The role of needs, benefits and difficulties in the adoption of Agriculture 4.0 solutions

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Abstract: Climate change, rising world population and biodiversity threats as well as power unbalances, shrinking margins and global competition are only some of the challenges that agriculture has to face in the upcoming years. New solutions belonging to the Agriculture 4.0 paradigm might prove to be an effective way to address these issues. However, in order for them to have an impact, besides being technically feasible, farmers must decide to invest in them and to actually use these solutions in their fields. Economic reasons might coexist along with other objectives and the solutions meant to satisfy certain needs might fail to do so according to farmers' perceptions. In order to clarify the needs beneath the choice to invest in certain Agriculture 4.0 solutions and the benefits and difficulties actually faced while using them, a survey has been conducted involving more than 200 farms. The data show that available solutions tend to satisfy farmers' needs, however additional efforts need to be put in place to address some difficulties that still characterise these technologies, such as interoperability, connectivity and competences.

Keywords: Agriculture 4.0; Digital innovation; Survey

1.Introduction

Agriculture 4.0, which refers to the harmonious use of several different technologies (connectivity, big data, internet of farming, etc.) in order to achieve a variety of objectives such as increasing yields, boost sustainability, value chain collaboration or improve labour conditions, is increasingly emerging and spreading as a paradigm which can help making agriculture a more sustainable and competitive sector (Sponchioni *et al.* 2019). This market reached 450 million of euros in Italy in 2019 (Osservatorio Smart AgriFood, 2019) with a +22% increase with respect to the previous year and digitalisation is increasingly under scrutiny by the European Commission as a mean to boost the sustainability of the European agricultural sector, both in terms of environmental impact and of farmers' income (EC, 2017).

Farm and farmers' characteristics often determine whether a certain technology will be adopted or not: the variables that are mostly considered are age, education, experience, cultivated surface, income and sector (Borges *et al.,* 2019; Barnes *et al.,* 2019; Pierpaoli *et al.*, 2013). Bigger and richer farms tend to adopt more technological solutions with respect to smaller and poorer ones, while age, education and experience show a more uncertain pattern. Moreover, while the maximisation of profits might be a major driver of technology adoption, some studies evidence also other needs like reduction in physical work (DeBoer, 2003; Thompson *et al.,* 2019).

In the literature, however, attention is mostly placed on the process of choosing a certain technology, while limited attention is put on the benefits and difficulties faced when using the solution, after adoption has been made or on the differences between solutions in fulfilling farmers' needs. Finally, a limited number of studies focus on the comparison between different solutions also in terms of benefits and difficulties (Kernecker *et al.,* 2019).

The aim of this study is to understand the needs and the perceived benefits and difficulties faced by farmers, as well as how they relate to adopted solutions. This is done through descriptive analyses based on data collected via a survey compiled by several Italian farmers. Finally, the obtained results can be useful both for policy reasons, to devise effective incentive schemes or to address barriers to adoption, and to technology producers, who can better tune their offer based on actual farmers' needs, perceived benefits and difficulties.

2.Literature Review

Agriculture 4.0 solutions can have a big impact on promoting environmental sustainability of agriculture through the reduction of greenhouse gas emissions thanks to a more efficient use of inputs, be them mechanical or chemical, or to a better use of the soil.

This, in turn, can have a positive impact on the economics of the farm owing to the saved resources. Besides this, innovative solutions can also boost productivity in order to face the demand driven by a growing population as well as curb operative costs to face global competition (Schimmelpfennig *et al.,* 2016; Balafoutis *et al.,* 2017).

The drivers of adoption are several and widely covered in the literature: if we purely consider an economic point of view, farmers seek to maximise their profits and therefore they will adopt a certain solution if it permits them to do so Besides this, also non economic reasons might be considered: for instance the possibility to simplify bureaucratic and managerial work necessary for the farm or reduce the burden of physical work (DeBoer, 2003; Thompson *et al.,* 2019).Other expressed needs are the ease of use and the perception that the technology will bring benefits to the farmer (Aubert *et al.,* 2012). Clearly, the fear of not being able to recover the investment (Long *et al.,* 2016; Kernecker *et al.,* 2019) might be a barrier to adoption.

