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Third Annual Report for Researchers On Research Priorities On The Use Of Sensor Technologies To Improve Productivity And Sustainability On Dairy Farms

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EXECUTIVE SUMMARY

Precision Livestock Farming (PLF) informs farm management through continuous automated real-time monitoring of production parameters, animal health and welfare and environmental impacts. The potential benefits associated with PLF are far-reaching: improved animal health and welfare associated with reduced use of antibiotics and treatment costs, increased productivity and product quality, and fewer adverse environmental impacts.

A survey was developed to identify research priorities regarding the use of sensor technologies to improve productivity and sustainability on dairy farms according to relevant professionals. The survey was distributed by 4D4F project partners and responses were collected between January 2018 and January 2019. In total, 300 responses were obtained, the majority of which were from farmers, followed by researchers and farm advisors, responses from veterinarians were limited.

Overall, the priority areas for research were mastitis, nutrition, reproduction and lameness. Most respondents had experience in more than one area of sensor functionality, most commonly in heat and mastitis detection. A large proportion of respondents felt there is not enough independent information available on the use of various sensors used in dairy farming.

The study has highlighted the following areas as the top priority for research:

- Sensors which can diagnose health issues, particularly mastitis, lameness and metabolic diseases. Especially conditions with complex aetiology, to identify the specific pathogenic (or other) cause.
- Improve the sensitivity and specificity of sensors for detecting oestrus, pregnancy and calving.
- Sensors for feed intake and feed efficiency as well as for rumination and metabolic diseases to better manage cow nutrition.
- Integration of multiple sensors and data into one system to provide real-time information and action points for farmers to base decisions on.
- Independent cost-benefit analysis of sensors to provide farmers with an idea the most appropriate applications for their farm and potential return on investment.

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1. INTRODUCTION

This report is part of the Horizon 2020 EU Data Driven Dairy Decisions for Farmers (4D4F) project investigating the use of sensors in dairy farming. It highlights areas for future research on the use of sensor technologies to improve productivity and sustainability on dairy farms. In particular, the report discusses the top future research priorities identified by farmers, advisors, researchers and veterinarians in project partner countries.

The dairy farming sector is facing substantial challenges, including reduced profit margins, food safety, antibiotic resistance, welfare and pressure from both government and non-governmental organizations to minimise farming activities which degrade the environment. Precision Livestock Farming (PLF) can be used to tackle some of these challenges through continuous automated real-time monitoring of production parameters, animal health and welfare, and the associated impact on the environment (Berckmans 2014). The dairy farming sector requires smart approaches which aim to increase efficiency while reducing the cost of production, improving general animal welfare and minimising environmental impacts.

The potential benefits associated with PLF are far-reaching: improved animal health and welfare associated with reduced use of antibiotics and treatment costs, increased productivity and product quality, and fewer adverse environmental impacts (Berckmans 2014). PLF is proving to be the next important technological breakthrough for the 21st century dairy industry as it can provide the farmer with real-time information about the animal and support speedy decision-making in the busy farming environment. This report therefore aims to identify areas to prioritise for future research on the use of sensor technologies to improve productivity and sustainability on dairy farms. It is hoped that the findings will provide some guidance to project funders in allocating future research funds. Additionally, it will also act to inform researchers working on sensor technologies, dairy cattle health, reproduction, nutrition, housing and other relevant areas that contribute to sustainable dairy production.

2. DAIRY FARMING AND THE USE OF SENSOR TECHNOLOGIES

2.1 Areas of dairy farming productivity

There are several key areas that determine productivity in dairy farming. These include mastitis, lameness, nutrition, metabolic diseases, reproduction, calf and youngstock performance, grassland management, and housing. Milking data and cow activity and behaviour provide useful indicators relating to these areas and data management is key to ensuring that information provides useful insight to inform decision-making on farms.

Mastitis is a major cause of economic loss in the dairy industry, but farmers often underestimate the costs associated with mastitis on their farm (Huijps, Lam and Hogeveen 2008). Clinical and subclinical mastitis cases contribute to reduced milk yields, higher treatment costs, more frequent antibiotic usage and early culling of animals (Huijps, Lam and Hogeveen 2008, Ibrahim 2017). With increasing focus on milk quality and demand for lower somatic cell counts, it is important that dairy producers have tools with high precision in detecting early signs of disease; they can act quickly, ultimately reducing mastitis incidence and effectively managing clinical cases.

