Vega *et al. Agriculture & Food Security* (2023) 12:18
https://doi.org/10.1186/s40066-023-00422-8

Agriculture & Food Security

RESEARCH

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Intermittent circulation of simplified deep flow technique hydroponic system increases yield efficiency and allows application of systems without electricity in Haiti

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Abstract

Background Many Haitians face severe food insecurity driven in part by a lack of adequate land for agriculture. Hydroponic systems can produce food without the requirement of arable land but are often prohibitively expensive and require electricity and water inputs that are impractical in most of Haiti.

Results A deep flow technique (DFT) system named the Levo International, Inc. Victory Garden was tested with lettuce under constant and intermittent circulation. The average per-system yield of BSS from both treatments was 3631.75, 5013.75 and 2836.25 g in three experimental replicates. In replicates one and two, there were no significant differences in yield per circulation regiment. For the third replicate, we found a greater yield in constantly circulating systems. Each constantly and intermittently circulated system used 2.3814 kWh of energy for an estimated cost of $0.45 and 0.1386 kWh of energy for an estimated cost of $0.03, respectively. There was a significantly greater yield of BSS per energy input (g/kWh) in intermittently circulating systems compared to constantly circulating systems. There were no significant differences in water usage according to circulation. Electrical conductivity (E.C.) and pH were not significantly different between circulation treatment groups, except for pH in our third replicate which was significantly higher in constantly circulating systems. E.C. decreased and pH increased between the first week and last reading. The Victory Garden was tested with bell peppers under constant circulation and systems yielded an average of 3592.94 g of fruit. An adapted version of the Victory Garden was tested in Pignon, Haiti with bell peppers under manual twice-daily circulation and yielded an average of 2574.13 g and 3308.35 g in two experimental replicates.

Conclusions Simplified DFT systems can produce both lettuce and peppers on par with field production. In this system type, we did not see a benefit to constantly circulating the nutrient solution.

Keywords Food security, Simplified hydroponics, Deep flow technique, Sustainable agriculture, Haiti

Background

We are facing a food security crisis. In 2015, the United Nations (UN) established a set of 17 Sustainable Development Goals (SDGs) with a target of achievement in 2030, including Zero Hunger as SDG 2 [5]. In 2021, 2.3 billion people were food insecure and 10% of people suffered from Hunger [6]. The 2022 UN SDG Report pointed to a growing global food crisis, with decreasing food security even before the global COVID-19 pandemic [6]. The

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COVID-19 pandemic has only worsened food insecurity for many of the most vulnerable globally [1, 7]. Food insecurity has many downstream effects that are deleterious to the health of people and societies. For example, food security is a key determinant and indicator of public health [8].

Agricultural intensification and expansion are necessary, because it is projected that an increase in global food production is needed to the order of more than 50% by 2050 [9–11]. However, modern agriculture places tremendous pressure on land resources often leading to land degradation [12]. Land degradation, broadly definable as loss of land productivity in either a biological or economic sense [13], is a global problem and barrier to sustainable agricultural production and food security [14]. Preventing and reversing land degradation is a key part of UN SDG 15.

One of the main drivers behind land degradation, especially soil erosion, is intensifying agriculture [15, 16]. For example, agricultural expansion was responsible for the vast majority of deforestation globally between 2000 and 2020 [6]. Over half of agricultural land globally is affected by degradation [17] with an annual loss of 24 billion metric tons of fertile soil [13] and a cost of around $8 billion [14]. Though continually greater production is necessary, land degradation will continue to lessen crop yields globally [10, 14]. Clearing of forests for agricultural production is dangerous, as trees perform carbon sequestration which decreases climate change driven by carbon emissions [2]. The development of sustainable agricultural systems is necessary to provide adequate nutrition for everyone [18].

