Horizon 2020
European Union Funding
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4D4F

WP5 Dissemination of Industry Feedback
Deliverable 5.3

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

Contractual Date of Delivery to the EC 28/02/2018
Actual Date of Delivery to the EC: 28/02/2018
Participants: IfA**,** EMU, VHL , ILVO, KUL, ZLTO, KIM, LAS, IRTA, KSLA, USAMV, DeLaval, Wim Govaerts& Co, and Liba
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Nature: Report
Document version: Final

Dissemination level		
PU	Public	☒
PP	Restricted to other programme participants (including the Commission Services)	☐
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CO	Confidential, only for members of the consortium (including the Commission Services)	☐

"*This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 696367*"

European Commission

DOCUMENT CHANGE RECORD			
Version	**Date**	**Notes / Change**	**Author**
V1.0	25/02/2018	First Draft	Joshua Onyango
V1.1	28/02/2018	Final	Joshua Onyango

EXECUTIVE SUMMARY

Precision Livestock Farming (PLF) can be defined as the management of livestock farming by continuous automated real-time monitoring of the health and welfare of livestock and the associated impact on the environment. The benefits associated with PLF are far-reaching: improved animal welfare, improved profitability, improved product quality, minimised adverse environmental impacts and reduced use of antibiotics through preventive health measures. A survey was developed to investigate the use of sensor technologies in relation to improved productivity and profitability on dairy farms, in order to give some guidance for further research priorities in the 4D4F research project for funding organizations around Europe. The survey was sent out in December 2017 to project partners in eight countries in Europe. The target audience were people in different occupations (farmers, veterinarians, farm advisors and researchers). In total, there were 158 replies by the end of January 2018 with the highest replies having come from farmers. Overall, the three top areas of dairy farming identified were; lameness, mastitis, and activity and behaviour. On experiences in the areas of functionality of sensors, most respondents were experienced in more than one area of sensor functionality. A significant number of respondents across all the occupations felt there that there is not enough information provided on the use of the various sensors used in dairy farming.

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

- Research on how to integrate sensors to single farm management system as part of the improvements required for the different sensor functionalities.
- Further research on sensors which can capture specific dairy cow health issues, and those with complex aetiology, for example, mastitis caused by *Escherichia coli* and infectious and non-infectious forms of lameness
- Specifically, farmers want research to focus on producing relatively cheap sensors and detailed cost benefit analysis which will help farms make informed decision whilst looking at the rate of return on investment .

In conclusion, the survey has highlighted several areas where research on sensor technologies should focus on in order to improve productivity and sustainability on dairy farms.

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TABLE OF CONTENTS

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1. INTRODUCTION

This report is part of the Horizon 2020 EU Data Driven Dairy Decisions For Farmers (4D4F) project looking into 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. The report, in particular, discusses the top future research priorities identified by farmers, veterinarians, advisors and researchers 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. There is an urgent need for precision approaches to tackle some of these challenges. The dairy farming sector requires smart approaches which aim to increase efficiency while reducing the cost of production, improving general animal welfare and minimising on the environmental impact.

Precision Livestock Farming (PLF) which can be defined as the management of livestock farming by continuous automated real-time monitoring of the health and welfare and the associated impact on the environment might be the immediate thought for farmers in addressing some of the issues associated with dairy production in the EU and across the world. This development is currently changing the shape of dairy farming across the globe, with the majority becoming more common in the developed countries. The benefits associated with PLF are far-reaching: improved animal welfare, improved profitability, improved product quality, minimised adverse environmental impacts and reduced use of antibiotics through preventive health measures (Norton and Berckmans, 2017).

PLF is proving to be the next important technological breakthrough for the 21st century dairy industry where it can provide the farmer with real time information about the animal, and to 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 a number of key areas that determine productivity in dairy farming. These include mastitis, lameness, nutrition, data management, milking data, activity and behaviour, metabolic diseases, calves and young stock, grassland management, and housing. Mastitis is a major problem that causes massive economic losses on most dairy farms thus the need to focus on improving udder health. Improved udder health has been associated with reduced usage of antibiotics, better animal welfare, improved production efficiency (Barberg *et al.*, 2007; Hogeveen and Lam, 2012). 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 which will help to take quick action which ultimately leads to reducing mastitis incidence and effectively managing any clinical cases.

Lameness is one of the most common dairy cattle issues which impacts on performance, profitability and general health and welfare. The disease has been shown to hinder the animal to express normal behaviour; less interaction with the rest of the animals in the herd thus reduced activities such as oestrus behaviour (Green *et al.*, 2002; Juarez *et al.*, 2003; Huxley, 2013). Undeniably, the problem justifies a cognisant effort on the part of every dairy to invest in whatever technology is needed to optimise foot health which is among the key areas for improved productivity. Metabolic diseases such as ketosis and subacute ruminal acidosis have also been associated with reduced productivity in dairy

farming, and any management system identifying early warning signs for such diseases would be ideal for the dairy farming business.

Dairy cow nutrition remains a fundamental pillar of farm businesses and measurements to improve the daily performance of the dairy enterprise are frequently followed by disappointing results. This is because the majority of systems lack the latest tools to monitor aspects such as daily intake. PLF technologies seem to be among the immediate tools which may help tackle both areas of feeding and nutrition in modern dairy farms. A number of these tools allow for measurements of parameters such as cow feeding behaviour and intake, rumen Ph, rumination, rumen temperature and *ß-Hydroxy Butyric Acid* levels which is a series of metabolic tests used in monitoring the transition dairy cow for energy balance and general health. Dairy cow activities, specifically, rumination often predicts cows at risk of metabolic disorders such as ketosis and sub-acute rumen acidosis among others (Norton and Berckmans, 2017).

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 more informed real-time decisions. Currently there are several sensors which are being used in many dairy farms across Europe and other countries. Specifically, these sensors are being employed on farms to monitor areas such as; reproduction activities, herd and individual animal health status, feeding and nutrition, milking data, and housing among others. Research on specific health parameter measurement in dairy cows have been documented. For example, Poikalainen and others demonstrated that infrared temperature patterns of 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). The findings demonstrate the use of precision technologies in detecting early signs of disease ultimately resulting to quick action for better animal welfare and general productivity.

Miura and others reported new developments in oestrus detection in cattle where they monitored ventral tail base surface temperature using a wearable wireless sensor. Even though the study was in its early stages, they concluded that automated monitoring of the surface temperature of the ventral tail base could help detect a substantial change around the time of expression of behavioural oestrus (Miura *et al*., 2017).

Table 1: Examples of dairy sensor technologies, what they measure and associated alerts

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

3. SURVEY AIMS AND OBJECTIVES

The survey aimed to identify research priorities for the Data Driven Dairy Decisions for Farmers (4D4F) project on the use of dairy sensors to improve productivity and sustainability on dairy farms across the European partner countries. It was based on the questionnaire which was distributed among the participating farmers, farm advisors, researchers and veterinarians in project partner countries.

The objectives of the questionnaire survey were;

- to gain information on areas which participants would regard as key in dairy farming where research should be prioritised with reasons for top three ranked categories.
- to identify participants' experience on the areas of sensor functionalities and suggestions for improvements.
- to identify three areas where participants would like to see more research into dairy sensors, data they produce and why research is required in the areas identified.
- to identify whether there is enough information provided on the use of the various sensor used in dairy farming.

