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Diffusion of precision livestock farming technologies in dairy cattle farms

M.C. Bianchi [a], L. Bava [a], A. Sandrucci [a,*], F.M. Tangorra [b], A. Tamburini [a], G. Gislon [a], M. Zucali [a]

[a] Department of Agricultural and Environmental Sciences, University of Milan, 20122 Milan, Italy
[b] Department of Veterinary Medicine and Animal Sciences, University of Milan, 20122 Milan, Italy

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ABSTRACT

The rising global demand for animal products and the growing public concerns about the environment and animal welfare require dairy farms to improve their efficiency and apply more sustainable farming systems. Precision Livestock Farming (**PLF**) could represent a valuable support in addressing these challenges. In recent years, dairy farms have been modernising and introducing new sensors and automatic systems for managing the herd. However, the diffusion of new technologies in Italian dairy farms is still limited and farmers are reluctant to invest in precision systems. The aim of the study was to investigate the presence of PLF tools in Italian dairy farms, the motivations, benefits and limits of technological investments from the farmers' point of view and the factors affecting the diffusion of technology. From November 2020 to June 2021, an online questionnaire was distributed and 52 responses were obtained. About 79% of the farms were located in Lombardy. The more represented milking system was the conventional milking parlour (73%), followed by automatic milking (19%). The average age of respondents was quite low: 35% of them was less than 40 years old and more than 50% was between 40 and 60. Statistical analyses were performed to evaluate the effects of different factors on the presence of technology at farm. The age of the farmer, the milk production level and the presence of an automatic milking system influenced the technological level of the farm. Precision systems that provide information on animal activity for the management of reproduction and on milk yield and flow are the most popular and are considered among the most useful. Management of reproduction and milk production are the areas where farmers appear to show interest for future investments as well. Younger farmers appear to have implemented more PLF systems than older ones, and they show a propensity to invest in latest generation precision tools. Farmers seem to have a growing interest in PLF, but some limits have been identified: the investment costs, followed by the lack of time to check information from sensor systems and the difficulty in data interpretation. As PLF technologies can play an important role in the development of sustainable, animal-friendly and efficient livestock production, further improvements and efforts are necessary to increase the propensity to PLF of dairy farmers. Results can be useful in the Italian context but also in other countries where dairy farming is rapidly intensifying but PLF is encountering resistance.

Implications

The survey investigated the diffusion of precision technologies and factors influencing their adoption in Italian dairy farms, as an example of a livestock sector that is rapidly intensifying but in which the diffusion of new technologies is slow. The results showed that farmers, especially younger ones, are interested in technology, notably in precision tools for reproduction management and milk yield monitoring, but cost and lack of time represent barriers to investments. Efforts are required by scientists, industry and extension services to increase the propensity to technology of dairy farmers, by better addressing their needs and adequately supporting them.

Introduction

The world population is expected to increase by around 20% within the next 30 years (UN, 2022) and, as a consequence, a significant increase in demand for animal products is foreseen. Dairy farmers will have to cope with conflicting requests: on one hand, they will have to increase their productivity to meet the demand for food, while on the other, due to the growing consumer interest

* Corresponding author.
E-mail address: anna.sandrucci@unimi.it (A. Sandrucci).

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in ethical aspects and environmental protection, they will have to be increasingly aware of the welfare and health of animals and the environmental impact of their farms (Bahlo et al., 2019).

As highlighted by Lovarelli et al. (2019), the improvement of economic, environmental and social sustainability of animal farming requires high levels of efficiency in the production processes. The high-output system of modern intensive dairy farms already accomplished high production efficiency levels and, according to Capper et al. (2009), milk production today can be considered more environmentally friendly than that of the postwar period. However, there is a need for further improvement in terms of efficiency and sustainability (Guerci et al., 2013). According to Gerber et al. (2013), greenhouse gas emissions of livestock farms could be reduced by 14–17% by improving manure management, optimising production processes, increasing feed quality and promoting animal health and welfare.

An important support in achieving all these goals is represented by Precision Livestock Farming (**PLF**). With the help of sensors and decision support systems, it is possible to constantly monitor animals and their performances also in large farms. This allows to make quick and informed management decisions, improving the efficiency of resource use. With PLF, farmers can ensure good health and welfare of their animals, achieving better productive and reproductive results and reducing the environmental impact per unit of product (Tullo et al., 2019).

Some studies showed that dairy farmers, among the available technologies for dairy farming, usually prioritise the introduction of systems for automated recording of milk production (Borchers and Bewley, 2015; Abeni et al., 2019). This type of technology uses sensors, like milk meters and flowmeters, directly applicable in the milking parlour for recording production variables at an individual level. The related decision support systems can provide important information about milking process, animal condition and udder health (Tamburini et al., 2010), thus enabling quick action for preventing milk losses and mastitis which frequently lead to early animal culling. As recently showed by Mostert et al. (2019), clinical mastitis is associated with an increase in greenhouse gas emissions per kg milk produced.

Among the management aspects that strongly influence the efficiency of a dairy herd, there are heat detection and reproductive management. In fact, a decisive role in affecting fertility is played by identifying the right time for insemination. Especially in large farms, where heat detection through visual observation of animal behaviour is difficult, automatic sensors for oestrus identification, such as activometers or pedometers, are almost indispensable. Mayo et al. (2019) reported that two thirds of precision monitoring tools for identifying oestrus correctly detected 15–35% more heats than visual observation performed four times a day. According to Abeni et al. (2019), activometers are able to detect about 70% of cows considered in oestrus.

Nevertheless, the diffusion of technology in Italian dairy herds does not seem as extensive as it would be desirable. This is despite the importance of the dairy cattle sector in the country: Italy is the fourth European country for total cow milk production (EUROSTAT, 2020) and the incidence of the dairy cattle sector on the value of Italian animal productions is about 30% (CREA – Research Centre for Agricultural Policies and Bioeconomy, 2022). The Italian National Institute of Statistics recently published a report on the diffusion of PLF in Italian livestock farms (ISTAT – Italian National Institute of Statistics, 2021). The report states that the percentage of livestock farms using precision tools does not even reach 40% of respondents.

