(07-012) - Design of new cow monitoring processes based on artificial intelligence, Data Science and immersive reality.

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Milk is considered a superfood, with nutritional benefits for the different stages of human life. It is projected that in the future the consumption of cattle milk will increase around the world. The pressure to generate more efficient production systems, alongside production metrics, as well as the impact on air, soil, and water pollution, is increasing.

Monitoring the routine and behaviour of cows on a constant basis is essential to ensure animal welfare, which translates into operating efficiencies and higher production with higher quality milk.

The use of Data Science, the generation of Predictive Models and the application of Artificial Intelligence (AI) will provide the possibility of better accompaniment to an industry that needs to reduce its ecological impact in order to continue providing a natural product of high nutritional value. This project presents an objective way to integrate and take advantage of information from different sensors, which will allow a more accurate analysis of the relationship between feeding, rumination and milking results generated by the robotic system.

Keywords: Environmental Engineering; Artificial intelligence; Data Science; Immersive reality

Diseño de nuevos procesos de monitoreo de vacas en establo basados en inteligencia artificial, ciencia de datos y realidad inmersiva

La leche es considerada como un super alimento, con bondades nutritivas para las distintas etapas de la vida del ser humano. Las proyecciones en el incremento del consumo de leche de ganado bovino se mantienen en el futuro de manera global. La presión por generar sistemas de producción más eficientes, en torno a métricas de producción, así como el impacto en la contaminación de aire, suelos y agua, va en aumento.

Monitorear la rutina y el comportamiento de las vacas de manera constante, es esencial para garantizar el bienestar de los animales; lo que se traduce en eficiencias de operación y mayor producción de leche con mayor calidad.

El uso de Ciencia de Datos, la generación de Modelos Predictivos y la aplicación de Inteligencia Artificial (IA) proveerá la posibilidad de un mejor acompañamiento a una industria que requiere reducir su impacto ecológico a fin de seguir proveyendo de un producto natural de alto valor nutrimental. El presente proyecto presenta una manera objetiva de integrar y aprovechar información de diferentes sensores, lo que permitirá tener un análisis más exacto de la relación entre la alimentación, la rumia y los resultados de ordeño generados por el sistema robotizado.

Palabras clave: Ingeniería ambiental; Inteligencia Artificial; Ciencia de datos; Realidad inmersiva

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1. Introduction

The intake of milk has taken on much greater relevance since it has been called a superfood. Cow's milk contains many nutrients including vitamin B12 and iodine, it's a great source of proteins, magnesium, and calcium (Heritage Foods Limited, 2019).

From the point of view of genetics, it is desired to have better animals, that is, those that produce the largest quantity of milk with the best quality. This is not new, for 5000 years human beings have sought the same thing. However, nowadays there is a need to integrate variables and data science that complement each other. It is at this point where artificial intelligence becomes relevant, because it could be the opportunity to find the best cow, in other words, the one that produces more milk, costs less, with less reproductive issues, and the most important thing, that it pollutes less. To achieve these goals, it is necessary to consider three elements: genetics of the cow, feed, and the care of the animal.

CAETEC (Experimental Agricultural Field from Tecnologico de Monterrey, Spanish acronym) is a living laboratory focused on the practice of techniques and theory seen in class to maximise the experiential learning of students according to the TEC 21 Model of the Tecnologico de Monterrey (challenge-based learning). Apart from the corn and oats production, it has a Cattle with milk production of dairy cows. The cycle starts from the selection of the corn seed until the production of milk. This paper will be focused only on the selection needs of Artificial Intelligence (AI) to select the best cows.

Together with the use of Data Science, the generation of Predictive Models, data science, and the application of Artificial Intelligence (AI) it is possible to propose better scenarios to reduce ecological impact and at the same time provide a natural product of high nutritional value.

This project presents a way to integrate and take advantage of information from different sensors, which will allow a more accurate analysis of the relationship between feeding, rumination, and milking results generated by the robotic system, together with the genetics and welfare of the cows.

2. Objectives

The objective of the present work is to propose a methodology that allows the implementation of AI in a dairy barn by the integration of information from different sources as sensors, which will allow a more accurate analysis of the relationship between feeding, rumination and milking results generated by the robotic system. As well as, to optimise dairy production of the barn by integrating data science, predictive models, and artificial intelligence to select dairy cows with superior genetics, feeding behaviour, enhance milk yield with more nutritional value, and environmental sustainability.

