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SCIENTIFIC PAPER

ASSESSING READINESS LEVELS OF PRODUCTION TECHNOLOGIES FOR SUSTAINABLE INTENSIFICATION OF AGRICULTURE

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Abstract: *The modern agricultural production is facing the problem of a growing society connected with the growing asking for food as well as different environmental threats. To solve this issue, agricultural production should be more sustainable and efficient which can be reached by using new technologies. In the paper the most important technologies, which were evaluated by different research methods to find how and when they could be used for a sustainable intensification of agriculture were highlighted by applying technology and market readiness models. By asking professionals from different fields of agriculture in practice as well as academia it was found that technologies that collect or utilize advanced data (sensors, drones) used for knowledge based management are more applicable for use, contrary to nanotechnologies where the costs of development and applications limits the readiness.*

Keywords: *Sustainability, Technology Readiness, Market Readiness, Poland, Germany*
(JEL Classification: *Q16*)

Introduction

Agriculture is a major area of human activity affecting both its safety and well-being and the environment in which it lives. It thus becomes the primary factor conditioning global changes. Agriculture should be treated as a complex system with inherent adaptive abilities (Maciejczak, 2017). The complexity of agriculture is the result of the interplay of its individual elements as well as the interconnections of elements throughout the system and between the system and its surroundings. Over the centuries the economic pressures have led to systemic domination of agriculture based on the mechanisms of commercialization, concentration, specialization, agrarian structural change and capital-intensive intensification. Such actions have led to the imbalance in both the natural and the social systems interacting with agriculture. Currently, agriculture is facing many problems, i.e. the need for the increase of food production by 60-110% by 2050 due to the population growth while ensuring at the same time the protection of the environment under the sustainability demand (Foley at al., 2005). In order to face these issues, the dominating concept of quantitative (solely economic) growth is being replaced by the approach of the development based on the qualitative - more sustainable nature. Tittonell postulates adaptation actions within the complex agricultural system, based on strategies for further intensification, however based on the sustainable assumptions (Tittonell, 2014). This could be induced in a number of different ways with only the two most effective ones being pointed out here. The first is called industrial intensification and aims to maintain the industrial path based on innovation in the technological and organizational sphere. The second named as agro-ecological intensification is focusing on the intensification of more targeted agro-ecosystems, the use of more production-friendly technologies that provide better harmonization of production and environmental objectives. The future prospect of modern industrialized agricultural systems is being challenged on several fronts because of its dependence on capital, external energy and agrochemical inputs, and for its adverse impact on biodiversity and on human health (Struik et al., 2014).

Regardless of the strategic options of sustainable intensification, this concept requires application of innovative technologies. Today agriculture is demanding technological solutions with the aim of increasing production or accurate inventories for sustainability while the environmental impact is minimized by reducing the application of agro-chemicals and increasing the use of environmental friendly agronomical practices. The technologies of modern agriculture are however in different stages of development and use. This significantly influences the dynamics of changes in agriculture. Therefore, the main objectives of the paper are threefold. Firstly, the paper aims to present, based on literature review, the needs and solutions for innovative technologies which are most promising for further development of modern model of sustainably intensive agriculture. However, due to the paper's limitations the discussion about the issues of the sustainability of the technologies will not be made. It is assumed that the selected technologies are sustainable based on the researches of other authors. Secondly, using the foresight approach, it aims to assess the technology and market readiness levels of selected technologies. Finally, based on experts' opinion, it will provide the recommendations for development and diffusion of the most perspective technologies. It is assumed that the more information for knowledge based management is collected by the technology the better its diffusion and use.

