

## Urban Hydroponics for Diversified Agriculture: Part II

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### **Problem Statement**

Achieving food security in urban areas has been proven to be challenging. The inability of urban areas to produce their food requirement means that food has to be imported from elsewhere, more often than not from faraway places. If we use lettuce as a model, the nearest source of lettuce for Metro Manila's consumption is Cavite, but still, most of the lettuce that is sold in the markets is from the Cordillera Region of northern Luzon. Lettuce served in hotels as a salad still comes from Mindanao or even as far away as Australia. Traffic congestion, rising fuel prices, and poor road infrastructure has produced a problem in transporting agriculture from rural areas to urban markets where people reside and where the food is consumed. Increase in rates of spoilage of perishable vegetables and transportation costs constitute a food security issue that needs to be addressed. Our proposed solution is urban agriculture. In the previous project, we had shown that raising lettuce hydroponically in open areas such as a building rooftop is not only feasible but may also be profitable. Issues of water and carbon footprints are also

addressed by this method. In this part of the world, Singapore is at the forefront of this technology.

Another method that addresses the environmental concerns of food security is organic farming. Organic farming may also be adopted for urban agriculture. Giving urban farming enthusiasts more choices of methods can help popularize the concept of urban agriculture. The surveys we had done indicate that organic farming is more popular to farming enthusiasts than hydroponics. Furthermore products of organic farming are perceived to be more nutritious than those that are chemically grown (using chemical fertilizers and pesticides). To be able to showcase the merits of hydroponics over other methods, we have compared the yield, growth parameters, nutritional value, and even the chemical contaminants that can be found in lettuce grown using both methods.

## **Review of Related Literature**

### **Urban Agriculture**

It is a widely accepted fact that high yields are central to sustainable food security given a finite land resource (Godfray et al., 2010; Foley et al., 2011), thus creating the motivation for innovative agricultural practices such as urban (e.g., hydroponics) and organic farming. Organic farming is a system aimed at producing food with minimal harm to ecosystems, animals, or humans (McIntyre et al., 2009; De Schutter, 2010). On the other hand, urban agriculture involves the growing, processing, and distribution of food and its by-products by way of intensive plant cultivation and animal husbandry in and around cities (Bailkey & Nasr, 2000). The purpose of urban agriculture is the growing and raising of food crops and animals for the explicit purpose of feeding local populations in urban areas (Goldstein et al., 2011). Among the benefits of urban agriculture include increased access to healthy and affordable produce for urban residents, while creating less pollution from transportation and waste products (Mukherji & Morales, 2010). However, to make full use of the potentials of urban agriculture, city officials should consider a more comprehensive approach for incorporating urban agriculture into their zoning regulations (Mougeot & International Development Research Centre Canada, 2004). To intensify support for urban farming, standards that would regulate the permitted urban farming activities as well as facilitate the sale of goods produced from those regulated activities should be created (Mukherji & Morales, 2010).

## Hydroponics

**The word *hydroponics* was first used by Dr. William F. Gericke in the 1930s. The term describes the agricultural applications of hydroponics, taken from the Greek words *hydro* (“water”) and *ponos* (“labor”; Agricultural Information, 2013).** Hydroponics is a method of growing plants without using soil. In hydroponics, plants get their nutrients directly from solution. This technology is not new. Experiments in growing mint plants without soil can be traced back to 17<sup>th</sup>-century France and England. By 1925, the United States began experimenting with different ways to make plant nutrient solutions in order to replace greenhouse soil that is difficult to maintain. This method allows plants to grow two to 10 times the amount in half the time.

Besides the commercial uses, people can grow plants hydroponically at home by setting up their own system. Home growers need to have the container in which to grow the plants, water that is mixed with nutrients, a light source that can be either natural or artificial lighting, a flow of oxygen, and an appropriate temperature maintained for the type of plant grown. Hydroponics is therefore a good solution for people who live in urban or suburban areas and want to grow and produce flower, fruit, and vegetable crops on a patio, small garden, rooftop, or garage. Many types of plants are suitable for growing hydroponically such as tomatoes, lettuce, carrots, strawberries, melons, parsley, and flowers. Growing plants hydroponically can provide families with fresh, uncontaminated produce that is harvested immediately before use.

Hydroponic technology produces many benefits in that it is highly productive and it conserves water and land. Normally, with hydroponics, plants grow inside enclosures that control temperature, light, water, and nutrition. Hydroponics is a cleaner way to grow plants and is useful when land and natural resources are scarce. The plants produced are of better quality than plants that come from soil because soil contains impurities and bacteria.

