When accuracy of measurements matter: economic profitability from precision agriculture

Giorgia Bucci
Department of Agricultural, Food and Environmental (D3A)
Marche Polytechnic University
Ancona, Italy
g.bucci@pm.univpm.it

Deborah Bentivoglio
Department of Agricultural, Food and Environmental (D3A)
Marche Polytechnic University
Ancona, Italy
d.bentivoglio@univpm.it

Matteo Belletti
Department of Agricultural, Food and Environmental (D3A)
Marche Polytechnic University
Ancona, Italy
m.belletti@univpm.it

Adele Finco
Department of Agricultural, Food and Environmental (D3A)
Marche Polytechnic University
Ancona, Italy
a.finco@univpm.it

Abstract **-** Starting from 1980s, Precision Agriculture (PA) has established itself as a modern farming management using digital techniques to monitor and optimize agricultural production processes. However, the debate about the relative magnitude of benefits and costs of PA technologies on individual farms is still going on. The profitability of precision agriculture depends on part of the spatial and temporal variability of the soil and on the other hand on the accuracy with which the measurements are made. On this premise, the present paper aims, firstly, to review the state of art of the economic profitability of PA, in relation to the technology adopted. Secondly to explore how Precision Agriculture Technologies could affect the productivity of a representative farm specialized in arable crop production. This study confirms the positive effect related to the application of Precision Agriculture Technologies (PATs).

Keywords - Precision Agriculture, Measurement; Standard economic analysis; profitability, Case study

I. Introduction

Defined by Leonard (2016) [1], as a means of producing on-site data to guide decision making, Precision Agriculture (PA) is a farm management approach which allows to manage the growing of crops for better yield and quality, through the measurement of physical parameters and collection of data. Starting from the 1990s, several definitions of PA have been given in the literature [2,3,4,5,6], but all the authors agree that this practice matches the agronomic inputs and the practices to site-specific conditions within a field and the improvement of the accuracy of their application [7]. In detail, we can consider PA as an integrated information and production-based farming system, designed to deliver high-end technology solutions to increase farm production efficiency and profitability while minimizing environmental impacts on the ecosystems and the environment. PA technologies are technology innovations that incorporate recent advances in modern agriculture providing evidence for lower production costs, increased farming efficiency and reduced impacts. Accuracy and precision are two relevant factors to consider when taking data measurements. They both reflect how close a measurement is to an actual value, but accuracy refers to how close a measurement is to a known or accepted value, while precision reflects how reproducible measurements are.

For a long time, in the field of Precision Agriculture Technologies (PAT), digital devices able to take a more accurate and precise measurements generally corresponded to higher investment costs. This economic constraint initially caused a limited diffusion of PA. To date, a wide range of different low-cost devices is available on the market, which allows a to meet accuracy requirement in the measurements.

In Italy, although the adoption rate of technology among farmers is still low due to socio-economic barriers [8, 9], however the market for smart agriculture technologies is growing, where technology providers are increasingly providing solutions that cover the entire field of the agri-food supply chain (AFSC). In particular, most of the solution covers the first step of the AFSC, that is the production phase, from cultivation to storage of the product to processors. According to a recent survey conducted by the Osservatorio Smart Agrifood [10], currently, the technologies available on the market are those that support the growing phase of the crop (46%) followed by seeding (23%) and harvesting (22%) (Figure 1).

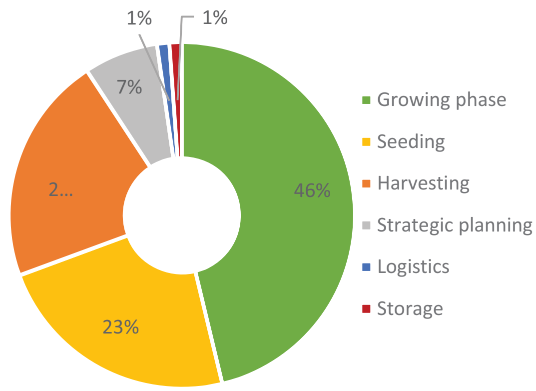

Figure 1: Most utilized PA technologies in the first step of the AFSC

The most widespread technologies on the market are related to the soil mapping (29%), machine control (27%) and precision interventions (21%), such as planting, fertilizing and distributing pesticides. The remaining part of these technologies are reserved for the farm and crop management and monitoring, respectively 18% and 5 % (Figure 2).

