The International Society of Precision Agriculture presents the
15th International Conference on
Precision Agriculture
26–29 JUNE 2022
Minneapolis Marriott City Center | Minneapolis, Minnesota USA

Farmers' and Experts' Perceptions of Precision Farming Impacts on Economic Efficiency, Food Security, Climate and Environmental Sustainability.

Clement Issaka Anaba[1], Abele Steffen[2], Carlo Forst-Gill[3]

[1]B.Sc. Natural Resources Management (Graduate), Department of Environmental Management, M.Phil. Climate Change (candidate), Department of atmospheric and Climate Sciences, University of Energy and Natural Resources (UENR), Sunyani-Ghana. Programme Staff, Environmental Protection Agency (EPA), Ghana.

[2]Professor for Economics of Rural Areas; Course Director B.Sc. Sustainable regional management. Department of Sustainable Regional Management, University of Applied Forest Sciences, Rottenburg- Germany.

[3]B.Sc. Resource Water Management (Graduate), University of Applied Forest Sciences Rottenburg, Germany, M.A. Sustainable Development Cooperation (Candidate), Technical University Kaiserslautern, Germany. Academic Staff Member, Coordinator of M.Sc. SENCE (Sustainable Energy Competence), University of Applied Forest Sciences, Rottenburg- Germany.

*Corresponding author: clementianaba@gail.com, clement.anaba.stu@uenr.edu.gh

A paper from the Proceedings of the
15th International Conference on Precision Agriculture
June 26-29, 2022
Minneapolis, Minnesota, United States

Keywords.
Baden-Württemberg, Precision Farming (Agriculture), Economic Efficiency, Environmental Sustainability, Food security, Climate Change, and Adoption factors.

Abstract.

Farming contributes around 20% of the international pollution heavily from carbon dioxide, methane and nitrous oxide, and produces approximately 50% and 70% of methane and nitrous oxide of the anthropogenic emission respectively. Precision Farming (P. F) offers the opportunity to deal with site-specific differences within a specific agricultural plot, thus increasing profitability and reducing adverse ecological effects. The German state of Baden-Württemberg is characterized by, in comparison to Northern and Northeast Germany, small farm sizes about 40 ha, as compared to the German average of 63 ha per farm and almost 250 ha in Brandenburg, where precision farming is already widely spread. Nonetheless, it is expected that the potential for precision farming in the area will increase, both because changes in farm and plot sizes as well as technological progress in precision farming.

To evaluate the potential for P. F in this region, a case study was conducted within Baden-Württemberg. Its aim was to appraise farmers and experts' perceptions of P. F and specifically assess their perceptions on economic efficiency of P. F, the role of P. F on food security, its potential impact on climate and environmental sustainability and factors influencing adoption of P. F.

The study revealed that P. F implementation is still at a low rate in Baden-Württemberg, with the average 11% adoption rate, contrary to 30%-50% in other states and compared to a national average of 30% adoption in Germany. It was revealed that most P. Fs in Baden-Württemberg were between 1-15 years of practice. P. Fs and experts rated the contribution of P. F on climate and environmental sustainability to be highest (39.4%) followed by food security (33.3%) and economic efficiency (27.3%). The benefits of P. F were weighed against its obstacles, with the benefits scoring 53.3% and the obstacles 46.7%. However, it takes a precision farmer approximately four years to overcome all obstacles and start making profit.

The study recommends that financial support for farmers should be provided especially during the introduction or early investment stage. Further important are the provision of area-wide free RTK correction signals, simplifications of P. F and technologies, special training programs, as well as the introduction of specific extension service systems and to integrate P. F topics in farmers' professional trainings and academic curricula.

List of Abbreviations

Abbreviation	Meaning
BMEL	Federal Ministry of Agriculture-Germany
MLR BW	Ministerium für Ländlichen Raum und Verbraucherschutz Baden-Württemberg
P. F or P. A	Precision Farming or Precision Agriculture = (Agriculture 4.0 or Digital Farming)
P. Fs	Precision Farms or Precision Farmers
N. P. Fs	Non-Precision Farms or Non-Precision Farmers
JRC of EC	Joint Research Centre of European Commission
CTF	Control Traffic Farming
RTK	Real Time Kinematic
EC	European Commission
CC	Climate Change

1. INTRODUCTION

1.1 Background

Agriculture contributes approximately 20% of the global carbon dioxide, methane and nitrous oxide pollution and produces 50% of the methane and 70% of the nitrous oxide of the human-induced emissions (Liebig et al., 2011).
There is evidence that increased production has led to significant harmful environmental consequences in terms of water pollution, greenhouse gas emissions and damage to our natural surroundings (Geiger et al., 2010; Kleijn et al., 2011) as cited by the JRC of the EC, (2014).
Excessive fertilizer use can contribute to problems of eutrophication, acidification, climate change and the toxic contamination of soil, water and air, while insufficient application of fertilizers may cause the degradation of soil fertility (Hayati, et al,. 2011).

According the BMELV, (2010) agriculture contributes to roughly 11% of Germany's greenhouse gas emissions. The contribution of agriculture towards overall CO2 emissions is 6%, nitrous oxide emissions 54% and methane emissions 51%. Cattle farming accounts for 93% of the methane emissions, mainly from dairy herds. Agriculturally utilized soils are also an emission source of climate-relevant gases.

