ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering
Tome XX [2022] | Fascicule 2 [May]

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HYDROPONICS IN PRECISION AGRICULTURE – A REVIEW

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Abstract: This review paper present hydroponics in precision agriculture. Hydroponics is a techniques for growing plants in nutrients solutions without soil, but only with water or nutrient rich solution in greenhouse under controlled environment within a short period of time. Among various hydroponic systems, the deep flow technique (DFT), nutrient film technique (NFT), and aeroponic systems have been commercially used with recirculated nutrient solutions. Since ion concentrations in the nutrient solutions change with time causing a nutrient imbalance, nutrient control systems with real–time measurements of all nutrients are required, but such systems are not yet available on a commercial basis. Instead, ion electrical conductivity–based hydroponic systems have been the second–best choice but suffer from nutrient imbalance. To improve the nutrient balance, periodical analysis of nutrient solutions and adjustment of nutrient ratios need to be conducted. As an advanced method, the ion–selective electrodes and artificial neural networks have been used to estimate the concentration of each ion. To protect the plants in plant factories from disease, disinfection systems, such as ultraviolet (UV) systems, are required. Root–zone environmental factors such as nutrient concentration, pH, dissolved oxygen, and temperature directly affect the growth of hydroponically grown plants. For real–time measurement of these factors, corresponding sensors are required. By assuming that the electric current increases with an increase of ionized nutrients in the nutrient solutions, electrical conductivity (EC) sensors are used to measure nutrient concentrations.
Keywords: Hydroponics, Precision Agriculture, Nutrient solution, Dynamic root floating, artificial medium

1. INTRODUCTION

Hydroponics Agriculture comes up as a solution to limited agricultural land that can lead to decline in agricultural production capacity (Ramos *et al*., 2019). Hydroponics comes from Greece, hydro means water, and ponous means work. Agricultural methods using hydroponics is one of the possible alternatives to the be able to practice agriculture even without extensive agricultural land (Cometti *et al*., 2013). Hydroponics is a techniques for growing plants in nutrients solutions (water containing fertilizers) with or without the use of artificial medium (sand, gravel, vermiculite, Rockwool, perlite, peat moss, coir, or sawdust) to provide support (Jensen, 1997). Hydroponics uses many techniques such as Deep Flow Technique (DFT), Dynamic Root Floating (DRF) technique, Nutrient Film Technique (NFT). On the other hand precision agriculture is an agricultural process that is technology–driven to reduce any wastage of resources and focuses on increasing the crop yield by helping the farmers make better decisions to improve the efficiency of farming. Liquid hydroponics system have no other supporting medium for the plant roots, aggregate systems have a solid medium of support. Hydroponics systems are further categorize as open (nutrients solution is delivered to the plant roots, it is not reused) or closed (surplus solution is recovered, replenished, and recycled).

The advantage of hydroponic farming methods is that it does not require soil media with vast land for agriculture, but agriculture can be done in a narrow area with water media. Each hydroponics plant is also treated without using pesticides, so it is safer to consume (Wahome *et al*., 2011). In hydroponics agriculture, there is a challenge of precision agriculture, especially for some sensitive plants (Surantha, 2019). Hydroponics farming methods need special treatment in controlling water temperature, water level, and acidity (pH) of nutrient solutions. To be able to produce plants that are good until the harvest period, they must carry out these treatments with regular checks every day (Charumathi *et al*., 2017; Cometti et al., 2013; Jensen, 1997). Recently, there has been an increasing interest in recirculating and reusing nutrients solution in closed growing systems as a means of reducing the cost and minimizing the environmental impact of hydroponic system, such as soil and water pollution induced by the used nutrient solutions. The pH and electrical conductivity (EC) of the solutions are usually monitored to evaluate the nutrient status of circulating hydroponics solutions used in green house plant production. However, such approach cannot provide sufficient information about ion imbalances induced by nutrient uptake in plants and the drainage ratio in plant growing beds because electrical conductivity is an indiscriminate measure that only indicates the total composition of nutrient ions. Examination carried out include checking the water content in the installation, the nutrients, the temperature and humidity of the air, which must be under the dose. If the quantity of one of the elements is excess or lacking, it can result in the inhibition of plant growth. The maintenance that must be done routinely every day causes agriculture with hydroponic method to be inefficient because it requires a considerable effort and requires high cost of maintenance (Mishra and Jain, 2015). This of course automatically impacts the selling price of hydroponic plants that are expensive. Therefore, although the method of hydroponics is the solution to the current problem of limited land, the complexity of treatment is an obstacle in its implementation.

