ICT Innovations and Smart Farming

Claus Aage Grøn Sørensen[1](✉), Dimitrios Kateris[2], and Dionysis Bochtis[2]

[1] Department of Engineering, Aarhus University, Finlandsgade 22, 8700 Aarhus N, Denmark
claus.soerensen@eng.au.dk

[2] Institute for Bio-Economy and Agri-Technology (IBO), Center for Research and Technology Hellas (CERTH), 6th km Charilaou – Thermi Road, 57001 Thermi, Thessaloniki, Greece
{d.kateris,d.bochtis}@certh.gr

Abstract. Agriculture plays a vital role in the global economy with the majority of the rural population in developing countries depending on it. The depletion of natural resources makes the improvement of the agricultural production more important but also more difficult than ever. This is the reason that although the demand is constantly growing, Information and Communication Technology (ICT) offers to producers the adoption of sustainability and improvement of their daily living conditions. ICT offers timely and updated relevant information such as weather forecast, market prices, the occurrence of new diseases and varieties, etc. The new knowledge offers a unique opportunity to bring the production enhancing technologies to the farmers and empower themselves with modern agricultural technology and act accordingly for increasing the agricultural production in a cost effective and profitable manner. The use of ICT itself or combined with other ICT systems results in productivity improvement and better resource use and reduces the time needed for farm management, marketing, logistics and quality assurance.

Keywords: Agriculture · Information and Communication Technology · Robotic · FMIS · Precision Farming Management

1 Introduction

ICT in agriculture is a highly innovative and rapidly advancing field of practice that aims to promote the development of remunerative agriculture using innovative applications that provide the farmers with accurate, relevant and timely information and services.

The ICT contribution to agriculture includes cost reduction, increase of efficiency and productivity improvement. But first the information requirements should be analyzed and documented and then adequate information systems (IS) should be developed taking into account the new challenges arising from the deregulation and the globalization of agriculture [1].

Having accurate and timely information about the seed, the water, the nutrients and protection of the plant plays a significant role for the success of the farming.

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Information-intensive and precise techniques of farming based on knowledge will be the leading factors of sustainable agricultural production. Thus, referring to the agricultural production management it is crucial that the benefits from the information providers such as the internet and other information and communication technologies (ICT) are made clear to farmers. Nevertheless, the use of ICT in the agricultural sector is not widespread and its economic potential is not utilized to the fullest. For instance, ICT could offer great support to managers but also policy makers when making a decision related to precision farming and livestock management [2].

An area of application for ICT lies in the improvement, through a better management, of the efficiency and sustainability in using inputs—land, soil nutrients, feed and fodder, water, energy, pesticides, labour and most importantly information—in agriculture. ICT also contribute to the reduction of the negative effects of pests and disease and to the aversion and mitigation of risks coming for example from inclement weather, droughts, floods and long-term change of climate. For the small farmers, these applications of ICT have not become yet mainstream. The economic returns from agriculture and access to affordable technology, useful in small farm operations, are the main constraints to a more widespread use of ICT in small holder agricultural production.

Information means empowerment through resources control and decision-making processes. An effective and efficient delivery system of basic information and technology services facilitates the end users critical role in decision-making towards improved agricultural production and processing trading. In the agricultural sector, with appearance of sustainable agricultural systems, information becomes a major input for agricultural production because sustainable agriculture is more information-intensive rather than technology-intensive.

However, the use of ICT in agriculture does have some weaknesses; among the most common problems is the fact that farmers do not know how to use such technology applications to their full potential, not to mention the non-availability of information sources in different languages, the considerable cost of the technology, plus the denial of the farmers to adopt a positive approach towards the use of ICT. Last but not least comes the human factor which transmits the Information Knowledge to farmers and their groups, having the ICT in the end to depend heavily on this unpredictable factor and its changes. Thus, it is crucial to find out to which extent ICT meets the farmers needs, in order to promote the ICT usage by satisfying most of their needs.

2 ICT Use in Agricultural

The use of ICT itself or combined with other ICT systems results in productivity improvement and better resource use and reduces the time needed for farm management, marketing, logistics and quality assurance. As time goes by, ICT improves the access of the farmers to information, knowledge, skills and technology, improves the productivity of the farm and its ability to take part in the markets, not to mention its contribution to increased sustainability and to the resilience of the farming systems while changing them to face the new challenges. Next figure shows the impact of ICT on agriculture section (Fig. 1).