Nonetheless, the CO2 balance of agriculture and forestry in Germany is clearly positive, because agricultural emissions totaling 133 million tons of CO2 equivalents including the manufacture of nitrogen fertilizers – is balanced off by absorption by plants of 168 million tons.

Despite these positive balances, agricultural production systems need to focus more on the effective conservation and management of biodiversity and ecosystem services in order to address the twofold objective of environmental sustainability and food security (FAO & PAR, 2011).

Precision farming offers the opportunity to deal with site-specific differences within a field in order to increase profitability and to reduce environmental impact, in particular by optimizing input application like fertilizer and pesticides (Reichardt M. 2007). By doing this, suboptimal application of such inputs, which basically means over-application and hence unnecessary environmental pollution like in particular the pollution of water bodies with nitrogen and phosphorus, can be avoided (MLR BW, 2017).

1.2 Problem statement and objectives

Despite all endorsement for P. F, YU (2000) stated that the economic viability of P. F will play a key role in determining if precision agricultural machineries will be broadly adopted.

A thorough comprehension of the intricacy of P. A adoption is necessary in order to develop adequate policies and initiatives which support the adoption of P. A technology (Grimaudo et al., 2012).

The German state of Baden-Württemberg is characterized by relatively small farm sizes compared to Northern and Northeast Germany in 2021 about 40 ha, as compared to the German average of 63 ha per farm and almost 250 ha in the Northeastern German state of Brandenburg (Table 1.1), where precision farming is already widely spread. Nonetheless, structural change is also affecting Baden-Württemberg's agriculture, as the number of farms has reduced by about 14 percent in the last ten years and a respective growth in farm sizes (destatis.de 2022).

Table 1.1: Comparison of average farm sizes and percentage of P. Fs in Baden-Württemberg and selected states in Germany.

State	Average farm size (ha)[1]	Estd. percentage of precision farms of total (%)[2]
Baden-Württemberg	36,5	11
Brandenburg	243,6	40
Mecklenburg-Vorpommern	279,2	40
Niedersachsen	72,7	35
Sachsen-Anhalt	271,4	48
Schleswig Holstein	81,5	30

[1] Source: destatis.de 2022, [2] Source: Expert estimations

In the study area of Baden-Württemberg, P. F is not yet very widespread, although the respective political authorities support the application of P. F through subsidies and financial support programs (MLR BW 2017). While in general it is stated that P. F is also suitable for smaller plot sizes (OECD, 2001; Paustian & Theuvsen, 2017; M. Reichardt et al., 2009; Remco & Poppe, 2016), it is also expected that with the ongoing structural change, the potential for precision farming will increase in this state.

Although many writers have examined the issues of precision farming (agriculture) with various objectives and suggested solutions towards the implementation of the technology, the perceptions and opinions of the end users have not broadly been assessed. Hence, there is the need to examine the perceptions of farmers and experts on the precision farming technology.

The main objective of the study is to appraise farmers and experts' perceptions of P. F and specifically to assess their perceptions of the economic efficiency of P. F, the role of P. F for food security, the role of P. F for climate and environmental sustainability and the factors influencing farmers' adoption of P. F technologies. The results of this study may initially be specific to Baden-Württemberg, however, they also may be transferrable to other sites undergoing a structural change from smaller to larger farms, in particular in other Central and Southeastern European countries as well as in Africa.

2. MATERIALS AND METHODS

2.1 Study Area and principal production systems

In 2018, a case study was conducted within Baden-Württemberg, one of the sixteen states of Germany. Baden-Württemberg is located at latitude 48º32'16''N and longitude 9º2'28''E (Figures 2.1 and 2.2).

