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Precision dairy farming: Opportunities and challenges for India

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ABSTRACT

Effective management of a dairy farm has to focus on individual animal apart from group or herd management since 'smallest production unit in the dairy is the individual animal'. In this context, precision dairy farming (PDF) aims to manage the basic production unit in order to exploit its maximal production capacity. PDF is the use of information and technology based farm management system to measure physiological, behavioural and production indicators of individual animals to improve management strategies, profitability and farm performance. PDF applications are finding their way on dairy farms, although there seem to be differences in the uptake of PDF applications between dairy systems. The authors have attempted to identify different PDF tools utilized across the globe and have highlighted the status of adoption in Indian scenario by highlighting about few farms/organizations involved in its utilization and uptake over the years. In this direction, the authors have also focused on several benefits and challenges faced by developing countries including India since the benefits are often not immediately apparent and they require more management expertise along with an investment of time and money to realize. In addition, the adoption rate depends on various factors like farmer education, farm size, perceptions of risk, ownership of a non-farm business etc. Addressing these issues is very essential for the uptake of technologies and hence, an effort has been made to propose strategies for adoption and operationalization of PDF in India and other developing countries where the similar scenario exists. The study also highlights that PDF in many developing countries including India is in its infancy, but there are tremendous opportunities for improvements in individual animal and herd management in dairy farms. The progressive farmers or the farmers' groups, with guidance from the public and private sectors, and professional associations, can adopt it on a limited scale as the technology shows potential for raising yields and economic returns on fields with significant variability, and for minimizing environmental degradation. Additional research needs to be undertaken to examine the adoption process for not only successful adoption of technology, but also to solve the issues associated with the technology adoption. Further, right extension approaches and advisory services for the farmers interested in PDF needs to be undertaken for its effective application under different socio-economic and ecological conditions.

Keywords: Dairy herd management, Information and communication technology (ICT), Precision dairy farming (PDF), Radio frequency identification (RFID)

Dairy farming is a decision-intensive enterprise on a daily basis, which must rely on holistic approach to maintain a profitable system that is accountable to consumers for well-being, environmental impacts, and product quality. However, the narrow profit margin in dairy farming has intensified the drive for increasing the production and efficiency. Among various options in effective management of dairy farm, focusing on individual animal is one of the effective methods apart from group or herd management. Maltz (2000) reported that 'smallest production unit in the dairy is the individual cow'. Hence, precision agriculture in general, and precision dairying in particular, aims to manage the basic production unit in order to exploit its maximal production capacity.

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Definition and concept of precision dairy farming (PDF)

Various authors and researchers have defined precision farming in number of ways. According to Eastwood *et al.* (2004), PDF is the use of technologies to measure physiological, behavioural and production indicators of individual animals to improve management strategies and farm performance. It can also be defined as information and technology based farm management system to identify, analyze and manage variability within farm management for optimum farm performance, profitability and sustainability. Spilke and Fahr (2003) stated that PDF, with specific emphasis on technologies for individual animal monitoring, aims for an ecologically and economically sustainable production of milk with secured quality, as well as a high degree of consumer and animal protection. Precision farming is based on information technology, which enables the producer to collect information and data for better decision making.

PDF refers to the use of technologies that makes farmers less dependent on human labour, supports them in their (daily) management, and helps them to improve their farm profitability (Bewley 2010, Kamphuis *et al.* 2015). These PDF technologies are more than equipment that solely automate (laborious) processes, for example automated mobile barn cleaner. The development of applications for precision dairy farming started in the 1970s with the development of electronic cow recognition (Kuip 1987). An important aspect of PDF technologies is to monitor health and production and translate the monitoring results in useful information for the herdsman and preferably tailor-made actions for the herdsman to follow (Hogeveen 2017). This concept is considered by some as the future of agriculture and allied sectors. This concept is also called as spatially prescriptive farming; computer aided farming; farming by satellite; high-tech sustainable agriculture; soil-specific crop management; site-specific farming; and precision farming (Mandal and Ghosh 2000, Singh and Chopra 2007).

Precision dairy farming (PDF) technologies

The main objectives of PDF are maximizing individual animal potential, early detection of disease, and minimizing the use of medication through preventive health measures. However, the most important technologies being utilized in PDF are discussed in brief.

Walking activity: Use of an automated system called pedometer allows monitoring of both walking activity and milk production in dairy farm. Edwards and Tozer (2004) reported that the tool can be used to observe dairy cows in their daily movements, including milking, eating, standing, and lying, and can detect changes in this measurement. Currently, daily walking activity is primarily being used for detection of estrus. Further, a decrease in daily walking activity, along with a decrease in milk yield, might be used as an early warning to identify potential disorders in dairy cattle. Fresh cow disorders, such as ketosis and digestive disorders could be detected 7 to 8 days earlier based on activity and 5 to 6 days earlier based on milk yield (Edwards and Tozer 2004). Therefore, daily walking activity may be a useful tool to detect transition cow disorders and prevent further reduction in milk yield loss. In a similar study, Mazrier *et al.* (2006) indicated that pedometer predicted lameness earlier than the appearance of the clinical signs in a herd of dairy cows by correlating pedometric activity (PA) with clinical cases of lameness.