978-1-7281-3611-0/19/$31.00 ©2019 IEEE

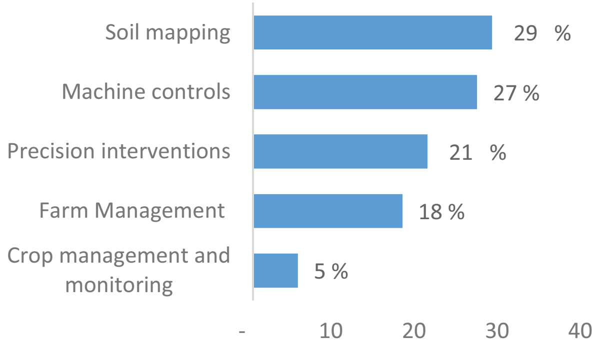

Figure 2: Most developed technologies present on the Italian market

The main crops treated with PA are fruit and vegetables (38%) cereals (35%), wine (23%) and olive oil (4%) (Figure 3).

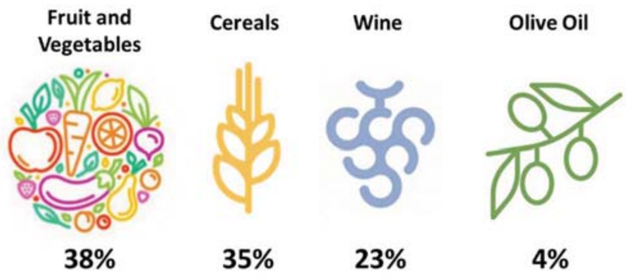

Figure 3: Main crops treated with PA

To date, even if there are affordable PA technologies available on the market, the application still remains circumscribed at few farms. In fact, in addition to the cost of investment, the adoption of the precision agriculture technologies has encountered other difficulties such as additional application or management costs and investment on new equipment, trained employees for the use of technologies and uncertainties found within the farming community, compared to the potential economic and environmental gains from their adoption [11,12,13,14,15,16, 17].

Given these premises, this paper discusses the economic benefits of PA, in relation to the accuracy of the measurement taken by different technologies, trying to answer the following research question: *"What is the economic profitability deriving from the adoption of high accuracy PA technologies?"*.

In order to reach this goal, we attempt to quantify the economic benefits of PA based on an Italian case study of a representative farm specialized in arable crop production which has invested in high accuracy PA. The case study method enables to explore and investigate a contemporary real-life phenomenon through detailed contextual analysis of a limited number of events or conditions, and their relationships. According to Yin [18] a case study research method is "*an empirical inquiry that investigates a contemporary phenomenon within its real-life context; when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used.*" Due to the limited availability of other cases for replication, in this study, we adopt either a single-case design.

The remainder of the paper is organized as follows: Section 2 presents a brief literature review. Section 3 indicates the methodology and data, section 4 provides the results. Finally, in section 5 we present conclusions and some policy implications.

II. Economic profitability of precision farming: a brief review

PA involves the use of digital technologies for the location, in a timely manner and in the right way to improve production while minimizing environmental impacts [19].

According to Pedersen (2017) [20], precision Agriculture Technologies for recording and mapping field and crop characteristics are divided into the categories below:

1. Global navigation satellite systems technologies (in fact these technologies record the actual position which can be used for different purposes such as guidance, mapping);
2. Mapping technologies;
3. Data acquisition of environmental properties (camera-based imaging, NDVI measurements, soil moisture sensors);
4. Machines and their properties Global navigation satellite systems (GNSS) technologies.