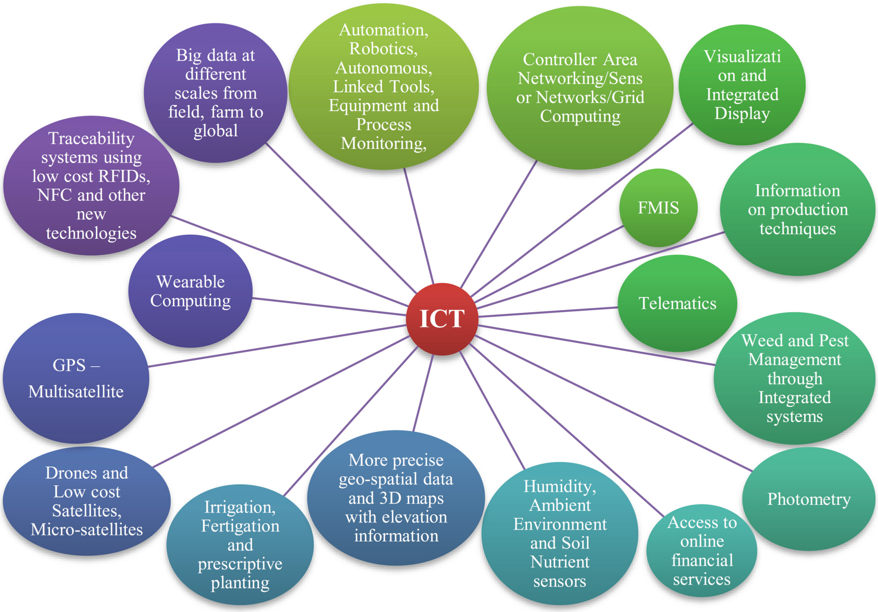

Fig. 1. ICT impact in agriculture section.

2.1 Role of ICT in Agriculture

In agricultural sector, ICT can be used in two ways: (a) Directly, where ICT is used as a tool that contributes directly to productivity of agricultural production, and (b) Indirectly, where ICT is used as a tool that provides information to farmers for making quality decisions in efficient management of their enterprises [3–5].

(a) Direct contribution of ICT to agricultural production

In direct contribution of ICT to agricultural production, the intensive use of ICT characterizes precision farming and subsequently smart farming. In order to increase the agricultural production, remote sensors techniques with support of geographic information systems (GIS), satellite technology, soil science and agronomics are used. ICT gives to the farmers the ability to track and react to weather condition changes on a daily basis. Meteorological stations on a field can be connected to farmers' computers in order to send information about current air temperature, relative air humidity, rainfall, soil moisture, wind speed and solar radiation. All these technologies of crop monitoring require substantial capital investments. Thus, mostly larger farms will make use of such technologies and also can afford to pay for them. Smaller farm enterprises cannot usually cope with such technologies.

(b) Indirect contribution of ICT to agricultural production

Most indirect benefits of ICT have to do with the facilitation and supporting of the decision-making. Farmers need timely and reliable information sources. Currently, most farmers depend on conventional sources of information that are unreliable and do not give timely information. The changes of the agricultural environment that the farmers face make information not only useful but necessary for them in order to stay competitive and survive on a globalized market. However, the efforts to provide such information will be revoked if farmers do not have some basic computing knowledge and skills in order to use not only the ICT but also the Web though which they can search for useful information, product prices, etc. and can communicate with colleagues from all over the world sharing ideas and of course making questions. Key is also the advice from researchers and agronomists on cultivation of crops and animals to be communicated efficiently to farmers. ICT helps researchers/adviser and farmers to communicate better promoting the agricultural development but also human relationships in the society, not to mention its contribution to the national economy.

