MEDITERRANEAN CITIES AND VERTICAL FARMING: FOSTERING SUSTAINABLE LOCAL FOOD PRODUCTION AND BUILDING NEIGHBOURHOOD ESPRIT DE CORPS

Joel L. Cuello

Department of Biosystems Engineering,
The University of Arizona

1. Introduction

In 2010, for the first time in the history of the world, the proportion of the world's population living in cities exceeded 50% (UN, 2014), despite the world's cities occupying only 3% to 4% of the planet's land area (Schirber, 2005). Such a proportion is projected to rise further to 60% by 2030 and to over 70% by the middle of the century, when global population is projected to reach 9.7 billion (FAO, 2009).

People the world over are drawn to live in cities because cities, quite simply, constitute the world's undisputed economic engine. Just 600 cities today account for about 60% of the global economic output (Dobbs et al., 2011). By 2025, the world's top 600 cities will be home to an estimated 220 million more people of working age and will account for more than 30% of the expansion of the potential global workforce (Dobbs et al., 2011). The biggest economic transformation the world has ever seen is occurring today simultaneously with the population expansion of cities in emerging markets, generating millions of new consumers with rising incomes and whose spending power will change the way the world shops – including people living in cities buying more of their food locally.

To meet the food demand of a global population that will increase from today's 7.6 billion to approximately 9.7 billion by 2050, the United Nations projects that food production will need to increase by 70%, necessitating a doubling in crop production (FAO, 2009; Ray and Schaffer, 2011).

In the Mediterranean region – which encompasses about 850 million hectares of land in 22 countries across southern Europe, the Middle East and North Africa – about 14% of land is agricultural (EC, 2014). Among the eight Mediterranean countries that were part of the EU in 2012 (Cyprus, France, Greece, Italy, Malta, Portugal, Slovenia and Spain), however, the proportion of agricultural land is larger, at 34% (EC, 2014). But at current rates of land degradation and urbanisation, it is projected that 8.3 million hectares of agricultural land will have been lost by 2020 in the Mediterranean since 1960 (EC, 2014). In that same period, the region's population will have doubled, effectively reducing by about 56% its agricultural land per capita from 0.48 to 0.21 hectares (EC, 2014), raising the grand challenge of food security in the region, especially among its Middle Eastern and North African countries.

The population expansion of cities in emerging markets generates millions of new consumers with rising incomes and whose spending power will change the way the world shops.

2. Urban agriculture and vertical farming

Given that agriculture already makes use of almost half of the land surface of the planet, consumes over 70% of all current freshwater withdrawals worldwide, and expends 30% of the global energy demand on food production and its supply chain, it is clear that a doubling of crop production will put enormous pressures on land, water and energy resources worldwide, particularly in arid and semiarid regions of the world, including the Middle East and North Africa.

Does it make sense, however, to grow food in cities or around cities to help meet the prodigious demand for food of the world's multiplying megacities? In 2016, there were 436 cities worldwide with a population of 1–5 million each, and 31 cities had a population of over 10 million each (UN, 2016). In 2030, these figures are projected to rise to 558 cities with a population of 1–5 million each and 41 cities with a population of over 10 million each (UN, 2016).

An affirmative stance for urban agriculture is in part supported by the argument that cities, with their infrastructures and centralised planning for supplying water and energy as well as for treating and reusing wastewater and even generating renewable energy, lend themselves well to organised and potentially more efficient utilisation of water and energy for crop production.

Urban agriculture takes on several forms, including establishing community gardens on vacant lots and, more recently, rooftop greenhouses. The company Gotham Greens built the first such commercial-scale facility in the United States in Brooklyn, New York in 2011, covering over 1,394 square meter (15,000 square feet) of production area and yielding over 45.4 metric tons (100,000 pounds) of fresh leafy greens annually (Gotham Greens, 2018). In 2015 the company opened its facilities in the Pullman neighbourhood of Chicago's south side, covering over 6,968 square meter (75,000 square feet) of production area and produces up to 10 million heads of leafy greens and herbs year-round (Gotham Greens, 2018).

