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Anaerobically-Digested Brewery Wastewater as a Nutrient Solution for Substrate-Based Food Production

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Abstract: Urban agriculture, due to its location, can play a key role in recycling urban waste streams, promoting nutrient recycling, and increasing sustainability of food systems. This research investigated the integration of brewery wastewater treatment through anaerobic digestion with substrate-based soilless agriculture. An experiment was conducted to study the performance of three different crops (mustard greens (*Brassica juncea*), basil (*Ocimum basilicum*), and lettuce (*Lactuca sativa*) grown with digested and raw brewery wastewater as fertilizer treatments. Mustard greens and lettuce grown in digested wastewater produced similar yields as the inorganic fertilizer control treatment, while basil had slightly lower yields. In all cases, crops in the digested wastewater treatments produced higher yields than raw wastewater or the no fertilizer control, indicating that nutrients in the brewery wastewater can be recovered for food production and diverted from typical urban waste treatment facilities.

Keywords: urban agriculture; reclaimed wastewater; controlled environment agriculture; soilless production; brewery; *Brassica juncea*; *Lactuca sativa*; *Ocimum basilicum*

1. Introduction

Urban agriculture is experiencing a resurgence in popularity in many parts of the world. Beyond the social benefits urban agriculture can provide, such as creating opportunities for community building, jobs, and education, as well as increased access to healthy food [1], urban agriculture is also gaining interest due to the possible environmental benefits it can provide to municipalities. Some of those benefits include increased green spaces, reduction of food imports, and nutrient recycling [2–5]; the latter is the focus of this paper. Modern cities function largely as nutrient sinks, with nutrients shipped in from rural locations through food and transformed to waste once consumed. Historically, and presently in the Global South, these nutrient-rich waste streams were and are prized for fertility in both rural and urban agriculture [5–7]. However, social stigma, concerns over sanitation, and potential presence of pathogens, nitrates, heavy metals, or pharmaceuticals [8] in urban wastewater make this integration a challenge today. Still, advocates argue that finding ways to recycle the organic fraction of waste streams to agricultural production in urban areas will not only reduce soil and water pollution, but also prove central to both urban waste management and agricultural production [9].

Integrating agricultural production with industries that produce wastewater suitable for irrigation may increase sustainability in both sectors [9,10] and reduce the challenge of reusing wastewater [11]. The brewing industry can serve as a model for wastewater and urban agriculture integration. The brewing process creates large amounts of wastewater that, if treated aerobically like most of the wastewater in the US, requires large amounts of energy for water treatment. This usually translates into substantial surcharges to the brewery [11]. The large energy requirement for treatment is due to processing the high number of organic compounds in the water. These organic compounds have the potential to produce hydrogen or methane energy if treated anaerobically, and the resulting nutrients could be a source of fertility for agricultural production [12–14].

Traditional soil-based agriculture may not be a feasible solution in urban environments due to soil contamination and the lack of available land. Soilless production, such as substrate-based, aquaponics (hydroponics) could offer a flexible solution adaptable to different settings [15]. Research has explored how to recycle wastewater for soilless production, mostly for hydroponic production, and found that if the wastewater or organic waste is mineralized and the optimal nutrient content is achieved, comparable yields to plants grown using inorganic fertilizer may be obtained. This has been shown using brewery wastewater [12]. In all cases, researchers promoted nutrient mineralization through either algae ponds [12], bioreactors [16], or introduction of desired bacteria in the system [17]. Part of the rationale of using organic substrates in this work is to enhance mineralizing and heterotroph bacteria and fungi populations [18] in order to promote organic matter breakdown and mineralization [19,20].

The objective of this research was to test the performance of both digested and raw brewery wastewater as a fertility source for substrate-based vegetable production. The use of both digested and raw wastewater seeks to explore the feasibility of using brewery wastewater for substrate production as well as to determine the potential benefits of digesting the wastewater. Three genetically diverse crops were used to study the adaptability of the brewery wastewater to grow high value crops suitable for controlled environment production in soilless media. Mustard greens (*Brassica juncea*) can be easily grown in soilless production as a leafy vegetable and are increasing in consumer demand, particularly in fresh salad mixes [21,22]. Lettuce (*Lactuca sativa*) is widely grown and studied in soilless production [23–26] and basil (*Ocimum basilicum*) is a popular herb that is also widely cultivated and studied in soilless systems [27,28].