An American report by Borchers and Bewley (2015) indicated that the most important obstacle limiting the use of innovative technology in US dairy farms is the lack of familiarity with the available technologies, along with a high cost-benefit ratio. The convenience of adopting technology varies widely among the farms depending on the attitudes of the farmers (Batte and Arnholt, 2003). Dairy, pig and broiler breeders from ten European countries surveyed about their experience with precision technologies pointed out, among the major disadvantages, the relative high prices of PLF equipment, the poor maintenance service by the delivering companies and the lack of broader experience with the systems in practice (Hartung et al., 2017).

With the aim of promoting the diffusion of technology in Italian dairy farms, improving their competitiveness and efficiency and making them able to respond to the needs of consumers, there is an urgent need to investigate the barriers that still limit the diffusion of technology. In particular: which dairy farms are most likely to invest in precision technologies? Which tools are considered most useful by farmers? What reasons guide the farmer's investments in technology? What are the main benefits of technology perceived by farmers? And what are the main weaknesses? Does the adoption of precision systems actually give results in terms of performance and health of the herd? The main aim of the study is to represent the diffusion of PLF technologies in a sample of Italian dairy farms, to explore the attitudes and opinions of dairy farmers on PLF solutions and to investigate which factors can influence the investment in technology. Secondary aim is to study the association between the technological level of the farm and productive, reproductive and health results of the herd. The approach of the research starts from a sample of Italian farms but the questions addressed are common to many other countries where the dairy cattle sector is well developed but still reluctant to the extensive use of new technologies.

Material and methods

Questionnaire and data collection

Starting from November 2020, a questionnaire was administered through the CLEVERMILK project website and social channels (Facebook, LinkedIn). Dairy cattle breeders were identified as recipients of the survey, with no specific conditions specified for respondents to be eligible to complete the questionnaire. The survey was closed at the end of June 2021: a total of 52 responses were obtained. The questionnaire was made up of five sections for a total of 53 questions, 33 open-ended and 20 multiple-choice; some questions were mandatory, others optional. The first two sections collected information about the characteristics of the farm (e.g. size, structures). The questions in the third section were about herd performances in terms of production, reproduction and health. In the fourth section, farmers were asked if they have, and for how long, technological systems for automatic monitoring of milk production, milk flow, milk electrical conductivity (**EC**), milk colour, milk quality, somatic cell count (**SCC**), bioindicators in milk, Body Condition Score (**BCS**), animal activity, rumination time, cow weight, lameness and DM of the ration. For each of these items, different options have been envisaged and different scores have been assigned as follows: a) presence in the farm of a precision instrument (Diffusion Rate Score): no = 0; yes = 1; b) time elapsed since the adoption (Adoption Time Score): scores from 1 (less than 1 year) to 5 (more than 5 years). More details about the scoring system are available in Supplementary Table S1. In this context, precision technologies included all types of sensor and digital systems regardless of the level of complexity.

In the fifth and last section, it was asked to the farmers to indicate three precision tools, among the systems already implemented at the farm, in order of importance from the point of view of improving farm management. Each instrument listed has been assigned to an area of interest (fertility management, milk yield monitoring, DM intake monitoring, health management, calf management) and to each area, a score was assigned (Utility Rate Score): score 3 for the most useful, 1 for the least useful (Supplementary Table S2). Then, for each tool, the score obtained from the response of each farmer was added up.

In the last section, farmers were asked to declare:

- the improvement obtained using technology. The answers were grouped into three categories: improved management, improved fertility, timeliness of interventions;
- the main reasons that have guided the investments in technology already made, using a Likert scale of 1 (Not at all important) to 5 (Extremely important). In order to draw up a ranking, the average of the scores obtained for each management area was calculated;
- the main obstacles to technological investment, choosing from five options. More than one answer has been granted;
- areas for future investments. Based on the responses, eight classes were created: 'milk production', 'reproduction', 'intake', 'animal health', 'localisation', 'production-animal health', 'production-reproduction', 'production-animal health-reproduction'. More details on the questionnaire are available in Supplementary Material S1.

Statistical analyses

The whole dataset was analysed using SAS software (version 9.4, 2012). In order to explore the dataset, descriptive statistics and Pearson's correlation analyses were performed. GLM procedure was performed in order to evaluate the effects of owner age, milk productivity level of the herd and herd size (classes based on frequency) on the diffusion of technology and time from adoption at the farm, according to the following model:

$$Y_{ijkl} = \mu + A_i + M_j + H_k + e_{ijkl}.$$

Where:

Y_{ijk} are the dependent variables, μ is the general mean, A_i is the owner age effect (i = 1–3; <40 years old; 40–60 years old; >60 years old), M_j is the milk yield effect (j = 1–3; <31 kg/d; 31–35 kg/d; >35 kg/d), H_k is the herd size effect (k = 1–3; <100; 100–200; >200 lactating cows), and e_{ijkl} is the residual error.

Moreover, two types of multivariate analyses were performed: Principal Component Analysis and Multiple Correspondence Analysis.

Results

The surveyed farms and the diffusion of technology

About 79% of the farms involved in the survey were located in Lombardy (northern Italy). The average herd and farm size were respectively 174 ± 171 lactating cows and 101 ± 105 ha of utilised agricultural area; the average daily milk yield was 31.3 ± 6.24 kg/head. In most cases, farms were intensive with lactating cows housed permanently indoor (88%); organic farming system represented only 4% of the sample. Surveyed farms mostly adopted loose housing with individual cubicles (85%) or permanent straw bedding (9%) whereas the remaining 6% of farms used a tie-stall system. In 73% of surveyed farms, cows were milked in milking parlours whereas in 19% of them there were one or more Automated Milking Systems (**AMSs**); about 8% of farmers declared other milking systems. The most represented age class of the 52 respondents was 40–60 years (52%), followed by < 40 years (35%); only 13% of the farmers were more than 60 years old. Fig. 1 shows the responses on the diffusion and timing of adoption of the main precision technologies used by farmers. Systems based on activity sensors (activometers) were the most popular precision instruments: over 78% of farmers used this technology. An almost as high percentage (about 73%) of the total surveyed population had milk yield measurement systems, and all respondents who did not adopt this technology were aware of the existence of these systems. The least common technological tools in the group of surveyed farms were systems for detecting bioindicators in milk (e.g. progesterone), with a diffusion of only 16%. About 12% of respondents have invested in technologies of this type for less than a year. High percentages of investments in the last year were also declared for technological systems for monitoring DM of the ration (14%), milk quality (12%), cow weight (12%) and rumination time (12%). The tools adopted in the surveyed farms for the longest time (over 5 years) were the monitoring systems for milk yield (43%) and milk flow (37%), followed by activometers (35%) and sensors for measuring milk EC during milking (33%). Among the technological equipment for dairy farms, the least known by farmers were the milk colour sensing systems (26% of farmers were unaware of their existence), followed by lameness detection systems (22%).