In order to identify the ways in which ICT can help agriculture, it is useful to view the farming life cycle as a three-stage process (Fig. 2) [6]:

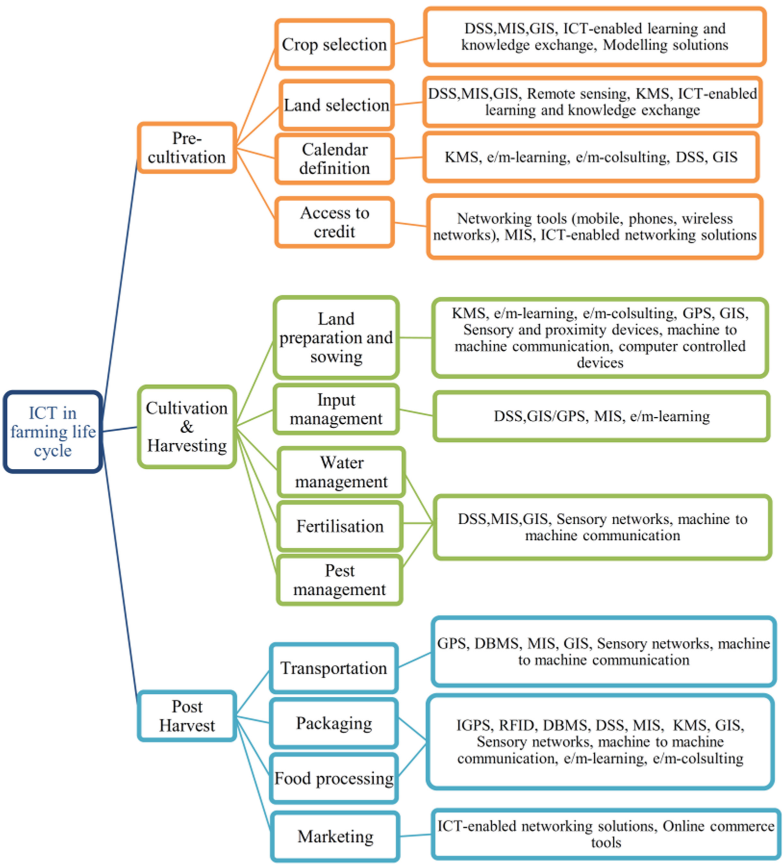

Fig. 2. ICT contribution in farming life cycle.

3 ICT and Automation

During 1990–2010 extensively changes in automated technology, plant varieties and livestock with improved genetic potentials lead to an evolution of the agriculture and other bio-production types increasing the scale and degree of specialization of farm operations. Consequently, agricultural production is mainly done by large, specialised units, which management is complex enough and therefore an important issue to deal with, especially when it comes to work operations. What is more, the technology used, including the machinery, is of high cost which tends to raise faster than returns to the point that an increase in efficiency results merely in the maintenance of the productivity and not in its improvement. In conclusion, the profit of the enterprise coming from development is solely contained within the marginal earnings of the production. In order this profit to be secured a rise in production and in operations management will be required based on an unprecedented level of flexibility and precision.

Concurrently farming operations need to comply with several regulations and standards in order for example to ensure food security, labour conditions, reduce environmental impact etc. This means that concerning the farming systems there should be considerations referring to efficiency, economy, environment and society. Thus, sustainability has become a key factor for bio-production meaning that the very nature of farm planning has changed in the last years. In the past farmers worked the traditional way of planning what crops to grow and which machines to use whereas nowadays there are implementation and scheduling issues to be solved using different production strategies and organizations of the farming system [7–9], giving more emphasis to the ability of the decision maker (or automation system) to do the right thing at the right time. The goal has become first to present the activities or operations needed to achieve a predefined goal, and next to set a timetable for execution as well as the resources to the operations in question. At the same time, it is necessary to comply with a number of temporal resource constraints. In the next years more, automation in bio-production operations is expected, which will certainly raise the demand for advanced management tools, like fleet management and logistics tools, for mobile units' scheduling, monitoring and on-line coordination etc. Also, system analyses and integration will be on the focus raising the need for operational data. The processing of stochastic planning system as a basis when making a decision requires a much more comprehensive description and quantification of labour and machinery data than in the past.

Due to the development of agriculture the scope of operations management has changed significantly from manual work operations to automated work operations, where the operator merely monitors the process. Sørensen [10], lists some of the most important developments of operations management in agriculture (Fig. 3).

The development mentioned above is clearly reflected in the topics of the last 2 decades. The topics have moved from the more classical work science developments to more comprehensive management systems using the methods of work science and ergonomics combined with advanced information technology system for automatic data acquisition and data processing. What is more the last years there is a strong focus on how technology and management can ensure sustainability of the bio-production development.