These technologies consent the recording of spatial differences in the factors relevant to crop growth, such as the quality of soil, the availability of water and fertilizers, or crop yield. This allows greatly improved efficiency of the resources made use of, leads to reduced waste of inputs and, in addition, improves the adjustability of biological-technical systems.

The work of Guo et al., (2018) [21] highlights how positioning accuracy represents a key factor for the precise management of agricultural operations. In the engineering fields, accuracy refers to how close a measurement is to the true value, but a more rigid definition is applied by the International Organization for Standardization, (ISO), which defines accuracy as a measurement with both true and consistent results. The ISO definition means that an accurate measurement has no systematic error and no random error. A key component of the precision farming management approach is the use of a wide array of digital devices, which allow taking accurate measurement in agriculture: this includes GPS guidance, sensors control systems, robotics, drones, autonomous vehicles, variable rate technology, GPS-based soil sampling, automated hardware, telematics, and software.

According to Perez-Ruiz and Upadhyaya (2012), [22], PA applications can be classified into three different categories, taking into account the different degree of accuracy in the positioning systems:

(i) **low accuracy** (meter level) can be used for asset management, tracking and tracing;

(ii) **medium accuracy** (sub-meter level) can be used for tractor guidance, via manual control, for lower accuracy operations such as spraying) [23], spreading, harvesting bulk crops and for area measurement and field mapping);

(iii) **high accuracy** (cm level) can be used for auto-steering systems on tractors and self-propelled machines (harvesters and sprayers.

PA has the potential to help farmers improve input allocation decisions, thereby lowering production costs or increasing outputs, and, potentially, increasing profits. However, there is still a scant known about the relative magnitude of benefits and costs of PAT on individual farms.

According to Zhang et al., (2002) [24], the impact of PA technologies on agricultural production is expected in two areas:

- profitability for farmers
- ecological and environmental benefits to the public.

However, both the profitability and the environmental benefits of PA continues to be difficult to predict evaluate and measure [25, 26]. According to the literature, the profitability of PA depends on different aspects including: the farm size, the type of crop, the technology adopted, the degree of spatial variability of soil attributes (e.g. soil types, fertility and organic matter) and yield response [27, 28, 29, 30].

Studies on PAT adoption emphasize that adopters tend to operate a larger agricultural area, and subsequently generate a higher income. This indicates the ability to accommodate some risk in investment of newer and larger technologies. Some studies highlighted that specialized farm in high-income crops such as vineyards and olive groves, are more likely to adopt PATs.

Economic profitability is a major concern when considering the adoption of any agricultural technology and the level of perceived profitability of adopting precision agriculture technologies has been found to dictate uptake identified knowledge gaps towards estimating the return on investment which leads to an inability to economically assess these technologies. A behavioral factor which has also been found to have a positive effect is the willingness of farmers to trust the technology. For example, a number of studies have found low levels of trust in the technology to be a key limitation for PATs adoption, relative to other factors. Thus, farmers are waiting for research results on the profitability of various PA technologies before increasing their investment significantly to adopt more technologies. On the one hand, PA is aimed at large holdings with a farm and capital structure that enables them to invest in expensive systems. On the other hand, it is a means to get farm management back to small scale farming processes with detailed knowledge about small units and management zones and enable farmers to treat each unit, whether it is a piece of land or an animal, with the same care as farmers did in previous times. This development is facilitated by the help of smart technologies that allow the farmer to gain detailed knowledge about the field and subsequently to treat the field accordingly. Despite these advantages, precision agriculture is adopted only by innovative farmers and the intelligent usage of precision farming data is still rather limited.

III. Data and methods

In order to determine the realistic benefits of the application of PA, a case study research was conducted. In details, the study focuses on a comparative economic assessment concerning the ex-post evaluation of PA adoption in a representative farm specialized in arable crop production in Italy.

A standard economic analysis was applied to determine profitability associated with precision agriculture techniques.

