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Hydroponic effluent as an alternative fertilizer in bell pepper production

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Abstract

As hydroponic systems expand and generate effluents, research has increasingly focused on their management due to potential environmental impacts. This study examined the effectiveness of using hydroponic effluents as fertilizer in bell pepper cultivation. The chemical composition of the effluents was analyzed and compared against water quality standards set by Resolution No. 222/02 of SEAM. The study employed two application methods (foliar and root) and three concentrations (0%, 50%, 100%) of effluents. A randomized complete block design was used to evaluate plant height, fruit number, and yield. Results showed that a 50% foliar application significantly increased plant height compared to the 100% concentration, with no significant differences in fruit number and yield. For root application, no significant differences were observed across the variables at different concentrations, although the best performance was noted at 50%. Comparative analysis between application methods revealed that root application resulted in taller plants but lower productivity. The study concludes that using hydroponic effluents as fertilizers affects bell pepper productivity, with a 50% concentration being most effective regardless of the application method.

Keywords: fertigation and foliar fertilization, liquid waste, nutrient recycling, resource optimization, seam resolution compliance

Introduction

Recently, there has been a significant increase in food production using hydroponic systems, notably Deep Flow Technique (DFT) (14%), Nutrient Film Technique (NFT) (36%), Aeroponic (8%), Ebb and Flow (3%), and other methods (13%) (Walters et al., 2020). In these systems, mineral nutrients are dissolved in water and distributed for agricultural production (Beltrano & Giménez, 2015). The efficient management of these nutrients and water is crucial, being considered the most important aspects of these technologies (Cowan et al., 2022).

The intensive use of water is a hallmark of these systems; for example, in DFT systems, it is estimated that only 35-40% of the initial nutrient solution is effectively utilized, resulting in a liquid waste of 60-65% (Maucieri et al., 2019). According to Sutton et al. (2013), over 80% of nitrogen (N) and between 25 to 75% of phosphorus (P) applied are lost, potentially causing significant environmental impacts. Cowan et al. (2022), emphasize that nutrient losses in agricultural systems can be extremely detrimental to the environment. Thus, developing appropriate strategies for the management of hydroponic waste is imperative to ensure water resource sustainability in agriculture and industry.

In Paraguay, the practice of directly discharging hydroponic effluents into the soil is common, which can lead to groundwater contamination and alter soil chemical composition, posing an environmental problem. The removal of N and P from effluents is an energy and financially intensive process, which has hindered the implementation of appropriate treatments at the national level (Karamati-Niaragh et al., 2019). A lack of knowledge about the components of the effluents is one of the main obstacles to their proper treatment and disposal. However, the nutrient-rich composition of the effluents can offer agronomic benefits when used

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as an irrigation source, potentially improving soil quality. Globally, the need to develop a circular economy that minimizes waste in agricultural systems has been widely debated (Barros et al., 2020), but national policies aimed at protecting natural resources in relation to these systems are still scarce.

Finally, the need to investigate the environmental impact of improper disposal methods for hydroponic effluents, especially due to the concentrations of N and P, is a growing concern.

In this context, the aim of this study is to assess the feasibility of using hydroponic effluents from a Nutrient Film Technique (NFT) system as an alternative fertilization source in bell pepper cultivation. Specifically, the study seeks to understand the impact of applying these effluents, through both fertigation and foliar fertilization, on soil health, water efficiency, and crop productivity. This objective addresses the need for sustainable strategies in the management of hydroponic effluents, aiming to minimize environmental impacts and enhance resource utilization efficiency in agricultural systems.

Material and Methods

The study was conducted at the Faculty of Agronomic Engineering of the National University of the East, Paraguay, from September 2020 to January 2021. The region, characterized by a subtropical climate, has an average annual precipitation ranging from 1700mm to 1800mm, a monthly average of 149.6mm, and an annual average temperature of 22.3˚C, according to DINAC (2020). The local soil was classified as Oxisol with a clay loam texture.

Initially, a soil analysis was carried out to determine its chemical characteristics before the start of the experiment. This analysis was conducted by the Soil Laboratory of the Faculty of Agronomic Engineering, and the results are presented in **Table 1**, detailing the soil's chemical characteristics in the 0-0.20m layer.

For plant preparation, bell pepper seeds of the cascadura ikeda variety were sown in almacigo with organic substrate. This procedure aimed at the germination, emergence, and development of seedlings. Once they reached the vegetative development of four true leaves, the seedlings were transplanted to their final location, each experimental plot consisting of six pots, each containing 20Kg of soil.

