The Concept, Definition and Economics of Vertical Farming

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Introduction.

Vertical Farming (VF) is big news; hardly a day goes by without prominent articles in the press about how VF is going to be big business, soon. How else will we produce enough food? How else 'save the planet'? The image presented, almost always, is of growing plants by artificial light in multiple layers within sealed sheds; and always one clear message - investment is needed now. Profitable businesses of that kind already exist, providing high-quality, locally-produced herbs and salads: less often mentioned is *Cannabis*, legal in many countries and another example of a VF crop which is business-viable, commanding high prices in the market. The argument that follows is not written in opposition to vertical farming but rather in support, by a firm believer, keen to clarify what is meant and what are the limits on what can be achieved any time soon.

As indicated, a sealed shed is the usual, present-day concept of VF though the originator of the term, Dr Dickson Despommier, did not define it that way. For him, indeed, VF means growing on many levels in a vertical stack so as to economise on land usage and have crops produced close to where they will be consumed. When referring to the enclosed, artificial-light, highly-technical kind Despommier uses the phrase, 'controlled environment vertical farming' (CEVF): in this article too the term VF itself is not confined to the use of artificial light within a fully-controlled environment.

How much food do people need?

The prime concern here is with the economics, the real costs of growing the necessary quantity food by VF, so we must first say a little about how much food humans need for survival. Roughly speaking, a human adult requires about 2,000 kcal per day, more if doing heavy work or sport. Carbohydrate and protein contain roughly 4 kcal/g whilst fats are somewhat more energy-dense at around 9 kcal per gram. Because of the peculiarities and limitations of our metabolism we need at least a little of each plus a range of minerals and micro-nutrients including the recognised 'vitamins', in tiny amounts. In a prosperous society it is easy to eat too much so that foods of rather low calorie but high vitamin content may fetch premium prices: nevertheless, if you don't get enough calories, and in digestible form, you will starve. Wheat flour contains only a little water and some 5-10% of protein, so, given some supplementation with other foods, 500g suffices for an adult for one day. Lettuce and tomatoes contain 95% or more water and the carbohydrate is nearly all indigestible fibre.

Lettuce and tomatoes alone cannot support human life, but wheat can with very little else added. Wheat is a staple foodstuff, the others are not. If we wish to provide sufficient food for the rapidly increasing population of the world, we must consider staples first and although there may be objections to conducting this discussion in terms of wheat (a few people react badly to some components of it) the same arguments must apply to all staples and wheat is a fair example to use for analysis of principles; as in an article, "Vertical Farms could grow all the wheat we need", which appeared in the online magazine Hortibiz in early August, based upon a scientific paper that had appeared a little earlier and whose authors include Dr Despommier (www.pnas.org/cgi/doi/10.1073/pnas.2002655117).

Could VF really do that? It is a very important question that deserves to be fully and critically examined.

How much wheat can be produced under artificial light, at what cost?

In an experiment over twenty years ago, Monje and Bugbee grew wheat to maturity in just 70 days in a controlled environment using light totalling 50 megajoules (MJ) per square metre per day. That's a total of 3500MJ/m^2. One unit of electricity (1 kWh) is 3.6MJ, so the electrical energy used was 972 kWh/m^2, and the yield of grain was 1.4 kg per square meter - 694 kWh per kg of grain, and mature grain contains some 10-11% water. Allowing for that water content, this means that about 0.55% of the light energy supplied was converted into protein and carbohydrate; which may seem very low but is in line with expectations from other work (https://trcboyde.net/downloading-the-sun.html). The paper then analyses how much more grain could be produced if changes are made to the conditions used by Monje and Bugbee - even more intense light, for 24 hours per day instead of 20 hours, and increased atmospheric carbon dioxide concentration. There is also a question of the proportion of grain produced versus straw and roots. Perfectly reasonably they introduce a somewhat better proportion of grain and assume that five harvests per year could be produced since each takes only 70 days.

The yield per harvest is higher and there are five per year; it should surprise no-one that a yield of 20kg per square metre per year seems attainable. That's 200 tons per hectare as compared with the current world record of 17 tons in the open field; and if we are using a 10-storey CEVF that is 2,000 tons per hectare of ground area.

In terms of quantity, the world could be fed that way, no doubt about it, but at what cost? The lengthy discussion may be hard to follow, but the eventual conclusion is not and is summarised here using actual figures from their Appendix. To produce 2,026,647 kg of grain is predicted to require 799,364,000 kWh of electricity at a cost of US$15,987,286. which works out at 394 kWh per kg; distinctly better than that old experiment, no real reason to doubt that it can be achieved, though still an awful lot of electricity. It is when we come to the money that serious questions arise. The cost of electricity is US$7.99 per kg product, but assumes supply at US$ 0.02 (2 cents) per kWh. If instead we assume 10 cents per kWh the cost per kg would be US$40 rather than US$8, and even the lower figure is many times more than the market price of wheat produced in the ordinary way - in 2017, US$ 210/ton FOB Gulf of Mexico; 21 cents per kg.

No businessman would invest in an enterprise which is guaranteed to lose money. There is a huge discrepancy between dreams and reality; no present business case for growing wheat in a CEVF and we must make clear the authors do not argue for doing so. They suggest that by 2050 the predicted margin of loss will be less, though still large because other costs are estimated at little less than that of electricity. They make a strong case for governments to prepare for the use of CEVF, so as to be ready in all respects for an otherwise predictable food-supply crisis; just like we should be ready to deal with future pandemic viruses; and in the same way, those preparations cannot be left to private business and private investors.

And in the meantime?

Why not just make better use of sunlight, with the nascent ***Sundownloader*** technology, without having to rebuild existing greenhouses? Temperature- and CO_2-controlled environments already deliver higher yields in greenhouses in old-fashioned, single-layer horticulture and there is nothing to prevent a VF having glass walls. Whatever price electricity may be, sunlight is free; free to download.

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