Application of the Esther 4.0 System in Hydroponics for sustainable production

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ABSTRACT
The problem of global hunger is a persistent and complex reality that affects millions of people around the world. According to data from the Food and Agriculture Organization of the United Nations (FAO), in 2023, among the approximately 7.975 billion people in the world, 900 million were in severe food insecurity characterized by a state of hunger, with 83 million in Latin America and the Caribbean. A significant increase compared to previous years, mainly due to the impacts of the COVID-19 pandemic (FAO, IFAD, WHO, WFP and UNICEF, 2023). According to the United Nations (UN, 2022), the forecast for 2050 is that the world population will reach 9.7 billion, requiring a 70% increase in food production, which will require more investments in agribusiness and family farming.

Keywords: Family farming, Food production, Global hunger.

1 INTRODUCTION

The problem of global hunger is a persistent and complex reality that affects millions of people around the world. According to data from the Food and Agriculture Organization of the United Nations (FAO), in 2023, among the approximately 7.975 billion people in the world, 900 million were in severe food insecurity characterized by a state of hunger, with 83 million in Latin America and the Caribbean. A significant increase compared to previous years, mainly due to the impacts of the COVID-19 pandemic (FAO, IFAD, WHO, WFP and UNICEF, 2023). According to the United Nations (UN, 2022), the forecast for 2050 is that the world population will reach 9.7 billion, requiring a 70% increase in food production, which will require more investments in agribusiness and family farming.

In Brazil, despite being known worldwide as an agricultural country, according to an FAO report (2023), in 2022, 70.3 million people were in a state of moderate food insecurity (when they have difficulty feeding themselves) and 21.1 million were severely food insecure. In the context of the Brazilian semi-arid region, for example, a region marked by scarcity of water resources, the situation of hunger is a reality. In this context, recurrent drought is one of the main factors that hinder food production and the availability of water for irrigation.

Indeed, the increase in the world's population and the consequent demand for food are critical issues that have raised concerns about the future availability of land for agriculture. Such as Montgomery (2007), who warned of long-term food supply challenges in the face of unsustainable agricultural practices and soil degradation, and FAO (2018), which highlighted that soil degradation and the loss of arable land are significant threats to global food security.

This concern is compounded by the fact that urban sprawl and infrastructure have been competing with agricultural areas, decreasing the availability of land for food production (FAO, 2019) and increasing water consumption. In this scenario, in which the natural water cycle is often interrupted due to pollution and increasing water scarcity, the adoption of reuse practices becomes imperative.

Conventional, sometimes inefficient, irrigation can be one of the main sources of water waste in food production. According to ANA (2019) in Brazil, the irrigation sector is responsible for approximately 75% of water consumption. It is in the face of this reality that water scarcity has become a global challenge that affects agriculture and food security, and it is therefore necessary to improve food production techniques.

That said, sustainable soil management strategies and incentives for responsible agricultural practices become injunctive to address this global challenge, such as the implementation of water reuse techniques, especially in hydroponic systems, which plays a crucial role in the search for sustainable solutions in food production.

The production of vegetables in hydroponics has been gaining prominence, for presenting higher productivity per area, better production scheduling, shorter cycle due to greater environmental control, lower incidence of pests and diseases, greater ease of execution of cultural treatments, elimination of nutrient losses by leaching, runoff, volatilization, fixation and retrogradation, resulting in a more rational use of fertilizers (MARINEZ, 2002).

In addition to the growing population mentioned, agriculture also faces a challenging scenario with the increasing unpredictability of the weather and everyday adversities. Climate change has intensified extreme weather events, such as prolonged droughts, heavy rainfall, and heat waves, which directly affect agricultural production.

In this context, the monitoring of the ideal parameters for the best vegetative growth stands out as essential for the control and prevention of losses of agricultural products. In hydroponics, for example, these parameters include the measurement of variables such as nutrient solution pH, electrical conductivity, temperature, relative humidity and dissolved oxygen concentration. Keeping these factors within the optimal ranges is essential to ensure healthy and quality vegetative development.

Technological monitoring tools can be developed through automatic systems, the use of sensors, IOT (Internet of Things), artificial intelligence, and applications in order to allow practicality and more assertive decision-making, with agility and efficiency (MASSRUHÁ, 2020). Thus, it is possible to ensure the maintenance of the production and quality of hydroponic crops, which eventually still suffer from changes in the ideal parameters, whether due to climate change, electrical or human failures, resulting in production losses (SANTOS, 2021).