A moderate positive correlation was found between the rate of diffusion of precision systems for milk yield and activometers ($r = 0.45$, $P < 0.002$). Herd size was slightly positively correlated with the rate and time of adoption of animal activity measurement systems ($r = 0.34$, $P = 0.016$; $r = 0.36$, $P = 0.009$), with the rate and time of adoption of milk flow measurement systems ($r = 0.35$, $P = 0.012$; $r = 0.42$, $P = 0.002$) and with daily milk yield per head ($r = 0.34$, $P = 0.02$). Average milk yield per head was positively related with the rates and times of adoption of measurement systems for milk yield, milk flow and milk EC (Supplementary Table S3), moderately related with the number of daily milkings ($r = 0.46$, $P < 0.001$) and negatively related to conception rate ($r = -0.49$, $P = 0.009$). Positive correlations, from moderate to high, were obtained among the number of daily milkings and rates and times of adoption of measurement systems for milk yield, milk flow, milk EC, milk colour, milk quality, milk SCC, animal activity and rumination time (Supplementary Table S3). The number of daily milkings was also positively correlated to both the average technological level ($r = 0.46$, $P < 0.001$), which includes all the monitoring and automation systems implemented at the farm, and the average adoption time ($r = 0.57$, $P < 0.001$).

Farmers' attitude and opinion about precision livestock farming technologies

The questionnaire asked farmers to indicate the most useful PLF systems among those already implemented on the farm. The results show that the most useful tools are considered to be those for managing reproduction, followed by the systems for monitoring milk yield (Fig. 2). Precision solutions for feed intake and health monitoring have also been mentioned quite frequently. The positive opinion of farmers about utility of precision solutions for reproductive management was positively related to the length of the calving interval ($r = 0.52$, $P = 0.02$) and negatively related to CR ($r = -0.59$, $P = 0.009$). When asked about the benefits observed as an effect of technology implementation, about 56% of farmers indicated "improvement in overall management", 27% pointed "improvement in reproduction management" and 18% indicated "timeliness of interventions". About the reasons that had driven the investment in technology that was already implemented at the farm, the improvement in heat detection, work management, and animal welfare and health were the main motivations (Table 1). Among the factors hindering investments in technology, the most chosen item was the "cost" (over 87% of the answers), followed by "lack of time" (25.5%) and "difficulty in interpreting data" (25.5%). "Poor support from PLF solutions producing companies"

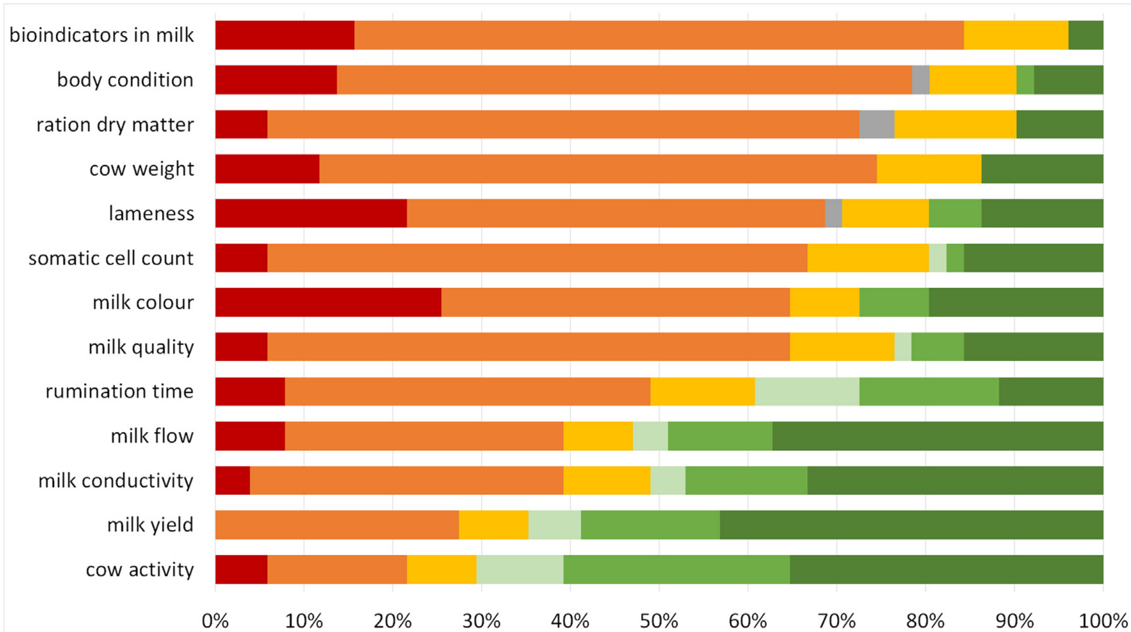

Fig. 1. Diffusion rate and adoption time of precision livestock farming systems in the studied dairy cattle farms classified on the basis of monitored indicators. Red bar = I have no precision systems to monitor this indicator and I do not know they were on the market; orange bar = I have no precision systems to monitor this indicator but I do know they were on the market; grey bar = I do not know; yellow bar = I have had precision systems to monitor this indicator for less than 1 year; light green bar = I have had precision systems to monitor this indicator for 1–3 years; green bar = I have had precision systems to monitor this indicator for 3–5 years; dark green bar = I have had precision systems to monitor this indicator for more than 5 years.

