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Automated Fertilizer Blending System to Reduce Nitrogen Loss and Water Runoffs: A Best Evidence Review

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Current precision farming has prompted an urgent need to reconsider a plant condition-based automated fertilization system. Besides, the growing population rate has increased significantly increased crop production. As a result, efficient fertigation and irrigation methods like precision farming have been widely used. However, poor irrigation has led to more than 50 % of nitrogen losses and water lost to the environment, leading to toxicity exposure to the farmers, soil degradation, water quality deterioration, and eutrophication. Eutrophication causes dense harmful algae blooms, weed growth, low dissolved oxygen (DO), harming the marine ecosystem, eventually suffocating fish and other aquatic species. Reactive nitrogen losses known as nitrification represent reduced potential crop growth or wasted fertilizer. Therefore, an optimal supply and efficient fertilizer use are essential to reduce nitrogen pollution and water runoffs. This paper provides a systematic review on developing a control-based automated fertilizer blending system using a programmable logic controller and the advantages of plant control-based compared to a time-based fertilizer blending system. Control-based fertigation system can minimize water consumption up to 60% and minimizing 30% of fertilizer use. Conclusively, the control-based automated system can be the best fertilizer-sufficient management practices that benefit crop production without causing environmental problems.

1. Introduction

The current agricultural production depends on fertilizers to provide essential mineral elements to ensure progressive crop growth and increase harvesting products. However, the leached nutrient may contribute to groundwater aquifers contamination, water runoff, and eutrophication. Qi et al. (2020) had mention that more than 50% nitrogen loss and water loss more due to poor irrigation system. Figure 1 shows the significant incidents cycle of nitrogen pollution. The fertilizer consists of nitrogen (N), phosphorus (P), and potassium (K). This nutrient can be divided into two types of fertilizers: fertilizer A and B in solid or liquid forms. Mismanaged fertigation, excessive nutrients, and irrigation lead to eutrophication, groundwater contamination, and a significant problem.

The excessive nitrogen in the water causes algae blooms called eutrophication which blocks the dissolved oxygen (DO) from penetrating the water. This phenomenon affects human health, soil contamination, leaching water quality, fatal aquatic organisms, and food web disturbance (Ngatia et al., 2019).

Automated fertigation systems such as control-based and time-based systems are recommended to solve the aforementioned ecological impacts. The time-based system is controlled of irrigation by a digital timer constantly (Samsuri et al., 2010). In comparison, the control-based system is a continuous supply of mixed nutrient solutions without daily monitoring and reducing manpower (Abd Rahman et al., 2018). Samsuri et al. (2010) had stated that a time-based system needs to set the timer by manpower. This time-based system led to excessive nutrients like vegetative growth and delayed fruit growth (Shamsuddin et al., 2020). However, a control-based

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system minimizes labor cost since it comprehensively regulates it without human intervention and mixed nutrient solution applied at an appropriate time and amount only, thus optimizing the use of the resources (Bezerra et al., 2017). The control-based fertigation system relies on the plant condition by using pH and soil moisture sensor installed in the plant to maintain the plant's excellent condition compared to the time-based system that depends on timely irrigation application without considering the plant condition (Salas et al., 2020).