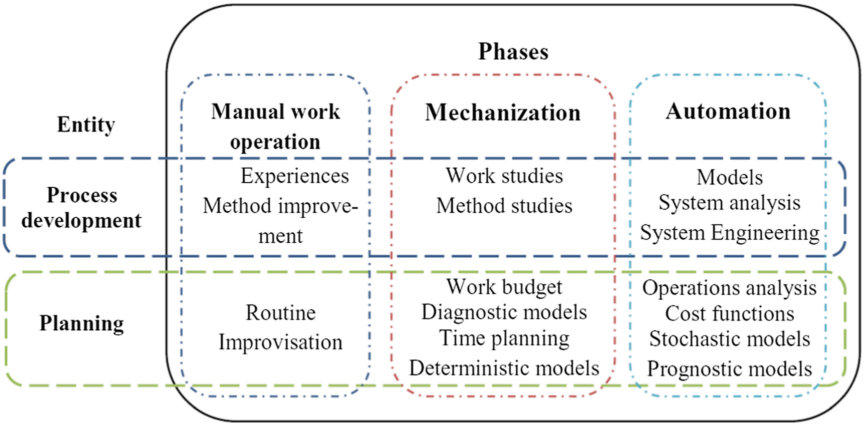

Fig. 3. The evolution of operations and system management in agriculture.

Apart from the hardware implementation also the software, this is to say the automation technologies for field operations, requires that new management techniques is implemented (e.g. site specific management systems, including precision spraying systems, precision irrigation systems, and monitoring on site of the processes auto-steering systems).

The management of the activities relates to:

– Open environment (arable farming and forestry domain),
– Semi-structured environments (controlled traffic farming systems, open air horticulture, vineyards, orchards etc.),
– Controlled environments (greenhouses, urban farming, animal production units, processing plants for agro-food, wineries, which are also in need of a task and operation management).

Last but not least, a form of internet application including some of the tools mentioned above could share the knowledge over specific sectors with the end users. Such an application could provide a real cost estimation as well as an environmental impact estimation of the agricultural operations. It could also be used planning activities, running and stopping the equipment, or simulating the activity of field robots. In general terms, the usage of the internet has the following pros [11]:

– The results obtained among different users could be standardizes using the same calculation method and with the same coefficients,
– Studies carried out in different conditions and locations could be compared because of the same coefficients,
– Standard data for non-expert users could be available for free,
– Installation and distribution costs for the software and the updates would not exist since the application would reside only in one server,

- Variant techniques referring to the environmental impact and the enterprise net return could be compared via several scenarios,
- A great range of scenarios would be available, due to the great number of users on the web,
- Worldwide farms and crop scenarios could be compared anonymously.

4 ICT and Agricultural Production

In order to improve the agricultural production, the farmers should be aware of the following information (Fig. 4) [3]:

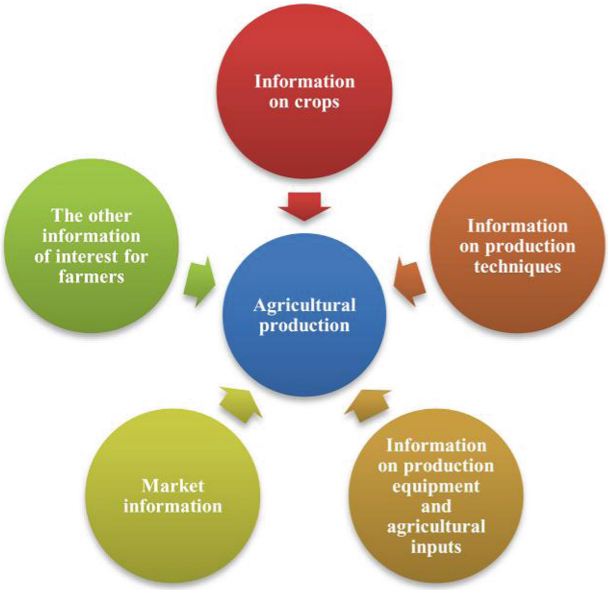

Fig. 4. Type of information in order to improve agricultural production.

Information on the crops: Field information can be collected and transferred via the Web or other types of telematics and be analyzed into reviews and statistics to which farmers may get electronical access to planning adapted to their own production. Such information may be over seeded crop categories, area of land with specific crops, time of dropping seed, time of harvest, yields etc.

Information on the production techniques: Production techniques developed by experimental institutes of agriculture and stations for agricultural improvement are also available to farmers via the internet.