Lameness is one of the most common dairy cattle issues which impacts on performance, profitability, health and welfare. Lameness hinders the expression of normal behaviour; cows show less interaction with other animals in the herd and reduced activities, including oestrus behaviour (Green, et al. 2002, Juarez, et al. 2003, Huxley 2013). Research suggests producers underestimate the prevalence of lameness (Cutler, et al. 2017), thus technological methods for lameness detection to improve foot health would be worthwhile developments.

Dairy cow nutrition is a key factor in profitable milk production. Nutritional requirements vary depending, in part, on the production stage of the animal and diet contributes to health and immunity (Sordillo 2016). Proper feeding requires knowledge of the nutrient-content of feedstuffs combined with the physiological needs of individual animals to formulate and adjust the feeding ration accordingly (Krasniqi, et al. 2018); PLF technologies could provide tools to facilitate optimal feeding on-farms.

Metabolic disorders such as ketosis affect milk production and are associated with an increased risk of developing other diseases (Raboisson, Mounié and Maigné 2014) and reduced reproductive efficiency (Rutherford, Oikonomou and Smith 2016), thereby affecting farm profit due to increased calving interval and reduced milk production (Reith and Hoy 2018). Systems which monitor reproductive parameters such as oestrus detection, and/or provide early warning signs for metabolic diseases would benefit dairy farming businesses.

2.2 Types of sensor technologies used in dairy farming

Sensor technologies are used in dairy farming to electronically monitor livestock, their environment, and to collect data to make informed real-time decisions. Currently there are several sensors which are being used in many dairy farms across Europe and other countries, examples of these are shown in Table 1. Sensor systems generally measure something about the cow, and changes in sensor data can be interpreted to inform about the cow's status. Sensor information may then be integrated with other sources to provide advice (Rutten, et al. 2013). Sensors are being employed on farms to monitor areas including, but not limited to:

- **Reproduction:** monitoring the activity of individual cows using pedometers or accelerometer systems can be used to identify behavioural signs of oestrus (Mottram 2016, Reith and Hoy 2018). In-line biosensors can detect markers for ovulation and pregnancy in milk, including levels of progesterone (Mottram 2016). Onset of calving can also be detected by restless activity, vaginal temperature changes, and tail mounted sensors measuring tail movement patterns triggered by labour contractions (Mottram 2016).
- **Animal health status:** accelerometers can also be used to record cow behaviour for rumination, feeding, lying and walking activity; decreased rumination and feeding time are associated with elevated somatic cell count, providing an early warning for clinical mastitis (Jaeger, et al. 2019). Infrared temperature patterns of a cow's body can be an indicator for hoof and udder health, where increased temperature readings were associated with early signs of lameness and mastitis

(Poikalainen, et al. 2012). In-line milk analysis can also be used to monitor udder health (Mottram 2016).

- **Rumination:** audio data can provide information about rumination and eating activities and wireless telemetry boluses allow measurements of rumen pH and/or temperature to alert to metabolic disorders (Mottram 2016).

Table 1: Dairy sensor technologies, what they measure and associated alerts

Type of Sensor	Measuring	Alerts
Movement/Location	• Activity/behaviour • Rumination • Eating time • Resting time • Lying time • Walking time	• Heat • Health • Calving • Lameness • Location
Milk Analysis	• Progesterone • Ketones • Lactate Dehydrogenase • Fat and Protein • Colour • Somatic cell count • Conductivity	• Heat • Ketosis • Mastitis • Milk quality • Milk quality • Milk quality, mastitis • Mastitis
pH	• Rumen pH	• Rumen health • Acidosis
Cameras	• Heat • Body form • Movement	• Mastitis • Ketosis • Lameness • Body condition
Thermometer	• Temperature	• Health • Calving • Water intake
Microphones	• Rumination time	• Rumination • Heat • Calving

3. SURVEY AIMS AND OBJECTIVES

A survey was used to identify research priorities regarding the use of dairy sensors to improve productivity and sustainability on dairy farms according to relevant professionals. The objectives of the questionnaire were;

- to gain information on key areas of dairy farming where research on dairy sensors and data should be prioritised, as perceived by participants.
- to identify participants' experience on the areas of sensor functionalities and suggestions for improvements.
- to identify areas where participants would like to see more research into dairy sensors and the data they produce, and why.
- to identify whether there is enough information provided on the use of various sensors in dairy farming.

