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AKADÉMIAI KIADÓ

Challenges of sustainable agricultural development with special regard to Internet of Things: Survey

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ORIGINAL RESEARCH PAPER

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ABSTRACT

If we want to increase the efficiency of precision technologies to create sustainable agriculture, we need to put developments and their application on a new footing; moreover, a general paradigm shift is needed. There is a need to rethink close-at-hand and far-off innovation concepts to further develop precision agriculture, from both an agricultural, landscape, and natural ecosystem sustainability perspective. With this, unnecessary or misdirected developments and innovation chains can be largely avoided. The efficiency of the agrotechnology and the accuracy of yield prediction can be ensured by continuously re-planning during the growing season according to changing conditions (e.g., meteorological) and growing dataset. The aim of the paper is to develop a comprehensive, thought-provoking picture of the potential application of new technologies that can be used in agriculture, primarily in precision technology-based arable field crop production, which emphasizes the importance of continuous analysis and

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optimisation between the production unit and its environment. It should also be noted that the new system contributes to reconciling agricultural productivity and environmental integrity. The study also presents research results that in many respects bring fundamental changes in technical and technological development in field production. The authors believe that treating the subsystems of agriculture, landscape, and natural ecosystem (ALNE) as an integrated unit will create a new academic interdisciplinarity. ICT, emphasizing WSN (Wireless Sensor Network), remote sensing, cloud computing, AI (Artificial Intelligence), economics, sociology, ethics, and the cooperation with young students in education can play a significant role in research. This study treats these disciplines according to sustainability criteria. The goal is to help management fulfil the most important expectation of reducing the vulnerability of the natural ecosystem. The authors believe that this article may be one of the starting points for a new interdisciplinarity, ALNE.

KEYWORDS

sustainable agriculture, IoT as ecological aspect, field robots, precision crop production

INTRODUCTION

The importance of the development of ecological and agronomic sustainability has been confirmed by a few studies. According to Tilman (1998) 50–65% of NPK (Nitrogen–Phosphorus–Potassium) fertilizer is lost, while from the remaining amount only 30–50% of the nitrogen fertilizers and 40% of the phosphorus fertilizers are taken up by plants (Tilman et al., 2002). The rest is discharged into groundwater and surface waters, respectively, moreover, it gets into the atmosphere. If farmers do not use site specific technologies, only 10% of herbicides and 1% of insecticides are useful for crops (Hannah, 2017). Similar problems occur with synthetic pesticides (Sharma et al., 2019). The situation has not improved since then, which has widened the gap of the reaction time between detection of environmental pollution and responding to it (Longchamps et al., 2018). One of the aims of the study is to present the key actions, research directions, and topics along with the adaptation of field experimental results that will advance the effectiveness of integrated ecological sustainability of the agro, landscape, and natural ecosystem in the upcoming years (3–5 years). Additionally, the study strives to inform farmers and contribute to the development of their sustainability mindset.

The 2030 Agenda for Sustainable Development (Sustainable Development Goals: SDGs), adopted by all United Nations member states in 2015, envisages global social, economic, and environmental reform. It is about recognizing that poverty, including hunger and limited access to healthy drinking water, cannot be reduced without reducing disadvantages to health. Furthermore, stimulating economic growth cannot be achieved without improving education. This document identifies 3 pillars:

1. Increasing productivity, reducing logistics costs, drastically reducing the local and global transport distances of crops, and reducing food losses and waste; all this to increase the available volume of production.
2. Information and communication technologies (ICTs) help to mutually learn about societies and their cultural values, and to bridge the digital divide.

3. Smart agriculture that is based on precision technologies, which through digitalization enables the optimization of production processes: ecological and economic sustainability, monitoring the production chain, and mitigation and exclusion of technologies that cause climate change (Trendov et al., 2012).

BACKGROUND – PRECISION AGRICULTURE

The concept of this paper is based on the practice and philosophy of precision farming. The definition of precision farming according to ISPA (International Society for Precision Agriculture) is: "Precision Agriculture is a management strategy that gathers, processes and analyses temporal, spatial and individual data and combines it with other information to support management decisions according to estimated variability for improved resource use efficiency, productivity, quality, profitability and sustainability of agricultural production." It cannot be disputed that precision production technologies have brought about significant positive changes in agriculture in developed countries, in line with the SDGs. However, globally, both synthetic fertilizer and pesticide usage are increasing (World Fertilizer Trends and Outlook, 2019; CIRAD Pesticides, 2022). This means that local results are not yet or only to a small extent reflected in global parameters. The green supply chain is in a direct connection with precision crop production. The advantages and disadvantages of the green supply chain are shown in Table 1.