The impact of land degradation is unevenly shouldered by developing countries [15], exemplified by a scarcity of arable land in Haiti. Forested land has been continuously cleared in Haiti since the colonial era for use in agriculture and fuel [19]. Haiti is a traditionally agrarian country, with 40% of Haitians participating in the agricultural sector, primarily consisting of small operations [20]. Land degradation in the form of deforestation and soil erosion due to charcoal production and agriculture have negatively impacted Haiti, where it is estimated that only one-sixth of all cultivated land should be considered arable [21]. An inconsistent and bimodal rainfall pattern coupled with a mountainous terrain, where 60% of land has a gradient of 20% or greater, further worsens the issue [21]. Farmers must continuously clear land higher in the mountains to find arable soil and this exacerbates soil degradation as trees with soil-holding capacity are cut down. As of 2014, 30% of Haiti's cultivated soil was deemed to have been permanently degraded [19, 22] and there is a near-total loss of primary forest [23].

In the face of decreased land productivity, need for food is high in Haiti. Farmers in the central plateau region of Haiti report crop losses due to inconsistent rains and unreliable water supply, which forces them to make calculated risks about when to plant crops (communication with Claudin Augustin, 2018). This water shortage fits with an ongoing reality where 4.4 million Haitians were expected to face severe food insecurity between March and June 2021 [20]. Food insecurity is especially persistent in drier areas without access to irrigation and the entirety of Haiti is projected to be in stressed or crisis Food Insecurity Phases [24]. Globally, and especially in Haiti, there is an increasing need for production from land that is likely to decrease in productivity. Therefore, we require creative solutions to increase food production without doing further damage to land sustainability. Hydroponics is an alternative to traditional agriculture that does not contribute to land degradation. Hydroponics is the growth of crops in aqueous nutrient solution without soil [25]. This is an ancient form of horticulture that has gained recently popularity and currently is used in almost every country, occupying as much as 95,000 hectares globally [18, 26]. Arable land is not a requirement and therefore hydroponics is applicable in any location with access to water and light. The implication of this separation of crop production from arable land is that unsustainable practices to create arable land for traditional production are not necessary. Hydroponic systems are often closed systems, meaning that water is recycled and remains within the system except what is lost via plant transpiration [25]. Closed system hydroponics are much more water-use efficient than open systems [27] and can be applied to both urban and rural settings [28–30]. Hydroponic systems can also reduce the need for food imports, as food can be grown locally even if traditional agriculture is not viable on the available land [31]. Hydroponic systems have the potential to economically outperform traditional soil-based growing systems [25, 32]. Importantly, hydroponic systems do not contribute to land degradation as they are not soil-based.

Our global food production system has become increasingly dominated by national or international-scale producers which has moved production from local farms [3]. This creates a need for long-distance transportation of food. However, recently there has been increased interest in local food production from both consumers and policymakers [3]. A recent case study in Bangladesh found that home garden interventions had multi-year positive impacts on vegetable consumption [4]. Hydroponic agriculture is a tool that can increase access to local nutritious food production if arable land is not available near to consumers, such as in most urban settings.

Hydroponic agriculture is a potential solution to the agricultural challenges that Haiti is facing. However, there are some limitations of hydroponics as typically used that prevent its easy application. Capital requirements and necessary expertise are barriers that prevent many individuals from becoming hydroponic producers. Most systems require constant circulation of water and continuous monitoring and adjustment of nutrients. All of these inputs can add up to prohibitively expensive costs [25]. In rural Haiti, electricity is an inconsistent and expensive resource. The vast majority of Haitians rely on wood-based fuel and only 20–40% of Haitians have any access to an electrical grid [33, 34]. There is little evidence that Haiti is poised to make progress towards providing energy access for the majority of citizens in the near future [34]. Therefore, for a hydroponic system to be impactful, it would need to be electricity free.

Some progress has been made to increase the accessibility of hydroponic systems. Simplified hydroponics have been used successfully in developing countries to increase access to fresh foods [29, 30, 35–37]. Bernard A. Kratky pioneered a non-circulating, non-aerated growing system [38]. This system design can produce a wide range of crops from fruiting plants to leafy greens and does not require energy inputs. However, this system requires lower cropping density, as all the water for an entire crop needs to be applied initially, compared to circulating systems [38].

Deep flow technique (DFT) systems involve the pumping of water up from a reservoir tank and across the roots of plants. The nutrient solution remains deep enough to cover the roots and typically constant circulation is used to ensure that oxygen content in the root zone remains adequate [39]. A benefit of DFT relative to non-circulating systems is an ability to constantly provide fresh nutrient solution, which allows for higher cropping density and production per area. There is a need for a simplified form of DFT which can be used to grow a variety of crops in tight areas. This simplified DFT system must be capable of growing high-value crops, require reasonable water inputs for a smallholder farmer and require only circulation that can be completed manually without electrical input.