## Organic Farming

Organic farming or agriculture matches—or even exceeds—conventional yields. While nonorganic methods resulted in slightly higher yields in developed areas, organic methods resulted in slightly higher yields in developing areas (Badgley et al., 2006). Other studies (Crowder et al., 2010; Bengtsson et al., 2005) have also suggested that organic agriculture can have a reduced environmental impact compared to conventional agriculture. Likewise, organic farms had been observed to withstand severe weather conditions better than conventional farms, sometimes yielding 70%–90%

more than conventional farms during droughts (see Lotter, 2003). It has been suggested that organic farming could actually produce enough food per capita to sustain the current human population (UNEP-UNCTAD, 2008). Organic agriculture can also improve farmer livelihoods owing to cheaper inputs, higher and more stable prices, and risk diversification (Scialabba & Hattam, 2002). However, organic farming is often an export-oriented system tied to a certification process by international bodies; therefore, its profitability can likely vary between locations and years (Valkila, 2009; Raynolds, 2004).

There are four types of organic farming models in the Philippines, namely, (1) indigenous organic farming, (2) traditional organic farming or the pre-“green revolution” type of farming, (3) large-scale commercial farms, and (4) the small-scale subsistence organic farming (Carating & Tejada, 2012). Indigenous agriculture is known to be intertwined with indigenous culture, customs, and beliefs and has largely remained isolated and unintegrated into the mainstream of Philippine agriculture. In more ways than one, indigenous organic farming mirrors natural farming in that they both are a closed system, which demands no inputs and mimics nature (Mirret, 2001). Traditional organic agriculture can be considered as a step-up development from indigenous farming practices. Traditional Filipino organic farmers are more likely to practice a variation of biodynamic agriculture that revolves around the concept of treating soil fertility, plant growth, and livestock care as ecologically interrelated tasks; proponents have described the method as a holistic understanding of agricultural processes (Abbot & Murphy, 2007). Large-scale commercial organic farming enables local producers to compete with multinational corporations and afford the cost of organic certification. They are known to adopt modern organic practices by doing their own breeding, fertilizer production, and pesticide concoction, vertical and horizontal integration of operations by waste recycling as they follow biodynamic and natural farming principles. Commercial organic farming is not necessarily all on the export trade, as they also focus on the increasing organic preferences of domestic consumers (Carating & Tejada, 2012). Conversely, small-scale subsistence organic farming is practiced by small-time farmers who wish to free themselves from depending on multinational agro-chemical companies and seed corporations. These farmers breed their own seed requirements, produce their fertilizers, concoct their botanical-based pesticides, and practice biodynamic and natural farming principles. Small-scale subsistence organic farms are into multiple cropping, diversified, and integrated farming so that they are sufficient in their food needs, selling the excess to be able to purchase those items needed but could not produce in the farm. Small-scale organic farmers are likely practitioners of bio-

intensive agriculture, which emphasizes greater yields despite a minimum area of land, while continually improving and maintaining the fertility of the soil (BIONICA, 2013).

## Conceptual Framework

The present project sought to establish that lettuce grown using urban hydroponics is comparable in productivity and marketability with those grown using organic methods in terms of nutrient content and environmental footprints. Metrics derived from the project include the amount of nutrient applied per growth output, the nutrient content of the yield and levels of chemical contamination in urban hydroponics measured against organically grown lettuce. This project hoped to derive added value to urban hydroponics crops by generating evidence that hydroponically grown lettuce is comparable if not better than those that are organically grown in terms of nutrient content. The comparative levels of contaminants to the harvested lettuce from both methods were also investigated to illustrate food safety.

## Research Questions

The following research question was addressed: How does hydroponics and organic farming of lettuce compare with one another in terms of:

1. Percentage germination, maturation period, and harvest yield when grown using hydroponics and when vermicasts applied as vermitea were applied as fertilizer;
2. The level of vitamins and mineral (vitamin A, vitamin D3, and vitamin E or  $\alpha$ -tocopherol) of the harvested yield when grown using hydroponics and when vermicasts are applied as fertilizer; and
3. The level of contaminants (heavy metals Cu, Pb, and Cd; diesel fuel combustion product oxirane, tetradecyl; plant metabolite 1,2 dithiane; and pesticides endosulfan and dieldrin) of the harvested yield when grown using hydroponics and when vermicasts are applied as fertilizer.

