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Method of Up-cycled Non-Circulating Hydroponics (MUNCH): A proof-of-concept experiment with Passive Organic Hydroponics using JADAM Liquid Fertilizer

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Abstract

Traditional mineral hydroponic solutions are resource intensive and energy demanding, so there is an interest to find more sustainable alternatives of nutrient sources for soilless cultivation. JADAM Liquid Fertilizer (JLF) provides a sustainable method for organic waste conversion to nutrient delivery in soil cultivation systems. However, its application in soilless cultivation systems remains unexplored, presenting a novel area for investigation.

This report details two experiments that utilized JLF prepared over six months from a mixture of 50L water and 50L of raised bed vegetable waste, primarily from tomato and cucumber plants. These experiments were conducted in Lund, Sweden between June 2023 and November 2023. The first experiment involved Big Leaf Basil grown in beach sand media, and Micro-Dwarf Tomato grown in a coco and perlite mix of substrate, both using the Kratky (passive hydroponic) method. The second experiment used Deep Water Culture (DWC) with the same basil species, also using the Kratky method. The outcomes in both setups were analyzed to determine the efficacy of JLF in hydroponic systems, with the clear advantage going to media-based systems.

Keywords: hydroponics, bioponics, JADAM, JLF, MUNCH, organic waste

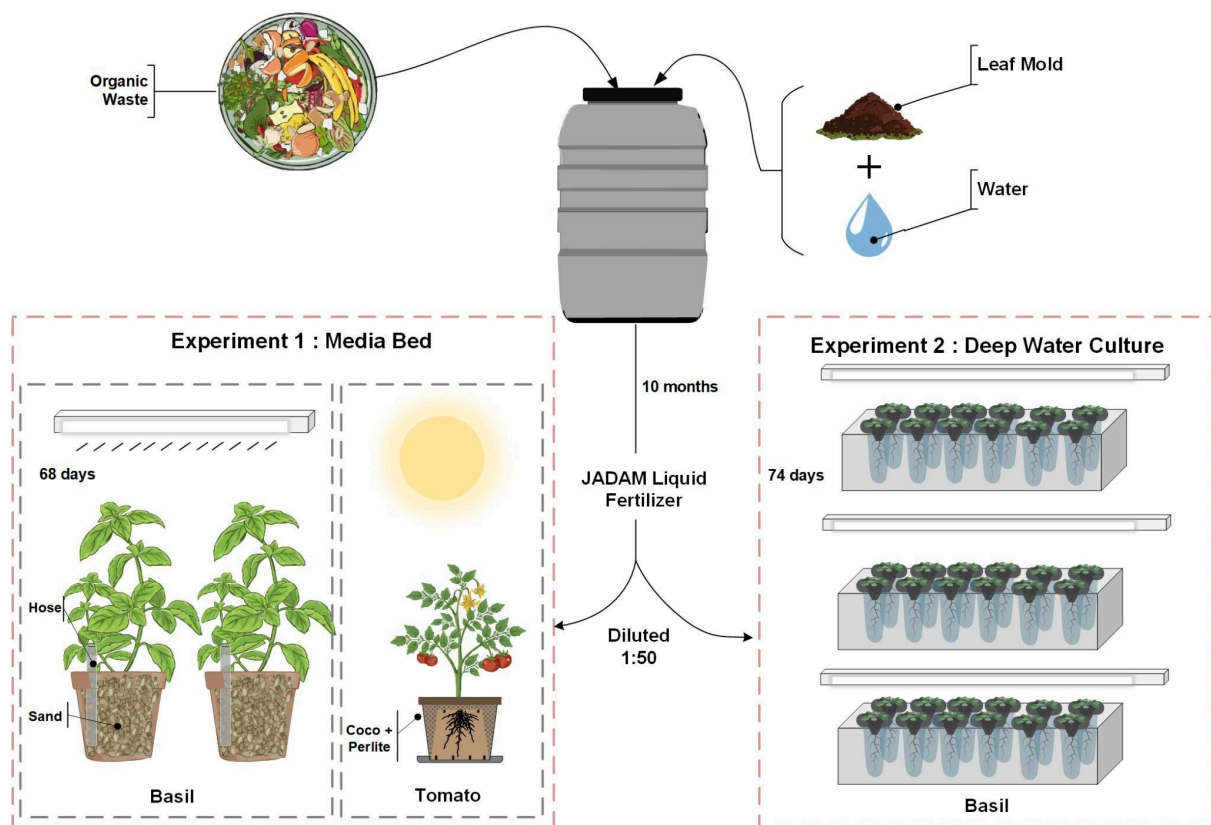


Figure 1: Graphical Abstract, courtesy of Akarsh Swamilingappa Annaiah

1. Background

Current mineral based hydroponic solutions provide great control in soilless cultivation, and great optimization at the different stages of growth for a variety of plants. However, they have raised sustainability concerns as they are resource intensive, energy demanding, and extractive, while also producing a lot of waste. The activities involved in the production of mineral based hydroponic solutions include: mining, ore treatment, chemical processing, and transportation. The whole process requires fossil fuels, electricity, chemicals, and water, to produce the nutrient solution. On the other hand, mining waste, greenhouse gases, and wastewater are also produced as a consequence (Dumitrescu, 2013).

The Kratky method is a well-documented way to grow hydroponically without the need for water recirculation or aeration. This method involves preparing a full-strength nutrient solution and allowing its absorption to create a moist-rich air space. In this space, so-called air-roots develop, preventing the formation of root-rot and bypassing the need for air pumps (Kratky, 2009). Typical hydroponic cultivation also requires active energy use, in the form of electricity, for processes such as water