The objective of this research was to develop a simplified DFT system that can be operated by a smallholder grower without access to arable land, electricity, running water or advanced training. In this study, we developed a simplified DFT system with primarily gravity-based circulation supported either by wooden or metal frames. We first tested the yields and water consumption of lettuce (*Lactuca sativa* L.) cv. Black Seeded Simpson (BSS) under constant circulation and with 94% reduction in circulation (four times daily for 20 min). Next, we validated that simplified DFT systems can produce a fruiting crop by growing bell peppers (*Capsicum annuum* L.) under constant circulation. Finally, we tested this approach in the target setting of rural Haiti, using only manual circulation to grow bell peppers.

Results

A simplified DFT approach was designed for this study (Fig. 1). DFT systems are usually run under constant circulation. To test the importance of constant circulation in our DFT systems, we compared yields of BSS in constantly circulating systems to systems circulated only four times daily for 20 min. DFT systems on a wooden frame,

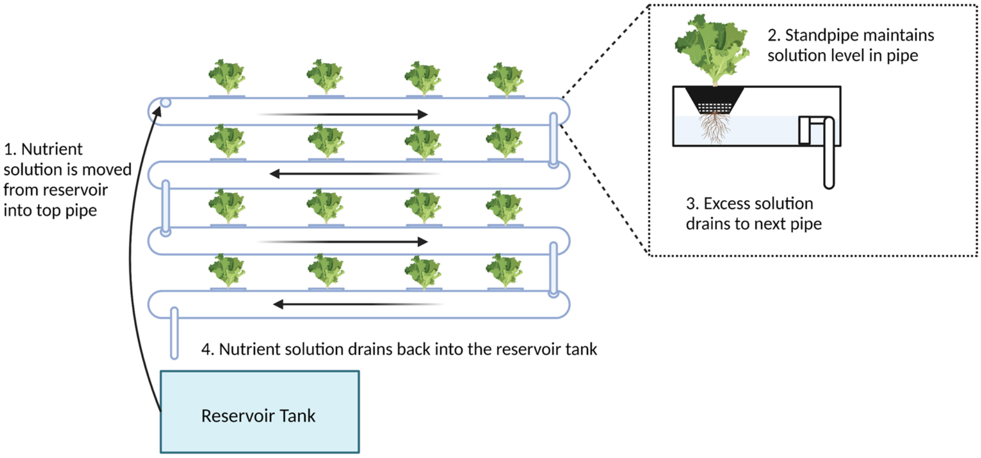

Fig. 1 Simplified DFT system uses a standpipe to maintain nutrient solution level. Nutrient solution is pumped up to a top pipe, where it fills the pipe up to the level of a standpipe. Then, excess solution above the standpipe level flows into the next pipe which also fills to a standpipe level. This process repeats until excess nutrient solution flows form the last pipe into the reservoir tank. The diagram was created with Biorender.com

named Victory Garden systems, were used for this experiment (Fig. 2). The average yield of BSS from all systems was 3631.75 g in replicate one, 5013.75 g in replicate two and 2836.25 g in replicate three. For replicates one and two, there were no significant differences in BSS yield per circulation regiment. For the third replicate completed during the summer, we found that there was a greater yield for the constantly circulating systems compared to intermittent circulation (Table 1). Therefore, BSS can be produced with DFT systems under intermittent circulation without substantial yield loss, though in some instances there may be a yield decrease compared to constant circulation (Table 1).

Constantly circulating systems is energetically costly. We hypothesized that intermittently circulating systems would produce greatly increased yields per energy usage. According to the U.S. Energy Information Administration, during June 2022, the average price per kWh of energy for commercial users was $0.1907 per kWh in Connecticut [40], and a constantly circulating system according to our experimental parameters uses 2.3814 kWh over 21 days while an intermittently circulating system uses 0.1386 kWh over the same time period. This translates to an estimated price of $0.45 per constantly circulating system versus $0.03 per intermittently circulating system. Yields per energy used were significantly higher in intermittently circulating systems than constantly circulating systems in all three replicates (Table 1).