4. MATERIALS AND METHODS

A word and web (google) version based questionnaire was designed with the main source of data provided by farmers, veterinarians, researchers and farm advisors from the 4D4F partner countries. The questionnaire had 5 sections which were; to identify the areas where research on dairy sensors and the data they produce should be prioritised, identify the respondents experience with regards to functionalities for sensors used in dairy farming and suggestions for improvement, identify three areas where research in dairy sensors and data they produce should be prioritised, ascertain 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 cleaned in Microsoft Excel (Microsoft Corp) for general analysis in order to be able to understand the trends for the variables in question. The questionnaire can be found in Appendix 1.

5. RESULTS

A total 158 completed surveys were received and deemed to be a fair sample size. The highest response came from farmers while lowest responses were from veterinarians. The breakdown on the number of responses by occupation can be found in table 2 and by country in table 3.

Table 2: Number of responses from the survey based on different occupations

Occupation	Number of responses
Farmer	53
Veterinarian	12
Researcher	45
Farm Advisor	48
Total	**158**

Table 3: Number of response from partner countries

Country	Number of response
United Kingdom	28
Sweden	21
Romania	29
Spain	10
Belgium	3
Latvia	25
Estonia	23
Netherlands	19
Total	**158**

5.1 Farmers

5.1.1 Areas where research on sensors and data they produce should be prioritised

The 3 areas of dairy farming identified by farmers where research on sensors and data they produce should be prioritised were: calves and young stock, mastitis and lameness (figure 1). The most important reasons for these 3 areas were both mastitis and lameness impacts on health and animal welfare including loss of production. For calves and young stock farmers pointed out that the health of animals starts here and they also make up the future herd.

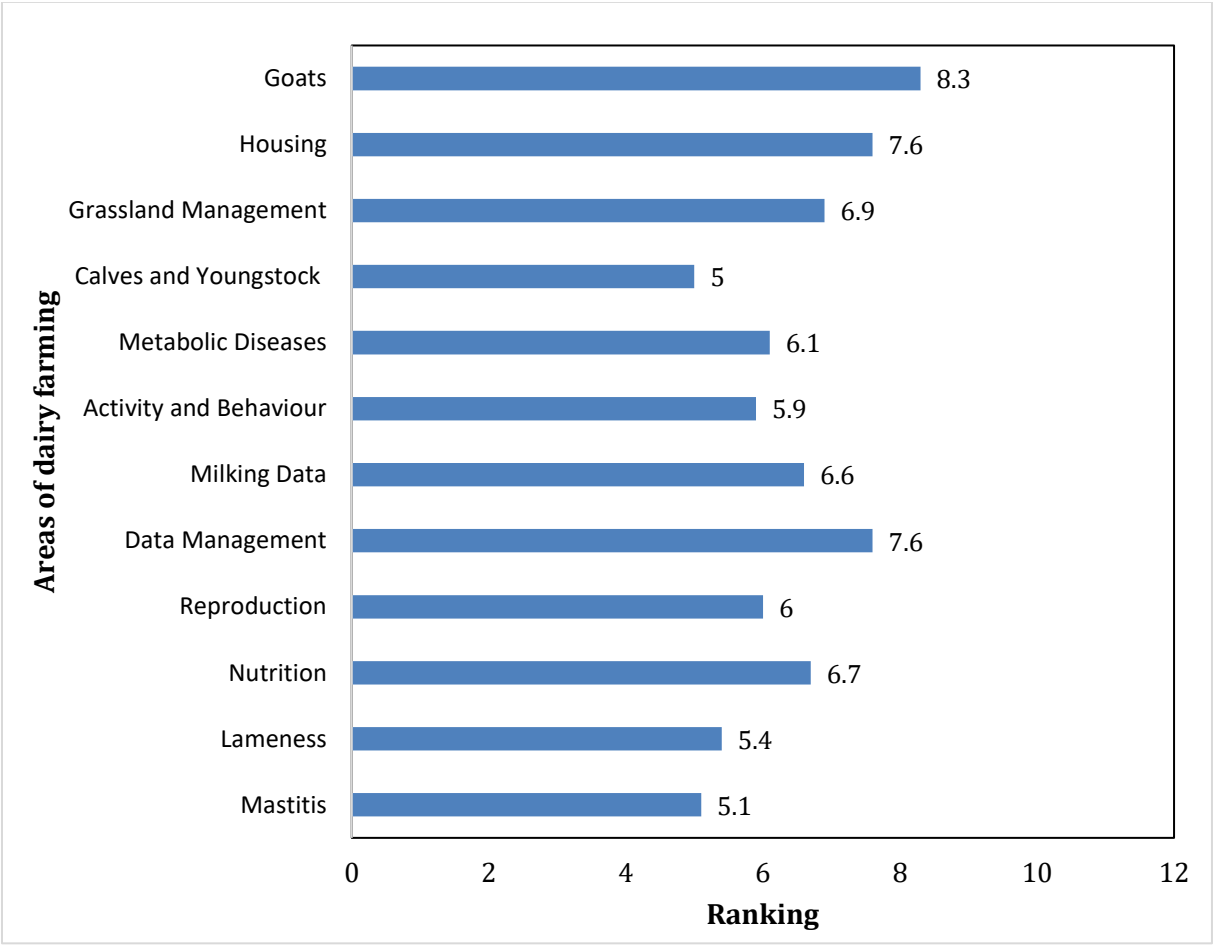

Figure 1: Response from farmers on areas of dairy farming ranked according to where research should be prioritised (1 = research should be prioritised in this area, 12 = not much research required). The figures have been calculated from specific area's total ranking averages.

5.1.2 Experience with sensor functionalities and improvements required

The majority of farmers reported to have experience in more than one areas of sensor functionality . Nine farmers indicated they did not have any experience with any of the sensor functionality (table 4).

Table 4:Farmers experience with areas of sensor functionality

Sensor functionality	Number of respondents
Mastitis	5
Location	1
Reproduction	1
Temperature	1
Lameness	1
Experience in multiple functionalities	35
No experience	9
Total	**53**

Table 6 shows areas of sensor functionality which require improvement as pointed out by farmers. The suggestions were that sensor data could be combined into an integrated system by making this available to the farmers with a number of options to deal with the problems experienced on farms. Farmers also want to have sensors improved to aid in detecting specific health problems, for example, in cases of mastitis caused by *Escherichia coli.* additionally, producing sensors which are not too costly was also an area pointed out by some farmers.

Table 5: Areas of sensor functionality which require improvement

Area for improvement	Number of respondents
Integrated system	16
Specificity	15
Cost	10
Longevity	3
No reply	9
Total	**53**

5.1.6 *Top 3 areas where more research is required and why*

The three areas identified by farmers where more research is required were mastitis, lameness, and oestrus. The full response can be found in table 7. Mastitis was pointed out to be the key welfare issue in dairy production by the majority of farmers. They also pointed out that better research on sensors in detecting mastitis could help with improved approaches to treatment as this would enable targeting drugs used. 17 out of 48 farmers identified oestrus as an area where more research is required. They argued that better oestrus detection will lead to more animals being served in a timely schedule. 5 farmers did not respond to the question.