The experimental design adopted was a randomized complete block with a factorial arrangement. Two study factors were established: Factor A, with two methods of application (foliar and root) and Factor B, with three dosages (0%, 50%, and 100%), each with four repetitions.

After the plants were installed, they were watered with running water for 14 days. From the 15th day post-transplant, the application of treatments with hydroponic effluents began, continuing until harvest. Water supply in the root application treatments was carried out until reaching field capacity, maintaining the same amount of water for all plots. For the foliar application treatments, a hand sprayer was used, supplying the water needs of the plants with running water.

Concurrently, an analysis of the chemical composition of the hydroponic effluent was conducted by the Food and Environment Control Laboratory, EcoNatura, in Asunción. The aim was to estimate the elements present in the effluent.

During the experimental period, daily monitoring of the plants was carried out until harvest. The variables evaluated included plant height (PH), number of fruits per plant (NFP), and yield (YLD), the latter being measured by the weight of the fruits from the first harvest in Kg. ha^{-1}.

Finally, the collected data were subjected to an analysis of variance (ANOVA) and mean comparisons by the Tukey test at 5%. This statistical analysis was performed using the Project RStudio software, 2019.

Results and Discussion

The chemical analysis of the hydroponic effluent, as presented in **Table 2**, revealed that the levels of phosphorus (P) and zinc (Zn) exceed the reference values established by Resolution No. 222/02 of the Secretariat of the Environment (SEAM) of Paraguay. This resolution defines the maximum permitted levels of these elements. While the excess of these elements is notable, the presence of copper (Cu), manganese (Mn), and iron (Fe) is essential for the proper development of plants.

Cowan et al. (2022) reported a 45% increase in P concentrations and 54% in NO_3 at the end of the cultivation cycle. Cade-Menun et al. (2017) highlight the importance of P for the growth, development, and health of plants. González et al. (2018) affirm that Zn is an essential micronutrient, with roles in protein synthesis,

Table 1. Chemical characteristics of the soil evaluated in the 0-0.20m layer.

Year	OM	pH	K	Ca	Mg	H+Al	Al	CTC	V
	gdm^{-3}	$CaCl_2$	-------	------	$mmolcdm^{-3}$	--------	-------	------	(%)
2020	1.97	0.00	0.33	4.83	1.52	5.35	0.45		55.53

Table 2. Chemical nutritional quantification of the hydroponic effluent from a DFT system:

Nutrients	Results	Reference value
Cuper (Cu)	0.08mg/L	1mg/L
Manganese (Mn)	0.59mg/L	SR**
Phosporous (P)	26mg/L	4mg/L
Total Iron (Fe)	1mg/L	SR**
Zinc (Zn)	0.14mg/L	5mg.L
pH	6.2	6.0-9.0

Reference taken from Resolution No. 222/02 issued by the Secretary of the Environment, which establishes the water quality standards in the national territory. Art. 7°. **SR: No Reference

chlorophyll formation, and starch-to-sugar conversion. Djurić et al. (2012) state that Cu and manganese (Mg) are vital for photosynthetic processes, directly affecting fruit yield and quality.

Hydroponic nutrient solutions primarily contain nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), iron (Fe), boron (B), copper (Cu), manganese (Mn), and zinc (Zn) (Kumar & Cho, 2014). The issue with hydroponic effluents is the need for periodic replenishment of the nutrient solution, generating effluents rich in N and P, which, if improperly discarded, can cause significant environmental contamination (Bertoldi et al., 2009).

The role of these elements found in the hydroponic effluent and their effect on plant height (PH), fruit number (FN), and yield (YLD) can be observed in **Table 3.** Considering the percentages of the doses used, there were no statistically significant differences for the variables of fruit number and yield when the treatment was applied foliarly in the three tested doses. Similarly, when the application was root-wise, no significant differences were observed in the three variables.

