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SUSTAINABLE APPROACH OF NUTRIENT FILM TECHNOLOGY BASED ON EFFICIENT WATER AND ENERGY USE - INTERMEDIATE RESULTS

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Abstract

The paper approach the greenhouse plant yield analyzing water and energy resources embedded in product when Nutrient Film Technology (NFT) is applied. Examining the process, identifying the phases, the intervening components, calibrating the model, it is possible, as intermediate results, to determine for each growth element the water and energy consumption, in order to offer solutions for reducing water, nutrients, electricity content, diminishing production costs and being environmentally friendly. The consequences are important for functional engineering of plant growth as well as for technological developments to make natural resources more efficient in a sustainable manner. The research will continue and will try to define the moment in the evolution of the culture in which harvesting is optimal from the point of view of the included resources, the resulting nutritional value, the minimum impact on the environment.

***Key words**: nutrient film technology (NFT); greenhouse plant yield; water and energy use; efficiency; sustainability.*

INTRODUCTION

Climate change as extreme phenomena, global population growth, global energy crisis related to resources or pollution, water shortages identified at certain points in time or in certain territories, all of these have major implications in the field of agriculture. General food safety, with a special emphasis on vegetables and fruits due to their beneficial effects on human health, represents the desired for which the manner of designing and managing agricultural activities needs to be adapted (Liantas et al., 2023). Improvements in horticultural breeding technologies that lead to quality, sustainable, and economically efficient products are valuable (Dobrin et al., 2018).

For the constraints listed, cultivation in protected spaces is a solution provided that it is carried out with the evaluation of the efficiency of water and energy use, the control of environmental factors (temperature, humidity, light, CO_2 concentration) imposes pressure on these two resources (Khan et al., 2018), cultivation in greenhouses being an example of horticultural practice with high quantitative and qualitative productions, which, however, involves high initial costs and during the exploitation period important consumption of water and energy.

The horticultural production (especially protected) - environment interaction is biunivocal: the resources included in the production affect the climate, it changes and alters the future conditions of plant growth; for example, waves of high and low temperatures strongly influence the operating parameters of a greenhouse because they require adaptation processes to maintain constant indoor plant growth conditions regardless of the values recorded in the external environment, such as: choosing genetic material resistant to water stress, natural ventilation for cooling and necessary humidity, the introduction of renewable energy sources, optimal exposure to light, horticultural technologies to reduce the duration of growth, etc., which would lead to sustainable options (Gruda et al., 2019). It is necessary to evaluate the efficiency of water and energy used per unit or kg of product obtained - kg product/m^3 water - WUE (water use efficiency), respectively kg of product/kWh - EUE (energy use efficiency) (Pennisi et al., 2020) as well as the impact on the general production environment in the greenhouse depending on the chosen hydroponic system, the season in which the culture is carried out, the energy mix, the temperature maintained at the plant root level and in the greenhouse atmosphere (Liantas et al., 2023).

The carbon footprint is a valuable indicator for evaluating the impact on, being able to be established for the entire process or for its components (water consumption, energy consumption). The European Commission (EU, 2021) recommends the environmental footprint in the form of PEF (Product Environmental Footprint) and OEF or EF (Organization Environmental Footprint) as a method based on LCA (Life Cycle Assessment) to quantify the environmental impact of products and organizations. For representative products and companies that have complied in determining the environmental footprint, data can be found in the EU LCA database (EPLCA, 2023). If production in greenhouses is considered the most conservative solution in terms of water use, much diminished compared to cultivation in open spaces, energy consumption represents the most important component of the environmental impact (Hirich, Choukr-Allah, 2017). Thus, according to the public data of FAO (2022), the share of CO_2-eq emissions from agri-food systems caused by energy use in 2020 in Romania was 83.1091% (FAO, 2023), the total CO_2- emissions eq from the use of energy in agriculture being 68496.7 ktons, respectively from the use of energy in farms 1647.321 ktons. By comparison, Portugal has a share of 41.3315%, with 36676.6 ktons and from energy use in farms 1256.6124 ktons, while Great Britain registers 72.5315%, with 298558.85 ktons, and from energy use in farms 2353.0178 ktons. Analyzing the variation in the share of CO_2-eq emissions in the period 2001-2020 (Figure 1), Romania had a slight upward trend, while Portugal has a strong decreasing trend, UK a slight downward trend as EU and Europe, with the specification that at the level of the EU and Europe as a whole, peaks were recorded during this period, higher than the end values, in 2011.

