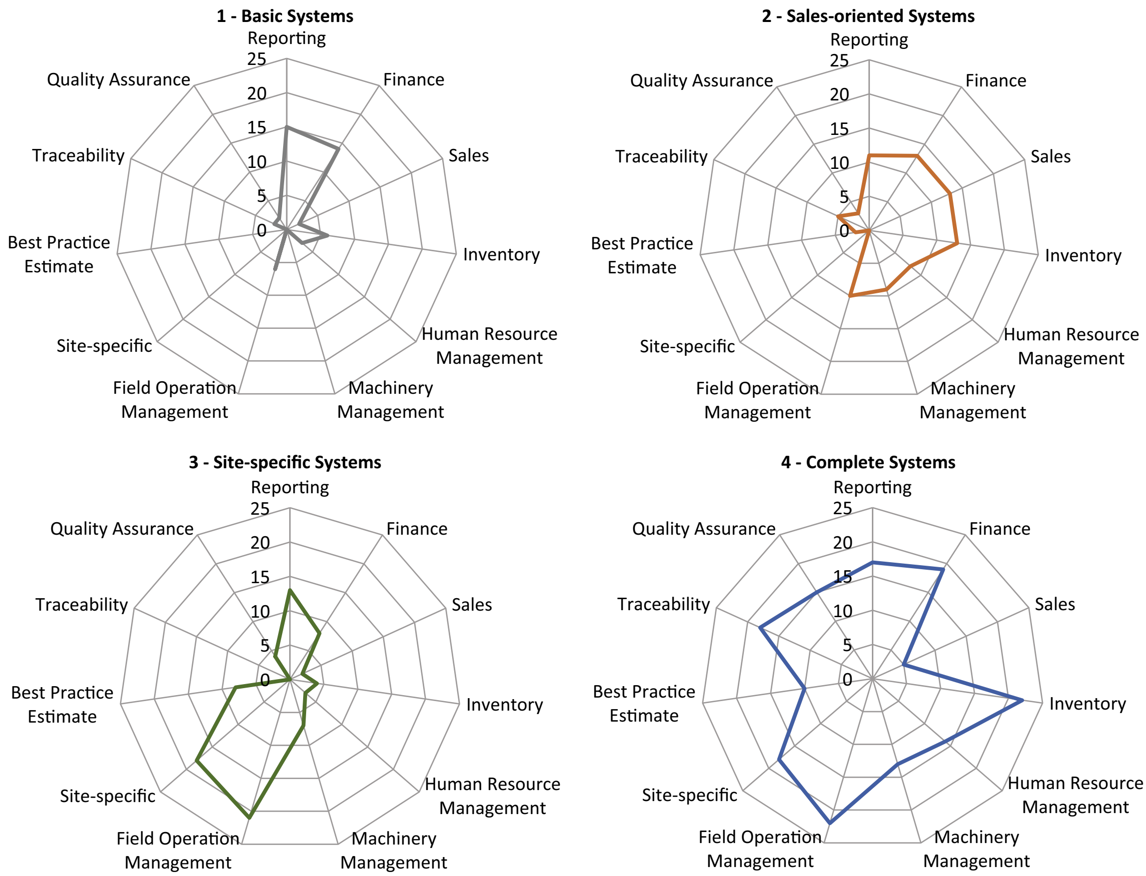

Fig. 4. Results of the cluster analysis showing the number of systems supporting a specific function, in each cluster.