3. Methodology

To implement AI into CAETECs system in the milking production stables, 4 steps must be done:

1. Identify and define which are the proper sensors and metrics to be used, and also ensure proper installation, define the frequency of data collection, and monitor analytics according to industry-established standards.
2. Generation of systems (new solutions, hardware, and software) that interconnect the equipment and methods already used on the farm. Equipment, facilities, and working methods must be modified in order to incorporate more visibility, ensuring a broader spectrum in the positive impact of the generated information.

3. Provide constant training at all levels of collaboration (e.g. operators, supervisor, suppliers, consultants, researchers, etc.).
4. Analysis and evaluation of trends and behaviour of individuals.

To establish the elements that are going to be part of the databases and will feed the algorithms of the AI, it is necessary to understand and define the sources of information and the importance of those for the selection of the best animals and to find out the definition of the process to ensure the best ambience of the cattle.

3.1 Lactation cycle of a dairy cow.

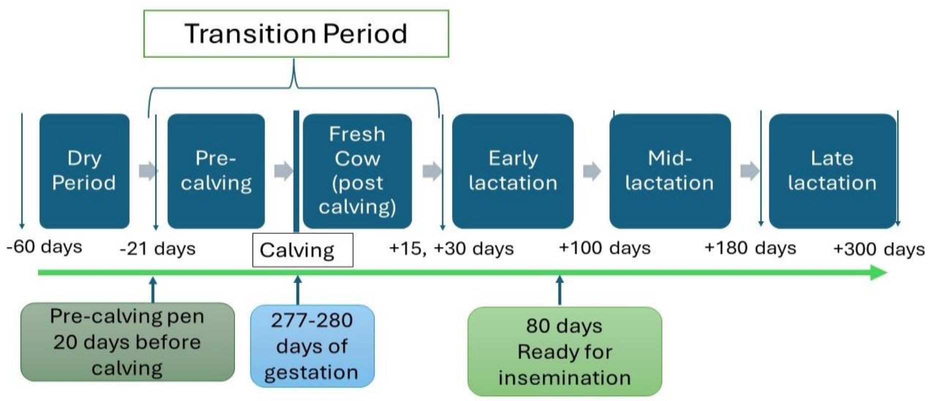
Milk production can be understood by analysing the lactation cycle. The cycle starts when the cow is at its dry period, it is in this period when the animal has already been diagnosed with pregnancy and includes 60 days away from giving birth. Research has found that if no dry period is provided for a cow, she will produce 25 to 30% less milk the next lactation (Bradmueller, 2024)**.** The cow should have a special diet, it should be energy restricted. In this period the cow must lose weight to ensure a safe and restful calving.

Ten days before the calving, the dry cows are moved to the next corral with a diet that must take care of the Ph and ions. At this stage, the rumination monitoring is essential because during the first step of labour, rumination and feeding decreases (Schirmann, *et al*., 2013). It is at this point that the sensors detect possible problems in case of occurrence and send alerts so that the cows can be treated on time.

After calving, cows are transferred to a fresh cow's barn. Their first colostrum and transition milk is collected at the CAETEC and it is used for feeding calves. In general, this process takes between 2 or 3 days after calving, but sometimes this could take 5 days. Once more, monitoring the milking process will determine the periods that are enough for the transition. It is expected to have between 1 and 2 milks per day until having between 3 or 4 milks on the 4th day after calving. Although the amount of milk at this stage is not too big, the stimulation will induce an increase in the production of milk.

Between 15 and 30 days after calving, and according to the animal condition, the cows are moved to one of the four lots. Cows now are part of the production herds. The days after calving are counted so that the flow or path over the milking robot is similar in each of the robots. After 100 or 120 days, milk yield reaches its peak of production. It is not possible to have many cows at peak production in the same robot because the milking time is longer, hence the distribution of cows within the barn should be with cows that are growing in the lactation curve with cows that are decreasing in the lactation curve. Here, the animals also use a motion sensor. In the CAETEC the insemination occurs at 80 days after calving. Figure 1.

Figure 1: Lactation cycle of dairy cows.



During the whole cycle gathering information to feed databases is crucial. Monitors and the know-how provided by the expert, in CAETEC is the vet, will provide important information that will add important features of the cow such as behaviour, wellness, care of the animal, nutrition, warnings, among others that in the future will feed the algorithms for AI.