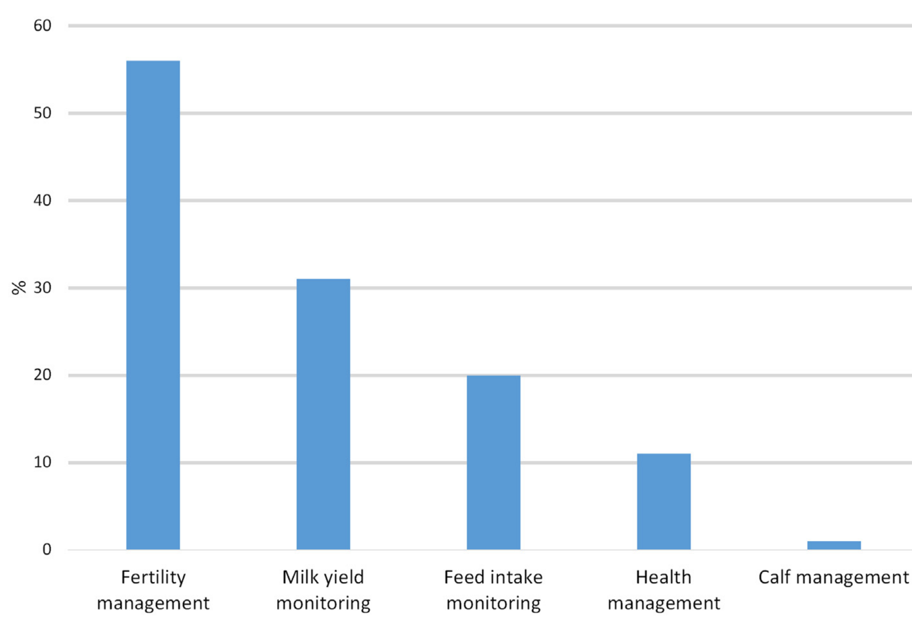

Fig. 2. Sum of utility scores of the monitoring systems implemented on the studied dairy cattle farms from the farmers' point of view for each area of interest.

and "poor reliability of automatic systems" were also chosen as investment barriers, reported respectively in 15% and 10.6% of the answers. About the time spent to check data provided by the precision systems, a moderate percentage of respondents (35%), who used at least one PLF solution, stated they devote more than 30 min a day checking data and alerts provided by the automatic monitoring systems. The rest of the farmers declared they spend less than 30 min a day. A low percentage of farmers (10%) reported they were used to monitor more than two aspects of their herds without the support of technology. Inseminations, lameness, mastitis, metabolic disorders, therapies, deaths and abortions are some of the variables monitored manually. Regarding the willingness to implement new PLF solutions in their farm, most of the respondents (almost 68%) indicated reproduction and milk production monitoring systems, or at least one of the two, as the most interesting.

Factors affecting farm technological level and herd performances

The effects of herd size, milk production level and owner age on the technological level of the farms were tested. Fig. 3 shows the variables controlled by automatic systems in farms characterised

Table 1
Drivers of investment in technology in dairy cattle farms according to the farmers' opinion using a Likert scale.

Items	n[1]	Mean score[2]	SD	Minimum	Maximum
heat detection	42	4.43	0.91	2.00	5.00
work management	41	4.32	0.91	2.00	5.00
animal welfare	42	4.21	1.07	2.00	5.00
animal health	43	4.19	1.07	1.00	5.00
milk yield	41	4.15	0.96	2.00	5.00
economic sustainability	42	4.05	1.01	2.00	5.00
milk quality	42	3.67	1.10	1.00	5.00
reducing human work	42	3.38	1.36	1.00	5.00
environmental sustainability	42	3.12	1.42	1.00	5.00
technological passion	42	3.10	1.43	1.00	5.00
technology already present	40	2.35	1.42	1.00	5.00

[1] Number of answers.
[2] Scores from 1 to 5; 1 = Not at all important; 5 = Extremely important.

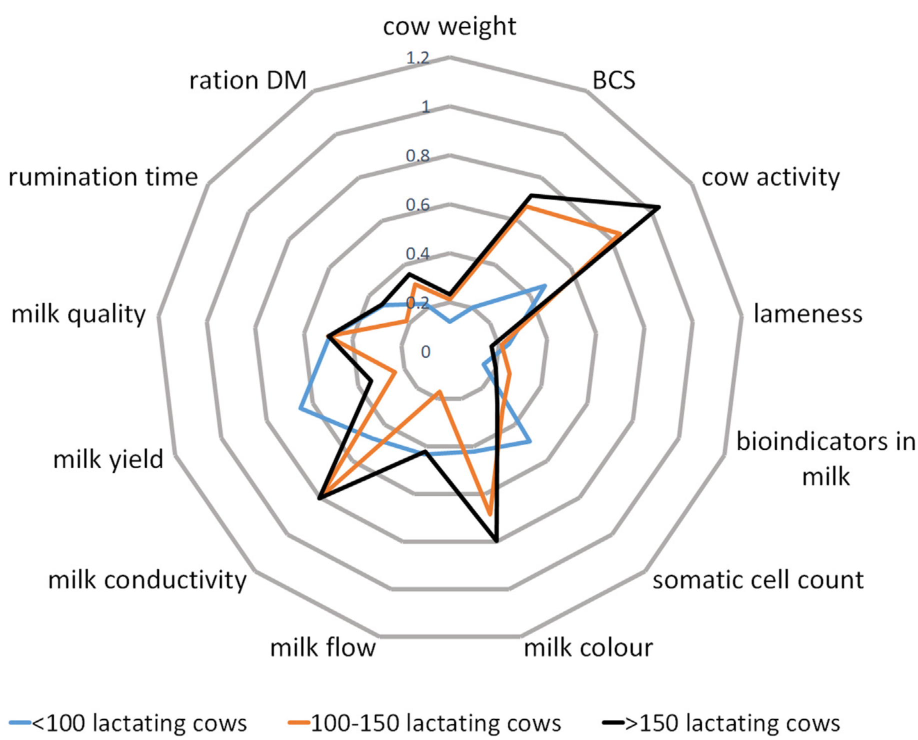

Fig. 3. Diffusion rate score of precision systems in dairy cattle farms characterised by different herd size. Abbreviations: BCS = Body Condition Score.

by increasing herd size (<100; 100–150; >150 lactating cows). The most important difference between classes was found for the systems used to monitor animal activity ($P < 0.05$): the smaller herds implemented less frequently activometers compared with larger ones. Farms with high-yielding cows differed significantly from the others ($P < 0.05$) for the wider diffusion of systems for monitoring milk flow and milk colour (Fig. 4). Fig. 5 shows the comparison between three groups of farms according to the age of the owner. Younger owners (<40 years old) invested more in technology, for almost all types of precision systems. In particular, they more frequently adopted precision systems for monitoring udder health indicators (bioindicators in milk, milk SCC, milk EC, milk colour; $P < 0.01$) and for evaluating the feeding ration DM and the animal welfare and health (BCS, rumination time, cow weight; $P < 0.01$).

