Where to go for sustainable and feasible vertical farming? A journey through resource use, environmental performances and viability indicators

Where to go for sustainable and feasible vertical farming? A journey through resource use, environmental performances and viability indicators.

F. Orsini[1], I. Zauli[1]

[1]Department of Agricultural and Food Sciences, Alma Mater Studiorum University of Bologna, Italy

Abstract

Food systems are responsible for a third of global greenhouse gas emissions and high water, soil and mineral nutrient consumption. Therefore, the study of innovative production techniques resilient to climate change and efficient in the use of resources assume considerable relevance. Vertical farming uses cultivation systems with high technological content. It takes place in climatic cells isolated from the external environment, where artificial lighting is used. The potential of these systems is often associated with the considerable saving of water and mineral resources, the reduced phytosanitary requirements or the reduced land use for agriculture. Major issues to be addressed mainly concern the high installation costs, the elevate energy requirements and environmental impacts associated with lighting. While we are witnessing a rapid development of these technologies in North America, Asia and Northern Europe, applications in the Mediterranean remain limited. Nonetheless, literature shows that main advantages of vertical farming may be observed in warmer climates, in which traditional greenhouse production techniques have to deal with limited water availability and higher energy costs for cooling. Therefore, there is the need for validating vertical farming technologies in experimental conditions. Within the European project H2020 "Food Systems in European Cities (www.foode.eu)" at the University of Bologna the first experimental vertical farm in Italy (AlmaVFarm) has been recently created. AlmaVFarm integrates vertical cultivation systems and energy-efficient lighting technologies aimed at identifying sustainable management protocols and genotypes most adapted to vertical farming conditions, identifying the main sources of impact and develop sustainable management technologies and protocols in both economic and environmental terms. Although the large-scale application of vertical farming is still to be validated in terms of environmental efficiency and productivity it appears that this technology can effectively integrate traditional agriculture, especially where the consequences of climate change will be more pronounced.

Keywords: Energy use Efficiency (EUE), Land Surface Use Efficiency (SUE), Water use Efficiency (WUE), indoor farming, Plant Factories with Artificial Lighting (PFALs), sustainability assessment

INTRODUCTION

Among the first indications on the possibility to grow plants on multiple vertical levels, a key reference is provided by an article from 2009, that called for the rise of Vertical Farms (Despommier, 2009). In the manuscript, plants cultivated inside high skyscrapers within the city boundaries were foreseen to enable feeding the global urban population. Although current vertical farms have never gone so high within the city landscape and staple crops are not yet viable on these systems, a global rise of the sector was experienced, mainly due to very rapid advances in LEDs technologies.

From a preliminary analysis of 10 international market studies, it emerges that vertical farming today represents an attractive investment, forecasted to reach a market value of USD 30 billion by 2030 thanks to venture capitals, investment funds, commercial banks, retailers, and private investors (Figure 1).

