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Urban Rooftop Hydroponics for Diversified Agriculture

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There has been significant research done on hydroponics as an agricultural production technique for vegetable production. The University of the Philippines in Los Baños has done groundbreaking 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 onsite production to onsite 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 seven billion people in 2012. How will all these people be fed while protecting and preserving the global ecosystem at the same time? Food production consumes a large amount of natural resources, that is, water, land, and minerals. Also, industrial agricultural practices based on chemical pesticides and herbicides, although it increases yield, have caused public health risks and ecosystem pollution.

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 & Hall, 2007). This has often led to environmental degradation (Millennium Ecosystem Assessment [MEA], 2003). The globalization of market forces, agricultural industrialization, migration, public policy, and cultural changes have transformed agriculture from a diverse, traditional, and smaller scale system into an agro-industrial system dependent on chemical inputs and mechanization (Conway, Murray, & Rosset, 1996; Perfecto, Rice, Greenberg, & Van der Voort, 1996). In *The Potential for a New Generation of Biodiversity in Agro-Ecosystems of the Future*, scientist and farmer Fred Kirschenman (2007) pointed out the basic assumptions for industrial agriculture. They are as follows: 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 pointed 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 pointed out that industrial agriculture, conventionally accepted worldwide, has reduced soil carbon content in Midwestern US soils from 20% carbon in the 1950s 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 buildup 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; National Research Council, 2000). Synthetic production of chemical fertilizers, pesticides, fungicides, and herbicides have resulted in large-scale industrialized energy-consumptive agriculture that many contend is not compatible with ecosystem preservation.

Writer and organic farmer Wendell Berry (1990) had admonished farmers for decades to preserve the fertility and ecological health of the land. Society, he contended, 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) maintained 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 preindustrial 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 and 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 increase food production and rural income (Estrada & Coates-Estrada, 2002; Daily, Ceballos, Pacheco, Suzan, & Sanchez-Azofeifa, 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). Landscape configurations that connect forests, maintain a diverse array of habitats, and retain high structural and floristic complexity generally conserve species (Benton, Vickery, & Wilson, 2003; Bennet, Radford, & Haslem, 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, that is, 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 is still capable of producing the same high agricultural yields. Critics of genetic engineering and coexistence state that transgenes cannot be contained and 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 trans-genes 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 (2000) maintained that growing global population needs will require either a high-yield agricultural production or more conversion of natural biomes and marginal land into agricultural production. This, of course, would damage natural ecosystems. Also, proponents say that the advantages of genetic engineering outweigh its disadvantages. The use of trans-genes 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.

David Homgren (2011) 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. Homgren stated, "I see permaculture as providing the eco-technic design solutions able to cushion the decline of non-renewable resources and accelerate the healing processes of nature by use of a broader range of species from similar climates around the world" (2011, p. 3). He believed that permaculture is a system that can accomplish that goal.

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Problem Statement and Policy Issue

The Philippines is rapidly urbanizing with almost 49% of Filipinos now living in urban areas, and by 2030, that number is expected to jump to 77% (Basingan & Ilagan, 2012). 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 have produced a problem in transporting agricultural products from rural areas to urban markets where more people reside and where the food is consumed more. An increase in rates of spoilage of perishable vegetables and transportation costs constitutes a food security issue that needs to be addressed. This project sought one solution—utilizing the rooftops of urban 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 several issues. First, it addressed the need for agriculture to be grown locally and consumed on-site, which is defined by coauthor Taylor as "diversified agriculture." This type of agriculture emphasizes the following characteristics: (1) It is grown on-site, which reduces the cost of transportation and spoilage, and (2) it meets the demand for on-site food supply, that is, 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 put them to productive use. Third, 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, which is a valuable resource. Fourth, it used a nutrient base that is recycled and controlled so that surplus nutrients are not emitted into the environment as pollutants, that is, 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 fifth, 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 would grow 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, and 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 the true price of traditionally grown lettuce incorporating externalities). The project hoped to prove that both an agricultural model and a business model could be created with 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, that is, 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 and areas of learning where students will have the opportunity to reconnect with nature and the food supply chain.

Research Questions

The following research questions were addressed:

- 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, and so forth.
- 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 nutrients use as compared to the traditional agricultural food supply chain.

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

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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.