The time of adoption of automatic monitoring systems for milk yield and milk flow showed moderate positive correlations with milk yield per head ($r = 0.36$, $P = 0.01$; $r = 0.42$, $P = 0.002$). Similarly, the average time of adoption of technologies (including all precision systems implemented at the farm) was also moderately correlated with milk yield per head ($r = 0.37$, $P = 0.007$). The diffusion rate and the adoption time of automatic systems for detecting mastitis (milk EC and SCC) did not show any relationship with milk SCC and percentage of cows treated with antimicrobial for mastitis. Similarly, the diffusion rate and the adoption time of activometers for heat detection were not correlated with reproductive performances expressed by **HDR** (Heat Detection Rate), **CR** (Conception Rate), calving interval and number of services per pregnancy (Supplementary Table S4).

Principal Component Analysis was used to study the relationships among the PLF tools implemented for monitoring the different aspects of the herd, the average technological level of the farm (Average Diffusion Rate Score, Average Adopting Time Score), the main characteristics of the farm and the herd performances in terms of milk production and quality, udder health and fertility. Fig. 6 shows that farms that have adopted precision systems for the longest time (Average Adopting Time Score) more frequently had systems for monitoring milk yield, milk flow, milk electrical conductivity and animal activity. On the other hand, PLF systems

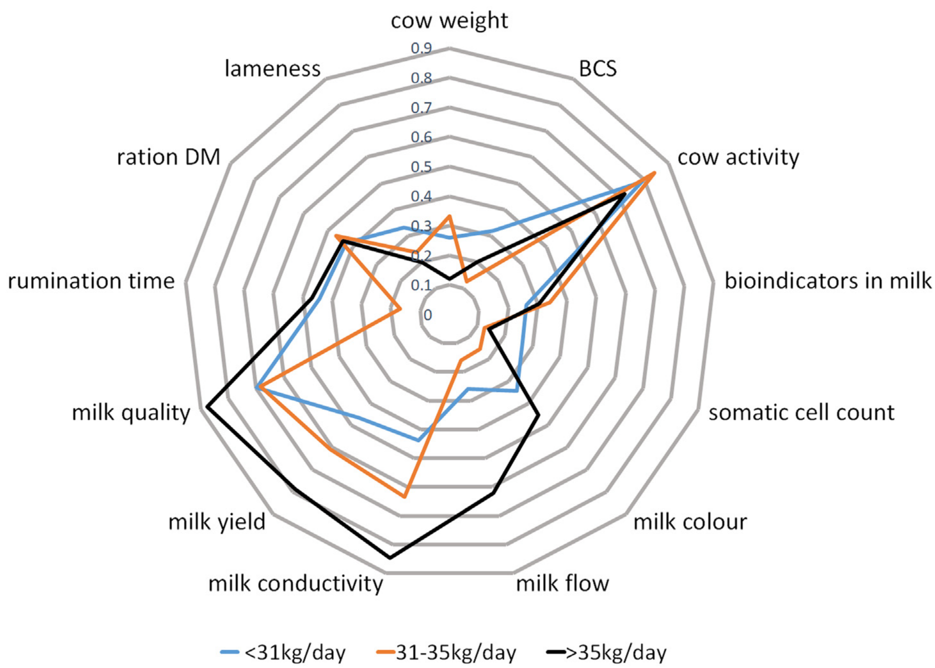

Fig. 4. Diffusion rate score of precision systems in dairy cattle farms characterised by different individual milk yield levels. Abbreviations: BCS = Body Condition Score.

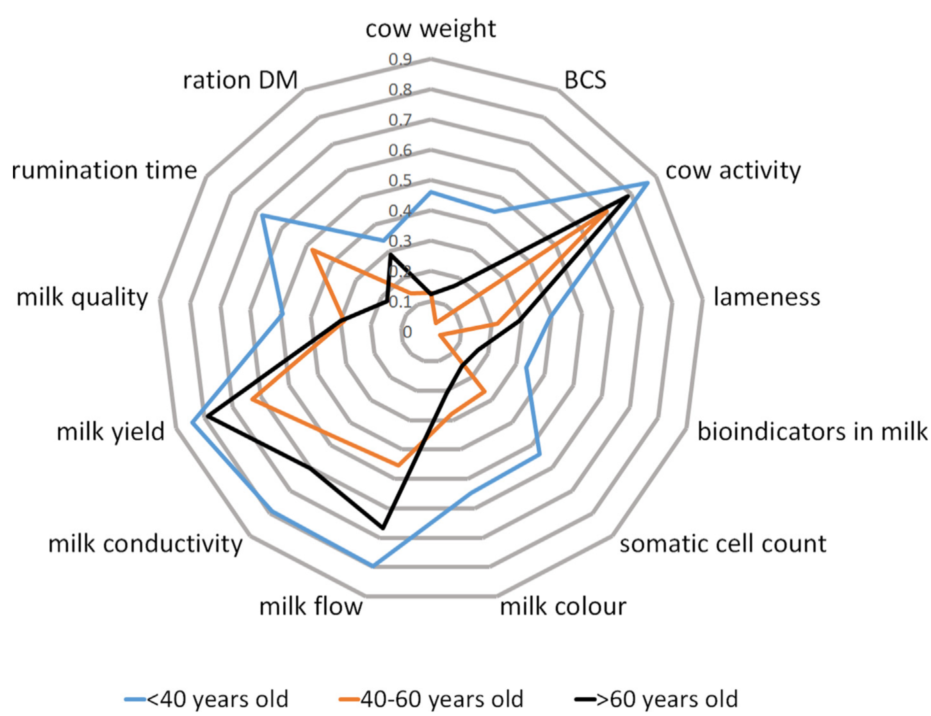

Fig. 5. Diffusion rate score of precision systems in dairy cattle farms with different owner ages. Abbreviations: BCS = Body Condition Score.

