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PRECISION FARMING – CONCEPTS AND PERSPECTIVES

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Abstract

The development of technologies in the 20th century led to evolution of precision agriculture concept. Nowadays, precision farming is usually associated with the use of GPS and satellite navigation, GIS, unmanned airplanes and drones, variable rate of application, as well as complex and sophisticated computer systems and software. On the other hand, the main question is related to the profitability and efficiency of these technologies and the opportunities for their adoption. The main purpose of the research is to investigate the most popular concepts of precision farming and to analyze the technical and economic efficiency of different technologies based on literature review. The results indicate that the adoption of precision farming technologies is closely related to the farmer's perception of and needs for institutional support. The promotion of precision farming under the Common Agricultural Policy is necessary in order to overcome the number of economic and environmental challenges and ensure sustainable development and green growth.

Keywords: inter and intra-field variability, site specific management, innovative technologies and practices.

JEL codes: Q16, Q55, Q56.

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Introduction

Precision farming has been a term in agricultural science and practice for a long time. Since the first precision farming workshop organized in Minneapolis in 1992, it became the subject of numerous conferences. In Australia, precision agriculture symposium has been held since 1997. Precision farming was formally recognized as a definition and concept in the United States of America by the US Congress in 1997.

For better understanding of the evolution of precision agriculture over the years, it is necessary to note some essential features of the concept. In the past, when the predominant forms of organization were small scale family farms, it was possible for farmers to observe the spatial variability of soil and its effects on crop production. As a result they managed the crop yield based on the differences. Mechanization of agriculture was, as a consequence, applied to economical crop management in large areas with uniform use of inputs. A farmer, who currently cultivates larger areas with uniform management, uses less agronomic information than 10 farmers who previously cultivated the same area. The development of the Global Positioning System (GPS) made possible to reverse the process. The implementation of GPS combined with special equipment capable of measuring the variability and application of inputs (fertilizers, herbicides) is essential for precision agriculture development.

The right agro techniques, crop varieties and rotation, chemical and fertilizer inputs, variation of conditions between fields and on one field, as well as crop monitoring, etc. allow the farmer to obtain high yields, minimize inputs and optimize profits.

The main objective of the study is to investigate the most popular concepts of precision farming and to analyse the technical and economic efficiency of different technologies based on the literature review.

The paper is structured as follows: first part analyses different definitions and concepts of precision farming. Second part presents the major components of precision agriculture. The third part presents economic studies related to the topic. Finally, the last part draws some conclusions and gives some recommendations.

Material and methods

The report summarizes precision farming definitions and observes the main concepts, technologies based on the results from various studies, documents, strategies. The study does not claim to be detailed and exhaustive but could be a starting point for conclusions and a prerequisite for further findings and measurements. The survey applies historical, comparative, monographic methods of analysis. This study uses the method designed by Knowler and Bradshaw (2007), providing the research stages step by step. Although the method does not involve statistical procedures, it is sufficient for fulfilling the objectives of this paper.

Results and discussions

Concept and definitions

Prior to the industrial revolution, small fields were typical for agriculture. In the past, farmers had a detailed knowledge of their production system without actually quantifying the variability. The mechanization and pressure for greater profit, caused domination of large-scale uniform, average agricultural practices. The advance of technology in the late 20th and early 21st centuries, allowed agriculture to develop. Nowadays, on agricultural market, when the profitability is getting lower, farmers look for technologies that minimize costs without reducing production.

Precision agriculture is a concept based upon observing, measuring and responding to field variability in crops or in aspects of animal rearing. The first official definition of precision agriculture came from the US House of Representatives in 1997, which identified precision agriculture as "an integrated information- and production-based farming system that is designed to increase long-term, site-specific and whole farm production efficiency, productivity and profitability while minimizing unintended impacts on wildlife and the environment" (US House of Representatives, 1997, Bill No. H.R.2534). This definition emphasizes management strategy using information technology and highlighting the improvements on production while reducing environmental impacts. It is important to mention that precision agriculture could be implemented not only to cropping systems, but also to animal industries, fisheries, forestry.

The definition presented by the US Congress noted that precision agriculture is an evolving management strategy. Its main feature is decision making with regard to resource-use and not necessarily the adoption of information technology. The decisions could depend on changes on one field at a certain time in the season or changes over a season or seasons. Better solutions could provide many benefits (economic, environmental and social) that may or may not be known at present.