Table 6: Research priorities areas identified by farmers

Research Priorities	Number of respondents
Mastitis	19
Lameness	12
Oestrus	17
No response	5
Total	**53**

5.1.7 *Information on dairy sensors*

35 farmers felt that there is a lack of enough information on the use of dairy sensors while 10 farmers agreed that the information provided on sensors is sufficient. Eight farmers did not response to the questions (table 7). The reasons for lack of enough information were that only commercial information is available most of the time. Lack of independent information about the economic efficiency of the sensors and how to maximize the use of sensor information were other areas pointed out by farmers.

Table 7: Farmers response on availability of information on sensors used in dairy farming

Enough information on the use of sensors	Number of respondents
Yes	10
No	35
No response	8
Total	**53**

5.2. Veterinarians

5.2.1 Areas where dairy sensors research should be prioritised

There was a low response from veterinarians (12) compared to the other occupations. The top three areas ranked by veterinarians where research should be prioritised were lameness, activity and behaviour and milking data (figure 3). The most important reasons for these 3 areas were the economic and welfare issues associated lameness while parameters on activity and behaviour is a good indicator of animal well-being. They also pointed out that several components of milking data can be used to explain early signs of disease.

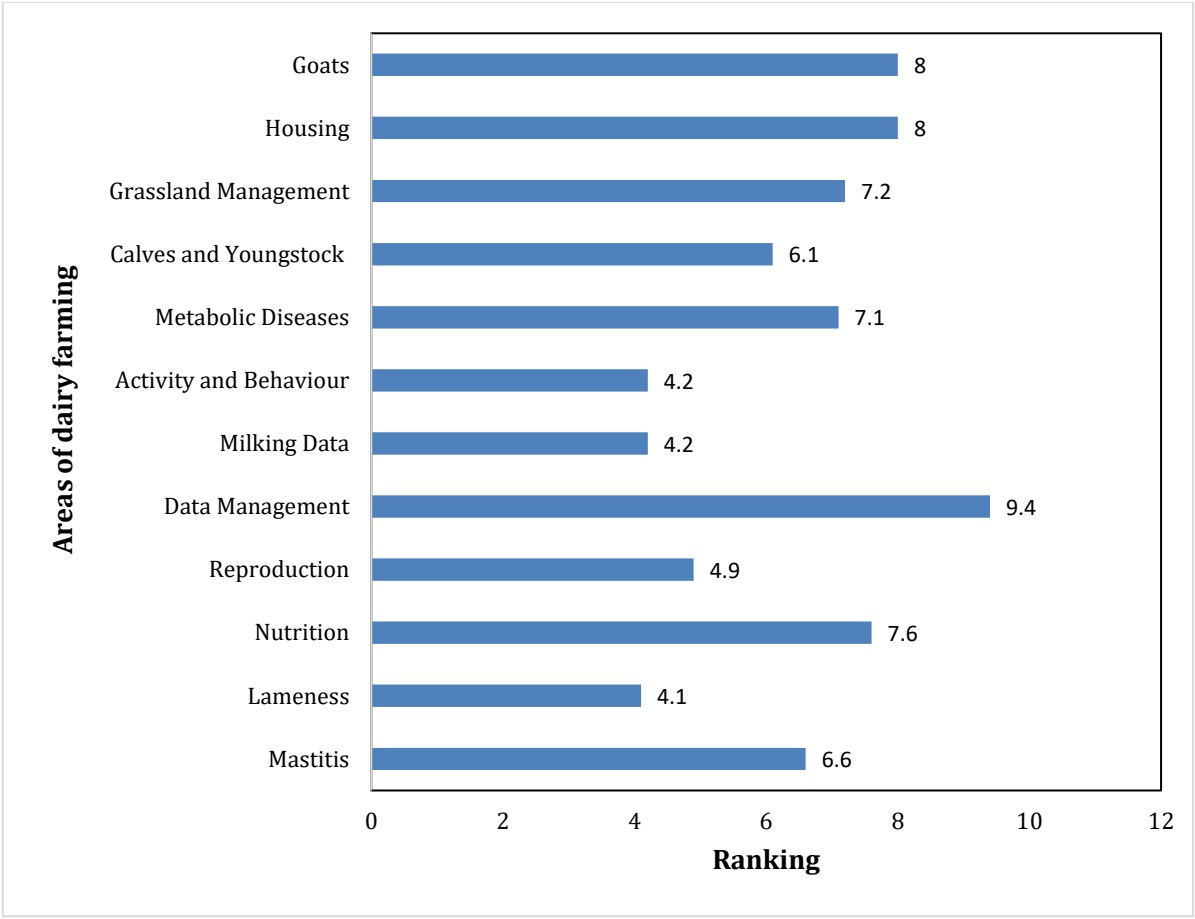

Figure 2: Veterinarians' responses on areas of dairy farming ranked according to where research should be prioritised (1 = research should be prioritised in this area, 12 = not much research required). The figures have been calculated from specific area's total ranking average.

5.2.2 Experience on areas of sensor functionality and improvement required

The majority of veterinarians (9 out of 12) reported to have experience in more than one area of sensor functionality while 2 were experienced in mastitis and reproduction sensors. One veterinarian did not answer the question (table 8). None of the veterinarians suggested any improvements on areas of sensor functionality.

Table 8: Veterinarians experience with areas of sensor functionality

Sensor functionality	Number of respondents
Mastitis	1
Reproduction	1
Experience in multiple functionalities	9
No experience	1
Total	**12**

5.2.3 Top 3 areas where more research is required and why

Table 8 shows top three areas identified by veterinarians where research should be prioritised. These were mastitis, lameness and metabolic diseases. Lameness, mastitis and metabolic diseases were all regarded to be important economic and welfare parameter in dairy production according to veterinarians.

Table 9: Three areas where research should be prioritised

Problems at the farm	Number of response
Mastitis	3
Lameness	6
Metabolic diseases	3
Total	**12**

5.2.4 Information provided on the use of dairy sensors

Figure 3 shows veterinarians response in relation to information provided on the use of dairy sensors. Fifty eight percent (7 out of 12) of the veterinarians felt that there is lack of sufficient information provided on the use of the various sensors used in dairy farming.

They felt that there was a lack of economic calculations about the effects of sensors and limited amount of scientific studies about different relationships between sensor results and animal physiological and pathological conditions.