To explain technology adoption, literature often focuses on farmers and farms' characteristics such as age, experience, education or cultivated surfaces (Borges *et al.,* 2019; Barnes *et al.,* 2019; Pierpaoli *et al.*, 2013), and only in limited cases the attention has been placed on the way in which farmers determine their strategies, for instance considering the set of available information, the perception of expected benefits and the awareness of a positive environment surrounding the farm (Annosi et *al.*, 2019, Kernecker *et al.,* 2019). Moreover, little attention is posed on the comparison between the different solutions adopted as well as on the relationship between chosen technologies and needs, benefits and difficulties.

3.Methodology

The aim of this research is to have a clearer picture of the Agriculture 4.0 solutions adopted by farmers, the needs that these solutions fulfil and the benefits and difficulties faced on actual use of Agriculture 4.0 solutions by Italian farmers . The purpose is therefore to explore the phenomenon, building on existing theories.

In order to gather data which is owned solely by farmers and which is subjective, that is needs and certain types of difficulties, a survey has been devised. Doing so allowed both to gather subjective data, as previously mentioned, and objective data, like age, cultivated surface and adopted solutions, which could be then used as control variables in the analyses.

Consistent with the purpose of this study, a descriptive survey has been devised since it enables to better understand how a specific phenomenon applies in a determinate context (Malhotra & Grover, 1998; Forza 2002)

The survey has been firstly tested with ten farmers and media dealing with farmers' activities in order to gain insights from actual respondents on possible difficulties and misunderstandings. Then, the revised survey has been submitted via email to a database of farmers exploiting existing networks of media partners whose main focus is agriculture and of farmers' associations. This leads to a potential and widespread coverage of the whole country.

The survey is composed of three parts: a) the introduction, which covers farm and farmers' characteristics b) questions about adopted solutions c) questions about educational needs and future plans.

Data have been collected over a period of five months. The survey has been sent to a non random sample of nearly 5000 potential respondents, while the total number of valid responses received, in which at least the use of Agriculture 4.0 solutions has been declared, is 419, leading to a rate of response of nearly 8%. The relatively low rate of response might be caused by the depth of the questionnaire itself that required a certain effort to be completed thoroughly, especially for those adopting more than one solution (Galesic & Bosnjak, 2009; Pennings *et al.,* 2002). The sample has been then restricted only to those farmers who declare they adopted at least one Agriculture 4.0 solution following the categorisation used in (Osservatorio Smart AgriFood, 2018). In order to filter these responses, farmers where asked to select those solutions in which they invested in previous years, choosing one or more of the following categories:

- farm management information system;
- solutions to map fields and cultivations;
- solutions to monitor and control agricultural equipment;
- decision support systems;
- solutions to monitor and control fields and cultivations;
- robots;
- drones for in field treatments.

Owing to the limited number of responses, robots and drones are dropped in subsequent analyses.

This led to a sample of 288 farms, mostly located in northern Italy (70% of the sample), well balanced in

terms of cultivated surface, mostly led by farmers whose age is between 40 and 60 (60% of the sample) and mainly producing cereals (59%) and wine (26%).

Although the population of adopters of Agriculture 4.0 solutions in Italy is not fully acknowledged, descriptive statistics are comparable with other studies (Annosi *et al.,* 2019).

For each solution selected, Farmers were asked to answer a series of questions regarding those needs that mostly influenced the choice of adopting a particular technology, the benefits perceived by using it, the difficulties faced while using it as well as other questions regarding the money invested, the property and the scope of the investment. In particular, for each solution farmers where asked to declare:

- on a scale from 0 to 5 (where 0 refers to no impact and 5 to maximum impact), the extent to which a certain need influenced the choice of investing in the solution;
- on a scale from 0 to 5 (where 0 refers to no benefit perceived and 5 to maximum benefit), the extent to which a certain benefit has been obtained thanks to the use the solution;
- on a scale from 0 to 5 (where 0 refers to no difficulty perceived and 5 to maximum difficulty), the extent to which a certain difficulty has been experienced while using the solution.