The economic analysis included the estimation of total costs and gross revenues. In details, the total costs include fixed and variable costs. Fixed costs constitute that portion of total cost that remains unchanged for a specific production plan regardless of whether more or less is produced. Fixed costs are therefore non-variable in the short term. They may, however, vary over the long term as a result of a change in the production plan. Examples of fixed costs are management, equipment depreciation and overhead, taxes etc. While variable costs are a function of output and are only incurred if there is production. There is therefore a relationship between the volume of production and these costs. Examples of variable costs are fertilizer, seed, herbicides etc. Production revenues (Gross revenues) are related to the sale of the product and any premium associated with cultivation (direct payments or premium included in the various RDPs of the regions). As for the sale, reference was made to the average yield per hectare made by the farmer and to the average price received by the farmer.

Comparing the two categories (ex-adoption and post-adoption) through the total costs and the gross revenues, it is possible to determine the operating income, i.e. the economic result achieved through management over a period. In order to assess the economic efficiency of precision farming practices, data for the analysis were collected by a questionnaire with direct interview.

IV. Results

The following paragraph reports the processing of the economic data of the case study. The data, after having been detected through a farm visit and interviews with the entrepreneur, have been revised in order to arrive at specific conclusions. In particular, summary and simplified tables were created that reports the total costs, the yields, the gross revenues and the net profit margin derived from crops production before and after the application of precision farming techniques (Table 1, 2, 3). The main items in the income statement are expressed in €/ha. The case study farm comprised 1300 hectares worked in PA. Of the agricultural land, 59% with corn, 41% is cultivated with wheat (durum and soft). From 2010 to 2016 the farm has invested with PA technologies for a total cost of about 200.000 € to collect information to be used to make decisions with greater precision and to optimize crop yields. The main investments include assisted steering (ISOBUS), service for georeferenced, production and soil mapping system, variable rate fertilizer spreader, machine for weeding and treatment with variable dosage distribution. In this analysis, the price received by the farmer for the production of the crops is quite similar for both types of farming (conventional or with PA technologies).

Table 1: Profitability analysis on corn

	Before PA (2009)	**After PA (2017)**
Total cost (€/ha)	2.300	2.287
Yields (Ton/ha)	12,5	13,5
Gross revenues (€/ha)	2.637	2.820
Net profit margin (€/ha)	337	533

Table 2: Profitability analysis on soft wheat

	Before PA (2009)	**After PA (2017)**
Total cost (€/ha)	1.350	1.300
Yields (Ton/ha)	6	7,3

Gross revenues (€/ha)	1.430	1.664
Net profit margin (€/ha)	80	364

Table 3: Profitability analysis on durum wheat

	Before PA (2009)	**After PA (2017)**
Total cost (€/ha)	1.186	1.120
Yields (Ton/ha)	5	5,7
Gross revenues (€/ha)	1.350	1.490
Net profit margin (€/ha)	164	370

The first aspect to be analyzed concerns crop yield and therefore on gross revenues. We note that in the transition between conventional agriculture and the application of PA technologies witnessed an increase of the yield: +8% for corn, +22% for soft wheat and +14% for durum wheat). The improvement of yields is associated with both direct and indirect effects of PA technologies. The direct effects derive from the optimization of production processes. The indirect effects derive from the greater knowledge on the state of soils and crops. In this way the farmer can make more timely decisions. In fact, the farmer has declared that the georeferenced mapping of his lands and of the working time for crops firstly allowed to quantify how much was actually the area worked in addition because of overlapping errors in different cultivation operation. In addition, the mapping of production and the soil analysis allowed to modulate seeds, fertilizers and herbicides according to the real need of the plants and the productivity of the soils. Consequently, eliminating the waste of time associated with overlapping in the field and eliminating the waste of different inputs through the use of fertilizer spreaders, machines for weeding, treatments and seeders with variable dosage distribution it was possible to reduce total cost and increased environmental sustainability. In particular, there is mostly a reduction in the variable costs that includes the cost of both mechanical operations (labor, diesel, lubricants) and technical means (seeds, fertilizers, crop protection products).