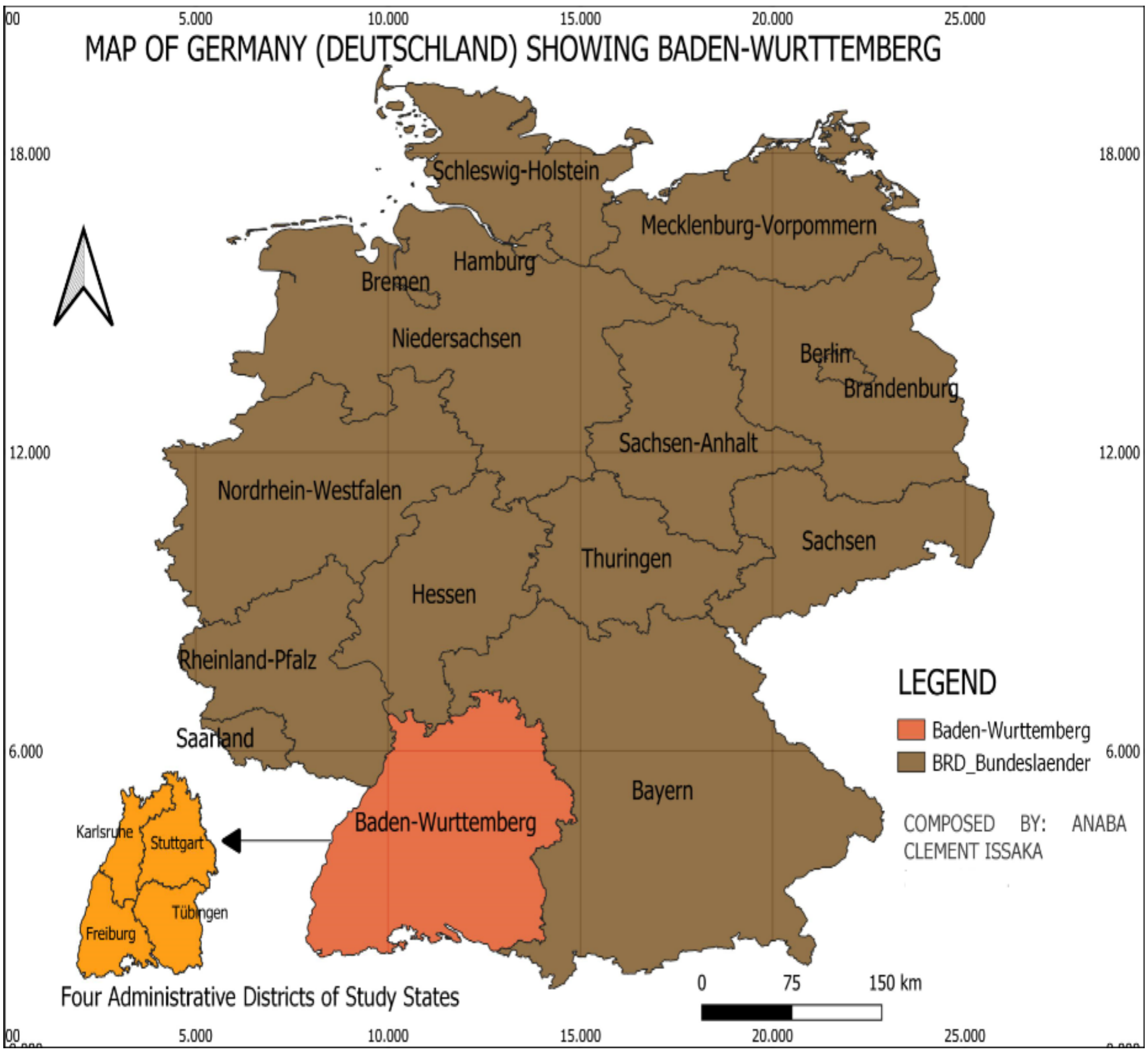

Figure 2.1 Map of Germany. Source of shapefile: Koordinaten_Umrechnung.xlsxv from Steffen Döring

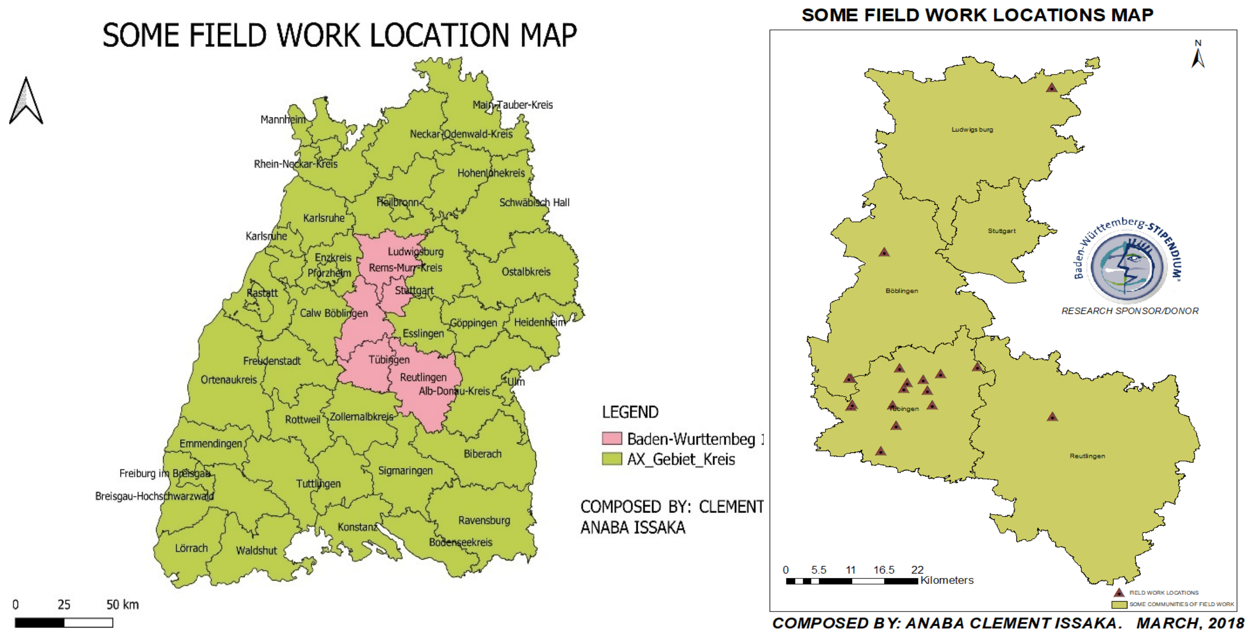

Figure 2.2: Location of surveyed farms **Source: composed by authors**

The main crops grown in Baden-Württemberg include cereals, in particular wheat, rye, barley, and oats, as well as to a lesser extent maize, legumes, oilseeds (especially rapeseed and sunflowers), vegetables, and potatoes. In terms of orchards and fruits, tree and berry orchards including apple, pear, as well as vineyards are the main business. Animal farming includes livestock farms, particularly both dairy and beef cattle, sheep, goats, pigs, equines, and poultry (LEL, 2019).