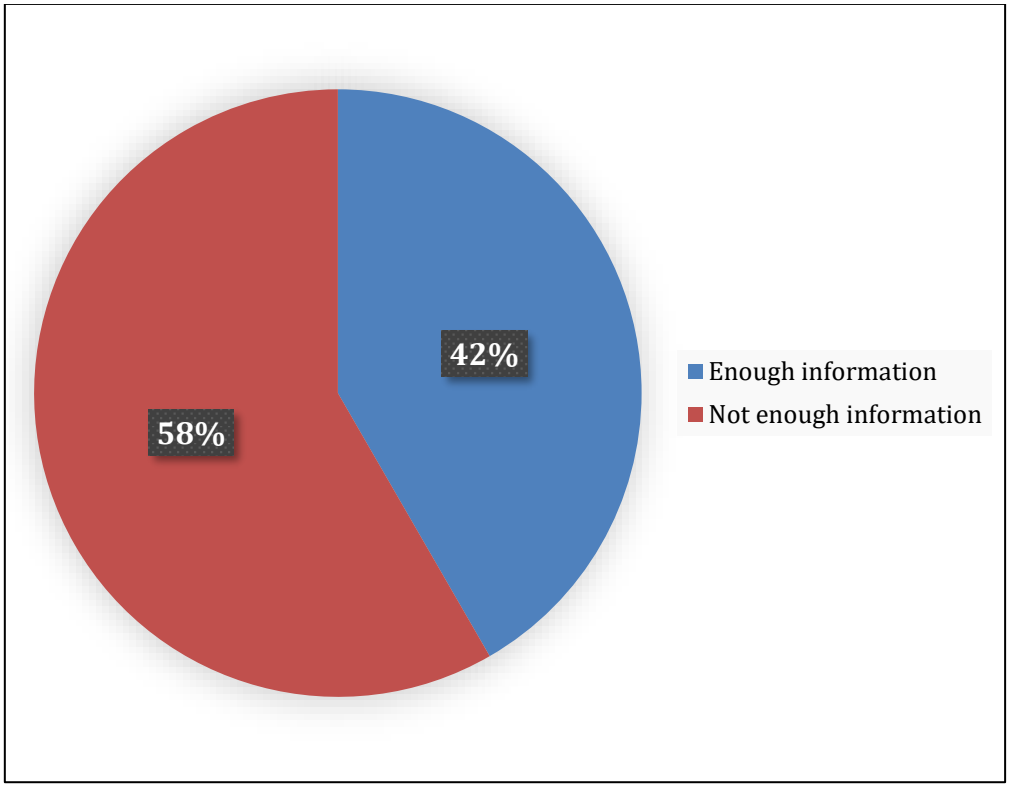

Figure 3: Veterinarians response on information provided on the use of sensors in dairy farming.

5.3 Researchers

5.3.1 Areas of dairy farming where research should be prioritised

Figure 4 shows researchers' responses with regards to areas of dairy farming where research should be prioritised. The top three areas identified were mastitis, data management with lameness and activity and behaviour having equal ranking. The most important reasons for these 3 areas was that there is a lot of data created with no standard operating procedures on how to use them and the need to combine data from multiple sources. Understanding on interpreting variation in the data is still poor according to researchers. They also felt that mastitis impacts on milk quality and health with antibiotic usage being a topical concern globally thus technology would help with early warning

signs allowing early treatments while lameness is a huge welfare issue with a lack of a better way of utilising the existing sensors to get more data out of a system.

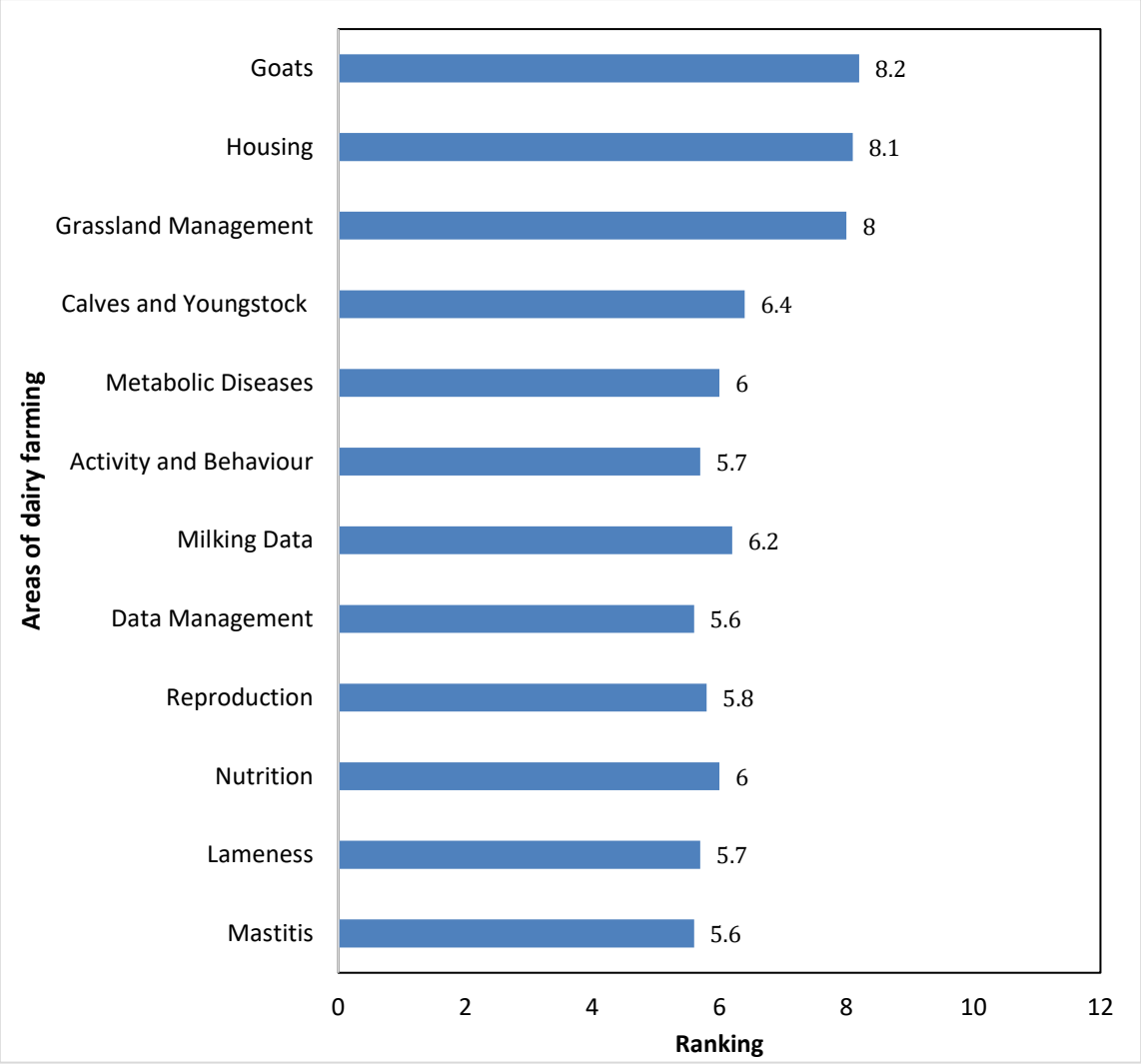

Figure 4: Responses from researchers on areas of dairy farming ranked according to where research should be prioritised (1 = research should be prioritised in this area, 12 = not much research required). The figures have been calculated from specific area's total ranking average.

5.3.3 Experience and suggestions for improving functionality of sensors

33 out of 45 researchers reported to have experience in more than one of the areas of dairy sensor functionality. 8 researchers were experienced in only one area while 4 did not have any experience (figure 5).

Improvements suggested for sensor functionality included better accuracy on standard operating procedures for when to carry out insemination during oestrus. Improvement on the specificity and decreasing cost of the existing sensors for lameness was also pointed out by the researchers. Better detection for subclinical mastitis pathogen detection would also benefit the dairy sector according to most researchers.