Finally, analyzing the net income obtained by difference between gross revenues and total costs, we can observe that in the passage between conventional agriculture and PA an increase is generated for all crops: 196 €/ha for the corn, 284 €/ha for the soft wheat and 206 €/ha for the durum wheat. These results are in line with different studies [31,32,33,34,35,36,37,38,39]. Thus, the adoption of precision agriculture practices can be a viable alternative to conventional production systems.

Finally, it is important to underline that in this study the key contributor to the profitability of the farm especially derived from the increase in crop gross revenue from increased yields. In detail, the higher yields, in combination with the slightly higher price received, due to quality improvements, increase crop sale revenues. Input cost savings are also important but not as significant. However, with respect to the variation in crop yield, an important notation should be done. We are aware that crop productivity is influenced by a complex set of factors, such as climatic conditions, and certainly not only by the possible introduction of a specific technology (e.g. PA). Despite this evidence, we must remember that the present paper involves a single-case study research. As such, it takes into consideration a contemporary event for which historical statistics are not available. Consequently, future research will need to be developed in order to confirm (or not) the validity of these results.

V. Conclusion and Policy Implications

Nowadays, the economic aspect is undoubtedly one of the most important factors to motivate the adoption of tools for precision farming within the farms. Many farms are, in fact, reluctant to introduce precision farming systems for the costs that need to be addressed and for uncertainty about the profitability of these technologies. In this article we have tried to calculate the profitability related to the use of agricultural systems of precision.

In this study, the potential benefits of managing crops using precision farming techniques include:

- the economic benefit of an increase in crop yield and a reduction in inputs, i.e. seed, fertilizer and agrochemicals but also less fuel use;
- the environmental benefit from a more precise targeting of fertilizer and agricultural chemicals.

To date, the knowledge and diffusion in the agricultural sector are still insufficient especially due to the scarcely aware of the positive role, both economic and environmental, that this farming system can have. However, while several studies have begun to demonstrate the economic profitability of PA technique, the assessment and quantification of environmental benefits are almost totally lacking in the literature. Some farmers do consider these benefits as part of their overall viability decision, based upon their personal values. But apart from general qualitative statements, there is no quantified environmental benefit assessment that can underpin an investment decision: this appears a significant omission that could be addressed by developing a methodology and/or tool to be available for the decision process.

In addition, the support from governments and other public institutions can play an important role in a wider adoption of PA. However, since PA benefits are not universal across Europe but rather specific to local conditions and to the farming systems in place, there is no specific measures or policies that support this type of agriculture. Today, different rural development measures under Pillar II of the CAP (Regulation EU No 1305/2013 of the European Parliament and of the Council of 17 December 2013) are suitable to play a role in fostering the development of this technology. Within the range of Pillar II, measures available for MS to support PA development through their RD programs are:

- Article 14 - Knowledge transfer and information actions
- Article 15 - Advisory services, farm management and farm relief services
- Article 17 - Investments in physical assets
- Article 28 - Agri-environment-climate
- Article 35 - Co-operation
- Article 55 56 57 - European Innovation Partnership for Agricultural Productivity and Sustainability (EIP-AGRI).

In particular, the EIP-AGRI can play an important role in both developing and mainstreaming precision farming in the

EU. Improved collaboration between farmers, farm service/technology industry and academics can speed up market introduction of PA technologies based on a robust evaluation of economic, agronomic and environmental benefits. In addition, EU governments have developed Industry 4.0 policies with the aim of strengthening industrial competitiveness and modernization of the manufacturing sector, including the agriculture. This policy supports especially the digitalisation of agriculture based on the development and introduction of new tool and machines in production.

Therefore, the uncertainties found within the farming community towards PATs, compared to the potential societal gains from their adoption, challenges policymakers to design targeted interventions which encourage their uptake.