Information on production equipment and agricultural inputs: Such information is provided by companies selling agricultural equipment. And may be accessible to the farmers via the Web as well.

Information on the market: Such information makes the farmers aware of the worldwide food market including product prices helping them to be more competitive and -why not- to address to markets where the products are valued higher. Furthermore, Information Technology may forecast the product demand and prices in the future helping the farmer (and trader) to plan not only the next season's crops, but also the selling price and the time of selling (now or later in an expecting high season).

Other information: Such information refers to weather forecast, availability of credit, expert advice over the crops, etc.

5 ICT Application in Agriculture

An area of application for ICT is in improving, through better management, the efficiency and sustainability in using inputs—land, soil nutrients, feed and fodder, water, energy, pesticides, labor, and most importantly, information and knowledge—in agriculture. The ICT also help reduce the negative effects of pests and disease and enable aversion and mitigation of risks such as from inclement weather, droughts, floods, and long-term change in climate. Through innovation, ICT continue to contribute to improving throughput of farming systems, increasing the quantity, quality, and marketability of outputs (e.g., food, energy, and biomaterials), supporting their marketing and enabling their effective and efficient consumption by households and communities and their ultimate recycling. The ICT helped pave the way for consumers to decide which products they can "responsibly" purchase, which seem to have higher food miles, and those whose production and safety can be traced all the way back to the fishpond. For the small, resource-poor farmer and producers in economically developing countries, these applications of ICT have not yet become mainstream. The economic returns from agriculture and access to affordable technology useful in small-farms operations are the main constraints in more widespread use of ICT in smallholder agricultural production. Figure 5 present the current application of ICT in agriculture [12].

Data Collection. Collection of agricultural and environmental data from biological and environmental sources, with or without human interaction. These data, after analysed and manipulated will feed auxiliary applications.

Number Crunching. Process of large datasets, modelling and simulation, image processing and visualization that helps plant and animal breeding, plant and animal epidemiology, management and market chain analysis agricultural meteorology, bioinformatics, farming systems research, etc.

Robotics and DSS. Data and information combined with the human factor are organized in order to help especially in semantical searching, diagnosis and farm and agricultural process automation.

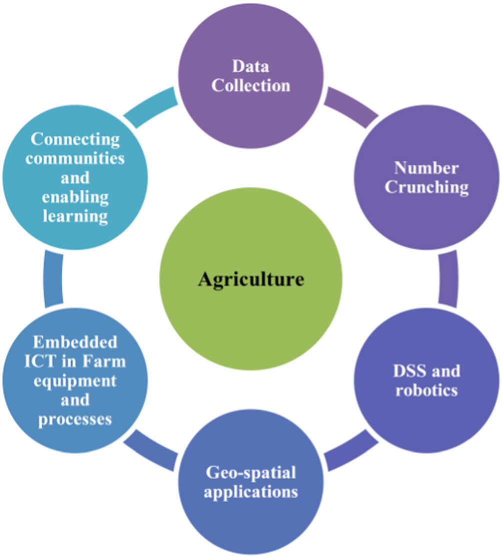

Fig. 5. Application of ICT in agriculture.

Embedded ICT in farm equipment and processes. Farm equipment and agricultural processes are more efficient as well as the transportation and marketing of the agricultural products, for example the use of RFIDs, Cellular Telephony and Wireless Internet in labelling, traceability and identity preservation.

Geo-spatial applications. Data and information related to geography and space to be managed contributes to planning of the land and water usage, to the utilization of the natural resources, the agricultural input supply and the commodity marketing, to the elimination of poverty etc.

Connecting communities and enabling learning. ICT helps researchers and farmers but also the communities of researchers to interact and communicate better promoting the agricultural development and the scientific research and publication. Furthermore, ICT promotes the cooperation between farmers and producers with the exchange of knowledge and technology which is very useful especially when problems arise.

5.1 Robotics

Robotics in agriculture is known from the past; it's been over 20 years that it is used in controlled environments. However, as computational power rises and costs are reduced robotics is spreading. Recently autonomous machines are developed in agriculture by researchers gaining serious interest. As a matter of fact a case scenario was to use many small efficient autonomous machines replacing tractors of large size [13–15]. Such vehicles are on duty 24 h a day, 7 days a week, whatever the usual weather conditions. Plus, they work normally (sensibly) in a natural/semi-natural environment for long periods, unattended, while carrying out a useful task.