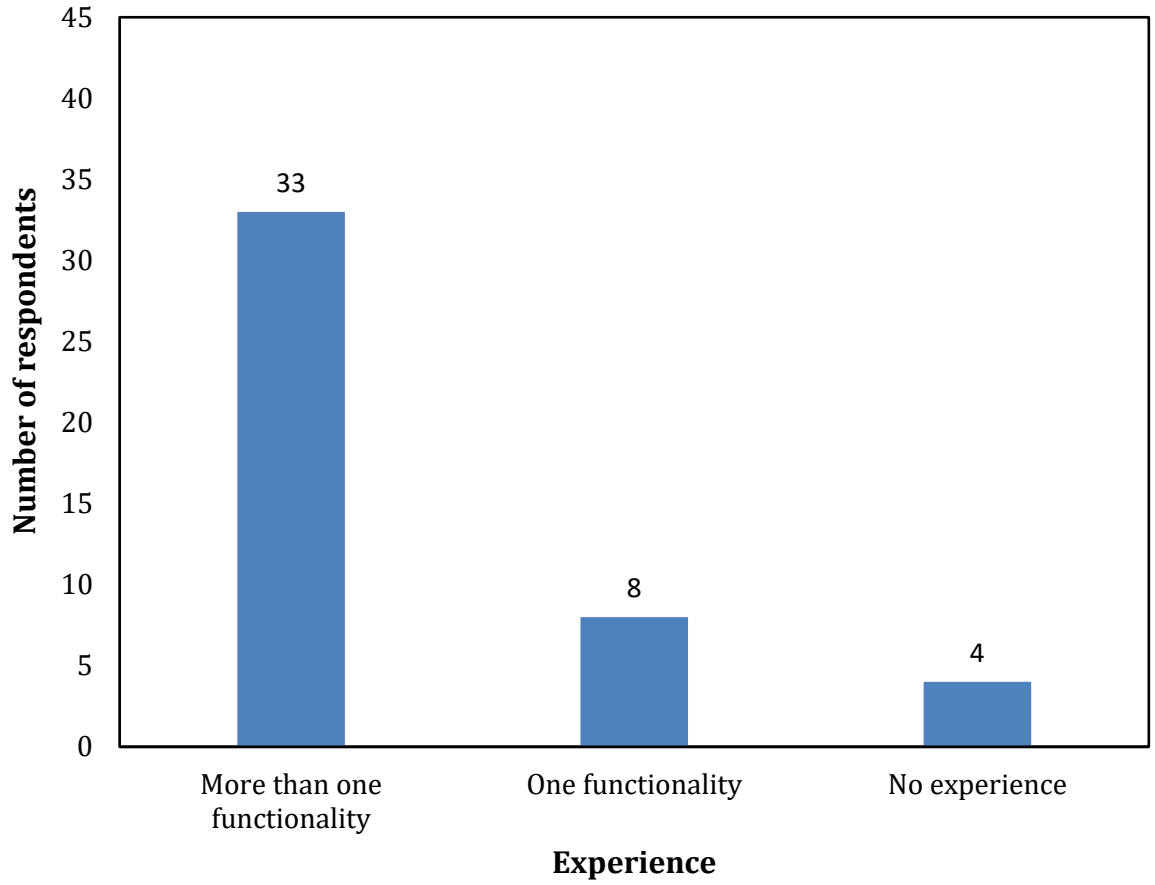

Figure 5: Researchers' responses in relation to experience in areas of sensor functionality.

5.3.4 Three areas where more research is required

Researchers identified activity and behaviour, lameness and mastitis as the three areas which call for more research in dairy sensors and data that they produce (table 10).

The reasons were that parameters associated with activity and behaviour could be utilised to help understand performance and animal welfare and general performance. Some researchers felt that data produced from sensors are not currently being utilised thus integration would bring a better way of making use of the data for better cow wellbeing. Research on more sensors which could be used to identify early signs of lameness and mastitis will help farmers reduce cost associated with the two diseases.

Table 10: Research priorities areas identified by researchers

Research Priorities	Number of respondents
Activity and Behaviour	15
Lameness	10
Mastitis	10
Integration of Data	6
No response	4
Total	**45**

5.3.5 Information on use of sensors in dairy farming

24 out of 45 researchers felt that there is not enough information provided on the use of various sensors used in dairy farming while fifteen did agree that there is enough information. Six researchers did not respond to this question (figure 6). Those in disagreement highlighted the need for combining different sensors to produce information to inform the management systems. They also argued that there is lack of validated studies looking at cost benefit to the farmer thus a call to have a more comprehensive economic analysis of the value of using the data produced from sensors. In addition, researchers felt that there should be a standard definition of traits or measurements across sensor manufacturers.

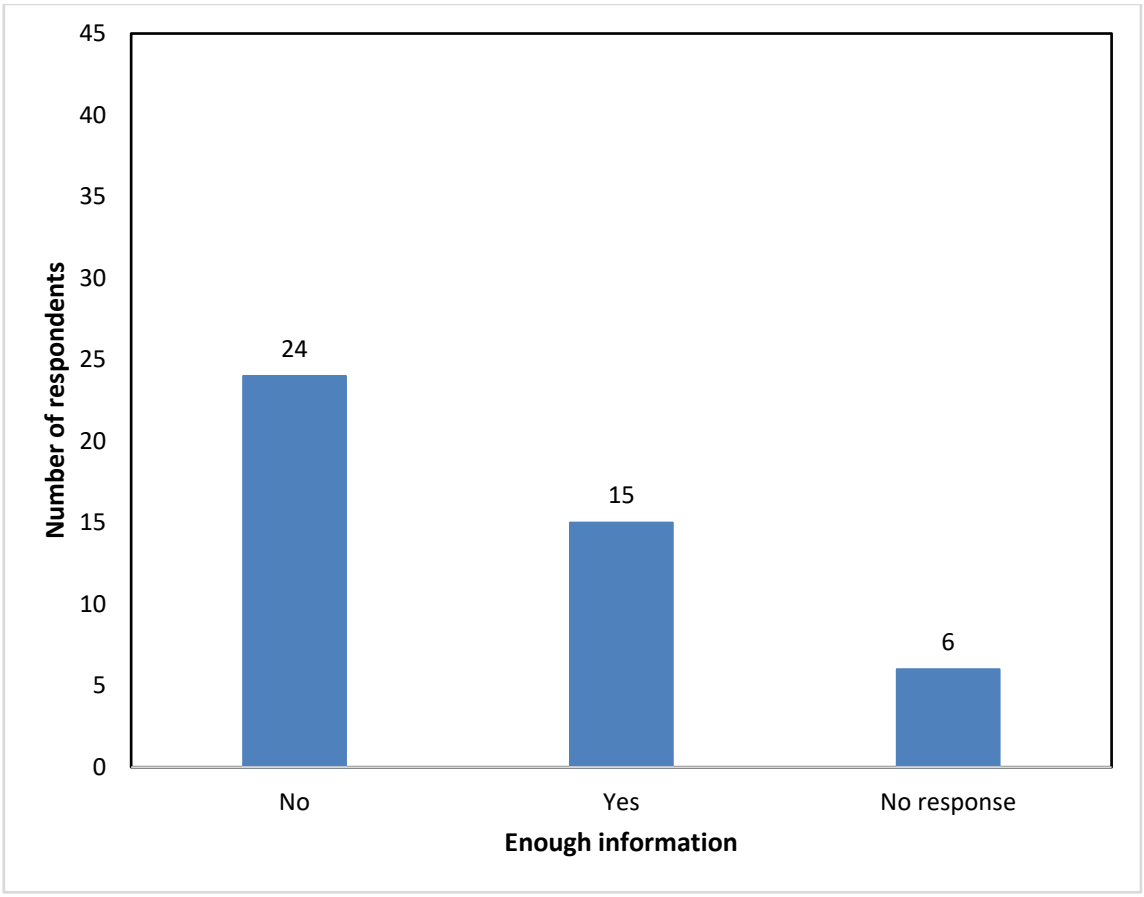

Figure 6: Researchers responses in relation to whether there is enough information provided on dairy sensors.