REFERENCES

[1] Leonard, E.C., 2016. Precision agriculture. Wrigley, C., Corke, H., Seetharaman, K., Faubion, J. (Eds.), Encyclopedia of Food Grains, vol. 4, Elsevier, Oxford, pp. 162–167.

[2] Pierce, F. J., & Nowak, P. (1999). Aspects of precision agriculture. In Advances in agronomy (Vol. 67, pp. 1-85). Academic Press.

[3] Stafford, J. V. (2000). Implementing precision agriculture in the 21st century. Journal of Agricultural Engineering Research, 76(3), 267-275.

[4] McBratney, A., Whelan, B., Ancev, T., & Bouma, J. (2005). Future directions of precision agriculture. Precision agriculture, 6(1), 7-23.

[5] Reichardt, M., & Jürgens, C. (2009). Adoption and future perspective of precision farming in Germany: results of several surveys among different agricultural target groups. Precision Agriculture, 10(1), 73-94.

[6] Gebbers, R., & Adamchuk, V. I. (2010). Precision agriculture and food security. Science, 327(5967), 828-831.

[7] Wagner, P. (2000). Problems and potential economic impact of precision farming. In 7th ICCTA: Computer Technology in Agricultural Management and Risk Prevention: Proceedings of the 7th International Congress for Computer Technology in Agriculture (pp. 241-249).

[8] Annosi, M. C., Brunetta, F., Monti, A., & Nat, F. (2019). Is the trend your friend? An analysis of technology 4.0 investment decisions in agricultural SMEs. *Computers in Industry*, *109*, 59-71.

[9] Long, T. B., Blok, V., & Coninx, I. (2016). Barriers to the adoption and diffusion of technological innovations for climate-smart agriculture in Europe: evidence from the Netherlands, France, Switzerland and Italy. *Journal of Cleaner Production*, *112*, 9-21.

[10] Osservatorio PoliMI Smart AgriFood (2018). L'agricoltura 4.0 in Italia: Domanda e offerta a confronto. Report

[11] Bucci, G., Bentivoglio D., Finco, A. (2018). Precision agriculture as a driver for sustainable farming systems: state of art in literature and research. In Quality - Access to Success, Vol 19, Pg.114-121.

[12] Bucci, G., Bentivoglio D., Finco, A., (2019). Factors affecting ict adoption in agriculture: a case study in italy. In Quality - Access to Success Vol 20 (S2) pg 122-129.

[13] Paustian, M., & Theuvsen, L. (2017). Adoption of precision agriculture technologies by German crop farmers. *Precision Agriculture*, 18(5), 701-716.

[14] Barnes, A., De Soto, I., Eory, V., Beck, B., Balafoutis, A., Sánchez, B., ... & Gómez-Barbero, M. (2019). Influencing factors and incentives on the intention to adopt precision agricultural technologies within arable farming systems. Environmental science & policy, 93, 66-74.

[15] Mancuso, T., Verduna, T., Blanc, S., Di Vita, G., & Brun, F. (2019). Environmental sustainability and economic matters of commercial types of common wheat. *Agricultural Economics*, *65*(4), 194-202.

[16] Pellegrini, G., Gallo, C., & Conto, F. (2016). The role of agricultural policies on environmental sustainability and human health: an explorative analysis in the OECD countries. *Quality-Access to Success*, *17*.

[17] Auernhammer, H., Demmel, M., Muhr, T., Rottmeier, J., & Wild, K. (1994). GPS for yield mapping on combines. *Computers and Electronics in Agriculture*, *11*(1), 53-68.

[18] Yin, R.K., (1984). Case Study Research: Design and Methods. Beverly Hills, Calif: Sage Publications.

[19] Larsen, W. E., Nielsen, G. A., & Tyler, D. A. (1994). Precision navigation with GPS. *Computers and Electronics in Agriculture*, *11*(1), 85-95.

[20] Pedersen, S. M., & Lind, K. M. (Eds.). (2017). Precision Agriculture: Technology and Economic Perspectives. Springer International Publishing.

