MAKING GLOBAL CITIES SUSTAINABLE: URBAN ROOFTOP HYDROPONICS FOR DIVERSIFIED AGRICULTURE IN EMERGING ECONOMIES

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Abstract: Food security will be a challenge for global cities in emerging economies. Traffic congestion, rising fuel prices, and poor road and logistical infrastructure has produced a problem in transporting agriculture from rural areas to urban markets where people reside and where the food is consumed. Urban roof agriculture is being explored in various global cities as a method to increase food security, enhance environmental awareness and as a key strategy for urban sustainability. This paper discusses the capacity of cities to reduce both their ecological and carbon footprints through utilizing under-used roof space in larger global cities to grow food. Data for quantifiable projections relies on a pilot project to develop a hydroponics installation on Saint Joseph Hall at De La Salle University in Manila, Philippines that grew lettuce which was consumed on-site.^ This project showed that growing lettuce on a rooftop is not only possible but may even be profitable. The methods developed demonstrate the capacity to minimize the ecological and carbon footprints of growing lettuce and micro greens by saving transportation and logistical costs, reducing greenhouse gas emissions, conserving water, and saving energy costs by using solar panels as a power source for pumps and aerators. This project is also particularly relevant for schools and universities, areas of learning, where students have the opportunity to reconnect with nature and the food supply chain.

Keywords: Food Security, Urban Sustainability, Rooftop Hydroponics, Urban Farming, Low-Carbon Cities

INTRODUCTION

A key strategy for global sustainability is to reduce both the ecological and carbon footprints of large, global cities. Today, nearly 50% of world's population lives in cities. By 2030, this percentage will increase to 60% and cities of the developing world are expected to absorb 95% of this growth. Although comprising only 3% of the earth's land area, cities consume most of the world's energy and materials and produce three-fourths of its greenhouse gases (Taylor, 2012). Large global cities, cities with a population of 10 million people or more, are set to number 26 by 2015. As determined by the United Nations Food and Agriculture Association (FAO), to feed large global cities it will take at least 6,600 tons of food imported each day. The world's cropland has only expanded by 12% while agricultural production has increased by 150%. This has lead to greater land degradation as 25% of agricultural land is highly degraded with another 36% classified as stable or slightly degraded. Besides land degradation, agriculture is the largest consumer of global freshwater, and issues of conflict and competition for water use are on the rise. Hence, not only will a move toward urban agriculture lead to more sustainable cities but a strong business case for urban agriculture can be made as well.

One of the major concerns for global sustainability is to respond to climate change through the creation of low-carbon cities. Generally, most strategies entail mitigating carbon through energy conservation and renewable energies such as solar and wind. Yet, it is the contention of this paper that urban agriculture, particularly roof-based hydroponics, should be moved into the mix of technologies designed to reduce carbon in cities. The concept of “distributed agriculture” enunciated in this paper is that agriculture should be produced and consumed in place, similar to distributed energy.

The development of urban agriculture meshes with one of the key models to measure and evaluate whether cities are transitioning to sustainability, the urban metabolism model (Figure 1). In this input-output model, materials and energy flow through the urban system, producing goods and services, and eventually waste outputs. The more materials, resources, and energy that are produced and consumed locally in the urban region constitute a significant measure of sustainability. Also, the more outputs (e.g. waste, pollution, etc.) that are minimized, reused or recycled also signifies sustainability. In this model, the greater the amount of food produced locally and consumed in place is a measure of sustainability. Hence, a move to urban agriculture should be considered as a prime strategy for moving toward low-carbon, sustainable global cities.

BACKGROUND

There has been significant research done on hydroponics as an agricultural production technique for vegetable production. The University of the Philippines at Los Baňos has done ground-breaking work in hydroponics and there are a number of Filipino researchers that are leaders in the field. What has not been done, and where this research is acutely relevant, is in the application of hydroponics to urban rooftops and the use of a competitive business model linking on-site production to on-site utilization, reducing the costs of the food supply chain. This model not only provides a sustainable solution to agriculture, but also provides a commercially viable business model.