for detecting milk SCC, milk composition and lameness were associated with a very high technological level (Average Diffusion Rate Score). The Multiple Correspondence Analysis (Fig. 7) explored the relationships among the average technological level, the average time of adoption and the main characteristics of the herd, the farm and the farmer. The Multiple Correspondence Analysis highlighted that the high technological level (Diffusion Rate Score > 0.4) is associated with high average adopting time score (>1.5), high daily milk yield (>35 kg/head), the presence of AMS at the farm and the age of the farmer below 40 years.

Discussion

The surveyed farms and the diffusion of technology

Most of the farms involved in the study were located in Lombardy. This aspect certainly influenced the results on the diffusion of precision technologies: in fact, as reported by a recent survey from ISTAT (2021), PLF is more widespread in farms from northern Italy, compared to other Italian geographical areas. According to ISTAT (2020) and AIA – Italian National Breeders' Association

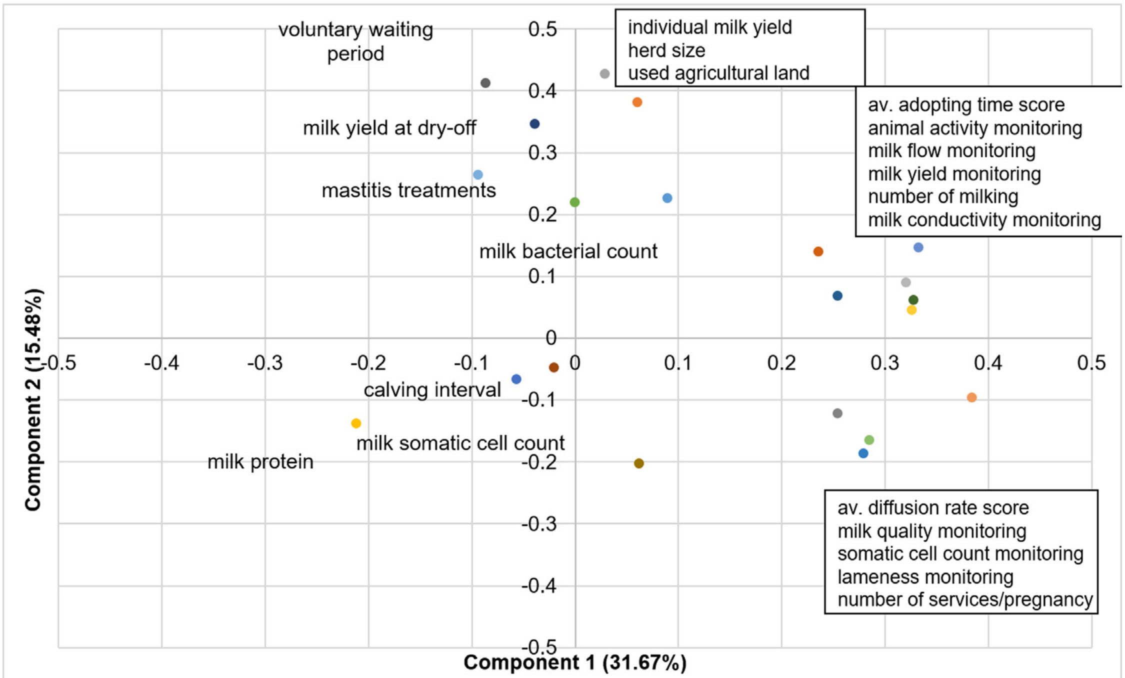

Fig. 6. Principal Component Analysis among the variables automatically monitored at the dairy cattle farms, the average farm technological level (Average Diffusion Rate Score), the time of adoption of technology (Average Adopting Time Score), and the herd performances in terms of milk yield, udder health and fertility.

Fig. 7. Multiple Correspondence Analysis performed on the main characteristics of the dairy cattle farm, the age of the farmer, the technological level of the farm (Average Diffusion Rate Score) and the time of adoption of technology (Average Adopting Time Score).

(2020), dairy cattle farms from Lombardy have an average milk yield per head higher than the Italian average (+8% per lactation) and their herds are larger (+59% in terms of adult cows per farm). These characteristics are associated with a greater propensity for PLF technology adoption (Abeni et al., 2019). The surveyed farms can be considered representative of the characteristics of the intensive dairy system in the Lombardy region in terms of both structures for animal housing, breeding system and production levels. The annual average milk production per cow was about 9% higher than the average value reported for Lombardy farms (AIA, 2020). This could partially be due to the fair percentage of farms using AMS (19%) that is comparable to what is reported for countries from northern Europe (Denmark, The Netherlands, Norway, Belgium, and Switzerland) where the AMS adoption rate is between 20% and 25% (Hogenkamp, 2018; Sigurdsson et al., 2019; Vik et al., 2019). AMS allows cows to be milked more than two times a day, favouring an increase in milk yield compared with the usual twice daily milkings in parlour (Hogenboom et al., 2019). A similar percentage of farms equipped with AMS (21.4%) was obtained in the survey about the spread of PLF in Italian farms (ISTAT, 2021). On the contrary, a recent study carried out by Abeni et al. (2019) in the province of Cremona reported a much lower diffusion of AMS (3.4% of the surveyed farms). The average technological level, which includes all the technological systems on the farm, and the average adoption time of technologies were both positively related to the number of daily milkings and the implementation of AMS on the farms. This result confirms that the presence of AMS, which incorporates a multiplicity of sensors and automatic monitoring systems (e.g. for concentrate intake, milk flow, milk production, milk EC, cow activity, milk colour, milk SCC, milk composition, BCS, lameness), is associated with high technological level of the farms. The AMS is destined to increasingly become the technological hub of the dairy farm in which an individual daily check-up of the conditions of lactating cows can be automatically carried out.