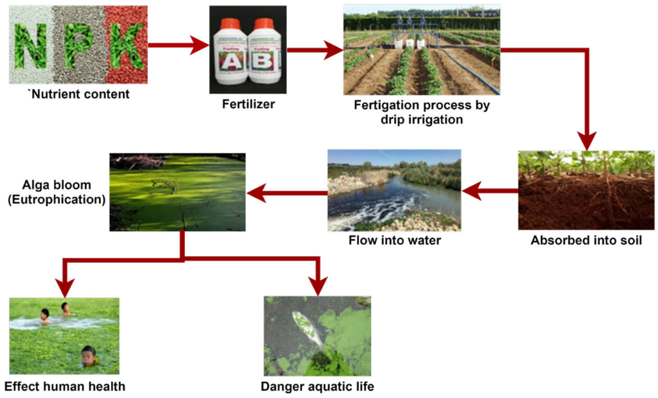

Figure 1: Major incidents of nitrogen pollution

The fertigation system had given the world of agriculture many advantages by using the nutrient content of nitrogen into the plant. However, without proper management use of this nutrient will cause nitrogen pollution. Table 1 shows the current issues related to fertigation from 2003 until 2020. In 2003, many research highlights efficient fertigation management due to groundwater contamination (Darwish et al., 2003). In 2006 investigation about irrigation and fertigation on tomato plants inside the greenhouse in Punjab Agricultural University found the development of tomato is better than open field crop fruits (Mahajan and Singh, 2006). Kafkafi and Kant (2013) investigate fertigation controls of plant growth and nutrient requirement through the irrigation process by developing a liquid fertilizer blend. Incrocci et al. (2017) recommend a new alternative to get the optimal nutrient requirement of crop yields applied through drip-irrigation systems and water uptake to the plant. Abd Rahman et al. (2018) proposes an automatic blending system by using electrical conductivity (EC) meter for rockmelon fertigation to automatically check the concentration level of the mixed nutrient solution according to the required electrical conductivity (EC) level. Boursianis et al. (2020) and González Perea et al. (2020) focus on IoT surveys with advanced technology and the dynamic simulation tool of the drip irrigation process in the agriculture industry. This research concluded that the revolution of the irrigation system had been improved year by year to keep water and nutrient loss, affecting the sustainability of plants, the planet, and people.

Table 1: The current issues related to fertigation from 2003 until 2020

Authors	Research Highlights	Key Performance Results				
		Time-based	Control-based	Minimize water runoff	Minimize nutrient loss	Increase plant growth
González Perea et al. (2020)	Fertigation scheduling optimization using dynamic simulation tools		/	/	/	/
Boursianis et al. (2020)	Smart farming and the internet of thing (IoT) in agricultural		/	/	/	/
Abd Rahman et al. (2018)	Automatic system of fertigation in greenhouse		/			/
Incrocci et al. (2017)	Optimal nutrient management on the crop production under fertigation		/	/	/	/
Kafkafi and Kant (2013)	Fertigation controls the growth rate and nutrient requirements of plants		/	/	/	/
Mahajan and Singh (2006)	Optimal water and nitrogen requirement of the plant by irrigation	/		/	/	/
Darwish et al. (2003)	Nitrogen management for the plant	/			/	/

Currently, agriculture underwent a fourth revolution by advanced technology in traditional farming practices. Technology such as Remote Sensing, the Internet of Things (IoT), Unmanned Aerial Vehicles (UAVs), Big Data Analytics (BDA), and Machine Learning (ML) are the new revolution to agricultural practices (Boursianis et al., 2020). The research gap is limited knowledge or literature related to highlighting the benefits of control-based system especially among farmers and agro practitioners. The literature on this topic never analysed their research trends. This paper provides a systematic review on developing a plant condition-based automated fertilizer blending system using a programmable logic controller (PLC) and the advantages of plant condition-based compared to a time-based fertilizer blending system.
This review helps agro farmers adapt to the control-based system and making a decision. This control-based system will contribute to the farmer by minimizing the losses of nutrient and water runoff into the environment, increase the yield crop, minimizing the labour cost, minimizing the cost of excessive fertilizer, and help the farmer in making a good decision. It also effectively applies the water and nutrient at appropriate times only, providing a satisfactory nutrient level to the plant growth development. Other than that, this control-based system can still be considered at a low cost. In addition, to achieve this goal, the three following research question (RQs) are explored:

- RQ1: What are technologies used in the control-based system of fertigations?
- RQ2: What is the implementation of precision agricultural recorded in literature?
- RQ3: How this control-based system can minimize nitrogen losses, water consumption and increase profit?

2. Research highlights

2.1 Macro-nutrients and micro-nutrients

A balanced nutrient requirement is essential to increase the yield of tropical crops and reduce the risk of adverse environmental impact. There were three significant roles in the global food production of nutrients; Nitrogen (N), Phosphorus (P), and Potassium (K) which is also known as a macro-nutrient. The most important nutrients include nitrogen for leaf and vegetative development, phosphorus for root and organic product creation, potassium for excellent hardiness, disease resistance, and general durability. In addition, agriculture productivity also required a small number of micro-nutrients like boron, iron, chlorine, manganese, zinc, and nickel. At the same time, the component of carbon, hydrogen, and oxygen have come from water and air (Nor et al., 2018).
However, these nutrients require proper crops management because the plants absorb too many nutrients, reducing the production of plants and increasing nutrient leaching due to toxicity. This waste leads to increased fertilizer costs and decreasing environmental quality. This excessive nutrient loss also leads to nutrient overgrowth and can cause delayed fruit growth (Shamsuddin et al., 2020).