recirculation or water aeration (Barbosa et al., 2015). Organic alternatives such as aquaponics, biaponics, and anthroponics, while improving the sustainability in terms of nutrient sourcing, also require energy in the form of electricity for water and/or air pumping in order to stimulate aerobic microorganisms, that convert complex organic compounds into plant-available compounds (Somerville et al., 2014). However, the use of this method with organic hydroponics typically leads to root rot, or incomplete nutrient uptake, as the lack of air and oxygen prevent certain aerobic metabolic processes, necessary for creating plant-available nutrients, from occurring (Stouvenakers et al., 2019).

The old Korean method known as JADAM Liquid Fertilizer (JLF), traditionally used for organic soil farming, offers a more sustainable potential by repurposing plant waste into nutrient-rich solutions in a purely anaerobic process (i.e partial anaerobic digestion). Anaerobic digestion is a biochemical process that converts organic matter into biogas and digestate through four sequential stages: hydrolysis, acidogenesis, acetogenesis, and methanogenesis:

1. Hydrolysis: Complex organic polymers are decomposed into simpler monomers by hydrolytic enzymes.
2. Acidogenesis: Acidogenic bacteria convert the resulting monomers into volatile fatty acids, alcohols, hydrogen, and carbon dioxide.
3. Acetogenesis: Acetogenic bacteria transform the volatile fatty acids and alcohols into acetic acid, hydrogen, and carbon dioxide.
4. Methanogenesis: Methanogenic archaea convert acetic acid, hydrogen, and carbon dioxide into methane and carbon dioxide, producing biogas.

For JLF preparation, organic garden waste such as leaves, stems, roots, flowers, and/or moldy fruit are added to a plastic container and fully submerged in tap or rainwater, with an additional inoculation of local leaf mold, and kept closed but not sealed over a period of weeks to months, with occasional manual stirring. The resulting liquid is filtered from remaining solids, diluted with tap or rainwater, and applied directly to the soil via normal

watering routines, or to plant leaves via spraying, thus enriching or amending the soil by returning nutrients to it (Cho, 2012).

Based on its successful application in soil cultivation, it was hypothesized that JADAM Liquid Fertilizer would contain sufficient plant-available nutrients to support vegetative growth in a soilless setting. This study aimed to test this hypothesis by careful system design to allow its use in a passive method such as the Kratky method. If successful, a new passive organic hydroponic method could be developed, allowing for the creation of soilless liquid fertilizer *in situ* from waste materials, and without needing access to electricity, enabling the sustainable cultivation of fresh produce in remote areas.