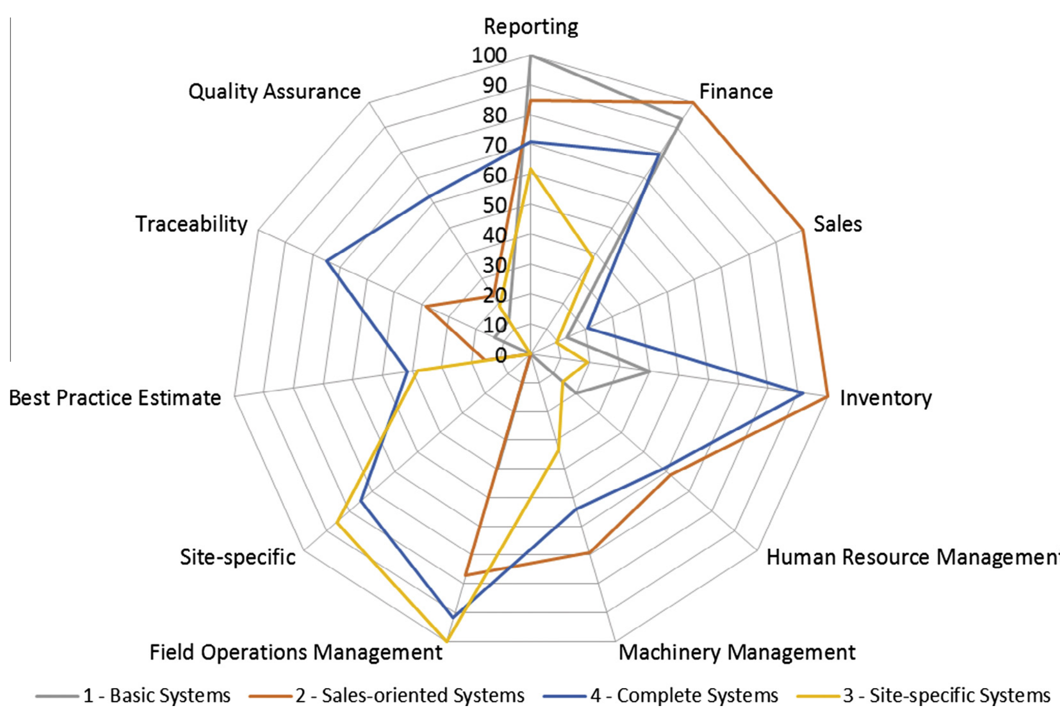

Fig. 5. Results of the cluster analysis showing the percentage of systems supporting a specific function, in each cluster.

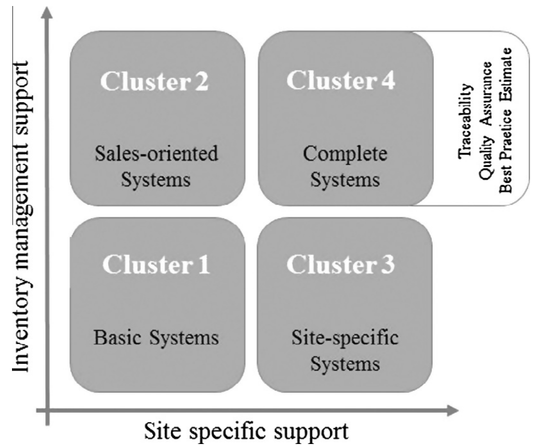

Fig. 6. Cluster categories.

5. Discussion and future perspectives

This study focused on crop production, and as such, applications for greenhouses were not considered due to their higher level of technological maturity. However, it is recognized that there are benefits to be gained from FMIS and DSS development in greenhouses in terms of efficient information handling and decision modeling (e.g. Taragola and Gelb, 2004). Additionally, simulation models representing wide application domains in crop production were not included, since these systems are currently mainly used within the scientific community and have not yet been commercialized. However, due to their solid scientific background and the increasing complexity of crop production, such models are expected to be implemented in the near future.

Results show that current research is focused on developing sophisticated systems and merging complex biological, physical, and chemical processes in crop production together with an increased level of awareness of environmental protection, food safety and quality. Moreover, current research try to accommodate the advent of PA through, for example, new spatial and temporal functionalities although key aspects like interoperability and data standardisation is still missing. As for the compliance with national and international standards for food safety and quality, and environmental protection, automated systems in this area is still missing and only preliminary research attempts are available. This will require designing FMIS complying with these new requirements, as presented in the FutureFarm project (Sorensen et al., 2010a,b). All in all, the increasing need for European farmers to demonstrate compliance to the auditing authorities will increase the need to implement FMIS aided by automated data collection.

The analysis of commercial software solutions revealed that current solutions mostly targeted everyday farm office tasks related to financial management and reporting (cluster 1) and, most specifically, those related to sales, inventory, and field operations management (cluster 2). Functions related to traceability, quality assurance, and best practice estimates are still in their infancy in most commercial applications. The support of PA technologies is limited to a very small group of systems (cluster 3) devoted primarily to field operations management. Furthermore, the group of systems that cover wider sets of functionalities (cluster 4) lacks basic sales functions.

It was observed that the FMIS architectures that were designed by academics in the 1980s have to a large extent become mainstream commercial applications today. Therefore, the more complex FMIS (for example in the case of PA) that are currently being designed by researchers around the world should be expected to move into commercialization in the coming decades. Nevertheless, it is to be noted that future drivers will probably focus on Internet connectivity, the Internet of things, and cloud computing (e.g. Pesonen et al., 2008; Kaloxylos et al., 2012). Future FMIS developments must emphasize closer cooperation between academia and software developers. Studies have shown the effectiveness of such cooperation through a user-centric and near-practice development process (Pesonen et al., 2008).