4. MATERIALS AND METHODS

A questionnaire was designed and made available on-paper and via a web platform (Google). The data collection period was January 2018 – January 2019. The surveys were distributed by 4D4F project partners to existing contacts and at national and international events and conferences aimed at collecting responses from farmers, veterinarians, researchers, farm advisors and other relevant professionals.

The questionnaire had five sections which were to identify: the areas where research on dairy sensors and the data they produce should be prioritised; respondents' experiences regarding the functionality of sensors used in dairy farming and suggestions for improvement; areas for further research and developments; whether there is enough information provided on the use of sensors in dairy farming to improve profitability, and gather any comments or suggestions in relation to research on sensor technologies.

Data was analysed using Microsoft Excel (Microsoft Office 365 Business) and open-responses were summarised and similar responses combined to understand trends for the variables in question. The questionnaire can be found in Appendix 1.

5. RESULTS

A total of 300 completed surveys were received and deemed to be a fair sample size. Table 2 shows the number of responses by country. Most responses came from the United Kingdom, Romania, the Netherlands, Latvia, Sweden and Estonia. A few responses were obtained from the United States of America, New Zealand, Turkey, Norway, Italy and Portugal.

Table 2: Number of survey responses based on country

Country	Number of Responses
United Kingdom	58
Romania	51
Netherlands	45
Latvia	37
Sweden	36
Estonia	25
Spain	21
Belgium	21
United States	1
New Zealand	1
Turkey	1
Norway	1
Italy	1
Portugal	1
Total	**300**

The highest and lowest response rates were from farmers and veterinarians, respectively, as shown in Table 3.

Table 3: Number of survey responses based on occupation

Occupation	Number of Responses
Farmer	129
Researcher	74
Farm Advisor	65
Veterinarian	32
Total	**300**

5.1 Research priorities regarding sensors and data they produce

As shown in Figure 1, there was a high level of variation in which areas of dairy farming were perceived as priorities for sensor research. On average, mastitis, nutrition and reproduction were ranked most important and goats and grassland management were ranked as lower priority regardless of occupation. Lameness, metabolic disease, calves and youngstock, and data management were also high in the average rankings for different professions.

Reasons given for top-ranked sensor research priorities are summarised in Table 4. Areas affecting farm productivity and profitability and animal health and welfare were key concerns. Sensors which could act as early indicators and increase the speed and/or effectiveness of treatments were considered particularly beneficial. It was often stated that too much data could be overwhelming and is of limited use without information being integrated into one single system for simple analyses to inform decision-making.