The main benefits of development of intelligent and autonomous agricultural robots are to improve efficiency, reliability, repeatable precision and minimization of soil compaction. The robots have potential for multitasking, sensory acuity, operational consistency as well as suitability to different operating environment, interaction, physical format and function (Table 1).

Table 1. Robot categories. In grey the robotic types used in agricultural production.

Robot categories	Operating environment	**Air**
		Ground
		Underwater
		Space
		Living organism
	Interaction	**Pre-programmed**
		Tele-operated
		Supervised
		Collaborative
		Autonomous
	Physical format	**Arm**
		Platform
		Exo-skeletal
		Humanoid
		Micro-Nano
		Metamorphic
	Function	Assembly
		Area process
		Interaction
		Exploration
		Transporting
		Inspection
		Manipulation

In agriculture, researchers focus on the design of specialized autonomous agricultural vehicles using various farming operational parameters since conventional farm machinery is crop and topological dependent.

A lot of field operations can be executed by specialized autonomous agricultural robots, offering more benefits than conventional machines. These platforms would be used for cultivation and seeding, irrigation, weeding, fertilizing, scouting and harvesting.

When it comes to harvesting, researchers develop rational and adaptable robotics for picking Cucumber [16], Tomato [17], Pepper [18, 19], Strawberry [20, 21], Eggplant [22], Melon and Watermelon [23], Other vegetables (Asparagus, Cabbage, Radish) [24], Rice and paddy fields [25] and Mushrooms [26], Cherry [27], Apples [28] and Citrus [29].

When it comes to robotic weed control a difficult task for the robots is to diversify between weed and crops. Researchers are developing autonomous robotic platforms for weed destruction [30, 31].

Last but not least when it comes to transplanting and seeding production, robotics apply to some of the operations (seeding, thinning, grafting, cutting sticking, transplanting etc.) [32].

5.2 Precision Farming Management

Agriculture bio-production systems in the future are expected to be of an unprecedented high precision during their operation. Thus, a high degree of embedded machinery intelligence is required combined with advanced operations management systems connected with mobile units, automated systems, advanced updated decision support systems, automatic data acquisition as an integral part of the machine operations at a total for traceability/documentation, production process with economic and environmental concerns. The above are included in precision agriculture (PA) and more recently Smart Farming, which shows the future of agricultural development and other types of bio-production.

In general terms precision agriculture (PA) shows what is the right thing to be done, the right place, the right time, and the right way; so the implementation of PA is based on technologies that define the term “right” [33]. In scientific terms, precision agriculture is an agricultural production management system that uses information and communication technologies (ICT) in order to take into account the spatial and temporal variability in fields and crops [34].

Precision agriculture as a management system is a closed-loop operation system, including data collection, interpretation, decision making, the performance of the designated actions, and last but not least the evaluation of the outcome, coming from the decisions application, and the reconsideration of the decisions that have been taken. During every cropping cycle the above data are recorded and stored in databases (libraries) as historical data for further use in the future (Fig. 6).

Precision farming is considered to contribute to the efficiency and the sustainability of the farming system in the future. The reduction of the environmental impact of the production – due to the input material reduction–, and the generation of valuable information for product traceability are the main two recognizable side benefits deriving from the implementation of PA. Precision farming promotes the development of a new integrated concept including advanced planning and control system and automated smart and robust machinery applicable for biosystems [7]. This will include production units that comply with a number of sustainability indicators such as minimized resource input, product quality and environmental impact. Consequently, precision farming focuses on the development of techniques and technologies which improve production efficiency, and on the environmental impacts measurement, modelling, and of course minimization. In detail, this includes integration of site-specific application of pesticides, fertilizers, and water and operations management (e.g. decision support systems, farm management information systems, web-based approaches and so on).

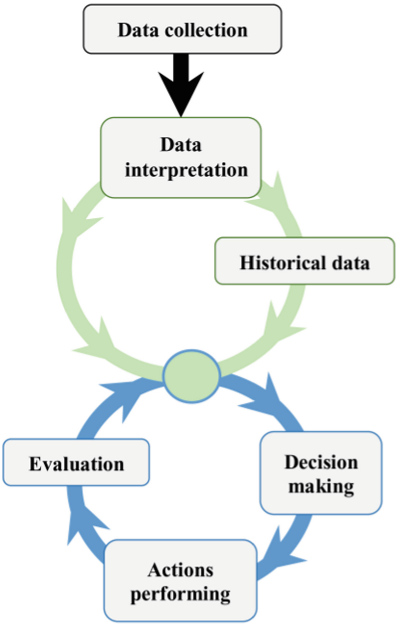

Fig. 6. The concept of precision agriculture as a management system.