MATERIAL AND METHOD

This paper uses different methodologies selected to correspond best to the goals set. The investigations are based on primary and secondary data sources. Firstly, the literature review of scientific papers was performed. Using different key words, based on abstract review, there were selected 79 papers, which later, after full text analysis, were reduced to 17. Based on the review 10 most promising technologies were selected, 6 from crop production and 4 from animal production. The primary data comes from the Real-Time Delphi survey. The rationale for the choice of the foresight heuristic Delphi method was more the hypothetical then empirical impact of selected technologies for modern agriculture. There was used Real-Time Delphi approach (GRISHAM, 2009). Using a web-based tool a qualitative and quantitative survey was held. The questionnaire was open from 1st May 2017 to 31st August 2017. There were identified 10 experts from two countries: Poland and Germany. From each country participated 5 experts being: farmers, technology developers and traders, consumers, policy makers and academics. All experts were chosen deliberately because of their knowledge about agriculture and its technological advancement. However, due to the relatively limited number of the experts, their opinions and through results of the foresight study should be considered with appropriate reservation. There was a basic assumption about possible application and impact of assessed technology in mid-term perspective of 2025 having in mind the needs of sustainable development. Two scales of Technology Readiness Level (TRL) and Market Readiness Level (MRL) were applied. TRL enables the assessment of the maturity of a particular technology and the consistent comparison of maturity between different types of technologies. It is based on a scale from 1 to 9, with 9 being the most mature technology (EARTO, 2011). MRL enables the assessment of the readiness of technology for commercialisation and diffusion. It is based on a scale from 1 to 5, with 5 being the most marketable (AASRUD et al., 2010). To analyse linkages between TRL and MRL the rho-Spearman correlation test was used (PARLIŃSKA and PARLIŃSKI, 2011).

RESULTS AND DISCUSSION

Modernisation in agriculture is a very relative concept (ILO, 1991). It differs very much depending on the country, the region as well as on individual farm perspective. Many factors are associated with the progress made due to implementation of new techniques, technology or other innovative solutions. Therefore, for the purpose of this research, the framework for the concept of the modernization of agriculture will be established. The analysis is limited to the European perspective with the focus on developed farms which are considered as enterprises. For such farms, implementation of innovations, esp. in forms of new technologies is attached to the umbrella approach of precision agriculture. It is a farming management concept based on observing, measuring and responding to inter and intra-field variability in crops, or to aspects of animal rearing (TAKACS-GYORGY et al., 2014). The benefits to be obtained are chiefly due to increased yields and/or increased profitability of production to the farmer. Other benefits are better working conditions, increased animal welfare and the potential to improve various aspects of environmental stewardship. As stressed by (WEISS, 1996) the implementation of precision farming has become possible as a result of the development of innovative technologies i.e. sensors, or drones combined with procedures to link mapped variables to appropriate farming practices such as tillage, seeding, fertilization, herbicide and pesticide application, harvesting and animal husbandry. Subsequently, it is relying on automatic monitoring of individual animals and is used to monitor animal behaviour, welfare and productivity as well as their physical environment. Advances in nanotechnologies could also be implemented in a wide spectrum i.e. for health maintenance of both animals and plants. Nevertheless, one needs to remember that the adoption of this concept encounters specific challenges not only due to the size and diversity of farm structures but also due to the readiness of available technologies to meet high demands of technological, economic, social and environmental efficiency. The detailed literature review enabled us to distinguish 10 technologies that could contribute the most to the development of precision agriculture (table 1).

The Delphi results of the technological and market readiness levels of selected technologies (fig. 1 and fig. 2) showed for both perspectives similar results. Also, the calculated rho-Spearman correlation between TRL and MRL confirmed a strong correlation on the level of 0.933 ($r < 0.001$). It means that the market readiness is closely associated with the technological readiness. The more technology is prepared to be implemented on the market the more market is creating conditions for its release.