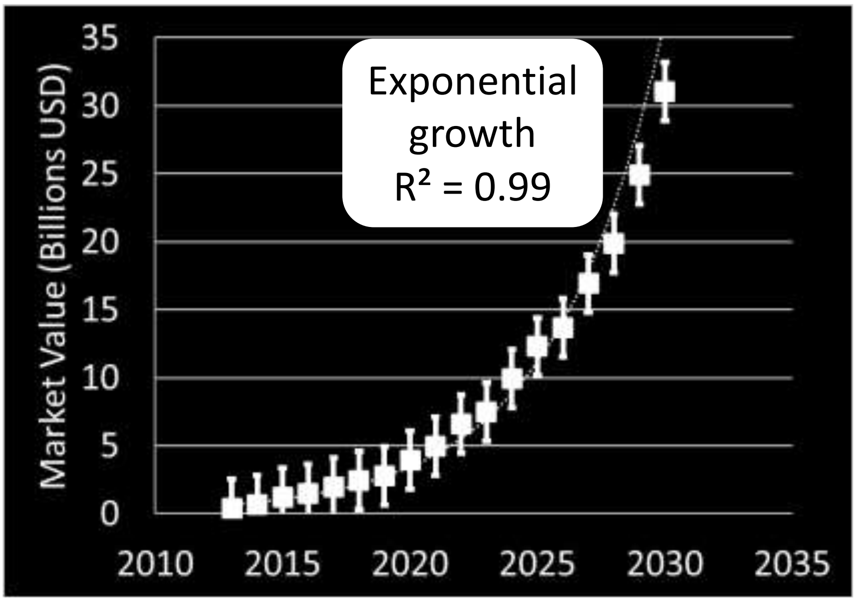

Figure 1. Graphic representation of vertical farming market value (Billions USD) exponential growth over the years. Average data from 10 independent market studies including PR newswire (New York, USA, 2019), Global Market Insights (Selbyville, Delaware, USA, 2020), BBC research (Denver, Colorado, USA, 2020), Grand View Research (San Francisco, California, USA, 2021), Markets & Markets (Dublin, Ireland, 2022), EMR (Sherydan Wyoming, USA, 2022), Precedence Research (Ottawa, Ontario, USA, 2022), Statista (New York, USA, 2022), Verified Market Research (Lewes, Delaware, USA, 2022), Next move strategy consulting (Assam, India, 2022).

The global rise of the vertical farming sector is also triggering a revolution in the farming sector. In the last decades, an aging phenomenon of the European farmers community has been observed. Indeed, only 11% of farmers are aged below 40 years old, mostly represented by male growers with family farms of small size and very limited investment capacity, generally below 10’000 euros. Alternatively, vertical farms have demonstrated to effectively engage a younger audience of growers, with more diversified gender and backgrounds. For instance, half of vertical farmers do not have any previous experience in agriculture, they often hold a degree, master or PhD or are entrepreneurs from non-traditional sectors, such as business, engineering, or IT. Therefore, this also ultimately result in large and unprecedent investments into the farming sector (Gasson et al., 1988; Pietola et al., 2011; Lowder et al., 2016; European Commission, 2021; Agritecture, 2022; FAO/EBRD study on Urban Agriculture, unpublished data).

As a matter of fact, the investment needed for vertical farming is usually higher than conventional agriculture or greenhouse. Indeed, for indoor farming the investment may reach values up to 1’000-3’000 euros m^{-2}, compared to values up to 300 euros m^{-2} for high-tech greenhouse m^{-2} (Table 1). However, considering the achievable yield, indoor farming may guarantee up to 90-170 kg m^{-2} $year^{-1}$ per layer, therefore an amount considerably larger than open field as well as greenhouses, where yield is usually around 2-4 and 40-70 kg m^{-2} $year^{-1}$, respectively. Moreover, ready-to-eat products from vertical farms entail a higher economic value. This value translates into higher selling prices and these products in the market can easily be sold between 7-14 euros kg^{-1}, unlikely fresh products produced in open field or greenhouse systems where price usually do not exceed 1.4 euro kg^{-1} for traditional agriculture or 7 euros kg^{-1} for greenhouse systems. Also, labor needed is consistently enhanced in indoor farming, providing increasing job opportunities although it also highly depends on the automation level of the system (Kozai and Niu, 2019; Raaphorst et al., 2019; Orsini et al., 2020 and unpublished data).

Table 1. Investment, yield, selling price for products and labor needed figures for the different cropping systems: open field, greenhouse, vertical farm.

	Investment (euro m^{-2})	**Yield (kg m^{-2} $year^{-1}$)**	**Selling price (euro kg^{-1})**	**Labour (worker ha^{-1})**
Open field	1-10	2-4	0.3-1.4	1, with mechanized harvest and seasonal workers
Greenhouse	10-300	40-70	0.5-7	4-10
Vertical Farm	1’000-3’000 of cropped surface	90-170 per layer	7-14	Up to 300 depending on automation

Considering the high R&D investment and the level of technology applied in vertical farming, research priorities are mainly focusing on facilities design and its components, such as LEDs, growing systems and climate control. Innovations is also taking place in terms of products diversification and quality improvements, as well as focusing on exploring monitoring and phenotyping tools and sensors. Under this framework of innovation, AlmaVFarm, the first experimental vertical farm in Italy, has been implemented in Bologna University within the European project Food System in European Cities (FoodE). AlmaVFarm represents a place for research, education, and sustainable technological innovation. Indeed, AlmaVFarm integrates vertical cultivation systems, energy-efficient lighting technologies and the possibility to independently modulate most cultivation parameters. AlmaVFarm hosts research tailored to identify sustainable management protocols and genotypes most adapted to vertical farming conditions, identifying the main sources of impact and developing sustainable management technologies and protocols in both economic and environmental terms. Through a journey exploring the different indicators for the evaluation of vertical farming sustainability, the present work aims to present figures on environmental and resource use performances of these innovative systems and the possible strategies to implement for further increase their efficiency in the future.