Milk yield and milk electrical conductivity: Lukas *et al.* (2009) demonstrated that significant changes in milk yield and electrical conductivity can be observed as early as 10 days before diagnosis of an adverse health event. Though, PDF technologies may alert the dairy farmer at an earlier stage giving time advantage, they do not indicate what type of disease is onset. This approach also fails to detect small changes in milk yield or milk electrical conductivity that are often associated with the onset of a health disorder (Edwards and Tozer 2004). Further, Khatun *et al.* (2017) also concluded that electrical conductivity along with other information (e.g. milk yield, milk flow, number of incomplete milking) may increase accuracy of detection and ability to determine early onset of mastitis.

Feeding behaviour and intake: Several studies have focused on feeding behaviour in terms of feed intake and production using commercially developed equipments which are readily available for monitoring activity at the feeder. Using an electronic feed monitoring system, Sowell *et al.* (1998) found that healthy animals spent more time at the feed bunk than morbid animals, and a greater percentage of healthy animals visited the feed bunk immediately following feed delivery. In a similar study, Quimby *et al.* (2001), using the same electronic behaviour monitoring system, detected animal morbidity approximately four days earlier than conventional clinical evaluations. Weary *et al.* (2009) also revealed that changes in animal behaviour can indicate illness, as well as the risk for illness. Early warning control measurements such as individual measurements of dry matter intake, feeding behaviour (Urton *et al.* 2005) and walking activity should therefore also focus on the period just before calving. Gonzalez *et al.* (2008) investigated that changes in short-term feeding behaviour of dairy cows occurred with the onset of the health disorders like ketosis, acute locomotory problems, and chronic lameness. Their algorithm resulted in detection of more than 80% of cows with acute disorders at least one day before diagnosis by farm staff. Short-term feeding behaviour showed very characteristic changes with the onset of disorders, which suggests that a system that monitors short-term feeding behaviour can assist in the early identification of sick cows.

Instrumentation: This involves a control system that consists of sensors that measure variables related to the system's state and actuators that provide input of mass, momentum or information to the system towards directional modification of the state. Laca (2009) has revealed that animal state is estimated by the history upto a recent time of position, activity, temperature, live weight and other physiological variables of all individuals in the herd. There are also unique opportunities to incorporate all relevant data and information in order to optimize the manager's basis for making decisions regarding the herd or the individual cow, but also for the development of optimal computer programs to be used by managers and advisers (Reddy 2012).

GPS: The use of GPS 'collar' for livestock including dairy animals has become widespread in the last two decades. This has opened the possibility of recording detailed position information for long periods of time, thus allowing a more complete understanding of the habits and causes of spatial distribution of ruminants (Laca 2009). Further, given the history of prices in electronic technology, it is very likely that with the proper investment in research and development, we can have cost effective herd information systems with which we will be able to see where and how all of our animals are and what they are doing at any time.

Animal behaviour sensors: Various types of sensors are necessary for a detailed record of behaviour. Mercury switches have been useful to document not only head movements but also walking and lying behaviour. There is a rich history of sensor development to detect and record kind and rate of herbivore behaviour. Sensors have been tested for measuring head angle (Schwager *et al.* 2007), head acceleration, leg acceleration, steps (pedometers), swallowing, jaw movements, biting and chewing sounds, weight, heart rate (Brosh *et al.* 2006), core temperature (Eigenberg *et al.* 2008), etc. The data recorded by these sensors is somewhat ambiguous, but models can be developed to infer activity. In specific, more research is needed to generate better sets of stimuli and training devices for livestock, including remotely controlled feeders. Finally, components have to be fully integrated into complete systems that can be commercialized, much in the way precision agriculture proceeded (Laca 2009).

Milk fat/protein ratio: The use of milk composition, in particular, fat: protein ratio, to indicate energy status has been around for some time (Grieve *et al.* 1986). Milk fat/protein ratio is evaluated as an indicator of negative energy balance using milk samples (Heuer *et al.* 2001). Further, Friggens *et al.* (2007) revealed that as compared to collection of samples monthly, use of automated sampling and inline milk analysis, substantially had higher frequency of measurement and an improvement in accuracy of energy status determination.

Rumen pH: Measurement of ruminal fluid pH is a reliable and accurate diagnostic test for ruminal acidosis. Individual dairy cows exhibit tremendous variation in the degree of acidosis they experience, even when fed and managed similarly (Beauchemin and Penner 2009). However, rumen pH could be used as an instrument steering rumen fermentation for optimal production and health of cows. Continuous monitoring of ruminal pH is possible through wireless telemetry which has the capacity to accurately detect subacute ruminal acidosis (Phillips *et al.* 2010).

Rumination: The percentage of cows ruminating at any given time has been considered by many people as an indicator of herd rumen health, as ruminal pH is affected by the amount of time the cow spends ruminating (Owens *et al.* 1998). Technologies for the automatic capture of rumination would allow for easy detection of changes in both individual cow and herd rumen health, and thus allow for the diagnosis of acute acidosis (Weary *et al.* 2009). An example of this is an electronic rumination monitoring system, which was validated by Schirmann *et al.* (2009) which would allow for easy detection of changes in both the individual cow, as well as herd rumen health, and thus, allow for the detection of a bout of acidosis.

Rumen temperature: The use of ruminal temperature in field situations depends on future development of a practical and cost effective intra-ruminal wireless telemetry temperature sensing device (Bewley 2009). They act as rumen sensors to measure temperature, pressure/motility and pH in rumen.

