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Is it time to take vertical indoor farming seriously?

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Is it time to take vertical indoor farming seriously? My answer is yes, and here are five reasons why.

First, a very large number of people suffer from micronutrient deficiencies and the health problems they cause. We do not know for sure how many, but the number that keeps coming up is 2 billion, or more than 25% of the world's population. Given the serious health consequences, it is fair to characterize this as a serious global public health problem. There is no indication that the number is falling at the global level. Rapid growth in low-income countries' urban populations, together with widespread urban poverty and dietary changes towards calorie-dense, nutrient-poor foods are resulting in a rapid increase in the number of urban households with micronutrient-deficient members.[1] While fortification, including biofortification, may play an important role in both urban and rural populations, it is no secret that access to a healthy and diversified diet, which includes vegetables and other micronutrient-dense foods, is the key to sustainable elimination of this public health problem. Although access to affordable vegetables does not assure their consumption, it is a precondition. Unfortunately, large shares of poor and non-poor urban households in both high and low-income countries do not have regular, daily, year-round access to fresh vegetables at prices they can afford. The so-called "urban food deserts" is the extreme case. But in many other urban areas, poorly functioning supply chains, seasonality, production and price volatility and other supply-factors mean that fresh vegetables are out of physical or economic reach to many millions of urban households or only available on an erratic basis and at high costs. Vertical, indoor production takes place in a controlled environment. Vegetables can be produced continuously year-round. As mentioned below, the factors causing production volatility in outdoor production are absent and so is the effect of seasonality. The key question, to which I will return in the discussion session, is to what extent increased supplies will be captured by those suffering from micronutrient deficiencies.

Second, the production of vegetables in open fields is associated with large risks and uncertainties from biotic and abiotic stresses, such as pest attacks, droughts, floods and strong winds. Climate change and associated irregular weather patterns and extreme weather events add to these uncertainties. Use of pesticides may introduce real and/or perceived health risks. Aeroponic or aquaponics production of vegetables in indoor, controlled environments, whether in high-rises or containers, will require no pesticides, no soil, no land, except for the building's or container's footprint, and only 5% of the water used in the production of the same quantity of vegetables in an open field.

Cutting water use by 95% is extremely important at a time with increasing water scarcity, drawdown of ground water levels and unsustainable management of surface water in many low-income countries and high costs of desalination. Waterlogging and salination of soils, a serious problem in many countries with extensive use of irrigation but lack of appropriate drainage facilities including those of Central Asia and the Middle East, would also be avoided as would water pollution and soil contamination. Using the most appropriate technology, the plant nutrient efficiency is much higher in indoor aeroponic or aquaponics farming than in open fields. Virtually all the nutrients applied are captured by the plants. The ability to apply only the water and nutrients needed by the plants provides the true illustration of what is often referred to as "precision farming". The cost and CO2 emission associated with the production of nitrogen fertilizers would be less as would pressures on the phosphorus and potash reservoirs. Contamination of streams and lakes by fertilizer run-off would not occur.

The yields of vegetables are higher and the growing cycle are shorter when grown with the most appropriate technology, including the most recent lighting management, in a controlled environment. Aerofarms, a large vertical indoor production facility for vegetables in New Jersey reports that it can produce 22 crops annually and several sources state that, with the environmental temperature and the bands of LED wavelengths optimal for growing conditions, a crop of lettuce can be produced in two weeks. The quantity of food lost is also lower in indoor production and a focus on green leafy vegetables means that a large share of the biomass produced is used for consumption. Results from research just published (Nguyen, 2017) show that increasing the CO2 in the air of controlled production environments, to very high levels has a significant positive impact on plant growth. Another preliminary research finding (Devlin, 2017) showing large yield increases (20% in tobacco) associated with genetically modified plants designed to use light more efficiently may become important for indoor production to further increase yields from interaction with the change of

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[1] The focus on urban malnutrition in this article is not to an attempt to downplay the serious nutrient-deficiencies in rural populations.

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bandwidth of LED lighting. At this point that is speculative and more research is needed to verify the findings from these very recent studies and their potential utility for vertical indoor production of vegetables.

Third, the supply chain for vegetables produced in open fields or greenhouses is frequently long for the obvious reason that land is required for cultivation. Infrastructure investments, CO2 emissions and related energy expenditures in transportation may be large. Vertical indoor farming can be undertaken within or near urban or peri-urban areas because its footprint is very small or put differently, yields per unit of land are very high. The supply chain would be short, the energy costs, nutrient losses and CO2 emission during transportation would be low and time from harvesting to consumer purchase would be very short, assuring freshness. The vegetables would be locally produced, a characteristic preferred by many urban consumers.