Showing the importance of resource management, Monteiro. (2009) highlighted that the lack of adequate monitoring of environmental parameters in agricultural areas can result in losses of up to 30% in the production of certain crops in regions affected by prolonged droughts. Costa (2001) demonstrated that failures to maintain optimal pH levels and electrical conductivity in the nutrient solution can lead to significant decreases in the productivity of hydroponic crops.

In addition, the lack of control over temperature and humidity can result in plant stresses, leading to additional losses (LANNA et al., 2021). In view of the above, it can be highlighted the urgent need to adopt effective monitoring practices to mitigate negative impacts on hydroponic crops.

2 OBJECTIVE

The main objective of this article is to present the impact that the ESTHER 4.0 system offers for the production and monitoring of meteorological and nutrient solutions, as an automated system for controlling the ideal parameters for hydroponic crops, which can be installed in hydroponics systems in rural and urban homes, private, public and cooperative schools.

3 METHODOLOGY

The work was carried out in three stages: in the first, a literature review was carried out, developed with articles published in the period from 2010 to 2023 in the electronic databases: Capes Portal, Scientific Electronic Library Online - Scielo and Google Scholar, using the descriptors: hydroponics, lettuce, nutrient solution, automation, monitoring, agriculture 4.0, artificial intelligence and their respective synonyms and combinations, in Portuguese and English. A project was developed to create the ESTHER system, which was approved and funded by FACEPE through the PRÓ STARTUP notice (2022), entitled "ESTHER: Automated hydroponics for sustainable food production with nutritional monitoring and remote control of measurable variables", carried out by the Startup team, incubated by UFPE, AI- SIM Engenharia.

The following stages took place from April to November 2023. In the second stage, the hydroponic system was created and, in parallel, the system for monitoring the parameters of vegetative growth for lettuce cultivation was idealized: the ESTHER.

In the third stage, the hydroponic systems were implemented in addition to ESTHER in four places previously authorized for testing the systems: the Municipal Center for Early Childhood Education CMEI Paulo Rosas, the DEN (Department of Nuclear Energy), the Elisabeth Mein Baptist Home and the UFPE Application School, all located in Recife, Pernambuco. The construction of the hydroponic system had lowcost material as raw material, based on PVC pipes and water reservoirs. This is also how the ESTHER monitoring system was built, using Arduino boards and sensors of the ideal parameters.

4 DEVELOPMENT

Hydroponics, as a soilless cultivation system, has significant advantages in optimizing water use. Wright (2009) emphasizes that hydroponics allows for precise control of the amount of water needed by plants, significantly reducing waste compared to traditional cultivation methods. In addition, the recirculation of the nutrient solution in hydroponic systems enables the reuse of water, maximizing its efficiency and minimizing the environmental impact (SAVVAS, 2010).

Despite being an ancient technique identified as a practice in several crops, hydroponics has currently reemerged, on a large scale, as a potential solution to the problems of food insecurity and social vulnerabilities, when implemented in family farming in the semi-arid region or in suburban agriculture, for example.

By incorporating a monitoring system of the ideal parameters for better growth of the crop chosen for cultivation, hydroponics stands out as one of the production technologies of agriculture 4.0. According to Molin et al (2015), precision agriculture is an approach that uses advanced technologies, such as global positioning systems (GPS), sensors, and specialized software, to optimize the management of agricultural resources. It allows the detailed monitoring of the variables of the production environment, such as soil, climate and vegetation, aiming at making more assertive decisions and increasing efficiency in agricultural production.

Digital agriculture, or agriculture 4.0, represents a natural advance of precision agriculture, complementing it through a vast number of information and data generated and analyzed. Thus, through technological innovations, agriculture is naturally migrating to the digitalization of all its activities, but without leaving aside the tools of precision agriculture (MASSRUHÁ, 2020).

The technological history of agriculture has gone through several remarkable phases. Initially, the development of more effective farming implements, such as plows and tractors, revolutionized production by allowing for large-scale cultivation. Subsequently, the introduction of chemical fertilizers and pesticides in the 1930s further boosted agricultural productivity. In recent decades, the incorporation of information and communication technologies (ICTs) in agriculture, coupled with the use of drones, remote sensors, and real-time data analysis, has given rise to precision agriculture.