Based on the experience so far, it can be stated that the advantages of precision technologies can only be realized with the help of larger databases in space and time. This is one of

Table 1. Supporting and inhibiting factors of the green supply chain inside and outside the company

	Supporting factors	Inhibiting factors	Source
Factors within the company	environmentally conscious corporate culture	lack of resources, slow return	Memon et al. (2017)
	high environmental risk corporate activity	cost-based corporate strategy	Adrodegari et al. (2017)
	existence of an environmental management system at the company	traditional performance evaluation system without environmental aspects	Hashi and Stojcic (2013)
	existence of a "green" strategy at the company	other (non-green) supply chain management priorities	Jankalová and Jankal (2018)
	managerial commitment to environmental protection	lack of managerial commitment	Suryani and Dianawati (2018)
Factors outside the company	environmentally conscious buyers	buyers preferring low prices	Wallace (2017)
	cooperating suppliers	weak supplier commitment	Nagy et al. (2018)
	subsidies, tender opportunities	weak industry regulation	Bonilla et al. (2018)

Source: Own compilation, 2022.

the purposes of the connection of Precision Agriculture (PA) and IoT (Internet of Things) technologies.

IOT AND SMART AGRICULTURE

The IERC (IoT European Research Cluster) definition states that IoT is: "A dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual 'things' have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network." Smart is a clever system with adaptability. Its implementation requires the processing of digitized databases and Big Data, and it is based on artificial intelligence, while also taking advantage of cloud computing. These are realized by IoT solutions. In fact, IoT builds on PA to monitor spatial and temporal changes in the field and its near and far environment, collect and analyze data, and undertake necessary interventions. The new system also contributes to the reconciling of agricultural productivity and environmental integrity (Robertson and Swinton, 2005). The up-to date IT conditions are ready to level up IoT, both in data collection and in interventions based on big data analysis.

The artificial intelligence with cloud computing is an umbrella support system of IoT. This requires the fusion of intelligent wireless sensors data: from remote sensing (UAVs: Unmanned Aerial Vehicles, satellites), data acquisition of tractors and other agricultural machines and devices, and robots (UGVs: Unmanned Ground Vehicles) with accurate positioning (GPS, RTK: Real Time Kinematic, Lidar). The WSN (Wireless Sensor Network) is a wireless network of spatially distributed sensors.

Sensors → MCU → Nodes → Gateways → Clouds (server)

Small-smart data logger robots can be considered as WSN systems. The sensors are connected to nodes, and in turn, the nodes provide communication between the sensors. The main architectural elements of a node are: connection of sensors, microcontroller, external memory, transceiver, and power unit. The LoRaWAN (Long Range Wide Area Network) is designed to operate with limited power consumption and is able to transmit sensor signals from up to 30–40 km away to a central server on flat terrain (Nyéki et al., 2020). The technology can also be operated using a mobile telephone network. The whole system is held together by the IoT (Fig. 1).

It is also expected that farmers have direct access to as much data as possible so that they can understand the background behind the decisions or expert advice in order for them to make decisions and even turn to a board that overrides the decisions of artificial intelligence (Nyéki et al., 2021). However, it is important to know that only processed data can be sent to the farmers otherwise they will not be able to participate in decision-making.

Nowadays in more and more cases, M2M (machine to machine) decisions are made without human intervention; the revolution of AI based decision-making has started. Currently, autonomous irrigation technologies have reached the "farthest" in the field of M2M (Sandeep and Nandini, 2019; Milind, 2014; Mudholkar and Mudholkar, 2010; Derus et al., 2019). Smart irrigation also plays a key role in groundwater pollution avoiding fertilization technologies (Stoleru et al., 2020). Goumagias et al. (2021) analyzed articles defining IoT published between