There are many other definitions of precision agriculture which depend on the different ideas of what the term should encompass. Some definitions focus on the strategic nature of precision farming: its ability to obtain data and convert it into information for the future decision making (Lowenberg-DeBoer and Boehlje, 1996). Other definitions concentrate on precision agriculture as a production system and management adaptation (McBratney, Bouma, Whelan and Ancev, 2005; Seelan, Laguette, Casady and Seielstad, 2003; van Meirvenne, 2003; Nemenyi, Mesterhazi, Pecze and Stepan, 2003; Cook and Bramley, 1998; Cook, Corner, Riethmuller, Mussel and Maitland, 1996). Some authors observe precision agriculture in a wider context and define the term as a philosophical shift in management. The main purpose of precision farming is to optimize long-term, site-specific and whole-farm productivity, and to minimize impacts on the environment (Whelan and McBratney, 2000, 2001).

In some studies precision farming is defined as an information technology applied to agriculture (Lowenberg-DeBoer and Boehlje, 1996). This definition is wider than the others, because it observed the potential benefits of precision farming that may extend beyond the farm-gate. They include also product tracking, quality monitoring and environmental performance measuring (McBratney et al., 2005).

Among others, the simplest description of precision agriculture is a way to "apply the right treatment in the right place at the right time" (Gebbers and Adamchuk, 2010, p. 829).

Precision agriculture and the application of information technologies, together with production experience could lead to: optimization of production efficiency and quality; minimization of environmental impact and risk.

In recent years, precision farming is evolving and today is defined as "an environment friendly system solution that optimizes product quality and quantity while minimizing cost, human intervention and the variation caused by unpredictable nature" (Gebbers and Adamchuk, 2010). These definitions of precision farming include terms related to risk, environmental effects and degradation, as significant issues in the 21st century. Precision agriculture becomes a management practice of increasing interest because it links to key drivers directly related to worldwide issues such as sustainable agriculture and food security (Gebbers and Adamchuk, 2010).

Precision agriculture involves the application of technologies and agronomic principles to manage spatial and temporal variation associated with all aspects of agricultural production in order to improve crop performance, optimizing returns on inputs, and environmental quality, reducing environmental impacts (Rees, Griffiths and McVittie, 2018; Garibaldi et al., 2017). In addition, European Commission (2016) reports the following benefits from precision farming: increased production, real time data and production information, better quality, improved livestock health and lowered production cost.

Precision farming is an innovative approach which implements technologies in order to reduce cost, risk and increase productivity, profitability and maintain sustainability.

Precision farming main components

The basic technology that led to the development of the concept of precision farming was the creation of the GPS system by the US Department of Defense in the late 1970s. GPS has the ability to determine the exact location, 24 hours a day, to within a few centimetres. This information could make field processing with great localization accuracy.

The implementation of precision agriculture is possible thanks to the evolution of sensor technologies that could be combined with procedures link mapped variables to appropriate farming management actions such as cultivation, seeding, fertilization, herbicide application, and harvesting.

The progress of precision farming is made in parallel with the rapid development and improved accuracy of the Global Navigation Satellite System (GNSS) since 1999. In fact, GNSS technology is widely used in many farms to perform tasks related to automatic control systems and use of geo-reference information. GNSS helps to the improvement machinery guidance, automatic control and controlled Traffic Management Systems.

Another significant component of precision farming is the use of Variable Rate Technology (VRT) which allows for precise seeding, planting optimization, density and improved application rate, efficiency of herbicides, pesticides and nutrients. As a result, reduced costs and environmental impacts could be achieved.

Recognizing different wave lengths multi-spectral and hyperspectral cameras on board and satellite platforms are often intended to provide information on vegetation indices, for example, monitoring for chlorophyll content, stress level and their variation in space and time data. Special attention is paid to the use of low-cost unmanned aerial vehicles (UAV), often called drones, but now more correctly termed remotely piloted aerial systems (RPAS), originally developed for military purposes.

Digital technologies could support European farmers to "achieve more with less". They also hold the promise to address current and future challenges, from climate change, responsible use of scarce natural resources, to food security. Existing and new technologies such as the Internet of Things, artificial intelligence, robotics and big data can contribute to making processes more efficient and can lead to the creation of new products and services.