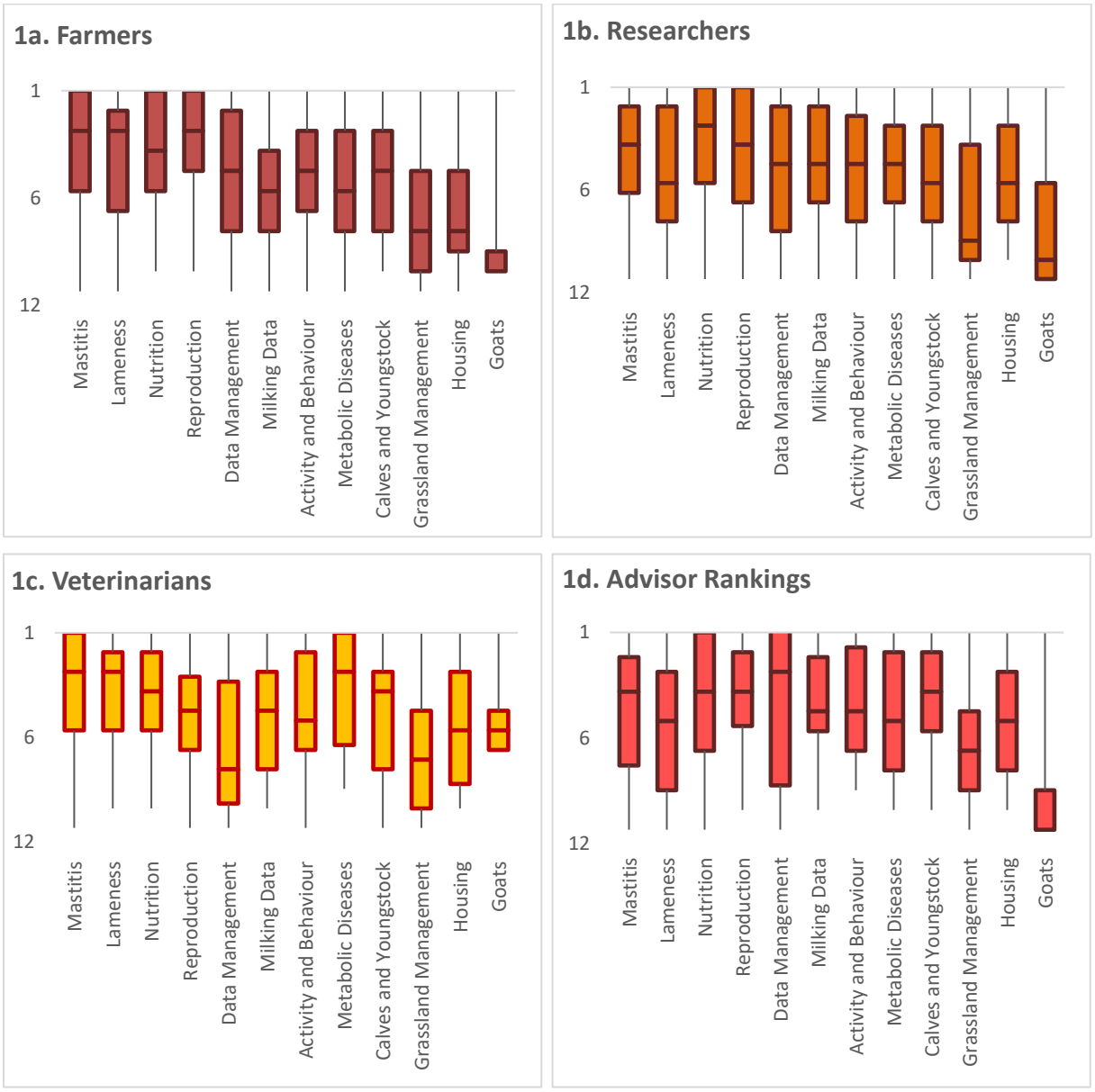

Figure 1: Interquartile ranges of the rankings for the areas of dairy farming where research should be prioritised (1 = most important, 12 = least important) arranged by occupation.

Table 4: Reasons given by respondents for their chosen research priorities

Research priorities	Reasons
Mastitis	High incidences and use of antibiotics on dairy farms need to be reduced Economic and production impacts Animal health and welfare implications Early detection for faster treatment e.g. using temperature alerts
Lameness	Commonly underestimated problem on dairy farms Economic and production impacts Animal health and welfare implications Need objective method of mobility scoring for faster, more effective treatment
Metabolic disease	Greater understanding would result in more effective treatment Economic and production impacts Animal health and welfare implications Early/preclinical detection allows for faster treatment
Nutrition	Difficult to evaluate without using technology "You are what you eat"; potentially affects various factors/problems Economic and production impacts Animal health and welfare implications
Reproduction	Economic and production impacts; improve cow longevity Replacement cows are important for herd health
Calves and youngstock	Need for more attention to this area of dairy farming Economic and production impacts; critical for performance and sustainability Future of the herd: genetic potential affects long-term health, welfare and production
Data management	Lots of raw data can be overwhelming and of limited use – interpretation is key Simplify data management and application for farmers Need for integrated data management systems, ideally cloud based. Need for easy cross-referencing, analysis and utilisation of data
Grassland management	Vital for cost-effective food production and sustainability Need to cope with effects of climate change
Activity and behaviour	Greater understanding can aid cow management and decisions Useful indicators of fertility, health and well-being
Milking data	Use data for animal selection and nutrition monitoring to improve milk production
Housing	Effect of housing system on production, efficiency, health and welfare Consider feeding system, water availability, hygiene and management for optimal housing.

5.2 Experience with sensor functionalities and improvements required

The majority of participants (74%) reported to have experience in two or more areas of sensor functionality and 5% did not respond to the question. Heat/oestrus detection and mastitis were the most common areas of sensor functionality with which respondents had experience (Figure 2).