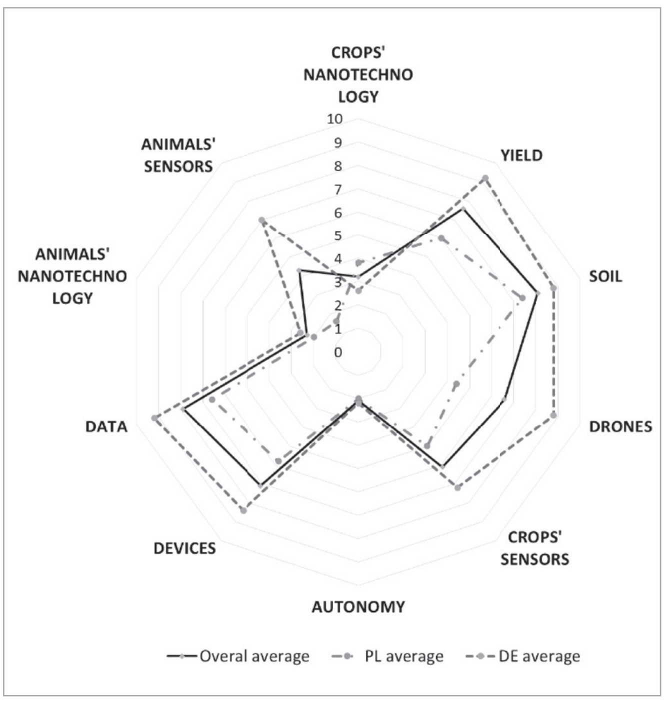
With this respect, the majority of experts agreed also on the importance of knowledge, which could be considered as a fourth dimension of market readiness (BOS et al., 2013). The farmers need to know how the technology works and what the benefits of its use are, not on experimental fields, but in other farms.

Table 1. Top 10 technologies of future sustainable agriculture – a literature review

Technology	Description	Authors
Crop production		
Nanotechnology	Use nanotechnology for disease control in crop production.	Fraceto et al., 2016, Kuzma & VerHage, 2006
Yield	Use all the data that is collected from guidance system to get an overview over your work and in- and output.	Takacs-Gyorgy et al., 2013, Francik, 2010
Soil mapping	Use tractor mounted sensors to get information about the nitrogen in the soil to control the fertilizer use.	Frewer et al. 2011, Sanders and Masri, 2016
Drones	Use drones to analyse e.g. the chlorophyll content of the crops to use fertilizer or pesticides more precisely.	Gozdowski et al., 2010, Dukaczewski and Bielecka, 2009
Sensors	Get more sensors connected through new and cheaper systems than SIM Cards.	Jensen et al., 2012, Ojha et al. 2015
Autonomy	Use fully autonomous tractors to reduce labour costs and work more efficiently.	Dukaczewski and Bielecka, 2009; Xiweia and Xiangdong, 2007
Animal production		
Devices	Use smart devices like electronic earmarks to get information about the position and health of animals.	English et al., 2013, Cupiał et al., 2015
Data	Use on-time software to get recent information about e.g. the feeding behaviour of your animals.	Tyler and Griffin, 2016, Cupiał et al., 2015
Nanotechnology	Use nanotechnology to make a more precise diagnoses as well as creating smart medicine.	Parisi et al., 2014, Głód et al., 2014
Sensors	Use more sensors to monitor and control different variables of the digestion and wellbeing of the animals.	Kopiński ,2014, Ojha et al., 2015