3.2 Cow monitoring systems and information sources

Gathering information from all of the possible sources, it will make it possible for the AI to integrate it in its algorithms. Information of experts, information of the cattle and of every cow is important to be collected. Several monitor systems have been proven to be efficient and necessary to follow the cattle cow's wellness and to improve production of milk. Monitoring systems currently used by CAETEC are described as follows.

3.2.1 Know-how of the expert

Although the knowledge of the expert is not a digital monitoring system, It provides important information of the animals that must be recorded and added to the databases. The vet observes the overall behaviour of the cow and records all the findings in a journal. This journal must be digitalised to feed the databases for the algorithms. For instance, the vet will follow the evolution of the heifer, heat periods in calves, cross measurements, etc.

3.2.2 Sense Hub™ monitoring system

In 1997 Merk and the French pharmaceutical Rhone-Merieux (now known as Sanofi) joined their divisions of animal health in a new company called Merial. After years in developing technology in animal health, in 2011 the name of the animal health unit changed to MSD Animal Health (Merck Animal Health in USA and Canada). In 2018, a new division for animal health was introduced in Mexico with the name "*Club Ganadero MSD*" as a new initiative to promote cattle health and to encourage the growth of cattle, vet pharmaceuticals and traders (Merck & Co., 2023).

The Sense Hub™ monitoring system provides real-time information of the cows. It helps to detect and fix very quickly problems with nutrition, reproductive and milk production; reducing costs associated with vet care and loss of productivity. Monitoring systems not only help improve the health and well-being of dairy cows, but also optimise milk production and quality, as well as save time and resources invested in the operation. It reduces the amount of manpower required to perform visual observations and minimises errors, thanks to its high accuracy (Merck & Co., 2023). This system is more used for taking care of the rumination of cows specially 60 days before and after calving, to ensure a safe and secure delivery day. Figure 2.

Figure 2: Sense Hub™ monitoring system

3.2.3 DeLaval VMS CLASSIC

DeLaval VMS (Voluntary Milking System) is a milking robot that maximises the economic benefits. It allows each cow to be milked to her individual needs and capacity, meaning each cow milks when day like in a calm and quiet environment without stress. The cow is identified by the system. Each tit is sanitate with an individual line and premilked and dried before milking. It has a touch screen which is an interface with the VMS system. It tracks information for every cow (DeLaval, 2024).

It looks for the farm profitability, animal welfare, and work efficiency. It links all parts of the farm: cow comfort, health, feeding, cow traffic, and reproduction. Figure 3 shows one DeLaval robot while Figure 4 shows a brush cylinder that helps the cow to feel more comfortable and with less stress. This brush has proven to reduce the stress in the cows and contributes to the wellness of the animals. Also, the need of ventilators in the months with the highest temperatures was discovered by the vet, hence these were introduced into the barns to improve the comfort of them.

Figure 3: DeLaval robot and DeLAval collar Behaviour.

Figure 4: DeLaval brush cylinder for comfort.

3.2.4 DeLaval activity metre system

DeLaval collar Behaviour analysis, is a collar that measures the activity of the cow individually (Figure 3). Together with DelPro Farm Management systems, it is possible to have information of the activities of cows and their behaviour instantly. Activity data is presented on screen in a graphical format. The software flags increased heat related activity for immediate action, while reduced activity triggers a 'low activity' health alert. Improves the probability of success in inseminations due to the detection of the start of standing heat, hence, the most important period of observation is between 60 and 120 days after calving. It also notifies the best time to breed each cow. It also provides somatic cell count information.

All the collected information is sent to a DeLaval farm management software four times per hour. Data is also transmitted every time a cow passes an ID reader, so when a cow enters the parlour for milking (DeLaval, 2024). A 24/7 monitoring of the whole cattle is possible with these systems.

3.2.5 Weather stations

Weather is another source of information that has to be monitored and should be another entrance for the database. Some of the variables that are collected by the weather station are: temperatures (maximum, minimum), cumulative daily rainfall, evaporation, etc. Cows are animals that are very sensitive to climate changes, wind, precipitation, etc. If there were a possibility to cross this information with the other systems, hence the welfare of the cows could be easier to manage; it could detect or explain possible changes in the behaviour of cows.

3.2.6 GREENFEED: the measurement technology

This system is provided by C-Lock Inc. (Rapid City, South Dakota USA) and was introduced to the market in 2010 (Hegarty, 2013; Hammond *et al.*, 2015). Since its introduction it is one of the most used methane emission measurement systems, alongside the sulphur hexafluoride tracer (SF6) (Della Rosa *et al.*, 2021).

