[1.]Iuliana GĂGEANU, [1.]Ana–Maria TĂBĂRAȘU, [2.]Oana–Elena MILEA, [1.]Gabriel GHEORGHE,
[1.]Mihaela NIȚU, [2.]Carmen–Otilia RUSĂNESCU

SIMULATION OF PLANT GROWTH IN DIFFERENT CONDITIONS

[1.] National Institute of Research – Development for Machines and Installations Designed to Agriculture and Food Industry, ROMANIA;
[2.] National University of Science and Technology POLITEHNICA Bucharest – Faculty of Biotechnical Systems Engineering, ROMANIA

Abstract: As the global population is continuously increasing, the supply of food with equal accessibility has become a major issue and future challenge. To meet both the worldwide demand for food security and new environmental needs, agriculture must increase food production and quality while decreasing its detrimental impacts on ecosystems and the environment). However, new agricultural land is limited, so sustainable production and increasing productivity of existing agricultural land is an important aspect to address global food security. Climate change affects precipitations, water flows, humidity and temperature. These changes will influence crop growth, phenology and yields, in the end leading to drastic changes in areas that are suitable for specific plant cultivation and land use changes. The paper presents considerations for the simulation of plant growth, taking into account temperature, lighting, water availability and fertilization.
Keywords: climate change; growth simulation; plant monitoring; food safety

INTRODUCTION

As the global population is continuously increasing, the supply of food with equal accessibility has become a major issue and future challenge. To meet both the worldwide demand for food security and new environmental needs, agriculture must increase food production and quality while decreasing its detrimental impacts on ecosystems and the environment (*USDA, 2015; Grusson et al., 2021*). However, new agricultural land is limited, so sustainable production and increasing productivity of existing agricultural land is an important aspect to address global food security.

Soil moisture has significantly decreased in the Southern region and increased in parts of northern Europe since the 1950s (*Destouni & Verrot, 2014; European Environment Agency Report No 1/2017*). Similar effects are expected for the coming decades, as the rise in average temperatures continues and rainfall patterns change (*European Environment Agency, 2021; Arvis et al., 2020*).

Climate change affects precipitations, water flows, humidity and temperature. The frequency and magnitude of extreme weather and climate events will increase, and the distribution and abundance of pest species and pollinators may change, Figure 1 (*Bocci & Smanis T., 2019; European Environment Agency, 2021*). These changes will influence crop growth, phenology and yields, in the end leading to drastic changes in areas that are suitable for specific plant cultivation and land use changes (*Ceglar et al., 2019; Ahsan et al., 2021*).

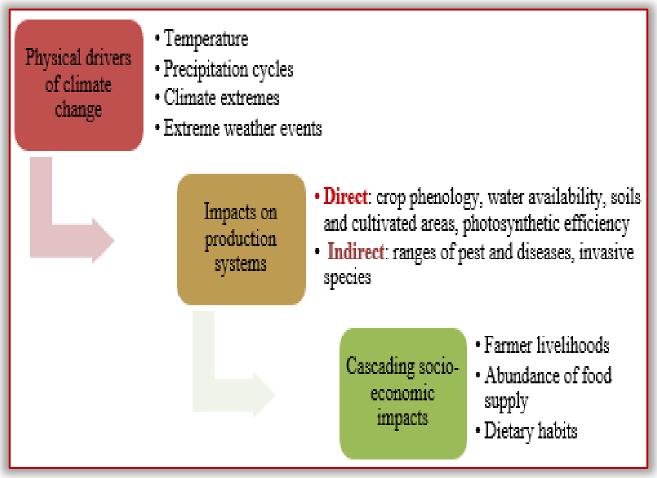

Figure 1 – Impacts of climate change on agriculture
(European Environment Agency, 2021, Arvis et al., 2020)

Also, fertilizers–pesticides–herbicides (FPH) play a sensitive role in food systems: they are applied in order to fertilize, protect crops from pests and diseases and to reduce food losses, but on the other hand they can have negative impacts on the environment and human health (*Ahsan et al., 2021; Aktar et al., 2009)*. The improper application of chemicals on crops may also contribute to accumulation of residues in food materials, soils and water. Vegetable production is an excellent example of intensive cropping systems that are indeed on the rise (*Eyhorn et al., 2015*).

Vegetable cropping systems are high–input and generally require large quantities of fertilization, frequent irrigation, and pest control.