The monitoring of hydroponic systems, especially on a large scale, emerges as an indispensable tool in the face of climate change and the daily adversities faced by farmers. Through the collection and analysis of accurate data, it is possible to prevent significant losses in production. The inclusion of technologies such as monitoring applications, automation and Artificial Intelligence not only optimizes production efficiency, but can also contribute to achieving 8 of the Sustainable Development Goals (SDGs), promoted by the United Nations (UN). They are: 1. Eradication of poverty; 2. Zero hunger and sustainable agriculture; 3. Health and well-being; 5. Gender equality; 7. Affordable and clean energy; 8. Decent work and economic growth; 10. Reduction of inequalities; 11. Sustainable cities and communities; 12. Responsible consumption and production.

Authors such as Grafton et al. (2018) predict an expansion of the use of IoT (Internet of Things), automation, artificial intelligence, and machine learning in agricultural decision-making, providing even more autonomous and adaptable systems.

The implementation of remote monitoring systems and the analysis of *agricultural Big Data* are also expected to play crucial roles in the assertiveness of future agricultural production processes. In addition, the growing importance of sustainability and environmental stewardship in agriculture suggests an increase in the use of low-impact agricultural practices, such as agroecology, promoting a more balanced and resilient approach to food production.

In view of the above, ESTHER was conceived and created, based on the principles that form the word (**And:** Clean Energy, **S:** Sustainability **T:** Technology **H:** Hydroponics **And:** Environmental Education and **R:** Water Reuse) used dand such tools of Digital Agriculture and provided in its pilot project the growth of 500 lettuces in total, in two of the places where the system was implemented, namely: Cmei Paulo Rosas and the DEN (Department of Nuclear Energy of UFPE), illustrated in the Figure 1 and Figure 2 respectively. The first results were presented at the Secretariat of Technology and Innovation of the state of Pernambuco and plantations and harvests were carried out together with the children, promoting environmental educationthe Figure 1 (b) shows the harvest event, whose lettuces were distributed among the students' families and continue to be produced.

Figure 1: (a) Presentation of the ESTHER System at the Secretariat of Science and Technology of the State of Pernambuco. (b) Harvest at the Paulo Rosa Nursery

Source: prepared by the authors (2023)

Figure 2: (a) Lettuce Production at the Department of Nuclear Energy of UFPE and (b) Miniature of the ESTHER 4.0 System

Source: prepared by the authors (2023)

The other two sites where the hydroponic benches were installed are in the maintenance phase for the addition of ESTHER and the start of agricultural production.

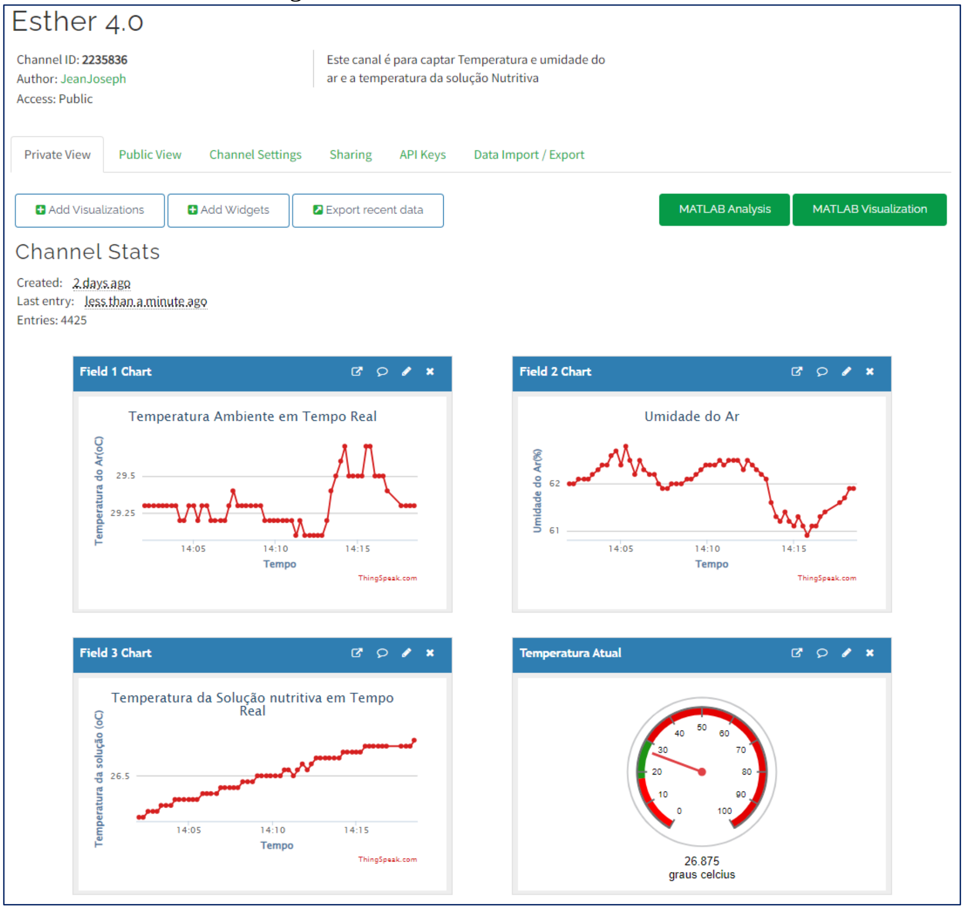
An essential component of the ESTHER 4.0 solution is the availability of information through online servers, accessible through dashboards on web or mobile platforms shown in the Figure 3. This approach allows for real-time monitoring of the quality of the nutritional solution used in hydroponic cultivation, as well as the creation of databases containing optimal compositions for the growth of different crops, including lettuce. Not only does this data benefit the crop itself, but it can also be used by scientists and academic communities in future research, fostering scientific advances and more effective and sustainable farming practices.