PA originates from the first years of organized agricultural production. However, this concept was implemented to small-sized farms, all over which the farmer was able to walk on foot and observe any changes to crop growth or emergency, taking instant actions such as to place locally more seeds or fertilizers. The decision leading to the actions was based on direct observation and included limited "stored" knowledge from previous observations. During the mechanization phase of agricultural production, it was more difficult to store and organize this knowledge especially as the size of the field area increased. To the above phase the economies of scale lead to a homogenous treatment of the large field areas, although there could be significant variations of yield and soil properties in large fields. Last but not least, the technology of that time could not support any type of PA application.

The global positioning system (GPS) was the first technology applied in agricultural operations. Next the yield mapping technologies followed initially in arable farming and in a stepwise manner in open air horticulture and in orchards.

Studies have demonstrated that usefulness and ease of use are crucial for technology adoption, provided that these aspects do not cause a significant increase in the production cost [35, 36]. Other adoption drivers include total income, familiarity with computers, land tenure, farm size, farmers' education, costs reduction or higher revenues to acquire a positive benefit/cost ratio, location and access to information (via extension services, service provider, technology sellers). Also, another key for the adoption of PA is the quantified cost-benefits derived from the use of technologies, such as auto-section control, remote sensing, areas of machine control, guidance, nutrient management, and variable seed rate.

Although during the recent decades there has been a fast development of technologies applied to PA, the adoption by the farmers, if any, was rather slow [37].

In order for a new technology to be implemented one or more of the following points need to be met:

- There is a proven economic benefit,
- There are significant advantages compared to the existing technology to be replaced,
- The new technology is less complicated that the old one,
- The new technology is reliable and robust,
- The new technology is supported by servicing and repair satisfactory enough.

Among the reasons of this low rated adoption lies the initial establishment cost of this new technology. This led to a new generation of third parties that provide site-specific technologies (yield mapping and variable rate applications) [38].

Roughly speaking, the cost of PA technologies depends on the followings 3 points:

- Equipment Depreciation
- Training Cost
- Variable annual data analysis Cost.

5.3 Satellite Navigation

The main navigation satellite navigation systems are:

- The NAVSTAR GPS (Navigation System with Time and Ranging–Global Positioning System). This system was created by the U.S. Department of Defence and the US Department of Transportation. It is composed of a network of 24 satellites placed into orbit. This system can be accessed anywhere. Near the earth can be accessed where there is an unobstructed line of more than four GPS satellites.
- The GLONASS (GLObal NAvigation Satellite System). This system was developed by the Soviet Union and is operated by the Russian Aerospace Defence Forces. It is also composed of a network of 24 satellites placed into orbit. GPS and GLONASS are both available worldwide both for private and commercial use.
- The GNSS (Global Navigation Satellite System). This is a civilian satellite navigation system (Europe).

Nowadays, there is a huge development in the applications of GPS in various domains. Selected applications include:

a. Vehicle navigation systems. This application improves the in-vehicle experience [39], increases safety [40] and helps the driver to orientate in unfamiliar environments. Based on a satellite navigation system the location of the vehicle is identified in relation to the destination provided by the driver. Both visual and auditory directions are offered in almost real-time.

b. Fleet management. This section regards the use of GPS to reach and store locations of origins, location of destinations, trip length and duration, various time stamps during travelling, travel modes and activities. All the traditional methods of activity diaries can be potentially replaced completely by this system. Also, this system can provide the data that can be used for further analysis of the transport systems [41–45].
c. Offshore drilling research.
d. Bridge deformation monitoring.
e. Aircraft approach and landing.
f. Agricultural machinery navigation.

5.4 FMIS (Farm Management Information Systems)

During the last decades, there is an incremental change of the agricultural productivity development from scaling of assets to optimization of assets; for example, there is a strong focus to the maximisation of profit and not to production. Agricultural machines as well as the farm units get bigger and more expensive over the years to the point that a higher degree of input/output management is necessary. However, any efforts towards this direction focus more or less to a single operations management rather than having an overall systems approach.

