A new automated drip irrigation and fertigation system for sugarcane crops

Diana Rose Rivera*, Sharaful-Ilmi Paduman, Leapheng Uon and Alvin Chua
Mechanical Engineering Department, De La Salle University, Manila Philippines

*Email: diana_rose_rivera@dlsu.edu.ph

Abstract. This paper presents a new automation system specifically design for sugarcane crops to optimize the irrigation and fertigation process against resource shortage and climate change. The system uses a programmable logic controller, sensors, actuators, and other mechanical equipment to control and manage the supply of water and nutrients based on the fertilizer requirement at sugarcane’s development stages. The simulation was done using a commercially available tool Picosoft V6.22, a software compatible with Allen Bradley Programmable Logic Controller. The economic analysis was also provided to show the advantages of using an automated irrigation as compared to the manual irrigation. Result of the analysis shows a payback period of a month as compared to 4.3 months for the manual irrigation system.

1. Introduction
The needs of irrigation in sugarcane have been recognized for over 100 years. In the Philippines, sugarcane farming has Php 87 billion annual contributions to the economy, which comprises of 65,000 farmers, 700,000 workers with 5 million dependents [1]. Based on the report by Philippines Statistics Office in 2014, in terms of its volume of production, sugarcane is the highest among all major crops, with 25,029,880 metric tons per year followed by rice with 18,967,826 metric tons [2].

Currently, the challenges in the sugarcane farming involves the changing climatic conditions and weather patterns (wherein water is a major limiting factor for productivity), the use of water and fertilizer consumption, and sugar production at a lower cost [1].

1.1. Irrigation methodology
Surface irrigation methods are the earliest known method for agriculture. It is the easiest and most practice irrigation recorded in history. More than three-fourths of the irrigated agricultural land is surface irrigated. However, the soil infiltration, as well as the soil and crop flow resistance, are to be considered [3]. On the other hand, unlike surface irrigation, sprinkler irrigation uses close pipelines for water distribution. The water is distributed over the area by using a mechanical device called sprinklers [2]. In sugarcane cropping, the use of sprinkler irrigation has 80% irrigation efficiency [4]. Moreover, another similar method to sprinkler irrigation is called center-pivot irrigation. Unlike the sprinkler method, this method is a well-engineered structure design to effectively deliver water to a large circular field. The water is fed from the pivot point at the center of the circle and each center has a main delivery pipe suspended over the field where sprinkles or spray nozzles can be spaced along the pipe [2]. This increases the irrigation efficiency of sugarcane to 85% [4]. Lastly, a well-known method to be used for the conservation of water is the drip irrigation method. This method reduces the...
amount of water consumption by allowing water to drip slowly to the roots of plants, either onto the soil surface or directly onto the root zone, through a network of valves, pipes, tubing, and emitters [3].

1.2. Nutrients for sugarcane crop fertigation
Since its introduction in the 1970’s, drip irrigation for sugarcane cropping has increasingly gained popularity and as of today, this system is the most precise, efficient and practical method of delivering water and nutrients to crop with 95% irrigation efficiency [3]. According to [4], 50% was reduced in water consumption and an increase of 25 to 30% efficiency in terms of the use of fertilizer. As compared with the global average yield of 59.4 ton/ha, cane tonnage harvest under drip irrigation varies between 120 and 190 ton/ha. Another aspect that should also be taken for the improvement of sugarcane cropping is the fertigation system. Fertigation is the supply of the nutrients in the field, specifically nitrate (N), phosphate (P) and potassium (K). The proper amount of nutrients (NPK) yields to a good quality soil, which in the later stage, led to good quality crop and yield production. However, the improper use of these fertilizers led to poor quality and low quantity of crops [5].

Sugarcane is a giant crop that generally requires a higher number of nutrient elements. Its growth development is divided into four stages, namely, germination and establishment (1-80 days), tillering or formative (81-130 days), grand growth period (131-300 days) and lastly, ripening and maturity (300-360 days) [4]. In sugarcane, nitrogen requirement is utmost during the tillering (formative) phase. If the nitrogen is applied more than the optimum amount, sugarcane production may drop. At the beginning of vegetation growth, the application of nitrogen has no negative effect but if the application is behind, reduction in the sucrose content are seen which leads to a decrease in the sugar yield [4]. Phosphorus requirement for sugarcane is greater in the formative phase. Adequate phosphate must be made available in the soil during the formative phase for absorption, otherwise, this will result to a reduction in sugar concentration while excessive dosage above the optimal rates resulted to a decrease in sugar concentration, yield, pol percentage, and purity. On the contrary, if the application is too low, pol percentage and purity increases [4]. Application of potassium at around six months is best to improve sugar recovery. Nevertheless, if the application is too high, this also resulted in a negative effect on the percentage of sucrose in the cane [4].

1.3. Existing automation for irrigation
The advancement in agriculture in terms of reducing manual labor and water consumption is no longer a problem, however, there is also a necessity to look into modern methods in terms of the proper supply of nutrients in the field to maintain the soil quality. In the works of [6], the system was designed to analyze the soil nutrient content in real-time to make a crop prediction. The average percentage of the basic nutrients (NPK) was determined as well as the suitable crop for the particular soil type. In the paper of [7], an electrochemical sensor is developed to determine the NPK present in the soil. While in the paper of [8], automation is used to restore the standard levels of NPK and proposed an automatic fertigation dispensary system using a single nutrient fertilizer (urea). However, these studies in the fertigation systems are still few and different fertigation problems are still need to be addressed.