Herd management software: The ability to digitally store herd information is a valuable tool for all farms, and a necessity for those desiring to utilize RFID to aid in farm management. Herd management software provides mechanisms for farmers to store individual animal data in a database. Additionally, the data, and results from any analysis/reports can then be viewed via a digital display or in hard copy documents. Such data or information storage, retrieval and manipulation capabilities provide farmers with an extremely valuable resource to aid them in their farm management activities and decisions.

Automated feed-dropping control units: Feed bins that have the ability to automatically drop a designated amount of feed into the feed trough of each individual cow have been demonstrated to be highly effective in dairy farms. Automated feed units provide a variety of benefits to farms, including reduced labor, cost savings, removal of possibility for human error, and of course the ability to automatically calculate and provide the required amount of feed for cows to sustain or increase in their milk production (Trevarthen and Michael 2008).

Body temperature: The largest potential benefit of employing an automatic body temperature monitoring system in a dairy farm would be in early detection of disease, illnesses, or disorders that plague the dairy industry (Maatje *et al.* 1987). In recent years, intensive fresh cow management programs have been established based upon using thermometers to detect fever (Aalseth 2005). Many of these fresh cow management programs are based on identifying animals with temperatures outside of a pre-established range and treating outliers. Hence, body temperature is the first and foremost sign to be detected during any disorders.

Body condition score (BCS): Only a few dairy farmers have integrated BCS based on visual evaluation in their daily management strategy mainly because it is fairly time consuming and subjective. Bewley and Schutz (2009) showed that there is a strong relationship between the angles measured by video imaging and the BCS as determined by trained evaluators. Further, Schroder and Staufenbiel (2006) investigated that measuring Backfat Thickness (BFT) by ultrasound is of added value compared with other body condition scoring systems because it is objective and precise. Ongoing research on automation of body condition scoring suggests that it must be incorporated into decision support systems in the near future to aid producers in making operational and tactical decisions (Roche *et al.* 2009).

Daily body weight: Meijer (2010) reported that measuring daily body weight is used in many automatic milking systems or automatic feeders as an indication for monitoring BCS and energy balance. However, the course of daily body weight of cows is not specific enough as an indication for BCS and energy balance because many factors other than real amount of body fat may influence body weight.

Remote sensing: Remote Sensing is the science and art of acquiring information (spectral, spatial and temporal) about material objects, area or phenomenon, without coming into physical contact with the objects, or phenomenon under investigation, furnishing large amounts of spatial and temporal data and the possibility of extracting climatic and ecological information. In remote sensing, information transfer is accomplished by use of electromagnetic radiation (EMR). This technology is also used for dairy herd management of the ranches in many developed countries.

Feed troughs with measuring capability: As per Trevarthen and Michael (2008), the capability to provide a specific amount of feed to each cow to meet their requirements is one of the most valuable capabilities for a dairy farm. Utilizing this approach will not only allow farmers to ensure that their cows are eating their required amount of feed, but will also aid to detect any cows that may be having a problem, such as illness.

Milk meters: Milk meters provide the amount of milk each cow provides at every milking session. To be useful, this information should be automatically recorded in the herd management database. Other pieces of information, such as the time at which the reading took place, the cows bail number, and duration of milking can also be derived from milk meters, and should be stored in the database (Trevarthen and Michael 2008).

Milking controller unit: According to Singh *et al.* (2014a), it is the device that controls the suction and suckling motion of the milking cups attached to the teats of each cow. Utilizing this system in combination with RFID technologies can generate a cow's complete milking history and milking pattern. Further, at a more advanced level, Trevarthen and Michael (2008) proposed that display devices be incorporated into the milking controller units, providing a mechanism to display a range of information to the dairy operator relating to the cow currently located in the milking bail. This could include any information stored in the herd management database.

Automatic drafting gates: As per Trevarthen and Michael (2008), the cows may be extracted for a wide variety of reasons, including the need for veterinary treatment, artificial insemination etc. The most useful location for these drafting gates is believed to be on the exit to the dairy, as this is where all lactating cows must pass at least twice a day. Operating in conjunction with herd management software, these gates would be a valuable asset to almost any dairy farm.

Digital device network: A form of digital network is required so as to enable the communication of devices between one another, with RFID readers and the central herd management software. There are essentially three methods of establishing such a network – wired, wireless or hybrid (Trevarthen and Michael 2008, Singh *et al.* 2014a).

Geographic information system (GIS): According to Babalobi (2007) and Johnson and Johnson (2001), GIS integrates hardware, software, and data for capturing, managing, analyzing and displaying all forms of geographically referenced information. Geographical Information Systems have tremendously enhanced ecological Epizootiology, the study of diseases in relation to their ecosystems. It has found increasing application for surveillance and monitoring studies, identification and location of environmental risk factors as well as disease prediction, disease policy planning, prevention and control. Reddy (2012) has reported that GIS could provide insight into the possibility of transmission of infectious diseases between herds. In the planning of eradication of diseases, GIS has the possibility to perform overlay analysis to find high or low risk areas for diseases which depend on geographical features or conditions related to the geography.

Automated calf feeder systems: Feeding calves in groups allows calves to express some natural behaviours that cannot be expressed when they are housed individually, but offers some challenges in relation to maintaining good health, another important aspect of animal welfare. Automated calf feeders for raising young calves in groups are growing in popularity as producers want more flexible labor management and consumers want animals to have a more natural life. Good health is achievable when using automated calf feeders to raise pre-weaned calves as long as appropriate management and maintenance of equipment are emphasized and implemented (Endres 2017, 2018).

