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WASTEWATER MANAGEMENT IN THE EXPERIMENTAL AGRICULTURAL FIELD OF TECNOLÓGICO DE MONTERREY

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Sustainable development is a priority goal at the Tecnológico de Monterrey; sustainability is sought as a competency for graduation in all academic programs under the TEC21 educational model. This ability should permeate laboratories and physical facilities, particularly in the Experimental Agricultural Field of Tecnológico de Monterrey (CAETEC). This is a space where collaborative projects of companies and technological development groups are carried out; in addition the CAETEC is also a space for comprehensive learning projects for students from various academic programs. This project's goal is to optimize the water resource of the milk withdrawal stables in order to recover the highest percentage of water used during the operation and treat it for agricultural irrigation via innovative and profitable processes. The current study demonstrates how agile and traditional methodologies were combined to create small sustainable development projects that converge in a single initiative to achieve the goals of reducing water consumption and wastewater treatment for use in precision agriculture projects.

Keywords: sustainable development; wastewater treatment; agile methodologies; resource optimization; higher education

GESTIÓN DE AGUAS RESIDUALES EN EL CAMPO AGROPECUARIO EXPERIMENTAL DEL TECNOLÓGICO DE MONTERREY

El Desarrollo sostenible es un objetivo prioritario en el Tecnológico de Monterrey; dentro del modelo educativo TEC21 se busca que la sostenibilidad se tenga como competencia de egreso en todos los programas académicos. Esta aptitud debe permear en los laboratorios e instalaciones físicas, en especial en el Campo Agropecuario Experimental del Tecnológico de Monterrey (CAETEC). Este es un espacio en donde se realizan proyectos de desarrollo tecnológico con empresas y se busca un aprendizaje integral de estudiantes de diferentes programas académicos. El proyecto que se busca trabajar se basa en optimizar el recurso acuífero de los establos de extracción de leche, con el fin de recuperar el mayor porcentaje de agua utilizada durante la operación y que sea tratada para el riego agrícola a través de procesos innovadores y rentables. La presente investigación refleja cómo se adaptaron las metodologías ágiles y tradicionales para diseñar pequeños proyectos de desarrollo sostenible que convergen en una sola iniciativa que logrará los objetivos de ahorro de consumo de agua, así como el tratamiento de aguas residuales para ser usadas en los proyectos de agricultura de precisión.

Palabras clave: desarrollo sostenible; tratamiento de aguas residuales; metodologías ágiles; optimización de recursos; educación superior

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1. Introduction

The Experimental Agricultural Field of Tecnológico de Monterrey (CAETEC) is an experimental laboratory for the use of multiple academic programs that Tecnologico de Monterrey offers, it has been used for over four decades as a learning space where collaborative projects of companies and technological development groups are carried out (Saavedra Gastélum *et al*., 2022). Nevertheless, its main focus is in regards to agriculture and agri-food projects (Tovar, 2021). Among its activities, the most important are the production of tomatoes of multiple varieties, milk production from Holstein cows, fodder production for livestock feed (oats and corn), and the production of both red and white wine grapes.

Water shortage is one of the world's main problems, it affects more than 40% of the global population; a subleading problem is the contamination of the water used in industrial and agricultural activities, which around 80% is dumped on rivers, lakes, and is filtered to the groundwater (United Nations, 2023). Therefore, among the 17 goals stated by the United Nations, the number 6, that focus on providing clean and accessible water to the population, and the number 12, centred on creating projects/companies with responsible consumption and production, are aligned with the paper's objective.

Moreover, sustainable development is a priority goal for Tecnológico de Monterrey; it is sought as a competency for the graduated profiles in all academic programs under its educational model and as a philosophy in all of their projects and infrastructures. For the CAETEC, it can be observed as the application of a sustainable agriculture principle that guarantees the rentability of the products while also applying efficient and clean energy systems (FAO, n.d.), thus the integration of precision agriculture technologies and techniques, novel monitoring systems to allocate feed variables based on animal nutritional standards, and innovations using data science can help to achieve this long-term goal at the CAETEC (Saavedra Gastélum *et al*., 2022).