Important part of the precision farming technologies is the farmer and his perceptions. This process started in the early 1990s by the best-oriented farmers with enthusiasm, followed by discouragement due to the lack of support and the relatively low profitability. The adoption of this approach is currently based almost entirely on the private sector, offering farmers, devices, products and services. Unfortunately national advisory services in the agriculture are very limited (Hristov, 2011).

Economic studies

The different definitions and studies concluded that better decision making in agriculture should provide a wide range of benefits. From the economic point of view, a review of 234 studies published from 1988 to 2005 showed that precision agriculture was found to be profitable in an average of 68% of the cases (Griffin, Lambert and Lowenberg-DeBoer, 2005).

According to the European Commission (2014) the benefits from precision farming are related to: crop yield improvements; optimization of inputs; and improvement of the management and quality of the work.

Weiss (1996) registers several benefits of precision farming – increased crop yields, applying inputs and minimizing cost through improved process control and reducing relocation of agrochemicals to the environment.

Swinton and Ahmad (1996) classified benefits into: those that affect profitability; those that affect business risk; those that affect environmental quality. Profitability depends on the extent of spatial variability of soil conditions, the size of a field and uncertainty about output and input prices (Murat and Madhu, 2003). The increased income from improved yields combined with improved input control could give gross margin benefits within seasons (Swinton and Ahmad, 1996).

The profitability of precision agriculture is a crucial factor for implementation of these farming technologies. Studies by Swinton and Lowenberg-DeBoer (1998) highlighted that determining the profitability is the most significant driver for precision farming adoption by farmers. However, the economic studies related to the profitability are unclear and not comparable (Bullock and Lowenberg-DeBoer, 2007). According to the European Commission (2014), economic studies related to the precision farming based on technologies implemented could be grouped into: VRT, Sensor-based pest management, Automatic guidance systems.

The most common precision agriculture technology is the yields monitor (Lowenberg-De Boer, 2003). The "yield monitor" has been one of the first information driven technology concepts in precision agriculture (Swinton and Lowenberg-DeBoer, 1998). The economic results of the adoption of variable rate application methods depend on the type of crop, field size and type of agriculture.

Economic studies of precision fertilizer management are based on farmers' expert assessment, trials and site-specific fertilizer response functions. Bauer and Linsley (cited by Goering, 1993), suggested soil sampling in order to determine the need for differential application of lime. As a result, some farmers reduced more than 40% of production costs with differentiated application of input. In his first work on spatial variability of crop yields, which was substantial for precision farming development as a concept, Smith, Goodman and Stuber (1985) presented a wheat crop map of Australia.

Other studies were related to spatially variable herbicide application (Miller and Stafford, 1993) or dynamic sensing of soil organic matter (Price and Hummel, 1994) and yield mapping (Vansichen and de Baerdemaeker, 1991; Searcy, Schueller, Bae, Borgelt and Stout, 1989; Stafford, Ambler and Smith, 1991).

Some authors (Anselin, Bongiovanni and Lowenberg-DeBoer, 2004; Meyer-Aurich, Gandorfer and Heißenhuber, 2008; Meyer-Aurich, Weersink, Gandorfer and Wagner, 2010) concluded that the economic gross advantage of site-specific management of nitrogen fertilizer depends on the type of sensor used and size of the field, with improvements on N efficiency by 10-15% when reducing the application, without impact on crop yield. The economic assessment suggested that the size of the field needed to be greater than 250 ha to obtain financial benefits.

On the other hand, studies in Denmark showed no economic effect of sensor-based fertilizer redistribution on the field according to high and low yield zones (Oleson et al., 2004). Potential explanations of the small benefits may be the slope of the profit function around the economic optimum (Pannell, 2006), perhaps due to the fact that the application rate is already near the optimum, therefore VR only has a marginal effect. Early economic papers in the US, from Lowenberg DeBoer and Boehjle (1996), also concluded that once the full cost of developing and implementing variable rate fertilizers is considered, it is unprofitable, especially if application was restricted to one or two fertilizers.

Precision irrigation and precision nitrogen fertilization are widely seen as an excellent method to save water and fertilizer and maximize yield (Zhao et al., 2017). On the other hand, several authors (Adeyemi, Grove, Peets and Norton, 2017; West and Kovacs, 2017) showed that the use of these technologies alone are not sufficient to increase the efficiency of the entire production process.