Methodology

The study employed the experimental design shown in Table 1, in order to compare the performance of hydroponics and organic agriculture. Growth data, which included percentage germination, maturation period, and harvest yield, were compared between both setups. Nutrient content and toxicity were also studied.

Table 1. The Experimental Design of the Study

Culture Method	Nutrient Source	Parameters
Hydroponics	Commercial nutrients	Growth data
Organic method	Vermitea	Nutrient content
		Toxin content

This project is a continuation of the hydroponics project (using the nutrient film technique) performed on the rooftop of St. Joseph Hall at De La Salle University. The setup is comprised of PVC pipes where the hydroponic solution is circulated every 8 hr using solar-powered pumps. The solutions were also bubbled with air using aquarium compressors that are also solar powered. All in all, 100 plants could be grown in this setup. The plants were protected from direct sunlight, wind action, and predatory birds by several layers of nets.

For this project, the lettuce (Romaine variety) was raised using the hydroponics method described above and using organic farming methods done in the De La Salle University–Dasmariñas campus. The organic methods used include the sowing of seedlings in pure garden soil in plots, sowing in different proportions of garden soil, and vermicasts in plots or in different containers (Table 1). The combinations are shown in Table 2 below. The plants will be harvested at maturation.

Table 2. The Media and the Corresponding Containers Used in the Organic Culture Method Used

#	Medium	Container Used
1	Pure garden soil	Garden plot
2	75% Garden soil: 25% vermicast	Garden plot
3	50% Garden soil: 50% vermicast	Garden plot
4	50% Garden soil: 50% vermicast	Small container

Table 2 continued...

5	50% Garden soil: 50% vermicast	Medium container
6	50% Garden soil: 50% vermicast	Large container
7	50% Garden soil: 50% vermicast	Halved bamboo shoot

### Procedures for Determining the Level of Nutrients of Harvested Lettuce Leaves

#### *Metal Analysis of Samples and Medium Used*

Analysis of metals in the samples was performed using the Shimadzu Atomic Absorption Spectrophotometer (AA-6300). One gram each of freeze-dried vegetable samples and oven-dried soil samples were subjected to dry ashing and acid digestion, respectively. Dry ashing was done by placing the vegetable samples on a dried crucible, which were heated using a furnace set at 480°C for 4 hr. The ash was treated with acid and was diluted to 25 mL using deionized water. Acid digestion of soil samples was done using a modified method by Badri (1984). Soil samples were placed into separate Erlenmeyer flasks, which were treated with 25:10 HNO<sub>3</sub>/HCl. The samples were placed on a sand bath maintained at 100°C. Digestion was ceased when the solution turned clear. The samples were filtered and were diluted to 25 mL using deionized water.

Metal standards (Cu, Pb, and Cd) with varying concentrations (0.05 to 10 ppm) were prepared from 1,000-ppm stock solutions to generate standard curves. Analysis of the standards and samples was performed using the Shimadzu Atomic Absorption Spectrophotometer (AA-6300). The amount of metals (ppm) present in the samples was calculated from the standard curve generated.

#### *Analysis of Vitamins A, D3, and E From the Harvested Lettuce Leaves*

HPLC analysis was performed on an Agilent Technologies 1200 Series HPLC with a UV detector. A reversed-phase C18 column was used as stationary phase.

The extraction of the three fat-soluble vitamins from the samples was patterned from a method by Konings et al. (1996). One gram of freeze-dried samples was placed in an Erlenmeyer flask. The samples were subjected to saponification for 40 min at 80°C after adding a mixture of 6-mL water, 4.2-g potassium hydroxide (KOH), 20-mL ethanol, and 0.25-g ascorbic acid. Distilled water (60 mL) was added to the flask to bring the ratio of ethanol/

water to 0.3. The saponified mixture was extracted with 9:1 n-hexane/ethyl acetate (20 mL × 3). The organic layer was collected and was evaporated at 40°C under reduced pressure. The residue was dissolved in 4 mL of n-hexane prior to analysis.

Standards with concentrations ranging from 0 ppm to 200 ppm were prepared for the standard calibration technique. Analysis was performed using an Agilent Technologies 1200 Series HPLC with a reversed-phase C18 column. The equipment utilized a gradient solvent system consisting of methanol/water at a flow rate of 1.0 mL/min. The analysis was monitored using a UV detector set at 210 nm for 21 min (Agilent Technologies, 1998; see Table 3 below). The concentrations of the vitamins were reported in micrograms per gram sample based on the generated calibration curves.