Withal, there are improvement opportunities within the CAETEC's system to achieve a higher grade of sustainability, the wastewater management system of the Holstein milk production cows stable is one of such spaces. The use of agile methodologies are the perfect tools to manage a project for this kind of initiative. Agile or adaptive methodologies are ideal for dynamic and changing projects. Traditional or predictive methods could be better due to the uncertainty in some stages of this project, which, when working on them, the scope and specifications can be redefined. It is proposed to replace the Project Charter with the Project Canvas for more precise and dynamic graphical monitoring. The first step of the methodology is to define the problem. Applying soft system methodologies, the research team identified stakeholders and defined who are the client, the actors, and the context of the project. Applying a Kanbas dashboard is necessary to determine every one of the activities (To Do) and make the assignment to the team.

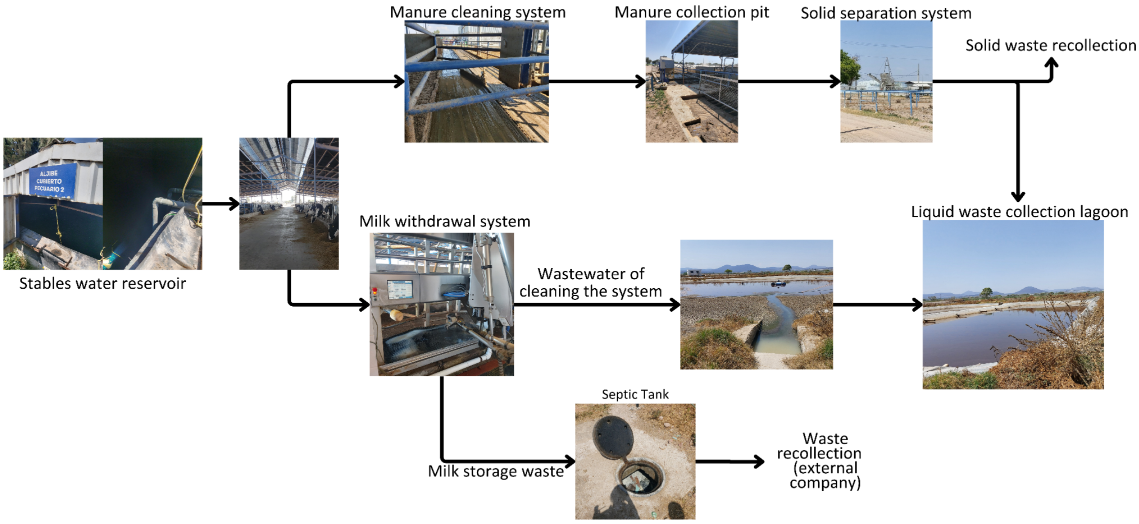
To implement this methodologies we first need to describe the actual system, how the waste is processed and what factors are involved, which are the manure of the production cows and the water consumed. And so, one Holstein cow weighs between 500 to 700 kg, it drinks from 120 to 150 litres of water everyday, and must eat between 3.2% to 3.3% of their living weight of fodder (National Research Council, 2001), which is produced in the CATEC, to produce a high quality milk. At present, the stables space can hold from 160 up to 180 production cows and are milked with three robotized withdrawal milk stations that each can milk 60 cows everyday, additionally it has a cleaning system where the manure and urine, sand from the cows' sand beds that fall, dripping water from the cows drinking stations, and additional water use to clean the stables is pull to a pit where it is collected (Figure 1). This project's goal is to optimise the water resource of the milk withdrawal stables in order to recover the highest percentage of water used during the operation and treat it for agricultural irrigation via innovative and profitable processes.

Figure 1: Cleaning waste system of the milk production Holstein cows at the CAETEC. (Own Source)

2. Methodology

To complete the paper's target, it must consider two main factors that are involved in the wastewater system (Figure 2): the manure mix of the cows and the water consumption of the stables. The best management model for this kind of project is agile methodologies because the research is a dynamic process, in other words, it is an adaptive process; furthermore using Kanban Dashboard to monitor the activity iteration is the best method for the present research.

Figure 2: Water distribution system of the stables at the CAETEC. (Own Source)



2.1 The manure of the Holstein cows

The fodder, which is the main source of nutrition and food for the production cows, must have a balance between the percentage of corn and oats silage consumed due to the metabolic challenge that producing milk infers (Tahir, 2012). This balance is determined with the manure as it is the main source of information to see if the balance is correct and it will not cause stress to the cow (National Research Council, 2001).