Vertical farming, meanwhile, constitutes the third form of urban agriculture. Vertical farming is generally defined as the production of crops in vertically stacked growing shelves or trays typically in an enclosed warehouse-type environment. In Japan, where vertical farming has been pioneered, the name "plant factory" is typically used (Ono and Watanabe, 2006). Vertical farms as pioneered in Japan typically employ hydroponics technology, or soil-less agriculture, through which crops are grown in liquid nutrient solutions. The crops are also provided with either exclusive or supplemental electric lighting using fluorescent lamps or light-emitting diodes (LEDs). Japan-designed vertical farms have always focused on developing controlled-environment hydroponic technologies for crop production because they enable intensive crop production with significantly increased yields (2x to 3x) at siificantly reduced water input (about 80–90% less) without the need for arable land and with a significantly reduced land footprint when compared with open-field farming.

The commercial development of vertical farms in Japan began in earnest in the 1980s. The 1980s saw the establishment of Daiei Biofarm and Miura Farm; the 1990s saw the establishment of La Planta, TS Farm and CosmoFarm; and in 2000's Fairy Angel and MIRAI were established (Ono et al., 2011). With the technology improvements achieved over the years, particularly in lighting technology, the production capacity of vertical farms in Japan has steadily risen. For instance, while the maximum production capacity of vertical farms in Japan in the 1990s was only 3,000 to 5,000 lettuce heads per day, the maximum production capacity for today's vertical farms in Japan reaches approximately 10,000 lettuce heads per day (Palus, 2014).

Vertical farming makes it possible to achieve both maximum crop productivity and quality constantly throughout the year, independent of local weather and climate, of whether arable land is available, and at 80–90% reduction in water consumption.

The concept of a modern skyscraper vertical farm was introduced by Dickson Despommier, a professor at Columbia University, in 2010 (Despommier, 2010). Owing to the subsequent association of the concept of vertical farms, fairly or unfairly, with grand architectural designs of awe-inspiring and often futuristic-looking edifices, the prospects for vertical farms in recent years have been significantly diminished by their projected high costs, particularly on account of the prohibitive costs of the conventional buildings needed to house the actual farms. Thus, to devise a new strategy for designing and developing vertical farms that can achieve economic feasibility, it has been crucial to decouple the concept of vertical farms from the conventional buildings with which vertical farms have become inadvertently intertwined.

3. Vertical farming 2.0: The Vertical Greenbox Solution

The "Vertical Greenbox Solution" was introduced as a new paradigm or strategy for designing vertical farms to achieve economic feasibility (Cuello, 2014). The Vertical Greenbox Solution, also known as Non-Building Vertical Farms (NB-VF), pertains to vertical farms constructed without using standard or conventional buildings, but using minimally-structured, modular and prefabricated structures that would be capable of supporting agricultural operations. The range in wall type for a module, for instance, could conceivably go from solid and non-transparent all the way to transparent plastic material, while the size range for a module could go from that of a used shipping container all the way to that of a sizable warehouse.

The Vertical Greenbox Solution paradigm prescribes the following three critical architectural features:

1) **Minimally structured** – reduced load-bearing requirement; reduced materials; reduced total weight; reduced plumbing and electrical services;
2) **Modular** – uniformity of growing space, hardware and environmental control; consistency of operational procedures; interchangeability of units; allows use of varied growing systems; allows development of turn-key operations;
3) **Prefabricated** – allows off-site construction and assembly of modules; significantly lower costs of construction and labour.

The modular boxes can be stacked vertically and arranged in a number of geometric configurations to achieve optimal use of land area and also to optimise growing operations, which could include the use of elevators to move growers to gain access to the individual modules. The possible geometric configurations for the Vertical Greenbox vertical farm include: (1) cylindrical configuration, where columns of the vertically stacked modules linked end-to-end radiate outwardly from a central core; and (2) linear configuration, where columns of the vertically stacked modules linked end-to-end are arranged in parallel.