2.2 Nutrients and water management

The plant required nutrients for plant growth development in terms of quantity and quality. This correlation between plant growth and nutrient requirement is shown in Figure 2 (Marschner, 1995). The graph shows that the plant growth has a better plant growth at 95% with an adequate range of nutrient concentration. In the deficiency range, the nutrient requirement of the plant is low, which also gives the low of plant growth. However, when the nutrient supply was excessive from what the plant required, it leads to the toxicity range to the plant growth. This excessive nutrient causes the wastage of nutrients, high cost of fertilizer, and degrade environmental quality (Shamsuddin et al., 2020).

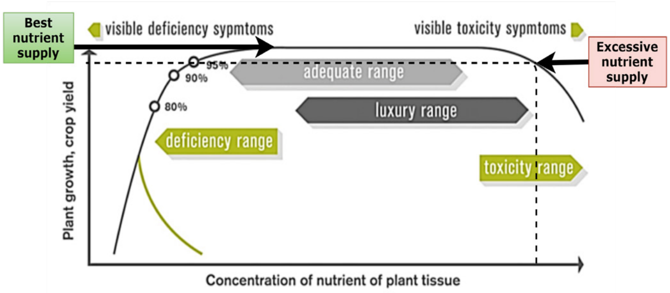

Figure 2: Plant nutrient requirement range (Marschner, 1995)

This excessive nutrient will flow in water runoff straight into freshwater and create eutrophication. This creates algal blooms and depleted oxygen which will cause fatal to the aquatic life and risk of environmental pollution.

2.3 Fertigation system

The first scientific application of fertigation was the use of sprinklers in the United States in 1958. The combination of drip irrigation was first applied to tomato crops in Israel (Incrocci et al., 2017). According to Adegboye et al. (2017), fertilizers and irrigation are defined as combining irrigation and fertilizer application to the soil to improve crop production and plant growth. There is three-stage farming fertigation, such as conventional farming, smart farming, and precision farming. Table 2 depicts the definition and device implementation.

Table 2: The comparison between conventional farming, smart farming, and precision farming

Criteria	Conventional Farming	Smart Farming	Precision Farming
Definitions	Focuses on manual fertilization and irrigation processes based on fixed time intervals that do not account for the crops' dynamics	Smart farming is a green technology approach since it reduces the ecological footprint of traditional farm and to increase the productivity in agriculture	Precision agriculture (PA) is smart irrigation, and the minimal use of fertilizers and pesticides in crops can further reduce leaching problems and environmental degradation, as well as the impact of climate change
Device Implementation	Use manpower and manual farming	Time-based and control-based technology	Use IoT, Artificial Intelligence, and remote sensing

2.4 Automated blending system

The automated blending system consists of sensors, an electrical conductivity (EC) meter, and a program logic controller (PLC). PLC is a control system that continuously monitors the status of input devices and makes decisions based on programs to control the quality of output devices. Automation includes increasing production speed, reducing costs, and effectively using resources. This research uses an electricity conductivity (EC) meter, as shown in Figure 3a, to automatically check the mixed nutrient solution's concentration level (solubility). While Figure 3b, the soil moisture sensor detects the change in soil moisture levels and sends a signal to the PLC. PLC-based irrigation controller automatically adapts the weather conditions, uses simple sensors, and carries the irrigation accordingly. This PLC will control a system that continuously monitors the state of the input device and makes a decision based upon the program to control the output devices (Sarojini et al., 2017). The pH sensor is shown in Figure 3c to prevent soil acidity. These three sensors need to reach the desired plant's accurate or available range reading, as tabulated in Table 3.