2.2 Database: Sample characteristics, survey type, data collection and type of data

The study was conceptualized as a case study of farms which either already practice P. F or would be suitable for P. F in principle, with a few exceptions. In total, nine farms practicing P. F. were surveyed and ten not practicing farms (N. P. Fs), of which most are principally suited for P. F (see Table 3.3). Labour endowment of the surveyed farms is depicted in Table 3.1. The concept of a case study was necessary because the number of P. F available for interviews is relatively small due to the conditions of P. F in Baden-Württemberg, but also due to the difficulties to conduct large scale farm surveys in this area, as willingness of farmers to participate is low and costs of surveying are considerably high.

Structured questionnaires were used for gathering information on the understanding and opinions from three target groups consisting of experts in P. F, farmers who use P. F technology and farmers who do not use the technology but might principally able to use it. In all three questionnaires, there were open-ended questions to give room for the respondents to be able to reveal all what they know about the technology. The rest of the questionnaires were more specific with respect to experiences, opinions and objectives of the study.

In addition to the farms, 14 experts were interviewed, those being members of farming societies and the academia.

2.3 Data Analysis

The data was analyzed using MAXQDA 2018 software. All manuscripts were imported to the software using the export/import function of the software. The answered questionnaires were first coded, using the objectives of the research as codes and assigning all answers that corresponded to an objective. After coding, the codes were exported to an Excel sheet along with the quotations, and the answers were scrutinized to eliminate duplicate retorts, giving 34 quotations as total distinct points covering all four key objectives. These points were re-coded with the objectives as codes and the distinct answers as quotations. The data was then analyzed using the analysis tool of the software and final results were displayed in bar graphs and pie charts.

3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 Farm characteristics of P. F and N. P. Fs in the study

The surveyed farms had farm sizes between 5 and 1.000 ha, with the P. Fs applying farms ranging from 100 to 1.000 ha and the N. P. Fs applying farms from 5 to 200 ha. The number of workers (family and non-family) ranged from 1 to 31, also depending on the production systems of the farms, with the N. P. Fs ranging from one to six workers, however, the P. Fs with a larger number of workers included a research farm of the University of Hohenheim and a poultry farm including biogas production (Table 3.1). The farm structure and type of farming show that quite a number of them would be suitable for one of the technologies of P. F listed in Table 3.5 (see also Figures 3.9a & b).

Table 3.1: Labour endowment of P. Fs and N. P. Fs

Number of labour forces	Number of surveyed farms (P. Fs and N. P. Fs)	
	PF	non-PF
1-5	5	7
> 5 -10	1	3
> 10	3	0

Source: Farm interviews

The majority of precision farms in the survey was practicing P. F for more than five years, with three of the farms practicing P. F for five to fifteen years, and two for even a longer period. Almost half of the P. F farms practice the technology for five years or less (Table 3.2).

Table 3.2: Years in operation of P. Fs

Years in operation	Number of surveyed P. Fs
1-5	4
> 5 -15	3
> 15	2

Source: Farm interviews

P. F practicing farms in the survey have a size from 100 ha upwards and beyond 300 ha, while N. P. Fs' farm sizes range from under 20 ha to a maximum of 150 ha (Table 3.3).

Table 3.3: Farm sizes of P. Fs and N. P. Fs

Farm size (ha)	Number of surveyed P. Fs
- < 20	0
20 - < 100	0
100 - < 150	3
150 - < 300	3
300 -	3
Farm size (ha)	Number of surveyed N. P. Fs
- < 20	1
20 - < 100	1
100 - < 150	6
150 - < 300	2
300 -	0

Source: Farm interviews

With respect to farm size, it is of interest that the surveyed experts stated that, although most of the P. F technologies are suitable for rather large farms sizes above 100 ha, there are also technologies that are considered to be suitable for smaller farms of 20 ha and above (Table 3.4). This indicates that in the future, more technologies might become suitable for smaller farm sizes as well.

Table 3.4: P. F techniques cost of adoption, and farm size most suitable to adopt

Technology	**Tools/ machines**	**Average costs in €**	**Actual function**	**Suitable farm size**
N-sensor	Sensor on the top of tractor	25.000	Fertilization	≥ 100 ha
Yield mapping; grain flow measurement	Harvester	10.000	Yield map	> 300 ha
Moisture map; sensor in grain flow	Harvester	10.000	Yield map	> 300 ha
Section control without RTK	Sprayer	5.000	Minimizing sprayer overlap, reduce pesticide + costs	> 20 ha
Autopilot, fully integrated	Tractors	Circa 15.000	Straight steering or parallel curve	≥ 150 ha
Remote control	Plot seeder	2.000-5.000	Automatic start of seeding while plot seeding	Trial technique
Mapping	Measurement tools; RTK antenna	Circa 10.000	Mapping fields, set moister points for trials	/

Source: Expert interviews

The study revealed that P. F implementation is still at a lower rate in the study area. The average adoption rate was found to be 11%, while in others states in Germany, it was found to be between 30% to 50% with average of 30% adoption rate in Germany as a country (Table 1.1).