In order to admit a good management of the activity, the creation of databases through registries becomes a fundamental resource to establish an interconnected network of producers and buyers, which can encompass a variety of actors, such as restaurants, community fairs and others involved in the food chain. This data bank, which is integrated into the platform, plays a crucial role in allowing growers and buyers to record detailed information about their crops, cultivation methods, and product availability.

With regard to the production of healthy foods, the first harvests were carried out, as illustrated in Figure 4 of a homemade lettuce production containing 30 lettuces that took a production time equivalent to 44 days.

The present study highlighted the remarkable impacts achieved with the implementation of the ESTHER 4.0 system. The adoption of this technology has led to significant savings of 90% in water consumption, resulting in a substantial reduction in water bill costs compared to conventional systems.

Figure 3 Dashboard and Esther Platform



Source: prepared by the authors (2023)

Figure 4: First harvest of the small production of 30 lettuces

Source: prepared by the Authors (2023)

In addition, the developed system showed effective savings of up to 75% in energy consumption. A crucial aspect of the implemented hydroponic system is the regular circulation of nutrient solutions to keep the roots of the crops properly moistened.

The ESTHER system operates for six hours a day, during periods of greater solar incidence, from 5:30 a.m. to 6 p.m., with shutdown intervals of 30 minutes, contributing to an effective management of energy consumption, optimizing the hydroponics systems already used, where they generally have a greater amount, on average, 12 hours more irrigation, which can be up to 24 hours a day. as well as some systems visited in Recife-PE.

In practical examples, such as in the Paulo Rosa nursery, a system capable of supporting 48 vegetables was installed, while in the University's Nuclear Energy Department, the capacity of the system is more expressive, reaching the number of 350 vegetables.

5 FINAL THOUGHTS

Hydroponics is an innovative agricultural farming technique that has the potential to revolutionize food production. Based on carefully balanced nutrient solutions, this technique allows for better control of growing conditions, resulting in increased efficiency, productivity, and sustainability. Hydroponics has been widely studied and implemented in different parts of the world, including Brazil, where it has been consolidating itself as a viable alternative to face the challenges of population growth, climate change and modern agriculture. This continuous research and development in this area will certainly open up new perspectives for agricultural production in the future.

This article showed an application of automation as a fundamental role in the controlled and sustainable development of agricultural crops, contributing to a more efficient, economical and environmentally responsible production. In this study, the significant impacts achieved by using the ESTHER 4.0 system were highlighted. The use of this technology has resulted in a remarkable 90% savings in water consumption, which equates to a substantial reduction in water bill costs compared to traditional systems.

In addition, the developed system has demonstrated efficient savings of up to 75% in energy consumption and, with continuous technological evolution, it is expected that automation will continue to play an increasingly relevant role in the agriculture of the future.

In this context, automation in hydroponics, evidenced with the implementation of ESTHER, has proven to be an efficient solution for increasing productivity and sustainability in urban agricultural production and can be expanded to communities in social vulnerability. The integration of mobile applications in the control and monitoring of hydroponics represents a promising step into the future, allowing for smarter and more agile crop management, providing greater efficiency and profitability to producers.

Finally, the study for the creation of ESTHER and its implementation suggests, for future research, the use of brackish, industrial and urban wastewater in hydroponics for vegetable garden crops; use of PET bottles and other recyclable materials on hydroponic countertops; implementation of Artificial Intelligence in automated monitoring systems in hydroponic crops.

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