The most represented age group among the respondents was between 40 and 60, followed by the class < 40 years old. A higher percentage of farmers > 40 years old was reported by Abeni et al. (2019) in the province of Cremona. The promotion and delivery methods of the questionnaire through the website and the social media certainly influenced the average age of the respondents. A farm structure survey (EUROSTAT, 2016) showed that more than 40% of Italian farms were managed by farmers more than 60 years old. Thus, the sample of our study is probably younger than the Italian dairy farmers' population. As pointed out by other authors, young people are more prepared to use technologies, and perhaps they trust more sensors and indications provided by PLF systems (Khanna et al., 1999; Abeni et al., 2019; Carillo and Abeni, 2020). In the surveyed farms, younger owners were found to invest more in technologies for almost all types of sensor systems compared to the olders. In particular, younger owners showed an interest towards tools for monitoring udder health, feeding ration and animal welfare and health. They seem to show a greater awareness towards the issues of animal welfare and health and, at the same time, seem more interested in some last-generation technological systems than older farmers. This may suggest that young farmers are more likely than others to adopt a pioneer attitude and are less influenced by the opinions of other farmers. The influence of peers is indicated as one of the determining factors in the choice to invest in innovative technologies (Naspetti et al., 2017).

The results of the questionnaire on the diffusion of technological instruments are similar to those reported by other surveys conducted in Italy as well as elsewhere (Borchers and Bewley, 2015; Abeni et al., 2019; Morrone et al., 2022): as expected, the authors highlighted greater diffusion of technological systems that have been on the market for several years (i.e. systems for measuring animal activity, milk yield, milk EC, milk flow). The high adoption rate of cow activity meters and milk yield measuring systems agree with other studies. Abeni et al. (2019) in a study involving 490 Italian dairy farms reported milk yield as the item most frequently measured by PLF solutions, followed by oestrous. Silvi et al. (2021) reported an 83% adoption rate of both cow activity meters and milk meter systems in Brazilian farms, confirming also the positive correlation between the adoptions of these two technologies. In a survey carried out by Borchers and Bewley (2015), daily milk yield and cow activity were selected by 109 dairy farmers as the aspects most frequently monitored by precision technologies on their farms. Results about the adoption rate of sensors for measuring milk EC in our survey agree with what is reported in the international literature. In the Netherlands, mastitis-detection systems based on milk EC measured during milking showed adoption rates of 35 and 93% respectively with conventional and automatic milking systems (Steeneveld and Hogeveen, 2015).

The least widespread PLF technologies adopted by studied farms were detecting systems for bioindicators in milk (e.g. milk progesterone). Despite the progesterone dosage in milk is the gold standard for oestrous detection (Tenghe et al., 2015), the cost of this technological solution restricts its extensive implementation (Harada et al., 2022). However, the fair percentage of respondents that have invested in this technology for less than a year suggests a growing interest by dairy farmers, similarly to what is reported by Abeni et al. (2019).

Farmers' attitude and opinion about precision livestock farming technologies

The questionnaire investigated the most useful type of smart tool, among the technologies already implemented at the farm, from the farmer's point of view. According to Pierpaoli et al. (2013), utility and ease of use are the most important drivers of technological investments. Perceived usefulness is reported by Naspetti et al. (2017) as the main determinant of farmers' intention to adopt innovative sustainable production strategies. The same authors suggested that researchers and advisers do not necessarily need to concentrate in making innovative practices easier to use, but demonstrate their practical usefulness with relevant empirical evidence.

Interestingly, farmers who pointed to reproduction management systems among the most useful tools appear not to reach such good reproductive performances with their herds. They probably perceive the need to optimise these parameters and seem to recognise technology as a valid help for this weakness. The results of a survey from the United States gave similar results even though the categories of tools and productive and reproductive indicators were slightly different (Borchers and Bewley, 2015).

When asked about the improvements obtained with the adoption of technologies at the farm, many farmers mentioned improvement in overall management or in reproduction management, and others indicated, as a benefit, timeliness in interventions; these advantages could be read as improvements in work efficiency and quality. Other surveys reported better life quality as primary benefit of technology (Schewe and Stuart, 2015). In addition to these benefits, in an official Italian report from ISTAT (2021), farmers declared, as an additional advantage of technology, greater ease in sharing information within the farm.

Considering the motivations that drive the investment in technology, the detection of heats, the management of the work and the improvement of animal welfare and health were the most important, from the farmers' point of view. The results differ from those of other surveys in which conditions inherent to the characteristics of the technologic systems and not related to the management advantages that it brings are highlighted: simplicity and ease of use and economic sustainability appeared to be decisive for the investment in technology (Batte and Arnholt, 2003; Pierpaoli et al., 2013; Borchers and Bewley, 2015; Abeni et al., 2019). However, in the study of Abeni et al. (2019), a substantial number of Italian farmers in addition indicated, as a very important motivation to invest in technology, the improvement of oestrus detection and animal health. Some other aspects, not emerging from this survey, such as the influence of the opinion of peers about the innovation on motivation and usefulness perception are cited by Naspetti et al. (2017). The same authors concluded that sharing knowledge and information among farmers is important to speed up the adoption of novel technologies and strategies.

