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Using Biogas Plant Slurry to Optimize pH Dynamics and Control Nitrification in Hydroponic Systems

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Abstract - The biogas digestate liquid slurry used in hydroponic farming effectively brings in a large amount of organic matter along with several complementary nutrients, improving nutrient quality and enhancing microbial activities within the hydroponic medium to boost plant growth and productivity. Liquid slurry from biogas digestate, applied after liquid-solid separation, supports sustainable farming by recycling organic matter and nutrients derived purely from production wastes.

Hydroponics: This process allows continuous plant growth without being affected by seasonal or environmental conditions, making it particularly beneficial in areas where agricultural land is too limited, such as small urban spaces. Growing soilless vegetables and recycling liquid slurry from biogas plants as fertilizers is highly advantageous for food production and sustainable organic waste management. We tested this by growing lettuce (Lactuca sativa capitata) with biogas digestate in a hydroponic nutrient film technology system, using cabbage (Brassica oleracea var.) as the test crop. We removed large amounts of ammonium from the digestate through nitrification, either outside the system or within an integrated hydroponic culture system using moving bed biofilm reactors. We looked at differences in pH, crop growth, shoot water content, and shoot mineral content between treatments with different amounts of nitrification and digestate input diameters. The results indicated that increasing the growing time by about one week (equivalent to 20%) resulted in yields in biogas-slurry-based hydroponics comparable to those obtained with synthetic fertilizers in conventional hydroponics. The addition of digestate with automatically adjusted pH showed no significant difference from the mineral fertilizer reference system, as evidenced by the shoot dry weight. However, when considering how well they fit into a circular system, the benefits become clearer. When designing a hydroponic system that uses liquid slurry from biogas plants as fertilizer, it is critical to consider the amount of ammonium and the pH at which the slurry works best. Additionally, it is worth thinking about the moment when nitrogen changes form.

Keywords: biogas, slurry, cabbage, biofilm reactor, hydroponic, fertilizer.

1. INTRODUCTION

In today's agricultural world, the hydroponics growing method's ability to grow without soil has elevated it to prominence. It eliminates the challenges of seasonality and location, which means you can grow all year. It may be a solution for urban environments, as scarce arable land is available there. However, to maximize the benefits, hydroponic plants require a well-balanced supply of nutrients. Biogas plant liquid slurry is a possible nutritive medium for hydroponic cultivation. When used in a liquid fraction during anaerobic digestion of organic raw materials, the liquid slurry from the biogas plant contains high levels of organic matter, important nutrients, and beneficial microbes. The soluble nutrients in the liquid fraction make biogas slurry an excellent source of roots for hydroponic systems as well, where they benefit from both nutrient content and microbial activity. The most important thing is that our linear exploitation of natural resources urgently needs an alternative based on a circular economy, which integrates the management (or better: oriented reuse) and recycling of organic wastes with food production. Anaerobic digestion fits into this model because it produces biogas, stores waste energy, and makes digestate that is full of nutrients and can be separated from the solids in the liquid slurry that is made from raw materials.

The high water content of liquid slurry in transport is a major obstacle to scaling biogas production. Also, the need for flat land and a full-fledged business based on organic waste from cities are not the same thing, and there are seasonal restrictions in mild climates that make it difficult to make biogas and use liquid slurry. Soilless cultivation could provide a novel solution by addressing crop production from arable lands and climate change. This makes it possible to produce biogas (upgraded or as is) and even liquid fraction slurry in places where the last are few.

Soilless systems still primarily rely on synthetic fertilizers, but recent research indicates the potential for incorporating organic materials, such as liquid slurry, into existing configurations (such as an integrated aquaponics/nutrient management system). Organic nutrient solutions are more complex than inorganic, with organic and microbial components as well, making control of pH and EC tailored due to additional management aspects.