The Arizona Green Box, a modular and movable shipping container designed by the author and his team of students at The University of Arizona to implement sustainable intensive production of high-value crops (e.g. lettuce and microgreens), is an example of a modular unit for a Vertical Green Box Solution. With its standard size, a used shipping container provides the following significant advantages in implementing movable and modular controlled-environment hydroponic boxes: (1) economical (about $2,000 or less per unit); (2) easily procured; (3) movable and easily transported (whereas a greenhouse building is typically fixed in location); (4) modular with standard size (thus, the configuration and arrangement of hydroponic cultivation systems inside a unit can be customised, optimised and standardised to be identical for all other units); (5) scalable (the modularity of the unit lends itself to convenient scalability through simple unit multiplication); (6) convenient control of physical environment (on account of the modularity of the unit); (7) can be stacked vertically one on top of the others if needed to save land area; and (8) easily secured.

4. Prospects for vertical farming in Mediterranean cities

The abundance of solar radiation in the Mediterranean region, especially in the Middle East and North Africa, makes possible the provision of renewable solar-based electricity to power vertical farms in the region. This represents a significant competitive advantage for the region economically, but is also a highly promising strategy to combat food insecurity while fostering environmental sustainability in the face of water scarcity, desertification, climate variability and other environmental challenges.

It would, of course, be unrealistic to expect Mediterranean cities as well as other world cities to become fully food secure by producing all of their food needs through vertical farming or any other means. At present, vertical farming is oriented toward the production of high-value crops.

Thus, the production of lower-value commodity crops (e.g. rice, wheat, barley, corn, soybeans, etc.), whose domestic supply is also regulated by most governments, remains best done in scalable open fields. The production, however, of higher value salad and vegetable crops and certain fruit (e.g. strawberry) – which is enormous and very resource-intensive when conducted in open fields – can be reasonably implemented in or around many cities around the world through vertical farming. This initial "division of labour" between open-field cultivation of commodity crops and production of high-value salad and vegetable crops through vertical farms, if implemented, would result in significant positive environmental impact worldwide in terms of significantly curtailing agriculture's inordinate use of water, nutrients, etc.

Vertical farming shows significant promise, not only in terms of its high potential for both economic and environmental sustainability, but also as an effective catalyst for community cohesion building and strengthening.

The production of salad-type crops is by no means insignificant. China and the United States, for instance, had a combined production of 18 million metric tons of lettuce in 2013, worth $8.4 billion, while Spain in the same year produced close to 1 million metric tons of lettuce, valued at $407 million (Benedict et al., 2014). China is also the world's dominant producer of spinach, producing 22.1 million metric tons in 2014, representing approximately 85% of the global supply (Worldatlas, 2017).

Vertical farming, similar to most open-field cultivation, requires the use of nutrients delivered through inorganic fertilisers. Vertical farms, however, have the advantage of almost 100% utilisation efficiency of fertilisers since the liquid nutrients are recycled and reused and, as the liquid nutrients are contained in a closed system, the nutrients do not leach out to pollute groundwater, which is frequently the case in open-field cultivation. The use of recovered or recycled nutrients from wastewater or animal farm operations – properly sterilised – could make the nutrient usage in vertical farms more environmentally sustainable.

Vertical farming has yet to emerge as an industry in the Mediterranean region, but the prospects are good and an industry is expected to emerge within a decade. The vertical farming hydroponic company AgraTech Farms, for instance, has recently established bases of operation in Madrid, Spain and Lisbon, Portugal. The company owns 16 acres of land just outside Lisbon that is zoned specifically for vertical farm hydroponics.

5. Vertical farming and esprit de corps (or social capital)

For the purposes of this paper, esprit de corps is equated with the formal concept of social capital, which the OECD defines as "networks together with shared norms, values and understandings that facilitate co-operation within or among groups" (OECD, 2007). Networks here pertain to "real-world links between groups or individuals," including "networks of friends, family networks, networks of former colleagues, and so on" (OECD, 2007). Thus, social capital is what builds trust within a group, enabling the members of the group to work together. Social capital "provides the glue which facilitates co-operation, exchange and innovation" (OECD, 2007).

Vertical farms can help build social capital in specific ways in the cities and communities in which they are located. It is important to note, however, that the vertical farm's economic sustainability and environmental sustainability, together, serve as the base for the vertical farm's social sustainability in that the latter would not exist and develop without the former.

The economic sustainability of vertical farms for a community encompasses income and wealth generation, jobs creation, business multiplier effects, etc. The environmental sustainability of vertical farms, meanwhile, focuses on the fostering of resource-efficient local food production.