Our hypothesis was that if the treatments with wastewater have similar nutrient profiles to the inorganic control treatment, crops should produce similar yields. We hypothesized that differences between the digested and raw wastewater treatments would be due to the higher nitrogen and lower organic carbon content of the digested wastewater as opposed to the raw wastewater treatment.

2. Materials and Methods

This research is part of a larger project that seeks to create an anaerobic wastewater treatment process to reduce carbon load of wastewater combined with urban food production via soilless agriculture. Specifically, we are interested in modeling a decentralized approach to this integration that could happen at various locations in an urban environment, unlike a centralized wastewater treatment facility. For this project, the anaerobic digestion process addresses two objectives: (1) to reduce organic load of the wastewater while producing hydrogen and methane energy and (2) to create a final water solution more suitable for plant uptake in soilless vegetable production, thereby closing a water usage loop.

Three experiments corresponding to three different crops—'Green Wave' mustard greens, 'Nufar' basil, and 'Salanova Green Butter' lettuce (Johnny's Selected Seeds, Waterville, ME)—were conducted between May and September 2018 at the University of Minnesota Plant Growth Facilities in St. Paul, MN, USA (44°59′17.8″ N lat., -93°10′51.6″ W long.). The experiments were the same in methods, only differing in crop type. Each experiment was set up as a completely randomized design, with $n = 5$ replicates of each of the four fertility treatments, for a total of 20 plants in each experiment.

Four different fertility treatments were evaluated: (1) an unfertilized control (i.e., only water); (2) an industry standard inorganic hydroponic fertilizer with the following concentrations: 150 ppm N, 52 ppm P, 215 ppm K, 116 ppm Ca, 53 ppm Mg, 246 ppm SO_4, 3 ppm Fe, 0.5 ppm Mn, 0.15 ppm Zn, 0.15 ppm Cu, 0.5 ppm B, and 0.1 ppm Mo, obtained by mixing 4 L of water with 2.56 g of $CaNO_3$ and 3.88 g of 5–12–26 (Jack's hydroponics fertilizers, JR Peters Inc., Allentown, PA, USA); (3) raw wastewater from a local brewery (Fulton Beer, Minneapolis, MN, USA); and (4) digested wastewater from the same brewery, diluted at 50% with deionized water after digestion (Dr. Paige Novak's laboratory, Dept. of Civil, Environmental and Geo-engineering, University of Minnesota, Minneapolis, MN, USA). All of the plants were watered with 100 mL of well water every morning, along with 50 mL of their respective fertility treatments six afternoons per week (Sunday to Friday), with rates based on previous experience; one day per week had only water applied. Fertility treatments were at the same greenhouse temperature when irrigating.

All raw and digested wastewater was collected before the experiments began and stored in 26.5 L polyethylene containers (Aqua-Tainer, Reliance Products, Winnepeg, Manitoba, Canada) in a cooler at 5 °C (Vollrath Inc., Sheboygan, WI, USA). A subsample of the digested and raw wastewater was submitted for analytical testing (Research Analytical Lab, University of Minnesota, St. Paul, MN, USA) for ammonium-N [29], nitrate/nitrite-N [30], and total phosphorus [31] at the beginning of the experiment. In the early stages of the project, a low nitrogen concentration in the digestate but a high electrical conductivity [32] was detected. Therefore, 150 mg/L of ammonium hydroxide was used for pH adjustment of the brewery wastewater instead of calcium carbonate as a means to obtain a digestate with higher nitrogen content but lower conductivity.

The three different crops—mustard greens, basil, and lettuce—were grown for six weeks in plastic containers with a 10.16 cm diameter and an 8.5 cm depth (Belden Plastics, Saint Paul, MN, USA) filled with a peat-based substrate (Professional Growing Mix #8, Sun Gro Horticulture, MA, USA). This substrate was chosen based on performance in preliminary experiments. Plants were started in a 128 plug tray (TO Plastics, Clearwater, MN, USA) in a peat-based propagating mix (Sunshine Propagation Mix, Sungro, MA, USA), and kept in a mist chamber, misted at intervals of 5 min for 7 days to encourage germination. The mean temperature was 25.78 ± 2.14 °C with 66.94 ± 16.29% relative humidity (RH). After germination, seedlings were moved to the greenhouse and placed on top of a flat 25.4 × 50.8 cm tray filled with 5 cm of water for 7–10 days. The photoperiod was set for long days (16:8 h day:night) with supplemental lighting supplied by high pressure sodium high intensity discharge (HID) lamps at a maxima of 1377 µmol m^{-2} s^{-1}. Mean temperature ±SD was 24.39 ± 4.24 °C. All environmental settings were controlled via an Argus Control Systems Ltd. computer (Surrey, BC, Canada).