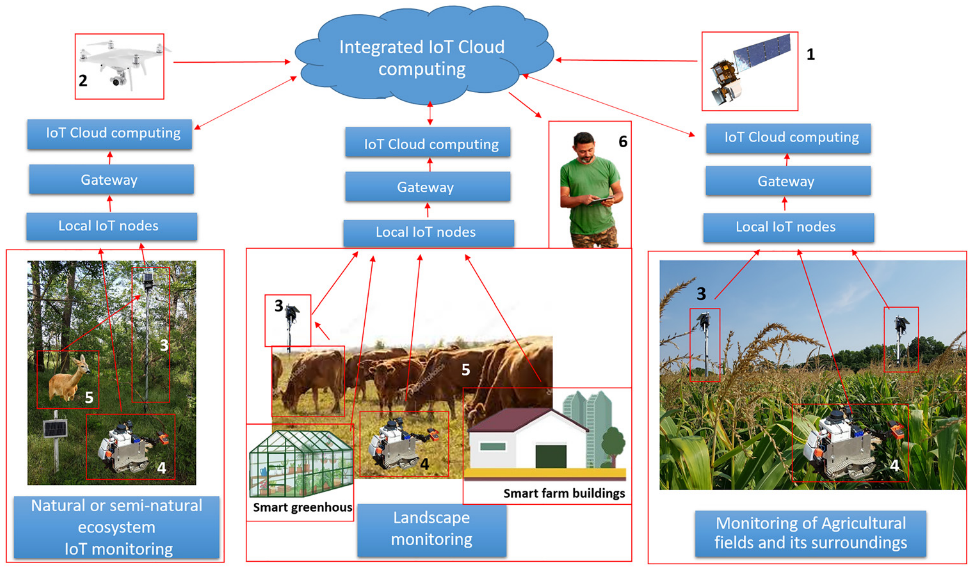

Fig. 1. Architecture of Mosonmagyaróvár- Agro-IoT (*Source*: own). **1** Satellite: Information on soil, plant, animal, plant diseases, etc., and tracking animal movements: GPS, RTK GPS; **2** Drone: Information on soil, plant, animal, propagation speed plant diseases, pathogens, and pests, wild damage, etc.; **3** Installed IoT station (nodes): soil (temperature, moisture content, EC_a, pH, O_2 and CO_2 emission, N, P, K), crop (stem thickness); **4** Small-smart data logger robots: microclimate (temperature, humidity, global radiation, atmospheric pressure), soil (surface temperature, temperature deeper, moisture constant, ECa, pH, N, P, K, AI interface, Lidar, leaf sampler, ultrasonic distance sensor, camera (RGB 360°), object classification, detection of different plant lesions; **5** Individual animal identification; **6** Farmer connected to the IoT system

2005 and 2019. The intensive development of a system that fundamentally determines the development of ICT and implements a paradigm shift, which constantly raises new points, for instance, in the definition of sustainability, is natural. The ever-expanding IoT platform service is also suitable for exploring contexts that have not arisen (or could have arisen) in practice or research so far, as there was not enough information (Big Data) available at the time. Furthermore, there was no proper mathematical method to process them. From the articles on IoT, it can be generally concluded that smart transport, smart cities, smart hospitability, smart homes, smart agriculture, and so on are the basic drivers of the formation and spread of the development of IoT. Through IoT, farm units, crops and animals, agricultural machinery, and fresh crops are integrated with microchips and broadband networks (Balamurugan et al., 2019; Kowsalya and Karthigha, 2022). IoT is a platform by which the connection system of devices is managed with real time links. Sustainable agriculture is the most diverse area where IoT can be used, as the characteristics of biodiversity, stochastic phenomena (weather), the symbiosis of living and inanimate systems require a complex approach (Division et al.; Wang et al., 2019; Bhatta and Thangadurai, 2019). IoT/AI can also play a significant role in mitigating adverse climate change and GHG (Greenhouse Gas) emissions (Abd El-Mawla et al., 2019; Harsányi et al., 2021).

One of the great advantages of IoT in agriculture is that it is possible to prepare for events that come from further distances from a given area (e.g., insect pest invasion) by using the data of the IoT station installed there. More and more emphasis is being placed on the Internet of Everything (IoE) in regard to ecological expectations (Kumar et al., 2021). This increases the efficiency of protection and thus reduces its cost; the same information bases (Big Data) can be used for different purposes in space and time, specifically, remote IoT systems can be connected to cloud-based computing capabilities (Baldassarre et al., 2018; Jaiganesh et al., 2017). It is also extremely important to note that the dynamic balance of natural and especially agro-ecological systems with IoT systems reveals correlations that were not possible with "static" databases, e.g., databases recorded annually or even every 2–3 years. Agricultural IoT is a perfect refutation of traditional thinking in which the belief that the physical, biological, and social worlds (systems) must be viewed separately (Struik and Kuyper, 2017). Through IoT, the network of these areas can be alternatively examined, for example from the perspective of circular farming too. Other advantages of this include: the efficient use (ecological sustainability, environmental protection) of soil, water, fertilizers, pesticides, etc.; reduction of production costs (profit increase); food safety; and the direct relationship between farmers and consumers (direct marketing). IoT contributes to the development of intelligent, smart farming technology, such as irrigation, nutrient replenishment, pesticide and weed management, monitoring of plant growth and development, sensing plant diseases, phenotyping, etc. On the other hand, it is also suitable for complex environmental analysis (Buttice, 2021). IoT system processes signals in various forms, performs data fusion, evaluates the data, and transmits commands that it executes by micro-controller (Bandi et al., 2017). The AI-based control systems are continuously optimizing the control of self-propelled or tractor-operated implements based on the data provided by the sensors. There is a need to be more and more focused on optimization in order to meet sustainability criteria (Afriyie et al., 2021).