The research falls under the category of sustainable agriculture. The global population is estimated to reach 7 billion people in 2012. How will all these people be fed while protecting and preserving the global ecosystem? Food production consumes large amounts of natural resources, *i.e.* water, land, and minerals. Also, industrial agricultural practices based on chemical pesticides and herbicides have caused public health risks and ecosystem pollution while increasing yield. Can the world provide food for its growing population and still maintain a viable environment?

The industrial revolution, with massive increases in fossil fuel production and use, spurred dramatic growth of human population and economies (LeClerc and Hall, 2007). This has often led to environmental degradation (MEA, 2003). Globalization of market forces, agricultural industrialization, migration, public policy, and cultural changes have transformed agriculture from a diverse, traditional and smaller scale system into a agro-industrial system dependent on chemical inputs and mechanization (Conway & Rosset, 1996; Perfecto *et al*., 1996). In *The Potential for a New Generation of Biodiversity in Agroecosystems of the Future* (2007), scientist and farmer Fred Kirschenman states points out the basic assumptions for industrial agriculture. They are: production efficiency can best be achieved through specialization, simplification, and concentration; intervention is the most effective way to control undesirable events; technological innovation will always be able to overcome production challenges; control management is the most effective way to achieve production results; and cheap energy to fuel this energy intensive system will always be available. Negative effects of these assumptions include biodiversity loss, loss of species and genetic diversity, severe degradation of health of inland and coastal waterways, high-energy use, and reduced or eliminated ecosystem resiliency. The 21st century has arrived with many believing that most of industrial agriculture’s assumptions have been found wanting, and are in need of regenerative thought and practice.

Over the past several decades, many writers point out that the trajectory of rapid growth of the past two to three centuries, with its reliance on natural resources and energy, may reach an environmental threshold or tipping point in the future (Odum & Odum, 2001). Industrial agriculture worldwide is energy intensive. They also point out that industrial agriculture, conventionally accepted worldwide, has reduced soil carbon content in Midwestern US soils from 20 % carbon in the 1950’s to its current 1-2 %. This contributes greatly to increasing soil erosion, vulnerability to drought, and decreasing nutrient values. Industrial practices break down soil carbon resulting in atmospheric release of CO_2, contributing nearly 20 % of the total atmospheric carbon dioxide emissions in the US. Globally, these conventionally accepted agricultural practices contribute 12 % of global greenhouse gas (GHG) emissions. Increasing population and industrial food production practices have resulted to excessive nitrogen build-up that eventually ends up in rivers and streams. This leads to eutrophication and episodic and persistent hypoxia in coastal waters worldwide (Nixon *et al*., 1996; NRC 2000). Synthetic production of chemical fertilizers, pesticides, fungicides, and herbicides has resulted in large-scale industrialized energy-consumptive agriculture that many contend is not compatible with ecosystem preservation.

Writer and organic farmer Wendell Berry has admonished farmers for decades to preserve the fertility and ecological health of the land. Society, he contends, must recognize this need, and learn, or relearn, to integrate their activities *with* natural ecosystems, including and especially integrating sustainable agro-ecosystems. Day *et al*. (2009) maintain that the functioning of natural ecosystems and the health of the human economy have been intrinsically linked throughout our evolution. Solar driven ecosystems powered the pre-industrial world; materials such as food, fuel, and fiber, as well as ecosystem services, such as clean freshwater, fertile soils, wildlife, and assimilation of wastes through inherent regenerative and assimilative capacities, were largely dependent on solar-driven ecosystems and agro-ecosystems (Day *et al.,* 2009).