The concept of IoT is more and more present in agriculture, guiding it in the direction of automation and intellectualization. A WSN, as a part of IoT, can act as a distributed measurement instrument that can offer improved information compared with a single manually operated instrument, especially in large areas. Considering the differences in parameters that can occur in large areas, multiple points have to be monitored.

A suitable solution is a WSN with long–range data transmission (*Centenaro et al., 2016*). The representative technology that can be successfully implemented in WSN (*Wixted et al., 2016*) for this type of network is LoRa (*Mekki et al., 2019*) developed by Semtech. For research and final user applications, Libelium released a wireless sensor node based on Arduino programming language with implementations in large areas through specific expansions boards. Libelium implemented more than 150 case studies with WSN, proving the applicability of the system for various real–life applications (*www.libelium.com/*).

The paper provides insights into the implementation of intelligent systems for simulating the growth of plants in various conditions, as a method for combating and reducing the impact of climate changes on agricultural crops and on food availability.

MATERIALS AND METHODS

An essential component of simulating plant growth is different environmental conditions. Researchers can investigate how various environmental elements, genetic factors, and management techniques affect plant growth and development. The following key conditions (figure 2) should be considered:

Temperature

Plants can thrive at temperatures between 4.5 and 36 degrees Celsius. The best temperature for growth varies depending on the species and stage of development, and it typically varies from night to day. Temperature affects a number of development processes. Respiration, a step in the photosynthetic process, maturity, flowering, fruit ripening, and dormancy are a few of these (*Janick J., 2019*).

Several temperature ranges can influence the growth and development of plants. It should be investigated how temperature affects plant development and yield by simulating various temperature situations.

Light

Plants are sensitive to light with wavelengths between 300 and 800 nm. Plants grown in the lack of light become etiolated. Chlorophyll is absent from etiolated plants, which are tall and wiry with long internodes and small, ungrown leaves. Their morphological expression of etiolation is connected to how light affect auxin synthesis and distribution.

The tissues generated in the light or the dark have the same anatomical characteristics, although light promotes some phases of growth while suppressing others, such as internode elongation (*Noggle & Fritz, 1983; Hartman et al., 1981*).

Light is a crucial element in the growth and development of plants. It should be investigated how light intensity, duration, and quality affect plant growth and development by modeling various lighting scenarios.

Soil moisture

It is well recognized that stomata closure, drought signaling in roots, reduced leaf water potential, and cellular dehydration are the main characteristics of moisture shortage.

Reduced cell size and growth, decreased cellular and metabolic activity, suppression of photosynthetic activity, turgor loss, production of reactive oxygen species, and altered carbon partitioning are all secondary or long–term impacts of soil moisture stress (*Jaleel et al., 2009; Bosco de Oliviera et al., 2013*).

Particularly during the germination and seedling stages, soil moisture levels can have an impact on plant growth and development. The impact of soil moisture on plant growth and development by can be assessed simulating various humidity situations.

Soil type

Living things, minerals, and organic substances all make up the soil. Decomposing materials like rotting plants and dead animals are where the organic matter in the ground comes from.

Since minerals are created when rocks are broken, the kind and quantity of minerals in the soil are influenced by the types of rocks that can be found nearby. Bacteria and earthworms are examples of the living creatures that make up soil. Plant growth is influenced by everything, including organic substances and ground–dwelling creatures (*USDA, 2015*).

Varying soil types can have an impact on a plant's growth and development because of differences in their nutrient and water–holding capacities. How different soil types affect plant development and yield can be investigated by testing growing the same plants on various soil types.

- **Nutrient availability**

Proper management of nutrients is crucial for preserving soil production. In order to make fertilizer recommendations for field crops, soil analysis is typically employed as a criterion. Soil fertility is a phrase used to characterize the quantity of nutrients present in the soil.

In order to forecast how plants will respond and manage nutrients, observations and tests are utilized to assess the availability of nutrients. Because of other factors like soil moisture content and soil temperature, the availability of vital nutrients to growing plants cannot be guaranteed even when there are sufficient total amounts of these elements present in the soil (*Fageria & Baligar, 2005*).

Nutrient availability is a critical factor for plant growth and development. By simulating different nutrient availability conditions, the effects of nutrient deficiencies or excesses on plant growth and yield can be studied.

- **Genetic factors**

Genetic factors can play a significant role in plant growth and development. By simulating different genetic factors, such as plant traits, heritability, and gene expression patterns, researchers can study the effects of genetic factors on plant growth and development.