Methodology

A hydroponics pilot project was undertaken on the rooftop of the Saint Joseph Hall at De La Salle University. This project was made up 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 an NFT (nutrient film technique) hydroponics installation for the growing of lettuce. There were a variety of hydroponics systems that were utilized, often determined by the type of vegetable grown. The NFT system was used because it consists mostly of lightweight 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 are considered to be strong concrete and easily adaptive to heavier vegetable products with longer root systems such as tomato). The amount of physical stress on a building is minimal using NFT, which is also ideal for growing leafy vegetables that 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 on the rotation of the sun and the specific location of the installation so that heat and wind effects would be minimized.

An important part during the installation was the building of a solar-panel water pump and aeration system for the NFT, which 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. The key in this part was to select an appropriate growth medium, that is, floral foam, coco peat, and so forth. It was initially hypothesized that coco peat constituted the best growth medium as it was locally produced, cheap, 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, its availability locally, and its being 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.

The materials required were NFT parts—PVC pipes, a water and nutrient reservoir, plastic pots, a coco-peat growth medium, floral foam, a solar panel–D.C. solar water pump and aeration system, a timer, a lightweight and nylon tented rain and sun shelter, and 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, that is, transportation costs, freshness and spoilage, and environmental impacts.

Results and Discussion

The following research questions were addressed:

1. 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, and so forth.

The hydroponics setup was installed at the northern end of the roof top of St Joseph Hall at De La Salle University, Manila. This building is six stories high with no immediate neighbouring taller structures. The location of the setup 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 (Fig. 1). Three layers of nets were found to be adequate to protect the plants against gusty winds and very heavy rainfall without lessening much of the sunlight penetrating the shed. However, we have apprehensions that the plants might be destroyed by strong winds and heavy rains caused by typhoons. For such emergencies, we have prepared waterproof 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 (Fig. 2). The water is bubbled and circulated for one hour every six 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 footprint of this setup is thus minimal.

Results of the germination studies indicated that growing mix (a soilless medium from compost material) is a better germination medium than coco coir. Of the three lettuce varieties tested using the growing mix, fanfare germinated fastest (faster by around one week) with green wave slower by a few days, and grandee had the slowest germination. The germination rate for fanfare was at 90%, which is higher than what the seed company

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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. The percentage germination of grandee was less than 20%.

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 were probably the cause of stunted growth typical of most plants grown in coco coir. On the other hand, survival and growth rates were better using floral foam as the substrate. The few deaths observed using floral foam was due to heavy rainfall and strong winds.

Figure 1. The hydroponics set up enclosed in a net-wrapped shed.

2. 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 wastewater from an urban tilapia farm as source of nutrients for lettuce. The growth rates and yield of lettuce in tilapia wastewater were 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 indicated that 140 L 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 L can support 100 plants using our methods and that our average yield per plant harvested is 25 g for green wave and 50 g for fanfare, then 140 L of nutrient solution is required to grow 2.5 kg and 5 kg of lettuce, respectively, or 56 L of nutrient solution is needed by green wave and 28 L is needed by fanfare to grow 1 kg of lettuce. According to Waterfootprint.org (2008), the global average water footprint of 1 kg of lettuce is equivalent to 130 L. The water footprint of our methods is less than half of the global estimates.

Figure 2. The closed hydroponics setup using PVC pipes.

3. 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.

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 PhP 2 only in 1990 but now by at least PhP 10. The retail prices are however much higher. The Bureau of Agricultural Research (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 be retailed at as low as PhP 75 and the imported kind can be sold at PhP 280. Hydroponically grown lettuce by RFM Hydroponics from Parañaque is sold at PhP 30 per pot or based on our estimates up to PhP 600 per kilogram (Fig. 3).

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 setup 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 footprint brought by our method most especially if the lettuce we are eating is imported.

Figure 3. Lettuce plants being sold by RFM Hydroponics at PhP 30 per pot. Photo from RFM Hydroponics (2011). Retrieved from http://www.sulit.com.ph/index.php/view+classifieds/id/1584565/Lettuce+for+Sale%2C+Fresh+Live+%2C+Lettuce+?referral Keywords=lettuce

Conclusions and Recommendation

This study shows that urban farming in open areas such as rooftops is not only feasible but also productive. The growing time is not only shorter and the yield is not only higher; the setup can also be designed so that the ecological footprint of the methods used is drastically reduced not only because the lettuce need not be transported from faraway places anymore but also because energy is saved 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: organic farming. A hydroponic method whose yield is not only higher but also has a better nutritional value than those grown organically will have a higher market value.

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