Hydroponic systems require inputs of water and fertilizer and maintenance of pH in an optimal range. To test whether intermittent and constant circulation are different in their water requirements we measured the water consumption of each system after harvest of BSS. We did not find a significant difference in yield per water usage or in average daily water usage based on circulation treatment in any of the replicates (Table 1).

To test whether fertilizer and pH values fluctuated differently in the circulation treatments, electrical conductivity (E.C.) and pH values were measured. E.C. is a proxy for the nutrient content of a nutrient solution and as growth was similar between treatment groups, we hypothesized that E.C. would be similar between constant and intermittent groups at the beginning and end of the experiment. In support of this hypothesis, E.C. values were not significantly different between treatments at the beginning or end of the experiments in all three replicates (Table 2). In all experimental replicates, E.C. decreased between the first week and the

Fig. 2 Victory Garden systems produce Black Seeded Simpson Lettuce. Photo is of four out of eight systems used immediately prior to harvest

Table 1 Comparison of BSS yields and water usage in constantly and intermittently circulated Victory Garden systems

Replicate	Treatment	Transfer date	Harvest date	Yield (g)	Yield per energy input (g/kWh)	Yield per water input (g/L)	ADWU (L)
1	Constant	20-Oct-21	9-Nov-21	3570.50 ± 205.72	1499.33 ± 86.39	58.84 ± 6.36	3.38 ± 0.38
	Intermittent			3693.00 ± 51.28	26,645.02 ± 369.96[a]	120.89 ± 78.36	2.25 ± 0.43
2	Constant	23-May-22	13-Jun-22	5177.50 ± 362.87	2075.32 ± 145.45	77.32 ± 34.50	3.44 ± 0.30
	Intermittent			4850.00 ± 141.61	33,402.2 ± 975.27[a]	85.42 ± 9.98	2.58 ± 0
3	Constant	15-Jul-22	4-Aug-22	3251.25 ± 93.43	1365.27 ± 39.23	22.90 ± 5.51	6.98 ± 0.34
	Intermittent			2421.25 ± 105.74[a]	17,469.34 ± 762.90[a]	19.54 ± 4.86	6.08 ± 0.34

[a] Significant difference between treatments according to a Welch's two sample *t*-test or Wilcoxon rank sum test, $p < 0.05$

Table 2 pH and E.C. of Victory Garden systems growing BSS under constant or intermittent circulation

Replicate	Treatment	E.C. Week 1	pH Week 1	E.C. final	pH final
1	Constant	1057.00 ± 27.11	7.13 ± 0.03	641.75 ± 70.49	7.22 ± 0.05
	Intermittent	1016.25 ± 36.42	7.09 ± 0.01	730.25 ± 63.60	7.12 ± 0.01
2	Constant	1008.75 ± 68.52	6.17 ± 0.03	919.75 ± 125.73	7.83 ± 0.04
	Intermittent	1132.75 ± 45.42	6.13 ± 0.03	824.50 ± 73.29	7.91 ± 0.04
3	Constant	752.75 ± 32.69	7.01 ± 0.06	619.75 ± 94.82	7.68 ± 0.01
	Intermittent	838.00 ± 33.27	6.89 ± 0.07	596.5 ± 25.47	7.4 ± 0.05[a]

E.C. values are measured in $\mu S/cm^3$. VIVOSUN pH and E.C. meters were used for all pH and E.C. measurements, respectively

[a] Significant difference between treatments according to a Wilcoxon rank sum test, $p < 0.05$

Fig. 3 Babylon systems produce bell peppers. Photo is of the four experimental systems used in this study

last reading. Readings were similar in replicate one and two, but were lower in replicate three (Table 2). There were no significant differences in pH at week one between circulation groups (Table 2). In replicates one and two, there were no significant differences in pH values at the end of the experiment (Table 2). In our third replicate, we found that the pH was significantly higher in the constantly circulating systems and in all replicates, the average pH was greater at the final reading than at week 1 (Table 2).