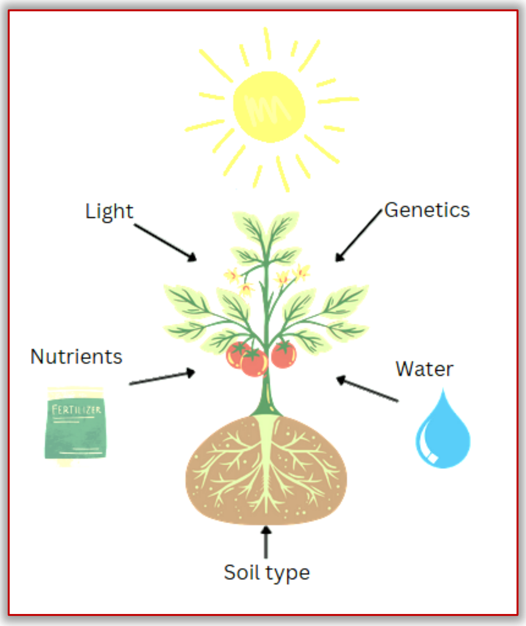

Figure 2 – Factors affecting plant growth

Overall, modeling different plant growth environments is crucial for comprehending the intricate interplay between many environmental, genetic, and management elements that influence plant growth and crop output. Simulated plant growth can assist scientists and growers in enhancing crop yields and minimizing the impact of agriculture on the environment.

RESULTS

There are numerous computer programs available that simulate plant growth, some of which include:

- **3D modelling models**: these programs simulate three–dimensional plant growth and development using mathematical models. They can be used to construct and test novel plant structures as well as to generate realistic virtual environments for studying plant behaviour.
- **Agent–based models**: these simulations depict how various components of a plant system—such as cells and organs—behave individually and in relation to one another to form emergent plant behaviour.
- **Physiological models**: the biochemical and physiological activities that take place inside a plant, such as photosynthesis, respiration, and nutrient intake, are simulated by these models. They can be applied to research how plants react to various environmental factors and to forecast agricultural output.
- **Machine learning models**: these models use algorithms predicting plant growth and development using information from actual plant growth studies. They can be used to forecast crop harvests, improve plant growth conditions, and create new plant varieties.

Apart from computer–based models, plant simulation modules can be used for simulating conditions that affect plant growth. A plant growth simulation module might include the following typical features:

- **Initial conditions**: The simulator allows the user to set the initial conditions for the simulation, such as the size and shape of the plant at the beginning of the simulation.
- **Environmental factors**: The simulator allows the user to adjust the environmental conditions in the module, such as the amount of light or water the plant receives, nutrients, weather conditions, etc.
- **Visualization**: The module may include tools for visualizing the growth of the plants over time, such as time–lapse videos.
- **Output data**: The module may provide output data on the growth of the plant, such as the size and shape of the plant at different points in time or the amount of biomass produced.
- **Validation**: The module may be validated using experimental data to ensure that it

accurately models the growth and development of real plants in the simulated conditions.

Plant simulation modules include:

- **Hydroponic systems**: Hydroponic systems are setups that allow plants to grow in nutrient–rich water solutions without soil. Hydroponic systems can be used to control the nutrient composition of the growing medium and to optimize the growth conditions for the plants.

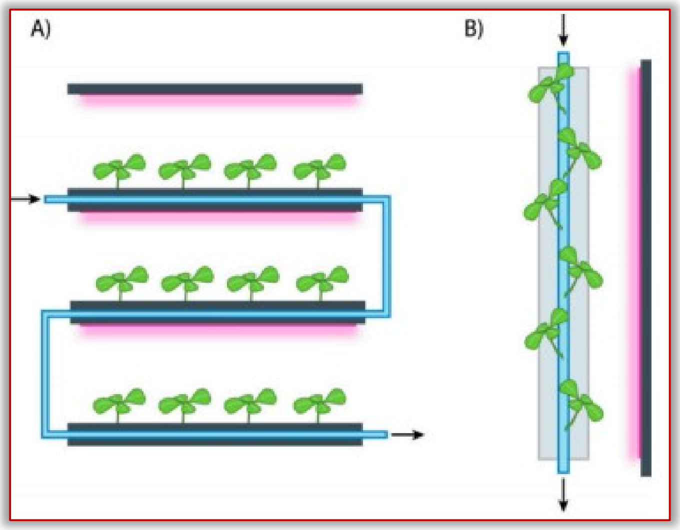

Figure 3 – Structure of the hydroponics vertical farm (Gentry M., 2019)
(A) Nutrient film technique. Each tray has LED lighting above it.
(B) Drip irrigation system. The column is dripped with nutrient water. This device can either allow for more natural daylight or be illuminated from the side by LEDs