Plant biomass, or final yield, was calculated for each plant at the end of the six weeks. Mustard green leaves longer than 10 cm were harvested weekly. Fresh weight of the leaves was recorded and then leaves were dried for 72 h at 70 °C in a hot air oven (Hatchpack, PI, USA) and dry weights were measured. The total above-ground biomass of mustard greens was calculated by adding the cumulative harvested yield to the dry mass of the above-ground plant material at the termination of this experiment. In the case of lettuce and basil, total above-ground biomass present at the end of the experiment was used as the measurement of yield.

Plant growth measurements were recorded weekly. The number of leaves on the terminal stem and stem width (mm) were measured on each experimental unit, or each plant, while chlorophyll level was measured using a soil-plant analyses development (SPAD) meter (SPAD 502, Spectrum technologies, IL, USA) for each leaf on each plant. The SPAD meter provides an output value between −9.9 to 199.9 in SPAD units; the higher the value, the greater the chlorophyll content [33]. The meter measures relative light absorbance at two different wavelengths (650 nm and 940 nm) [34].

Water quality of the leachate (collected after watering with 100 mL of well water) was measured weekly for pH, EC, infiltration, and nitrates. Three out of the five replications of each treatment were sampled, for a total of 12 samples from each crop, which were randomly selected at the beginning of the experiment. Infiltration time was measured as the duration of time from pouring the water until there was no standing water on the substrate surface. Electrical conductivity (EC) and pH of the collected leachate was measured using an electronic pH and EC meter (Milwaukee mw802, Milwaukee Electronics, WI, USA). Nitrate levels of the leachate were measured using a LAQUA twin NO3-11C pocket nitrate reader (Horiba scientific, Minami-ku Kyoto, Japan).

Statistical analyses were conducted using R software (The R foundation, v.3.4.1) to determine significance using Analysis of Variance (ANOVA). If the null hypothesis of no significant differences was rejected, mean separations were accomplished using Tukey's honestly significant difference (HSD) test at a significance level of $\alpha = 0.05$. Plant chlorophyll content and growth parameters were also tested for correlation with yield, using Pearson's correlation test at a significance level of $\alpha = 0.05$.

3. Results

3.1. Biomass and Yield

Fertility treatment had a significant effect on the number of harvested leaves (data not shown) and total above-ground biomass of mustard greens (Table 1). Fertility treatment also had a significant effect on total above ground biomass of lettuce and basil (Table 1). Mustard greens and lettuce plants grown using digested wastewater produced a similar amount of total above ground biomass when compared to plants in the inorganic fertilizer treatment, while raw wastewater plants performed at the same level as those in the no fertilizer treatment (Table 1). For basil, the highest biomass was observed in the inorganic fertilizer followed by digested wastewater treatments (Table 1). Mustard greens in both the inorganic fertilizer and digested wastewater treatments reached harvestable size the second week of the experiment and produced until week 6, while mustard greens grown in the raw wastewater only were harvestable on week 6, and no plants reached maturity in the unfertilized control treatment.

Table 1. Mean ± SE total above-ground biomass, or per plant dry weight (g), for mustard greens, lettuce, and basil grown with different fertility treatments in a greenhouse in St. Paul, Minnesota in 2018. One-way ANOVA results for fertility treatments were performed on each parameter and crop. Values within the same column with different letters are significantly different (Tukey's HSD, $\alpha = 0.05$).

Fertility Treatment	Total Dry Weight Per Plant (g)		
	Mustard Greens	**Lettuce**	**Basil**
No fertilizer	0.19 ± 0.04 b	0.19 ± 0.03 b	0.46 ± 0.02 c
Inorganic fertilizer	0.58 ± 0.02 a	2.83 ± 0.11 a	3.57 ± 0.09 a
Raw wastewater	0.29 ± 0.08 b	0.46 ± 0.09 b	0.73 ± 0.13 c
Digested wastewater	0.56 ± 0.04 a	2.09 ± 0.46 a	1.95 ± 0.36 b
ANOVA	F(3,16) = 16.33 $p < 0.01$	F(3,16) = 27.51 $p < 0.01$	F(3,16) = 50.71 $p < 0.01$

3.2. Plant Growth

Due to the leaf removal from mustard green plants, plant growth was monitored using stem width at the substrate level. No significant fertility treatment effects were found for mustard stem width during any of the weeks (data not shown). Weekly stem width measurements were moderately correlated with weekly harvest ($r = 0.57$, $p < 0.01$).