DEVELOPMENT OF SENSORS

Sensors are being installed in more and more machine components, providing designers and operators with information on the characteristics of dynamic (field) loading of systems, repetitive biotic and abiotic stresses. By comparing the data of sensors placed in the soil, in crops, and in animals, technical improvements that are soil-, plant- and animal-friendly, regarding criteria of ecological and economic sustainability, can be implemented (Baillie et al., 2018).

Improvements are made mainly in physical and non-contact proximal detection (Mouazen et al., 2020). A lot of important data can be collected by sensors that are moved in the soil in vertical and horizontal directions or remain in a fixed ground position. Smaller and smaller sensors are being used; nanotechnology is emerging (Prasanna, 2017). Furthermore, this is not just about animals in which data is collected through the microchips inserted into their bodies, but it is also about the possibility of obtaining information from plants with nano-sized sensors. In this way, changes in physiological conditions in living organisms can be monitored that are a result of changes in external conditions (meteorological events, appearance of microorganisms, use of pesticides and fertilizers, etc.). Nanotechnology (1 nm $= 10^{-9}$ m) means that smaller and smaller things that are information gatherers can be connected to each other, and interactions between them can be analyzed (Balamurugan et al., 2019; Li et al., 2020). At the same time in soil testing, tests based on hyperspectral reflectance can detect moisture content, texture (particle size distribution), chemical composition, and other physical properties of the soil by means of devices moved above the soil, in the soil or in the laboratory under defined light conditions (own reference).

Yield estimation can be done with Normalized Difference Vegetation Index (NDVI) cameras mounted on UGV (in this case small-smart robots), drones, aircrafts, and satellites (Candiago et al., 2015). The accuracy of the estimates can be increased with hyperspectral cameras and using NDRE (Normalized Difference Red Edge) cameras.

Colour-based crop (fruit) ripeness tests can be performed using an Artificial Neural Network (ANN) and Principal Component Analysis (PCA). To classify fruits gloves are used that integrate multiple sensors, which include touch pressure sensors, imaging, inertia measurement, positioning, and RFID (Radio Frequency Identification) (Vohland et al., 2017; Jia et al., 2017; Mouazen et al., 2013; Navas et al., 2021; Kultongkham et al., 2021). This reduces losses during manual harvesting and increases the speed of the operation. Additionally, the conditions for classification of a crop according to its direct quality are created and subsequent loss-making classification can be avoided.

Combining IoT and UAV is a symbiosis of two very useful new technologies in the field (Almalki et al., 2021). The drone is also suitable for harvesting fruit with the help of artificial vision and a suitable gripping tool (James, 2021). Autonomous UAV fruit-picking robots have already been put into use. Artificial bees are increasingly taking on the role of natural pollinators (Schaft, 2018). UAVs with visual and olfactory properties can also be used as environmentally friendly, insecticide-free “insect diversion” in the future. However, Dorin (2020) sees the use of robotic bees as an ecological disaster.

When sensing weeds, the task is to differentiate between weeds, soil, and culture. Thus, electro-pneumatic (mechanical) weed control needs to be performed between the stems. Determining the location and size of the stems can be done with a laser and a self-guiding machine using RTK GPS (Ambrus, 2021).

The electronic tongue can detect the presence of glyphosate and other non-selective herbicides (Bataller et al., 2012). The electronic tongue is also suitable to detect bacterial infections (Al Ramahi et al., 2019). The artificial nose provides information in many areas, including air humidity, soil conditions, appearance of insects, fungi, bacteria, degree of infestation, applied fertilizers, etc.; all phenomena that change odours in the air can be detected near the sensor (Laothawornkitkul et al., 2008; Cui et al., 2018). The combination of the electronic tongue and nose increases the efficiency of detection. This area will soon open up new opportunities in methods for sensing biological, chemical, and physical phenomena in the field.

Bio-acoustic sensors can also open new perspectives in information gathering, including the detection of insect pests (Trilar and Gogala, 2012).

Using infrared sensors (thermal cameras) weeds, insects and larvae can be detected. In addition, the extent of damage and biotic and abiotic plant stresses can also be detected (Pineda et al., 2020; Mesterházi, 2004).