Many believe that efficient, sustainable ways to support food production through regenerative and mutualistic ecological design while requiring less energy is currently available. Studies in Mesoamerica provide scientific evidence that certain agricultural landscapes and practices contribute to biodiversity conservation while simultaneously contributing to increased food production and rural income (Estrada & Coates-Estrada, 2001; Daily *et al.,* 2003; Mayfield & Daily, 2005). Heterogeneous agricultural landscapes that retain abundant tree cover (as forest fragments, fallows, riparian areas, live fences, dispersed trees, or canopies) provide complementary habitats, resources, and landscape connectivity for a significant portion of the original biota (Harvey *et al.*, 2006*a*). Landscape configurations that connect forests, maintain a diverse array of habitats, and retain high structural and floristic complexity generally conserve species (Benton *et al.,* 2003; Bennet *et al*., 2006).

Organic agricultural practices can often provide the means for building agricultural and associated ecosystem resiliency in the face of climate change. Regenerative organic agricultural practices can increase biological activity in soil organic matter. This improves carbon sequestration of soil by removing carbon from the air, while also increasing water retention and improving system resiliency. Manure-based soil systems show an increase in carbon storage over legume-based organic systems. Also, energy use and carbon dioxide emissions are substantively reduced through organic practices. In a farm study of organically grown corn/soybeans, Pimentel (2006) demonstrated that a 33 % reduction in fossil-fuel use was possible. By adopting an organic system that used cover crops or compost instead of chemical fertilizer, GHG emissions were reduced.

Coexistence in agriculture refers to a state where different primary production systems, *i.e.* organic, industrial, and genetically modified (GM) systems, occur simultaneously or adjacent to one another while contributing mutual benefit (Altieri, 2006). Genetically modified agriculture has been viewed by some as a technological innovation that can substantially increase yield while contributing much less ecosystem damage than traditional industrialized agriculture but still capable of producing the same high agricultural yields. Critics of genetic engineering and coexistence state that transgenes cannot be contained, that they will move beyond their intended destinations. Also, other problems can occur such as hybridization with weedy relatives and contamination with other non-GM crops (Marvier, 2001). Opponents maintain that releases of transgenic crops can promote transfer of transgenes from crops to other plants, and can transform wild/weedy plants into new or more invasive weeds (Rissler & Mellon, 1996). Unless whole regions are declared GM free, they maintain, the development of distinct systems of agriculture will be compromised. Proponents of GM crops such as the Royal Society of London *et al.* (2000) maintain that growing global population needs will require either high yield agricultural production or more conversion of natural biomes and marginal land into agricultural product. This, of course, would damage natural ecosystems. Also, proponents say that the advantages of genetic engineering outweigh its disadvantages. The use of transgenes can reduce the need for chemical pesticides and herbicides as biotechnology can select genetic input that can strengthen predator resistance. Food output could increase if spoilage could be limited, if food shelf life could be extended genetically, particularly for high value fruits and vegetables, while placing less stress on natural ecosystems. Also, the loss of topsoil could be minimized through a no till application of seed.

Researchers such as David Homgren, holds that food production can be compatible with ecosystem presentation if permaculture is universally adopted. Permaculture is a food production system that is modelled on interactions seen in nature and draws from all the sciences, both physical and social. It is an agricultural system that is based on agro-ecological approaches to food production that the author believes can preserve, and actually promote, ecological health of natural systems. The author states, “Greater emphasis needs to be placed on using resources efficiently to create a productive and stable living environment.” He believes that permaculture is a system that can accomplish that goal.