This technology is an automated monitoring gas emission system that with the integration of a pellet bait feeder pushes for voluntary visitation of the animal to measure methane, carbon dioxide and even oxygen, hydrogen, and hydrogen sulphide emissions from individual ruminants, usually cattle (Hristov *et al.*, 2015; Jonker *et al.*, 2020; Smith *et al.*, 2020; Zhao *et al.*, 2020; C-Lock, 2024).

Moreover, it is considered a short-term and static device (Hammond *et al.*, 2016). Measuring about 20 animals per day, approximately; with a CH4 flux greater than 60 g/d and 1,00 d/g for CO2. Nevertheless, the data can vary depending on the size of the pen/pasture, quantity and the objectives of the study (Zhao *et al.*, 2020; C-Lock, 2024).

Forbye, this automated technique can work for indoor pens, free-stall barns, or grazing conditions (Jonker *et al.*, 2020; Zhao *et al.*, 2020). It registers the timing and number of times each animal enters its head, leading to obtain controlled, reliable, and direct results (Hegarty, 2013; Zhao *et al.*, 2020). Nevertheless, several factors must be taken into consideration during measurements, wind direction and speed, for example, can impact the measurements (Zhao *et al.*, 2020). Another example is operator or researcher needs, which includes set-up, necessary inputs from the user, and other experimental factors (Jonker *et al.*, 2020)

3.2.6.1 How does it work?

It is a gas flux quantification system that uses a similar principle to those of the respiration chamber, the main difference is that the measurements are only taken when voluntary animals place its head into the device (Huhtanen *et al.*, 2015; Jonker *et al.*, 2020).

The device measures gas emission using hot film anemometer, multiple infrared sensors, and a extractor fan which induce airflow past the cow's head when the head is entered to the system, and thus the short-term air that is produced, either exhaled breath and/or burps, is gathered and sampled throughout the day (Hammond *et al.*, 2016; Smith *et al.*, 2020; Zhao *et al.*, 2020).

Moreover, it is an all-time accessible and non-invasive system, that uses small baits to attract and encourage animals to stay between 3-7 min (Hegarty, 2013; Hammond *et al.*, 2016; Smith *et al.*, 2020; Zhao *et al.*, 2020; Kumari *et al.*, 2020). It also can be programmed with specific waiting periods between sampling periods, nonetheless, total diet and its chemical composition, feeding periods and feed dispenser set-up must be taken into consideration to prevent measurement differences and bias (Hegarty, 2013; Jonker *et al.*, 2020).

The data generated of each animal is logged and processed through a cloud-analysis system developed by the C-Lock, GreenFeed manufacturer (Zhao *et al.*, 2020; C-Lock, 2024).

3.2.6.2 Features of the system

It has several components that are vital during the measurement process of the GreenFeed technology (Figure 5), such as CH4 and CO2 sensors, head position sensors, air filter, feed bin, air collection system (pipe, air flow metre, and fan) RFID Tag Reader, and Tracer (Huhtanen *et al*., 2015).

Figure 5: GreenFeed System.

Furthermore, each unit has gas regulators and an auto-calibration system that enhances the dynamic between user and device (C-Lock, 2024), along with animal identification, bait dispenser, air handling, and gas flow quantification (Jonker *et al.*, 2020). Moreover, there are additional product options that could increase the performance, such as extended hopper, HD Webcam, wind sensors, among others (C-Lock, 2024).

3.3 Genetics

Another important feature for improving the quality and quantity of milk production is the genetics. In genetics, the goal is, and always has been, looking for better animals. This applies for 100 years ago or 5000 years ago, therefore, for 5000 years the human being is looking for the same. What does a better animal mean? An animal that gives more production with the best quality. Unfortunately, sometimes there is no cross-reference with other kinds of information. For instance, a cow can give more milk, but it also consumes more food, or it gives more problems, or it's more restless, etc.

There may be 1000 characteristics that could cross, that's where artificial intelligence can come in. If it were possible to cross all these variables with the help of AI, then genetic improvement can be achieved to produce the best animals that give more milk with better quality. In other words, more litres of milk per cow, more fat per cow, and more protein per cow. Also, more milk in less time, so that the cow doesn't get sick, and the production of milk generates less pollution.