To test whether bell peppers could be grown in simplified DFT systems, we grew them under constant circulation in Connecticut. Systems yielded an average of 3592.94 g of fruit with a standard error of 214.52 g. This is above the benchmark in-soil yield for peppers in Connecticut [41]. To test whether a minimal circulation approach could be applied to grow bell peppers without access to electricity, we grew Yolo Wonder bell peppers under manual twice-daily circulation in systems with a metal frame, called Babylon systems, in Pignon, Haiti (Fig. 3). Per system yields under manual circulation averaged 2574.13 g with a standard error of 140.84 g in the first replicate. In the second experimental replication, yields averaged 3308.35 g per system with a standard error of 303.63 g.

Discussion

We found that a simplified DFT approach without water replacement could provide yields of peppers and lettuce plants comparable to typical in-soil approaches. When circulation was decreased by 94% to only four times daily for 20 min, the yield of BSS was only minimally affected or not affected at all. As yields in intermittently circulating systems were either not decreased or only slightly decreased, an over 94% reduction in energy usage leads to significantly increased yields per energy inputs. As electrical power is not readily available for many residents of Haiti, we tested this drastically reduced circulation method with manual circulation in an adjusted system design. Yields without applied electricity still were in a normal range. This data supports our approach as a viable form of agriculture in the central plateau of Haiti that can be used by families and smallholder farmers to increase their food security and produce crops for sale at local markets. The Babylon systems can provide access to pepper production for farmers who are unable to irrigate fields or count on unreliable rainfall and can be used on non-arable land.

Research generally suggests that increased oxygenation increases yields [42]. Lower levels of circulation would likely decrease the oxygen content of the nutrient solution. For two of our trials, we did not see increased yields under constant circulation and therefore it is plausible that constant circulation does not significantly increase the oxygen levels of the nutrient solution relative to intermittent circulation in the context of our systems. Therefore, further research is warranted to see if systems can be adjusted to allow for increased oxygenation. Possible methods include adjusting the reservoir tank by making it smaller or wider. Another option is to increase fall distance between pipes to allow for greater water disturbance. Future research will focus on the dissolved oxygen concentration of the nutrient solution under different circulation regimes.

The interaction between temperature and circulation requirement was not examined. We found that yields were slightly decreased in intermittently circulated systems compared to constantly circulated systems in our third BSS trial, which took place during the summer when temperatures reached as high as 39 °C. This trial had increased water usage for all system treatments compared to the two previous trials. E.C. values were lower for this trial as well, which may be due to a combination of increased transpiration rates and increased water additions to the systems which dilutes nutrient salts. Cooler water can hold more oxygen and it is possible that constant circulation increases oxygen levels of the nutrient solution in warmer temperatures in a way that is not relevant in cooler temperatures. Temperatures in Pignon, Haiti regularly exceeded 30 °C during the described pepper trial but a comparative treatment with constant circulation was not possible due to electrical limitations.

It is unknown whether decreasing circulation would have an impact on disease susceptibility. If lower levels of circulation do indeed decrease oxygen levels in the nutrient solution, this would likely increase susceptibility to pathogens such as members of the *Pythium* genus [43–45] which are major threats to hydroponic production. On the other hand, increased circulation could also promote pathogen dispersal through a hydroponic system. Overall, we posit that increased circulation may be beneficial of simplified DFT systems may be beneficial under some temperature or disease pressure conditions, but is unlikely to overcome the benefit of decreasing electricity costs.

Hydroponic systems are typically priced out of the reach of smallholder growers and families. However, our work demonstrates that there are options for simplification of system inputs to increase access. More research is needed to understand where cutbacks can be made in simplified systems. For example, most hydroponic growers will regularly replace the entirety of the nutrient solution on a regular basis to avoid nutrient imbalances. We found this to be an unbearable cost of water; therefore, we developed a protocol to avoid this waste by maintaining lower E.C. levels to limit the risk of ion buildup. It is true that limited assessment of the composition of the nutrient solution leads to greater risk of nutrient imbalances, which can have impacts on plant yield. Further work is needed to refine protocols for hydroponic systems which can be completed by growers with simple tools such as E.C. meters that limit water usage.