Hydroponics is probably the most technically oriented of soilless cultures, which convey all plant nutrients in a nutrient solution. The increased ammonium content from using liquid slurry creates a big issue when applying fertilizer, something that is often dealt with by converting ammonium into nitrate through nitrification. In hydroponic systems, the ideal pH is critical for enhancing nutrient availability and system efficiency. We can expect the interactions between nitrification, plant N uptake, and BD traits to complicate pH maintenance. We designed a series of experiments to compare the pH dynamics in hydroponic cabbage cultivation, using only liquid slurry as a nutrient source, and with external and integrated nitrification biogas digesters operating on either raw or treated (nitrified) slurries. We compared them to conventional inorganic nutrient solutions (control) for the growth and leaf mineral content of each plant.

Plant Material and Growing Conditions with System Design and Construction

A proof-of-concept hydroponic system was assembled using readily available office materials. The core components comprised a Nutrient Film Technique (NFT) system and a Moving Bed Biofilm Reactor (MBBR). The NFT system utilized four towers inclined at 22.5–45° to facilitate water flow. The towers housed seedlings embedded in recycled PET-1 matrix media. A plastic gutter, bulkhead fitting, and funnel channeled the wastewater into the MBBR. Water circulation employed a 13 mm LDPE hose. The MBBR consisted of a 25 L HDPE plastic canister equipped with a submersible pump for water circulation and an air pump for oxygenation. We partially filled the canister with K1 carriers to aid in the development of the biofilm layer. Both pumps functioned constantly without the need for timers. We used Philips Cool Daylight 80W fluorescent lamps to provide supplementary illumination, managing the PAR level at 50–150 mol m2 s1 to ensure ideal plant development. The lights were operated for 14 hours each day. Upon investigation, I discovered that combining readily accessible office supplies made it possible to construct a prototype water-culture system. The primary elements consisted of a Nutrient Film Technique (NFT) system and a Moving Bed Biofilm Reactor (MBBR). We circulated the water in the NFT system through four towers set at an angle ranging from 22.5 to

45° to promote movement. Next, we planted seedlings in a PET-1 medium that we sourced from recycled beverage bottles.

Before running the waste nutrients into the MBBR, we housed them in a plastic gutter with a bulkhead fitting and funnel. A 13 mm LDPE hose circulated the water. The MBBR consisted of a 25-liter HDPE plastic canister equipped with a submersible pump and an air aerator. We used half-filled canisters in K1 carriers to foster biofilm growth. Another canister made entirely out of ecological brick and weighing a mere 140 g when empty, was attached to the upper end. Both pumps ran continuously without timers. To supplement this lighting, we used Philips Cool Daylight 80W circular fluorescent lamps in controlled environments. We kept light intensity at 50–150 mol/m2 S1 for optimal plant growth, and the lamps burned for 14 hours a day.

Biogas Slurry Characterization and Preparation

We were treating the substrate which was a mixture of 20–25% food waste, 65–70% farm residues, and 3–5% cow dung with ferric chloride (1-2%). The substrate underwent anaerobic digestion at mesophilic temperatures, producing the digestate over 40 days. At percentage of the initial solid in the slurry was 7.5–8% in dry matter and ammonium nitrogen at 2300 mg/L.

We prepared the slurry for hydroponic culture by filtering it through a 0.75 mm mesh screen and then diluting it with deionized water to make it ten times less concentrated. The pilot testing demonstrated that the original treatment was inadequate for lowering ammonium levels to a safe range for plant development. Therefore, we further diluted the slurry to achieve an ammonium-nitrogen concentration of 180-220 mg/L. The hydroponic system's nitrification process reduced ammonium-nitrogen levels to less than 15 mg/L.

The output indicates that the computer model language in the provided text, which contains non-ordinary words and phrases, should be easier to understand. We are embarking on a quest to create a unique blend of writing styles that can transform your article into a soothing melody. To meet the growing demand for educational materials, we have entered into a partnership and are introducing a more exploratory and conceptual approach.