RESULTS AND DISCUSSION

Land Surface Use Efficiency in Vertical Farms

Generally, Land Surface Use Efficiency (SUE) is considered as the fresh biomass produced per unit of land occupied. In vertical farm facilities, cultivation space explores the vertical dimension, therefore considerably increasing the available surface for crops growth and optimizing cultivation area. For instance, the surface needed to obtain 1 kg of fresh lettuce (*Lactuca sativa* L.) per day ranges from 93 m^2 in open field to 9 m^2 in greenhouse. In vertical farming, the necessary space is further reduced, as only 0.3 m^2 for 10 cultivation layers are needed (Barbosa et al. 2015, Pennisi et al., 2019; Orsini et al., 2020). In addition, vertical farming allows the adoption of techniques that cannot be implemented in open field conditions nor in traditional greenhouses. For instance, strategies such as dynamic plant spacing, which consists in the adaptation of plant spacing according to the growth stage in order to maintain an optimum Leaf Area Index (LAI), may provide advantages in terms of productivity per land surface unit (Ioslovich and Gutman, 2000; Ohyama et al., 2000; Hang et al., 2019). Similarly, dynamic plant spacing may also provide advantages in terms of air recirculation at canopy level, although its viability is highly dependent on the vertical farm level of automation (Van Delden et al., 2021).

Water Use Efficiency in Vertical Farms

Water Use Efficiency (WUE) is calculated as the fresh biomass produced per unit of water used. Overall, in vertical farms, WUE can be influenced by different factors, ranging from light management to the growing system typology selected and the climate control applied. Light may play a major role on the water use efficiency of vegetables, and, accordingly, finetuning light spectrum and light intensity is a key research priority. However, results gathered from studies showed that different light parameters may be needed according to the species or cultivar used to obtain an optimal WUE. In basil (*Ocimum basilicum* L.) it has been observed a maximized WUE when a Red and Blue ratio (RB) equal to RB=2 or RB=3 has been applied using LEDs, obtaining up to 45 g FW L^{-1} H_2O (Pennisi et al., 2019a). Similarly, for lettuce (*Lactuca sativa* L.) it has been pointed out that RB=3 was associated with increased WUE (75 g FW L^{-1} H_2O), in comparison to other red and blue combinations (Pennisi et al., 2019b). Furthermore, alternative wavelengths are also explored for WUE analysis and research display how, with a constant Photosynthetic Photon Flux Density (PPFD) of 250 μmol m^{-2} s^{-1}, the addition of white (W) to an RB spectrum was also able to increase the WUE in green lettuce compared to RB or RB supplemented with a green (G) portion. On the other hand, the same results have not been observed for red lettuce cultivar, where no significant differences among light treatments were observed (Pennisi et al., unpublished data). Beside light quality, playing with light intensity may also modify the efficiency of water used in terms of fresh biomass obtained. Pennisi et al. (2020) showed that applying a PPFD equal or greater than 200 μmol m^{-2} s^{-1} in lettuce and a PPFD≥250 μmol m^{-2} s^{-1} in basil lead to enhanced WUE, resulting in up to 60 and 38 g FW L^{-1} H_2O for lettuce and basil respectively.

Beyond light, the type of growing system applied in the vertical farm environment may also affects WUE. A comparative assessment of hydroponics and aeroponics for lettuce cultivation carried out in AlmaVFarm showed that aeroponics was 2.2 folds more efficient in water use than hydroponics, possibly due to substrate water retention in hydroponic systems. Nevertheless, it must also bear in mind that water used in a vertical farm not only include irrigation systems, but also water used for climate control and facility cleaning, which account for 30% of the total amount. However, about 67% of the irrigation water can be recovered from de-humidifiers systems, therefore allowing a higher WUE (L. Carotti, personal communication).

