Comparative Analysis on Lettuce Quality Produced From Urban Agriculture and Organic Farming

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ABSTRACT

A previous project has proven that urban agriculture is feasible and more environment friendly than traditional agriculture. The question if the yield of urban agriculture through hydroponics is comparable to organic farming or not arose. Evidence gathered showing comparability should provide added value to the products of urban agriculture. This can in turn make the practice of urban agriculture not only more profitable but also more attractive. A hydroponics setup was placed in the rooftop of St. Joseph Hall of De La Salle University in Manila. The organic farming setup was placed in the grounds of De La Salle University in Dasmariñas City, Cavite. Both locations are in urbanized locations, but the Dasmariñas setup is also in the vicinity of farms and orchards. Results indicate that hydroponically grown lettuce can be grown faster. However, the nutrient content of the yield and other chemical contaminant content for both methods of agriculture are comparable with one another.

Keywords: Urban agriculture, hydroponics, organic farming, romaine lettuce, Dieldrin

The majority of the world's population resides in urban areas, and the urban population is estimated to grow by 1.84% per year between 2015 and 2020 (Global Health Observatory, n.d.). As the global urban population is expected to exceed 6 billion by 2045, managing urban areas represents an important development challenge for the 21st century (United Nations, 2014). One of the issues in creating a sustainable urban environment involves ensuring adequate food supply. Urban agriculture presents itself as a viable practice in achieving food security. 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 in order to feed the local populations (Bailkey & Nasr, 2000, and Goldstein et al., 2011). Considering that high yields are central to a sustainable food supply given a finite land resource in urban areas (Godfray et al., 2010, and Foley, et al., 2011), creating the motivation for innovative agricultural practices such as hydroponics and organic farming is thus imperative if food supply in cities is to be maintained. 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).

Hydroponics is a method of growing plants without using soil. In hydroponics, plants get their nutrients directly from solution, and this method allows plants to grow 2 to 10 times the amount in half the time (Agricultural Information, 2013). Hydroponic technology produces many benefits in that it is highly productive and it minimizes water and carbon footprints (Taylor et al., 2012, and Carandang et al., 2013). 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 soil-borne pathogens. Thus, hydroponics is 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.

On the other hand, organic farming is a system aimed at producing food with minimal harm to ecosystems, animals, or humans (McIntyre et al., 2009, and De Schutter, 2010). Organic farming or agriculture matches or even exceeds yields from conventional farming. While nonorganic methods result in slightly higher yields in developed areas, organic methods result in slightly higher yields in developing areas (Badgley et al., 2006). Other studies (Crowder et al., 2010, and Bengtsson et al., 2005) have also suggested that organic agriculture can have reduced environmental impact compared to conventional agriculture. 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 farmers' livelihood owing to cheaper input, higher and more stable prices, and risk diversification (Scialabba & Hattam, 2002).

In a previous project (Taylor et al., 2012, and Carandang et al., 2013), it was shown that raising lettuce hydroponically in open areas such as a building rooftop not only is feasible but may also be profitable. The objectives of this study were, first, to determine if the lettuce grown using urban hydroponics is comparable with those grown using organic methods in terms of productivity, nutrient content, and environmental footprints. Metrics used in this study 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. The results obtained from the present study can add value to urban hydroponics crops by generating evidence that hydroponically grown lettuce is comparable if not better than those that are organically grown, The second objective is to compare the levels of contaminants in the harvested lettuce from both methods to check for food safety.

MATERIALS AND METHODS

In the present work, Romaine lettuce (*Lactuca sativa* L.) was grown using the hydroponics and organic farming methods. The hydroponics setup was constructed on the rooftop of a six-story building at DLSU in Manila. It was constructed using PVC pipes through which the hydroponic solution is circulated every eight hours using solar-powered pumps. The nutrient solution is aerated by bubbling air using aquarium compressors. A total of 100 plants are grown in this setup. The plants are protected from direct sunlight, wind action, and predatory birds by several layers of nets.