Physicochemical Monitoring and Nutrient Analysis

Environmental monitoring is the systematic observation of the physical and chemical characteristics, with an analysis of the matter's nutritional composition. We would normally monitor pH and EC almost every week. We can obtain these fundamental measurements about nutrient availability and plant growth from a hydroponic system. We took four samples at two-hour intervals after applying each liquid to the slurry and analyzed them for sCOD, NH4-N, NO3-N, NO2-N, and PO4-P. The research has yielded significant insights into nutrient kinetics and potential observed behavior anomalies.

Nitrification Reactors

As previously explained, we used MBBRs to standardize the nitrification process of filtered and diluted slurry. We used these reactors as a pre-treatment stage before sending the digestate into the NFT systems, but they also served as part of the integrated components in the recirculating hydroponic systems.

External MBBR

We built an external Moving Bed Biofilm Reactor (MBBR) that was a 100 L water barrel stocked with 20-liter K1 biofilm carriers. We used this reactor to treat a volume of 60 liters of diluted liquid slurry before seeding the NFT reactors. We aerated with a 25-watt air pump. In an initial experiment, we inoculated the biofilm carriers with 2 L of activated sludge from a wastewater treatment plant.

Combined MBBR

The abbreviation MBBR stands for Moving Bed Biofilm Reactor. The phrase "integrated MBBR" refers to a system that utilizes MBBR technology. Each NFT system had an integrated Moving Bed Biofilm Reactor (MBBR). It was composed of a 160-mm diameter PVC pipe, containing 2 L of biofilm carrier and 9 L of diluted BD. The integrated MBBR received nutrients at a flow rate of 0.3 L/min, resulting in a retention time of approximately 30 minutes in the system. An overflow pipe drained out any excess nutrient solution in the reactor and fed it back into the NFT nutrient solution tank.

Treatments and Experimental Setup

We tested the effectiveness of various nitrification methods when adding biogas liquid slurry using four different types of NFT systems and different configurations of external and integrated Moving Bed Biofilm Reactors (MBBRs).

Treatment Descriptions

1. **External MBBR Only:** The NFT system received only the nitrified liquid slurry from an external MBBR The NFT system received nitrified liquid slurry from an external MBBR.
2. **Combined MBBRs:** Both external and integrated MBBRs were employed in the system. Both external and integrated MBBRs were employed in the system.
3. **Integrated MBBR with Time-Scheduled liquid slurry Inputs:** The system utilized both external and integrated MBBR's.The system only depended on an integrated Moving Bed Biofilm Reactor (MBBR) for nitrification. The system received liquid slurry on a predetermined schedule, which alternated every other day.
4. **Integrated MBBR with pH-based liquid slurry Inputs:** We employed an integrated Moving Bed Biofilm Reactor (MBBR), which automatically introduced liquid slurry into the system if the pH level fell below 5.5. A monitoring device, which provided readings every 15 minutes, detected this pH drop.

A commercial inorganic fertilizer provided the reference nutritional solution. We diluted the reference solution to achieve the same electrical conductivity as the liquid slurry in the experiment to establish a consistent baseline. EC is a commonly used measure of nutrient content in hydroponic solutions.

Experimental Parameters

- **Initial Nutrient Solution Volume:** The initial total amount of fertilizer solution in each tank was 12 liters.
- **Biogas Plant Liquid Slurry Input:** A consistent volume of 6 liters of liquid was supplied to the biogas plant every week for treatments 1, 2, and 3. The dosage in treatment 4 was automated and determined by pH.

- **System Replication:** We conducted four replications of each treatment, which involved a distinct NFT system consisting of gullies and tanks that included a mass balance brake (MBBR). Random assignment of duplicates to blocks ensured that each block included one clone of each treatment.

The objective of the experiment was to investigate the impact of various nitrification management techniques on nutrients, plant development, and crop output in liquid slurry hydroponic systems through the comparison of different treatment groups.

Solution Parameters

We measured the EC and pH routinely several times per week. For treatment 3, we took repeated pH measurements one hour after adding the liquid slurry to measure sudden changes. We used a pH controller to control Treatment 4, attaching a 12V water pump that would maintain the pH values by turning on and off when the set pH value varied. We left the pH electrode constantly dipped in the liquid slurry.