The food consumption follows the dry matter intake formulated by National Research Council (2001) (Eq. 1), it takes into consideration the nutrient content that a lactating cow must meet. At the CAETEC the daily consumption of a lactating Holstein cow ranges between 3.2% to 3.3% of their living weight and generates an average of 40 to 50 kg of manure per day, as a result there can be a production between 6400 kg to 9000 kg of manure everyday in the stables depending on the quantity of cows that are being milked (National Research Council, 2001), Table 1. Forbye, the food balance also affects the consistency or fibrocity that the dung may have, and thus also alters the ease of the cleaning system to move it. However, at present the manure cleaning system at the CAETEC uses around 50000 litres of water every four days to move the manure to the pit, but it must also take into account that there could be traces of sand from cows sand bed that changes the properties of manure to a more rough mixture.

$$DMI\ (kg/d) = (0.372 \times FCM + 0.0968 \times BW^{0.75}) \times (1 - e^{(-0.192 \times (WOL + 3.67))}) \qquad (1)$$

Where:

- DMI = Dry Matter Intake (kg/day)
- FCM = 4 percent fat corrected milk (kg/day)
- BW = body weight (kg)
- WOL = week of lactation
- $(1 - e^{(-0.192 \times (WOL + 3.67))})$ = Depression DMI adjustment during early lactation.

Table 1: Minimum and maximum production of manure everyday. (Own Source)

One cow			
Minimum conditions		Maximum conditions	
Percentage of food	3.2% living weight	Percentage of food	3.3% living weight
Weight of a cow	500 kg	Weight of a cow	700 kg
Daily food intake	16 kg	Daily food intake	22.4 kg
Manure production	40 kg	Manure production	50 kg
Stables (160 cows)		Stables (180 cows)	
Total manure production	6400 kg	Total manure production	9000 kg

2.2 The water consumption of the CAETEC stables

Within the water consumption, there are two main variables to consider, the drinking water consumption in the stables (drinkers and equipment washes) (Figure 3), which is then disposed of by a separate drainage system and meet the second variable at the final wastewater reservoir point, and the amount of water needed to clean the stables, which is was mentioned before.

Figure 3: Water usage at the CAETEC. (Own Source)

As said before, one Holstein cow can drink from 120 to 150 litres of water everyday, which must be 6.6 times of their dry matter intake per day (National Research Council, 2001), currently the stables have 170 production cows plus 26 that are in a dry-rest period (period before the birth of the calf) adding to a total of 196 cows, which have a daily consumption of approximately 29400 litres of water. On the other hand, the robotized milk withdrawal system has a different water consumption for each component, this is presented on Table 2.

Table 2: Water consumption of the stables system at the CAETEC

Component	Water consumption per wash (litres)	Number of washes done everyday	Daily water consumption (Litres)
Robot 1	216	2	432
Robot 2	125	2	250
Robot 3	130.6	2	261.2
BCC (intermediate tank)	125	2	250
FCC (milk storage tank)	166	1	166
		Total water consumption	1359.2

3. Results

3.1 Water consumption at the CAETEC

By leading to the period norm of the stables cleaning, there is a theoretical total water use of 173,036.8 litres every four days (Table 3). This is far from the adequate consumption of water that should be needed, the variable that can be changed is the water usage in regards to cleaning the stables, whose optimal proportion of water to manure should be 2:1. It's worth mentioning that the resulting combination of manure and sand causes it to have segmented stone properties and consequently affects the internal mechanism of the pump during extraction for its separation between solids and liquids; this is to be resolved by changing the sand to another material.

Table 3: Total water consumption for every 4 days at the CAETEC

	Daily water consumption (litres)	Every 4 days water consumption (litres)
Cleaning stables	-	50000
Stables withdrawal milk system	1359.2	5436.8
196 cows daily water intake	29400	117600
	Total water consumption	173036.8

The present challenge focuses on the water consumption during the cleaning of the stable. However, researchers consider that a priority must first optimise the accumulated water after separation of solids, so that the residual liquid is treated and used in open field irrigation.

3.2 Water profile needed and biotechnology process to be implemented

According to Ofori *et al.* (2021) there are several impacts that using wastewater as a irrigation source can have in the soil and the plant: A) It can be considered as a nutrient supply, because of the presence of organic matter there are important macro- and micronutrients that can be added, specially it increases the concentration of nitrates, potassium, and phosphorus which improves the soil fertility and are essential for the physiological and biochemical processes in the development of the crops; furthermore, this impact can help in the long term by the reduction of fertilisers that are needed (Chojnacka *et al*., 2020). B) Because there is presence of organic matter, carbon is also present; the concentration of this nutrient influences the soil stability, the colour, nutrient turnover and holding capacity, and the supply of energy for the plants microbiomes. C) In a long term view, the use of treated wastewater can affect the structure and properties of soil, because it can cause degradation of the soil if the composition is not the best beneficial, it can accumulate sodium, bicarbonates, and other compounds that can change the pH and affect the plant production. D) While having a high concentration or availability of nutrients can improve and accelerate the growth of the crops and thus increase the yield, it can as well lead to plant toxicity due to excess supply of nutrients; the principal factor in the nutrient uptake revolved in the root system and the nutrient concentration around it, so if the balance of trace elements concentration is disturbed there is accumulation and a decrease in the plant growth (Ofori *et al*., 2021).