For lettuce and basil, the number of leaves per week was used as a measurement of plant growth. Significantly different numbers of leaves per lettuce plant were counted in weeks 2–6 ($p < 0.05$) between treatments. In weeks 2–5, lettuce grown in inorganic fertilizer treatments had the highest number of leaves, while in week 6, lettuce from both inorganic fertilizer and digested wastewater treatments had a similar number of leaves. Total number of lettuce leaves at the end of the experiment was positively correlated to final above-ground biomass ($r = 0.89$, $p < 0.01$). Basil plants, too, had a similar number of leaves through the first week, but subsequent significant differences were found in weeks 2–6 ($p < 0.01$) between treatments. In later weeks, basil from the inorganic fertility treatment had the highest number of leaves. Similar to the case of lettuce, at the end of the experiment, the total number of basil leaves was highly correlated to final above-ground biomass ($r = 0.97$, $p < 0.01$). Overall, plants from both inorganic and digested wastewater treatments appeared marketable for all crops (Figures 1–3).

Figure 1. Image of 'Green Wave' mustard green plants (day 42) grown in University of Minnesota's Plant Growth Facilities greenhouse (St. Paul, MN). Plants were grouped by fertility treatment in rows; from left to right: digested wastewater, raw wastewater, inorganic fertilizer, and no fertilizer.

Figure 2. Image of 'Salanova Green Butter' lettuce plants (day 42) grown in University of Minnesota's Plant Growth Facilities greenhouse (St. Paul, MN). Plants were grouped by fertility treatment in rows; from left to right: digested wastewater, raw wastewater, inorganic fertilizer, and no fertilizer.

Figure 3. Image of 'Nufar' basil plants (day 42) grown in University of Minnesota's Plant Growth Facilities greenhouse (St. Paul, MN). Plants were grouped by fertility treatment in rows; from left to right: digested wastewater, raw wastewater, inorganic fertilizer, and no fertilizer.

3.3. Chlorophyll Content

In all crops, the chlorophyll content of the digested wastewater treatments stayed at a similar level to inorganic fertilizer treatments throughout the 6 weeks (Table 2). Significant differences in SPAD values of mustard greens were not found until weeks 5 and 6 ($p = 0.03$), where digested wastewater treatments had the highest chlorophyll content and raw wastewater the lowest (data not shown). SPAD values for mustard greens in were not correlated with weekly harvest ($r = 0.05$, $p < 0.56$).

Table 2. Mean chlorophyll content (SPAD values) averaged across 6 weeks for mustard greens, lettuce, and basil grown with different fertility treatments in a greenhouse in St. Paul, Minnesota in 2018. Values within the same column with different letters are significantly different (Tukey's HSD, $\alpha = 0.05$).

Fertility Treatment	**Chlorophyll Content, SPAD Units**		
	Mustard Greens	**Lettuce**	**Basil**
No fertilizer	22.23 ab	13.33 c	17.79 c
Inorganic fertilizer	21.01 a	20.76 a	25.93 a
Raw wastewater	20.40 b	17.21 b	21.50 b
Digested wastewater	24.13 a	20.42 a	26.22 a
ANOVA			
	F(3,133) = 8.32 $p < 0.001$	F(3,116) = 22.72 $p < 0.001$	F(3,116) = 43.85 $p < 0.001$

Significant differences between SPAD measurements became apparent in the fourth week, where digested wastewater and inorganic fertilizer treatments had the highest chlorophyll content; the six-week average is shown in Table 2. SPAD values at the end of the experiment were correlated with lettuce total biomass ($r = 0.78$, $p < 0.05$).

We observed significant differences in the SPAD values of basil plants grown in the different fertility treatments as early as week 2 and continuing through week 6 ($p < 0.01$). In all cases, basil leaves from the digested wastewater and inorganic fertilizer treatments had the highest chlorophyll content, followed by raw wastewater treatment (Table 2). Basil SPAD values were correlated with total dry biomass at the end of the experiment ($r = 0.77$, $p < 0.01$).