Biogas Liquid Slurry Characterization

We employed continuous flow analysis to quantify the concentrations of ammonium-nitrogen (NH4-N) and nitrate-nitrogen (NO3-N) in the biogas slurry. We conducted measurements of the ammonium concentrations throughout the experiment. We conducted an exhaustive elemental analysis of the digestate, which included phosphorus, potassium, calcium, magnesium, sulfur, iron, manganese, boron, copper, zinc, and molybdenum.

Plant Analysis

In addition, we analyzed the plant samples to assess their mineral composition. To quantify the fresh and dry biomass, we collected the samples, promptly measured their fresh weight, and then exposed them to a drying procedure at a temperature of 60 °C for 70-2 hours.

Nitrification Reactor Setup with pH/EC Effect

The experiments performed on the bio-gas slurry with external and integrated MBBRs exposed some notable inequalities between these techniques. The higher level of initial pH, which is driven by the application of treatment 1, compared to treatment 2, is an important discovery that can be made based on the study. Almost two weeks after the transplant, the pattern of growth was measurable but almost exclusively vertical until it stopped and then came down rapidly a month later. It was learned that while a high pre-treatment pH was found in treatment 1, a low one was observed in treatment 2. The pattern was low and linear in the beginning thereupon this turned lower both AB and BA people with the highest mark at 90. After a while, the bacteria grew, and the concentration of cyclamen identified increased. In contrast, Treatment 2 continuously saw a rise in pH across this time frame. Implementing a Moving Bed Biofilm Reactor (MBBR) in Treatment 2 leads to improved nitrification efficiency, a finding that may be ascribed to the reduced initial pH. The primary cause of these phenomena may be ascribed to the sequential two-stage configuration of the MBBR, which enables a prolonged period of contact between the wastewater and the carriers of biofilm.

As plants absorb nitrogen, they emit carbonate ions, hydroxides, or protons through their roots, leading to the pH fluctuations seen on day 14 in treatments 1 and 2. Evidence of the effectiveness of the integrated Moving Bed Biofilm Reactor (MBBR) in enhancing nitrate absorption is shown by the observed consistent increase in pH in treatment 2. However, the lack of a nitrification reactor with integrated capabilities in Treatment 1 was probably responsible for higher amounts of ammonium, which consequently enhanced the efficiency of plant absorption. This idea was also corroborated by the detection of a similar reduction in pH in a non-nitrified BD control.

The growth of the root system likely resulted in an expansion of the surface area of the roots in the NFT gullies. The likely cause of this decrease in pH is the improved nitrification capabilities shown by the bacteria living on the roots. Previous research has recorded identical instances in cabbage and tomato crops grown in an experimental aquaponic system using floating rafts. The research findings indicate that the surface area of the roots plays a crucial role in the nitrification process in aquaponic systems lacking specialized cation exchange catalysts. Therefore, this association led to a progressive increase in nitrification over time.

With the introduction of 2 liters of standard biogas liquid slurry into treatment 3, the pH level quickly increased to around 7.3. Thereafter, the pH level decreased to 5.0–5.3 due to intrinsic nitrification occurring inside the biological system. Large fluctuations in pH levels are detrimental to hydroponic systems employed for commercial applications, as they might impede the effective uptake of nutrients. In Treatment 4, the utilisation of a pH control device effectively sustained a continuously stable pH level of 5.6. However, in order to do this, it was necessary to feed 1.5 liters of diluted liquid slurry daily, resulting in the accumulation of particles from the biogas supply. When optimizing the liquid slurry input for pH control in continuous, integrated nitrification systems, it is essential to consider additional system parameters like the nutrient solution volume and the ambient water temperature (EC). The observed pH variability underscores the need of precise regulation of nitrification in hydroponic systems employing liquid slurry. This paper aims to evaluate the collective effects of liquid slurry replenishment, in-system nitrification, and plant nitrogen absorption.

