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COMMENTARY

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Vertical farming for crop production

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Vertical farming is a well-established method of cultivating high-value vegetables and fruits. However, the practice of growing staple crops in vertical farms is still a new and evolving issue. Recently, a wheat crop annual yield of 11.7 kg per m^2 ground area was demonstrated in a vertical farming facility (https://www.infarm.com/news/another-step-towards-a-future-where-food-insecurity-is-a-thing-of-the-past). Vertical farming involves the cultivation of crops in vertically stacked layers in a highly controlled indoor environment, offering several benefits, including but not limited to higher water and nutrient efficiency, reduced use of pesticides and herbicides and decreased agricultural pollution. To enable large-scale production of staple crops through vertical farming, efforts must be made to optimise photosynthesis and growth dynamics for increased yields, breed crops that are more efficient for vertical farming and cut down energy costs. Combining vertical farming with photovoltaics-based electricity generation can help increase the overall light energy use efficiency and represents a potential way forward.

Recently, Infarm has announced a breakthrough in vertical farming by successfully producing wheat in an indoor farm and achieving an impressive yield of 11.7 kg per m^2 ground area (https://www.infarm.com/news/another-step-towards-a-future-where-food-insecurity-is-a-thing-of-the-past). This projection equates to 117 tons per hectare per year, making a significant milestone in the journey towards growing staple crops for global food security through vertical farming.

The concept of vertical farming was first proposed over two decades ago by Prof. Dickson Despommier from Columbia University in the US[1] and by Prof. Toyoki Kozai from Chiba University in Japan.[2] It involves growing crops in vertically stacked layers in a highly controlled environment, leveraging modern technologies such as sensors, artificial intelligence and robotics etc. Vertical farming offers potential solutions to several critical challenges in modern agriculture, including land scarcity, water conservation, climate control and food security. It has often been proposed as an approach to meet the projected 70% increase in food demand by 2050. According to the Food and Agriculture Organization of United Nations, the world's arable land area has decreased by 33% since 1961, and was approximately 1.38 billion hectares in 2019 (https://worldpopulationreview.com/country-rankings/arable-land-by-country). The average annual increase in crop yield per unit area, at about 1.5% since 1961, is insufficient to meet this rising demand for food production.[3] By growing crops on multiple stacked layers and maximising yield per plant growing area, vertical farming holds the promise of dramatically increasing food production. For example, for wheat production, the yield in vertical farming theoretically can be as high as 220–600 times of that achieved in conventional farm land.[4]

In addition to expanding planting/growing areas, vertical farming also offers numerous additional benefits. By growing crops indoors, it protects crop production from environmental and weather disruption, while optimising environmental parameters, such as light, temperature, humidity and CO_2 levels. Vertical farming also boasts water use efficiency through the reuse of drained water and recapturing of transpired water as well as improved nutrient efficiency and reduced agricultural pollution and greenhouse gas emissions.[5] With crops grown in isolation from the outside environment, the utilisation of chemicals such as pesticides and herbicides can be reduced, offering another huge ecological advantage. Additionally vertical farming can be practiced in urban areas, reducing transportation and storage costs and bringing crops closer to consumers. Technologies developed for vertical farming may also be adapted for use in space exploration.

Vertical farming has garnered significant attention among academic, investment and industrial communities due to its numerous potential benefits. Over the past two decades, there has been rapid progress in the production of leafy greens using vertical farming methods.[2] However, the challenge of producing staple crops in a cost-effective manner remains a significant obstacle. The high operational cost, particularly electricity cost associated with the use of LED lighting make it difficult to achieve economic success in this area.[6] The estimated cost of producing vegetables or crops through vertical farming is substantially higher than conventional agronomic practices.[4] To overcome this challenge, efforts must be made to increase crop growth and reduce energy costs simultaneously.

Firstly, optimising photosynthesis for greater yield: Several factors in vertical farming can be adjusted. The light recipe, including the photoperiod, light levels and light quality (spectrum, intensity and frequency), can be optimised to increase photosynthetic efficiency; similarly, the nutrient recipe, CO_2 levels, air movement speed and temperature can be optimised to boost photosynthesis.

Secondly, breeding for efficiency: Modern breeding and improved management practices have significantly increased crop yields, as demonstrated by the rise in average yield of major cereal crops from 1.35 to 4.07 tons per hectare from 1961 to 2020.[7] However, there has been limited effort to breed crops specifically for vertical farming. Some of the desired features of such crops include a compact stature, a shorter growth cycle, and early flowering, while biotic and abiotic stress tolerance are less critical. One such example is rice with a shorter lifespan and compact stature that has already been developed in 2018.[8]

Thirdly, optimising growth dynamics: Developing phenotyping platforms to capture morphological and physiological information of plants in vertical farming and creating robust models to predict crop growth and development are key steps towards optimising growth dynamics and achieving higher yields under vertical farming. These platforms and models will provide the foundation for optimising environmental management protocols as well as for creating optimal control protocols through machine learning.[9]

Fourthly, reducing energy cost: In vertical farming, energy is consumed to produce constant light, maintain temperature and air quality, and running water and nutrient system; among which, about one half of energy is used to power artificial lighting.[4] To make vertical farming a viable option for producing staple crops at scale, utilising renewable energy sources, such as solar and wind energy, is essential and not just an option. One solution is to integrate a photovoltaic-based electricity production system with the vertical farming facility,[10] especially using those agricultural photovoltaics which can offer energy conversion efficiency higher than either photovoltaic system or crop production system alone.[11] In this context, there is a high demand for technologies that enhance the efficiency of converting solar light into electricity through photovoltaics and converting electricity into light through LEDs. In this context, great opportunities lie in the optimisation of LED spectrum to match the demand for optimal photosynthesis and improvement of photovoltaic systems.

The progression from field cultivation to greenhouse and finally to vertical farming represents a step-by-step increased level of control over the growing environment. While high yields are achievable in vertical farming, this comes at a significant cost and energy expenditure. Currently, vertical farming seems more suitable for fresh plant products with a high value per unit fresh weight.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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