- **Aeroponic systems**: in an Aeroponic system, plants are grown in an environment where air with very little water or mist and without soil are used. In this system, the plant roots are suspended in air. So, the roots are nourished by misting the root zones with a nutrient solution on a continual basis by using a fine sprayer to ensure that the roots get sufficient oxygen.

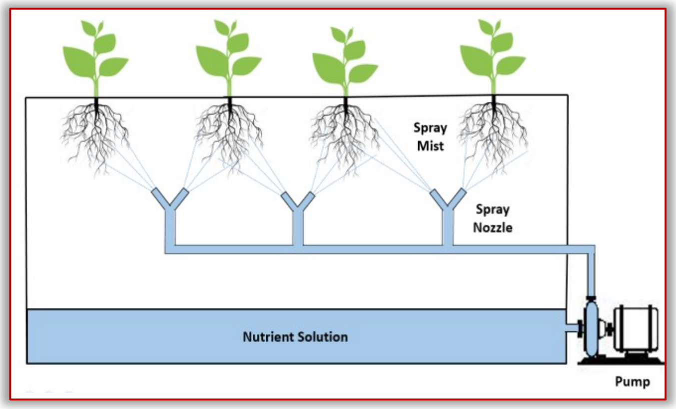

Figure 4 – Schematic diagram of an aeroponic system
(*Gupta & Ganapuram, 2019*)

- **Complete plant growth chambers**: Specialized environmental chambers known as "plant growth chambers" are created to replicate the conditions necessary for plant growth. In addition to other environmental elements, they can be used to regulate parameters like temperature, moisture, light intensity, and CO_2 levels. In these systems, the level of CO_2, moisture content and nutrition status within the chambers are monitored and controlled for maintaining simulated growing conditions with the help of a fully integrated computer management system.

CONCLUSIONS

- The use of plant growth simulation in agriculture has the potential to revolutionize the way in which crops are established, grown and managed.
- By providing more efficient and sustainable methods of monitoring and controlling the environment, plant simulation models and physical modules have the potential to improve the efficiency and profitability of agricultural operations, as well as to improve land use soil health.
- However, further research is needed to overcome the technical and financial challenges associated with computer aided and physical modules for plant simulation in this context, to allow more widespread adoption and use of these systems in agriculture.
- The employment of plant simulation can help farmers and researchers in the future to change both crop technologies and cultivated plants in accordance to current climate and soil factors that are found in particular areas and adapt their activity to foreseen changes in water availability, temperatures, light and nutrients.

Acknowledgement

This research was supported by the Romanian Ministry of Research Innovation and Digitalization, through the project "Intelligent plant growth systems under controlled environmental conditions" – PN 23 04 01 04– Ctr. 9N/01.01.2023 and through Program 1 – Development of the national research–development system, Subprogram 1.2 – Institutional performance – Projects for financing excellence in RDI, Contract no. 1PFE/30.12.2021.

References

[1] Ahsan D., Brandt U.S., Faruque H. (2021). Local agricultural practices to adapt with climate change. Is sustainability a priority?, Current Research in Environmental Sustainability, Volume 3, 100065
[2] Aktar MW, Sengupta D, Chowdhury A. (2009). Impact of pesticides use in agriculture: their benefits and hazards. Interdiscip Toxicol. 2(1):1–12
[3] Arvis, B., et al. (2020). Consequences of global climate change and their impacts on Europe – a view on agricultural commodities, report for the European Environment Agency, Ramboll France, Aix–en–Provence.