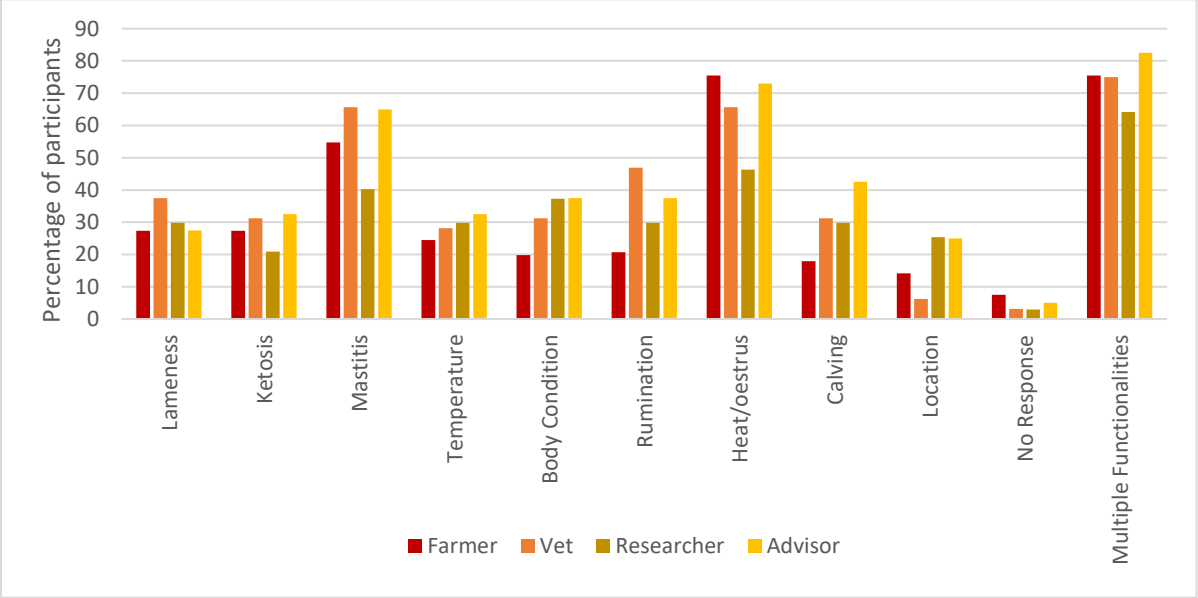

Figure 2: Proportion of respondents with experience of different sensor functionalities arranged by occupation.

The areas of sensor functionality which participants perceived to require improvement are shown in Table 5. Respondents called for more information from sensors which could be actively used to address problems e.g. diagnosing the cause of lameness and mastitis. It was also stressed that sensor data should be combined into an integrated system, requiring collaboration between manufacturers to ensure compatibility of their products, to give a comprehensive overview of the farm and any problems. Ultimately any data must be presented in a simple, user-friendly and informative format. Some were concerned about data protection (who owns the data and can utilise it) but creation of a centralised database to benchmark and share solutions was considered beneficial.

Table 5: Areas of sensor functionality which require improvements and why according to respondents

Area for improvement	Reasons
Lameness detection	Need to account for individual differences between cows Go beyond identifying lame cows to diagnose the cause of lameness Suggest improvements for ground tracks Improve identification of locomotion problems at an early stage. Link to aspects such as housing/grazing/feeding/ground tracks.
Mastitis detection	More targeted sensors to identify cause and improve treatment Improve application by giving specific treatment advice
Nutritional management	Increase precision and improve system for rumen feeding Could adjust ration according to phases of a production cycle, milk production and physiological status Utilise milk data to improve computerised feed management decisions
Reproduction	Improve heat detection accuracy to serve cows at optimal time Improve calving monitoring and detection of related diseases Tail-mounted sensor for calving monitoring falls off too easily
Calves and youngstock	Few sensors available to monitor health in young calves (first 14 days) Could use smart body temperature monitoring
Housing	Improve identification of animal preferences for position/other animals Improve hygiene monitoring/management Monitor effects on reproduction and milk production
Cost of technology	Technology must become economically viable for any farm Improve durability and battery life to span the life of the animal
Integration of data systems	Standardise platforms so data from multiple systems are compatible and can be viewed and analysed from a single application Enable centralised data storage for benchmarking and sharing solutions to problems to allow farmers to learn from one another Could integrate a section to represent market demands
Sensor accuracy, reliability, specificity and sensitivity	Must give better results with fewer false positives or negatives. Improve identification of early indicators of disease Focus more on sensors that directly measure an issue and are unambiguous Give more specific information for more targeted action
Link sensor data to actions/results	Translate sensor data into results and information to alert farmers to issues Use data from a combination of sensors to create and implement action plans Analysis of data with clear communication about cow/farm