Variable-rate lime application could increase annual return based on a study using simulation models for soybean and corn (Bongiovanni and Lowenberg-DeBoer, 2000) in the U.S. and Canada.

Godwin, Wood, Taylor, Knight and Welsh (2003) analysed the potential for precision farming for cereal production in Great Britain. The study looked at several precision farming systems and determined the profitability and the optimal farm sizes, using a partial budget approach. According to this paper the cost of precision farming methods depend on the technology, depreciation and current interest rates, and the harvest area.

Based on the analysed studies it could be concluded that economic margins of precision fertilizer applications increase with increasing fertilizer and crop prices. High-value crops, could be achieved with higher profitability with the implementation of VR technologies.

Other important component of precision agriculture, the pest-specific management has economic and environmental effects. In specific studies, it was reported that the variable rate spraying by sensor controlled technology reduced insecticide use by 13% on average while maintaining the biodiversity on agricultural fields (Dammer and Adamek, 2012). Considerable savings occur with fuel, seed, chemical and fertilizer. Some studies show that precision farming methods could reduce the usage of fertilizers, seed and spray use by 4% for a given yield (Rainbow, 2004).

Automatic guidance systems have also developed in the last decades across the globe. The minimum area required for light bar systems to recover the capital cost is 100 to 130 ha, while for an automatic guidance system this rises to 300 to 450 ha (Frank, Gandorfer and Noack, 2008; Heege, 2013).

The economic benefits of guiding systems in the UK were estimated for a 500 ha farm (Knight, Miller and Orson, 2009), but the benefits grow if other more complex systems are adopted, such as controlled traffic farming.

In Germany, economic benefits due to savings of inputs were assessed for the case of winter wheat. The benefits of automatic guiding systems are associated with reducing the cost of inputs, but also on the higher yields and improved soil structure from the reduced area of compaction. Other benefits important for the farmer are the work speed, work comfort and ability to extend the working hours on the field.

An innovative method is the automatic section control, which uses geo-referencing data from a GNSS device to control section. The implementation of this method provides economic advantages due to input savings (Shockley, Dillon, Stombaugh and Shearer, 2012). If an auto-guidance system is already installed the economic advantage of the automatic section control is even higher.

Several research and studies concentrate on specific agricultural sector – wine production in France (Mazzetto, Calcante, Mena and Vercesi, 2010), Spain, and Italy (Borgogno Mondino and Gajetti, 2017); olives localized in the Mediterranean areas. According to van Evert, Gaitán-Cremaschi, Fountas and Kempenaar (2017), a site-specific management in olive orchards is leading to an increase in productivity and product quality. In addition, Nawaz and Ahmad (2015) and Choudhary et al.

(2018), report that precision agriculture technologies could be integrated in a novel approach which leads to acceptable profits together with sustained production levels while concurrently conserving the environment.

McBratney et al. (2005) supposed that the existing researches about precision farming are not focused on the whole farm management. More than 90% of the studies observed the single fields on experimental farms or commercial farms. According to McBratney et al. (2005) the biggest deficiency of precision farming method is a well-constructed quantitative formulation of optimization criteria for cropping management that includes environmental impact.

Precision farming could provide a management approach optimizing both agricultural production and profitability (European Commission, 2014). The increased profitably could be related to the reduction of inputs which reflects the production cost.

Precision agriculture included also some benefits for social and working conditions. For example, auto-steer systems are available for a variety of tractor models making the work less fatiguing. As well, the evolution of precision dairy farming technologies provide tremendous opportunities to improve delivery of automatic individual cow management applications and thus reduce labour requirements such as milking two times per day, and there are also arguments of increased animal welfare (Atanasov and Popova, 2010).

The other very significant benefit of precision farming is the environmental effects. Soil and water quality benefits could result from decreased or precise application of inputs such as nutrients, pesticides, and irrigation water (Bongiovanni and Lowenberg-DeBoer, 2004).

On the other hand, the environmental effects of precision farming have been little assessed with no quantified figures available (European Commission, 2014). The benefits of higher profitability could be easily calculated and seen. By contrast, it could take years for environmental effects to appear and to be investigated. Therefore, new surveys related to this field are recommended.