Activity-based heat detection with a bolus system located in the dairy cow's rumen: The detection of cows in heat has become more and more difficult over the past decades due to changes in animal behaviour and management. Besides timed breeding programs, which are often costly due to poor conception rates, the use of activity monitoring systems developed into a reliable and accepted method in farms worldwide. While activity was previously only measured by collars, ear tags or pedometers, for the first time a new system delivers an activity-based heat detection system with data directly from the rumen (Stein 2017). Performance tests confirmed the accuracy of the system. Together with its advantages in handling, it is shown to be a reliable, innovative alternative for progressive heat detection and general herd monitoring.

Stein (2017) has revealed that the whole system consists of a measuring device located in the rumen of the animal (bolus), meaning that additional devices such as pedometers, collars or ear tags are not required. The bolus is administered orally and stays in the rumen for the animal's lifetime without the risk of loss or shifting. It measures rumen temperature and activity (via accelerometer) continuously at 10 min intervals with activity measurement not affected by rumen motility. The recordings are read out by a simple plug and play infrastructure (Base Station and Repeater). The software functions as an online platform for data and alert access, general organization and data sharing with veterinarians, consultants or farm staff. Further, the dairy cows' history of previous successful conception by inseminations can be documented in the software to calculate the expected lactation (Stein 2017).

Edge computing in dairying: Gans (2017) refers Edge Computing as the aggregation and analysis of data by an individual or group for the purpose of studying that data and using it to improve a system or process. This technology can be differentiated into two subgroups: Cloud Computing when data is aggregated and stored for use by a single network user, or Fog Computing when that data is distributed among many network users. With data sharing, farmers can make decisions based on more information and data from farms in similar locations, parlor styles and herd size/breed, among other things (Gans 2017, Yousefpour *et al.* 2019).

Calving detection: Management during calving is important for the health and survival of dairy cows and born calves. Although the expected calving date is known, this information is imprecise and farmers still have to check a peripartum cow regularly to identify when it starts calving. Hogeveen (2017) and Rutten *et al.* (2017) have pointed that a sensor system that predicts the moment of calving could help farmers efficiently check cows for calving. Observation of a cow prior to calving is important because dystocia can occur, which requires timely intervention to mitigate the adverse effects of dystocia on both cow and calf. Since farmers have less time available per cow, sensors might aide farmers with the detection of the precise moment of calving (Hogeveen 2017).

Estrus detection systems: In the late 1980's and early 1990's, research into the use of pedometers to detect estrus was carried out (Holdsworth and Markillie 1982, Redden *et al.* 1993). More recently, 3D-accelerometers are becoming available and are used to detect estrus (Valenza *et al.* 2012, Lovendahl and Chagunda 2010) and assist in undertaking estrous synchronization. Besides these activity-based automated estrus detection systems, other systems are also available, for instance, a progesterone measuring system (Friggens and Chagunda 2005). The detection system may be combined with a system to optimize the time of insemination. For some individual cows it can be economically beneficial to extend the time of insemination (Steeneveld *et al.* 2012).

Assessment of pastoral resources: Reddy (2012) has reported that pastoral system modelling using Resource Assessment for Pastoral System (RAPS) avoids limitations of the traditional techniques of assessing carrying capacity, and brings the methodology in line with GIS, GPS and remote sensing technologies. The RAPS model primarily uses Metabolisable Energy (ME) as the forage-livestock integrator. The aim of this tool is to quantify and better understand the complex mix of pastoral resources available to herder groups to support sustainable resource-led management. The pastoral risk assessment and forecasting programme is designed to give early-warning to herders, technicians and administrators of the possibility of serious conditions during forthcoming lean season, and particularly relates to the provision of adequate livestock feed supply and shelter (Reddy 2012).

As dairy operations continue to increase in size, monitoring and managing of livestock have become more challenging and complex and require enhanced management ability (Edwards *et al.* 2015, Bewley 2016). However, the need for any of these technologies depend on the requirement for different farmer segments, resource availability, herd size, risk taking ability of the farmer etc.

Potential benefits of precision dairy farming

The PDF has various benefits which are often not immediately apparent and they require more management expertise along with an investment of time and money to realize. Some of the important benefits include increased efficiency, reduced costs, improved product quality, minimized adverse environmental impacts and improved animal health and well-being (Bewley 2010). Further, the same study has also pointed out that PDF technologies become more feasible, because of increased reliance on less skilled labour and the ability to take advantage of economies of size related to adoption of technology. All these are possible, since dairy operations continue to increase in size and have a greater prospect for future. The use of precision technology is increasingly providing farmers with the means to reduce labor requirements and improve management of large herds (Bewley 2010, Eastwood *et al.* 2012 and 2015). For example, in dairy farming, these technologies perform daily milk yield recording, milk component monitoring, pedometers and heat detection monitoring, automatic temperature recording devices, milk conductivity indicators and daily bodyweight measurements etc. A study conducted by Van Asseldonk *et al.* (1999) has emphasized that PDF technologies allow dairy producers to make more timely and informed decisions, resulting in improved productivity and profitability. Also, dairy management and control activities can be automated, which provide a recommendation for the manager to interpret.