Genetic improvement is never going to be definitive because they are biological systems, so there are multiple factors that are interacting all the time. Genetic improvement is never going to be definitive because they are biological systems, so there are multiple factors that are interacting all the time. Furthermore, the constant rate of technological innovation has elevated the dairy system development, from which genetic selection plays a major role (Brito *et al.*, 2021). Nevertheless, there are several index tools or genetic considerations that must be taken into consideration. The company Select Sires (2024) offers several designations for these genetic considerations, all with the aim to have an improve genetic selection and to help the dairy producer achieve their management and production goals:

- FeedPRO: it is considered an index to designated sires that have been selected to optimise production, improve health, and reproductive traits, while reducing feed intake and thus operation costs.
- FertilityPro: this designation to sires considers the industry sire conception rate value, as well as semen quality. This with the aim to improve pregnancy rates.
- GrazingPRO: is a designation to sires that focus on transmitting daughter fertility, greater longevity, mobility, component yields, and stature, without compromising daughter pregnancy rate and Somatic Cell Score.
- Mastitis RestantPRO: is an indicator that uses CDCB Mastitis Resistance, CDCB Somatic Cell Score and Zoetis Mastitis Resistance to identify sires which will pass genetic improvements to the next generation.
- RobotPRO: is a designation to sires, which are selected by component and milk yield and quality, udder health and functional traits, longevity and durability. All characteristics that are important factors to consider for robotic milking systems.
- Showcase: this indicator is for sires that have breed-leading type or show-winning pedigrees.
- *gender* SELECTED Ultraplus: is an index that selects sires with sex-sorted semen availability.
- Elite Sexed Fertility: is a designation that identifies sires that will have high sex-sorted semen conception rates.
- GForce: this designation is based on a strict genomic evaluation to increase reliability in young sires, moreover, it also adds the pedigree data.

- GForce+: in addition to the previous it also includes rigid semen quality standard, sire conception rate (SCR), leading to a designation for an outstanding genetic merit, reliable sire stack and calving ease.
- Progeny proven: is a designation to reliable sires that have evaluation with genomic and daughter performance data.

Besides the sires' designations (or badges) that the company Select Sires provides, there is a Holstein Sire Directory with a complete description of the sires. For each animal is possible to know the following characteristics: Origin of data, Proof month/year, Daughters and herds with lactation records, Net Merit (NM$), Dairy Wellness Profit Index (DWP$), Type (PTAT), UDC (Udder Comp.), FLC (Feet & Legs Comp.), BWC (Body Weight Comp.), D (Dairy Capacity Comp.), Total Performance Index (TPI), Somatic Cell Score (SCS), Mastitis (MAS), Productive Life (PL), Liveability (LIV) Daughter Pregnancy Rate (DPR), Heifer Conception Rate (HCR), Cow Conception Rate (CCR), Fertility Index (FI), Sire calving ease, Wellness Trait Index® (WT$®), Daughter Calving Ease (DCE), Daughter stillbirth, Calf Wellness Index™ (CW$™), Herd Health Profit Dollars (HHP$), Sire Conception Rate (SCR), Another traits: Stature, Dairy Form, Strength, Body Depth, Rump Width, Rump Angle, Rear Legs Side View, Rear Legs Rear View, Foot Angle, Feet and Legs Score, Fore Udder Attachment, Rear Udder Height, Rear Udder Width, Udder Cleft, Udder Depth, Rear Teat Placement, Front Teat Placement, Teat Length, among others.

In the CAETEC the most important characteristics for the selection of the sires are high milk production (must be above 1000), net merit, somatic cell count (fewer cases of mastitis), robotpro, finally sires modified genetically to reduce methane gas in the cow (smaller stomach).

In order to show the need of AI in the selection of genetics of the sires, a decision tree was done to see all the possibilities of sire's selection for only four specific types: A2A2, High HHP$, Mastitis resistant PRO, and Polled Genetics. Results are shown in the following section.

4. Analysis and results

To select the best cow, a decision tree was done to show all the possibilities of sire's selection for only four specific types. Among all the sires that are available, in 2024 there two trademarks Select Sires of A2A2: A2A2 Proven Sires and A2A2 GForce™ Sires. There are 16 possible A2A2 GForce™ Sires with 16 variables that can be analysed for selecting the best cow with decision theory. Also, there are 10 possible A2A2 Proven Sires with also 16 variables to choose from.