3.1.2 Survey results: Expert and farmers' ratings of benefits and costs of P. F

For the specific objectives of the study, P. Fs and experts rated the contribution of P. F on climate and environmental sustainability to be highest (39.4%), followed by the contribution to food security (33.3%), whereas economic efficiency (27.3%) was ranked significantly lower (Figure 3.1). Environmental impacts mentioned include less chemical pollution or emissions through the effective or rather minimized and precise use of operating resources such as fertilizer, pesticides, herbicides, fuel etc. Another argument given was the improvement of soil quality by protecting biotic and abiotic environment through controlled traffic and thus compaction prevention and proper soil tillage.

In terms of food security, it was affirmed that the correct quantity of fertilizer is applied in the right place specific for the plant use and in the right growth period of the plant where particular fertilizer and specified quantity is needed. It was added that competition of weed with crops for nutrients and water is reduced in P.F by effective and timely control of weeds so that crops have access to all the quantity of resources for proper growth and higher yielding. A strong augment was made that P. F helps to produce high quality food and higher yields with less land and operating resources, as compared to whole farm management system. Positive economic effects were considered to be the reduction of operation costs, both in organic and conventional farming systems, with slightly higher cost savings in the latter system, reduced labour costs and yield increases. Farmers estimated that they can save up to 15% operating costs, whereas yields are stable or are considered to increase slightly by about 2%.

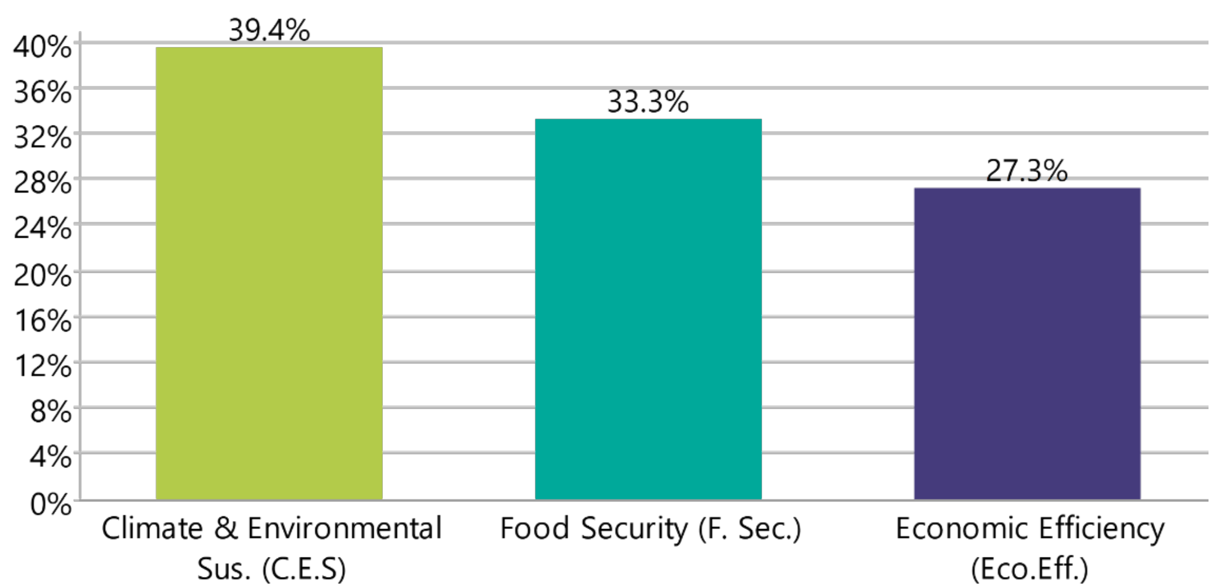

Figure 3.1 Rating of key impacts (benefits) of P. F by experts and farmers.

Participants also weighed the benefits of P. F against its obstacles, with the benefits rated at 53.3% and the obstacles at 46.7%, which basically means that the benefits slightly outweigh the obstacles as perceived by the farmers (Figure 3.2).