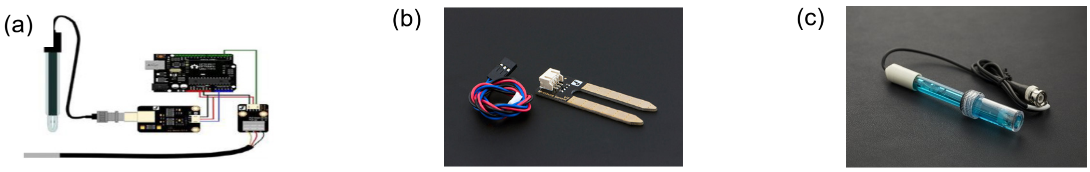

Figure 3: (a) EC meter, (b) Soil moisture sensor, (c) pH sensor

Table 3: The attributes, parameters of sensors and physical plant growth

Attributes	Parameters (Unit)	Authors
EC meter	1.7-3.5 dS/m	Abd Rahman et al. (2018)
Soil moisture sensor	70-80 %	Pollo (2018)
pH sensor	5.5-6.8 pH	Shamsuddin et al. (2020)
Plant height	118.07 ± 59.01 cm	Shamsuddin et al. (2020)
Size of fruit	Increase up to 21.7 % from the standard size	Steidle Neto et al. (2014)
Crop yields	Increase up to 10.5 %	Steidle Neto et al. (2014)

The process diagram of the automated blending system is illustrated in Figure 4. The system was developed into three stages. The first stage is preparing three stock tanks consisting of fertilizer A, fertilizer B, and water. Then, the nutrients and water will be pumped up into the blending tank for the mixing process. The EC meter measures the concentration of the dissolved nutrients.

Once the nutrient is mixed well, the pumping motor will pump the nutrient mixing into the plant by drip irrigation. The pH and soil moisture will be measured by pH sensor and moisture content sensor. These sensors transmit the signal to the PLC as the central control unit. The PLC receives the sensor's signal and determines if the input is within the present range required by the plant. If the measured signal of soil moisture content or pH is not within the required range, the output valve of the blended nutrient solution will be fully closed or open. The PLC will be the central processing unit, which will respond to the input signals from the sensors and turn on or off the necessary equipment to maintain the system at a present level. The operation of system flow in a closed-loop process.

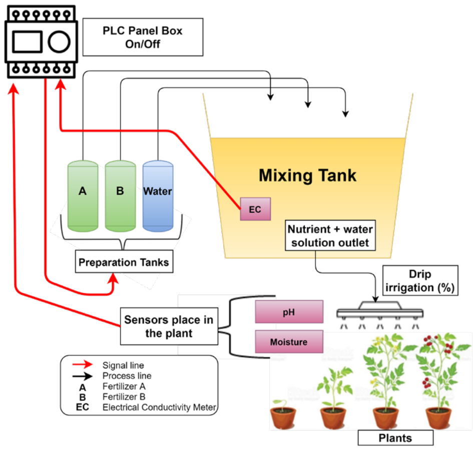

Figure 4: The process diagram of automated blending system in fertigation

2.5 Advantages of fertigation system

Cisternas et al. (2020) had described numerous benefits of this automated system will increase agricultural productivity, as mentioned in Table 4, which positively impact the planet's sustainability, people, and profits.

Table 4: The advantages of the control-based system

Environment	Economic	People
• Minimizing the nitrogen pollution into the water body and soil • Minimizing the use of herbicides and pesticides and required workforce • Minimizing water consumption about 60% and minimizing 30% of fertilizer use (Wageningen University and Research Centre, 2010)	• Minimizing losses and waste of other resources • Minimizing costs by only applying fertilizer where they are required • Reduce the variability and inputs costs • Increase the yield of crop • Minimizing the labour cost by 15-20% and increase the yield by 32.5% (Pramanik et al., 2014)	• Contributes to an adequate decision making • Allow quickly deciding and implementing management actions • Minimizing the risk exposure to labour in the field

3. Conclusion

In conclusion, an innovative control-based system is an excellent alternative for precise fertigation management in saving water and nutrients with enhanced nutrient uptake, growth, yield, and crop quality. The motivation of the review is to assists farmers to make quantitative decisions from plant growth, technical production, economics, and environmental management using a control-based system. The control-based fertigation provides a sustainable nutrient supply by minimizing 30% of fertilizer and avoiding water runoff up to 60% water saving to keep plant growth at an adequate range. This system offers efficient resources, reducing unnecessary capital investment and environmental pollution in the agricultural industry. A proper and systematic control-based system minimizes water, fertilizers, herbicides, pesticides, and the required workforce in the farm, enabling the harness of high crop yield, simultaneously ensuring a healthy soil and environment, as compared to time-based fertigation. Therefore, control-based fertigation can potentially increase agricultural profit and controlling environmental pollution for achieving sustainable farming practices. However, the control-based system is not well adopted among the farmer due to a lack of knowledge in technology. Thus, we recommended in the future to approach the farmer about the benefits of using a control-based system by providing awareness and training about the control-based system.

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