5.3 Areas where more research is required and why

Most participants requested further research in areas which could best help to achieve optimal animal health and productivity (Figure 3). Animal health and welfare were key concerns mentioned in relation to a variety of areas and participants would value further research and tools to enable early/subclinical disease detection; it was suggested that activity and behaviour could be used to identify early warning signs for problems regarding housing, stress and production. Areas relating to farm efficiency and profitability were also of interest; either due to sources of loss e.g. mastitis, lameness and poor fertility which contribute to culling rates, or as drivers/indicators for productivity, including good health, body condition, nutrition, rumination and calves/youngstock. Data management was also considered a priority research area to be able to cross-reference and link data in an integrated system which provides action points; a common example would be to link milking data with nutritional information to calculate feed efficiency and optimal feeding rations.

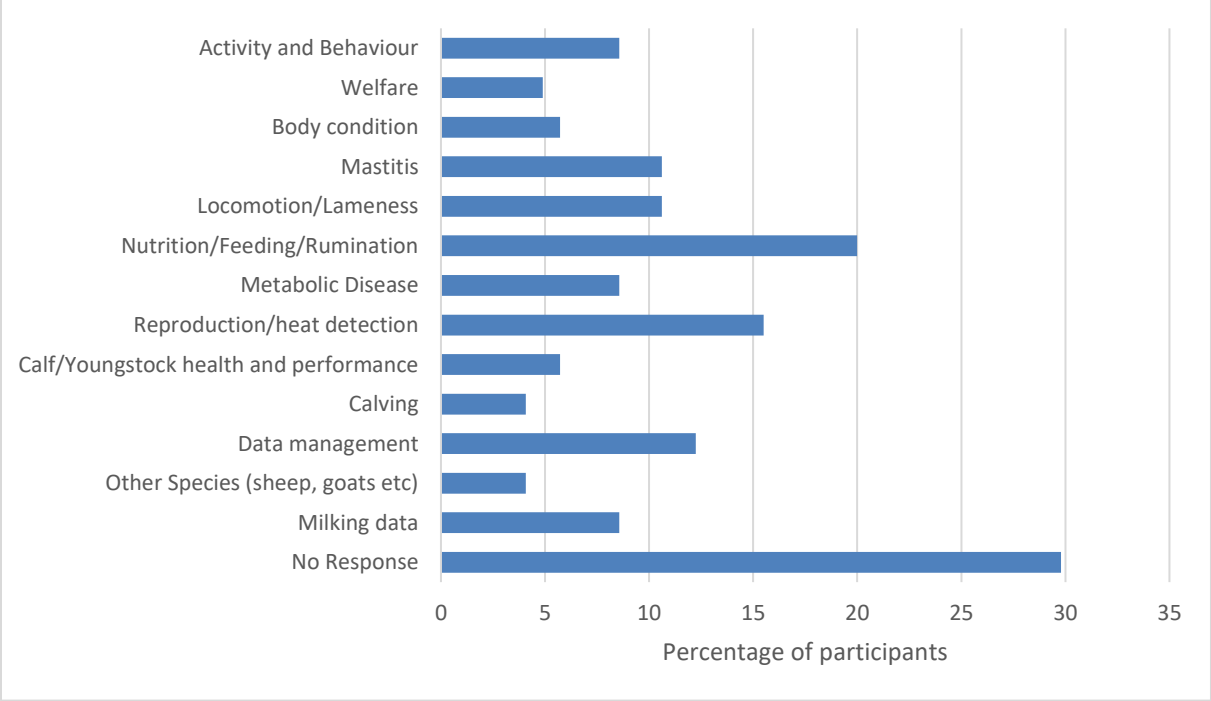

Figure 3: Proportional representation of most frequently mentioned areas in which respondents felt more research is required