Energy Use Efficiency in Vertical Farms

Energy Use Efficiency (EUE) is a parameter used for assessing the effectiveness of the system in obtaining the highest value of fresh biomass per kWh consumed. Being vertical farms a closed environment for plant cultivation, energy costs are mostly related to lighting management and climate control. Similarly, also the energy source used may affect the energy efficiency of the system. Studies reported that 42-80% of the electricity costs are related to light, whereas climate control account for 16-43%, and only 10-15% of the energetic requirements is related to production facilities (Yokoyama, 2019). In particular, LED lighting represents the highest energy expenditure in indoor farming, where also inefficiencies in lamps' electricity conversion into light may also result in increased energy costs for climate control. According to a recent studies carried out in AlmaVFarm, energy used for LEDs lighting amount to 51%, whereas 47% is destinated to climate control of the indoor environment, and only 2 % to the cultivation facilities (L. Carotti, personal communication). However, supplying AlmaVFarm education services in the first place, such increased energy for climate control can be associated with frequent door opening due to data collection and student activities, as well as to the limited size of the experiment over the whole indoor factory volume, and the need for optimizing the crop management strategies. Accordingly, it was also observed that the comparison between hydroponics and aeroponics in terms of EUE did not display significant differences, with a similar fresh biomass yield. (L. Carotti, personal communication). Nonetheless, several strategies to enhance concurrently yield and EUE in the vertical farms can be planned, modulating light parameters and crop density, as well as adopting smart climate solutions and adequate energy sources.

Increasing plant density might concurrently enhance the fresh yield and the efficiency of lighting energy used during the whole cycle. For instance, by increasing planting density up to 270 plants m^{-2}, a doubled EUE has been observed, compared to lowest density (L. Carotti, personal communication).

The light spectrum adjustment is a feasible strategy aimed at providing only selected light spectra regions beneficial for plant physiological processes. Given that light wavelengths are not equally absorbed by plants, by selecting determined light region energy consumption can be significantly reduced. Concurrently, light spectrum management may also lead to increased yield and qualitative traits in leafy vegetables. For instance, by substituting as little as 30 µmol m^{-2} s^{-1} of RB radiation with Far Red (FR) wavelengths a 2-folds increment of EUE can be achieved (L. Carotti, personal communication). Similarly, also finetuning the light spectrum together with light intensity may increase the efficiency of energy used, with species-specific performances. Indeed, in lettuce it has been observed a maximum EUE with an RB≥3 or when a PPFD was set at 200 and 250 µmol m^{-2} s^{-1} (Pennisi et al., 2019b, 2020b). Instead, for basil highest EUE has been assessed at RB≥2 and a PPFD fixed at 250 µmol m^{-2} s^{-1} (Pennisi et al., 2019a, 2020b) Another research has been carried out in AlmaVFarm on kale (*Brassica oleracea* L. var. baby kale) baby leaf, where different RB ratio as well as RB spectra partially substituted by W wavelengths were tested. In particular, when RB in a ratio of 1 with a 45% of the spectra substituted by W wavelengths, the lowest lighting EUE was reached, as well as the lowest yield and shorter plants, especially compared to RB=1 without W wavelengths (I. Zauli, personal communication).

Adjusting light photoperiod may also allow EUE increase. As reported by Pennisi et al. (2020), optimized efficiency of energy used has been obtained when 16 hours of light and 8 hours of dark were daily applied for several crops, against 20 or 24 h day^{-1} of light. In particular, results highlighted that up to 138 g FW kWh^{-1} for lettuce and 61 and 65 g FW kWh^{-1} for basil and chicory (*Cichorium intybus* L.) respectively can be reached. Instead, rocket (*Eruca sativa* Mill.) EUE was not affected by different photoperiods (Pennisi et al., 2020).

Furthermore, the application of pulsed light application in indoor farming may also lead to greater EUE when applying pulsed RB=3 light with low switching frequencies for blue diodes (e.g., adopting 293 kHz instead of high frequency at 850 kHz) (Carotti et al., 2021).