A principle that articulates the need to continually improve the resource-use efficiency while increasing the crop productivity of vertical farms is Cuello's Law, that is, a projected industry goal that crop productivity with respect to resource use in a tech-dense indoor farm (including vertical farms) should double every four to five years (Cuello, 2016). This means that at least every half a decade in the next 10 years, tech-dense vertical farms should achieve a doubling of crop productivity per square-meter of land area, per litre of water, per kilogram of nutrients and/or per kilowatt of energy. Cuello's Law is a challenge posed to the vertical farming industry to further innovate and help meet this century's massive food demand while securing resource sustainability.

Certain vertical farms are already attaining impressive resource productivity levels. The Mirai Company in Japan, for instance, reportedly produced 10,000 heads of lettuce per day over an area of 2,323 square meter (25,000 square feet) using 99% less water and 40% less power than outdoor fields. With the gradual advent and application of artificial intelligence strategies in vertical farms, periodic doublings of resource-based productivity levels are anticipated to be attained in the coming decades.

6. Vertical farming's SANE benefits

Vertical farming helps build social capital in cities and communities in which they are located through its SANE social benefits (Cuello, 2016). The acronym SANE stands for the following:

S - Safety of Fresh Food
A - Access to Fresh Food
N - Neighbourhood Building and Strengthening
E - Enabling of Equity Building

S - Safety of Fresh Food. A major factor that has been enabling vertical farm enterprises to make rapid and successful inroads into China's numerous big cities is the series of high-profile food contamination cases that have scandalised China's citizens in recent years, fuelling the demand in cities all over China not only for fresh produce, but also for scalable crop production systems that are demonstrably safe to consumers. Chinese consumers experienced a "crisis of confidence" in their nation's food industry after it was discovered that melamine was found in domestically produced baby formula in 2008, making 300,000 babies sick and resulting in at least six premature deaths. Subsequent stories on "fake eggs, diseased pork, recycled oil, mislabelled meat" (South China Morning Post, 2018) together with the unregulated use of pesticides on crops and antibiotics in aquacultured fish and aquatic animals only deepened the distrust felt by consumers toward their food industry, ultimately leading to clamorous calls for reforms. The subsequent emergence of vertical farms and other forms of urban agriculture (e.g. greenhouses) around Beijing and Shanghai, for instance, has attracted many consumers in part because they can observe how the crops are cultivated in controlled or semi-controlled environments which the consumers perceive to be not only efficient, productive and promoting premium crop quality, but also safe. When city residents gain the confidence that their food supply is safe, it certainly helps build the social capital in the city's many communities and helps dispel a troubling communal sense of anxiety, distrust and unrest.

A - Access to Fresh Food. Vertical farms in and around cities not only help collapse the distance fresh crops travel from the farm to the dinner table – which in the United States averages 1,500 miles – but also help make possible the elimination of myriads of food deserts. The United States Department of Agriculture (USDA) defines food deserts as areas of the country that are lacking or devoid "of fresh fruit, vegetables, and other healthful whole foods, usually found in impoverished areas. This is largely due to a lack of grocery stores, farmers' markets, and healthy food providers" (American Nutrition Association, 2011). The modular types of vertical farm, such as a movable shipping container repurposed as a Green Box, can constitute an innovative, practical and cost-competitive strategy to grow and deliver fresh vegetables to food deserts, especially given that conventional greenhouses remain costly to build. Modular and movable vertical farm units also lend themselves readily to emergency food aid for natural-disaster relief in cities and wherever there may be food shortage and famine.

N - Neighbourhood Building and Strengthening. Vertical farms can foster community cohesion, building and strengthening by encouraging community participation and involvement in their production operations. Social farming applied to vertical farming constitutes one notable example. The United Nations (UN) Food and Agriculture Organization (FAO) defines social farming (also called care farming) as "a farming practice that uses agricultural resources to provide social or educational care services for vulnerable groups of people" (FAO, 2014). Social farming is widely practiced in Europe, directed towards such vulnerable groups as people with intellectual or physical disabilities, ex-combatants, convicts, etc. Thus, social farming is the use of agriculture to help vulnerable groups of people to integrate back into society through providing them with new skills, accompanied with the feeling of utility and self-appreciation. Social farming helps promote the group's "rehabilitation, social inclusion and employability" (FAO, 2014). Further, vertical farms can readily serve as a de facto centre or focal point of activities for communities through volunteerism among the youth or senior citizens, educational tours for students, internships for students, etc. The direct capacity of vertical farms to help build social capital in communities through the foregoing programmes and activities should not be underestimated.