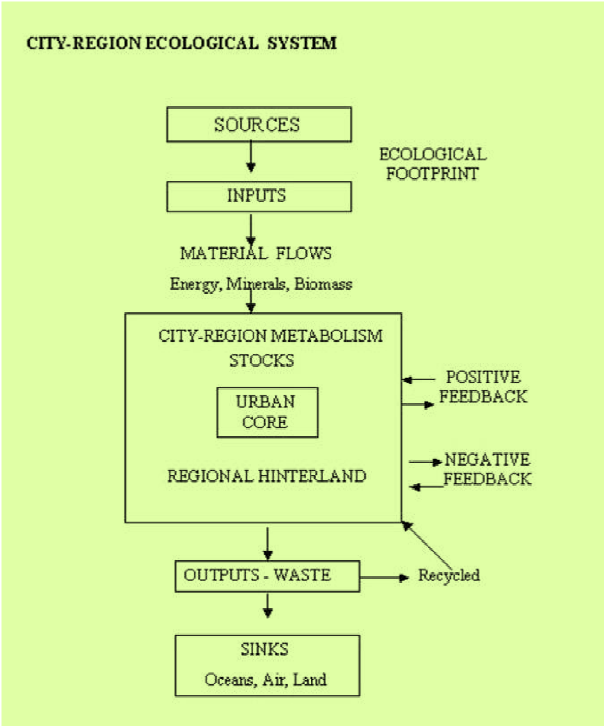

Figure 1: Urban Metabolism Model (Taylor, 2012)

Figure 2: The hydroponics set up enclosed in a net wrapped shed.

PROBLEM STATEMENT/POLICY ISSUE

The Philippines is rapidly urbanizing. In 1980 only 39% of the population lived in urban areas. By 2020 this is projected to increase to 73%. Much of this urbanization has occurred in its largest cities. Metro Manila, for instance, contains close to 12 million people, many living in dense communities with a large building stock. 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. This project sought one solution - utilizing the rooftops of buildings to grow vegetables. Already a number of cities are exploring this option. Singapore has calculated that they have 212 hectares of available building rooftops that are underutilized and have the capacity of producing 39,000 tons of vegetables annually. Other cities such as Montreal, Toronto and New York are exploring the possibilities of urban rooftop agriculture as well.

This project developed a hydroponics installation on the rooftop of Saint Joseph Hall at De La Salle University that cultivated lettuce that was consumed by the community on-site. This pilot project hoped to address the following issues. First, it addressed the need for agriculture to be grown locally and consumed on site, which is defined by co-author Taylor as "distributed agriculture." This type of agriculture emphasizes the following characteristics: 1. it is grown on site which reduces the cost of transportation and spoilage; 2. it is grown at a wide variety of smaller sites; and 3. it meets the demand for on-site food supply, *i.e.* the immediate deployment of food through an existing food delivery infrastructure (canteens).

Second, the project utilized an underdeveloped and vacant urban space resource - building rooftops - and puts them to productive use. Three, it employed a type of agriculture, hydroponics, that does not use soil but, in this case, a continuous flow of water to grow food. This type of agriculture uses only 10% of the water requirements for traditionally grown agriculture, saving water, a valuable resource. Four, it used a nutrient base this is recycled and controlled so that surplus nutrients are not emitted into the environment as pollutants, *i.e.* the wastewater runoff of nitrates for agriculture into streams and rivers. Also, the amount of nutrients applied was professionally managed which saved cost through a more efficient application regime. And five, through hydroponics, a controlled environment was maintained in order to reduce diseases, pest infestation, sunlight application and shading, and temperature, all factors that can contribute to crop loss but through scientific management can produce greater yield.

CONCEPTUAL FRAMEWORK

The proposal sought to establish a pilot program for an urban rooftop hydroponics installation that grows lettuce. It utilized the NFT (Nutrient Film Technique) whereby continuous water is pumped through PVC using a solar water pump. Metrics derived from the project were measured: amount of water used per growth output; amount of nutrient applied per growth output; the cost of production of growth output measured against traditionally grown lettuce produced in rural areas and trucked to the local university canteen (cost of rooftop hydroponics measured against a true price of traditionally grown lettuce incorporating externalities). The project hoped to prove that both an agricultural and business model can be created that incorporates the growth and consumption of vegetables on-site as an alternative to traditionally grown vegetables grown in rural areas and trucked to institutional food consumption sites, *i.e.* any place where food is consumed commercially. The project identified areas such as malls, universities, schools, public buildings with canteens, and corporate sites with canteens as ideal locations for the commercial application of this concept. It is particularly relevant for schools and universities, areas of learning, where students have the opportunity to reconnect with nature and the food supply chain.