Although greenhouse crops are an important part of agricultural production, and this way of cultivation is very energy-intensive, there are only a few researches dedicated to this field (Paris et al., 2022), the Netherlands having a research department of Wageningen University which is dedicated to identifying solutions to reduce the dependence on gas in energy production, to reduce the amount of energy, to achieve sustainable productions, to reduce costs so that Dutch horticulture survives (Wageningen University & Research, 2020).

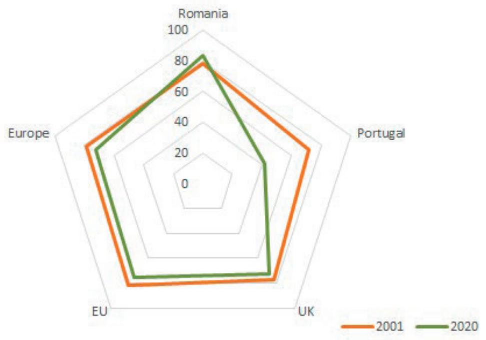

Figure 1. Share of CO_2-eq emissions for Romania, Portugal, UK, EU, Europe, years 2001 and 2020

Control includes temperature, humidity, water and fertilizer, light, CO_2 concentration, horticultural technologies leading to impressive increases in yields, up to 6 times (Paris et al., 2022). Options for greenhouse heating include air heaters, district heating through pipes, boilers, cogeneration systems, natural gas, heat pumps, with energy sources that can be based on fossil fuels, coming from the national energy system, own plants that provide both heat as well as electricity, respectively heat pumps, any combination of these variants being possible. It could be noticed that the literature consulted covers either warm areas, where cooling is the main concern, or cold areas, where, on the contrary, heating is predominant; in temperate zones, both aspects occur, making it more difficult to choose the solution and requiring temperature regulation almost throughout the year!

In order to determine the embodied energy in the case of protected crops, energy inputs from the production of fertilizers, for pumping the water-nutrient mixture, for the production of the growth support, for water recirculation, etc., are included, the age of the greenhouse being directly proportional to its consumption (Paris et al., 2022).

The elimination of energy based on fossil fuel to protect the environment and achieve a sustainable process is the subject of the European project AgroFossilFree (EU, 2020) started in October 2020 which addresses improving the efficiency of energy use; none of the scientific articles that are uploaded on the project platform on the topic of "resource conservation agriculture/energy efficiency" address the growth of horticultural products in controlled environments.

MATERIALS AND METHODS

In order to define the NFT water and energy use it is needed to identify the process stages, to establish the component activities, the flows, inputs and outputs, the influence factors and the way of estimating the weights, the definition of the functional units. The steps are:

- the choice and purchase of seeds, in this case being the Lollo Bionda and Lollo Rosa varieties from Holland Farming - 90% germination, i.e. a total of 1340 seeds for a number of 1200 germinated plants;
- planting them in pressed peat pellets 33 mm Jiffy - 1200 pieces;
- placing in the Jiffy-pot and maintaining it until the root system develops;
- replanting of seedlings with Jifyy pots in 6 troughs with NFT system from the greenhouse compartment whose dimensions are 8 m wide, 20 m long, 6.2 m height at the crest, with an area of 160 m^2 and a volume of 912 m^3;
- all plants are permanently fed with nutrient solution that is formed with 1 m^3 of water in which 10 l of nutrient solution A and 10 l of nutrient solution B are added; for nutrient solution A and the nutrient solution B the recipes at 0.25 m^3 are shown in Tabel 1.