In parallel with the adoption of precision farming, there are a number of constrains that make difficult the implementation of the method. Some of them are related to cultural perceptions of farmers and lack of expertise and knowledge, while others are associated with the higher star-up cost and risk and uncertainty of the investment. There are some challenges with the public support and the need of special services and education.

Promoting precision agriculture through the CAP is a really important step toward green and sustainable development of agriculture. On the other hand, the measures should be effective and well targeted. Therefore, further analysis is necessary to focus on potential benefits and the specific agricultural sectors or farm practices.

From the three of the EU Space Programmes, which will support the agriculture sector the most important role will be played by COPERNICUS, which gives access to information relevant for understanding climate change, water management and biomass. The new EU COPERNICUS programme 2014-2020 should provide easier and cost-free access to satellite data but only at 10m or lower resolution.

The LEADER approach is direct reflection of changes in Common Agricultural Policy (Shishkova, 2017) and also supports precision farming.

Galileo and EGNOS (which strengthen the signal of the US GPS system) on the other hand will have heavy impact on the precision farming giving the opportunity of significant reduction of resources and labour.

The EU has strong commitments involving the implementation of the PA systems, which must deliver in near future the accessibility for larger number of farmers of all levels. Population of the Planet has larger needs of food supplementation, which is in direct challenge with lowering levels of natural resources. The common policy of the EU is to introduce, provide access to and create a positive environment for all farmers to be part of the PA schemes. This will happen with the implementation and development of a system for integration the technical progress, but will also need some sufficient funding in order to educate and translate the benefits to all farms and give access and financial support for adoption of these systems.

Conclusions

Based on the analysis some conclusions could be drawn:

- Precision farming is an emerging concept, which develops rapidly in the past two decades. There are various definitions by different authors that represent particular dimensions of the term.
- Precision farming could be an answer to a lot of challenges associated with the climate change and environmental protection. Precision agriculture could increase the quantity and quality of agricultural output while using less input.
- On the other hand, the economic studies in the field are not comparable and the specific environmental effects of precision farming are little documented.
- There are still many raising questions related to the adoption of the techniques. The need of special skill, the investment cost and low profitability, lack of support and advisory services are obscuring the process in many countries in the EU.
- In the EU there is a need of special schemes and measures in order to implement precision agriculture in all sectors and farm types.

References

Adeyemi, O., Grove, I., Peets, S., Norton, T. (2017). Advanced monitoring and management systems for improving sustainability in precision irrigation. *Sustainability*, 9(3), 353. DOI: 10.3390/su9030479.

Anselin, L., Bongiovanni, R., Lowenberg-DeBoer, J. (2004). A spatial econometric approach to the economics of site-specific nitrogen management in corn production. *American Journal of Agricultural Economics 86*(3), pp. 675-687. DOI: 10.1111/j.0002-9092.2004.00610.x.

Atanasov, D., Popova, B. (2010). Sustainable development characteristics of different dairy farms in Bulgaria. *Trakia Journal of Science*, Vol. 8, Suplement 1, pp. 245-253.

Bongiovanni, R., Lowenberg-DeBoer, J. (2000). Economics of Variable Rate Lime in Indiana. *Precision Agriculture 2*(1), pp. 55-70.

Bongiovanni, R., Lowenberg-DeBoer, J. (2004). Precision agriculture and sustainability. *Precision Agriculture*, 5, pp. 359-87.

Borgogno Mondino, E., Gajetti, M. (2017). Preliminary considerations about costs and potential market of remote sensing from UAV in the Italian viticulture context. *European Journal of Remote Sensing*, 50(1), pp. 310-319.

Bullock, D., Lowenberg-DeBoer, J. (2007). Using Spatial Analysis to Study the Values of Variable Rate Technology and Information”. *Journal of Agricultural Economics, 58*(3), pp. 517-535.

Choudhary, K.M., Jat, H.S., Nandal, D.P., Bishnoi, D.K., Sutaliya, J.M., Choudhary, M., Yadvinder-Singh, Sharma, P.C., Jat, M.L. (2018). Evaluating alternatives to rice-wheat system in western Indo-Gangetic Plains: Crop yields, water productivity and economic profitability. *Field Crops Research*, 218, pp. 1-10. DOI: 10.1016/j.fcr.2017.12.023.

Cook, S., Bramley, R. (1998). Precision agriculture – opportunities, benefits and pitfalls of sit--specific crop management in Australia. *Australian Journal of Experimental Agriculture*, vol. 38, pp. 753-763.