RESEARCH QUESTIONS

The following research questions were addressed. (a) What is the best design for an urban rooftop hydroponics installation? This question dealt with issues related to physical location of the installation, it sought to control heat, sunlight, moisture, etc. (b) What quantities of water and nutrients are optimal for growing lettuce in urban rooftop hydroponics? This question tested whether urban hydroponics sufficiently reduces water and nutrient use as compared to the traditional agricultural food supply chain. (c) What are the costs of urban hydroponics lettuce production based on the model of on-site production and on-site consumption and compare this price to the price of lettuce purchased on-site for the local canteens? This question dealt also with whether the true costs of lettuce production is contained in the wholesale price of lettuce and whether a premium should be placed on on-site grown lettuce due to its superior taste due to freshness as measured by the amount of time from picking to consumption. (d) How much carbon reduction can occur by growing lettuce and micro greens on building roofs in Metro Manila? And, how much roof space would be needed to meet the demands for lettuce supply in Metro Manila?

METHODOLOGY

A hydroponics pilot project was undertaken on the rooftop of the Saint Joseph at De La Salle University. This project consisted of two parts: an installation part and an operations part.

In the installation part, a space of approximately 18.5 m^2 was utilized to install a NFT (Nutrient Film Techniques) hydroponics installation for the growing of lettuce. There are a variety of hydroponics systems that could be utilized, often determined by the type of vegetable grown. The NFT system was used because it consists mostly of light-weight PVC piping, uses less water and nutrients, and is easily adapted to the physical limitations of some rooftops (although the rooftops of building in Metro Manila to be strong concrete and easily adapted to heavier vegetable products with longer root systems such as tomato). The amount of physical stress on a building is minimal using a NFT system, which is also ideal for growing leafy vegetables which are short rooted and do not place great weight on a building. A second installation issue is what was referred to as the "sun positioning system" through the construction of a nylon-tented rain and sun shelter based upon the rotation of the sun and the specific location of the installation so that heat and wind effects were minimized.

An important part of the installation part was the building of a solar panel water pump and aeration system for the NFT that meant that the system had its own off-grid power supply and did not use energy from any fossil fuel base.

The second part of the project was the operations portion. The key in this part was to select an appropriate growth medium, *i.e.* floral foam, coco-peat, etc. It was initially hypothesized that coco-peat constituted the best growth medium, *i.e.* as it was locally produced and cheaply and readily available. A second issue was the nutrient solution. A selection of a nutrient solution was based on its capacity to be cheaply manufactured, is local, and is suited for the particular vegetable that is being grown. And finally, a third issue was to explore the varieties of leafy vegetables that can be grown using rooftop hydroponics.

Materials Required

NFT parts - PVC pipes; Water and Nutrient Reservoir; plastic pots; Coco-peat growth medium; floral foam; Solar Panel- D.C. solar water pump and aeration system; timer; Light-weight and nylon tented rain and sun shelter; lettuce seeds.

A literature survey was undertaken to access the cost of wholesale purchasing of lettuce for on-campus canteen consumption and the source of this produce to determine the true costs of production, *i.e.* transportation costs, freshness and spoilage, and environmental impacts.

RESULTS AND DISCUSSION

The following research questions were addressed: (a) What is the best design for an urban rooftop hydroponics installation? This question dealt with issues related to physical location of the installation, it sought to control heat, sunlight, moisture, etc.

The hydroponics set up was installed at the northern end of the roof top of St Joseph Hall at De La Salle University, Manila. This building is 6 stories high with no immediate neighbouring taller structures. The location of the set up was a vacant space and is directly exposed to the elements. To protect the plants from direct sunlight, heavy rainfall and strong winds, a shed was constructed using steel pipes as framework and nets wrapped around the whole structure as covering material against the elements (Figure 2). Three layers of nets were found to be able to protect the plants against gusty winds and very heavy rainfall without lessening too much the sunlight penetrating the shed. However, we had concern that the plants might be destroyed by strong winds and heavy rains caused by typhoons. For such emergencies, we have water proof canvas sheets ready on hand to cover the roof side of the shed.