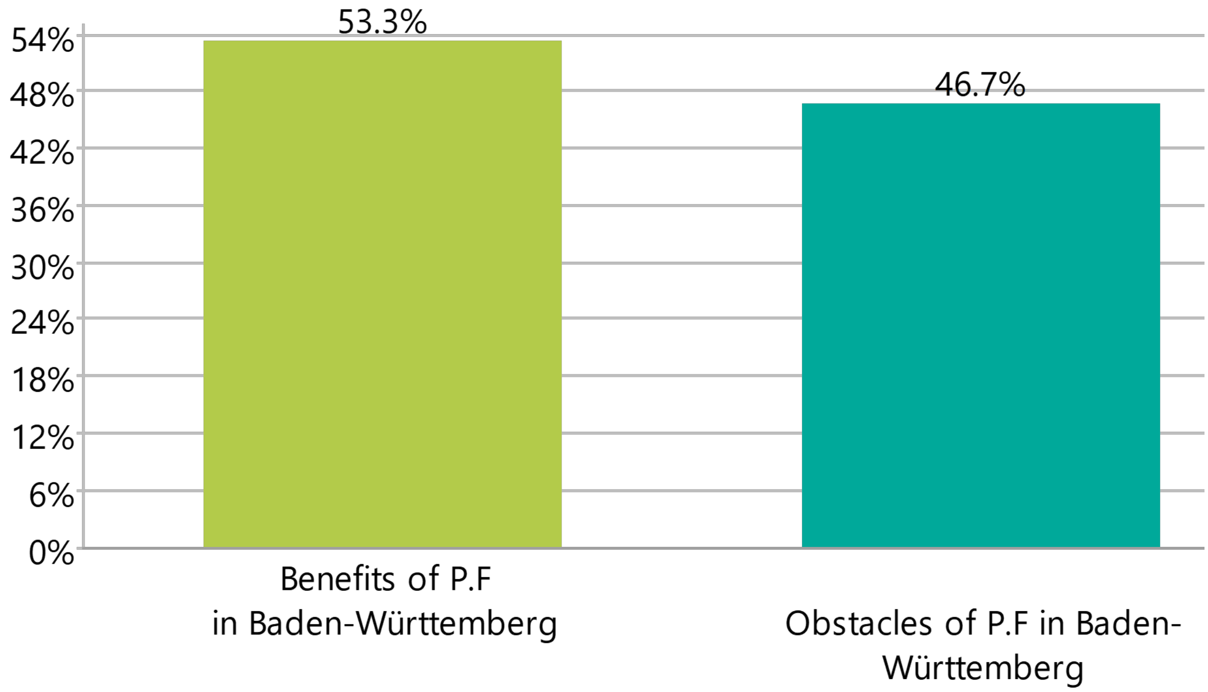

Figure 3.2: Rating of benefits of P. F against its obstacles by farmers and experts.

The perceived benefits were that plot operations were more specific, real time-based, when enhanced through e.g. aerial photo technology, and also more versatile, which also holds for animal care. Another point was the reduction of workload and the fact that in particular field work gets less exhausting and more comfortable. P. F also enables a more continuous and less peak-driven labor, also under e.g. difficult weather conditions, and it optimizes administrative labor. Optimized production is also considered to increase food safety, e.g. through the potential of P. F to improve animal health and welfare.

As mentioned by the farmers, obstacles of P. F are high investment costs and long break-even periods. The vast majority of farmers rates the costs of investment in P. F to be very high. There also seems to be a lack of knowledge on optimal P. F technologies in terms of suitable farm sizes and farming systems. Another issue are high skill requirements. In particular, the handling of IT hard- and software poses obstacles to older farmers or farm workers, for example, who have to be trained (at high costs) or are in jeopardy of getting unemployed. The lifetime cycle of equipment is a problem, as farmers fear to be outdated by technological progress. Data acquisition, data security and management is another issue mentioned, much as the technology problems like system failures or lack of compatibilities between different technologies and services and/or providers respectively. The technology dependence and the risk of operational failures impose a further obstacle to the investment in P. F.

The above depicted estimations made by the surveyed farmers result in respective expectations by the target group with respect to efforts having to be made to overcome the obstacles. Farmers estimate that it would take four years to overcome all obstacles and start making profit, with the estimations ranging from one to three years up to more than seven years (Figure 3.3). It should be positively noted that the majority of farmers consider the adaptation phase rather short, however, if a farmer belongs to the group that estimates the "overcome-period" as very long, they are not very likely to adopt.

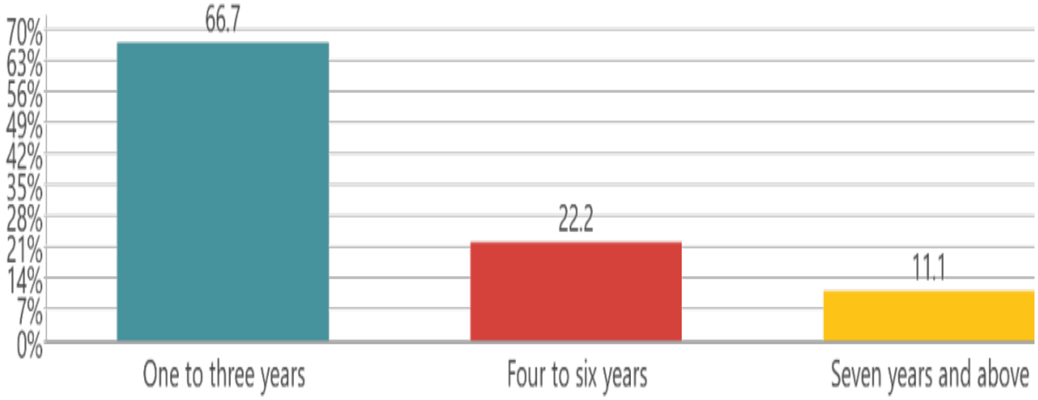

Figure 3.3: Number of years it takes to overcome P. F obstacles after adoption; according P. Fs

The expected or estimated adoption rates of P. F reflect the above reservations, as the majority of experts surveyed state that the adoption rate in the State of Baden-Württemberg should be very low.