5.4 Advisors

5.4.1 Areas of dairy farming where research is required

Advisors identified the following 3 areas as to where research is required. These were lameness, metabolic diseases and mastitis (figure 7). Most important reasons for these 3 areas were; for metabolic diseases there is need to have an automated check for actual areas such acidosis while mastitis and lameness were the most costly diseases which also impact on dairy herd health and welfare. Research on these areas will therefore help with early disease detection with reduced antibiotic use.

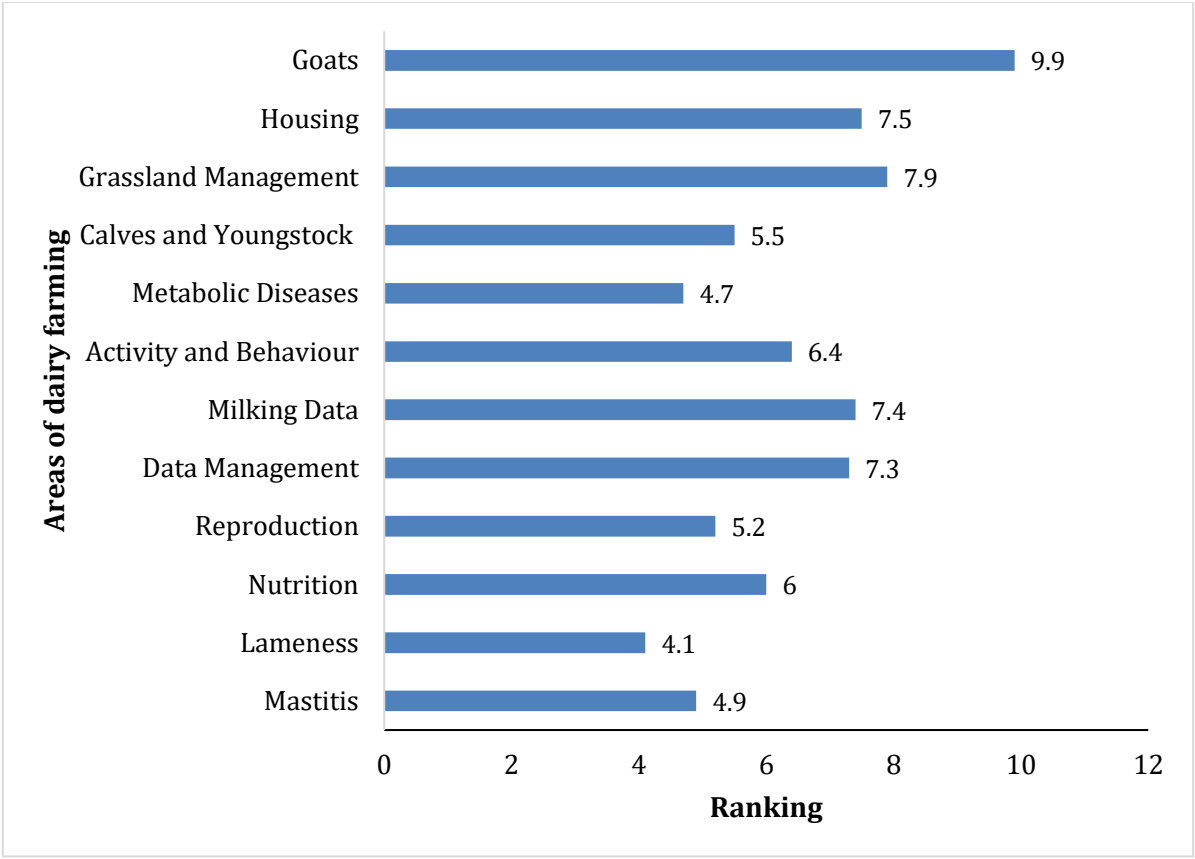

Figure 7:Response from advisors on areas of dairy farming ranked according to where research should be prioritised (1 = research should be prioritised in this area, 12 = not much research required). The figures have been calculated from specific area's total ranking average.

5.4.2 Experience and suggestions for improving sensor functionality

Thirty seven advisors were experienced in more than one sensor functionality with four having experience only in one of the areas. Two of the researchers had no experience while five did not respond to the question (figure 8). The suggestions for improving sensor functionality were that it would be worth developing sensors which can specify lameness rather than relying on those measuring activity.

It would be worth paying more attention to sensors that measure one parameter and will make the result understandable for farmers, for example, determining the somatic cell number or specific pathogen. The majority also highlighted the need for integrating data

to enable the farmer have available a number of options about resolving problems on the farm.