Bewley (2010) has indicated that integrated, computerized information systems are essential for interpreting the mass quantities of data obtained from PDF technologies. This information may be incorporated into decision support systems designed to facilitate decision making for issues that require compilation of multiple sources of data. Further, Bewley (2010) and Eastwood *et al.* (2015) have reported that, by identifying changes in physiological parameters, a dairy manager may be able to intervene sooner depending on the clinical signs of stress or illness. These easily observable clinical symptoms are typically preceded by physiological responses not obvious to the human eye (e.g. changes in temperature or heart rate). Thus, in the similar direction, technologies for physiological monitoring of dairy cows have great potential to supplement the observational activities of skilled herd persons, which is especially critical as more cows are managed by fewer skilled workers (Hamrita *et al.* 1997, Bewley 2013 and Singh *et al.* 2014b). Also, in PDF, different input and output aspects in and around the animal are managed and controlled both simultaneously and automatically (Bos *et al.* 2018). However, in the absence of precision technologies, livestock management decisions will be based almost entirely on the judgement and experience of the livestock farmer. Hence, quantification of these aspects through precision technologies provides an objective measure for identifying individual animals or groups of animals (Parsons *et al.* 2007).

Status of precision dairy farming in India

Currently, PDF applications are finding their way on dairy farms, although there seem to be differences in the uptake of these applications between dairy systems. In India, few farms/ organizations have adopted precision technologies which were developed with the help of Indian and foreign companies in dairy farming sector. Some of the cases or models are discussed in this paper to highlight the fact that PDF is still in infancy in India and few other developing countries. In the year 2000, the National Livestock Identification Scheme (NLIS) made the use of radio-frequency identification (RFID) tags which contain a microchip that can be read electronically in a fraction of a second by producers who have a suitable reader. These systems provide accurate identification of cows and are linked to pedigree, management events, treatment records, electronic milk meters, computer-controlled feeding, automatic sorting and weighing, etc. (Singh *et al.* 2014b). On the similar lines, National Dairy Development Board (NDDB) has developed an Information Network for Animal Productivity & Health (INAPH), a desktop/ netbook / android tablet-based field IT application that facilitates the capturing of real time reliable data on breeding, nutrition and health services delivered at farmer's doorstep. The application can be operated through computers/netbooks as well as hand-held devices (Windows phone & Android tablets) with internet connectivity. Data collected in the field is stored in the central database at NDDB, Anand. In the absence of network connection (offline mode), there is a provision for data to be captured and stored for later synchronisation with the central server through the GPRS network.

INAPH is equipped to send messages to farmers, providing appropriate advice regarding their animals, when required. Web based reports are available to the managerial team and other decision makers for analysis. The system is designed to meet the various information needs of farmers,

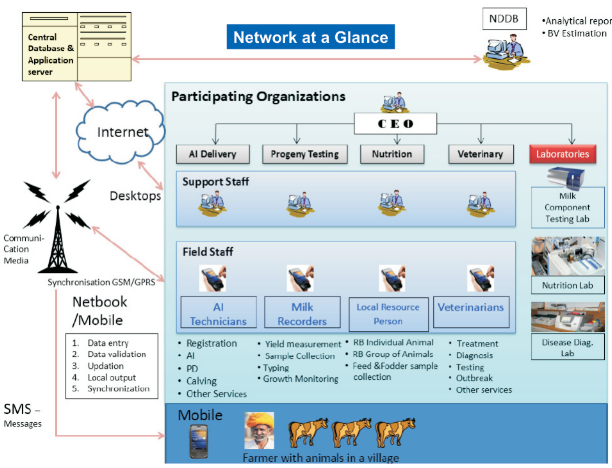

Fig. 1. Framework of INAPH (INAPH-NDDB 2019).

field technicians, end implementation agencies such as Milk Unions/Federations, Producer Companies, analysts and policy makers. However, this project is in the initial stage and requires great efforts since large number of animals in India are scattered in rural areas indicating wide geography. The field level application of this project is also constrained by several problems like network, connectivity, poor knowledge of the farmers etc.

Some organized farms in private sector in India have adopted RFID based animal identification and farm automation management system, e.g. Chitale Dairy in Pune, Sangamner Milk Union, Maharashtra, Lakshya Dairy in Haryana and Kopordem Farm at Valpoi in Sattari Taluk in North Goa to begin tracking and to ensure accuracy of the data related to each animal. Most of the RFID based solutions for identification and farm management in India are being provided by multi-national companies like DeLevel and Westfilia. Various insurance companies and research groups are making efforts to develop RFID based animal identification, data recording and complete farm management system applicable for small holding dairy farmers at low cost. In one of the case studies, farm animal management and automation use a tiny microchip, or radio frequency identification (RFID) tag, punched on animals' ear sends information about daily dietary needs and feeding details etc. to a radio sensor located inside the farm premises. This, in turn, communicates with computer systems at the BG Chitale Dairy located in Bhilavadi village of Sangli, Maharashtra. The data collected by this system is then accessed real time by dairy managers and other supervisors for carrying out specific activities, such as monitoring the health and changing the feed composition. Controlled feeding process, early diagnosis of illness and pedigree analysis of cows and buffaloes resulted in 3–4 times better milk yield than the national average at Chitale Farm. By predicting problems, illness can be mitigated with the focus on better health management (Ruhil *et al.* 2013). Interestingly, Chitale dairy maintains a database of more than 10,000 animals, along with a complete progeny and medical history by deploying a 'cows-to-cloud' strategy.