In general terms, it can be concluded that, despite the considerable efforts of developers, FMIS still remain at the periphery of agricultural technology and has yet to serve its intended purpose as a mainstream knowledge transfer tool or an innovative aid supporting effective decision making in agricultural production (Parker, 1999; Lawson et al., 2011).

A crucial aspect of FMIS is the knowledge management within the decision processes in the form of dedicated DSS. The development of knowledge-based system in the farming sector requires key components, supported by Internet of things, data acquisition systems, machine-to-machine communications, effective management of geospatial and temporal data, traceability systems along the supply chain, and ICT-supported stakeholder collaboration. The process of building knowledge-based systems for agriculture will be supported and supplemented by industrial developments (Lewis, 1998). Special attention should also be given to interoperability and the availability of standardized formats used on defined data infrastructure elements in the agrifood sector, advanced by, organizations such as the Open Geospatial Consortium (OGC).

As was recently documented by Lawson et al. (2011), farmers who use FMIS are benefiting from them, since these systems have had a major impact on crop management and have provided objective standards. However, functional improvements are still needed to facilitate wider acceptance within the farming community.

6. Conclusions

This paper presented a targeted review of the state of the art in Farm Management Information Systems (FMIS) from both an academic and commercial perspective. The academic analysis covered mainly the areas of systems architecture, applications, FMIS in Precision Agriculture (PA) and future trends, while the commercial analysis included 141 FMIS packages focused on crop production in open-fields. Results indicated that on the question of academic research and its ability to accommodate advanced systems like PA, academic research tend to analyze more complex systems, capturing new trends involving spatial and temporal management, as well as distributed system involving internet of things, future internet and web services. As regards the commercial applications, these tend to focus on solving daily farm tasks and aim to generate income for the farmers through better resource management and field operations planning. In terms of the commercial applications being able to adopt the innovations from research, this is the case to a large extent but it is foreseen that software vendors must put extended efforts on adopting the more advanced systems and closely cooperate with academia in order to accommodate the requirements from, for example, PA.

Key research representing areas for further development and improvement for currently available academic and commercial applications include improvements in technology, adaptation motives, hindrances, specific new functionalities and greater emphasis on software design governed by usability and human–computer interaction. In this respect, the diffusion of information management as business innovation in the farming community could benefit from the comprehensive research developed in the last decades on the adoption of ICT and e-commerce among both consumers and small businesses.

This study has provided a stepping stone for further development of FMIS. In the past, a key issue was the adoption of farm computers, but this has advanced to include more sophisticated information and communication solutions suitable for PA. The evolution of FMIS must take into account the human-related nature of business processes, specifically for marketing/sales and supply chain functions, where the social aspects have greater relevance. This awareness is necessary to ensure the required advancement from the basic use of farm data recording and processing systems to the adoption of a sophisticated FMIS that truly supports the farm manager's decision making process.

The results of this research provides FMIS software developers and vendors with a comprehensive overview of the state of the art of FMIS applications, including updated knowledge of FMIS packages on the market, while farm managers and service providers can gain an overview of the available FMIS that can meet their needs. Importantly, the results identified new functionalities like distributed management systems that must in the near future be implemented in FMIS if the farming community is to fully embrace possibilities and the benefits of PA.