To manage the imbalances in nutrient ratios in electrical conductivity based systems, periodical adjustments of recycle nutrient solution is required. However, the use of periodical adjustment to manage nutrient ratios has several limitations. For example, periodical adjustments cannot help farmers to respond rapidly to unexpected changes in nutrient ratios in hydroponic solutions. In addition, the intervals of adjustment vary depending on the plant species and climates.

Currently, bench–top or portable analyzers equipped with ion–selective electrodes (ISEs) are used to measure the concentration of individual ions in hydrogen solutions. However, for on–site nutrient monitoring (Figure 1), which requires frequent immersions of the (IESs) in solutions, the accuracy of the determination of nutrient concentrations is strongly affected by the signal drift and reduced sensitivity over time, which could be caused by manual calibrations, sampling, and the maintenance involved in the operation of ions selective electrodes are used to measure the concentrations of individual ions in hydroponic solutions. However, for on–site nutrient monitoring, which requires frequent immersions of the ion selective electrodes in solutions, the accuracy of the determination of nutrient concentrations is strongly affected by the signal drift and reduced sensitivity over time, which could be caused by manual calibrations, sampling, and the maintenance involved in the operation on ion selective (De Marco and Phan, 2003; Han *et al*., 2020).

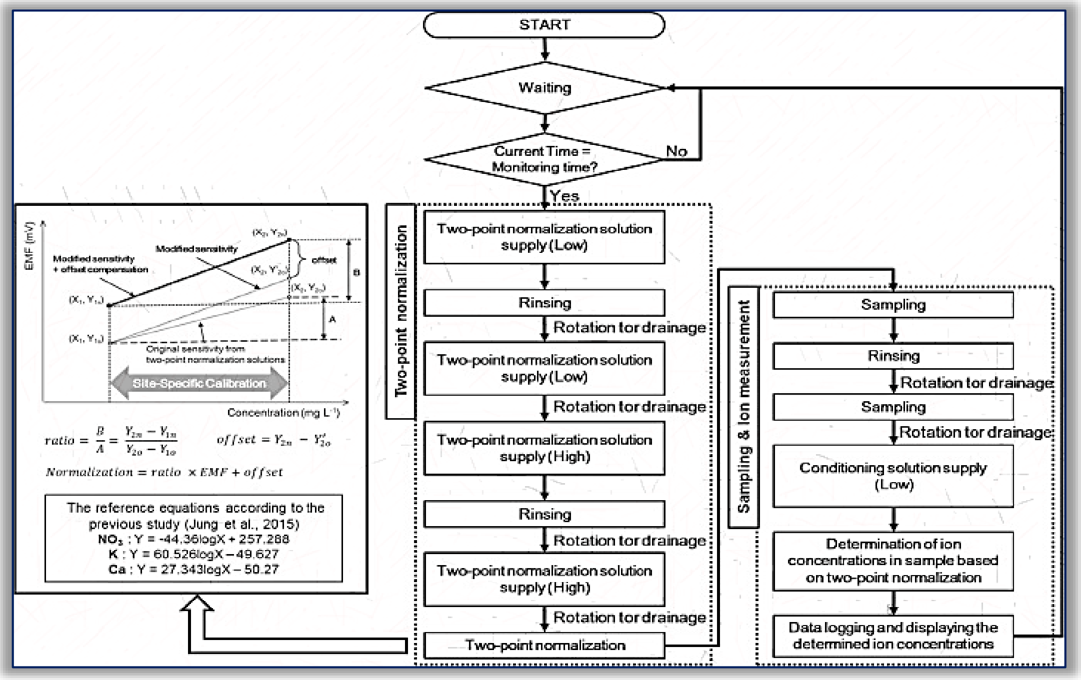

Figure 1: Flow of operation implemented in the on–site ion monitoring system. Source: Cho *et al.* (2018).

In this regard, a computer–based measurement system that performs automatic solution sampling and electrode calibration makes it possible to improve the nutrient concentration measurement (Kim *et al*., 2007, 2013). Ideally, an automated sensing system for hydroponic nutrients would be able to periodically calibrate the electrodes and continuously measure the nutrients in a hydroponic solution, while automatically performing calibration and introducing sample solutions (Jung *et al*., 2015).