Table 3. Agilent Technologies 1200 Series HPLC with a UV Detector Data

Injection volume	5 µL
Column temperature	20°C
Mobile phase	A = Water B = Methanol
Gradient system	At 0 min 90% B At 15 min 100% B At 20 min 100% B At 21 min 90% B (column wash)
Flow rate	1.0 mL/min
UV detector	210 nm
Column	Supelco C18 25 cm × 4.6 mm × 12 µm

*Analysis of Pesticide Residues From the Harvested Lettuce Leaves and Medium Used*

Analysis of pesticide residues was done using a Perkin–Elmer gas chromatograph (Clarus 500 GC) with an Elite 5MS GC column and characterized using MS. The method used for the pesticide analysis is patterned from an official method by AOAC International (2007). The method employed is a Quick, Easy, Cheap, Effective, Rugged, and Safe (QuEChERS) procedure, which is being used by many researchers focusing on pesticide analysis. One gram of sample was placed in a tube, followed by spiking with 80 µL of 500 mg/L of Endosulfan standard. A 1.00 mL of acetonitrile (with 1% acetic acid) and 0.5 g of 4:1 magnesium sulfate/sodium



acetate ( $\text{MgSO}_4/\text{NaOAc}$ ) were then added to the same tube. The tube was vortex mixed and was centrifuged at 4,000 rpm for 5 min. The upper layer was collected and was transferred into a 2-mL plastic vial. Then, 0.2 g of Florisil was added to the tube for sample clean-up. The vial was vortex mixed and centrifuged at 13,000 rpm for 2 min. The final extract was filtered by Millipore and was transferred into a GC vial prior to instrumental analysis.

The amount of pesticide residues was calculated using the internal standard addition method and was reported as microgram of pesticide residue per gram sample. The parameters used are summarized in Table 4 below.

Table 4. Perkin–Elmer Gas Chromatograph (Clarus 500 GC)  
With an Elite 5MS GC Column Data

Carrier gas	Helium (30 cm/sec)		
Injector temperature	275°C		
Injection type	Splitless		
Oven program	T	Hold Time	Rate
	80°C	0 min	20°C/min
	290°C	4.75 min	End
GC inlet temperature	275°C		
Ion source temperature	275°C		
Scan range	40–450 m/z		

**Statistical analysis.** All data reported are mean values of at least a duplicate setup and at least duplicate samples or duplicate instrument readings. All comparisons between data from the hydroponics setup and the organic method setup were subjected to Student’s *t*-test ( $\alpha = 0.05$ ) to determine if there is a significant difference between the two results.

## Results and Discussion

### Comparison of Growth Effects in Terms of Percentage Germination, Maturation Period, and Harvest Yield

The percentage germination in both setups (the hydroponics method and the organic method) was at around 85%, which is close to what has been advertised by the source of the seeds (Condor quality seeds from Allied

Botanical Corporation). However, the plants grown using the hydroponics method or using the hydroponics medium grew faster and were harvestable already 21 days after sowing (Table 5). The plants grown organically using vermicasts as nutrient source and garden soil as medium were harvested 52 days after sowing.

The harvest yield or mean weight at harvest of lettuce grown using different media and containers is also shown in Table 5. The soil-grown lettuce plants do not vary much in harvest weight regardless of container. Analysis by Student's *t*-test also indicated that there is no difference in the mean harvest weights of lettuce grown in garden plots and those grown in containers, although plant density apparently affects the harvest weight inversely meaning smaller containers (thus more densely planted) seem to have lower yield.

Even if the hydroponically grown lettuce was smaller at harvest size, as indicated by Student's *t*-test, maturation takes less than half the time as that grown in soil. These results indicated that the overall harvest yield of hydroponically grown lettuce could be higher (even if yield in terms of biomass is lower) since the maturation period is shorter, and therefore, more harvesting could be done in the same period as in the organic method.