Recent advances in agricultural RTD (ICT, robotics, processing and operations management tools) and their application has raised dramatically the efficiency in production and the sustainability using integrated processing, planning and control systems. Managers or automated decision-making systems (FMIS) control or give instructions to machine systems or production units based on internet meteorological data, history data of the management system or other information sources. The generation and the execution of a plan gets into a system, having this way the effects of actions, unexpected incidents and new information that attributes to a plan validation, refinement, or reconsideration monitored.

Information has many sources including sites, raising the expectations from the information systems. McCown stated that when an information system, the focus should be on learning the farmers behaviour [46]. Software developers should interact with farmers in a user-centric approach.

The enhancement of FMIS is apparently influenced more by business factors rather than specific farming activities [47]. Plans should be conditional using data from observations, databases, sensors and tests. Management information systems (MIS) are an integral part of a management system and supports several tools such as for example enterprise resource planning (ERP), information systems (IS) etc. ERP, which is an industry concept, involves management activities that support business processes within the production system. The management systems support multiple levels planning processes and identify any key performance indicators (KPI's) [48]. Typically, ERP is connected directly to information systems using databases and including applications for the finance and human resources of an enterprise.

MIS analyses other systems that deal with the operational activities in the production system. Thus, MIS becomes a part of the total planning and control activities covering the management of human resources, technologies, and procedures of the enterprise. As part of scientific management, MIS relates to the automation or support of human decision making [49].

Sørensen et al. refers to the structure of the various management systems in an enterprise or a production system [50] (Fig. 7).

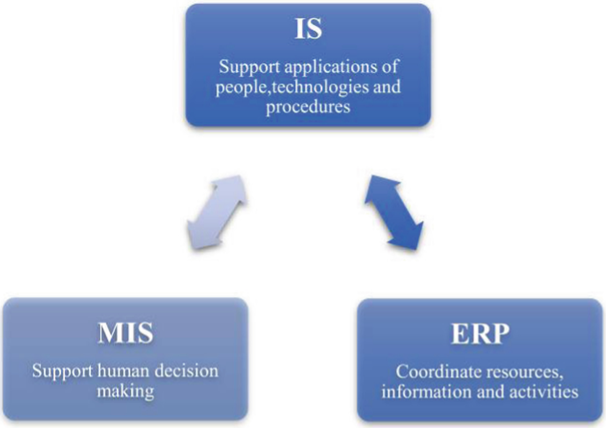

Fig. 7. Concept of management information systems.

Thus, a Farm Management Information System (FMIS) is considered as a system for the data collection, processing, storing and disseminating in order the operations functions of the farm to be executed.

Machinery have increased greatly agricultural productivity in the last decades. This development integrates with advanced automation and extensive use of embedded Information and Communication Technology systems. Such technologies allow the collection of site-specific information in detail during operation of field machinery, conventional, e.g. tractor with implement, or non-conventional autonomous vehicles, e.g. robots. Through targeted decision support systems or directly bearing an online control the resource input is reduced and the production is of high quality and, what is more, environmentally friendly. Task planning and formulation involves a time schedule referring to the predicted crop development, weather forecasts, etc. The task settings are transferred to the tractor/implement for control or implements' adjustment. In case of a difference between the executed work and the formulated plans, there will be corrections. The final result is recorded, documented and the data are stored for future projects or learning.

The task management function helps the farmer to schedule and control the field operations. When the operation and task plan are formulated, they are transferred to the machinery. The task plan give the guidelines for the machine field movements and control the agronomic operations. In case of no knowledge attained within the estimated time of a task plan, it should be reformulated in order for an optimal operation to be maintained (dynamic task plan). Concurrently with above planning, the system analyses and predicts the evolution of the system status (for example field and crop development, machine performance etc.).

6 Conclusion

In conclusion, it can be mentioned that the use of ICT in agriculture, itself or combined with other ICT systems results in productivity improvement and better resource use and reduces the time needed for farm management, marketing, logistics and quality assurance. As time goes by ICT improves the access of the farmers to information, knowledge, skills and technology, improves the productivity of the farm and its ability to take part in the markets, not to mention its contribution to increased sustainability and to the resilience of the farming systems while changing them to face the new challenges.

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