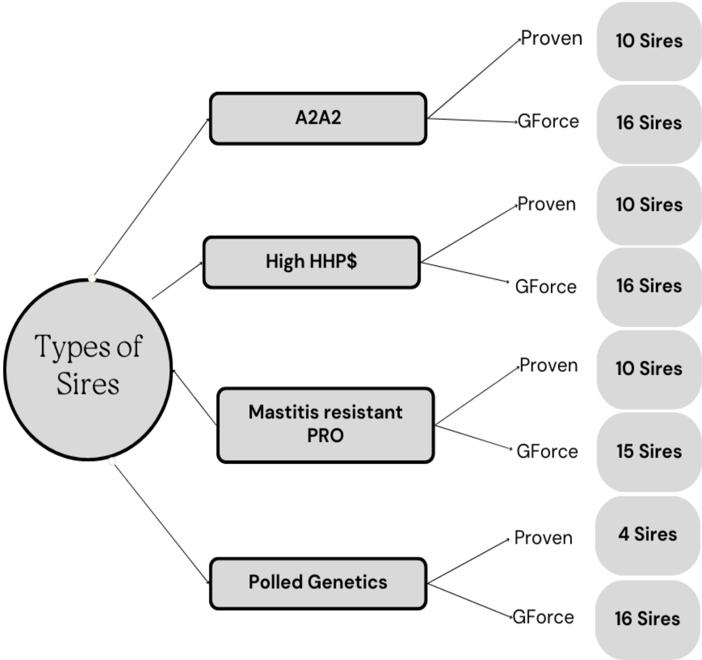
If you wish to select a sustainable cow, High HHP$ Proven Sires is designed to create healthier, longer-living cows that reduce herd turnover while lowering the carbon footprint. Again, you can choose between two types: High HHP$ Proven Sires and High HHP$ GForce™ Sires, with 16 variables each one to be analysed.

If you select a Mastitis resistant PRO type, again you can choose between two types: Mastitis resistant PRO Proven Sires with 10 possible sires and Mastitis resistant PRO GForce™ Sires with 15 possible sires; with 16 variables each one to be analysed.

If you select a Polled Genetics type, again, you can choose between two types: Polled Genetics Proven Sires with 4 possible sires and Polled Genetics GForce™ Sires with 21 possible sires; with 16 variables each one to be analysed.

Hence if you select only genetics for these 4 special cases of sires, you must decide between all the possible outcomes plus the analysis of your preferences among the 16 variables per sire. See Figure 6 for the decision tree.

Figure 6: Decision tree for selection sires from 4 types



If you want to make your decision according to badges, sires could have or not badges, this generates a total of 512 possibilities of different selection of badges, multiplied by the 21 variables times 16 characteristics you will have 172,032 ways to select sires.

5. Conclusions

There are several monitoring systems in the market, if a farm has them, all the information provided must be added to the database. In CAETEC, only those monitoring systems are implemented, but the need for improving the processes every day will open the door for new innovation and new products. Hence, the algorithms are going to be fed all the time. There is no final version of them. The gathered information, data, and the analysis of them have to be handled in a responsible and ethical manner.

The use of AI to analyse the behaviour of dairy cows will ensure the wellness of the cattle, because it will take into account all the information gathered from sensors and experts. The AI with Data science will permit analysis of the characteristics of the sires and the possibility to select the best matches to optimise the cow production according to algorithms. As we showed, the possible ways to select sires according to their characteristics are huge. Hence it is important to generate databases fed by sensors as Sense Hub™, all the information that is provided by the robot DeLaval, and the know-how of the veterinarian (journal information). A *cow-match* can be created to try to find the best characteristics based on the analysis of the databases, statistics, data science and of course algorithms that will permit the AI to make the best decision.

It is important to say that even if the probabilities of success are pretty high, there is no certainty in the results, therefore data science and predictive models must intervene to try to minimise errors and to measure the probability of successes in all the steps of the process.

There are many technological solutions on the market but few opportunities for farmers to acquire and manage them. The monitor systems are expensive and not all the farmers have the capability to afford them, or at least not more than one of them.

As a future work, should be important to find the best day to inseminate based on the milk projection with the use of data science. Modelling predictive models to get the best equilibrium in the conversion rate, i.e. Intake vs milk production. To find through statistical analysis and design of experiments the combination of factors that maximises the health (reproductive health), for example: nutrition, genetics, and disease control.

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Communication aligned with the Sustainable Development Goals