The city of Atlanta in Georgia, United States, serves as a noteworthy example of a city that has been proactively promoting urban farming and which in the process has been reaping significant benefits in neighbourhood building and strengthening. Atlanta's Mayor's Office of Resilience launched its urban agriculture programme to help address the problems posed by food deserts in the city by establishing a goal of bringing local food within a half mile or 10 minutes of 75% of city residents by 2020 (Williams, 2017). Today there are over 90 community gardens and 300 urban farms within the city.

Each urban vertical farm could be designed not only to become an integral part of its community, but each vertical farm could deliberately make the community it belongs to an integrated ecosystem in itself

Truly Living Well (TLW) is one such urban farm, growing 15.9 metric tons (35,000 pounds) of herbs, fruits and vegetables, and selling directly to neighbours and residents around the city at various markets four times per week (Okona, 2017). The farm's Community Supported Agriculture (CSA) programme allows its subscribers to fill their baskets at those markets 13 times a year at discounted rates of $400 per year for a full-share membership and $195 per year for seniors (Okona, 2017). Further, TLW's programmes provide interaction and instruction with master urban farmers. An Urban Grower boot camp for working adults and students is conducted on weekends, while a Young Urban Growers programme is specifically designed for children (Okona, 2017). Thus, TLW is not only an urban farm in Atlanta, but has become a de facto education and training centre for urban farming in several communities across the city.

E - Enabling of Equity Building. The specific type of vertical farm employed in a community could spur and enable members of the community to cooperate together and participate in vertical farming as a business enterprise. For instance, the modular type of vertical farm such as a movable shipping container repurposed as a Green Box is certainly more affordable to community associations or cooperatives than conventional greenhouse buildings which are costly to build. One conceivable scenario is for a city to build the modular units of vertical farms and then lease or rent the modular units to various community groups, including neighbourhood associations, student groups and even schools. Thus, vertical farms can help build and grow the community's social capital (or equity) as well as its financial equity.

7. Conclusions

Given the significant diversity among Mediterranean countries in terms of economic development, technological advancement, geographical and climatic conditions as well as levels of environmental degradation, designing solutions for fostering sustainable local food production and building neighbourhood esprit de corps in urban areas across the Mediterranean is not an easy task. Vertical farming as a solution, however, shows significant promise owing to the potential of its controlled-environment and soil-less production strategy to be made independent of the vagaries of local climate and geographical conditions and on account of its high water and nutrient-use efficiencies, thereby fostering environmental sustainability. It helps that numerous countries in the region receive abundant supplies of solar radiation, which could then be harnessed to produce renewable electricity to power the various operations of the vertical farms. Further, vertical farms, especially the modular and movable types, lend themselves readily as effective catalysts for community cohesion building and strengthening.

Realising the promise of the economic and environmental sustainability of vertical farms in cities across the Mediterranean will require not only capacity building for the scientific and technical knowledge and skills that are necessary to design, build, operate and manage vertical farms, but also the business management and financial expertise and resources needed to establish entire urban ecosystems for vertical farms – with distributed production facilities and supply chains – both locally and regionally. And realising the potential for social sustainability of vertical farms will also require proactive cooperation and partnerships between vertical farms and their communities. The role of local governments in inciting and facilitating such business-community partnerships through financial and other incentives will also be crucial. Establishing robust and vibrant urban ecosystems for vertical farms will clearly require proactive government-private-community partnerships. In so doing, each urban vertical farm could be designed not only to become an integral part of its community, but each vertical farm could deliberately make the community it belongs to an integrated ecosystem in itself – economically, environmentally and also socially.