One current problem is the varying levels of nutrients to be supplied to the crop during its development stage. Therefore, this paper presents a novel automation of fertilizer and water deployment to sugarcane crops for optimal crop growth and utilization of resources. Currently, there is no automation system design to address the varying amount of nutrients requirements at every stage of sugarcane cropping. In this study, the automation system is consists of the sensors, controllers, and actuators integrated for performance. A ladder program was also developed to suit the automation methodology suggested.

2. New automation concept
2.1. Nutrient requirement
The dosage of fertilizer for the sugarcane crop depends on the current nutrients in the soil. In the Philippines, the optimum nutrient level for the soil is shown in table 1. The soil fertility rating should also be in standard level or higher to achieve the optimum harvest.

| Growth Stages of Sugarcane | Days after planting | Nutrients (kg/ha/day) | Reference |
|---------------------------|--------------------|-----------------------|-----------|
| Germination and establishment | 1-30 Days          | 1.2 0.10 0.20          | [4]       |
| 31-80 Days                |                    | 1.5 0.40 0.24          | [4]       |
| Tiltering or formative    | 81-110 Days        | 2.00 1.00 0.40         | [4]       |
| 111-150 Days              |                    | 0.75 0.30 0.75         | [4]       |

2.2. Sensors and automation equipment

The new automated irrigation and fertigation system presented in figure 1 includes the water and fertilizer preparation area, dripping system, programmable logic controller, sensors, and the sugarcane field.

**Figure 1.** Automation system flow chart.

2.2.1. Water level sensor, NPK sensor, soil moisture sensor

Water level sensor is a mechanical device connected to a switch where the mechanical part is the actuator. This turns the connection on/off when the water level reaches a certain level. NPK sensor identifies the essential nutrient present in the soil. The electrochemical sensor, an NPK sensor type are connected to the analog input port of PLC controller board.

**Figure 2.** PLC block diagram.

2.2.2. Programmable logic controller
The flowchart shown in figure 3 describes the algorithm implemented for the irrigation and fertigation system. The type of PLC used in the proposed system is the Allen-Bradley (AB Type). The PLC unit includes the input, processing, and output unit as shown in figure 2. The signals from the sensors (moisture, nutrient, water) are transmitted to the input module of the PLC. The PLC are now capable of transferring the command to the processing unit to properly interpret the signals (if the NPK, moisture, and water level data is high or low). The processing unit sends signals to the output unit for the action to be done to the actuators (to open/close the valves and to turn on/off the water pump).

**Figure 3.** Algorithm of PLC ladder program.

3. Simulation

3.1. Program modules

Due to the limitation of the software used, the program is set to three modules: Module 1 is the supply of nutrients (NPK) to the field during the different sugarcane growth stages. Module 2 for monitoring of the nutrient content in the soil. Module 3 for the water level conditions in the tank and the automated drip irrigation system (water supply in the field).

3.2. Automation scenarios

The automation process is done using the Picosoft V6.22, a software compatible with Allen Bradley PLC. Four scenarios are made from the modules to do the simulation for the entire system. Scenarios 1 for the nutrient requirement per day during the germination and development period, Scenario 2 for checking of nutrient contents in the soil before scheduling the fertilizer supply, Scenario 3 for monitoring the water level in the tank, and Scenario 4 for the supply of water to the field. *(Simulation encoding upon request).*

4. Conclusion

Based on the proposed design simulated using the Picosoft Allen Bradley software, the simulation shows the automation process of supplying the exact amount of water and fertilizer requirements of the sugarcane crop can be obtained. The economic analysis *(economic analysis excel sheet upon request)* concluded that the proposed automation system can yield an optimistic profit as compared to the manual irrigation method.

Although the simulation and algorithm for the parameters in the growth of sugarcane have been designed and simulated, the design is only set for one hectare since the values obtained such as the fertilizer requirements are limited. If the system is to be scaled for use in larger farms, the appropriate size should be designed such as the size of water tanks and the dripping system.

**Acknowledgments**

The authors would like to acknowledge the financial support of the Department of Science and Technology - Engineering Research and Development for Technology (DOST-ERDT), Commission on Higher Education (CHED), and ASEAN University Networks (AUN).
Reference

[1] J. Armando N. Espino, “Recent Developments in Irrigation Practices for Sugarcane Industry,” Laguna (2017).

[2] Crops, M., & Of, S. (2015).

[3] J. Holden and P. McGuire, “Irrigation of Sugarcane Manual,” (2014).

[4] Netafim, “Sugarcane Cultivation with drip irrigation,” (2014).

[5] Energy, N., & Alliance, E. Agricultural Irrigation Initiative: Overview of Center Pivot Irrigation Systems (2015) https://doi.org/10.1109/SPAWDA.2008.4775854

[6] D. Vadalia, M. Vaity, K. Tawate, and D. Kapse. “Real Time soil fertility analyzer and crop prediction,” Int. Res. J. Eng. Technol., 4, no. 3, pp. 3–5 (2017).

[7] R. Sindhuja and B. Krithiga, “Soil Nutrient Identification Using Arduino,” Asian J. Appl. Sci. Technol., 1, no. 4, pp. 40–42 (2017).

[8] A. Amrutha, R. Lekha, and A. Sreedevi, “Automatic soil nutrient detection and fertilizer dispensary system,” Int. Conf. Robot. Curr. Trends Futur. Challenges, pp. 1–5 (2016). https://doi.org/10.1109/RCTFC.2016.7893418