According to the respondents, the most limiting factor for the diffusion of technology at the farms was the "cost". This is in agreement with the results reported by Bewley et al. (2015). A more limited number of farmers in our survey reported "lack of time" and "difficulties in interpreting the data" as other obstacles. "Poor technical support" and "poor reliability of instruments" were also indicated as barriers to the investment in precision technologies. As regards the time spent by the farmer checking the data provided by the precision systems and the related software applications, the results of this survey suggest that farmers have little propensity to dedicate time to technology. They probably have not yet realised that adopting precision livestock systems involves, first of all, changing their way of working. In other studies, the concern about the time required to manage data and information was negatively correlated with the presence of technology on the farm (Abeni et al., 2019) and was indicated by many farmers as a reason for a lack of investment in technology (Bewley et al., 2015). Dairy, pig and broiler European breeders from ten European countries indicated, among the major disadvantages of technology, the relative high prices for PLF equipment, the poor maintenance service, and the lack of practical experience with the systems (Hartung et al., 2017). Furthermore, farmers do not use all tools in the same way. Allain et al. (2016) reported that, among farmers equipped with heat detection tools, some delegate the task entirely to the smart systems, while others prefer to verify in person the information. On the other hand, it is important to have user-friendly and time-saving interfaces developed for data control (Van Hertem et al., 2017). Some authors stressed the importance of developing better processes for disseminating knowledge and strengthening the skills of actors, for the successful functioning of precision farming innovation systems (Eastwood et al., 2017). The same authors underlined that, rather than the development of computer skills, a new and different approach to farm management is essential for farmers. Regarding the willingness to further invest in new technologic systems on their farms, the responses showed that farmers have a very high interest in technology and it is therefore important to find ways to adequately meet this demand and positive attitude.

Factors affecting farm technological level and herd performances

The implementation on the farm (and the time elapsed from implementation) of monitoring systems for milk yield, milk EC and milk flow are positively associated with average milk yield per head of the farm. In particular, farms with high-yielding cows showed significantly higher diffusion rate of milk flow and milk colour monitoring systems. The relationship is probably-one-to-one as the monitoring systems, especially those related to milk yield and milk emission, can allow to highlight abnormalities and correct any errors with positive effects on production performances. Milk flow, for example, can provide interesting information on the correctness of milking routine, milking efficiency and udder health (Sandrucci et al., 2007). At the same time, however, the farms with the higher milk yield per cow are also those in which management is more attentive and farmers rely on data rather than on habits or feelings for their managerial choices. In a recent study, Carillo and Abeni (2020) found a positive relationship between technology adoption (regardless of the category of tool adopted) and herd productivity in terms of milk yield per cow. Similarly, in our study, high production level emerged from Multiple Correspondence Analysis as associated to high average technological level. On the contrary, Steeneveld et al. (2015) did not record any change in herd productivity after investment in sensor systems on dairy farms.

Larger farms showed a higher rate of adoption of activometers for measuring animal activity and have also been using them for longer; this is consistent with the greater difficulty to visually identify heat symptoms in large farms. Abeni et al. (2019) reported similar results for dairy farms from the province of Cremona. Activity sensor systems can facilitate heat detection, but they can also provide interesting information on the presence of lameness or general cow welfare. In our study, the implementation of activometer systems did not show any positive relationships with fertility expressed by HDR, CR, calving interval and number of inseminations per pregnancy. This may seem surprising considering that farmers have indicated these systems as the most useful, have stated that they have seen improvements in reproduction management, and have also expressed their intention to invest in precision systems for heat detection in future. Similarly, no relationship emerged between precision systems for mastitis detection (provided by milk EC or milk SCC sensors) and udder health (based on milk SCC from official controls and the percentage of cows treated with antimicrobials for mastitis). The shortage of clear indications and quantification of the effects of the adoption of PLF solutions on herd performances and health was also underlined by Lovarelli et al. (2020). Herd production, fertility and health depend on many factors among which the most important are animal genetics, feeding, managerial level, but also structures, equipment and working staff attitudes and skills can have a significant role. Some of these factors are only partially under the control of the owner and can cause stiffness, limiting the farmer's ability to improve management even when information and alerts from the PLF systems advise him to do so. Moreover, as previously highlighted, the attitude of the farmer to verify the numerical results and his willingness to use indications to modify his management can be very different. Finally, there are differences between the technologies available in terms of reliability of measurements and algorithms, as well as the clarity with which the results are shown. All of these reasons can affect the effectiveness of technology investments in improving the efficiency of the herd and the conditions of the animals.

Bias and limitations

Farmers using the Internet, email and social networks may have been more likely to access this web-based survey. Partly for this reason, the sample of farmers who responded was mainly from northern Italy, the Italian region where there are the most intensive, productive and modern dairy farms, and appears to be younger than the average Italian farmers' population. Consequently, the sample may not have been fully representative of the Italian dairy farming and this may have strongly influenced the results. Further limitations related to the type of survey are that questions may not have been correctly interpreted by the farmers or that the farmers may have intentionally declared false or not true data. Moreover, precision technologies recorded in the survey included all types of sensor and precision systems regardless of the levels of complexity. The ease of use and effectiveness of these tools can vary greatly depending on the possibility of storing data and processing them to provide alarms or indications for decision support.

Conclusions

Precision livestock farming is not yet as widespread as it should be in Italian dairy cattle farms and the effectiveness of technology seems still insufficient to play a significant role in the development of a sustainable, animal-friendly and efficient livestock production. To speed up the diffusion process and make the impact of technology more effective, further efforts are required by all the actors: researchers, industry, extension services and farmers. In particular, besides the improvement of reliability of sensors and algorithms that underlie the precision systems and the development of user-friendly and time-saving interfaces, the exchange of knowledge and experiences among farmers has to be promoted, together with a proper support for a more efficient use of technology. The results of this survey can be useful in the Italian context but also in other countries where dairy farming is rapidly intensifying but Precision Livestock Farming is encountering resistance and is advancing slower than it could.

Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.animal.2022.100650.

Ethics approval

Not applicable.

Data and model availability statement

None of the data and models were deposited in an official repository, they are available upon request.

Author ORCIDs

Luciana Bava: https://orcid.org/0000-0001-6521-3195.
Anna Sandrucci: https://orcid.org/0000-0002-1014-0088.
Francesco Maria Tangorra: https://orcid.org/0000-0002-5476-1265.
Alberto Tamburini: https://orcid.org/0000-0002-3371-6254.
Giulia Gislon: https://orcid.org/0000-0003-0389-7960.
Maddalena Zucali: https://orcid.org/0000-0002-2380-3274.

Author contributions

M.Z. designed and directed the work; M.Z., M.C.B, A.T. and G.G. processed and interpreted the experimental data; M.Z., A.S. and M.C.B. drafted the article; L.B., A.S., F.M.T and G.G. critically revised the manuscript. All authors have read and agreed to the published version of the manuscript.

Declaration of interest

None.

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