The list of proposed needs, benefits and difficulties has been devised based on literature (Long *et al.,* 2016; Kernecker, 2019; Thompson 2019) and on frequent interactions with farms, farmers' associations, media and equipment producers. The needs, benefits and difficulties that have been chosen are presented in the following tables:

Table 1. List of expressed needs

Variable Name	Description
N_Sustainability	Increase in environmental sustainability
N_Awareness	Increase in awareness of farm's activities
N_Cost	Reduction in costs
N_IntWork	Ease bureaucratic and managerial work
N_Quality	Increase in production quality
N_Variability	Reduction in variability
N_Revenues	Increase in revenues
N_Physical	Ease physical work

Table 2. List of perceived benefits

Variable Name	Description
B_Input	Reduction in inputs
B_TimeEquip	Reduction in the time spent with agricultural equipment
B_TimeInt	Reduction in the time spent for bureaucratic and managerial tasks
B_TimePhys	Reduction in the time spent for physical tasks
B_Variability	Reduction in the variability of the outcomes in terms of quantity and production quality
B_Yields	Increase in yields
B_QualityExt	Improvement in visible product characteristics (shape, colour, …)
B_QualityInt	Improvement in non-visible product characteristics (taste, internal defects, …)
B_Monetisation	Data monetisation

Table 3. List of perceived difficulties

Variable Name	Description
D_Competences	Lack of competences
D_Connectivity	Lack of connectivity
D_Interoperability	Lack of interoperability
D_Assistance	Insufficient technical assistance
D_NonFunctioning	Non-functioning of the solution
D_Investment	Lack of return on investment
D_Scalability	Lack of scalability

Since every respondent was asked to list all the adopted solutions and to attribute a score on needs, benefits and difficulties for each of them, valid responses might be characterised by several values. In order to allow comparison and define a ranking, for each respondent and for each need, benefit and difficulty, only the highest score has been kept. All these values have been summed across the respondents in order to calculate a priority score, which is then used to define a ranking among the needs, benefits and difficulties.

If instead we look at the solution level, since the aim is to emphasize the differences in the way in which different solutions fulfil different needs or generate different benefits or difficulties, average values have been considered by taking the mean of all the values expressed by each respondent for a specific combination of solution and need benefit or difficulty.

The results that are obtained through these calculations are then analysed through descriptive statistics with the aim to highlight the comparison among them.

4.Results

According to survey's result, sustainability is the main expressed need driving technology adoption with a score of 1142, followed by the increase in awareness over farm's activities (1116), the reduction in costs (1115) and the ease in bureaucratic and managerial work (1110). Reduction in physical work (870) and increase in revenues (902) score low.

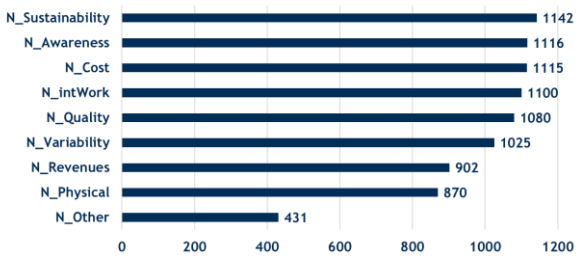

Fig.1 Expressed needs. Base: 259 farms

Reduction in inputs is the main perceived benefit (969), followed by the reduction in the time spent using agricultural equipment (840) and in the one spent for managerial and bureaucratic tasks (809). Benefits related to data monetisation (618) and the increase in production quality (665 external quality and 624 internal quality) have a low result.

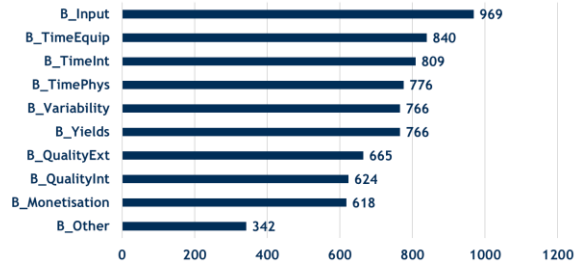

Fig.2 Perceived benefits. Base: 225 farms

Lack of competences (566), lack of connectivity (541) and lack of interoperability (538) are the main difficulties faced by farmers when using Agriculture 4.0 solutions, while the return on investment (476) seems not to be an issue.