Conclusions

In conclusion, simplified DFT systems with minimal gravity-based circulation can produce both lettuce and peppers on par with field production. In this system type, we did not see a benefit to constantly circulating the nutrient solution. This technology has broad potential applications for food insecure populations facing shortages in water and arable land. It is also possible to use this technology to sustain greater yields. The field of hydroponic technology is pushing towards increased mechanization and environmental control, but at the same time, we should explore its limits in the opposite direction to maximize its applicability.

Methods

Victory Garden system design and operation

The Levo International, Inc. Victory Garden system was used as the experimental unit for this study with a simplified DFT approach (Fig. 1; Table 3). One system contains four connecting 4-in. diameter PVC pipes, a hose and reservoir tank in an A-frame layout supported by a wooden frame (Fig. 2). Each system is 5 ft in width by 2 ft in depth. 20 plants are held in 3-in. net pots supported by holes cut into the PVC pipes. Four holes are drilled into each of the top two pipes and six holes are drilled into each of the bottom two pipes. The reservoir is used to store a fully dissolved mixture of water, 158 g of Jack's (J. R. Peters) 5-12-26 NPK fertilizer and 98 g of 15-0-0 NPK calcium nitrate. For pepper production, every 3 weeks a half-strength booster fertilizer of 79 g of NPK fertilizer and 49 g calcium nitrate were added as E.C. typically drops by approximately half after 3 weeks of pepper growth. E.C. was monitored weekly to ensure that it did not exceed 2000 $\mu S/cm^3$. As BSS was harvested after 3 weeks, additional fertilizer was not added. The total maximum volume of nutrient solution held by each system is about 40 gallons, with approximately half of it stored in the reservoir. A 5-W pump is used to move nutrient solution from the reservoir tank up to the top

Table 3 Simplified DFT hydroponic systems used in this study

System	Type	Design	Circulation options	Power	Support material	Volume	Water level (in.)
Victory Garden	Deep flow	A-frame	Constant or Intermittent	Electrical	Wooden frame with PVC resting in it	40 gallons	3
Babylon	Deep flow	A-frame	Intermittent	Manual	Metal frame, with wire to hang PVC	40 gallons	3

pipe. Nutrient solution is maintained at a level of 3 in. within the pipes due to standpipe placement. This level was chosen because it is the minimum level at which the bottom of the net pot maintains contact with the nutrient solution. When nutrient solution is added to a pipe via the pump this increases the water level. Nutrient solution therefore flows between the pipes in a descending order back down to the reservoir tank. Water was added to the reservoir tank as need to maintain the nutrient solution level. VIVOSUN pH and E.C. meters were used for all pH and E.C. measurements, respectively.

Babylon system design and operation

The Babylon system used a similar design as the Victory Garden system with the following described adjustments (Fig. 3; Table 3). Pipes were hung by metal wires from a metal frame (Fig. 3). Circulation was completed manually by moving nutrient solution with a five-gallon bucket from the reservoir tank and pouring the solution into the top pipe through a funnel until water moved throughout all pipes for a minimum of 5 min. Either 16 or 32 Yolo Wonder pepper plants were grown in each system.

Seedling production

Seeds were planted into 1 in.^{2} rockwool blocks. The rockwool sheet was watered frequently so the blocks were constantly moist. At the true leaf stage seedlings were thinned to one seedling per hole and quarter-strength nutrient solution was added in place of water. Once seedlings were 2 in. tall, they were transferred to 3-in. diameter plastic net pots. Once transferred, perlite was added to the pots to stabilize the seedlings. Seedlings were watered daily with quarter-strength fertilizer or water on an alternating basis. Seedlings were transferred into the Victory Gardens when they had three or four true leaves and roots were long enough to come through the holes of the net pots, at approximately 3 weeks for BSS and 4 weeks for bell peppers.

Study locations and experiments

Bloomfield, CT, U.S.A. Eight Victory Garden systems were used outdoors to produce Ace bell peppers (Johnny's Seed). Systems were constantly circulated. Yields of pepper fruit per system were recorded in grams (Additional file 1: Table S1).