Additionally, to the above-mentioned strategies, the components of the LEDs itself, the diode, can have different efficiency in converting electricity into photons. Therefore, the different spectral components may also affect the energy that the system consume to generate light. Red diodes result to be more efficient compared to Blue one, as more photons are released by LEDs emitting at longer wavelengths. Photosynthetic Photon Efficacy (PPE) of Red diodes has been observed to be around 2.3-2.6 µmol J^{-1}, consistently higher in comparison to the values of 1.8-2.0 µmol J^{-1} commonly associated with Blue (Park and Runkle, 2018).

However, the working temperature of the LED lamps may also alter the actual efficiency of the diodes. Therefore, diodes may both enhance their efficiency as a response to increasing junction temperature, as in the case of Blue diodes, or even decrease it, as has been observed on Red diodes (Pennisi et al., 2019a). In a recent review by Paucek et al. (2020), a worldwide inventory of LEDs manufacturer and lamps efficacy has been performed, displaying that most lamps today in the market have a declared efficacy of 2 to 3 μmol J^{-1}.

Climate system are also a crucial component of vertical farm environment. Therefore, by working on smart climate control system it is possible to improve EUE as well. For instance, by shifting from a heat-pump climate control to a co-generation system would allow to save up to 30% of energy, where also the adoption of a more evolved system such Heating, Ventilation and Air Conditioning (HVAC) may further promote the EUE (Yokoyama, 2019).

Lastly, energy source is a limiting factor for vertical farm energy use efficiency as well, also in consideration of the energetic crisis. Some strategies, such as the adoption of renewable sources or energy mixes can be a possible action to cut off energy expenditure. Although solar panels are often considered the solution for feeding structures like indoor plants factories, the amount of energy and space needed must be carefully studied. In a recent study by Van Delden et al. (2021), the total area needed for feeding with solar panels a vertical farm with 9 layers located in the Netherlands has been calculated to be equal to 28 m^2 per 1 m^2 of growing surface in the indoor farm. However, this figure only account for the energy needed for lighting system, while the energy required for climate control is not considered. Although these values of needed space for supplying solar energy are massive, it should be considered that often vertical farming rises in urban facilities where suitable rooftops may host large photovoltaic systems, that could potentially contribute to energy requirements. In addition to renewable energies, energy mixes may be a solution. Martin and Molin (2019) reviewed the energy source scenario in a Swedish vertical farm comparing the use of a Swedish electricity mix (e.g., large share of hydropower and nuclear energy with a limited share of fossil sources) versus the Nordic electricity mix (e.g., larger share of fossil fuels). Results obtained highlighted that by using the latter, the GHG emissions were almost doubled in the most resource efficient case.

CONCLUSIONS

Vertical farming is growing as a valid alternative to traditional plant production systems, enabling to take advantage of the urban resources and potentially taking place in vacant buildings. Indeed, the elevated level of innovation found in indoor farms is currently attracting public and private, and engaging the youngest generations into agriculture. When analyzing vertical farms, several impacts must be considered, which can ultimately undermine the sustainability of the system itself and should therefore be improved. Considering structures and spaces hosting vertical farms, retrofitting of existing buildings is a scarcely used practice, due to safety rules or architectural elements (columns, low floors) that hinders the creation of climatic cells. The construction of new buildings for hosting vertical farms is more common, although leading to exacerbate soil sealing. Moreover, given the transient nature of vertical farm start-ups sector, there is also a risk of impacts exacerbation when phenomenon like bankruptcy occurs. Besides, there is still room for improvement in terms of energy, water and space efficiency, despite some indicators already present good figures. Suitable crop species should be used, with lowest impacts, applying also appropriate crop management along the production cycle. Although it is evident that land use efficiency can be enhanced through vertical farming, as well as water use efficiency, several strategies may further increase these aspects. For instance, appropriate light management and especially the recovery air humidity through dehumidification may provide an additional improvement of WUE. Similarly, working on adequate growing systems and applying dynamic plant spacing and multiple layering can additionally reduce land use. However, most of the expenditure still derive from energy use for light and climate requirement. Thus, reducing the energy needs of vertical farming should be a top priority, especially in a climate change scenario. Therefore, strategies may include adoption of efficient environmental control systems as well as improved light use efficiency, focusing on advanced light management by adjusting light spectrum, photoperiod, and intensity according to the crop. Lastly, the energy source used also has a high impact on the sustainability of indoor farming. However, an adequate analysis of feasibility of the best energy source must be considered in advance, also evaluating the local supply and available spaces. Overall, it emerges that additional research is needed to explore and develop a range of innovations in indoor farming in order to overcome the current limits of the technology.