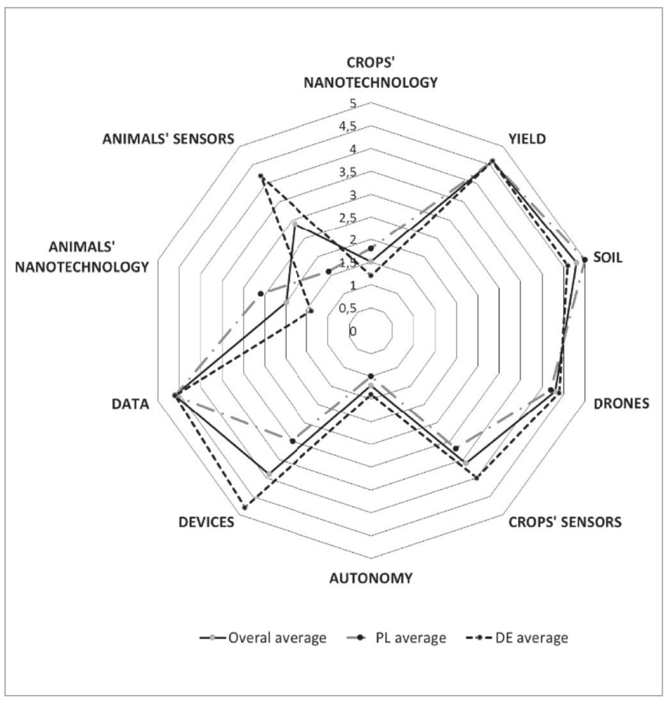
Source: own research results, 2017

Fig. 1. Technology Readiness Level of analysed technologies.



Source: own investigationreview

Fig. 2. Market Readiness Level of analysed technologies.



Source: own investigationreview

The analysis and evaluation of the different opinions of the experts showed that there are many similarities as well as differences in the way Polish and German experts are seeing the market and technology readiness of the chosen technologies. The average value for nanotechnology in crop production in terms of technology readiness was 3.2. This is a quite low value. The German experts saw an average TRL at 2.6 and the Polish experts at 3.8. The market readiness was on average also very low (1.5). With 1.8 the Polish experts were more optimistic with this technology while the German experts saw it at a low value of 1.2. The most common opinion was that nanotechnology in crop production is an interesting technology but application will need more time and a high investment. Some experts were not optimistic at all but this is often the case when talking about technologies of the far future. Nanotechnology in animal production seems to be again a technology that will be more interesting in far future. Thus, it gets low values of TRL (overall average 2.3, Germany 2.6 and Poland 2) and MRL (overall 2, Poland 2.6 and Germany 1.4). It is interesting that those values are lower than the values for Nanotechnology in crop production. The argumentation was in part the same, but it seems that the experts are more comfortable to use this technology with crops than with animals. Despite the numerous potential advantages of nanotechnology and the growing trends in publications and patents, agricultural applications have not yet made it to the market (Parisi et al., 2015). Several factors could explain the scarcity of commercial applications, i.e. agricultural nanotechnology does not demonstrate a sufficient economic return to counterbalance the high initial production investments (Chena and Yadab, 2011).

Collecting data from your guidance system is far readier in terms of technology and market readiness. With an overall average TRL of 7.6 and 9.2 in Germany and 6 in Poland and an average MRL of 4.6 in general, in Poland and Germany the technology is already adopted in those countries. From German experts, there were concerns about the user-friendliness of the product. In Poland, this technology is just used by big farms which means that there is some space for development. Beside data collection, soil analysis was also a technology that was ranked highly in terms of readiness levels. The average values for TRL were 8.1 overall, 7,4 for Poland and 8.8 for Germany. The values for MRL were 4.8 in general, 5 in Poland and 4.6 in Germany. This technology is also already adopted to the market and needs some improvements in terms of costs so that also small farmers can use it. As informed by some authors data collecting and analysis will form new dimension for decision making in agriculture (WANG et al., 2006). The big farms already benefit from the bid data approach and through contribute for sustainable intensification. Now the gravity point is moving towards smaller farms whom needs to see the direct benefits for the cost-effectiveness of their operations and risk reduction as well as for external benefits for the environment and society, i.e. reducing carbon emission.

Drones had average values more in the middle field (6.6). What was interesting is that the TRL for Germany (8.8) and Poland (4.4) were quite different. The same occurred for the MRL where the average for all was 4.1, for Poland 3.8 and for Germany 4.4. The German experts were still not happy about the costs. Furthermore, experts argued that the technology is not useful due to the fact that modern satellite pictures could bring the same information. The Polish experts were really sure that this technology will help to become more sustainable. Mazur showed that drone technology will give the agriculture industry a high-technology makeover, with planning and strategy based on real-time data gathering and processing (MAZUR, 2016). PwC estimates the market for drone-powered solutions in agriculture at over 30 billion USD. The show that thanks to robust investments and a somewhat more relaxed regulatory environment, it appears their time has arrived, especially in agriculture (PwC, 2016).