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References

Abt, V., Perrier, E., Vigier, F., 2006. Towards an integration of farm enterprise information systems: a first analysis of the contribution of ERP systems to software function requirements. In: 4th World Congress on Computers in Agriculture and Natural Resources, July 24–26, Orlando, FL.
Attonaty, J.M., Chatelin, M.H., Frederick, G.F., 1999. Interactive simulation modeling in farm decision-making. Comput. Electron. Agric. 22, 157–170.
Bange, M.P., Deutscher, S.A., Larsen, D., Linsley, D., Whiteside, S., 2004. A handheld decision support system to facilitate improved insect pest management in Australian cotton systems. Comput. Electron. Agric. 43, 131–147.
Berry, J.K., Delgado, J.A., Khosla, R., Pierce, F.J., 2003. Precision conservation for environmental sustainability. J. Soil Water Conserv. 58, 332–339.
Blackie, J.M., 1976. Management information systems for the individual farm firm. Agric. Syst. 1, 23–36.
Boehlje, M.D., Eidman, V.R., 1984. Farm Management. Wiley, New York.
Canavari, M., Centonze, R., Hingley, M.K., Spadoni, R., 2010. Traceability as part of competitive strategy in the fruit supply chain. Br. Food J. 112 (2), 171–186.
Cardín-Pedrosa, M., Alvarez-López, C.J., 2012. Model for decision-making in agricultural production planning. Comput. Electron. Agric. 82, 87–95.
Chaudhary, S., Sorathia, V., Laliwala, Z., 2004. Architecture of sensor based agricultural information system for effective planning of farm activities. In: Proceedings of the 2004 IEEE International Conference on Services Computing.
Cohen, Y., Cohen, A., Hetzroni, A., Alchanatis, V., Broday, D., Gazit, Y., Timar, D., 2008. Spatial decision support system for Medfly control in citrus. Comput. Electron. Agric. 62, 107–117.
Doluschitz, R., Schmisseur, W.E., 1988. Expert systems: applications to agriculture and farm management. Comput. Electron. Agric. 2, 173–182.
Engel, A.B., Choi, J.Y., Harbor, J., Pandey, S., 2003. Web-based DSS for hydrologic impact evaluation of small watershed land use changes. Comput. Electron. Agric. 39, 241–249.
Fountas, S., Ess, D., Sorensen, C.G., Hawkins, S., Blumhoff, G., Blackmore, S., Lowenberg-DeBoer, J., 2005. Farmer experience with precision agriculture in Denmark and the US Eastern Corn Belt. Precision Agric. 6, 121–141.
Fountas, S., Wulfsohn, D., Blackmore, S., Jacobsen, H.L., Pedersen, S.M., 2006. A model of decision making and information flows for information-intensive agriculture. Agric. Syst. 87, 192–210.
Gladwin, H., 1989. Ethnographic Decision Tree Modelling. Sage Publications, London.
Hair, J.F., Black, W.C., Babin, B.J., Anderson, R.E., 2010. Multivariate Data Analysis, seventh ed. Prentice Hall, Upper Saddle River, NJ.
Hameed, I.A., Bochtis, D.D., Sørensen, C.G., Vougioukas, S., 2012. An object oriented model for simulating agricultural in-field machinery activities. Comput. Electron. Agric. 81, 24–32.
Harwood, T.D., Al Said, F.A., Pearson, S., Houghton, S.J., Hadley, P., 2010. Modelling uncertainty in field grown iceberg lettuce production for decision support. Comput. Electron. Agric. 71, 57–63.
Hearn, A.B., Bange, M.P., 2002. SIRATAC and CottonLOGIC: persevering with DSSs in the Australian cotton industry. Agric. Syst. 74, 27–56.
Jensen, L.A., Boll, S.B., Thysen, I., Pathak, B.K., 2000. Pl@nteInfo®—a web-based system for personalised decision support in crop management. Comput. Electron. Agric. 25, 271–293.
Kaloxylos, A., Eigenmann, R., Teye, F., Politopoulou, Z., Wolfert, S., Shrank, C., Dillinger, M., Lampropoulou, I., Antoniou, E., Pesonen, L., Huether, N., Floerchinger, T., Alonistioti, N., Kormentzas, G., 2012. Farm management systems and the future Internet era. Comput. Electron. Agric. 89, 130–144.
Kaloxylos, A., Groumas, A., Sarris, V., Katsikas, L., Magdalinos, P., Antoniou, E., Politopoulou, Z., Wolfert, S., Brewster, C., Eigenmann, R., Terol, C.M., 2014. A cloud-based farm management system: architecture and implementation. Comput. Electron. Agric. 100, 168–189.
Kamran, S.M., DePuy, W.G., 2011. Farm management optimization using chance constrained programming method. Comput. Electron. Agric. 77, 229–237.
Karetsos, S., Costopoulou, C., Sideridis, A., Patrikakis, C., Koukouli, M., 2007. Bio@gro – an online multilingual organic agriculture e-services platform. Inf. Serv. Use 27, 123–132.
Kitchen, N.R., 2008. Emerging technologies for real-time and integrated agriculture decisions. Comput. Electron. Agric. 61, 1–3.