Cook, S., Corner, R.J., Riethmuller, G., Mussel, G., Maitland, M.D. (1996). *Precision Agriculture and risk analysis: An Australian Example*. Proceedings of the 3rd International Conference on Precision Agriculture ed. P.C. Robert, R.H. Rust and W.F. Larson, pp. 1123-1132.

Dammer, K., Adamek, R. (2012). Sensor-Based Insecticide Spraying to Control Cereal Aphids and Preserve Lady Beetles, *Agron. J. 104*(6), pp. 1694-1701.

European Commission (2014). Precision agriculture – An opportunity for EU farmers – Potential support with the CAP 2014-2020. European Union, 2014.

European Commission (2016). The Internet of Things. Digital Agenda for Europe. European Commission.

Frank, H., Gandorfer, M., Noack, P.O. (2008). *Ökonomische Bewertung von Parallelfahrsystemen*. GIL-Jahrestagung in Kiel, pp. 47-50.

Garibaldi, L., Gemmill-Herren, B., D’Annolfo, R., Graeub, B.E., Cunningham, S.A., Breeze, T.D. (2017). Farming approaches for greater biodiversity, livelihoods, and food security. *Trends in ecology & evolution, 32*(1), pp. 68-80. DOI: 10.1016/j.tree.2016.10.001.

Gebbers, R., Adamchuk, V. (2010). Precision Agriculture and Food Security. *Science*, Vol. 327, No. 5967, pp. 828-831, DOI: 10.1126/science.1183899.

Godwin, R.J., Wood, G.A., Taylor, J.C., Knight, S.M., Welsh, J.P. (2003). Precision Farming of Cereal Crops: a Review of a Six Year Experiment to develop Management Guidelines. *Biosystems Engineering, vol. 84*(4), pp. 375-391.

Goering, C. (1993). Recycling a concept. *Agricultural Engineering*, November, p. 25.

Griffin, T., Lambert, D., Lowenberg-DeBoer, J. (2005). Economics of Lightbar and Auto – Guidance GPS Navigation Technologies, in Precision Agriculture '05. J.V. Stafford, ed. Wageningen Academic Publishers, Wageningen, Netherlands.

Heege, H. (ed.). (2013). *Precision in crop farming*. Dordrecht: Springer.

Hristov, K. (2011). Institutional problems small farms face when applying for assistance under the rural development program 2007-2013. *Trakia Journal of Sciences*, Vol. 9, Suppl. 3, pp. 83-87, ISSN 1313-7069, ISSN 1313-3551.

Knight, S., Miller, P., Orson, J. (2009). An up-to-date cost/benefit analysis of precision farming techniques to guide growers of cereals and oilseeds. *HGCA Research Review*, No. 71, pp. 115.

Knowler, D., Bradshaw, B. (2007). Farmers' adoption of conservation agriculture: A review And synthesis of recent research. *Food Policy, 32*(1), pp. 25-48.

Linsley, C., Bauer, F. (1929). *Illinois Agricultural Experiment Station*. Circular 346.

Lowenberg DeBoer, J., Boehjle, M. (1996). *Revolution, Evolution or Dead End: Economic perspectives on precision agriculture*. In: P. Robert et.al, Precision agriculture, proceeding of the 3rd International Conference on Precision agriculture, 1996, Madison, WI, USA.

Lowenberg-DeBoer, J. (1996). Precision Farming and the New Information Technology: Implications for Farm Management, Policy, and Research: Discussion. *American Journal of Agricultural Economics, vol. 78*(5), pp. 1281-1284.

Lowenberg-DeBoer, J. (2003). *Precision farming or convenience agriculture*. In: Australian Agronomy Conference, 11, 2003, Geelong, Victoria. Solutions for better environment: proceedings. Geelong, Victoria: Australian Society of Agronomy.

Mazzetto, F., Calcante, A., Mena, A., Vercesi, A. (2010). Integration of optical and analogue sensors for monitoring canopy health and vigour in precision viticulture. *Precision Agriculture, 11*(6), pp. 636-649.

McBratney, A., Bouma, J., Whelan, B., Ancev, T. (2005). Future directions of Precision Agriculture. *Precision Agriculture, vol. 6*(1), pp. 7-23.