5.4 Information on dairy sensors

Approximately 43% of the participants answered that there is insufficient information about using sensors. 25% of participants did not respond to this question. The main criticism was that available information was commercially biased. Participants requested independent information providing a comprehensive cost-benefit analysis that gives clear information about the potential return on investment as well as economic efficiency expected from utilising sensors according to farm size. A list comparing the different sensors available, their compatibility with other sensors and data management systems, and which farm aspects they assess would support decisions aiming to address problems on farm. Information about the practical applications of data, ideally including farmer-led training/demonstrations on farms using sensor technology was also suggested, which could be made possible by forming a list/database of livestock farmers that are using sensors. There was also call for greater access to research for farmers, veterinarians and advisors and wider dissemination of information in a variety of languages which accounts for the wide-ranging education levels in the farming sector.

6. DISCUSSION

A much greater response rate by farmers than from any other occupations indicates good engagement but may also reflect greater numbers of farmers compared to other dairy professionals in the population. Low uptake by veterinarians could reflect selection bias from the types of events where responses were sought, or that veterinarians are less aware of the application of sensors in dairy farming and require more targeted information to promote the use of PLF techniques in preventive health management. Responses from outside the European partnership countries indicates a global relevance to utilising sensors in dairy farming and the potential reach of 4D4F.

The high level of variation in rankings for research priorities suggests there are no stand-out aspects of dairy farming which are of interest per se. The aim of research or the overall effect is perhaps more important than which specific area is studied. Consistently throughout the questionnaire sections, participants indicated that they were interested in information that could improve animal health and welfare and farm productivity and profitability – the areas in dairy farming which contribute to these topics are vast and overlapping. This may explain why there was little agreement on which areas of dairy farming research should be focused on since different individuals would have different opinions about which farm factors most effect herd health and profitability. However, there was general agreement that mastitis, nutrition, reproduction and lameness were important research priorities. Advisors also prioritised data management and veterinarians favoured animal health issues, indicating the importance of these areas to those professions. Veterinarians' opinions deviated most from the three other groups, which could be due to the poor response rate from veterinarians; only 32 answered the survey and they were spread among eight countries. Goats were consistently ranked as a low priority which was not surprising; dairy cattle are more common than dairy goats and few goat farmers participated in the survey.

Most respondents had experience with one or more sensor functionalities, with mastitis and heat detection being the most common applications. This is in line with previous

research indicating that adoption of sensors by farmers is low, except for activity monitoring or pedometer systems used for detection of oestrus, or mastitis sensor systems associated with automated milking systems (Steeneveld and Hogeveen 2015). Participants were wary about the reliability and accuracy of sensors, with several requesting a reduction in false positive or negative results. Several suggested improvements to sensor functionalities related to the subclinical diagnosis of mobility problems and mastitis. Thermal imaging (E.g. Miracle Tech) combined with activity sensors (e.g. CowAlert) can be used for subclinical diagnosis of the cause of lameness. This indicates that respondents were unaware of all the available technology. Most interest in further research was for the areas of metabolism and rumination, oestrus detection, mastitis, lameness and data management. Nutrition and rumination sensors is an area of great potential. Further developments are needed to measure feed intake with high precision. A reliable solution for measuring feed intake will have large impacts on productivity, animal health and farm economy.

Farmers and advisors being unaware of the most recent developments in sensor technologies are not the only hurdles to overcome. Previous research found reasons for not investing in sensor systems included other investment priorities on the farm, uncertainty about the cost-benefit of investing in sensors, expecting poor integration of sensor data with other farm systems and software, and waiting for improved versions of sensor systems (Steeneveld and Hogeveen 2015). These concerns can be affected by how recently sensor technologies were developed. Sensors for oestrus detection were first developed in the 1980s (Mottram 2016) and significant technological improvements have been achieved since then, making them worthwhile immediate investments. Newer technologies may still undergo further development and the economic benefit of adopting these sensor systems is uncertain so investment is likely to be postponed (Rutten, et al. 2018). Farmers are unlikely to utilise sensor technologies if they do not have the information to make informed decisions. This may be why many participants from the current survey desired independent research showing cost-benefit analyses for the adoption of sensor systems for a range of farm sizes and systems as well as a

comprehensive list of sensors which compares their functionality and compatibility with other systems and software. These issues have been partially addressed on the 4D4F website (https://www.4d4f.eu) where a 'technology warehouse' provides an overview of commercial technologies available, but further research particularly on the return on investment for adopting sensor technology is required.