Martinelli et al. (2014) provided detailed information on methods for recognizing plant diseases, highlighting the importance of methods of remote sensing. McLennan and Mahmoud (2019) presented an automated pain facial expression detection system for sheep in order to identify diseases.

SUSTAINABLE AGRICULTURE FROM A BROADER PERSPECTIVE (TECHNICAL DEVELOPMENT, ENERGY BALANCE, ETHICAL REMARKS)

The essence of natural ecological sustainability is that the system maintains its functions, processes and biodiversity over a longer period of time (Struik and Kuyper, 2017). Accuracy of our knowledge, experience, measurement methods, and the increase in the number of sensors in space and time will result in a permanent rethinking of the concept.

At present, we have very little knowledge of the ecological relationship between agricultural production, rural landscape and natural ecosystem, and on the economic values of agriculture and the service provided by a landscape and natural ecosystem. To create a wide range of services related to the production of food and fibre, and raw materials in a landscape and natural ecosystem, comprehensive research is needed that considers ecological expectations and social economy that is linked to policy innovation and dissemination of scientific knowledge and public education.

From a management point of view, an important question is: How do scientific results and practical experience relate to each other? New methods need to be developed to assess the practical applicability of scientific results to minimize wasted knowledge (Irwin et al., 2018; Hansson, 2019). Agricultural production basically consists of the integrity of three pillars: genetics, environment, and management (Hatfield and Walthall, 2015). With the technology provided by management, these factors need to be optimized ecologically and economically regardless of whether decisions are made by human or artificial intelligence. The level of optimization of the integrated 3 basic pillars also determines the utilization of the production potential and the yield that can be realized in the field for the given pre-crop, genotype and meteorological conditions.

In the case of agricultural production, the following basic aspects must be considered in agro-ecological sustainability:

- Fossil neutral production technologies, including biogas-based N fertilizer production.
- Nutrient replacement without nitrification and eutrophication of groundwater and surface water.
- Reduction of emissions of nitrogen compounds, CO_2 and CH_4. Production without soil erosion, salinization, acidification, and harmful compaction.
- Avoidance of environmental pollution of chemicals (mainly pesticides).
- Reduction of waste in post-harvest technologies.
- Pursuit of the greatest biodiversity around the field.

For this to be realized, the energy balance analyzing method has to have a realistic picture, as social and other non-material factors can be assessed using a unified approach. The broader our knowledge and more accurate the energy balance, which also includes the material balance, the better we can learn about and meet the sustainability criteria, and the optimal energy input. The energy balance can also quantify harmful emissions from agriculture. However, the energy by which emitted CO_2 can be extracted from the air and the energy use of extraction of nitrate and nitrite content from groundwater should also be calculated. It is a locally, thermodynamically open dynamic system in which the efficiency of energy input (technological and energy use for environment protection) must be maximized (Ulanowicz, 1972; Jordan, 2016; Neményi and Milics, 2010).

According to Bogdanski (2012), both food and bio-energy production in ecosystem approaches should be combined, like in agroforestry or integrated crop, livestock, and biogas systems. The author argues that system-oriented analysis is needed to analyze these complex, interdisciplinary and large-scale phenomena; increase food security; and mitigate the contribution to greenhouse emissions.

The current and future large population can only be safely supplied with food and healthy drinking water when food production is done under controlled conditions with a reduction in its ecological footprint; however, that requires compromises. The risks of the 6th extinction crisis of species need to be considered, i.e., irreversible processes should be avoided (Cafaro, 2015). Pest adaptation and resistance processes in the vicinity of land used for production due to technological or other anthropogenic interventions are a special problem. This is one of the reasons why IT monitoring must be performed continuously in nearby and far-off environments from the fields.

Taking into consideration environmental conditions and management, four areas can be highlighted in the field of technical and ICT developments:

1. A new concept for the development of machines used in crop production and especially robots. According to Blackmore (in Hannah, 2017), agricultural machine manufacturers still think in machines and not in systems.
2. Increasing the efficiency of IoT (Li et al., 2020; Mudholkar and Mudholkar, 2010).
3. Expanding the possibilities for joint use of IoT/AI (CIRAD Pesticides, 2022).
4. Moral and ethical issues in the light of sustainable developments (Müller, 2022).

In connection with the above criteria, one of the fundamental ethical issues arising from the relationship between agricultural production, human beings and natural ecosystem is that there is a significant reduction in the self-regulatory capacity of ecosystems through intensive technologies. Ecological self-regulatory property means that a dynamic equilibrium is established under given conditions; the waste of one individual is the food of another (Margulis, 2013). This mechanism prevents the disintegration of this biological cycle and the overgrowth of some individuals (species). There are no self-regulatory solutions to reduce pollution in agricultural production and to avoid serious violations of the conditions of ecological sustainability. It can only be based on the common sense of humanity, and on all current and future scientific, technical, and ICT findings. Otherwise, the consequences of wrong practice will occur decades later to the detriment of future generations.