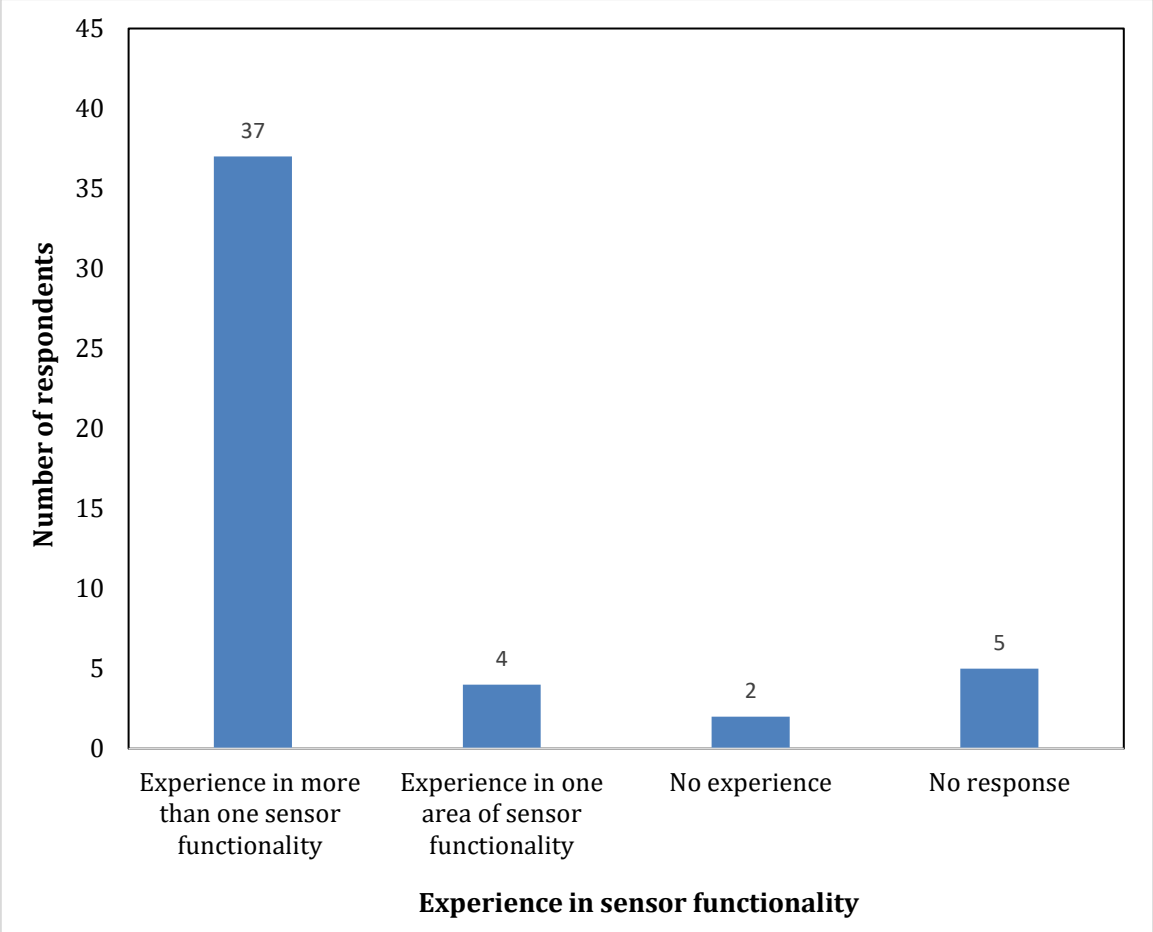

Figure 8: Advisors' responses in relation to experience in dairy sensor functionality.

5.4.3 Top 3 areas where research is required

11 out of 29 advisors felt that more research was needed on lameness, with the same numbers (11 out of 29) for mastitis. 9 out of 29 were for integration of data with decision support systems while 3 out of 29 felt that more research should be focused on cost benefit analysis. Five of the advisors did not respond to the question (figure 9). The advisors felt that both lameness and mastitis impact on the welfare of animals while integration of data would support decision making process on farms. Having information on the financial gains for the farmer was also stressed by the advisors.

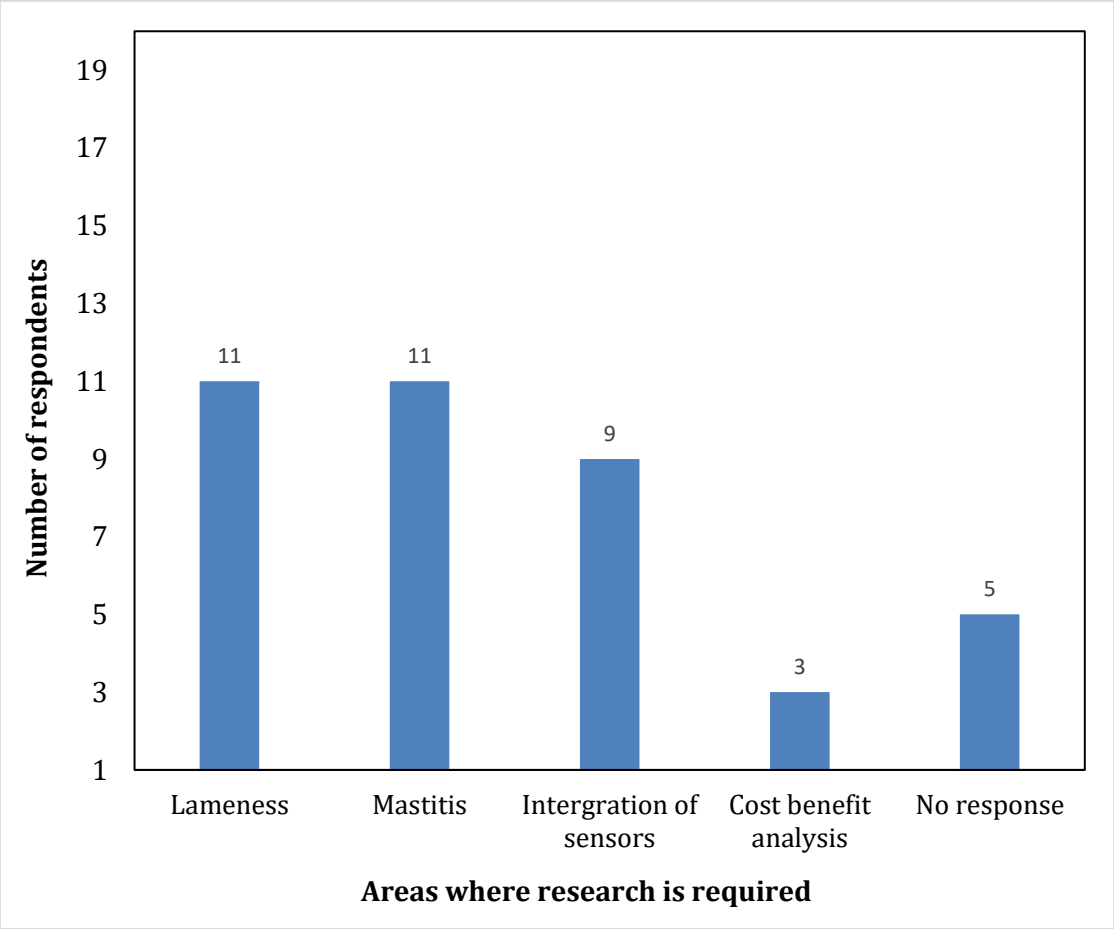

Figure 9: Advisors' responses in relation to areas where research is required.

5.4.4 Information on the use of sensors in dairy farming

The majority of advisors (29 out of 42) felt that there is not enough information provided on the use of various sensors used in dairy farming while thirteen felt that the information available was sufficient. Six advisors did not respond to the question (figure 9).