COWEL is a computer-based decision support system that contains attributes regarding housing and management conditions. These attributes are technical specifications that contain various technical units called levels. These levels are ranked from best-to-worst regarding welfare, based on scientific information about animal-based parameters. This information, inserted in the model as statements, was weighted depending on the impact it has on welfare by using weighting categories. Ursinus *et al.* (2009) have depicted that COWEL can be used to rank new husbandry systems on a welfare scale and it can be handy tool for evolving a new sustainable and welfare friendly system for the dairy sector.

On the similar lines, AFIMILK is an innovative management system which provides a professional and comprehensive tool to make day-to-day herd management decisions. It consists of a series of modules among which a farmer can choose one or many of the modules in the configuration. With the input from all the engaged modules, the software can provide daily breeding reports, general fertility analysis, health monitoring, milking efficiency reports, automatic generation of veterinary check lists based on parameters, cull planning, herd size and milk production planning etc. to the farm manager. This platform has provided dairy producers the technology and knowledge to profitably produce high-quality milk for almost 40 years. By advancing technology and introducing innovations, this management system meets the dairy sector's changing needs and stands at the forefront of management software and sensors (Berger and Hovav 2013).

MOIRA (Management of Insemination through Routine Analysis) is a computer program that is a module of DAISY, the Dairy Information System which suggests when to inseminate the animal (Williams and Esslemont 1993). This decision support system uses the results of milk progesterone tests to determine when to inseminate cows. The MOIRA program plans a series of weekly tests for each cow, to check for estrous cyclicity. Subsequently, the program lists cows for alternate day tests to identify the days when they should be served, and if necessary, a cow can be served without being seen in heat. The work which led to the development of MOIRA showed that ovulation detection rates of 98% were achieved; in commercial herds the rate is around 85%. As pregnancy rates were unchanged, the effect of MOIRA is to reduce calving to conception interval and the culling rate for failure to conceive. The use of the program has produced an estimated extra net profit of 52–54 pounds per cow in different herds (Williams and Esslemont 1993).

A proof of concept application using Information and Communication Technology (ICT) in the dairy sector was developed by the Centre for Electronics Governance at the Indian Institute of Management, Ahmedabad (CEG-IIMA). The application aims at helping the dairy farmers with timely messages and educating them on the care for their milch cattle and enhances the production of quality milk. It also aims at assisting the dairy unions in effectively scheduling and organizing the veterinary, artificial insemination, cattle feed and other related services. The application uses Personal Computers at the milk collection Centres of the Dairy Cooperative Societies (DCS) having connectivity to an Internet Service Provider (ISP). The application includes two components—a Dairy Portal (DP) and a Dairy Information Services Kiosk (DISK) (Aware and Kshirsagar 2017).

In another study, SARSA Green in West-Bengal has developed the Geographical Information System for integrated dairy farm management which helps in integrating the whole dairy farm in a more precise way to get correct information about various aspects. GIS has added new vistas in the field by including different units like fodder production, shed management, cattle feed plant, diary plant and different farming system (Ghose *et al.* 2019)

The researchers at Mumbai Veterinary College, Mumbai under the leadership of Dr. Abdul Samad developed a software, known as Herdman, which was used in conjunction with the animal Radio Frequency Identification Device tags (An active RFID tag) and cell phones' text messaging capability, in order to access information regarding cows and buffaloes. In this farm, the system targets, information regarding each animal's health, breeding, milk yields etc. The ear is tagged with an RFID inlay, which has a unique ID number of each cow or buffalo, giving regular updates related to its health or milk production. The system also has option for cell phones with text messaging functionality. When visiting an animal, a service provider would use his cell phone to enter the last four digits of the ID number encoded to an animal's RFID chip, and then describe whatever services he performed, or the observations he made. Farmers could later use their own cell phones to access data about their animals from Chitale Dairy's database, input by service providers (such as milk production, or the tentative date for pregnancy etc.). As per the cost and benefit analysis presented by Samad *et al.* (2010), the implementation of such a system is economically beneficial because the cost of investment can be recovered even if 1% of fraudulent claims are prevented due to availability of accurate and reliable data. They have implemented such system in 5,000 dairy animals spread over more than 10 villages with an average of 2 to 3 animals per farmer in Thanjavur district, Tamil Nadu, India. The cost of maintenance of the system can be met from the improved services that would enhance productivity, minimize losses due to management errors and enhanced market price of the animals due to availability of data.

Ruhil *et al.* (2013) and Ruhil and Mohanty (2011) have discussed about the development of wireless sensor network for animal management. The focus of this IIT-Delhi and NDRI, Karnal Project was to develop a wireless ad hoc sensor network (WSN) to identify the animals through sensor nodes and to monitor the behaviour of animals which include the movement (3D), jumping, position, temperature etc. Such data is required to monitor the behavioural changes in the animals which in turn helps in heat detection, early diagnosis of ailments like mastitis, lameness etc. and also in assessing the comfort zone of animals, group behaviour etc. Data transmission is in ad hoc manner instead of fixed base station. It has also developed Smart Bucket with weight, temperature, pH and conductivity sensor to collect all the information regularly and to transmit the information to the central server for data recoding and analysis for health management of animals. The unique feature of the system is that the veterinary health worker (VHW) is able to register and enter new records only when the RFID reader connected to a mini laptop is within reading range of the associated RFID tag.