Table 5. The Mean Weight of Lettuce Harvested Using Different Farming Methods, Media, and Containers

	Medium	Container Used	Plant Age at Harvest (days)	Mean Weight (g) [Sample Size]
1	Hydroponics solution	Hydroponics set up	21	5.2 [100]
2	Hydroponics solution	Hydroponics set up	21	5.5 [100]
3	Hydroponics solution	Hydroponics setup	21	7.5 [100]
4	Pure garden soil	Garden plot	52	10.6 [26]
5	75% Garden soil: 25% vermicast	Garden plot	52	9.1 [22]
6	50% Garden soil: 50% vermicast	Garden plot	52	6.8 [33]
7	50% Garden soil: 50% vermicast	Small container	52	6.8 [28]
8	50% Garden soil: 50% vermicast	Medium container	52	10.2 [22]
9	50% Garden soil: 50% vermicast	Large container	52	11.9 [21]
10	50% Garden soil: 50% vermicast	Halved bamboo shoot	52	8.3 [15]

### Comparison of Nutrient Value in Terms of Vitamin and Mineral Content

To be hale and hearty, we need proper nutrition, exercise, and a healthy lifestyle. Proper nutrition is an essential part of this regiment, and vitamins and minerals are essentials that we get from our food. The US Food and Drug Administration (USFDA) lists 13 vitamins that are recommended to be taken daily. As vegetables including lettuce have to be transported across large distances before they reach the consumer, we limited the monitoring of the vitamin content of lettuce in this study to the vitamins that remain stable during storage. These are vitamins A, D, and E. Copper was also monitored because it has served as an essential mineral for biochemical reactions at low quantities but could have toxic effects at large concentrations.

Vitamin A plays a role in a variety of functions throughout the body including vision, gene transcription, immune function, embryonic development and reproduction, bone metabolism, blood cell formation and maturation, skin and cellular health, and antioxidant activity. Derivatives of vitamin A are also currently in use for cancer, HIV, and dermatological purposes (Sommer, 1995; WHO, 2014). The most prominent symptom of vitamin A deficiency is impaired vision. An overdose of vitamin A is also not healthy. The symptoms of overdosage of vitamin A are given in Table 6.

Table 6. The Mean Vitamins and Mineral Content of Lettuce Grown Using Two Different Methods

Nutrient	Hydroponics Levels (µg/g)	Organic Method Levels (µg/g)	Recommended daily intake	Vitamin or Mineral Information	Overdosage (mg or µg/d) (Primary Reference Is USEPA or USFDA)
Vitamin A	60–83	58.6–69.4	600 µg	Vitamin A in food and as a supplement	Extremely high doses (>9,000 mg) can cause dry, scaly skin; fatigue; nausea; loss of appetite; bone and joint pains; and headaches.
Vitamin D (cholecalciferol)	0.0–44.6	5.9–6.1	5 µg	Vitamin D in food and as a supplement	Large doses (>50 µg) obtained from food can cause eating problems and ultimately disorientation, coma, and death.
Vitamin E (tocopherol)	2.43–23.58	8.29–8.82	10 mg	Vitamin E in food and as a supplement	Doses larger than 1,000 mg cause blood clotting, which results in increased likelihood of hemorrhage in some individuals.
Copper	0.23–0.63	0.63–95.9	2 mg	Copper in food and as a supplement	As little as 10-mg copper can have a toxic effect and gram quantities are potentially lethal.

Results of this study indicated that the vitamin content of lettuce in both agricultural methods used is at the same level as shown in Table 6. If we consider that the average amount of lettuce intake in a meal is from 50 to 100 g, the amount of Vitamin A from lettuce already satisfies the recommended daily intake of 600 µg.

Vitamin D (the form we detected is cholecalciferol) is responsible for enhancing intestinal absorption of calcium and phosphate. We can get vitamin D from diet, but we can also synthesize vitamin D (specifically cholecalciferol) in the skin, from cholesterol, when sun exposure is adequate. Thus, this makes the practice of exposing infants to early morning sun for the purpose of strengthening the bones. Vitamin D deficiency is known to cause bone diseases including rickets, osteomalacia, and osteoporosis and muscle aches and weaknesses and muscle twitching (Heaney, 2004; Holick, 2007).

As with vitamin A, the results of the study showed that the levels of vitamin D in lettuce harvested from both agricultural methods are in the same dimensions. Furthermore, the vitamin D levels from the lettuce that were harvested from both setups are high and can even be toxic when lettuce is eaten in large quantities. As shown in Table 6, vitamin D obtained from food in concentrations greater than 50 µg can already cause eating disorders and in extreme concentration even coma and death. This should not be surprising since wild lettuce had been reported previously to be toxic (Besharat et al., 2009).