3.4. Water Test

Comparing the total nitrogen ($T_N = NH_4 - N + NO_2 - N + NO_3 - N$) between the digested wastewater (50% diluted) and the raw wastewater, there was higher ammonium-N content in the digested wastewater, 171.50 ppm compared to 7.23 ppm (Table 3). The ammonium content of the digested wastewater was similar to that used in the inorganic fertilizer control and within the 100–250 ppm recommended range [35,36]. The only concerning factor was that the N ratio ($R_N = NH_4 - N/NO_3 - N$) [37] was extremely high: >1000, and since all the N was in the form of ammonium, this could generate problems of ammonia toxicity and yield reduction [38,39], though this was not observed. Phosphorus tests showed an orthophosphate concentration as low as 22 ppm in the pure digested wastewater (Table 3), a level similar to our previous hydroponic experiments [32] and lower than the raw wastewater, which can be explained by the 50% dilution of the digester leachate before use.

Table 3. Solution test results (pH, electrical conductivity (EC), ammonium-N, nitrate/nitrite N, total phosphorus) for each fertility treatment. Nutrient levels of digested and raw wastewater were obtained from laboratory testing while nutrient levels of inorganic fertilizer obtained from the fertilizer formulation (see Methods).

Fertility Treatment	pH	EC	Ammonium-N	Nitrate/Nitrite-N	Total Phosphorus
Digested wastewater	8.40	1.87	171.50	<0.1	22.00
Raw wastewater	4.40	0.84	7.23	<0.1	79.88
Inorganic fertilizer	6.10	1.72	0	150	52
No fertilizer [1]	7.90	0.24	-	-	-

[1] Tests for ammonium, nitrate/nitrite or phosphorus were not applicable for the unfertilized control.

3.5. Leachate Monitoring

Water infiltration time increased over time in raw wastewater treatments, while digested wastewater showed similar monitoring trends compared to the inorganic fertilizer treatments (data not shown). Nitrate, EC, and pH data of these leachate samples are reported in Table 4 averaged across weeks and crops, as fertility treatment effects were greater than crop effects. Overall, the highest nitrate levels were observed in the leachate from the beginning of the experiment (data not shown), and on average, N levels were highest in leachates from the digested wastewater and inorganic fertilizer treatments (Table 4). At the beginning of the experiment, the leachate was acidic (pH = 5.5–6), but turned more neutral through the experiment (data not shown); raw wastewater treatment leachate was the most basic (Table 4). Electrical conductivity also declined over time, with highest levels measured in the digested wastewater and inorganic fertilizer treatment leachate.

Table 4. Leachate measurements (Nitrate-N, EC, and pH) for each fertility treatment averaged across 6 weeks and crops (mustard greens, lettuce, and basil) grown with different fertility treatments in a greenhouse in St. Paul, MN in 2018.Values within the same column with different letters are significantly different (Tukey's HSD, $\alpha = 0.05$).

Fertility Treatment	Leachate Characteristics		
	Nitrate-N (ppm)	EC (DS/cm)	pH
No fertilizer	340 b	0.51 b	6.52 b
Inorganic fertilizer	604 a	0.90 a	6.36 bc
Raw wastewater	440 ab	0.65 ab	6.85 a
Digested wastewater	653 a	0.97 a	6.22 c
ANOVA			
	F(3,248) = 5.343 $p < 0.01$	F(3,248) = 5.283 $p < 0.01$	F(3,248) = 35.93 $p < 0.001$

4. Discussion

Fertilizing with digested wastewater produced similar yields for lettuce and mustard greens compared to plants grown using commercial inorganic fertilizer. For basil, yields were lower when using the digested wastewater, but still significantly higher than the treatments that received only raw wastewater or well water. Therefore we suggest that digested brewery wastewater has the potential to provide plants with the required nutrients to obtain high yields, at least with certain crops. This is consistent with a similar study that grew tomato, *Solanum lycopersicum*, using digested brewery wastewater [12] and other research that successfully used nutrient solutions partially or totally made with wastewater or organic waste for soilless production [10,39–42].