The processing of the lagoon manure wastewater is the paper's main focus, in order for this water resource to be reused in the irrigation of the open fields that produce the Holstein cows' food, the water must have certain characteristics for it to be passed to the soil, especially to have the essential nutrient components to have a high quality fodder production. Such characteristics are achieved by filtering and organically degrading biomass waste with the help of beneficial fungi and bacteria; this will provide a greater bioavailability of nutrients to plants, which represents improving the soil structure (organic matter and pH).

The optimization process starts by first characterising the water, meaning determining what microbiome the water contains, what concentration of macro- and micronutrients it has, are there other trace elements present, and what biological/chemical processes are happening. With this information then we can determine the best treatment option to have the desired profile for its use in irrigation.

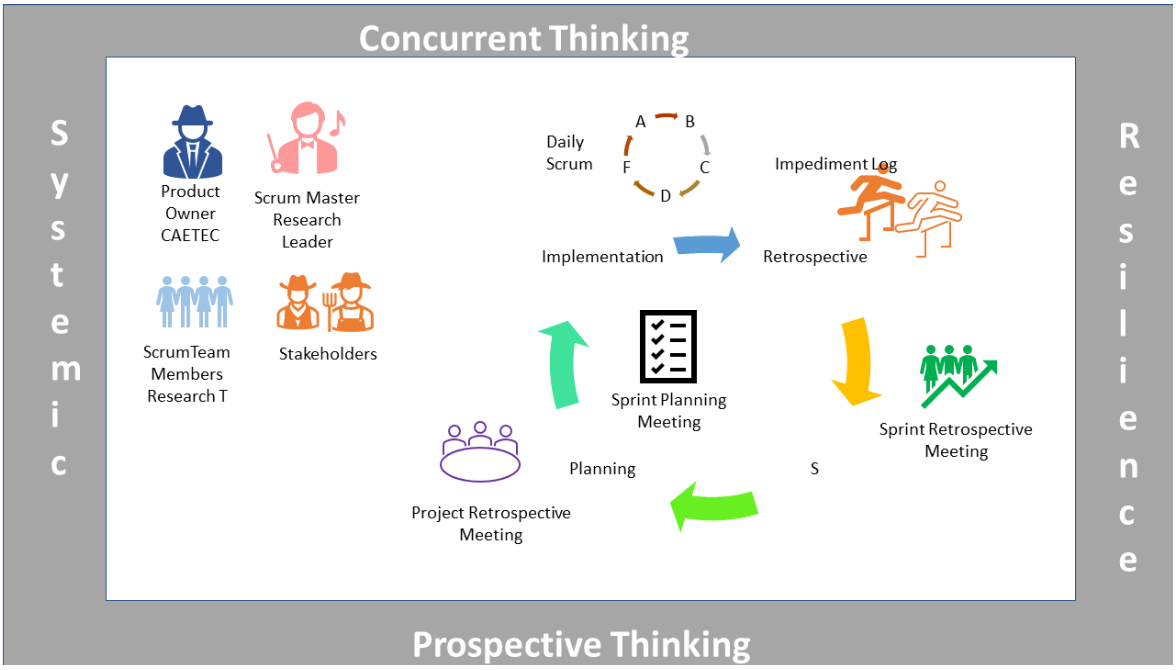
By reviewing similar cases in the literature, and considering the inlets of the wastewater lagoon, which are the manure mix wastewater liquid after the solid separation and the milking robot cleaning wastewater (Figure 5), researchers propose that a biological process is the best solution to be implemented as the treatment due to the high organic matter content that the wastewater must have. Nevertheless, there are small traces of milk in the residual cleaning water of milking robots and so must consider that there are fats and greases that are being carried out and may present a challenge in the wastewater treatment (Chen *et al.*, 2020). Thus, the use of enzymes or bacteria can be a solution in several senses of the challenge, preventing an excess of nutrient content in the water by using it as energy and being able to degrade refractory compounds (Chen *et al.*, 2020).