2. Materials & Methods

The experiment took place at the temporary location of PonicLabs in Lund, Sweden. PonicLabs is an enterprise focused on developing sustainable hydroponics methods, designs, techniques, and processes.

The experimental set-up was located in a testing room without any source of natural light. Two separate experiments were conducted:

1. The "Media Bed experiment" took place in a Secret Jardin Dark Propagator DP120 Grow Tent. This tent had dimensions of 120x60x120cm, featuring a smaller space above and a larger space below. There was an additional smaller experiment conducted outdoors in a balcony;
2. The "DWC experiment" was conducted in an IKEA ALGOT shelf unit. This unit measured 200x40x83cm and had 3 installed shelves.



Figure 2: Experimental set-up showing the Media Bed experiment with the buckets, sand, and hoses. Note that only the two buckets closest to the camera were used for the experiment. Photo taken on 2023-06-28.

The "Media Bed experiment" consisted of two 12 L polypropylene buckets containing ~8 L of beach sand from Smygehuk, Sweden. In each of the buckets, a 20 mm diameter garden hose of 25 cm length connects the bottom of the bucket with the surface. At about 50 cm of distance from the top edge of the bucket are 2 LED lights of 87 cm length, spaced 22 cm

apart, with specifications: 230V, 15W, 1500 Lumen, 6400 K light temperature, and PPFD (100 mm) $115 \mu\text{mol/s/m}^2$, from Nelson Garden. PPFD stands for Photosynthetic Photon Flux Density in, and it's a measure used in horticulture and plant science to quantify the amount of photosynthetically active radiation (PAR) that reaches a plant's surface. The lights were placed on a 14 h on, 10 h off mechanical timer. In the left bucket from Figure 2, the beach sand had been rinsed with regular tap water extensively, while the other was left untouched.



Figure 3: Experimental set-up showing the Media Bed experiment with the “pot-in-pot-in-tray” design, prior to adding the coco+perlite mix. Post-experiment photo taken on 2024-06-18.

The main container was a 6.28 L polypropylene pot with a slitted bottom. Inside this, another pot was placed upside down. This inner pot, also made of polypropylene with a slitted bottom, had a volume of 2.78 L. The arrangement of these two pots created a space between them with a volume of 3.5 L. This space was filled with a growing medium, consisting of a 50/50 mix of coco and perlite. Such a pot contained a bottom tray at the bottom for fertigation, and was placed outside in a balcony facing south, next to raised beds and other containers growing in soil. This 'pot-in-pot-in-tray' system design was originally devised by B. A. Kratky as a variation of his commonly used upside down pot growing method. This method typically involves placing an inverted pot within another pot, creating a space for growing medium while allowing for efficient water and nutrient management. The technique aims to optimize root aeration and nutrient absorption in hydroponic systems.



Figure 4: Experimental set-up showing the DWC experiment with the empty Harvy prototypes, prior to adding the water and seedlings. Post-experiment photo taken on 2024-06-18.

The “DWC experiment” consisted of six 10 L Harvy prototype containers by Nelson Garden/Hemmaodlat, each with six cuttings each, placed in a rockwool cube each inside the standard Harvy net pot. Above each Harvy (40 cm distance from surface of container) there was 1 LED light strip of 60 cm length, with specifications: 230V, 15W, 1500 Lumen, 6400 K light temperature, and PPFD (100 mm) 115 $\mu\text{mol/s/m}^2$, from Nelson Garden. They were placed on a 14 h on, 10 h off mechanical timer. For each IKEA ALGOT shelf installed, there were two Harvy prototypes placed, with two LED lights per shelf. Each Harvy was filled with ~10L of tap water prior to addition of seedlings and diluted JLF.



Figure 5: Close-up photo of the surface of the JADAM Liquid Fertilizer after more than a year. Photo taken on 2023-09-06.