Research shows that automatic measurement systems were developed in conjunction with a two–point normalization method to quantify NO_3^-,K^+, and Ca^{2+} ions in hydroponic solutions with an acceptable level of accuracy (Cho *et al*., 2018; Jung *et al*., 2015; Kim *et al*., 2007, 2013). It was reported that the use of a two–point normalization, consisting of a sensitivity compensation followed by an offset adjustment, was effective in standardizing the responses of multiple electrodes for each ion. However, the predictive capability of the developed systems was only validated in a polycarbonate chamber growing lettuce or in a laboratory using paprika hydroponic solutions obtained from a greenhouse. To enhance the practical use of the previously developed ion measurement systems (Jung *et al*., 2015), for hydroponic solutions in real green houses, the ultimate goal of this study was to develop an on–site ion monitoring system with robustness and an easy–to–use user interface that could automatically measure the concentration of three macronutrient ions (NO_3^-,K^+, and Ca^{2+}) in recirculating hydroponic solutions as these are closely related to the yield and nutritive quality of plants (Cho *et al*., 2018).

2. PRECISION AGRICULTURE IN MACRO–NUTRIENTS MEASUREMENTS

Within the field of precision agriculture, the accurate in–field measurements of the macronutrients nitrate, phosphate, and potassium in soils and hydroponic growth media is a vital component to controlling crop yields and plant disease (Dordas, 2008; Kim *et al*., 2009). The role of phosphate is particularly important in cellular metabolism and the production of nucleic acids, with a phosphorous (P) deficiency resulting in the stunted growth of plants and poor development of root systems (Leigh and Wyn Jones, 1984). However, an overdosing of the nutrient through phosphate rich fertilizers leads to significant leaching of labile phosphate into the local water table. This can lead to a population explosion in species of blue algae, and subsequently the eutrophication of nearby ponds and water supplies (Ding *et al.*, 2010). As such, the control of phosphate content in the environment is critical. Another challenge has been the determination of a portable sensor design that can selectively measure the concentration of inorganic phosphate present within a growth media.

Phosphate displays cross–interference with other common nutrient cations such as NO_3^- when measures using conventional electrochemical sensors based on electro–conductivity (EC) measurements or ion selective electrodes (Li et al., 2016). This is due to the structure of the orthophosphate ion, with the central P atom covalently bonded to four oxygen atoms, creating a hydrophilic sphere around the anion and resulting in high enthalpy of hydration, making it difficult to detect. Another challenge to detection is that the structure of the phosphate molecule present is highly dependent on the pH of the environment, where it exists as $H_2PO_4^-$ and H_3PO_4 in acidic environments, whereas it takes the forms of PO_4^{3-} and HPO_4^{2-} in alkaline environment (Li et al., 2016).

A solution to the challenges associated with cross–interference is the introduction of a molecularly imprinted polymer as a selective sensor recognition element. Molecular imprinted polymer are biomimetic materials that contain three–dimensional binding sites similar to those of enzymes used in biosensors (Van Dorst et al., 2010). A molecular imprinted polymer consists of three key components: a cross–linked hydrocarbon polymer network that provides structure to the material; a functional monomer containing side groups that allow for non–covalent bonding interactions at the binding sites; and a template molecule around which the binding sites forms (Haupt and Mosbach, 2000).

Kugimiya and Takei (2008) successfully demonstrated the ability to imprint phosphate in a series of papers where a molecular imprinted polymers was created using a diphenyl phosphate template with a binding site based on N–allylthiourea for applications in water remediation and phosphate recovery. Kugimiya and Takei (2006) further established the suitability of phosphate selective molecular imprinted phosphate for use as sensing elements by using carbon nanotubes as a method for electrical transduction to detect the binding event of a phosphate molecular polymers using dipentyl phosphate as the template.

Recently, several research groups have reported automatic control systems for hydroponic cultivation (Mishra and Jain, 2015; Sarkar, 2004; Surantha, 2019). An automated pH and nutrient–control system was constructed based on the conductometry (Saaid et al., 2015). As for the monitoring of nutrient components using several ion sensors, there are several paper (Domingues *et al.*, 2012; Fakhrurroja *et al.*, 2019; Mishra and Jain, 2015).