Vitamin E (tocopherol) is a fat-soluble antioxidant that stops the production of reactive oxygen species formed when fat undergoes oxidation (Brigelius-Flohé & Traber, 1999). However, more recent studies have suggested that its cell-signalling function is its main role and that it may not have a significant role in antioxidant metabolism (Zingg & Azzi, 2004; Azzi, 2007). Other functions of tocopherol include enzymatic activities, gene expression, and neurological functions. Vitamin E deficiency can cause spinocerebellar ataxia, myopathies, peripheral neuropathy, ataxia, skeletal myopathy, retinopathy, impairment of the immune response, and red-blood-cell destruction (Tanyel & Mancano, 1997; Hathcock, 1997; Fuller et al., 1998; Traber et al., 2008; Steinraths et al., 2008; Pekmezci, 2011; Traber & Stevens, 2011; Bromley et al., 2013).

Copper is an essential nutrient involved in the function of several enzymes. Copper is required for infant growth, host defense mechanisms, bone strength, red- and white-blood-cell maturation, iron transport, cholesterol and glucose metabolism, myocardial contractility, and brain development. Copper deficiency can result in the expression of an inherited defect such as Menkes syndrome or in an acquired condition (Olivares & Uauy, 1996).

Comparatively, both treatment groups have high levels of copper in relation to the recommended daily intake for this essential nutrient, but the copper levels of lettuce cultured using the organic method are higher than the hydroponically grown group. This should be a positive character for the plant, but the high levels of copper in lettuce also support the allegation that lettuce can be toxic. According to the United States Environmental Protection Agency (USEPA), 10 mg in the diet can already be toxic, and gram quantities can be lethal.

A potential source for the high copper levels observed in the two setups is the copper in the floral foam used in the hydroponics setup and in the vermicast in the organic farming setup. Floral foams are used to improve water absorption by plants in a controlled amount (Landrock, 1995). However, the copper content in the medium of both setups was in the low milligram-per-gram levels or parts per thousand. The level of copper in the floral foam is about 25% of that found in the vermicast. Floral foams can also contain resins, the components of which include phenol and formaldehyde.

### **Comparison of the Level of Contaminants**

Plants can take up chemical contaminants from the soil or other media. Contaminants from the soil tend to travel through the plant via absorption of the roots and adsorption on the surface of plant organs. Although plants readily contain minerals in their different compartments, they could accumulate additional metals depending on their physiological capacity (Peralta-Videa et. al, 2009; Tomas et. al., 2012). Containers used in planting crops could also affect chemical contaminant uptake. Containers used in planting vary from woods, tires, metals, plastics, and clay pots (Vick & Poe, 2011). The use of wood does not affect heavy metal consumption by plants until 1994, when lumber was treated with chromium, copper, and arsenic. Studies found that these metals could be deposited into the soil and absorbed easily by plants (Rahman et al., 2004). Plastics are generally used in planting and have been found to have no effect on metal absorption. However, plastics that are made of polyvinylchloride may contain metal residues such as lead, zinc, cadmium, and copper, which are absorbed by the soil and the plant (Mathe-Gaspar & Anton, 2005).

Some of these contaminants like heavy metals are considered to be toxic to humans. Copper, cadmium, and lead are the most common heavy-metal contaminants found in the soil that could be transferred to plants. Copper though is essential for plants' cellular processes, but relatively high amounts may be detrimental to the plant and to those who consume these plants. Cadmium and lead are found to be more toxic than copper. Nevertheless

plants do not accumulate or absorb a substantial amount of lead due to its ability to bind tightly with the soil particles. This is even if lead is found mostly on the surface of the leaves or the roots (Angima, 2010). Cadmium on the other hand is found to be mobile in soil and could be readily absorbed by plants at neutral and alkaline pH (Vick & Poe, 2011). High amounts of copper could generate free radicals leading to cancer as well as damage of proteins, lipids, and DNA (Brewer, 2010). Cadmium poisoning targets the liver, placenta, kidneys, lungs, brain, and bones, while lead poisoning could trigger birth defects, retardation, vertigo, seizures, weakness, and paralysis (Roberts, 1999; Ferner, 2001).