It is also important that information is translated into different languages. Many farmers are not multi-lingual so resources must be available in their native language for inclusivity. Also, many farms employ hired personnel from other countries and may require information to be available in other languages to support their staff. Some farmers were also wary of research conducted in other countries or farming systems so research and information must also translate to different farming contexts.

Regardless of what is studied, and which data sensors collect, the importance of data management and integrated systems is clear. Data is useless unless the farmer can learn something from it and act upon it. Cross-referencing data from different sensors and information sources (e.g. current market price for feed) and displaying the analysis in a simple format, perhaps linked to Standard Operating Procedures, would have the most useful impact for a farm business. However, most research has focused on techniques that monitor the cow's status without further supplementing that data from other sources (Rutten, et al. 2013), and often investigate one issue at a time, whereas a farm deals with multiple interlinked issues. Hence, there is much work to be done on data integration.

7. CONCLUSION

In summary, respondents were most interested in the application of sensor technologies to areas of animal health and welfare and farm efficiency and profitability. Health issues, particularly mastitis, lameness and metabolic disorders, were key areas of interest to better identify the causal factors contributing to conditions and improve early diagnosis for more efficient treatment. Most experience in sensor functionalities related to mastitis and heat detection, suggesting further research efforts to assure farmers of the

effectiveness and financial return on investment for the application of sensor technologies to other aspects is required. Data management and integration of systems is an extremely important element of sensor technologies to ensure that farmers can invest in systems which provide useful outputs which are at least compatible with, if not integrated with, other systems and software. PLF technologies are extremely useful tools in dairy farming, but sensor technologies must be proven to be useful and cost-efficient for farmers to consider them worthwhile investments.

8. RECOMMENDATIONS

This study has identified several areas in dairy farming which would benefit from further research about the application of sensor technologies. The top recommendations for further research are listed below:

- Sensors which can diagnose health issues, particularly mastitis, lameness and metabolic diseases. Especially conditions with complex aetiology, to identify the specific pathogenic (or other) cause.
- Improve the sensitivity and specificity of sensors for detecting oestrus, pregnancy and calving.
- Sensors for feed intake and feed efficiency as well as for rumination and metabolic diseases to better manage cow nutrition.
- Integration of multiple sensors and data into one system to provide real-time information and action points for farmers to base decisions on.
- Independent cost-benefit analysis of sensors to provide farmers with an idea the most appropriate applications for their farm and potential return on investment.

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APPENDICES: APPENDIX 1

This is a questionnaire into the use of sensor technologies to improve productivity and sustainability on dairy farms.
Your answers will influence the areas where future research is prioritised.

Contact details	
Name	
Email	
Occupation (please tick)	
Farmer	
Vet	
Researcher	
Farm advisor	
Other (please specify)	

1. Where should research on dairy sensors and the data they produce be prioritised. On a scale of 1 to 12, rank in the order of importance of each area. Give reasons why for your **top 3** ranked categories? Please note each score can only be used once.
   1 = Research should be prioritised in this area
   12 = Not much research required.

Areas of dairy farming	**Ranking**	**Why**
Mastitis		
Lameness		
Nutrition		
Reproduction		
Data Management		
Milking Data		
Activity and Behaviour		
Metabolic Diseases		
Calves and Youngstock		
Grassland Management		
Housing		
Goats		

2. The following are examples of functionalities for sensors used in dairy farming. Please tick the categories where you have experience. Do you have any suggestions for possible improvements?

Sensor functionality	**Have experience (please tick)**	**Comments/ Improvements required**
Lameness		
Ketosis		
Reproduction		
Mastitis		
Temperature		
Body condition		
Rumination		
Heat/oestrus		
Calving		
Location		

3. Which **3 areas** would you like to see more research into dairy sensors and the data they produce and why?

More research required	**Why?**

4. Do you feel there is enough information provided on the use of the various sensors in dairy farming to improve profitability?

a) Yes b) No

If no, what specific information is lacking?

.....

5 Please provide any other comments or suggestions in relation to research on sensor technologies

Thank you for completing the research questionnaire.