BAIF Development Research Foundation, Pune has developed a method of rapid pregnancy test in which cattle or buffaloes would be diagnosed for pregnancy after 18–19 days. This method is initially being enabled for sorted semen inseminations in which animals are tagged with a code while performing the first insemination. Later the AI worker of BAIF would receive a message after 17–18 days with a reminder to undertake pregnancy diagnosis through the tags. This has been beneficial for farmers in different states since the pregnancy of the animals are being diagnosed at the age of 18–19 days instead of waiting for 3–4 months as in the conventional method.

FarmTree is another handcrafted tool to enrich dairy farmers with the ability to use data to unleash massive economic value across the dairy farmers in different Indian states. This is a farmer's diary which lets the farmer to record his farm data, analyze it and present it for maximizing dairy farm output. This tool tracks lactation performance and identifies the most 'profit-making' and 'loss-making' cattle from the entire herd. It assesses the recorded milk data of cattle on varied parameters like yield, Fat and Solids-not-fat (SNF). FarmTree consistently tracks Milk productivity and improves breeding performance. It tracks various farm dynamics like farm expenses, cost of feed and its performance, milk performance, per litre production cost, breeding performance, days of peak milk, monthly profitability, among multiple other factors which make a difference. This tool is used by farmers in majority of the states in North India including Gujarat, Uttar Pradesh, Rajasthan, Haryana and Punjab.

It is clear from the above mentioned studies that use of these technologies presents an opportunity to improve farm productivity and address future on-farm challenges related to environmental, animal care, and socio-ethical issues. However, greater clarity is needed to ascertain farm system-level benefits (monetary and non-monetary) associated with the use of some precision technologies, to minimize investment uncertainty for farmers and to guide technology development. However, PDF has the potential to improve management decisions beyond what is possible through intuition and experiential management processes alone, and to reduce the adaptation period when farmers change systems.

Problems /Challenges for adoption of PDF technologies

Though, precision farming concept has the tools for overcoming the infield variability, its practicality and applicability questions are to be answered. The adoption rate depends on various factors like farmer age, level of formal education, learning style, goals, farm size, business complexity, increased tenancy, perceptions of risk, type of production, ownership of a non-farm business, innovativeness in production, overall expenditures on information and use of the technology by peers and other family members. Plethora of studies (Mandal and Ghosh 2000, Bewley 2009, Samad *et al.* 2010, Yule and Eastwood 2012, Ruhil *et al.* 2013) have discussed different problems/ lacunae that hinder the adoption of this concept not only in India but also in many of the developing countries.

The major problem is the presence of large number of animals which are scattered across wide geographical rural areas. Majority of these dairy animals belong to small farm size/herd size and resource poor farmers who cannot afford such technologies. Further, these animals also belong to multiple species and multiple breeds with different economic parameters creating difficulty for adopting this technology. The small size farms and heavy investment in the technology increase cost of inputs (labour, equipment, maintenance etc.) leading to high cost of milk production. Poor availability of IT tools and infrastructure, computer illiteracy of farmers or rural animal health workers also contribute to non-adoption of this technology at field conditions. Further, Driessen and Heutinck (2015) and Eastwood *et al.* (2019) have also identified a moral challenge in the ethics surrounding the precision technology which may trigger debates in society around animal welfare. These technologies have focused on technology development and on-farm use without considering socio-ethical implications and have excluded certain actors such as citizens and consumers. Further, it has been argued that PDF will reshape the practice of farming, with less 'hands-on' management and a more data-driven approach (Eastwood *et al.* 2012).

As a general rule, PDF technologies should pay for itself in order to get adopted by dairy farmers. At the moment there are not very many economic calculations available to evaluate the cost-effectivity of current PDF technologies. Further, an increased level of automation also heightens dependency, if one component in the integrated system fails then the whole system may not work. This issue also has to be examined from the manufacturers and service providers' perspective. Furthermore, this technology also demands regular data collection, analysis and interpretation of the available data which may be performed by a skilled human resource. However, availability of local technical expertise for interpretation and decision making in this emerging field is very low or negligible. Different skills will be required across the farming team to enact and adapt these technologies (Eastwood *et al.* 2017, Higgins *et al.* 2017), along with adapted advisory structures, potentially leading to displaced farm staff and service providers. Under several circumstances, PDF performance may be affected by antenna patterns, geographical location, tag orientations, equipment failure, low temporal resolution etc. Sometimes, problems like data transfer error due to excess input and output may also be observed.

Despite the growing demand, adoption rates of most commercially available PDF technologies are limited. Farmers have indicated uncertainty regarding investment in PDF technologies (Borchers and Bewley 2015, Eastwood *et al.* 2015, Steeneveld and Hogeveen 2015) and this uncertainty might be due to a lack of information on the added economic value when these PDF technologies are implemented on farm. Reasons not to invest in PDF technologies included farmers' perception that current commercially available PDF technologies have not proven themselves in the field (yet), that they are technically unreliable, and have an uncertain return on investment (Russell and Bewley 2013, Borchers and Bewley 2015;

Steeneveld and Hogeveen 2015). This lack of clear cost benefit information is one of the most limiting factors for commercialization of PDF technologies (Banhazi *et al.* 2012). Further, few studies have also shown slow adoption rates of precision farming (Batte and Arnholt 2003) due to small farm size, farmer age, education level, computer illiteracy etc. The advantages posed by the technology are often not immediately apparent and they require more management expertise along with an investment of time and money to realize (Bell 2002). Further, Ruhil *et al.* (2013), have expressed for a warrant about further research for its wider application especially for the small holders keeping one or two animals.