Nutrient solutions contain different chemical compounds, each of those needed: nitrogen (nitrate, NO_3, ammonium nitrate, NH_4NO_3) is essential for leaf growth and general plant development, Potassium (Potassium oxide, K_2O, Potassium nitrate, KNO_3, Potassium sulfate, K_2SO_4) contributes to the health of the plants vascular system and helps to regulate enzymatic processes, Iron, Fe is vital for the synthesis of chlorophyll and the efficient functioning of the photosynthesis process, Mono Potassium Phosphate, KH_2PO_4 and Magnesium sulfate, $MgSO_4$ are important for cellular energy, microelements (Zinc sulfate, $ZnSO_4$, Copper sulfate, $CuSO_4$, Sodium molybdate, $MoNa_2O_4$, Borron, B) are essential for biochemical processes at the cellular level.

Tabel 1. Nutrient solutions recipes

Nutrient solution A		Nutrient solution B	
Component	Quant (kg)	Component	Quant (kg)
water	250.00	water	250.00
NO_3	18.75	KH_2PO_4	7.50
K_2O	12.50	KNO_3	12.50
NH_4NO_3	1.25	K_2SO_4	2.50
HNO_3 (1.4 kg/l; 63.7% conc)	1.59 (1.75l)	$MgSO_4$	2.50
Fe (6% conc)	6.50	KCl	1.25
		HNO_3 (1.4 kg/l; 54.6% conc)	1.37 (1.5l)
		$ZnSO_4$	$12.50.10^{-3}$
		$CuSO_4$	$10.00.10^{-3}$
		B	$5.00.10^{-3}$
		$MoNa_2O_4$	$5.00.10^{-3}$

A quantity of approx. 95 l/day is used (result as an average of a period of 3 weeks from the location - 2000 l being prepared).

- recirculation is done permanently, the pump being LOWARA SHE 32-160/22/C with a flow rate of 27 m^3/h, a variable pumping height between the minimum admissible of 18 m and the maximum admissible of 32.5 m, a power of 2.2 kW;
- the water used comes from the precipitation captured and stored in an underground tank of 100 m^3 from which it is taken with a vertical mixing pump GRUNDFOS CR 20-03 A-F-A-E-HQQE with a flow rate of 21 m^3/h, $H_{pumping\ min}$ 34.6 m, $H_{pumping\ max}$ = 43.9 m, power 4 kW; the water mixed with the nutrient solution is then transmitted to the compartment tank from where it is permanently transmitted to the gutters;
- the compartment is heated with the help of a 1162 kW power plant (serves the entire assembly, which has an area of 2756 m^2) which is fueled by methane gas; in the premises, the heat agent with a temperature of 70^0C circulates through pipes, where it reaches by using a GRUNDFOS MAGNA 32-80 180 pump with a minimum power of 10 W and a maximum of 140 W;
- the 6 troughs are divided as follows:

  2 - control - receive only nutrient;

  2 - sample 1 - they receive nutrients and are oxygenated with an air pump with 4 channels, 4 membranes and Sera Precision air 550 R plus regulation, having the characteristics: maximum 550l/h, 150 mbar, power 12 W;

  2 - sample 2 - receive nutrients, are oxygenated, are subjected to LED light max 12 h/day, depending on the lighting data provided by the meteorological station; the LED light is provided by 4 Kathay Waterproof Plant Grow

lamps with a wavelength of 380-840 nm and a power of 100 W;

- the compartment monitors the CO_2 concentration and "corrects" it by bringing it to a general constant by operating the ventilation hatches, according to the graph provided by the PRIVA software; 2 T56B4 type engines are used with a maximum power of 0.11 kW;
- to protect the crop in case of solar radiation exceeding the value of 500 W/m^2, the side curtains are automatically activated by means of a T56B4 motor with a maximum power of 0.11 kW;
- to protect the crop in case of outside temperatures lower than 5^0C, the thermal barrier type curtains are activated automatically by means of 2 tubular motors 230 W and actuation time 10 min per direction.