To save on water by minimizing loss through evaporation, a closed hydroponics system was devised using PVC pipes (Figure 3). The water is bubbled and circulated for 1 hour every 6 hours using submersible pumps and aerators. The whole system is powered by a solar panel. The mini-weather station installed recently to monitor, air temperature, relative humidity and to predict rainfall is powered by rechargeable batteries. The environmental foot print of this set up is thus minimal.

Results of the germination studies indicate that growing mix (a soil less medium from compost material) is a better germination medium that coco coir. Of the three lettuce varieties tested using the growing mix, fanfare germinated fastest (faster by around 1 week) with green wave slower by a few days and grandee had the slowest germination. Germination rate for fanfare was at 90% which is higher than what the seed company claims (85%). On the other hand, the germination rate for green wave was only at 69% which is lower by 16% from what is claimed. Percentage germination of grandee was less than 20%.

Figure 3: The closed hydroponics set up using PVC pipes

Figure 4: Lettuce plants being sold by RFM Hydroponics at PhP 30 per pot. Photo from RFM Hydroponics. 2011. http://www.sulit.com.ph/index.php/view+classifieds/id/1584565 /Lettuce+for+Sale%2C+Fresh+Live+%2C+Lettuce+?referralKeywords=lettuce

Table 1: Reduction of CO2 in Lettuce Supply to Metro Manila through the Substitution of Rooftop Hydroponics for Traditional Imported Lettuce

SOURCE	CO2 SAVINGS in Tons
Food Miles from Air Freight	1,544.95
Food Miles from Truck Freight	283.18
Energy Building Efficiency of Green Roofs	134.54
Total CO2 Reduction in Lettuce Hydroponics	1,962.67

Using coco coir as the growth substrate of lettuce also presented problems. Most prominent of which is that the growing roots get entangled with the coco coir fibers which apparently inhibited root growth and development. Underdeveloped roots are probably the cause of stunted growth typical of most plants grown in coco coir. On the other hand, survival and growth rates were better suing floral foam as the substrate. The few deaths observed using floral foam was due to heavy rainfall and strong winds.

(b) What quantities of water and nutrients are optimal for growing *Lactuca sativa* (lettuce) in urban rooftop hydroponics? This question tested whether urban hydroponics sufficiently reduces water and nutrient use as compared to the traditional agricultural food supply chain.

During a preliminary study, we tried using waste water from an urban tilapia farm as source of nutrients for lettuce. The growth rates and yield of lettuce in tilapia waste water was very poor in comparison to a commercial hydroponics medium comprised of Peters Hydrosol (derived from potassium phosphate, potassium nitrate, magnesium sulphate, boric acid, copper EDTA, iron EDTA, manganese EDTA, sodium molybdate and zinc EDTA) and Peters calcium nitrate in 1:1 proportions and fortified with magnesium sulphate and ferrous sulphate.

Results of the experiment indicate that 140 liters of nutrient solution is enough to support 50 lettuce plants to maturity (around two weeks after germination). On extremely warm and dry days, there might be the need to replenish evaporated water. Nevertheless, the nutrient solution after two weeks is still able to grow a second batch of lettuce before more nutrient solution needs to be added. When we consider that 140 liters can support 100 plants using our methods and that our average yield per plant harvested is 25 grams for green wave and 50 grams for fanfare, then 140 liters nutrient solution is required to grow 2.5 kg and 5 kg of lettuce respectively or 56 liters of nutrient solution is needed by green wave and 28 liters is needed by fanfare to grow to 1 kg. According to Waterfootprint.org (2008), the global average water footprint of 1 kg of lettuce is equivalent to 130 liters. The water footprint of our methods is less than half of the global estimates.