McBratney, A., Whelan, B. (1999). *The "null hypothesis" of precision agriculture. Precision Agriculture '99* (Part 2). Ed. J.V. Stafford, Proceedings of the 2nd European Conference on Precision Agriculture, Odense Congress Centre, Denmark, 11-15 July 1999, pp. 947-957.

Meyer-Aurich, A., Gandorfer, M., Heißenhuber, A. (2008). Economic analysis of precision farming technologies at the farm level: Two German case studies, In" O.W. Castalonge, *Agricultural Systems: Economics, Technology, and Diversity*. Hauppage NY, USA: Nova Science Publishers, pp. 67-76.

Meyer-Aurich, A., Weersink, A., Gandorfer, M., Wagner, P. (2010). Optimal site-specific fertilization and harvesting strategies with respect to crop yield and quality response to nitrogen. *Agricultural Systems 103*(7), pp. 478-485. DOI: 10.1016/j.agsy.2010.05.001.

Miller P.; Stafford J. (1993). Spatially selective application of herbicide to cereal crops. *Computers and Electronics in Agriculture, 9*(3), pp. 217-229.

Murat, I., Madhu, K. (2003). Stochastic Technology, Risk Preferences, and Adoption of Site-Specific Technologies. *American Journal of Agricultural Economics, vol. 85*(2), pp. 305-317.

Nawaz, A., Ahmad, J. (2015). Insect pest management in conservation agriculture. In: *Conservation agriculture* (pp. 133-155). Cham: Springer.

Nemenyi, M., Mesterhazi, P., Pecze, Z., Stepan, Z. (2003). The role of GIS and GPS in precision farming. *Computers and Electronics in Agriculture*, vol. 40, pp. 45-55.

Oleson, J., Sørensen, P., Thomsen, I.K., Eriksen, J., Thomsen, A.G., Berntsen, J. (2004). Integrated Nitrogen input systems in Denmark In: Mosier, A.R., Syers, J.K., Freney, J.R., *Agriculture and the nitrogen cycle*. Washington, Covelo, London: Island press, pp. 129-140.

Pannell, D. (2006). Flat earth economics: The far-reaching consequences of flat payoff functions in economic decision making. *Review of Agricultural Economics*, 28, pp. 553-566.

Price, R., Hummel, J. (1994). *Soil organic matter content prediction using visible and near infrared wavelengths.* Paper No. 94 – 1056. St Joseph, MI, USA: American Society of Agricultural Engineers.

Rainbow, R. (2004). *Getting into Precision Agriculture – The Basics*. Precision AgNews Winter and Southern Precision Agriculture Association. 2nd June 2006.

Rees, R.M., Griffiths, B.S., McVittie, A. (2018). Sustainable Intensification of Agriculture: Impacts on Sustainable Soil Management. In: Ginzky, H., Dooley, E., Heuser, I., Kasimbazi, E., Markus, T., Qin, T. (eds.). *International Yearbook of Soil Law and Policy*, vol. 2017. Cham: Springer.

Shockley, J., Dillon, C.R., Stombaugh, T., Shearer, S. (2012). Whole farm analysis of automatic section control for agricultural machinery. *Precision Agriculture*, Vol. 13, Issue 4, pp. 411-420.

Searcy, S., Schueller, J., Bae, Y., Borgelt, S., Stout, B. (1989). Mapping of spatially variable yield during grain combining. *Transactions of the American Society of Agricultural Engineers, 32*(3), pp. 826-829.

Seelan, S., Laguette, S., Casady, G., Seielstad, G. (2003). Remote sensing applications for precision agriculture: A learning community approach. *Remo Sensing of Environment, vol. 88*(1), pp. 157-169.

Shishkova, M. (2017). Social Network Analysis of the Organizations Implementing Leader Approach in Bulgaria. *Bulgarian Journal of Agricultural Economics and Management,* Vol. 3, pp. 35-39.

Smith, J., Goodman, M., Stuber, C. (1985). Genetic variability within U.S. maize germplasm. I. Historically important lines. *Crop Science*, 25: pp. 550-555.

Stafford, J., Ambler, B. (1994). In-field location using GPS for spatially variable field operations. *Computers and Electronics in Agriculture*, 11, pp. 23-36.