SUSTAINABLE INNOVATIVE AGRICULTURE IN DEVELOPED AND DEVELOPING COUNTRIES

Sustainable agro-innovation can only be considered if it meets ecological expectations, i.e., it is environmentally friendly; contributes to increasing biodiversity on and around the field; is climate-neutral or mitigates the adverse effects of climate change; and reduces disparities in living standards between developed and lagging countries, particularly by eradicating hunger and ensuring that all humans have access to healthy drinking water (Neményi, 2020a). Only after meeting these criteria should economic analyses be carried out in terms of innovation, new technologies or operations, not only globally but also locally. This is the basis of moral and ethical expectations. Thus, in developed countries the rise in living standards described by the exponential curve cannot be realized, so convergence should start; otherwise, we will further increase the gap in living standards between developing and developed countries, which could have unforeseeable consequences in the long run. On the other hand, different aspects need to be considered in developed and developing countries in the innovation process (El Bilali and Allahyari, 2018).

The First Industrial Revolution and subsequent three served to replace man's physical strength by increasing productivity. This is, in fact, a technical and scientific evolution. The essence of the second machine age (Brynjolfsson and McAfee, 2014), which began in the last decade, is that artificial intelligence is increasingly taking over the decision-making role. Here also, there is a "danger" that AI will seemingly not make decisions in our interest. A number of moral and ethical issues are also raised, e.g. local and global conflicts of interest. Even now the exploitation of these countries still exists in many areas, hindering the development of developing countries (Neményi, 2020b).

In addition to the many advantages of intensive technological development, there are also two fundamental disadvantages: it removes inhabitants of developed countries from nature and increases social and economic disparities between developed and developing countries. The demand for growth in food production associated with population growth in developing and the least developed countries must also be realized in a sustainable way. Developing countries should not make the mistake of developed countries by implementing yield increases in an intensive, polluting way (Antle and Ray, 2020). Rich countries are on a path of strong technical development and innovation, and this is an unstoppable process. The developing countries suffer the most from the adverse effects of climate change caused by developed countries (Nordhaus, 2013). Consequently, one of the important criteria for global sustainable development is to reduce economic disparities between developed and developing countries.

"Yield increases in poorer nations will require significant investments in innovative adaptation of technologies to new soil types, climates, and pests as well as new infrastructure" (Tilman et al., 2011). Through investment IoT production can be more profitable, more cost-effective, and the extra income generated can be used to carry out innovation activities or even reduce the price of products.

The agriculture in rich countries is currently living in the age of the Fourth Industrial Revolution, which, through the Internet of Things (IoT), enables the use of intelligent sensors that communicate with each other and the environment. Robots, UAVs, airplanes, satellites also provide data. In developing countries, remote sensing will be the most important data provider for IoT systems. Data is processed using artificial intelligence by leveraging the capabilities of cloud computing.

According to Soulard (2014): "… an agro-engineering activity focuses on advanced technologies in agriculture rather than in the context of hyper-technological agriculture in developed countries; secondly, a climate-smart development perspective, taking into account the challenges of climate change and food security in the redesign of agricultural systems, especially for small farms in developing countries".

The authors of this paper believe that IoT adaptation could revolutionize healthy food and drinking water supplies in developing countries, focusing on remote sensing during data collection.

FIELD ROBOTS

Asimov's Laws of Robotics published in the short story "Runaround" in Astounding magazine (1942) (Handbook of Robotics, 56th Edition, 2058 A.D. (Asimov, 1950)) are: "First Law: A robot may not injure a human being or, through inaction, allow a human being to come to harm; Second Law: A robot must obey the orders given it by human beings except where such orders would conflict with the First Law; Third Law: A robot must protect its own existence as long as such protection does not conflict with the First or Second Law."

Further research is needed on how the above robotic principles could be applied in agricultural practice. The authors are convinced that smart-small machines will gain more and more popularity, which will lead to intensive development of robots. This will contribute to the increase of small farms' efficiency and at the same time the biodiversity should be increased.

The point of autonomous robots is that they can make unprogrammed decisions. At the same time, managers' expectations can be formulated, which the robot takes into account, e.g., deciding whether a particular crop can be harvested or is not yet ripe enough. They can also decide what quality of crop, shape, colour, and size meet the given standards. Such tasks can only be performed by taking advantage of artificial intelligence, which in the above case would be the use of digital artificial image processing. Fendt has developed seed sowing robot swarms (Xaver) that operate in rows (Erkelens, 2022).