3. PRECISION AGRICULTURE USING INTERNET OF THINGS

Water scarcity has now become a global problem. The agricultural sector is largely being affected by this. Hence, a few smart irrigation techniques are adopted and practiced. Commercial sensors for agricultural irrigation being one of the techniques are very expensive for smaller farmers. However, low–cost sensors have now come into the picture that is easily affordable and used for irrigation management and agricultural monitoring (García *et al.*, 2020; Goap *et al.*, 2018; Rawal, 2017; Saraf and Gawali, 2017). Internet of things nodes such as Arduino boardsn are ultilized for internet of things based irrigation systems. With the help of soil moisture sensors, the status of the moisture content in the soil is obtained.

Using this techniques of smart irrigation, the water sprinkler is automatically switched on/off. This technique minimizes water wastage. In the absence of such a technique, excess water can drain deep into the soil layers. This pollutes the groundwater as the excess water reaches the root sector which consists of vital nutrients. The latter may bring about under irrigation which generates a big reduction in the crop quality as well as quantity (Iyer et al., 2020; Pernapati, 2018). Sensors are being used in various aspects of agriculture such as water management, soil monitoring and weather monitoring. The internet of things make a smart controlling that

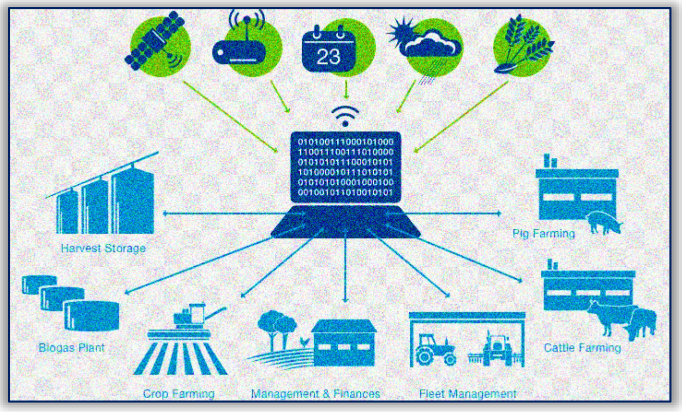

Figure 2: Precision agriculture

can automatically control plants nutrition and water needs. By utilizing internet of things technology, each sensor device can communicate or send data to a cloud server to be processed and monitored in real time (Baoyun, 2009). Each sensor is to be connected to Arduino to control plants needs automatically using fuzzy logic. For instance, electrical conductivity sensors will detect if the nutrient levels in the installation are reduced so that the control system will automatically add nutrients to the plant (Figure 2).

— Global positioning system (GPS)

Global Positioning System (GPS) enables the users to determine the absolute or relative location of a feature on or above the earth's surface. Global positioning system orbiting around the earth at an altitude of 12,550 miles, these satellites are in predictable locations; hence, we refer to the system of satellites as the Global Positioning System constellation. Precision agriculture is an integrated crop management system that endeavors to match the kind and amplitude of inputs with the genuine crop needs for minute areas within a farm field (Hamuda *et al*., 2016; Nawawi and Ismail, 2017; Payne *et al*., 2013). Global Positioning System sanctions farmers to work during low overtness field conditions such as rain, dust. GPS has withal given ascend to field mapping which is a system for computer availed field data amassment that takes several factors into account such as inventory of crop types, ascension levels, field boundaries, nearby roads, irrigation systems, etc. The precision of GPS sanctions farmers to engender farm maps with precise acreage for field areas, road locations, and distances between points of interest. GPS sanctions farmers to accurately navigate to categorical locations in the field, year after year, to accumulate soil samples or monitor crop conditions (Yinong et al., 2005). The tractor guidance set off, steering automatically. It moves up and down the field utilizing the minimum quantity of fuel. Virtually, none of the seed is misplaced. The earth is orbited by 24 different GPS satellite, computer vision will permit appropriate pesticide use and weeds and crops can be more easily differentiated. The object of soil sampling was to determine the average soil test level for the field. The result is the faculty to apply fertilizers in areas where utilization will be maximized and money spent minimized. Individual map layers can be engendered for each nutrient. Advantage of GPS is providing better farm records essential for sale and succession. It is a novel method which guides farmer for better agriculture and farming. It provides better information for management decisions.

— Geographic information system (GIS)

Geographic Information System is extensively used in the field of agriculture. Geographic Information System collects, manages, and analyzes data provided by geographically obtained information. GIS mainly focuses on analyzing spatial data which is nothing but the information based on geographic space. This spatial data is handled by GIS, which provides data management, manipulation, and analysis (Balamurugan et al., 2014; Chen et al., 2002; Sharma et al., 2018).