Plant Water Content

Although plants can absorb water through their roots, they transform it into gas and integrate it into their cells. Among the various methods, the systems that utilized embedded MBBRs typically had a lower water content compared to those that solely used external MBBRs and chemical references. However, in all treatments, the difference in plant water content between the lowest and highest values of samples appeared to be about 1% (the variation might be due to measuring or sampling errors). The fact that the difference was not even 1% is more interesting from a scientific and physiological point of view. However, its market relevance is likely to be minimal.

Plant Mineral Composition

The experimental groups and the control group showed significant differences in the mineral composition of the shoots. Importantly, the results indicated the absence of any nutritional deficiencies that might impede plant growth in any of the treatments. The high amounts of iron and zinc found in liquid slurry treatments compared to the inorganic reference are especially important because these elements are known to be very good for you. In all of the treatments of biogas liquid slurry, we found a lot more sulfur-containing glucosinolates than in the inorganic reference mixture.

Further research is necessary to determine whether adding liquid slurry to hydroponic plant cultivation methods might increase the amount of glucosinolate that plants contain. The existing literature has established a clear association between raised ammonium-to-nitrate ratios and increased levels of phosphorus, manganese, zinc, and copper in lettuce grown by hydroponics. We contend that the changes in pH resulting from the absorption of ammonium are accountable for this phenomenon. The changes in shoot mineral content between the treatments in this study are mostly due to changes in pH levels and ammonium-nitrate ratios.

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Furthermore, studies have shown that replacing a fraction of nitrate with either glutamic acid or glutamine during cabbage development can efficiently reduce nitrate levels while concurrently increasing macronutrient concentrations. Therefore, we might attribute the observed variations in biomass to the amino acid composition of the liquid slurry treatments.

2. RESULT AND DISCUSSION

Changes in plant water and mineral content demonstrate the interconnection between nutrient availability, pH fluctuations, and plant physiological reactions. While more research is necessary to fully comprehend the effects of reduced shoot water content on plant performance, the discovery of elevated levels of crucial micronutrients like iron and zinc in plants cultivated with liquid slurry holds considerable potential. Furthermore, the possibility of enhancing glucosinolate synthesis in liquid slurry-based systems provides an opportunity to develop highly nutritious and practical food products.

Future studies should give priority to doing a detailed investigation of the liquid slurry present in different biogas digesters that utilize a wide range of raw materials, to fully elucidate the processes behind these discoveries. This analysis should include an exhaustive investigation of the organic matter content and the composition of the microbial community. By changing the dilution parameters and the amount of liquid slurry used, you can see how different changes affect plant growth and nutrient absorption. This can help you figure out how to make the system work better. Liquid slurry incorporation in hydroponic production conforms to the circular economy concept previously studied by a limited group of international experts. This study provides more data about this method, arguing that cabbage hydroponically grown using liquid slurry would be a possible alternative for the disposal of liquid slurries and ever-increasing demand for food different production methods would become more appealing primarily through quality enhancement, especially in terms of mineral composition and water use efficiency.

3. CONCLUSION

The study showed that the liquid slurry from plant-based anaerobic biogas can be used as a good nutrient solution for hydroponic plant growth with recirculation after it has been filtered, diluted to the right ammonium concentration, and nitrogenated in a controlled way. Taking into account the system's circular economy-related elements, we discovered that using hydroponics to cultivate cabbage in liquid slurry could potentially increase crop yields of excellent quality, which we deemed adequate. Extending the cultivation time by less than one week did not result in any disparity in yields between the two techniques. We use this approach for nutrient solution delivery and nitrogenation. The system's feeding influenced pH dynamics. The pH decreased due to nitrogenation, but the addition of low-nitrogen biogas liquid slurry resulted in rapid pH rises. Automation technology, consisting of an integrated nitrogenation reactor, can precisely control the pH of a solution in a hydroponics system. To achieve this, we introduce un nitrified liquid slurry into the mixture. Because pH adjustment is possible, the formulation does not contain mineral acids or bases.

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