Kok, R., Gauthier, L., 1986. Development of a prototype farm information management system. Comput. Electron. Agric. 1, 125–141.
Kruize, J.W., Robbemond, R.M., Scholten, H., Wolfert, J., Beulens, A.J.M., 2013. Improving arable farm enterprise integration – review of existing technologies and practices from a farmer's perspective. Comput. Electron. Agric. 96, 75–89.
Kuhlmann, F., Brodersen, C., 2001. Information technology and farm management: developments and perspectives. Comput. Electron. Agric. 30, 71–83.
Lawson, L.G., Pedersen, S.M., Sorensen, C.G., Pesonen, L., Fountas, S., Werner, A., Oudshoorn, F.W., Herold, L., Chatzinikos, T., Kirketerp, I.M., Blackmore, S., 2011. A four nation survey of farm information management and advanced farming systems: a descriptive analysis of survey responses. Comput. Electron. Agric. 77, 7–20.
Lewis, T., 1998. Evolution of farm management information systems. Comput. Electron. Agric. 19, 233–248.
Lilburne, L., Watt, J., Vincent, K., 1998. A prototype DSS to evaluate irrigation management plans. Comput. Electron. Agric. 21, 195–205.
Mackrell, D., Kerr, D., von Hellens, L., 2009. A qualitative case study of the adoption and use of an agricultural decision support system in the Australian cotton industry: the socio-technical view. Decis. Support Syst. 47 (2), 143–153.
Magne, M.A., Cerf, M., Ingrand, S., 2010. A conceptual model of farmers' informational activity: a tool for improved support of livestock farming management. Animal 4, 842–852.
Murakami, E., Saraiva, A.M., Ribeiro Jr., L.C.M., Cugnasca, C.E., Hirakawa, A.R., Correa, P.L.P., 2007. An infrastructure for the development of distributed service-oriented information systems for precision agriculture. Comput. Electron. Agric. 58 (1), 37–48.
Nash, E., Dreger, F., Schwarz, J., Bill, R., Werner, A., 2009a. Development of a model of data-flows for precision agriculture based on a collaborative research project. Comput. Electron. Agric. 66 (1), 25–37.
Nash, E., Korduan, P., Bill, R., 2009b. Applications of open geospatial web services in precision agriculture: a review. Precision Agric. 10 (6), 546–560.
Nikkilä, R., Seilonen, I., Koskinenet, K., 2010. Software architecture for farm management information systems in precision agriculture. Comput. Electron. Agric. 70 (2), 328–336.
Norušis, M.J., 2011. IBM SPSS Statistics 19 Statistical Procedures. Prentice-Hall, Upper Saddle River, NJ.
Ohlme, 1991. On-farm computers for farm management in Sweden: potentials and problems. Agric. Econ. 5, 279–286.
Papadopoulos, A., Kalivas, D., Hatzichristos, T., 2011. Decision support system for nitrogen fertilization using fuzzy theory. Comput. Electron. Agric. 78, 130–139.
Parker, C., 1999. Decision support systems: lessons from past failures. Farm Manage. 10, 273–289.
Parsons, D.J., Benjaminb, L.R., Clarkec, J., Ginsburgc, D., Mayesb, A., Milneb, A.E., Wilkinson, D.J., 2009. Weed Manager—a model-based decision support system for weed management in arable crops. Comput. Electron. Agric. 65, 155–167.
Peets, S., Mouazen, A.M., Blackburn, K., Kuang, B., Wiebensohn, J., 2012. Methods and procedures for automatic collection and management of data acquired from on-the-go sensors with application to on-the-go soil sensors. Comput. Electron. Agric. 81, 104–112.
Pesonen, L., Koskinen, H., Rydberg, A., 2008. InfoXT – user-centric mobile information management in automated plant production. Nordic Innovation Centre, Finland.
Plant, E.R., 1989. An artificial intelligence based method for scheduling crop management actions. Agric. Syst. 31, 127–155.
Plénet, D., Giauque, P., Navarro, E., Millan, M., Hilaire, C., Hostalnou, E., Lyoussoufi, A., Samie, J., 2009. Using on-field data to develop the EFI_information system to characterize agronomic productivity and labour efficiency in peach (*Prunus persica L. Batsch*) orchards in France. Agric. Syst. 100, 1–10.
Robbemond, R., Kruize, J.W., 2011. Data standards used for data-exchanged of FMIS. LEI, Wageningen University, Holland (published 4 November 2011), available at <https://sites.google.com/site/agrilabreferences/>.
Sahu, R.K., Raheman, H., 2008. A decision support system on matching and field performance prediction of tractor-implement system. Comput. Electron. Agric. 6, 76–86.
Sante-Riveira, I., Crecente-Maseda, R., Miranda-Barrosa, D., 2008. GIS-based planning support system for rural land-use allocation. Comput. Electron. Agric. 63, 257–273.