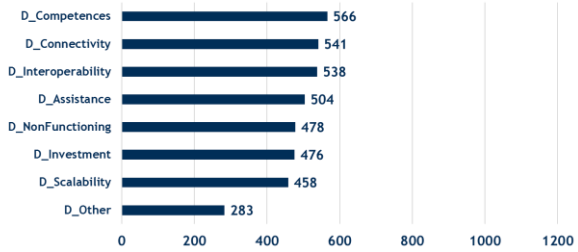

Fig.3 Perceived difficulties. Base: 212 farms

Farmers seeking sustainability mainly adopt decision support systems as well as systems to monitor and control fields and cultivations, instead awareness drives the adoption of farm management information system. There is no clear predominance of a solution over the remaining ones if we look at the other needs.

Input reduction is mainly achieved through agricultural equipment and fields monitoring as well as through decision support systems. Farm management information system mainly eases bureaucratic work, while it scores low in all the other reported benefits. Decision support systems and remote monitoring of fields and cultivations score high in each perceived benefit and they seem to be relatively more important concerning the increase in quality. Finally, no surprise that reduction in the time spent with equipment and reduction in the time spent for physical work are mainly achieved through monitoring and controlling of agricultural equipment.

Lack of competences mainly affects solutions to map fields and cultivations and solutions to monitor and control agricultural equipment. These score high also in lack of connectivity and in lack of interoperability. Farm management information system and decision support systems are instead characterised by low values in each category.

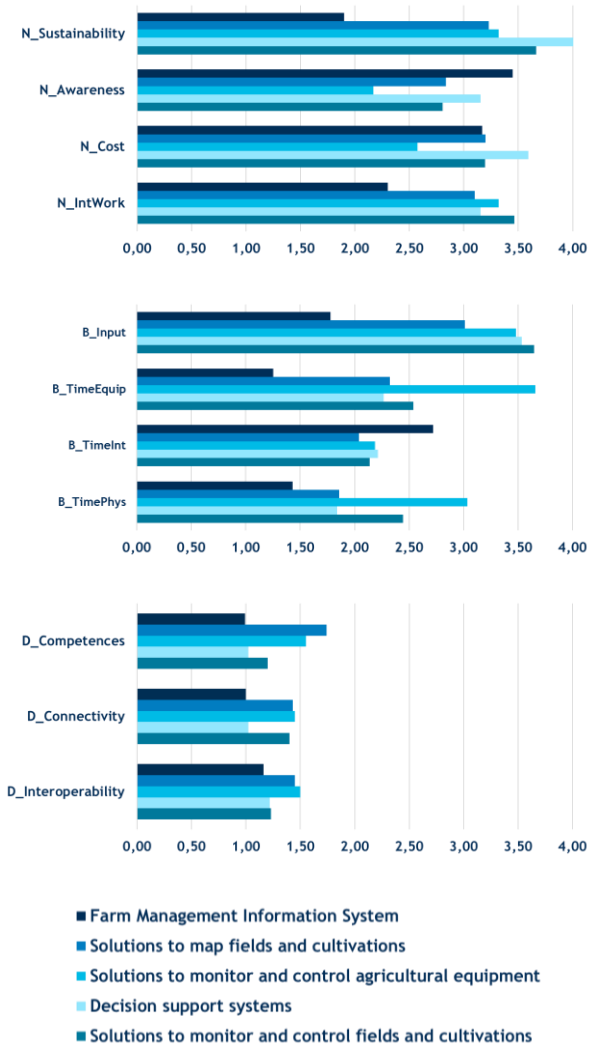

Fig.4 Expressed needs, perceived benefits and perceived difficulties by adopted solution

5.Discussion

Concerning expressed needs, we observe that sustainability is the main driver of technology adoption, followed closely by the need to have a greater awareness on the activities done at the farm, to reduce costs, which is related to the previous one, as well as by the need to simplify managerial work, that is to say ease all those aspects that might distract farmers from what they are meant, and most probably what they chose, to do, that is to say farming.. Jointly considering sustainability and cost reduction suggest the interest in looking for solutions that can make farming more sustainable and at the same time do not introduce additional burdens to farmers, therefore Agriculture 4.0 solutions might solve, or at least ease, this dichotomy by pursuing both objectives at the same time, for instance optimising the use of inputs.