For field data collection robots, whether self-propelled or integrated with self-propelled implements, to become widespread, current prices need to be reduced. The two most important computing platforms in regard to field robots are Arduino and Raspberry Pi. Proximal sensors fixed on smart-small robots collect information in places, such as soil, groundwater, closing leaves or crops covered rows, etc., that cannot be detected by other means, e.g., by drones, airplanes or satellite at a given vegetation time. Smart-small robots could bring revolutionary change in this area. The possibility of continuous monitoring of microclimate characteristics should be highlighted.

One of the key challenges of today is 5G, without the use of which digitalization of agriculture cannot move forward. However, its impact on the living environment needs to be clarified (Tang et al., 2021; Thielens et al., 2018).

Priority should be given to the use of a robotic workforce, which offers many economic benefits, among other things, the continuous collection of data on soil, plants and its environment in the field and its surroundings. This is how the goals of M2M, the Second Machine Age, and autonomous arable production can be achieved in the future.

Due to the widespread use of robots, a large number and variety of jobs have ceased to exist and this weighs heavily on decision-makers. First, we need to rethink what opportunities artificial intelligence, as a decision-making system, will allow human collaboration. On the other hand, we need to examine what methods and opportunities can be used to make retraining effective. Experience from human–machine (AI) interactions will play a significant role in this. The development and application of training simulators for agricultural machinery in education will intensify. The emergence of a new discipline, general human retraining, lies before us.

One challenge that we face by using more and more sophisticated technology, especially in the workforce, is that there could be a lack of trust in robots (and AI). However, by creating the right rules in regard to robots, humanity can recognize and reap the benefits they provide (Szujó, 2018).

Smart factories and smart farms have many challenges waiting to be solved, in both cases using artificial intelligence, such as CPS (Cyber Physical Systems), Big Data, IoT, and cloud computing, could be the answer. There are significant expectations for the development of robots in agriculture. In industrial plants, very often the product moves, and the intervention robot is in a fixed position. However, in agriculture, except for animal husbandry (milking robots, individual feeding systems, etc.), robots move, for example in crop production. Robots are self-propelled with manipulators. These units are able to perform tasks on the plants (e.g., taking samples from plants based on pictures of leaves taken by a camera; pushing sensors into the soil; and trying to move the human hand gently when harvesting soft fruits that are sensitive to mechanical stress [strawberries, raspberries, currants, etc.], while also providing information on maturity, size, colour, etc.). Data acquisition robots can continuously validate using sensors attached to the soil, soil surface, or plants connected to the IoT, as they pass along information to the IoT database.

The 4 basic features of robots are:

1. Artificial intelligence;
2. Versatile sensing capability;
3. Mobility;
4. Modern energy supply (expectation of green energy).

The development direction with FT2T (From Toy To Tool) is the further development of a robot originally developed for high-skill gaming with an artificial intelligence interface and free-to-use software. Through development, the robot can take samples from soil and plants, take photos, and can be equipped with a LIDAR, acoustic sensors, thermal imager, and more. This provides today's agriculture with tools that can collect cheap and large databases in a relatively short time (Szujó, 2018; Ambrus et al., 2022). Through a FT2T data logger, a whole new phenomenon can expand; we can involve very young people, 10–15-year-olds, in technological developments by taking advantage of their interest in computing. Small-Smart robots' development for agriculture is progressing also through Small Robot Company.

SOCIO-ECONOMIC ASPECT OF SUSTAINABLE AGRICULTURE

Balmford et al. (2008) published a comprehensive study on the economics of ecosystems and biodiversity. The IoT system presented in the study can contribute to the further development of the method and the clarification of the findings. According to the authors, a paradigm shift is also needed in the sense that the local population needs to be more involved in local research than before. Thus, the utilization of research results can be significantly improved.

When using robots, sustainability and human well-being raise both ethical and economic issues that increase yields, and at the same time reduce environmental pollution and increase biodiversity. Robotics facilitates the development of more diverse forms of ownership, as the use of robots can also increase the profitability of smaller businesses. Extremely dirty, monotonous, and dangerous jobs can be undertaken by robots. The disadvantage is that robots can increase capital, economic, and political concentration in which case people move further away from nature, thus the gap between rural and urban, and rich and poor can increase (Gupta et al., 2022). Future taxation of robots could also create the possibility of an unconditional basic income.