[21] Guo, J., Li, X., Li, Z., Hu, L., Yang, G., Zhao, C., and Ge, M. (2018). Multi-GNSS precise point positioning for precision agriculture. *Precision agriculture*, *19*(5), 895-911.

[22] Pérez Ruiz, M., & Upadhyaya, S. (2012). GNSS in precision agricultural operations. Intech.

[23] Xue, X., Lan, Y., Sun, Z., Chang, C., & Hoffmann, W. C. (2016). Develop an unmanned aerial vehicle based automatic aerial spraying system. *Computers and electronics in agriculture*, *128*, 58-66.

[24] Zhang, N., Wang, M., & Wang, N. (2002). Precision agriculture—a worldwide overview. Computers and electronics in agriculture, 36(2-3), 113-132

[25] Atherton, B. C., Morgan, M., Shearer, S. A., Stombaugh, T. S., & Ward, A. D. (1999). Site-specific farming: A perspective on information needs, benefits and limitations. *Journal of soil and water conservation*, *54*(2), 455-461.

[26] Lowenberg-BeBoer, J. (1997). Economics of precision farming: payoff in the future.

[27] Swinton, S. M., & Lowenberg-DeBoer, J. (1998). Evaluating the profitability of site-specific farming. Journal of production agriculture, 11(4), 439-446.

[28] Roberts, R. K., English, B. C., & Mahajanashetti, S. B. (2000). Evaluating the returns to variable rate nitrogen application. Journal of Agricultural and Applied Economics, 32(1), 133-143.

[29] Lambert, D., & Lowenberg-De Boer, J. (2000). Precision agriculture profitability review. Purdue Univ..

[30] Batte, M. T., & Arnholt, M. W. (2003). Precision farming adoption and use in Ohio: case studies of six leading-edge adopters. Computers and Electronics in Agriculture, 38(2), 125-139

[31] Biermacher, J. T., Brorsen, B. W., Epplin, F. M., Solie, J. B., & Raun, W. R. (2009). The economic potential of precision nitrogen application with wheat based on plant sensing. Agricultural Economics, 40(4), 397-407

[32] Godwin, R. J., Richards, T. E., Wood, G. A., Welsh, J. P., & Knight, S. M. (2003). An economic analysis of the potential for precision farming in UK cereal production. Biosystems Engineering, 84(4), 533-545.

[33] Griffin, T. W., & Lowenberg-DeBoer, J. (2005). Worldwide adoption and profitability of precision agriculture Implications for Brazil. Revista de Politica Agricola, 14(4), 20-37.

[34] Kingwell, R., & Fuchsbichler, A. (2011). The whole-farm benefits of controlled traffic farming: An Australian appraisal. Agricultural Systems, 104(7), 513-521.

[35] Robertson, M., Carberry, P., & Brennan, L. (2007). The economic benefits of precision agriculture: case studies from Australian grain farms. Retrieved March, 12, 2012

[36] Bucci, G., Bentivoglio, D., Finco, A., & Belletti, M. (2019). Exploring the impact of innovation adoption in agriculture: how and where Precision Agriculture Technologies can be suitable for the Italian farm system?. In IOP Conference Series: Earth and Environmental Science (Vol. 275, No. 1, p. 012004). IOP Publishing

[37] Pierpaoli, E., Carli, G., Pignatti, E., & Canavari, M. (2013). Drivers of precision agriculture technologies adoption: a literature review. *Procedia Technology*, *8*, 61-69.

[38] Orsini, R., Basili, D., Belletti, M., Bentivoglio, D., Bozzi, C. A., Chiappini, S., ... & Malinverni, E. S. (2019). Setting of a precision farming robotic laboratory for cropping system sustainability and food safety and security: preliminary results. In IOP Conference Series: Earth and Environmental Science (Vol. 275, No. 1, p. 012021). IOP Publishing.

[39] Kingwell, R., & Fuchsbichler, A. (2011). The whole-farm benefits of controlled traffic farming: An Australian appraisal. Agricultural Systems, 104(7), 513-521.