References

American Nutrition Association. "USDA Defines Food Deserts". *Nutrition Digest*, vol. 38, no. 2 (2011). http://americannutritionassociation.org/newsletter/usda-defines-food-deserts

Benedict, C.; Grahn, C. and Miles, C. *Salad Crops*. Washington State University Extension Program. Slides, 2014.

Cuello, J.L. "Re-Imagineering the Vertical Farm: A Novel Strategy in the Design and Development of Vertical Farms". *Urban Agriculture Magazine* (2014). The RUAF Foundation. Leusden, The Netherlands.

Cuello, J.L. "Twin Strategies to Achieve Sector Sustainability for the Vertical Farming Industry in the Next Five to Ten Years". *Agritecture* (2016) (online) https://www.linkedin.com/pulse/twin-strategies-achieve-sector-sustainability-forthe-ten-henry

Despommier, D. *The Vertical Farm: Feeding the World in the 21st Century*. St. Martin's Press. New York City, 2010.

Dobbs, R., S. Smit, J. Remes, J. Manyika, C. Roxburgh and A. Restrepo. *Urban world: Mapping the economic power of cities*. McKinsey Global Institute. McKinsey & Company, 2011.

European Commission. "Science for Environment Policy: Mediterranean Land Degradation Threatens Food Security". European Commission DG Environment News Alert Service, edited by SCU, The University of the West of England, Bristol, 2014.

FAO. *2050: "A third more mouths to feed"*. Food and Agricultural Organization of the United Nations. Rome, Italy, 2009. (online) http://www.fao.org/news/story/en/item/35571/icode/

FAO. "Social farming (also called care farming): an innovative approach for promoting women's economic empowerment, decent rural employment and social inclusion. What works in developing countries?". Global Forum on Food Security and Nutrition (2014). http://www.fao.org/fsnforum/activities/discussions/care-farming

Gotham Greens. 2018. (online) http://gothamgreens.com/our-farms/

OECD. *Human Capital: How What You Know Shapes Your Life*. OECD Insights, 2007. ISBN: 9789264029088

Okona, N. "Growing Community and Feeding the Revolution on an Atlanta Urban Farm". *Civil Eats* (June 14 2017) (online) https://civileats.com/2017/06/14/growing-community-and-feeding-the-revolution-on-an-atlanta-urban-farm/

Ono, E. and H. Watanabe. "Plant Factories Blossom: Production in Japan Steadily Flowers". *Resource*. ASABE, St. Joseph, MI, 2006.

Ono, E.; Usami, H.; Fuse, M. and Watanabe, H. "Operation of a Semi-Commercial Scale Plant Factory". *ASABE Paper*, no. 1110534. ASABE, St. Joseph, MI (2011).

Palus, S. "Japan's Massive Indoor Farm Produces 10,000 Heads of Fresh Lettuce Every Day". *Smithsonian*, 2014. (online) https://www.smithsonianmag.com/smart-news/japans-indoor-farm-supplies-10000-heads-fresh-lettuce-every-day-180952142/

Ray, D. and Schaffer, D. "How will the world double crop production by 2050?" *Western Fram Press* (April 2011). (online) http://www.westernfarmpress.com/management/how-will-world-double-crop-production-2050

Schirber, M. "Cities Cover More of Earth than Realized". *Live Science* (March 2005) (online) https://www.livescience.com/6893-cities-cover-earth-realized.html

South China Morning Post International Edition. China Food Safety (January 10, 2018). http://www.scmp.com/topics/china-food-safety

UN *The World Cities in 2016 Data Booklet*. 2016. UN Department of Economic and Social Affairs. United Nations, New York, 2016.

UN *World Urbanization Prospects 2014 Revision*. Department of Economic and Social Affairs. United Nations, New York, 2014. (online) https://esa.un.org/unpd/wup/publications/files/wup2014-highlights.pdf

Williams, D. "Grant will help convert utility easements to urban farming". *Atlanta Business Chronicle* (August 11, 2017). (online) https://www.bizjournals.com/atlanta/news/2017/08/11/grant-will-help-convert-utility-easements-to-urban.html

Worldatlas.com. World Leaders in Spinach Production. 2017. (online) https://www.worldatlas.com/articles/world-leaders-in-spinach-production.html