[4] Bocci, M. and Smanis, T. (2019). Assessment of the impacts of climate change on the agriculture sector in the southern Mediterranean: foreseen developments and policy measures, Union for the Mediterranean.
[5] Bosco de Oliveira A, Alencar NLM, Gomes–Filho E. (2013). Comparison between the water and salt stress effects on plant growth and development In: Akıncı S, editor. Responses of organisms to water stress: Agricultural and Biological Sciences. IntechOpen Publisher.
[6] Ceglar, A., et al. (2019). Observed northward migration of agro–climate zones in Europe will further accelerate under climate change, Earth's Future 7(9), p. 1088–1101.
[7] Centenaro M., Vangelista L., Zanella A., Zorzi M. (2016). Long–range communications in unlicensed bands: The rising stars in the IoT and smart city scenarios, IEEE Wireless Communications, vol. 23, no. pp. 60–67.
[8] Cook, B.I., Smerdon, J.E., Seager, R. et al. (2014). Global warming and 21st century drying. Clim Dyn 43, 2607–2627
[9] Destouni G., Verrot L. (2014). Screening long–term variability and change of soil moisture in a changing climate, Journal of Hydrology, Volume 516, p. 131–139
[10] European Environment Agency Report No 1/2017, Climate change, impacts and vulnerability in Europe 2016 – An indicator–based report.
[11] European Environment Agency. (2021). Global climate change impacts and the supply of agricultural commodities to Europe
[12] Eyhorn F, Roner T, Specking H. (2015): Reducing pesticide use and risks – What action is needed? https://pdfs.semanticscholar.org/
[13] Fageria N.K., Baligar V.C. Nutrient availability. (2005). Encyclopaedia of soils in the environment. Pp. 63–71
[14] Gentry M. (2019). Local heat, local food: Integrating vertical hydroponic farming with district heating in Sweden. Energy 2019, 174, pp. 191–197.
[15] Grusson Y., Wesstrom I., Joel A. (2019). Impact of climate change on Swedish agriculture: Growing season rain deficit and irrigation need, Agricultural Water Management, Volume 251, 106858.
[16] Gupta M. K., Ganapuram S. (2019) Vertical farming using information and communication technologies.
[17] Hartman, H.T., W.J. Flocker and A.M. Kofranck. (1981). Plant Science Growth, Development and Utilization of Cultivated Plants. Prentice–Hall, Inc. pp. 676.
[18] Jaleel CA, Manivannan P, Wahid A, Farooq M, Al–Juburi HJ, Somasundaram R, et al. (2009). Drought stress in plants: a review on morphological characteristics and pigments composition. Int J Agric Biol. 11(1): 100–105.
[19] Janick J. (1979). Horticulture Science. W.H. Freeman and Company, San Francisco. pp.608.
[20] Mekki K., Bajic E., Chaxel F., Meyer F. (2019). A comparative study of LPWAN technologies for large–scale IoT deployment, ICT express, vol. 5, no. 1, pp. 1–7.
[21] Noggle, G. R. and G. J. Fritz. (1983). Introductory Plant Physiology, 2nd Edition. Prentice–Hall Inc. Englewood Cliffs, New Jersey. pp. 625.
[22] Norris C.E., Congreves K.A. (2018). Alternative Management Practices Improve Soil Health Indices in Intensive Vegetable Cropping Systems: A Review. Front. Environ. Sci. 6:50
[23] USDA. (2015). World Agriculture Supply and Demand Estimates. U.S. Department of Agriculture.
[24] Wixted A. J., Kinnaird P., Larijani H. et.al. (2016). Evaluation of LoRa and LoRaWAN for wireless sensor networks, Sensors, 30 Oct.–3 Nov. 2016.
[25] Quan M., Liang J. (2017). The influences of four types of soil on the growth, physiological and biochemical characteristics of Lycoris aurea (L' Her.) Herb, Sci Rep. 7: 43284.
[26] *** www.libelium.com/ (accessed on April 25th, 2023).

Note: This paper was presented at ISB–INMA TEH' 2023 – International Symposium on Technologies and Technical Systems in Agriculture, Food Industry and Environment, organized by University "POLITEHNICA" of Bucuresti, Faculty of Biotechnical Systems Engineering, National Institute for Research–Development of Machines and Installations designed for Agriculture and Food Industry (INMA Bucuresti), National Research & Development Institute for Food Bioresources (IBA Bucuresti), University of Agronomic Sciences and Veterinary Medicine of Bucuresti (UASVMB), Research–Development Institute for Plant Protection – (ICDPP Bucuresti), Research and Development Institute for Processing and Marketing of the Horticultural Products (HORTING), Hydraulics and Pneumatics Research Institute (INOE 2000 IHP) and Romanian Agricultural Mechanical Engineers Society (SIMAR), in Bucuresti, ROMANIA, in 5–6 October, 2023.

ISSN: 2067–3809