Table 1. Experimental Design of the Study

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

The other batch was grown in an orchard area at the DLSU–Dasmariñas campus using organic methods. Seedlings were sown in pure garden soil in plots with different proportions of garden soil and vermicasts in plastic seedling bags. The combinations are shown in the Table 2.

Table 2. 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
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

Metal Analysis. Analysis of the metal content of the samples was performed using a Shimadzu Atomic Absorption Spectrophotometer (AA-6300). In a typical run, one gram each of freeze-dried vegetable samples and oven-dried soil samples was subjected to dry ashing and acid digestion, respectively. Samples were dry ashed in a porcelain crucible at 480ºC for 4 hours. The ash was treated with HNO_3 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 treated with 25:10 HNO_3/HCl in Erlenmeyer flasks and heated over a sand bath at 100ºC. Digestion was stopped when the solution turned clear. The samples were filtered and diluted to 25 mL with deionized water prior to AAS analysis.

Vitamin A, D_3, and E Analysis. The method used was an adaptation of the method of Konings et al. (1996) using an Agilent Technologies 1200 Series HPLC with a UV detector and a reversed-phase C18 column. The gradient solvent system consisted of methanol/water at a flow rate of 1.0 mL/min. The results were reported in μg/g sample.

In a typical run, 1 g of freeze-dried samples was saponified for 40 min at 80ºC with 6 mL of water and 4.2 g of potassium hydroxide (KOH). The saponified mixture was extracted with 9:1 n-hexane/ethyl acetate (20 mL × 3). The organic layer was collected and was evaporated at 40ºC under reduced pressure. The residue was dissolved in 4 mL of n-hexane prior to analysis.

Table 3. HPLC Analysis Parameters

Injection volume	**5 µL**
Column temperature	20ºC
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

Pesticide Residues Analysis. The method used for the pesticide analysis was adapted from an official method by AOAC International (2007) using a Perkin–Elmer gas chromatograph (Clarus 500 GC), Elite 5MS GC column, and MS detector.

In a typical run, 1 g of sample was placed in a tube and spiked with 80 µL of 500 mg/L of endosulfan standard. Acetonitrile (1.0 mL, with 1% acetic acid) and 0.5 g of 4:1 magnesium sulfate/sodium acetate ($MgSO_4$/NaOAc) were then added. The tube was vortex mixed and was centrifuged at 4000 rpm for 5 min. The upper layer was collected and transferred into a 2-mL plastic vial followed by addition of Florisil (0.2 g). The vial was vortex mixed and centrifuged at 13000 rpm for another 2 min. The final extract was filtered by Millipore and was transferred into a GC vial prior to analysis. The results were reported as microgram of pesticide residue per gram sample.

Table 4. Gas Chromatography–Mass Spectroscopy Parameters

Carrier gas	Helium (30 cm/sec)		
Injector temperature	275C		
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 duplicates. Data from the hydroponics and organic methods were subjected to Student's *t*-test ($\alpha = 0.05$).

RESULTS AND DISCUSSION

The percentage germination in both batches (the hydroponics method and the organic method) were at ~85%, in agreement with the packet label (Condor quality seeds from Allied Botanical Corporation). However, the plants grown using the hydroponics method had a higher growth rate and were ready/matured for harvest within 21 days from sowing (see Table 5). The plants grown organically using vermicasts as nutrient source and garden soil as medium were ready/matured for harvesting 52 days after sowing.

The harvest yield or mean weight at harvest of produce from different growing conditions

Table 5. Mean Weight of Lettuce Harvested Using Different Farming Methods

#	Medium	Container Used	Plant Age at Harvest (days)	Mean Weight (g) [Sample Size]
1	Hydroponics solution	Hydroponics setup	21	**5.2** [100]
2	Hydroponics solution	Hydroponics setup	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]

are shown in Table 5. The soil-grown plants do not vary much in harvest weight regardless of container. Analysis by Student's *t*-test also indicated 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 a lower yield.