Fourth, climate change and related extreme weather events are causing higher risks and uncertainty in agricultural production. Increasing temperature brings new pests and plant diseases for which solutions may not be available. Higher frequency of extreme weather events are resulting in large production fluctuations with frequent crop losses, large yield variations and volatile food prices. Production of vegetables in open fields is particularly volatile. As climate change proceeds, the benefits from enhanced control of the production environment will be even more obvious to assure a continued supply of a diversified portfolio of foods to meet nutritional needs. While insurance schemes and subsidies may help protect farmers and consumers from excessive food price volatility, they do not reduce production fluctuations. Research to make vegetable varieties and production patterns more resistant or tolerant to biotic and abiotic stresses is urgently needed. Unfortunately, the focus on existing research, including that undertaken by the CGIAR, continues to be on food staples and not vegetables.

Fifth, continued population growth and increasing incomes translate to increasing food demand. With a current annual population increase of more than 80 million and an expected increase from the current 7.5 billion to about 9.5 billion people by 2050, the world population will require about 50% more food by 2050. More than half of the population of developing countries now reside in urban areas and estimates are that it will increase to two-thirds by 2050. An increasing share of the food demand will come from urban areas in low and middle-income countries and the debate about the so-called urban agriculture, of which vertical indoor farming is a part, is taking on increasing importance. The on-going diet transition is shifting the demand from basic food stables to vegetables, fruits, foods of animal origin and processed foods. The nature of the diet transition is important for nutrition. Will consumers shift to more nutrient-dense foods such as fruits, vegetables and animal source foods or will they move towards more calorie-dense processed foods with high content of sugar, sweeteners and fat but relatively poor in micronutrients? The answer will be influenced in part by physical access and relative prices. Enhanced access and lower prices for vegetables can be expected to lead to increasing consumption, a healthier diet and better nutrition. High vegetable prices and low prices for calorie-dense packaged foods leads to unhealthy diets, overweight, obesity and related chronic diseases. Vertical indoor vegetable production can help expand the supply and lower prices. At the same time, it can relieve the pressure placed on land, water and biodiversity by the increasing food demand.

1. Discussion

When Despommier wrote his path breaking book “The Vertical Farm: Feeding the World in the 21th Century” some 7 years ago (Despommier, 2010), I was a member of the chorus of critics that rejected his idea as a mere pipedream. My rejection was based on economics. It would be much too expensive to produce food indoor using artificial lighting. Others argue that it is unnatural. They argue that all food should be produced in soil and with natural lights. I do not support that position. Still others argue that the problem of micronutrient deficiencies is caused by lack of consumer demand for fruits and vegetables rather than lack of access. The evidence I am familiar with suggest that high prices and lack of physical access are important reasons for the low levels of vegetable consumption.

I have now given up membership in the chorus of critics to become an agnostic. I am agnostic rather than a believer because, while technological change has greatly changes the economic relationships in favor of vertical indoor farming or container farming, during the last 7 years, we may not be there yet. In particular, much more evidence is needed to estimate the economic feasibility of vertical indoor vegetable production in urban areas of low-income countries and the extent to which experience from high-income countries and city states are relevant for low-income countries. So, I believe it is premature to issue a proclamation that vertical indoor production of vegetables is key to the solution of micronutrient deficiencies in urban populations worldwide. But I firmly believe it would be a mistake to continue to ignore opportunities associated with vertical indoor production of vegetables. Based on the limited evidence we have from existing production units, it appears that the tipping point for when it becomes economically viable, may have been reached in a significant number of cases and we may well be very close to the tipping point in many other locations. As further discussed below, the behavior of venture capitalists is one indication.

Taking its potential seriously means taking action to push it over the tipping point for the benefit of people's nutritional status and health. In my opinion, solid economic analyses of past experience and current practices are urgently needed. A search for such analyses gave very limited results. A study by Banerjee (2014) provides an economic analysis of a hypothetical production unit and concludes that “growing food in vertical farms might be a feasible venture”, and that “it is a possibility which needs to be further investigated”. Not exactly a ringing endorsement. A study by Shao et al. (2016) outlines analytical methods but I found no studies of the production costs and incomes from actual producing units. It appears that such analyses are done by the producers themselves and not made available in open access.

One clear economic outcome relates to bankruptcy. A number of vertical indoor food producing units have suffered that fate, including FarmedHere in Illinois, USA, Potponics in Georgia, USA and others. However, others such as Urban Produce and Plenty in California, USA, Plantagon in Sweden and Aerofarm in New Jersey, USA are operating and presumably making a profit, although information is not readily available. A 70,000 square foot facility, Aerofarm, which began operation last year, is the largest producing unit in the United States and possibly in the world. Several large producing units are also in operation in Japan, Singapore, Taiwan, South Korea and elsewhere. It is likely that some or all of them are receiving direct or indirect government subsidies. We need analyses of why a number of past efforts have gone bankrupt while others seem to be making money either with or without government subsidies and price premiums. We also need analyses of the extent to which micronutrient-deficient consumers are benefitting and whether diets are becoming healthier.