Looking at the link between needs and adopted solutions, the adoption of decision support systems is mainly influenced by sustainability and reduction in costs. These solutions allow farmers to make informed decisions to optimise their agricultural practices, therefore reducing all those activities that are not needed and, in some cases, reducing their impact on the environment. The relevant data needed to fully exploit their capabilities come from different sources, among them sensors applied on the fields or on agricultural equipment (Navarro-Hellìn *et al.,* 2016). However, the solutions that include these elements seem to have a lower score compared to decision support systems, especially concerning the reduction in costs, probably because they are characterised by higher initial investments and more uncertain returns on them or because it is not fully clear their impact on reducing labour costs and equipment usage. Farm management information system, instead, is chosen mainly to increase the visibility on the farm and, therefore, to reduce costs. The limited impact of the remaining needs might be related to the fact that these solutions are supporting tools, therefore it might not be fully understood how they relate to other solutions to fulfil farmers' needs. Finally, it is interesting to note that the impact of reducing intellectual work and reducing physical work on those solutions that monitor and control agricultural equipment is similar, meaning that there is not necessarily a trade-off between these two needs.

Concerning perceived benefits, the one that is mainly achieved is the reduction in the use of production inputs such as water or agrochemicals. As explained earlier, this partly fulfils the expressed need of increasing the sustainability of agricultural practices. Besides this, the fact that the perceived benefits related to the reduction in other types of inputs, for instance labour or equipment, are greater than those related to the increase in yields or

production quality is in line with the expressed need of reducing costs. This match is also reflected in the solutions adopted (especially decision support systems and solutions that monitor fields and cultivations), however it is worth noting the case of farm management information system concerning bureaucratic and managerial work. If we look at these elements from the point of view of the expressed needs, their impact on farm management information system is the lowest among the defined categories. If instead we look at perceived benefits, this solution scores highest. Although this discrepancy might be due to different interpretations by respondents, it is interesting to underline the difference between expectations and actual perceptions which can be reduced through better information.

The difficulties that are mostly perceived by farmers when using Agriculture 4.0 solutions are lack of competencies, lack of connectivity and interoperability. Lack of competences might be related to the fact that in order to achieve the best benefits from these new digital tools it is important to have the right skills and to know how to use them. This of course extends also to those who work in the farm and who have to use the equipment, regardless the skills of the conductor of the farm. Lack of connectivity might be a relevant problem, especially in marginal areas, since many functions provided by Agriculture 4.0 might be unavailable without connectivity, for instance cloud computing or remote sensing. Finally, concerning lack of interoperability, having many different devices and being not able to exploit economies of scope might imply a loss of resources and an underutilisation of the adopted solutions.

According to respondents, mapping solutions are those that require most competences, followed closely by other solutions implying remote sensing. Software like decision support systems and farm management information system are both characterised by low levels of lack of competences and lack of connectivity, however they differ concerning return on investments and scalability: while decision support systems seem to be those solutions that pay off more easily, farm management information system do not seem to be that clear in optimising the investment. Scalability is instead a greater issue for decision support systems, while it seems not to be relevant for farm management information system.

6.Conclusions

The research carried out and presented in this paper investigated the expressed needs and the perceived benefits and difficulties of Italian farmers adopting Agriculture 4.0 solutions, delving into the differences between the adopted solutions in order to gain insights on technology adoption. A descriptive survey has been carried out, and the results of a total of 288 farms have been analysed.

The results show that sustainability is the main expressed need when choosing to invest in Agriculture 4.0 solutions, followed closely by the increase in the awareness on farm activities and by cost reduction. According to the respondents, these needs are satisfied by the chosen solutions mainly through the reduction in the inputs used for cultivations. The solutions that mostly allow this matching are decision support systems and solutions to monitor and control fields and cultivations, since they are able to gather all the relevant data and to extract useful information to assist farmers in their decisions. These are followed closely by those solutions that monitor and control agricultural equipment, which allow farmers to easily and precisely apply the best methods to optimise inputs. However, some difficulties to be solved still remain: lack of competences, lack of connectivity and lack of interoperability are those mainly reported by farmers.

The insights presented in this paper could shed some light on the actual needs of farmers and the way in which they form their decisions: this can be useful for both policy makers willing to devise effective incentive schemes as well as for technology providers, who can narrow the informative gap between demand and supply and who can devise solutions more in line with farmers' needs.