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

Our results indicate that the vitamin content of lettuce in both production methods are comparable (Table 6). As with Vitamin A, the results of the study indicate that the levels of Vitamin D in lettuce harvested from both methods are comparable and are quite high (Table 6). The two groups have high levels of copper relative to the recommended daily intake. The copper levels in lettuce grown using the organic method is higher than the hydroponics group. (Note: According to the United States Environmental Protection Agency (USEPA), 10 mg/gram in the diet can already be toxic and gram quantities can be lethal.)

A possible source of copper observed in the two setups might be a) the floral foam used in hydroponics and b) the vermicast in the organic farming setup. This remains to be confirmed. 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 (ppt). The level of copper in the floral foam is about 25% of that that is found in the vermicast.

Other 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,

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

Nutrient	Hydroponics Levels (μg/g)	Organic Method Levels (μg/g)	Recommended Daily Intake	Vitamins or Mineral Information	Overdosage (mg or μg/d) (primary reference is USEPA or USDFA)
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 of copper can have a toxic effect, and gram quantities are potentially lethal.

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 (Vic & Poe, 2011).

Interestingly, the use of wood did not affect heavy metal uptake by plants until 1994, when lumber was treated with chromium, copper, and arsenic. Studies found that these metals could be deposited to the soil and absorbed easily by plants (Rahman et al., 2004). Plastics are generally used in planting and were 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).

The heavy-metal contaminants from the two setups (hydroponics and organic farming) were at the same levels with one another (see Table 7). As was mentioned 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. However, the measured levels of the heavy metals 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

Table 7. Mean Chemical Contaminant Content Detected in Lettuce Grown Using Both 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 g/adult individual	United States Center for Disease Control

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 compounds produced by algae; it has been isolated from *Laurencia brandenii*. Aside from the antimicrobial activity, the extracts also have termicidal effects (Manilal et al., 2011). In addition, oxirane is also a known fumigant or sterilant used in fumigating heat-sensitive hospital equipments, 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 human 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 from breathing oxirane is 0.09 ppm for about 14 weeks and that 5 to 20 years of exposure (3- to 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 are of the same levels (see Table 7 above). For the hydroponically grown lettuce, urban traffic might be a possible source. This was apparently the same situation in the organic method setup. The vermicast and heavy traffic in the vicinity may have contributed to the oxirane contamination.

Dithianes are organo-sulfur white crystalline 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 human, animals, and plants and the exposure route of this compound (IRIS, 2012). Also, the absorption, distribution, metabolism, and the 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 probably did not come from the medium and 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 foliages such as cotton (Zitko, 2003). Dieldrin was found to be a nervous-system poison and a potential carcinogen. Also, epidemiological studies revealed that 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 in the workplace and the ingestion of contaminated foodstuff. In the United States, dieldrin was detected in foods analyzed from markets such as dairy and poultry products, egg, legumes, and root and leafy vegetables, and this was associated with the absorption of dieldrin from the soil. Intermediate and chronic duration oral MRL of dieldrin were found to be 0.0001 mg/kg/day (15–364 days 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 was detected in the floral foam and the vermicast used as medium.

Endosulfan is a restricted-use 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 to 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 & Duraisamy, 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) and are comparable.

The floral foam used in the hydroponics setup contains endosulfan. As floral foams are used for increasing the “shelf life” of cut flowers, endosulfan might have been applied by the suppliers of floral foam. 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.

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 cycles and therefore a higher yield. In terms of nutrient value, there is little or no difference between the lettuce from both setups. This is also the same observation found for the contaminants in plants from both setups. Overall, data gathered from these experiments suggest that lettuce plants grown using the hydroponics method are 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 as nutritious as the organically grown plants. The question of whether hydroponically grown lettuce is safer to eat than organically grown lettuce is not easy to answer. The contaminants found in lettuce are a factor of where they are grown and what materials have been used in the cultivation process. It is of no surprise that plants are able to pick up chemicals from the environment as we observed and suggests that such be taken into account when implementing urban agriculture.

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