Tests prior to the experiments, determination of the empty operation values associated with the system, establishment of calculation relationships and correlations - prior to the experiments, the compartment was emptied, sanitized and sterilized, so as to avoid the effects on the plants generated by pathogenic factors. For this activity, 500 l and 15 l of aqueous solution with 150 ml of MEMOCLEAN disinfectant were used, the washing being carried out with a pressure washer with a power of 2.8 kW.

RESULTS AND DISCUSSIONS

The operating values are derived from the characteristics of the equipment involved, as summarized in Figure 2, analyzing every process involved in production.

The number of hours of equipment operation is shown in Figure 3, dividing the type into permanent, periodic, or occasional categories.

For preparation of nutritious materials – (approx. 95 l/zi) values listed in Tabel 2 are to be taken into consideration.

Estimation by measurement and calculation of values for water and energy consumption - The energy measuring meters were installed quite late, so that only the periods of vegetation in which the heating, administration of nutrient solution, pump were constantly used were captured of air, LED lighting and an average value of 91 kW/day was determined, of low relevance given the small number of records, to be recalculated after each week and correlated as far as possible with the growth stages of the lettuce plants.

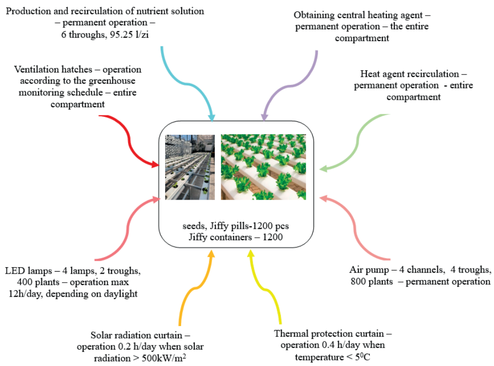

Figure 2. Embedded values in NFT system lettuce production

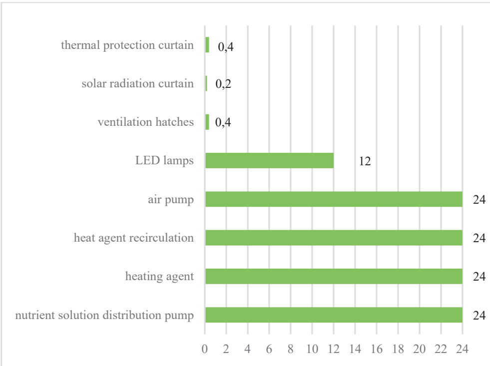

Figure 3. Equipment operation hours

Tabel 2. Nutrient solutions intake per day

Solution A		Solution B	
Component	Quant (l/day)	Component	Quant (l/day)
Water	82.00	Water	82.00
NO3	6.15	KN2PO4	2.46
K2O	4.10	KNO3	4.1
NH4NO3	0.41	K2SO4	0.82
Fe	1.968	MgSO4	0.82
HNO3	0.52234	KCl	0.41
Total	95.15034	ZnSO4	4.1
		CuSO4	0.00328
		B	0.00164
		MoNa2O4	0.00164
		HNO3	0.44772
		Total	95.6428

Regarding the calculation estimation of water and energy consumption, it is considered that:

- water for making the thermal agent is used in a closed circuit, so it is not considered
- the water for the nutrient solution is approx. 90 l/day;

- water for sanitizing the compartment before the experiment 0.5 m^3, meaning 16.67 l/day, if the value were uniformly distributed during the experiment;
- energy consumption for every activity is detailed in Figure 4.