The JADAM Liquid Fertilizer began its production in August 2022, using a 60 L HDPE barrel filled with approximately the same volume of uncompressed raised bed waste from an urban balcony. The waste material consisted primarily of plant debris: approximately 70% leaves and stems, 20% flowers, and 10% moldy fruit, predominantly from tomato and cucumber plants. The plant waste inside the barrel was then submerged in ~50 L of regular tap water, and around ~1-2 L of leaf mold from Lunds Ladugård forest was added. The barrel had a lid

placed to maintain the conditions anaerobic, and had only the occasional manual stirring with a stick during the period of ~10 months in a balcony. During that period, the liquid inside the barrel froze occasionally during the winter.



Figure 5: Addition of seedlings in the Media bed experiments (upper left photo of the unrinsed bucket taken on 2023-07-13, upper right photo taken on 2023-06-21), and DWC experiments (lower photo taken of bottom shelf on 2023-09-14).

The plants used were *Ocimum basilicum* in the variety Big Leaf Basil (Largo Dolce Per Vasi) for the Media Bed experiment with sand, and for the DWC Experiment, *Solanum lycopersicum* in the variety Red Robin (micro-dwarf tomato) was used. The basil was obtained from cuttings of previous adult non-flowering plants, and placed in rockwool cubes until the formation of visible roots through the cubes, whereas the tomato was grown from seed in a vermicompost mix, and transplanted to the Coco+Perlite mix, with gentle root rinsing beforehand.

Table 1: Overview of experiment start and end dates, duration, dilution of liquid fertilizer used, the fertigation/irrigation schedule for each of the experiments, and total number of plants used.

	Start date	End Date	Experiment Duration	Dilution of JLF	Fertigation schedule	Number of plants
Media Bed (Sand)	2023-06-28	2023-09-04	68 days	1:50	Nutrient Solution: 180mL of JLF every 2-4 weeks; Watering: 180mL of tap water if the sand dried, every 1-2 weeks	2
Media Bed (Coco+Perlite)	2023-06-21	2023-09-04	75 days	1:50	Nutrient Solution: 180mL of JLF every 2-4 weeks; Watering: 180mL of tap water if the mix dried, every 1-2 weeks	1
DWC	2023-09-14	2023-11-01	48 days	1:50	300mL JLF at start; Additional 500mL JLF after 2 weeks (2023-09-30)	36

In designing the Media Bed experiments, it was believed that a bottom irrigation schedule would prevent substrate displacement. This approach involved either delivering nutrient solution through the garden hose to the bottom of the sand or via the tray at the bottom of the pot with the Coco+Perlite mix. Preventing substrate displacement was important as it could potentially affect root and seedling stability. The design relied on the naturally wicking effect of the substrate, which would allow nutrients placed at the bottom to become available to the seedling roots above.

Additionally, the use of partial irrigation would prevent the full soaking of the substrate. This would allow for the development of aerobic microorganisms in the higher surface area environment of the substrate, which would allow them to convert any unprocessed compounds from the JLF into more plant-available nutrients. In the “pot-in-pot-in-tray” design using the Coco+Perlite mix, the bulk of the volume would contain moist-rich air, allowing for the tomato plant to develop so-called “air roots” that help the plant prevent root-rot.

The success of Deep Water Culture (DWC) cultivation using JLF would indicate that the fermentation process effectively converts nutrients into plant-available forms. Such a result would suggest that substrate-based systems may be unnecessary when using JLF, potentially simplifying hydroponic setups.

The calculations for the quantity, frequency, and dilution ratio of JLF were primarily derived from JADAM guidelines for soil application, supplemented by the author's empirical data from previous organic hydroponic (biaponics) experiments.

3. Results

3.1 Media Bed Experiment

Throughout the Media Bed experiments, each bucket/pot utilized between 360 and 720 mL of diluted JLF, averaging 540 mL. This corresponds to the use of 7.2 to 14.4 mL of original JLF (average of 10.8 mL), diluted at a ratio of 1:50. The total water consumption, excluding the dilution factor for JLF, ranged from 720 to 1620 mL per bucket/pot, with an average use of 1170 mL of tap water.



Figure 6: Final photo of the Media Bed experiment on sand prior to harvest, with the rinsed sand on the left, and the unrinsed sand on the right, photo taken on 2023-09-04.