Finally in the optimization process, researchers must assess if the water after the treatment can be use as a long term irrigation water source, it can be done by evaluating the salinity of the soil, which refers to the accumulation of salts (water-soluble species: sodium, magnesium, iron, calcium, chloride, among others) in the soil. The sodium adsorption ratio is correlated with the percentage of exchangeable sodium, which in other words is a measurement of the soil's sodicity, and thus being a perfect way to see if the treated wastewater is suitable to irrigation to the crops; nevertheless the concentration must be within the limit to prevent loss of soil structure stability, reduction of soil moisture content, and modification of the plant anatomy and physiology (Ofori *et al.*, 2021).

3.3 The implementation of Agile Methodologies

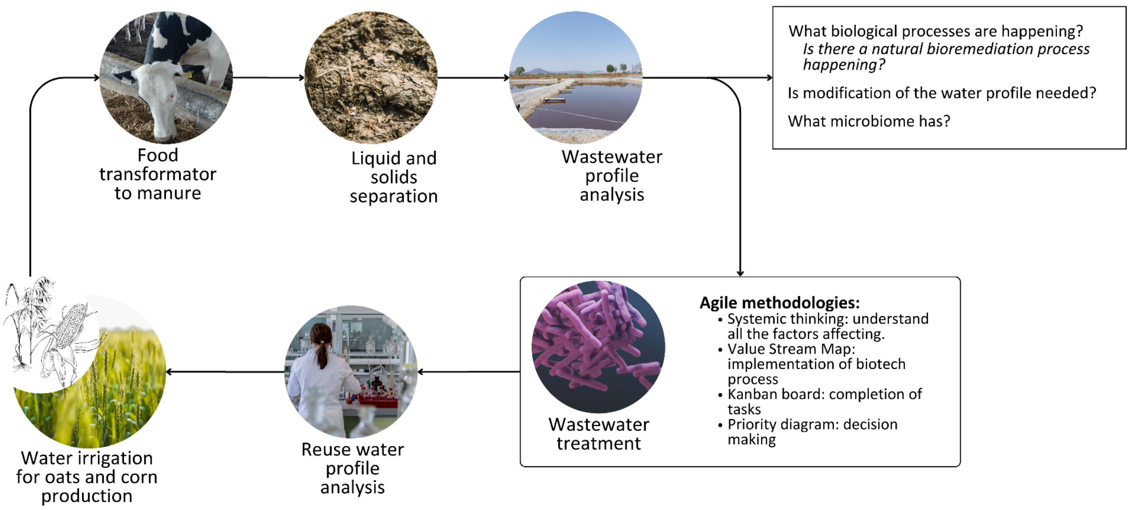
Soft systems methodologies, Porter's force analysis, and the Iceberg Tip help to have a good diagnosis at the start and every step of the project focusing on the problematic situation towards a correct definition of the problem (Gonzalez *et al*., 2022) and with the help of agile methodologies, in this case Scrum, will allow having good control of the project. The process for the treatment of wastewater needs frequent reviews, especially if a biological process is implemented, as a sprint project agile philosophy (Rocha *et al.,* 2021) will improve the management of the wastewater treatment (Figure 4).

Figure 4: Research Agile Framework



Furthermore there is a need for an adaptive model for the administration of the overall project; a traditional approach is not possible in managing this type of project because it is dynamic and requires constant reviews at each stage to indicate the project's continuity or to give it a new approach, which is essential during the treatment of wastewater. Moreover, Figure 5 shows the iterative process, in which the CAETEC´s CEO is named Product Owner, and the research leader is the scrum master; the planning process is defined based on the soft system analysis, and the sprints are defined regarding the "To Do"s.

Figure 5: Process for the treatment of the wastewater lagoons, showing the implementation of agile methodologies. (Own Source)



4. Conclusions

Because the use of agile and soft system methodologies during the implementation of this process is novel, the documentation of the project can and will become a reference *modus operandi* for local producers that have similar challenges. In regards of the CAETEC, this papers only focuses on a small part of the whole system; among the challenges it faces as a infrastructure, the monitoring and data control in their greenhouses systems, the need to improve the sewer system, the change from a side roll to a frontal irrigation system are among the most present, thus, future works that will deal with the mentioned and new challenges can use the basis of this project as way to start their implementation. What's more, these solutions seek to generate a closed system in the CAETEC, which in the long term benefits each stage of the process, avoiding the generation of waste and creating a sustainable infrastructure, leading to a circular model.

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