The agriculture systems need a major transformation from the traditional practices to precision agriculture or smart farming practices to overcome these challenges. Geographic information system (GIS) is one such technology that pushes the current methods to precision agriculture (Brisco et al., 1998; Kim et al., 2009; Tayari et al., 2015).

— Hydroponics for fodder production

The production of agricultural and livestock sector is very seasonal and the climate is the main cause. In order to make the production as continuous as possible the application of new production techniques is required. Thus, a hydroponics (Saaid et al., 2015) system for fodder production allows that there is a food supplement for animals on a farm, continuously and at any time of the year. Several systems exist to produce fodder using hydroponics techniques (Figure 3), and are currently applied in horticulture and fodder production (Kammar *et al*., 2019; Matthew *et al*., 2011; Naik *et al*., 2015). Recent works report the use of hydroponics in urban areas (Haberman et al., 2014), for instance, in urban vacant areas, industrial rooftops, and residential yards, revealing its potential use. In recent years hydroponic systems started to be automated. Nowadays commercial solutions do exist, even open source solutions such as the Hydroponics Automated Platform (Lakshmanan et al., 2020).

Figure 3: Hydroponics fodder production in urban areas.
Source: Haberman *et al.* (2014).

— Deep flow technique (DTF)

Deep Flow Technique (DFT) is a hydroponic method that uses water as a medium to supply nutrients to plants through ponds. Plants are cultivated in drainage channels with a nutrient solution that is about 4–6 cm in height that flows continuously, where the roots of plants are always submerged in the nutrient solution. Nutrition solutions will be collected back into the nutrient basin, then pumped through a distribution pipe to the planting pond continuously (Kammar *et al*., 2019; Mishra and Jain, 2015).

— Nutrient film techniques (NFT)

Nutrient Film Techniques ,which uses a thin film of water typically flowing down a narrow channel, with plant roots partially in the water film, may confer advantages over gravel bed and floating systems, such as the ease and economic advantages of construction and the substantially lower weight of the components. However, NFT has not yet received much research attention in aquaponics systems, despite it requiring lower water volumes and being one of the most often used and best under–stood hydroponic growing systems (Alipio *et al*., 2019; Mohammed and Sookoo, 2016).

— Aeroponic system

Aeroponic systems are a specialized version of hydroponics where the roots of the plant extend only in air and the roots are directly sprayed with a nutrient water mix (the recipe). In aeroponic, oxygen is surrounding the roots at all times. Surplus oxygen accelerates nutrient absorption at the root surface (Christie and Nichols, 2003; Nir, 1981; Weathers and Zobel, 1992)

4. CONCLUSIONS

Precision agriculture techniques help save resources along with increasing the crop yield. Techniques like hydroponics consume less water and space and has a high growth rate compared to traditional farming techniques. Technologies like Global Positioning System and Geographical Information System help farmers make better decisions based on the data collected and analyzed. Internet of Things based smart irrigation with the help of sensors used for monitoring reduces water wastage. Crops grown using precision agriculture produce a huge amount of data; a technology like Big Data is used to extract beneficial information from the bulk data obtained. Internet of Things and cloud increase agricultural efficiency. These are some of the methods used to help overcome the inefficiencies in farming and helps meet the demands of today's competitive world. The papers reviewed shows that smart monitoring and controlling for hydroponics can be done using Internet of Things technology. The Internet of Things is used to monitor the water and nutrition needs of plants. Among various hydroponic systems, the deep flow technique (DFT), nutrient film technique (NFT), and aeroponic systems have been commercially used with recirculated nutrient solutions. Since ion concentrations in the nutrient solutions change with time causing a nutrient imbalance, nutrient control systems with real–time measurements of all nutrients are required, but such systems are not yet available on a commercial basis. Instead, ion electrical conductivity–based hydroponic systems have been the second–best choice but suffer from nutrient imbalance. To improve the nutrient balance, periodical analysis of nutrient solutions and adjustment of nutrient ratios need to be conducted. As an advanced method, the ion–selective electrodes and artificial neural networks have been used to estimate the concentration of each ion. To protect the plants in plant factories from disease, disinfection systems, such as ultraviolet (UV) systems, are required. Root–zone environmental factors such as nutrient concentration, pH, dissolved oxygen, and temperature directly affect the growth of hydroponically grown plants. For real–time measurement of these factors, corresponding sensors are required. By assuming that the electric current increases with an increase of ionized nutrients in the nutrient solutions, electrical conductivity (EC) sensors are used to measure nutrient concentrations.

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