Lowenberg-DeBoer et al. (2019) state that about 5,000 works have been published and studied since 1991. In each of them, a scenario was found in which automation, specifically robotization is a profitable investment. All studies concern developed countries and many of the burning issues raised in these also appear in developing countries. Economic and social research is needed to understand the problems of developing countries in this area; farmers and researchers, as well as machine builders, often have differing views. As less and less human labour is needed, the "bigger is better" principle will no longer apply. In the traditional system machinery and equipment are owned by the farmer, while under the new economic conditions the farmer leases the machines or enters a contract to service them. Using a win-win strategy, profitable technologies can be applied with environmental and social benefits. With the development of sensor networks and software, human–robot cooperation will become smaller and smaller, the robot(s) will take over more and more tasks from humans by utilizing artificial intelligence.

Among the economic issues, it should be highlighted that robots increase production efficiency and productivity. Self-propelled transport vehicles (including trains) reduce the cost of transporting goods. For seasonal work (weed control, harvesting, etc.), including packaging goods, robots can play a significant role in reducing labour problems. The operation of robots on small farms can also be profitable, and at the same time environmentally friendly at a high level, as the IT service can be implemented on-line using cloud computing. Robots can also play a significant role in organic farming, especially in sectors that require significant manual labour.

THE IOT ECOSYSTEM AND THE INTERDISCIPLINARITY OF THE AGRO-, LANDSCAPE AND NATURAL ECOSYSTEM (IALNE)

By treating the three living disciplines (agriculture, landscape and natural ecosystem) as an ecological unit, the sustainability criteria can be effectively implemented. Obviously, priority should be given to the natural system. Both landscape and agro-ecology must be subordinate to natural ecology in order to minimize the volatility of the natural system, and preserve its functions and biodiversity.

According to the authors, the time has come for IoT to be involved in integration as a fourth subsystem. The question arises as to what can be used to relate a living system to a non-living one. The answer comes from nature, as similar information and communication networks operate in nature. Song et al. (2015) stated that adjacent trees exchange photosynthetic carbon through a mycorrhizal network. From this, it was concluded that there is also an exchange of information with this network, through which a forest can repair damage. The importance of the use of IoT is highlighted by Galle et al. (2019) in their discussion on the Internet of Nature system. This is primarily about urban ecology. They state that the IoT functions are in many ways like an information system for nature. Many issues still need to be clarified today in the area of communication between IoT and plants, e.g., the form in which the IoT can predict environmental insect attacks on plants.

In the future, the importance of plants used in biosensor research will increase (Manzella et al., 2013). At the same time IoT, as an additional subsystem, not only can participate in forecasting, but can also help understand the functions of all three ecosystems, both individually and as an integrated system at a much higher level than before.

DISCUSSION AND CONCLUSIONS

The article sought to show that IoT is a driving force for the global and local development of ICT and at the same time contributes to a social paradigm shift. The agricultural IoT is a perfect refutation of the traditional thinking in which the belief that the physical, biological, chemical, and social worlds (systems) should be considered separately. Through the IoT the network of these areas can be alternatively examined, for example, from the perspective of circular farming.

With the help of IoT we can get to know the natural and social processes around us in much more detail than before. Not only can the accuracy of diagnoses be increased, but also the responses to it with a more complex approach. It also contributes to the implementation of global ethics in the field of social change. In addition, it provides basic information for optimizing artificial intelligence and human interactions. At the same time, it facilitates the transition from the decision support role of artificial intelligence to decision-making.

One of the great advantages of IoT in agriculture is that it is possible to prepare for the events that come from further distances from a given area (e.g., insect pest invasion), using the data of the IoT station installed there.

The authors want to point out the importance of the integration of natural-, landscape-, and agro-ecological research. An important task is the synchronization of agricultural, landscape, and natural ecosystem management. The authors also tried to provide support for the formation of public attitudes. This article draws attention to the fact that the difference in living standards between rich and poor countries hinders global and local sustainable development. The paper proves that agricultural, landscape and natural ecosystem management can be integrated by IoT. IoT can be considered as the fourth additional subsystem. New perspectives are opening up as the symbiosis of IoT and living systems deepens. Both the living and the ICT systems learn from each other; therefore, the efficiency of communication grows.

We can state that a significant area of research from the point of view of sustainability is the drastic reduction in the use of synthetic chemicals and the increase in its efficiency or exclusion of them. This finding applies especially to weed control, where modern chemical-saving solutions only exist for large-scale operations (John Deer Blue River). At the same time, it is very important to reduce losses in post-harvest technologies (drying, storage, transport, etc.), especially in developing countries (Alam et al., 2018). These are basic expectations to be met for providing healthy food and drinking water supply to the estimated 9.8 billion earthborn by 2050 while considering ecological sustainability criteria.

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