Lack of validated research results concerning the effects of application, high capital input and high costs in developing countries including India is a common problem. This has ultimately led to lack of success stories, demonstrated effects, input use and its yields etc. leading to reduction in the interest of the farmers to adopt the technology. In this context, Ruhil *et al.* (2013), has expressed for a warrant about further research for its wider application especially for the small holders keeping one or two animals. The economic implications of technology adoption must be explored further to increase adoption rates of Precision Dairy Farming technologies (Bewley 2013). While many benefits of PDF come from labour and skills related areas, some farmers perceive PDF as a double-edged sword, in some cases covering a lack of staff skills but in others, leading to de-skilling of farm staff. All these issues have led to poor adoption of these technologies across developing countries including India.

Strategies and Way forward

In the present situation, the potential of precision agriculture in general and precision dairying in particular is limited by lack of appropriate measurement and analysis techniques for various important factors (National Research Council 1997). The limitation in data quality/availability has also become a major obstacle in the demonstration and adoption of the precision technologies. In this context, an effort has been made to propose strategies for adoption and operationalization of precision dairy farming in India and developing countries where the similar scenario exists.

- Creation of multidisciplinary teams involving scientists in various fields, like dairying, engineers, manufacturers and economists to study the overall scope of precision farming.
- Since the tools are costly, formation of farmers' cooperatives, self help groups or community organizations would be one of the solutions in developing countries like India.
- Pilot study should be conducted on farmer's field to show the results of precision farming implementation.
- Creating awareness through right extension approaches and advisory services amongst farmers about effective application of the technologies. This is possible by understanding the impact of PDF for the farming communities under different socio-economic and ecological conditions.
- Additional effort needs to be directed towards implementation of management practices needed to fully utilize the information provided by these technologies. Controlled university research on precision dairy farming simultaneously with field on-farm adoption should be practiced.
- Promote the technology for progressive farmers who have sufficient risk bearing capacity since the technology requires capital investment.
- Provide complete technical backup support to the farmers to develop pilots or models, which can be replicated on a larger scale.
- PDF applications need to address a clear problem associated with clear actions or standard operating procedures (SOP). By using the information collected by PDF systems, the production performance of the cattle can be improved, making these systems more cost-efficient.
- The management systems must use the data to provide useful information to 'time poor' farmers or herd managers in a clear and efficient manner which align with potentially diverse farmer needs and resource management.
- New legislative and policy issues and additional market compliance demands also need to be considered by the concerned agency. Further, protection of the farmer's privacy and data ownership also need to be ensured.
- Before investing in a new technology, a formal investment analysis should be conducted to ensure the suitability of technology in catering the farm needs.
- Effective coordination among the public, private sectors and growers is, therefore, essential for implementing new strategies to achieve fruitful success.
- Advances in technologies fuelled by consumers of information and application open a window of opportunity to create cost-effective systems for large scale precision dairy production.
- The technologies need to be flexible enough to be relevant to a range of farmer perspectives and farm business structures.
- The research and extension professionals needs to improve their skills and performance to offer decision support to PDF farmers by user-centric and design-oriented approaches.
- The role of extension professionals and advisors is to act as a sensemaker in the smart farming innovation system, rather than a mere promoter or barrier to technology uptake.

As there are no well recognized approaches and blueprints to the emerging perspectives, but only the concepts and principles can be operationalized through research and effective implementation. Efforts to address the above mentioned aspects would improve the adoption

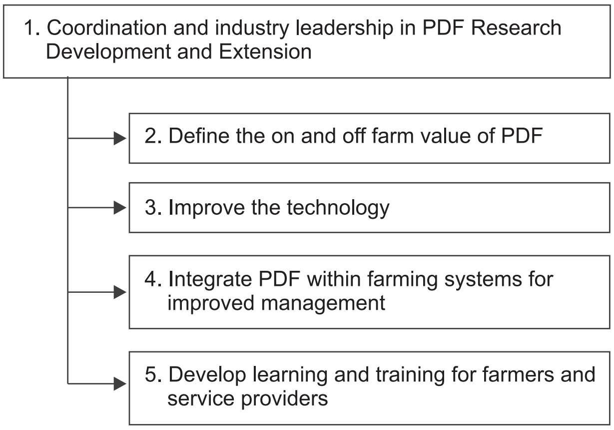

Fig. 2. Proposed focus areas (Eastwood and Jago 2012).

and operationalization of precision dairy farming in India and other developing countries where the similar scenario exists. In this direction, Eastwood and Jago (2012) has proposed five focus areas as one of the strategies for uptake of this technology (Fig. 2).

Conclusion

Precision dairy farming in many developing countries including India is in its infancy but there are tremendous opportunities for improvements in individual animal and herd management on dairy farms. The progressive farmers or the farmers' groups, with guidance from the public and private sectors, and professional associations, can adopt it on a limited scale as the technology shows potential for raising yields and economic returns on fields with significant variability, and for minimizing environmental degradation. Additional research needs to be undertaken to examine the adoption process for not only successful adoption of technology but also to solve the issues associated with the technology adoption. Further, right extension approaches and advisory services for the farmers interested in PDF needs to be undertaken for its effective application under different socio-economic and ecological conditions.

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