Sensors left also some room between both experts. In general, the TRL was 6,1 while the value in Germany was 7.2 and in Poland 5. The market readiness was in average 3.5 and in Poland 3 and Germany 4. The opinion of the Polish experts was really positive on that technology. The opinions of the German experts were also positive. One expert said that the technology will only be important if a farmer uses a completely automatic system. For sensors in animal production the average value for TRL was 4,3 while Germany was really high with 7 and Poland really low with 1.6. The MRL was in average 2.8 while in Poland 1.4 and in Germany 4.2. The Polish experts are seeing many problems in the difficulty of measuring the values. German experts were more optimistic, due to the fact that sensors are getting cheaper. One key of this technology is that the data should be made usable. One can agreed that sensors-based technologies provide appropriate tools to achieve the sustainability goals (Pajares et al. 2013). The explosive technological advances and development removed many barriers for their implementation, including the reservations expressed by the farmers themselves. Precision Agriculture is an emerging area where sensor-based technologies play an important role.

With autonomy in crop production, that last technology was a big topic of the future. The TRL in general was 2.1 in Germany 2.2 and in Poland 2. The MRL was low as well. In average, it was 1.4 in Germany 1 and in Poland 1. The biggest problem from German experts were the legal issues while the Polish experts argued more that autonomy will just be a topic of some niches. In animal production, the devices got an average TRL of 7.1. The value for Poland was 5.8 and the value for Germany 8.4. The MRL was 3.9 in average, 3 in Poland and 4.8 in Germany. Here you can see again big differences. The Polish and German concerns are that this technology is too expensive to be adopted. For data analyses in animal production the values of TRL are also different. In average, it is 7.9 while for Poland it is 6,6 and for Germany 9.2. The MRL is in both cases 4.6. In Germany, the technology should be better developed in terms of usability. The Polish doubts are connected with the farmers' knowledge for using this technology. The autonomous tractors were among the first autonomous vehicles by land, water or air but only now are they starting to be sold in volume (HARROP et al., 2017) showed. Current driverless tractor technologies build on recent developments in hybrid powertrains - more controllable and environmental - other autonomous vehicles and new agricultural technology. The idea of a versatile, programmable driverless tractor emerged in 2011 and 2012 out of "follow me" technology. It indicates that the capability to execute autonomous actions or doing this remotely enabling better decision making and actuation, not only at the production stages, but also throughout the whole value chain.

CONCLUSIONS

The conducted research confirmed that development of modern model of agriculture requires strategic options based on sustainability approach applied similarly and comprehensively on the intensification concept. This could be obtained and driven by the application of modern technologies. These technologies have a great potential to provide benefits of sustainable values. It was proved, however that the technologies that could bring these values are on different technological readiness and thus its market readiness is also different. The highest TRL and MRL results showed technologies that collect (i.e. sensors or drones) or use (soil or yield management systems) of data. The lowest results were obtained with very advanced technologies connected to nanomaterials. This suggest that for sustainable management of modern agriculture the more detailed data are needed and the more technology is fulfilling this requirement for knowledge building the bigger its readiness and diffusion. On other hand nanotechnologies, which development is very expensive are very promising, but in mid-term perspective they application due to the costs and efficiency is limited.

It needs to be pointed out that the technological development of agriculture, based on a number of technologies coming concurrently from outside the agricultural sector, such as global positioning systems, cloud computing, drones and the Internet of Things (IoT), under the sustainability framework, raises also significant legal and socio-ethical questions. These concern the terms of safeguarding sustainable agri-food production, the conditions under which farmer - related data are collected and processed and the role of the individual farmer. This requires further research as more technologies will be ready for commercial use in close future, that will make the significant difference for the future.

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