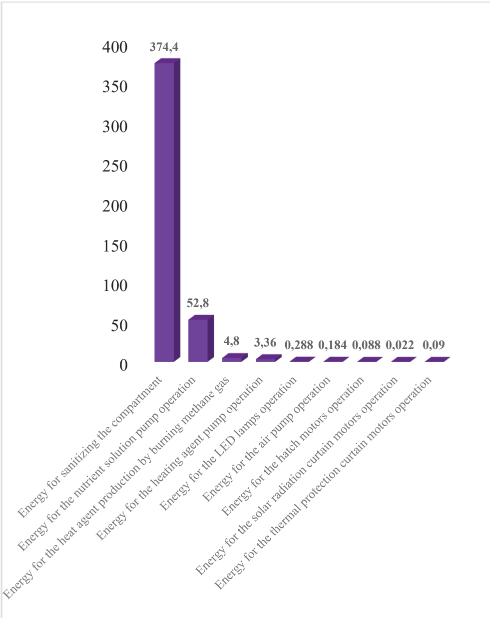

Figure 4. Energy consumption (kWh/day)

Considering that the entire amount of energy is obtained from Thermo-Electric Plants based on methane gas, at a conversion of 1 kWh * 0.2 = 1 kg CO_2 then the CO_2 emission values will result per day as in Figure 5, and for the entire experiment it is estimated of 2.616 tons CO_2 emission.
The highest CO_2 emission value comes from the heating system, followed by the system administrating the nutrient solution.
In percentage terms, 85.86% represents the heat agent production by burning methane gas and the other 12.11% the nutrient solution pump operation, only 2.03% being targeted for any other activity.
For efficiency of using energy, it could be analysed the graph in Figure 6.
It seems to be suggested that the period with the maximum efficiency of energy use is the maturity, its earlier harvesting leading to less judicious use.

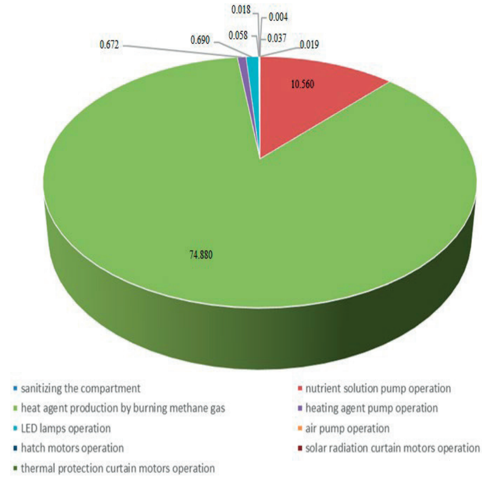

Figure 5. CO_2 emission (kg CO_2/day)

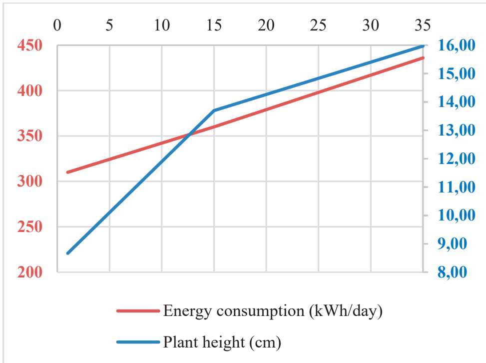

Figure 6. Energy consumption over lettuce growth in time

CONCLUSIONS

Global warming, the increase in energy demand, the change in food preferences with a preponderance of plant-based food, the increase in the incidence of obesity, all of these are arguments for augmentation of protected areas vegetable production, in a sustainable manner.
The research presents lettuce planting in NFT system of a reasonable density value, returning to 7.5 plants/m^2; the amount of energy is about and a consumption of 436 kWh and approx 95 l/day of water represents 80 ml/day.plant, and 178 m^3/ha.month, only 12% compared to classic irrigation systems in unprotected spaces or field crops, where the value is about 1500 m^3/ha month of water.

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Next research stage will adress the impact of the values in the process, the elements that lead to the highest values in correlation with the stages of development of lettuce plants in the NFT system will be followed, making the connection between the lettuce nutritional value and the efficiency of energy use, respectively plant dimensions.

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