Schweik, C.M., Stepanov, A., Grove, J. Morgan, 2005. The open research system: a web-based metadata and data repository for collaborative research. Comput. Electron. Agric. 47, 221–242.
Shaffer, M.J., Brodahl, M.K., 1998. Rule-based management for simulation in agricultural decision support systems. Comput. Electron. Agric. 21, 135–152.
Sonka, S.T., 1985. Information management in farm production. Comput. Electron. Agric. 1, 75–85.
Sørensen, C.G., 1999. A Bayesian network based decision support system for the management of field operations. Case: harvesting operations. Ph.D. thesis, Technical University of Denmark, 193 pp.
Sørensen, G.C., Fountas, S., Nash, E., Pesonen, L., Bochtis, D., Pedersen, S.M., Basso, B., Blackmore, S.B., 2010a. Conceptual model of a future farm management information system. Comput. Electron. Agric. 72, 37–47.
Sørensen, C.G., Pesonen, L., Fountas, S., Suomi, P., Bochtis, D., Bildsøe, P., Pedersen, S.M., 2010b. A user-centric approach for information modelling in arable farming. Comput. Electron. Agric. 73, 44–55.
Sørensen, G.C., Pesonen, L., Bochtis, D., Vougioukas, S.G., Suomi, P., 2011. Functional requirements for a future farm management information system. Comput. Electron. Agric. 76, 266–276.
Stafford, J.V., 2000. Implementing precision agriculture in the 21st century. J. Agric. Eng. Res. 76, 267–275.
Steffe, J., 2000. Evolution of the farm environment: the need to produce a general information system. In: Beers, G., Poppe, K.J., de Putter, I. (Eds.), Agenda 2000 and the FADN Agenda. Agricultural Economics Research Institute (LEI), The Hague, pp. 88–97 (Project code 63403).
Steinberger, G., Rothmund, M., Auernhammer, H., 2009. Mobile farm equipment as a data source in an agricultural service architecture. Comput. Electron. Agric. 65, 238–246.
Taragola, N., Gelb, E., 2004. Information and communication technology (ICT) adoption in horticulture: a comparison to the EFITA baseline. EFITA, 2004.
Teye, F., 2011. A conceptual model for collaboration-based farm management information systems. Master's thesis, Helsinki Metropolia University of Applied Sciences.
Thompson, S.C., 1976. Canfarm – a farm management information systems. Agric. Administr. 3, 181–192.
Thomson, A., Willoughby, I., 2004. A web-based expert system for advising on herbicide use in Great Britain. Comput. Electron. Agric. 42, 43–49.
Thorp, R.K., DeJongeb, C.K., Kaleitac, L.A., Batchelord, D.W., Paz, O.J., 2008. Methodology for the use of DSSAT models for precision agriculture decision support. Comput. Electron. Agric. 64, 276–285.
Tozer, R.P., 2009. Uncertainty and investment in precision agriculture – is it worth the money? Agric. Syst. 100, 80–87.
Trépos, R., Masson, V., Cordier, M.O., Gascuel-Odoux, C., Salmon-Monviola, J., 2012. Mining simulation data by rule induction to determine critical source areas of stream water pollution by herbicides. Comput. Electron. Agric. 86, 75–88.
Tsiropoulos, Z., Fountas, S., Liakos, V., Tekin. A. B., Aygun. T., Blackmore, S., 2013a. Web-based Farm Management Information System for Agricultural Robots. EFITA, WCCA, CIGR 2013 Conference, Torino, Italy, 23–27 June, 2013 (in CD).
Tsiropoulos, Z., Fountas, S., Gemtos, T., Gravalos, I., Paraforos, D., 2013b. Management information system for spatial analysis of tractor-implement draft forces. In: European Conference on Precision Agriculture, Precision agriculture'13, pp. 349–356.
Verstegen, J.A.A.M., Huirne, R.B.M., Dijkhuizen, A.A., Kleijnen, J.P.C., 1995. Economic value of management information systems in agriculture: a review of evaluation approaches. Comput. Electron. Agric. 13, 273–288.
Zhang, T., Ramakrishnan, R., Livny, M., 1996. BIRCH: an efficient data clustering method for very large databases. In: Proceedings of the 1996 ACM SIGMOD International Conference on Management of Data, SIGMOD'96. ACM, New York, NY, pp. 103–114.