No significant differences were observed between the rinsed and unrinsed sand treatments. Both sets of plants achieved a height of 50 cm, with leaf lengths averaging approximately 10 cm, characteristic of the Big Leaf Basil variety. The leaves exhibited healthy morphology, with no signs of discoloration or nutrient deficiencies. Overall plant growth appeared unaffected and robust when cultivated with the diluted JLF nutrient solution.



Figure 7: Final photo of the Media Bed experiment on Coco+Perlite mix prior to harvest, brought inside for better lighting conditions during photography, photo taken on 2023-09-04.

The micro-dwarf tomato plants attained an expected height of 20 cm and yielded 12 tomatoes, consistent with the typical production for this variety. The plant exhibited no discoloration, and the plants showed no signs of disease or stunted growth, indicating appropriate fertigation and nutrient availability. Notably, this plant was cultivated outdoors and exposed to a broader range of environmental conditions (e.g., humidity, wind, light variation, temperature) compared to the controlled indoor experiments.

3.2 DWC Experiment

The DWC experiment had a total use of diluted JLF per Harvy of 800 mL, or 16 mL of original JLF. Each Harvy also used 10 L of tap water that was not replenished or changed.



Figure 8: Photo taken two weeks after the beginning of the DWC Experiment of the bottom shelf (2023-09-30)

Around the two week mark (2023-09-30), an assessment was made of the growth. There was vegetative growth observed, but the overall plants had smaller leaves and of a lighter green color. As a result, it was decided to add an additional 500 mL of diluted JLF on top of the previous 300 mL diluted JLF, totalling 800 mL of diluted JLF.



Figure 9: Final assessment of the DWC Experiment. Photo taken of the middle shelf on 2023-11-01

At the end of the DWC Experiment, 48 days after its beginning, and despite an additional amount of diluted JLF added, there was still reduced vegetative growth, leaf discoloration and necrosis, and flowering observed.

4. Discussion

The Media Bed Experiments demonstrated the feasibility of integrating JADAM Liquid Fertilizer (JLF) in a passive hydroponic system. This was achieved by employing an inert wicking substrate and implementing a bottom-feeding partial irrigation method. Given that fruiting plants like tomatoes have higher nutrient requirements compared to herbs such as basil, the results suggest that the fertigation schedule with diluted JLF provided an adequate nutrient supply. Overall, the performance of JLF in a passive media system was comparable to expectations for a mineral hydroponics system.

In the DWC Experiment, the observed slow vegetative growth, smaller leaf size, discoloration, necrosis, and early flowering suggest suboptimal nutrient availability. One potential explanation is an insufficient JLF dosage. However, compared to the successful Media Bed Experiments, a more plausible explanation is that the JLF process does not generate all essential plant-available nutrients, or does so in insufficient quantities, from the partial anaerobic digestion process. The presence of an inert substrate with aerobic conditions and surface area (e.g., sand or coco/perlite mix) in the Media Bed experiments likely supports the proliferation of aerobic microorganisms. These microorganisms play a crucial role in metabolizing complex compounds from the JLF process into plant-available nutrients, making these nutrients accessible near the plant rhizosphere for uptake.

While a pure passive DWC system with JLF would have incredible potential for sustainable hydroponic cultivation, its failure in this experiment is an important point in future system designs, highlighting the importance of the bottom-feeding partial irrigation system design, utilizing an inert substrate. This later design has now been named as M.U.N.C.H. or Method of Up-cycled Non-Circulating Hydroponics, which emphasizes how organic waste is up-cycled into a useful nutrient solution, and how such method does not require water or air circulation. This combination enables the sustainable cultivation of plants without the use of soil in even remote areas, where access to energy is intermittent or non-existent, where soil quality is poor, and access to conventional hydroponic mineral fertilizer difficult.

Considering the novelty of this method, future experiments should explore in more detail the microbial and chemical science behind the JLF production, and its interaction with a passive substrate-based hydroponic design. Optimizing the duration of JLF considering its soilless application, reducing substrate use within a M.U.N.C.H. cultivation, and creating dosing guidelines and other best practices for this novel method of hydroponics would also greatly benefit future scientific and commercial applications.

5. References

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