3.2 Discussion

In particular, obstacles and hindrances mentioned by the farmer show the problem that such obstacles are not merely quantitative economic issues like investment costs and amortization periods, but also qualitative issues, being related to skills and training issues, the fear of technology failure and uncertainty about several management issues like provision of services and alike. Respectively, the majority experts rate the costs of adoption of P. F as high or very high, with only a minority stating that they expect low costs of adoption (Figure 3.4).

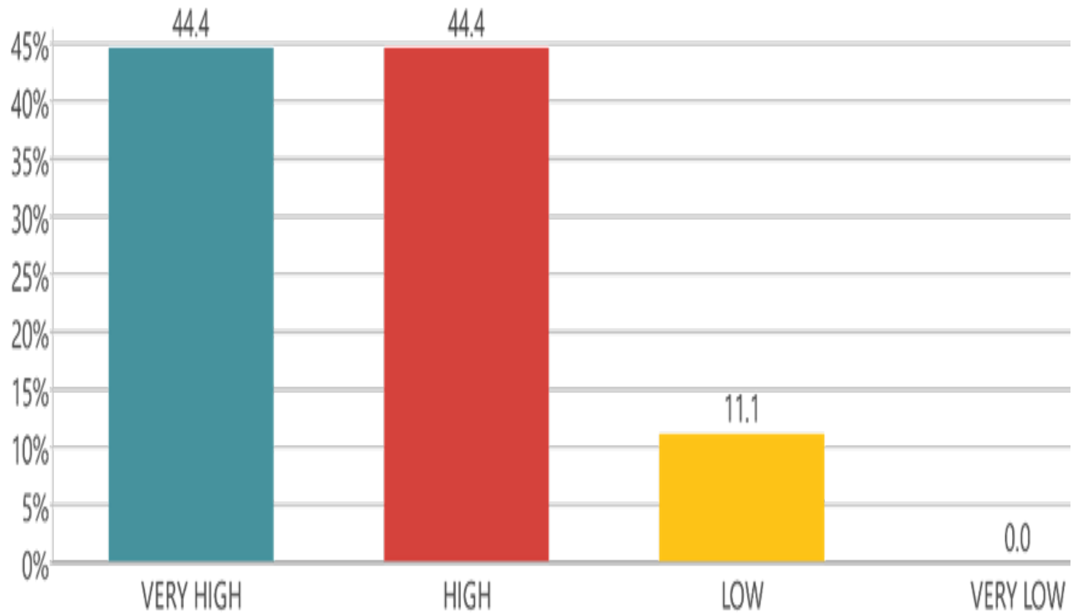

Figure 3.4: Rating of cost of adopting P. F by P. Fs and experts.

This clearly indicates the need for extension services and training support for farmers willing to introduce P. F, as also stated by the farmers themselves (Figure 3.5). It may also be that the subsidy programmes in Baden-Württemberg mentioned in Chapter 1.2 need to be better advertised or set up in a more user-friendly way.

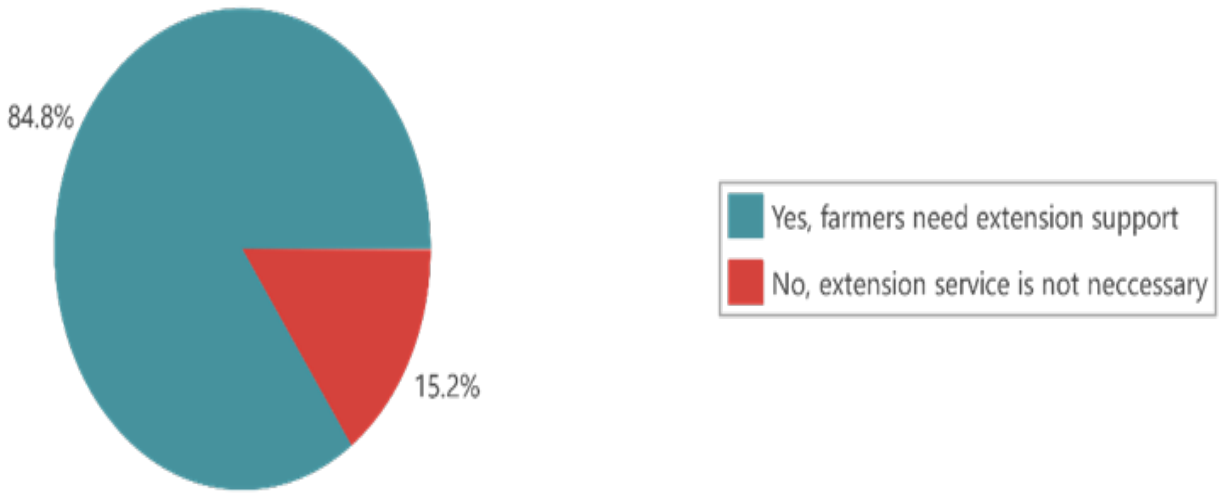

Figure 3.5: Rating the need for extension service/expert support in P. F adoption