Table 7. The Mean Content Chemical Contaminants Detected in Lettuce Grown Using Two Different Methods

Contaminant	Category	Hydroponics Levels (µg/g)	Organic Method Levels (µg/g)	LD50 (Human)	Reference
Cadmium	Heavy metal	6.9–11	7.5–11	20–130 mg/kg	United States Food and Drug Administration
Lead	Heavy metal	0.22	0.19–0.31	714 mg/kg	United States Center for Disease Control
Copper	As heavy metal	0.23–0.63	0.63–95.9	Gram quantities (adult individual)	United States Environmental Protection Agency
Oxirane, tetradecyl	Bioactive compound or sterilant	6.9–11	7.5–11	100–200 mg/kg	United States Public Health Service
1,2 Dithiane	Bioactive compound or pesticide	94	13	410 mg/kg (in rodents)	America Chemical Society
Endosulfan	Insecticide	0.74–1.46	0.48–1.34	35 mg/kg	United States Environmental Protection Agency
Dieldrin	Termicide	—	—	5 mg per adult individual	United States Center for Disease Control

The heavy-metal contaminants of the two setups (hydroponics and organic farming) were at the same levels with one another (Table 7). As was mentioned above for copper contamination, the heavy-metal content of the floral foam and the vermicast can be potential sources of the heavy

metals analyzed from the harvested lettuce leaves. In terms of heavy-metal contamination, the measured levels in the leaves are not yet at hazardous levels.

Four other chemical contaminants were identified in the GC–MS assay, namely, oxirane, dithiane, dieldrin, and endosulfan. These compounds were consistently present in all of the chromatograms and were selected to be monitored due to their potential adverse effects on humans, vegetation, and the environment. The four compounds are found to be components of insecticides or pesticides.

Oxirane or ethylene oxide is commonly used as an intermediate in producing industrial chemicals (e.g., ethylene glycol and acrylonitrile) and used in the formulation of products such as soap, detergent, adhesives, antifreeze, and pesticides such as thiiranes (Surendra et al., 2004). Oxirane, tetradecyl has also been identified as a type of additive in plastic production (Saker & Rashid, 2013). Oxirane is also a bioactive compound produced by algae; it has been isolated from *Laurencia brandenii*. Aside from the antimicrobial activity, the extracts also have termiticidal effects (Manilal et al., 2011). In addition, oxirane is also a known fumigant or sterilant used in fumigating heat-sensitive hospital equipment, medical products, cosmetics, and food such as spices, grains, dates, walnuts, copra, and peas. (NTP, 2011) Oxirane was found to be a harmful substance and may cause numerous effects on humans such as sore throat, vomiting, nausea, dizziness, blurred vision, and convulsions. Moreover, epidemiological studies on both humans and animals revealed the potential carcinogenic properties of oxirane (OSHA, 2002). Occupational, consumer (foodstuff), and environmental (air, water, soil) contact are the main exposure routes for oxirane in humans. From a toxicological study, the minimum risk level (MRL) for long-term exposure of humans to breathing oxirane is 0.09 ppm for about 14 weeks and that 5 to 20 years of exposure (3–430 ppm levels in air) could cause serious problems in hand and eye coordination. Longer exposure and higher concentrations of oxirane could lead to more serious effects. Human effects from eating or drinking oxirane are not known; however, it could cause immediate death in rats (ATSDR, 1990). Plant employees exposed to oxirane are limited to 1.0-ppm aerial exposure in an 8-hr time-weighted average (OSHA, 2002). Minimum toxic levels (MTL) and minimum effective levels (MEL) of oxirane as fumigants in plants and vegetables are not known.

The oxirane content of both hydroponically and organically grown lettuce is of the same levels (see Table 7 above). For the hydroponically grown lettuce, the heavy traffic at Taft Avenue and even the floral foam used as a medium are a potential source of the oxirane. This is apparently the same situation in the organic method setup. The vermicast and heavy traffic in the vicinity contributed to the oxirane contamination of the lettuce harvested.

Dithianes are white crystalline organosulfur compounds that are used in the formulation of certain pesticides and insecticides. There are very few researches and studies done on the adverse effects to humans, animals, and plants and the exposure route of this compound (IRIS, 2012). Also, the absorption, distribution, metabolism, and excretion in living organisms are not well known (Schieferstein et al., 1988). However, dithiane is a novel inducer of ER stress proteins (Asmellash et al., 2005). For both setups, dithiane did not come from the medium but most likely from other plants in the vicinity (see Table 7 above).