Table 3. Hydroponic effluents applied foliarly and radicularly with different doses (0, 50, and 100%), and their effect on plant height (PH), number of fruits per plant (FN), and yield (YLD $Kg.ha^{-1}$):

	Foliar			Root		
Dosis (%)	PH	FN^{ns}	YLD^{ns}	PH^{ns}	FN^{ns}	YLD^{ns}
0	36.5ab	3	0.448	36.2	3	0.43
50	40.0a	4	0.460	43.0	2	0.42
100	33.5b	3	0.375	42.8	5	0.29

Significant for the Tukey test at 5%. ^{ns} not significant

Sediyama et al. (2014), found that productivity was not affected by different fertilizer doses in bell pepper cultivation. Araújo et al. (2007), observed that with the presence of biofertilizers applied to the soil, an increase in dosage led to increased fruit productivity. Notably, for the variable of plant height (PH) in foliar application, statistical differences were observed where a 50% dose of hydroponic effluent presented a greater plant height compared to other treatments, showing a difference of 6.5 cm compared to the treatment using a 100% effluent dose. Sediyama et al. (2014), obtained greater plant development at higher doses with fertilizer characteristics of Cu=1.41 mgL^{-1}, Mn=1.62 mgL^{-1}, P= 164.65 mgL^{-1}, Zn=10.24 mgL^{-1}, and pH=6.72. In contrast to our findings, the higher effluent dose showed a lower plant height compared to the other doses.

The direct use of effluent on the plants affected their development and production in bell pepper cultivation due to the high content of P in the effluent used in the study. This aligns with Hegazi et al. (2017), who observed that plant height was impacted by the P content, as P is involved in key plant functions such as cell division, energy storage and transfer, photosynthesis, enzyme regulation, and nutrient transport (Taiz et al., 2015).

When the methods of application (foliar and root) were analyzed independently (**Table 4**), significant differences were observed in plant height (PH). Root application showed a greater plant height compared to foliar application, but this did not increase yield. For the variables of fruit number per plant (FN) and yield (YLD $Kg.ha^{-1}$), no significant differences were observed between the methods of application. This could be due to P's active role in protein synthesis, where deficiency leads to reduced growth (Novoa et al., 2018), and excess P can lead to early fruit maturation and reduced yield, as P is essential in plant energy metabolism (Wei et al., 2020).

Table 4. Average values of plant height (PH), number of fruits per plant (FN), and yield (YLD $Kg.ha^{-1}$) in relation to the method of application (foliar and root):

Aplication	PH	FN^{ns}	YLD^{ns}
Foliar	36.66b	3	0.42
Root	40.66a	3	0.38

Significant for the Tukey test at 5%. ^{ns} not significant

Aguilera-Acuña et al. (2006), showed that P's mobility is very low, affecting its efficiency when applied through a drip system, leading to differences in plant height between foliar and root applications. Thus, root application positively influenced plant development for this variable. Oliveira et al. (2004), demonstrated the importance of using high doses of fertilizers, regardless of the application method, to meet the nutrient demand of bell pepper crops and enhance their reproductive and productive capacity. This information aligns with our results, as higher concentrations of hydroponic effluent in different application methods yielded greater productivity.

There is a strong connection between nutrient absorption and plant development, with yield being extremely dependent on this association and the movement of nutrients within the plant. While in intensive agriculture, the main source of fertilization is often organic for its long-term economic and chemical benefits, mineral fertilization becomes necessary as it is readily available to ensure proper initial plant development (Sediyama, 2014). Hydroponics fully utilizes mineral sources to provide nutrients to plants, with the minerals present in the effluent being highly soluble, explaining the significant differences in yield from the first production period.

While fertilization is an indispensable activity in crop fields to obtain high yields, Ribeiro et al. (2000), state that it represents, on average, 23.4% of the total production cost. The use of hydroponic effluents as alternative fertilizers can be considered at a national level. In addition to allocating hydroponic waste to a profitable activity, it is economically viable as it does not incur extra expenses and positively influences the yield of bell pepper cultivation. Moreover, it is environmentally friendly, as it does not violate the water quality parameters within the national territory established by Resolution No. 222/02 issued by the SEAM.

In conclusion, this study demonstrates that despite some limitations, the use of hydroponic effluents in bell pepper cultivation can be an effective strategy for optimizing resource use and minimizing environmental impact. This aligns with the principles of sustainable agriculture and responsible waste management, addressing both economic viability and environmental stewardship in agricultural practices.

Conclusions

The hydroponic effluent generated in hydroponic crop production requires careful disposal due to its concentrated nutrient content. This study suggests the potential for its reuse in bell pepper cultivation, especially when applied at a 50% dose via root application. Such a practice does not adversely affect yield parameters and offers an environmentally sustainable solution. Reutilizing these effluents not only mitigates the risks associated with direct soil disposal but also aligns with sustainable agricultural practices by reducing waste and enhancing resource efficiency. This approach contributes to the broader goal of minimizing the environmental footprint of hydroponic systems while maintaining agricultural productivity.

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