It is no surprise that the initial costs of new innovations and technologies and the risk of failure are high. Just think of the cost of the first computer or the cost of the first laboratory-based beef patty, not to mention all the initiatives that failed. The question is whether commercial scale vertical indoor production can compete with more conventional production processes such as open field production and greenhouse production at the current or expected future levels of technology and energy prices. Venture capitalists seem to think that recent technological change and new knowledge from early adopters, including those who went bankrupt, offer real opportunities for economically viable production units. The fifth annual conference organized by - and mostly for - venture capitalists to share information about and promote vertical indoor farming was recently completed in Las Vegas. I have not attended any of the conferences but the

information describing them, indicate a great interest in investing in indoor food production and – for the more risk averse participants – to produce and sell equipment for others to take the risk and ripe the benefits of indoor food production.

Another important factor is whether full costing, which would include the social and environmental costs, such as the public and private costs of nutrition-related poor health and low productivity, is used for the comparison. Clearly, the environmental costs are much lower for indoor farming that conventional open field farming methods, particularly when based on renewable energy sources. Just think of the relative impact on water, land and biodiversity of indoor versus outdoor production, not to forget reduced greenhouse gas emission, the use of pesticides in outdoor farming and the very efficient use of fertilizers in indoor production. But as long as the cost to societies of environmental degradation is not included in the farmers' costs, efforts to enhance the sustainability of natural resource management will not be valued in the product market.

Nevertheless, even in a full cost competitive framework in which environmental and health externalities are included in production costs, the key cost factors in indoor farming are undoubtedly energy and capital costs. Will recent trends in improved efficiencies and resulting dramatic unit cost reductions of renewable energy, including dramatic cost-reducing, efficiency enhancing changes in lighting and solar power, continue and will that bring indoor production of vegetables over the tipping point? Will current low capital costs continue and will there be enough inexpensive outdated factory buildings available for remodeling? Would governments consider moving existing subsidies on basis food staples, such as wheat, rice and maize to vegetables, including those produced indoor? Such a shift would serve nutrition goals.

How do consumers respond to vegetables produced under indoor controlled environments? Will such foods be appreciated because they have been produced locally with less water and no pesticides or will they be rejected because their production method is "unnatural"? They do not conform to the US and EU definition of organic foods because they are produced without soil. I am aware of only one attempt to assess consumer reactions and the conclusion was that consumers did not detect any difference among lettuce produced in vertical indoor facilities, greenhouses or in the open field. They did express some hesitation about the unnatural production method (Coyle and Ellison, 2017). While we are waiting for more studies, it may be safe to assume that the relative price will be the most important factor determining consumer demand. The price at which the vegetables can be sold is also important for the expected nutrition effect. If a price premium is required to make vertical indoor production of vegetables economically viable, low-income consumers suffering from micronutrient deficiencies are unlikely to benefit.

Will advocacy groups form to oppose such foods, following the success of advocacy groups to hinder the full benefits from modern science such as genetic engineering for agriculture and food? Cox (2016) presents a strong opposing view to indoor farming, arguing that it makes little or no sense to farm under artificial light. He is not opposed to some forms of controlled environment agriculture as long as the plants get their energy directly from the sun and not through artificial light. He does not discuss the potential nutrition effects, which is the core of this article. These and many other questions deserve attention in the context of improving human and environmental health in both high and low-income countries. More evidence is urgently needed to guide the debate and decision-making by both governments and the private sector.

One final concern. As somebody who, during most of his professional career has argued for more support for smallholder agriculture, including the transition from the production of food stables to high-value agricultural commodities such as fruits and vegetables, I am somewhat concerned that vertical, indoor production of vegetables, which is likely to be subject to large scale economies, will take the market away from smallholders. However, given the enormity of the micronutrient deficiency problem, the widespread lack of access in many urban areas, and the desire to expand the consumption of vegetables reflected in the rapidly increasing demand for them, I believe the market will be sufficiently large to accommodate both indoor and outdoor production. Indoor production should be seen as complementary to more conventional production and supply chains not substituting for them.

I am much more concerned about the large-scale outdoor production unit outcompeting smallholders. Efforts to promote increased production of fruits and vegetables on small farms in low-income countries have been very disappointing. The progress has been very slow, in part due to poorly functioning supply chains and large post-harvest scale economies and partly because agricultural research continues to prioritize productivity increases in staple foods, while all but ignoring the opportunities for increased productivity and lower unit costs in vegetables. How much longer do the 2 billion people suffering from poor health caused by micronutrient deficiencies have to wait for action to be taken? Let's take all options for solving this humanitarian and economic problem seriously, including an option that 7 years ago looked like a pipedream. We need more solid evidence, not unsubstantiated rejection.

Conflicts of interest

The author has no conflicts of interest

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