Lettuce and basil plants that were only harvested once, compared to the multiple harvests of mustard leaves, exhibited the highest chlorophyll content in the inorganic fertilizer and digested wastewater treatments. Moreover, the higher chlorophyll contents at the end of the experiment were strongly positively correlated with yield. This reinforces the conclusion that digested brewery wastewater was able to provide enough nutrients, particularly N, for the plants to produce chlorophyll at the same level as the inorganic nitrogen of the synthetic fertilizer [23,28]. In contrast, SPAD values were not different among treatments for mustard greens. This could be due to the effect leaf removal had on plant health, since stress is a factor known to reduce SPAD measurements [33]. SPAD values for inorganic and digested wastewater were similar to those reported by other authors on basil grown in hydroponic and aquaponic systems [28]. Lettuce in inorganic and digested wastewater treatments obtained much higher SPAD values than those reported for plants hydroponically grown with reclaimed organic wastes [43], and similar to lettuce plants hydroponically grown with 150–200 ppm of total N [23]. The additional ammonium-N we added as a buffer and additional nutrient source is likely the reason for this finding.

Notably, most of the nitrogen present in the digested brewery wastewater came from the addition of ammonia in the digester. This addition may seem to contradict our research objective of growing horticultural crops with the digested wastewater, but due to the low nitrogen concentration found in the wastewater, increasing nitrogen concentration was needed to successfully grow plants, similar to what other studies found [39–42]. Ammonia can increase the risk of ammonium toxicity and nitrogen deficiency [44,45] in some crops, while in other species, like lettuce, it may be the preferred nitrogen source [17,38]. This highlights the need for further research on crop suitability for digested wastewater production in order to better understand which crops may produce acceptable yields, as well as the factors driving those differences and how to enhance nitrification for those crops where nitrate is preferentially taken up. Many factors affect nitrification rates including: pH of the substrate, substrate material [46], temperature [47], ammonia to nitrate ratio, carbon to nitrogen ratio [16], original bacteria population levels, and inoculation [19,37]. Additionally, future studies should test how to optimize this ammonia addition to minimize nitrogen concentration in the final effluent. A possible way to increase this nutrient removal could be through the recirculating of the nutrient solution in the system [48,49].

This study did not address the nutrient composition of the mature plants, nor of the wastewater nutrient solutions, besides nitrogen and phosphorus. No evident nutrient deficiencies were observed in any of the plants, though the plants used reached harvestable maturity relatively quickly and a different response might occur when growing longer maturing or fruiting crops [50]. Micronutrient deficiencies could also occur due to the alkaline pH of the digested wastewater [51]. A nutrient solution could also affect nutrient profile and taste of the produce [23], as the lack of certain elements like silicon or sodium do not lead to deficiencies but can effect quality and yield [25,52,53]. The high levels of sodium detected, around 130 ppm, did not exhibit salinity effects on the plants, but this should be considered in future analyses due to the issues with sodium accumulation in both the nutrient solutions and substrates [54,55]. Further understanding how the brewing process affects those nutrient fluctuations may help anticipate them.

5. Conclusions

This research shows that it is possible to use anaerobically digested brewery wastewater to grow different crops and obtain commercially acceptable yields. Anaerobic digestion is not only a possible way to produce energy [13,56], but also to adjust nutrient profiles and create a better nutrient solution for soilless production. Thus, it is possible to integrate brewery wastewater treatment with soilless urban agriculture. This integration, and energy generation through anaerobic digestion, could help reduce the high environmental footprint that many soilless urban farms have [57] and be a good way to increase food system sustainability by promoting nutrient reuse and reducing waste treatment energy requirements [5,10]. This integration of sectors opens the door to further synergies; for example, if the soilless production happened in protected environment, CO_2 from the brewing process could be used to enhance plant growth [58], the high temperature of the wastewater [14] could heat the growing space, or spent grains could be a large component of the substrate mix instead of peat [59]. Still, in order to promote the implementation of those solutions, there is a need to develop the knowledge and technologies. Important practical considerations will also need to be made, such as synchronizing digestate production and availability with crop needs, as well as scalability of this model.

The best method to integrate both soilless urban agriculture and brewery wastewater treatment still remains unclear. In this article, we have researched how to solve some of the agronomic and technological challenges of this integration, but additional complementary research is needed pertaining to the economic, legal, and social challenges of this decentralized urban system. Urban agriculture can provide food close to home, improve water use efficiency, and utilize locally available sources of nutrients, if other support systems exist. The economic viability of this integration would likely depend, in great measure, on successfully creating a marketing strategy that demonstrates value in sustainably managing urban waste streams and producing food locally.

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