Stafford, J., Ambler, B., Smith, M. (1991). *Sensing and mapping grain yield variation*. Proceedings of Symposium & Automated Agriculture for the 21st Century, pp. 356-365. St Joseph, MI, USA: American Society of Agricultural Engineers.

Swinton, S., Ahmad, M. (1996). *Returns to Farmer Investment in Precision Agriculture Equipment and Services*. Proceedings of the 3rd International Conference on Precision Agriculture, ed. P.C. Robert, R.H. Rust and W.F. Larson, pp. 1009-1018.

Swinton, S., Lowenberg-DeBoer, J. (1998). Evaluating the Profitability of Site Specific Farming. *Journal of Production Agriculture*, 11, pp. 439-446.

US House of Representatives (1997). Bill No. H.R.2534. An Act to reform, extend and repeal certain agricultural research, extension and education programs and for other purposes. Title IV – New research, extension and education initiatives. Subtitle B – Precision Agriculture. Retrieved from: http://thomas.loc.gov/cgi-bin/query/z?c105:H.R.2534.

Van Evert, F., Gaitán-Cremaschi, D., Fountas, S, Kempenaar, C. (2017). Can Precision Agriculture Increase the Profitability and Sustainability of the Production of Potatoes and Olives? *Sustainability, 9*(10), 1863. DOI: 10.3390/su9101863.

Van Meirvenne, M. (2003). Is the Soil Variability within the Small Fields of Flanders Structured Enough to Allow Precision Agriculture?”. *Precision Agriculture, vol. 4*(2), pp. 193-201.

Vansichen, R., de Baerdemaeker, J. (1991). *Continuous wheat yield measurement on a combine.* Proceedings of Symposium &Automated Agriculture for the 21st Century, pp. 346-355. St Joseph, MI, USA: American Society of Agricultural Engineers.

Weiss, M. (1996). Precision farming and spatial economic analysis: Research challenges and opportunities. *American Journal of Agricultural and Applied Economics*, vol. 78, pp. 1275-1280.

West, G., Kovacs, K. (2017). Addressing Groundwater Declines with Precision Agriculture: An Economic Comparison of Monitoring Methods for Variable-Rate Irrigation. *Water, 9*(1), pp. 28.

Whelan, B., McBratney, A. (2000). The "Null Hypothesis" of Precision Agriculture Management. *Precision Agriculture 2*(3): pp. 265-279(15).

Whelan, B., McBratney, A. (2001). *Precision agriculture in Leading Edge (included in Australian Grain), vol. 11*(4), pp. 46-48.

Zhao, B., Ata-Ul-Karim, S.T., Liu, Z., Ning, D., Xiao, J., Liu, Z., Qin, A., Nan, J., Duan, A. (2017). Development of a critical nitrogen dilution curve based on leaf dry matter for summer maize. *Field Crops Research*, No. 208, pp. 60-68. DOI: 10.1016/j.fcr.2017.03.010.

ROLNICTWO PRECYZYJNE – KONCEPCJE I PERSPEKTYWY

Abstrakt

Rozwój technologii w XX wieku doprowadził do ewolucji koncepcji rolnictwa precyzyjnego. Obecnie rolnictwo precyzyjne jest zwykle związane z wykorzystaniem nawigacji GPS i satelitarnej GNSS, GIS, bezzałogowych samolotów i dronów, zmienności dawkowania, a także złożonych i wyszukanych systemów komputerowych i oprogramowania. Jednakże najważniejsze pytanie dotyczy opłacalności i skuteczności tych technologii oraz możliwości ich przyjęcia. Głównym celem pracy jest badanie najpopularniejszych koncepcji rolnictwa precyzyjnego oraz przeanalizowanie technicznej i ekonomicznej skuteczności różnych technologii w oparciu o przegląd literatury. Wyniki wskazują, że przyjęcie technologii rolnictwa precyzyjnego jest ściśle związane ze sposobem ich postrzegania przez rolnika i wymaga wsparcia instytucjonalnego. Promowanie rolnictwa precyzyjnego w ramach wspólnej polityki rolnej jest konieczne w celu przezwyciężenia szeregu wyzwań gospodarczych i środowiskowych oraz zapewnienia zrównoważonego rozwoju i ekologicznego wzrostu.

Słowa kluczowe: różnorodność warunków między polami i w obrębie jednego pola, gospodarowanie specyficzne dla obszaru, innowacyjne technologie i praktyki.

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