(c) What are the costs of urban hydroponics lettuce production based on the model of on-site production and on-site consumption and compare this price to the price of lettuce purchased on-site for the local canteens? This question dealt also with whether the true costs of lettuce production as contained in the wholesale price of lettuce and whether a premium should be placed on on-site grown lettuce due to its superior taste due to freshness as measured by the amount of time from picking to consumption.

According to the Bureau of Agricultural Statistics (BAS, 2011), the average national wholesale prices of lettuce has more than tripled from PhP 12 in 1990 to PhP 43 in 2010 with Metro Manila prices higher by five times. The retail prices are however much higher. BAR (2005) reported that the lettuce markets are in the major urban centers of Manila, Cebu, Iloilo City and Cagayan de Oro City. The retail prices vary primarily whether the lettuce is imported or locally grown. Two of the more popular varieties are Iceberg and Romaine. Locally grown Iceberg can retail at as low as PhP 75 and the imported kind can be sold at PhP 280. Hydroponically grown lettuce by RFM Hydroponics from Paraṅaque is sold at PhP 30 per pot or based on our estimates up to PhP 600 per kg (Figure 4).

Including the cost of electricity for sterilizing the water used for preparing the nutrient solution, the total cost of materials per 100 plants is less than PhP 500. If we are to sell the lettuce at PhP 30 per pot, PhP 3,000 will be earned per harvest or a profit of PhP 2,500. If we are to recover the cost of the whole set up or PhP 100,000 and that one cycle of germination and growth period takes a month, then at least 40 months or 3.3 years is needed. The main profit however is the reduction in the ecological foot print brought by our method most especially if the lettuce we are eating are is imported.

(d) How much carbon can be reduced through rooftop hydroponics for growing lettuce in Metro Manila? And secondly, how much urban roof space would be needed to replace traditionally imported lettuce with lettuce grown through rooftop hydroponics? [1]

In order to determine carbon reduction of rooftop hydroponics, it is necessary to calculate the amount of lettuce supplied annually to Metro Manila. Through discussion with the primary provider of lettuce to the major supermarkets in Metro Manila, it was determined that 50% of the lettuce is distributed through the major supermarkets and the remaining 50% through local markets (open markets, sari-sari, etc.).[2] Dizon Farms, the primary distributor of lettuce to Metro Manila, ships by air freight 12 tons of lettuce in 3 flights per week from Cagayan de Oro, Mindanao, Philippines to Metro Manila, a distance of 786 km. It is estimated that the amount of lettuce supplied annually to Metro Manila supermarkets is 624 tons. With an equal amount supplied by the open markets and smaller stores, another 624 tons was added, making a total of 1,248 tons of lettuce supplied annually to Metro Manila. The local markets receive their lettuce by diesel-truck delivery from Benguet Province in Luzon, a distance of 563.27 km, a 6 hour trip due to poor road infrastructure and traffic congestion.

Two calculations were made. The first was on the amount of carbon that could be reduced through lettuce production on rooftops in Metro Manila. This calculation is based on zero food miles, a term which refers to the distance food is transported from the time of its production until it reaches its market, that is associated with rooftop hydroponics. Since rooftop food in produced and consumed on-site, rooftop hydroponics produces little or no carbon from food miles. Air freight food miles of lettuce, which is 50% of the lettuce market, was 2.48 tons of CO2 per ton of lettuce shipped to Metro Manila. This produces an annual emission of 1,545.95 tons of CO2.[3] Most of the remaining 50% of the lettuce market is trucked from Benguet Province, and its food miles were calculated at .45 tons of CO2 per ton of lettuce. Hence, the annual CO2 emission of nearer truck-based lettuce was found to be 283.18 tons.[4] Totalled, the amount of CO2 from food miles for the annual import of lettuce to Metro Manila was calculated to be 1,829.13 tons. This is the annual savings in CO2 from the transition from importing lettuce to on-site production and consumption of lettuce through rooftop hydroponics in Metro Manila.