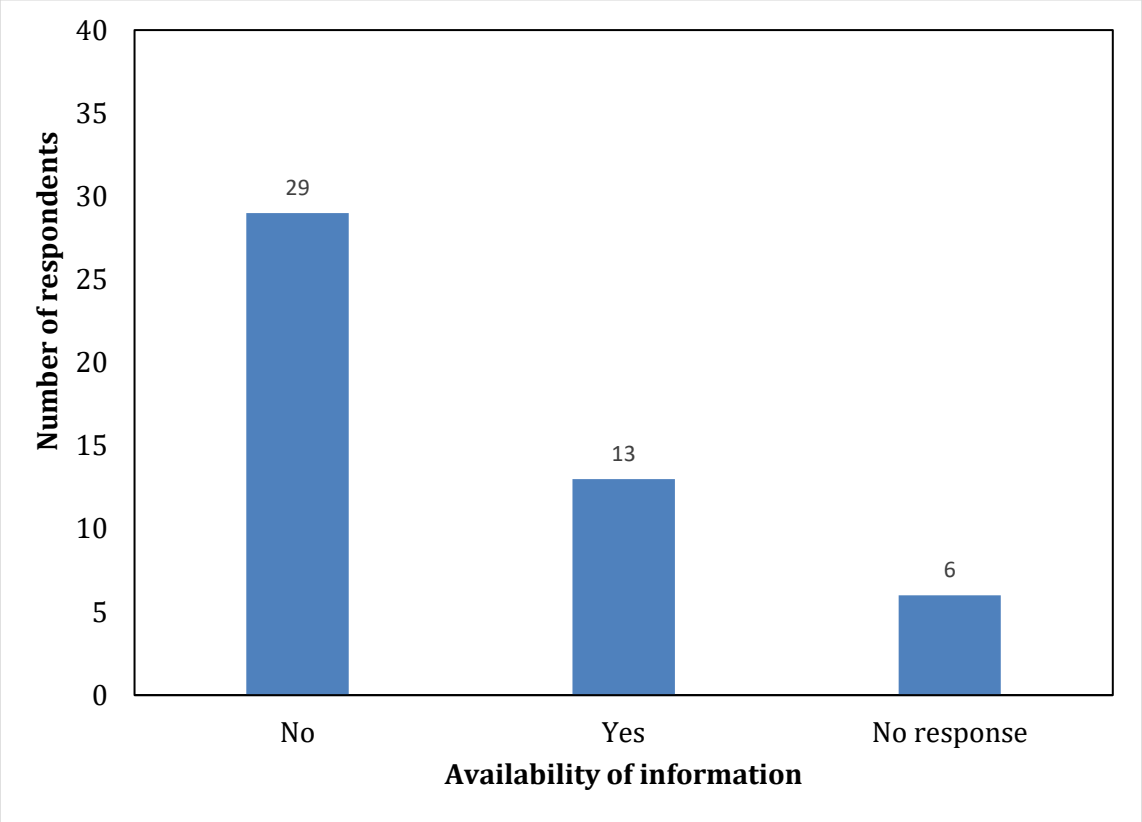

Figure 10: Advisors' responses in relation to availability of information on dairy sensors.

Specifically, the areas identified to be lacking were lack of enough information on profitability following the uses of sensors. It was also pointed out that there are no best practice guides available to the farmer. Some of the respondents also felt that currently there is no information written / published in a language understood by farmers in some countries.

6. DISCUSSION

This study has focused on use of sensor technologies to improve profitability and sustainability on dairy farms within 8 project partner countries with a view to identifying top future research priorities. The discussion summarises these findings.

It was clear from the outset that feedback provided by participants identified common areas which were of importance in dairy farming. There was also a dearth of information concerning research on sensor technologies and data that they produce on the most important areas of dairy farming. The key areas identified by the respondents from various occupations were; lameness, mastitis, metabolic diseases, activity and behaviour, calves and young stock and milking data. It is interesting to note that there was agreement between the majority of the different groups of respondents on the most significant areas of dairy farming, notably on mastitis, lameness and activity and behaviour. Furthermore, farmers pointed out calves and young stock as another area of significance importance. Veterinarians, researchers and advisors also pointed out milking data, data management and metabolic diseases as areas where research on dairy sensors and data they produce should be prioritised. It is interesting to note some of the differences in views on areas for research between the various occupations, a finding which calls for closer working relations between all the occupations.

The most important reasons why the majority of respondents were in agreement that mastitis and lameness were the main areas where research should be prioritised was that both diseases have a significant welfare and economic effect in dairy farming. In addition, mastitis has been reported to impact on milk quality, and with antibiotic usage being important issue globally, posing a major risk to public health. These findings were in agreement with research by Ogola *et al*. (2007) and Oliver *et al*. (2011) who reported that mastitis impacts on milk quality and antimicrobial resistance following treatment with antibiotics respectively. Research focusing on improving the specificity of sensor technologies in these areas would therefore help with early warning signs for disease improving treatment success resulting in reduced disease losses, increased longevity, and

improved animal well-being. The respondents also felt that lameness is a huge welfare issue with a lack of a better way of utilising the existing sensors to get more data out of a system and thus research on better ways on how farmers can utilise data from the systems would be beneficial.

On the area of experience in the various areas of sensor functionalities, the majority of occupations were experienced in the different areas of sensors functionalities (lameness, ketosis, reproduction, mastitis, temperature, rumination, oestrus, calving and location). However, a marginal number of farmers (9 out of 53) reported to have no experience in the several areas of sensor functionality, a figure higher compared to those reported in other occupations. The moderate number of farmers reporting to have no experience on sensor functionality could have been due to factors such as cost, data complexity or lack of information on the benefits of sensor technologies in dairy farming.

An increasing number of sensors are being used in dairy herds. For example, milk analysis, rumination, temperature and activity all of which commonly use sensor technology though with separate software systems. The current study reported the need for research on integrating sensors as part of improvements required for the different sensor functionalities, an area which has not been well explored. With myriad of sensors currently available, dairy farmers are facing a data overload and a lot of data is not being fully utilised. Research on integrating systems, will therefore help with better use arising from combined data avoiding duplicate data entry, thereby optimising the alerting sensitivity, and improving the overall system performance.

The other area where respondents felt improvement was needed was having sensors which can identify specific pathogens or health issues, for example, in cases of mastitis caused by *Escherichia coli* or specific infectious and non-infectious forms of lameness. This would enable a targeted approach on treatment and unravel those diseases which tend to have complex aetiology. The findings are in agreement to studies by Van Nuffel *et al*. (2015) who reported that no efficient automated lameness detection system is available on the market yet an area which research should be prioritised whilst undertaking

research on sensor functionalities. Cost was also an area highlighted by farmers and researchers. Developing low cost sensors could be one of the best way to encourage more farmers to adopt to using sensors in improving productivity on dairy farms.

There was strong agreement between the occupations that more research on lameness and mastitis should be undertaken, a similar highlight reported earlier in the discussion. The areas of metabolic diseases and activity and behaviour were also reported by veterinarians and researchers where they felt that further research on parameters associated with activity and behaviour could be utilised to help understand performance and animal welfare. Metabolic problems can have a significant effect not only on a cow's lactation performance, but also fertility performance thus sensors yielding specific early warning signs will help minimise the impacts associated with metabolic problems currently being reported in dairy farming.

The current study also found a significant number of respondents across all the occupations felt there is not enough information provided on the use of the various sensors in dairy farming. The majority felt that currently there is very limited detailed research on cost benefit analysis at both herd and individual animal level. Advisors also reported that there is no information written in a language understood by farmers in some of the countries, an area worth considering by those who are responsible with publishing information on the various dairy sensor technologies. Another important gap which was pointed out by the researchers was that a standard definition of parameters across sensor manufacturers is lacking. The findings highlight the need for more studies on cost benefit analysis so that farmers can be fully informed on rate of return on investment. Additionally, having information written in farmer native language would encourage better uptake of dairy sensors.

7. CONCLUSION

In summary, respondents felt that use of sensor technologies offers a number of benefits which may help in the improvement of animal health and welfare and ultimately increased farm business profitability. The problems of limited research on the various areas of dairy farming health issues, top most being mastitis and lameness, integration of multiple sensors on farm management systems, cost benefit, and having sensors finer precision in detecting specific pathogens still remains a big obstacle if farmers are to invest further on precision livestock technologies. It is therefore of great importance that research be implemented in the different areas identified in this report to ensure that we have the appropriate sensor technologies available for the dairy farming sector for it to be sustainable and even continue in the future generations.

8. RECOMMENDATIONS

This study has identified a number of areas in which further research is required in the use of sensor technologies in dairy farming. The top recommendations for further research are listed below:

- Research on how to integrate multiple sensors and the data that they produce to improve timely decision making from the alerts.
- Further research on sensors which can capture specific dairy cow health issues, and those with complex aetiology, for example, mastitis caused by *Escherichia coli* and infectious and non-infectious forms of lameness
- Research on producing cheap sensors and detailed cost benefit analysis which will help farms make informed decision whilst looking at the rate of return on investment .
- It would also be beneficial having a standard definition of parameters across the sensor manufactures.

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10. APPENDICES

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 areas. 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.