Hamden, CT, U.S.A. At the Connecticut Agricultural Experiment Station, Victory Garden systems were used to produce BSS. Systems were located inside a greenhouse where temperature was not regulated, but ranged between 15 and 22 °C in replicate 1, 17 and 29 °C in replicate 2, and 21 and 38 °C in replicate 3. Four systems were constantly circulated, and four systems were intermittently circulated. The treatments were arranged in an alternating fashion to allow for electrical connection. All systems contained 20 plants. For the intermittent treatment, the pump ran for 20 min four times per 24 h and the continuous treatment ran the entirety of the experiment duration, apart from those same 20-min time periods when the intermittent system was running to avoid overloading the electrical system. E.C. and pH were measured with VIVOSUN E.C. and pH meters at 1 week after initiation of the experiment to allow complete circulation of the system and then the week of harvest (Additional file 2: Table S2). After 3 weeks in the systems, the aboveground mass of individual plants was weighed in grams (Additional file 2: Table S2). Further analysis was not completed so that the harvest could be donated to a local food pantry. The total decrease in water held by the system reservoir tank was measured in gallons and then converted to liters by multiplying by 3.7854 and then this was divided by the number of days in the experiment to calculate average daily water use (Additional file 2: Table S2). Three independent replicates of this experiment were completed (Additional file 2: Table S2).

Pignon, Haiti. At the Many Hands for Haiti location, Babylon systems were used outdoors to produce Yolo Wonder peppers. In alternating arrangement, 2 systems contained 32 plants and 2 systems contained 16 plants. Fruits harvested from each system were weighed in grams (Additional file 3: Table S3). Two independent replicates of this experiment were completed (Additional file 3: Table S3).

Data analysis and visualization

Kilowatt hours (kWh) were calculated by multiplying the 5-W power of the pump by the duration of the experiment and dividing by 1000 to adjust watt hours to kWh (Additional file 2: Table S2). References to a benchmark for per area production were based on a bulletin from the Connecticut Agricultural Experiment Station bulletin (Maynard 2018) which found the average of pepper production to be 31,200 lbs. per acre. This is equivalent to 327 g per ft^2. This study also found that bell pepper (*Capsicum annuum*) cv. California Wonder peppers, similar to the cv. Yolo Wonder peppers grown in Haiti, yielded 23,232 lbs per acre which is equivalent to 241 g per ft^2 (Maynard 2018). Both Victory Garden and Babylon systems have a footprint of 10ft^2 meaning that target pepper yields for a system was 3270 g of fruit or in 2410 g in the specific case of California Wonder Peppers.

For Table 1, a Welch's t-test was used with a significance value of 0.05 for comparisons between treatment groups for measurements that had a normal distribution. A nonparametric Wilcoxon rank sum test with a significance value of 0.05 was used to test for differences between treatment groups for measurements with a non-normal distribution. A Shapiro–Wilk test was used to test for normality with a p-value cutoff of 0.05 (Additional file 4: Table S4). Figure 1 is created with Biorender.com. Statistical analyses were completed in R version 4.0.2 [46].

Abbreviations

DFT	Deep flow technique
BSS	Black Seeded Simpson Lettuce

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40066-023-00422-8.

Additional file 1. Yield of pepper fruit in individual Victory Garden systems in Bloomfield, CT.

Additional file 2. Yield, water and electrical inputs, electrical conductivity and pH for individual Victory Garden growing Black Seeded Simpson Lettuce in Hamden, CT in three replicates.

Additional file 3. Yield of pepper fruit in individual Babylon systems in Pignon, Haiti in two replicates.

Additional file 4. Results from Shapiro-Wilk test for normality for experimental metrics completed in R version 4.0.2 [46].

Acknowledgements

The Connecticut Agricultural Experiment Station and Many Hands for Haiti provided facilities for the operation of the trials. We are thankful to Christian Heiden and Mark Meyering for contributions to the development of the systems used in our study and to Dr. Eduardo Bernal and Taylor Klass for comments on earlier versions of this manuscript.

Author contributions

IV completed all trials with lettuce and was a major contributor in analyzing data and writing the manuscript. DB and GA completed the trial testing pepper yields in Pignon, Haiti and contributed to designing the experiment. WH completed the trial in Bloomfield, Connecticut. NH was a major contributor to experimental design and writing the manuscript. All the authors read and approved the final manuscript.

Funding

IV, DB and GA were funded by nonspecific donations to Levo International, Inc.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Received: 10 May 2022 Accepted: 2 May 2023

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