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Vertical farming: a holistic approach towards food security

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An Editorial on the Frontiers in Science Lead Article

Vertical farming goes dynamic: optimizing resource use efficiency, product quality, and energy costs

Key points

- The vertical farming industry has grown significantly in the last 15 years and continues to attract interest from various stakeholders due to the system's innovative nature.
- The benefits of vertical farming extend beyond boosting the food supply; they also include reducing agricultural pollution, safeguarding biodiversity, and producing safer food.
- Vertical farming can significantly contribute to Earth's regeneration by reducing the need for extensive land use required by agriculture, which is crucial as the global population grows.

Vertical farming has been in existence for a mere 15 years. From an economic perspective, by any standard, vertical farming is a fledgling industry. Yet, it has achieved a robust growth rate during that short period. Apparently, vertical farming is an idea whose time has finally arrived. According to a *New York Times* review article in 2022, "vertical farming is expected to grow to $9.7 billion worldwide by 2026, from $3.1 billion in 2021, according to ResearchAndMarkets.com, a data analysis firm" (1). A more recent economic assessment suggests: "According to a new report from Fortune Business Insights, vertical farming will grow seven-fold between now and 2030, soaring to more than $27B in value globally in 2030 from a little over $4B in 2022" (2). Most would regard this as a remarkable compound annual growth rate, considering that there were no vertical farms anywhere in the world in 2010 when I wrote my book, *The vertical farm: feeding the world in the 21st century and beyond* (3). After its publication, the idea of raising crops in multistory, specially designed buildings began attracting a wide range of players, but after just 2 years, there were fewer original startups, and more second-generation vertical farms worldwide, especially in Japan.

The earthquake and tsunami in Fukushima, Japan, on 16 March 2011, served as a catalyst for change in that small country. It is important to note that Japan is largely

forested and mountainous; only 13% is arable. When the tsunami hit Sendai, Japan lost 5% of its farmland in just over an hour. In the immediate aftermath, several renowned Japanese industries, including Mitsubishi, Toyota, Toshiba, and Panasonic, were motivated by governmental incentives to contribute to the establishment of vertical farms across the country. This collective effort, along with the participation of large greenhouse food producer, Spread, has positioned Japan as a leader in the vertical farm industry. Other countries, such as Singapore and the United States, have also made significant strides in this field, with approximately 2,000 vertical farms currently operating in the US.

The advantages of vertical farming systems (VFS) are numerous and include year-round farming without the need for soil, control over environmental parameters, and the ability to establish vertical farms in areas where land is scarce. In their lead article, Kaiser et al. (4) summarize these features and lay out the future of the VFS, addressing what the science of controlled environment agriculture needs to improve upon if vertical farms are to become a welcome, integral part of every urban landscape.

One of the critical considerations for ensuring the success of vertical farming is providing a reliable, affordable, and sustainable energy source. A novel strategy proposed by Kaiser et al. (4) is the use of dynamic light intensity patterns that respond to changes in electricity prices, potentially reducing costs in VFS. An emerging technology such as hydrogen fuel cells (5) is also considered to be a promising solution. The substantial advancements in the hydrogen fuel cell industry in recent years bring us closer to a future where the lack of renewable energy will not be a barrier to VFS operations. This focus on sustainable energy sources not only ensures the industry's continued growth but also underscores its commitment to environmental responsibility, offering hope for a greener future without sacrificing quality of life.

The singular environmental event that is driving agriculture from its traditional rural roots to an urban indoor iteration is, of course, rapid climate change. Outdoor crop failures in just the last 5 years due to a range of volatile environmental parameters have had significant negative effects on global food systems, driving up the price of basic food items so high (6, 7) that hundreds of millions, perhaps even billions, of people now cannot afford to eat in a healthy way. Vertical farming presents a promising approach that could contribute to addressing the problem, particularly if all governments recognize the crucial importance of food as a necessary resource for survival. "*Imagine a world without hunger*" is the mantra of numerous non-governmental organizations working toward this future. There is now a clear way forward employing vertical farming technologies that offer the possibility that in the not-so-distant future (8), everyone living in urban environments will have adequate amounts of nutritious food items to bring to the dinner table.

There are also important concerns associated with traditional outdoor farming, such as environmental degradation and loss of biodiversity. The expansion of farmland often involves deforestation or the burning of grasslands, disrupting ecosystems that are essential for sequestering carbon and maintaining soil health. By adopting vertical farming, crops can be grown on less land, while old structures can be repurposed as farms, reducing the need for additional farmland and preserving biodiversity and ecosystems. This sustainable approach is particularly beneficial in areas that rely on forest or mountain degradation to produce food.

Industrial farming creates pollution due to runoff and in doing so, relegates most of the world's estuaries off-limits to commercial fishing. Estuaries are where most marine fish species and numerous crustaceans (shrimp, crabs, and mussels) lay their eggs. Agricultural pollution, mostly due to nutrient overloading in the estuary with runoff laden with nitrogen fertilizers, kills off most of their newly hatched offspring. As a result, most of these fragile ecosystems no longer function at maximum efficiency. VFS, with their closed and circular systems, significantly reduce the environmental impact of fertilizers and other pollutants typically associated with traditional outdoor farming. The flexibility of vertical farming to be integrated with other food production systems, such as aquaponics, offers other advantages by minimizing waste and recycling inputs. If given enough financial support, this approach has the potential to provide a stable supply of crops and seafood.

Another striking benefit of vertical farming is the significant food safety it provides by minimizing the contact of fresh produce with harmful microbes. For example, VFS greatly reduce the risk of contamination from soil-borne and transmitted pathogens because the crops are grown in a soilless culture. This minimizes the chance of parasitic organisms such as hook- and roundworms reaching consumers. These parasites are often transmitted through human feces, which, in some areas of the world, are used as untreated fertilizer by farmers and backyard gardeners, and through the consumption of such locally grown, contaminated produce, diseases can often be transmitted. In addition, the closed-loop irrigation systems used in VFS significantly minimize the incidence of vector-borne diseases, such as malaria and schistosomiasis, which are prevalent among farmers in traditional agricultural settings. In places where farming is the main economic driver, introducing vertical farming could therefore contribute to enhancing both public health and economic resilience.

In summary, we must come to realize that we are all part of nature and not its enemy. Each of us is linked to every other living entity. What happens to the forests and oceans affects everyone. That is how nature works. So far, we have survived, but without a concerted worldwide effort to renew damaged natural systems, things will just keep getting worse. Many predict that nothing will improve until humanity becomes relegated to the fossil record.

The easiest way to save ourselves (and everything else, too) is to simply leave nature alone. Farming worldwide now commandeers a land mass the size of South America to barely feed 8.8 billion people. What happens when our population goes to 10 billion? The choice is ours. All the scientific data necessary to understand what the problem is has been collected and is out there for all to absorb and digest. Ignorance is no longer a valid excuse for not acting to fix

the problems we have created. It is my firm belief that vertical farming will play a major role in Earth's rehabilitation.

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