Dieldrin is a white to tan crystalline solid that is mainly used to control termites. Dieldrin is used and applied to soil and seed dressing applications as well as to crops and foliage such as cotton (Zitko, 2003). Dieldrin was found to be a nervous-system poison and a potential carcinogen. Also, epidemiological studies revealed that the long-term exposure to dieldrin increases risk and susceptibility to breast cancer, and this is correlated to the estrogenicity of the compound (Snedeker, 2001). Exposure to dieldrin may be occupational, consumer, and environmental.

Apparently, lettuce does not take up dieldrin from the medium (see Table 7 above). The undetectable levels of dieldrin in the leaves of lettuce analyzed may be related to the relative low solubility and stability of dieldrin (it is also slowly metabolized by organisms).

In humans, exposure to dieldrin may be due to inhalation of dieldrin in workplace and the ingestion of foodstuff contaminated with dieldrin. In the United States, it was detected in foods analyzed from markets such as dairy and poultry products, egg, legumes, root, and leafy vegetables, and this was associated with the absorption of dieldrin from the soil. Intermediate- and chronic-duration oral MRLs of dieldrin were found to be 0.0001 mg/kg/day (15–364 days of oral exposure) and 0.00007 mg/kg/day (365 days or more), respectively. MTL and MEL to plants and vegetables were not determined (ATSDR, 2002). Dieldrin was not detected in the plant samples analyzed but were detected in the floral foam and the vermicast used as medium.

Endosulfan is a restrictedly used insecticide with a cream to beige crystalline solid appearance. This chlorinated hydrocarbon is widely used against the proliferation of aphids, fruit worms, beetles, termites, moth larvae, and white flies, and it is applied directly on crops and soil. It is released in the environment and consumed by living organisms through several routes: air, water, soil, and food. This pesticide is subjected to long-range aerial transport, and it could be detected at remote locations from sources and to where it was used. In water, endosulfan may be oxidized and undergo biotransformations to produce endosulfan sulfate and endosulfan diol, the former being more toxic and the latter being less toxic than the parent



compound. (Vivekanandhan et al., 2012). As an insecticide, endosulfan is directly applied to soil and crops, and it is chiefly converted to the sulfate form and could penetrate into plants.

Dietary intake (as residue in foodstuff such as fruits and vegetables) is the main exposure route of endosulfan. However, the endosulfan levels from both setups were low in comparison to the lethal doses ( $LD_{50}$ ) prescribed for humans (see Table 7 above) and at the same levels with one another. Generally, endosulfan targets the nervous system of both humans and animals. Exposure to high concentrations of endosulfan could result to hyperactivity, tremors, decreased respiration, dyspnea, salivation, tonic-clonic convulsions, and death to humans. The acute and intermediate oral MRL of endosulfan to humans and animals are 0.007 mg/kg/day and 0.005 mg/kg/day, respectively (ATSDR, 2013).

The floral foam used in the hydroponics setup contains endosulfan. As floral foams are used for increasing the “shelf life” of cut flowers, endosulfan could be used by the suppliers of floral foam as an insecticide to get rid of aphids that may spoil the presentation of the bouquet. The endosulfan contamination in the hydroponics may have been from the floral foam. As an insecticide, endosulfan is directly applied to soil and crops, and it is chiefly converted to the sulfate form and could be taken up by plants. The situation in the organic farming setup is different. There is no endosulfan detected in the vermicast. The possible sources of endosulfan in this case are the surrounding farms and gardens in the vicinity. As mentioned above, endosulfan can travel distances as wind-borne particles.

## Conclusion

The results of the present study indicate that the hydroponics method shortens the growth period although the yield of the organically grown lettuce is larger and heavier. However, the shortened maturation period can be translated to more planting seasons and therefore a higher yield. In terms of nutrient value, there is little or no difference between the lettuce leaves from both setups. This is also the same observation regarding the contaminants found in plants from both setups. Overall, data gathered from these experiments suggest that lettuce plants grown using the hydroponics method is in fact comparable to organically grown plants in terms of nutrient content. These findings add value to urban agriculture in the form of hydroponics because the yield is not only higher but also is comparatively speaking as nutritious as organically grown plants. The question of whether hydroponically grown lettuce is safer to eat than organically grown lettuce is not easy to answer. Apparently, the contaminants found in the lettuce are

a factor of where they are grown and what materials have been used in the cultivation process. Interestingly, our observations also suggest that plants are able to pick up chemicals from the environment, so one should be more aware of his/her surroundings when cultivating plants most especially in the urban environment.

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