A second consideration about the carbon savings from rooftop hydroponics is the amount of carbon reduction that occurs through building cooling and the reduced need for air conditioning. While lettuce and micro greens sequester carbon in their leaves (40% carbon), this study did not calculate the amount of carbon sequestration that rooftop hydroponics would provide. Studies of plant carbon sequestration generally emphasize soil-based carbon sequestration. But, based upon research completed in New York City on green roofs, it is calculated that for every 96 sq. meters of rooftop vegetation an equivalent of 62.59 kg of carbon is reduced through better building systems efficiency. [5] The amount of carbon that can be reduced in Metro Manila through building energy savings, if lettuce is grown on rooftops and not imported, is calculated to be 134.54 tons. This figure is based on the total amount of lettuce supplied to Metro Manila at 1248 tons and the formula of an average of 100 tons of lettuce capable of being grown on 15,000 sq. meters of rooftop.[6] This produces the need for 187,200 sq. meters of rooftop availability to meet all the needs of Metro Manila for lettuce at current demand.

CONCLUSIONS AND RECOMMENDATION

This study shows that urban farming in open areas such as rooftops is not only feasible but is also productive. The growing time is not only shorter and the yield is not only higher, the set up can also be designed so as that ecological foot print of the methods used is drastically reduced not only because the lettuce need not be transported from faraway places anymore but energy is saved also by using alternative sources of power supplies such as solar powered pumps and aerators. Furthermore, water conservation is also enhanced by the hydroponic method adopted in this study.

To add value to our hydroponic product, it will be necessary to compare the quality and quantity of the yield with the other method that has a growing number of consumers, organically farming. A hydroponic method whose yield in not only higher but also has a better nutritional value than those grown organically will have a higher market value.

And finally, a major consideration for sustainability is to transition to sustainable cities. One key measure of sustainability is the move to low carbon cities. This is a necessary strategy for climate change mitigation. Through rooftop hydroponics, it was found that only 187,200 sq. meters of rooftop was needed to meet all of the current requirements for lettuce in Metro Manila. This would create a total carbon savings annually from just one vegetable of 1,962.67 tons.

NOTES

[1] There are assumptions made in these calculations that were derived from reasoning and not from extensive survey research. While it is recognized that rooftop hydroponics will reduce the carbon footprint of Metro Manila, the exact amount presented by the researcher is only a best estimate.

[2] These figures constitute best estimates that were determined through Interview by Robert W. Taylor of Ronald Canja, Distribution Manager for Metro Manila, Dizon Farms, May 30, 2012.

[3] CO2 from Air Freight was determined at 3.15 grams of CO2 per gram of aviation fuel (www.carbonindependent.org). Although aviation fuel has 1.9 times more global warming capacity than CO2 since it contains nitrous oxides and water vapour, this was not factored into the final estimate of CO2.

[4] Calculations were based on 3.2kg of CO2 produced per liter of diesel fuel. This figure was supplied by Herman Nandapawar, International CDM Specialist, Energy Climate Change Expert, Asian Development Bank to Robert W. Taylor on June 6, 2012.

[5] This estimate is based on the work of Cynthia Rosenzweig in "(Soil) Carbon Sequestration in the Urban Environment," World Bank, May 13, 2009. She calculated that for every 1000 sq. ft. (96 sq. meters) of green roof in New York City 138.19 lbs. (62.682 kg.) could be saved during the three summer months. Since her calculations were derived from soil-based green roofs and not from vegetation produced through hydroponics, and that Metro Manila has 12 months of building cooling needs rather than just 3 months, only 25% of her carbon savings per 1000 sq. ft. of roof were used. Also, although no exact estimate of carbon savings was provided, Changi General Hospital in Singapore placed hydroponics on their roof and noticed that "the hydroponics plants planted on the roof help absorb heat, making naturally ventilated wards cooler." Accessed through www.greenroofs/pview.php?id =565 by Robert Taylor, June 20, 2012.

[6] This estimate is based on a hydroponic greenhouse, Gotham Greens, in Brooklyn, New York City that projected 100 tons of lettuce and micro greens per 15,000 sq. meters.

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