4. CONCLUSION AND RECOMMENDATION

Precision Farming is yet to come to a relatively small-structured region in terms of agriculture, like the southwestern German State of Baden-Wuerttemberg. This region may serve as an example for wider regions in Europe, where P. F is not yet present but will be an option in the future, due to structural change with farms getting bigger and technological innovation, making P. F suitable also for smaller farms. It is therefore important to assess the economic benefits and costs, as well as the social and also psychological obstacles to the adoption of these new technologies. This study approaches the issue of costs and benefits, opportunities and obstacles not from a merely academic point of view. It deliberately examines the views of the main stakeholders, the farmers who are potential adopters and non-adopters and therefore the crucial decision makers in the process of introducing P. F. Results of the survey show that introducing P. F on a wider scale will not be easy, as many reservations by actual and potential adopters are observed. While benefits of precision farming are well perceived and accepted, costs and obstacles are also quite prominent. While the environmental and societal benefits seem to be weighted higher than the actual enterprise or private benefits, obstacles are perceived both at the investment and managerial levels, the latter including problems of stable and secure handling of data and technologies, but also socio-psychological reservations arising from a lack of training or human capacity and skills.

Consequently, if society wants to increase the acceptance and adoption rate of P. F, it has to follow two types of measures: First, it has to support investments to reduce the investment risk and increase the economic attractiveness of P. F. Secondly, training and extension has to be increased and focused on the needs and fears of potential investors, in order to remove the social, organizational and managerial obstacles of P. F investments. Given the environmental and social benefits of precision farming, such societal or governmental efforts are well justified.

ACKNOWLEDGEMENTS

This research received full funding from the Baden-Württemberg-Stiftung hence, the researchers are very grateful. However, the content of this paper is a sole work of the researchers and was not in any way influenced by the Baden-Württemberg-Stiftung.

Appreciation also goes to Dr. Amos T. Kabo-bah, Nina Schäfer and Kate Afram for their organizational and administrative contribution throughout the research.

Much gratitude is hereby given to Mr. Abdallah Ali-Nakyea and his family for the diverse charities made in the life of Anaba before and during the research. The families of the authors have been supportive throughout the work of this paper and deserve much love and appreciation.

REFERENCES

Aubert, B. A., Schroeder, A., & 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. https://doi.org/10.1016/j.dss.2012.07.002

Bongani Ncube, W. M. and A. F. (2018). Precision Agriculture and Food Security in Africa. *ResearchGate*, *July 2019*. https://doi.org/10.1007/978-3-319-71486-8

destatis.de (2022): Betriebsgrößenstruktur landwirtschaftlicher Betriebe nach Bundesländern. online: https://www.destatis.de/DE/Themen/Branchen-Unternehmen/Landwirtschaft-Forstwirtschaft-Fischerei/Landwirtschaftliche-Betriebe/Tabellen/betriebsgroessenstruktur-landwirtschaftliche-betriebe.html, accessed on 25.3.2022.

FAO & PAR. (2011). *Biodiversity for Food and Agriculture Contributing to food security and sustainability in a changing world* (I. Bioversity (ed.)). The Food and Agriculture Organization of the United Nations and the Platform for Agrobiodiversity Research. http://www.unwater.org/downloads/waterscarcity.pdf

Hayati, D., Ranjbar, Z., & Karami, E. (2011). *Measuring Agricultural Sustainability*. *5*. https://doi.org/10.1007/978-90-481-9513-8

Joint Research Centre (JRC) of the European Commission (EC); Monitoring Agriculture ResourceS (MARS) Unit H04; Pablo J. Zarco-Tejada, Neil Hubbard and Philippe Loudjani1. 2014. "Precision Agriculture: An Opportunity for Eu Farmers- Potential Support With the Cap 2014 - 2020." *European Union*: 56

Landesanstalt für Landwirtschaft, Ernährung und Ländlichen Raum (LEL) (2019): Agrarmärkte Jahresmärkte 2019. Schwäbisch Gmünd

Ministerium für Ländlichen Raum und Verbraucherschutz Baden-Württemberg (2017): FAKT Förderprogramm für Agrarumwelt, Klimaschutz und Tierwohl Baden-Württemberg. Stuttgart.

OECD. (2001). *A DOPTION OF T ECHNOLOGIES FOR S USTAINABLE F ARMING S YSTEMS W AGENINGEN W ORKSHOP P ROCEEDINGS*. www.copyright.com

Paustian, M., & Theuvsen, L. (2017). Adoption of precision agriculture technologies by German crop farmers. *Precision Agriculture*, *18*(5), 701–716. https://doi.org/10.1007/s11119-016-9482-5

Reichardt, M., Jürgens, C., Klöble, U., Hüter, J., & Moser, K. (2009). Dissemination of precision farming in Germany: Acceptance, adoption, obstacles, knowledge transfer and training activities. *Precision Agriculture*, *10*(6), 525–545. https://doi.org/10.1007/s11119-009-9112-6

Reichardt, Maike. (2007). *What do German Farmers think about Precision Farming ?* 28–29.

Remco Schrijver, Krijn Poppe, and C. D. (2016). *Precision agriculture and the future of farming in Europe Scientific Foresight Study*.

YU, M. (2000). *Economic and Environmental Evaluation of Precision Farming Practices in Irrigated Cotton Production.* [Texas Tech University]. https://ttu-ir.tdl.org/ttu-ir/bitstream/handle/2346/12539/31295016527805.pdf?...1