This study represents a first step of a wider research, and there are still some limitations to be addressed: one of them is related to the sample size, where a wider and more targeted one should be used to gain insights on the whole population of Italian farmers, comprising both adopters and non adopters. Besides this, the data collected do not allow to define a clear causal nexus between needs and adoption since this relationship is self reported by respondents. Further studies might build on the evidences of this paper by using a more quantitative approach.

References

Annosi, M.C., Brunetta, F., Monti, A. and 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.

Aubert, B. A., Schroeder, A., and Grimaudo, J. (2012). IT as enabler of sustainable farming: An empirical analysis of farmers' adoption decision of precision agriculture technology. *Decision support systems*, 54(1), 510-520.

Balafoutis, A., Beck, B., Fountas, S., Vangeyte, J., Wal, T. V. D., Soto, I., ... and Eory, V. (2017). Precision agriculture technologies positively contributing to GHG emissions mitigation, farm productivity and economics. *Sustainability*, 9(8), 1339.

Barnes, A.P., Soto, I., Eory, V., Beck, B., Balafoutis, A., Sánchez, B., Vangeyte, J., Fountas, S., van der Wal, T. and Gómez-Barbero, M. (2019), Exploring the adoption of precision agricultural technologies: A cross regional study of EU farmers, *Land Use Policy*, 80,163-174.

Borges, J.A.R., Oude Lansink, A.G.J.M. and Emvalomatis, G. (2019), Adoption of innovation in agriculture: A critical review of economic and psychological models, *International Journal of Innovation and Sustainable Development*, 13(1)36-56.

European Commission (2017). *The future of Food and Farming*, Communication from the commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM(2017) 713 Final

Forza, C. (2002). Survey research in operations management: a process-based perspective. *International Journal of Operations & Production Management*, 22(2), 152-194.

Galesic, M., and Bosnjak, M. (2009). Effects of questionnaire length on participation and indicators of response quality in a web survey. *Public opinion quarterly*, 73(2), 349-360.

Kernecker, M., Knierim, A., Wurbs, A., Kraus, T., and Borges, F. (2020). Experience versus expectation: farmers' perceptions of smart farming technologies for cropping systems across Europe. *Precision Agriculture*, 21(1), 34-50.

Long, T. B., Blok, V., and 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.

Lowenberg-DeBoer, J. (2003). Precision farming or convenience agriculture. In *Solutions for a better environment–Proceedings of the 11th Australian Agronomy Conference'. Geelong, Vic.(Australian Society of Agronomy).*

Malhotra, M. K., and Grover, V. (1998). An assessment of survey research in POM: from constructs to theory. *Journal of operations management*, 16(4), 407-425.

Navarro-Hellín, H., Martínez-del-Rincon, J., Domingo-Miguel, R., Soto-Valles, F., and Torres-Sánchez, R. (2016). A decision support system for managing irrigation in agriculture. *Computers and Electronics in Agriculture*, 124, 121-131

Osservatorio Smart AgriFood (2019). *Il digitale è servito! Dal campo allo scaffale, la filiera agroalimentare è sempre più smart*, Report, Milan.

Osservatorio Smart Agrifood (2018). *Coltiva dati. Raccogli valore. La trasformazione digitale dell'agroalimentare*, Report, Milan.

Pennings, J. M., Irwin, S. H., and Good, D. L. (2002). Surveying farmers: A case study. *Applied Economic Perspectives and Policy*, 24(1), 266-277.

Pierpaoli, E., Carli, G., Pignatti, E., and Canavari, M. (2013). Drivers of Precision Agriculture Technologies Adoption: A Literature Review. *Procedia Technology*, 8, 61-69.

Schimmelpfennig, D., and Ebel, R. (2016). Sequential adoption and cost savings from precision agriculture. *Journal of Agricultural and Resource Economics*, 97-115.

Sponchioni, G., Vezzoni, M., Bacchetti, A., Pavesi, M. and Renga, F. M. (2019). The 4.0 revolution in agriculture: a multi-perspective definition. *In Summer School F. Turco-Industrial Systems Engineering*,143-149.

Thompson, N.M., Bir, C., Widmar, D.A. and Mintert, J.R. (2019), Farmer perceptions of precision agriculture technology benefits, *Journal of Agricultural and Applied Economics*, 51(1),142-163.