ACKNOWLEDGEMENTS

The research leading to this publication has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No. 862663.

Literature cited

Agritecture. (2022). Global CEA Census Report. Way Beyond and Agritecture consulting. 56 pp.

Barbosa, G.L., Gadelha, F.D.A., Kublik, N., Proctor, A., Reichelm, L., Weissinger, E., Wohlleb, G.M., and Halden, R.U. (2015). Comparison of land, water, and energy requirements of lettuce grown using hydroponic vs. conventional agricultural methods. Int. J. Environ. Health Res., *12(6)*, 6879-6891.

Blanken, W., Cuaresma, M., Wijffels, R. H., and Janssen, M. (2013). Cultivation of microalgae on artificial light comes at a cost. Algal Res. *2(4)*, 333-340.

Carotti, L., Potente, G., Pennisi, G., Ruiz, K.B., Biondi, S., Crepaldi, A., Orsini, F., Gianquinto, G., and Antognoni, F. (2021) Pulsed LED Light: Exploring the Balance between Energy Use and Nutraceutical Properties in Indoor-Grown Lettuce. Agronomy *11(6)*, 1106.

Despommier, D. (2009). The rise of vertical farms. Sci. Am. *301(5)*, 80-87.

European Commission. (2021). https://agriculture.ec.europa.eu/news/ageing-europes-farmers-remains-major-challenge-rural-areas-2021-04-08_en.

Gasson, R., Crow, G., Errington, A., Hutson, J., Marsden, T., and Winter, D. M. (1988). The farm as a family business: a review. J. Agric. Econ., *39(1)*, 1-41.

Hang, T., Lu, N., Takagaki, M., and Mao, H. (2019). Leaf area model based on thermal effectiveness and photosynthetically active radiation in lettuce grown in mini-plant factories under different light cycles. Sci. Hortic. 252, 113-120.

Ioslovich, I., and Gutman, P. O. (2000). Optimal control of crop spacing in a plant factory. Automatica, *36(11)*, 1665-1668.

Kozai, T., Niu, G., and Takagaki, M. (eds.). (2019). Plant factory: an indoor vertical farming system for efficient quality food production, 2nd edn (Academic press), pp. 516.

Lowder, S. K., Skoet, J., and Raney, T. (2016). The number, size, and distribution of farms, smallholder farms, and family farms worldwide. World Dev. 87, 16-29.

Martin, M., and Molin, E. (2019). Environmental Assessment of an Urban Vertical Hydroponic Farming System in Sweden. Sustainability, *11(15)*, 4124.

Ohyama, K., Yoshinaga, K., and Kozai, T. (2000). Energy and mass balance of a closed-type transplant production system. Water balance. J. Soc. High Tech. Agr. *12(4)*, 217–224.

Orsini, F., Pennisi, G., Zulfiqar, F. and Gianquinto, G. (2020). Sustainable use of resources in plant factories with artificial lighting (PFALs). Eur.J.Hortic.Sci. 85(5), 297-309.

Park, Y., and Runkle, E. S. (2018). Spectral effects of light-emitting diodes on plant growth, visual color quality, and photosynthetic photon efficacy: White versus blue plus red radiation. PLoS One, *13(8)*, e0202386.

Paucek, I., Appolloni, E., Pennisi, G., Quaini, S., Gianquinto, G., and Orsini, F. (2020). LED lighting systems for horticulture: business growth and global distribution. Sustainability *12(18)*, 7516.

Pennisi, G., Blasioli, S., Cellini, A., Maia, L., Crepaldi, A., Braschi, I., Spinelli, F., Nicola., S., Fernandez., J.A., Stanghellini, C., Marcellis, L.M.F., Gianquinto, G., and Orsini, F. (2019a). Unraveling the role of red: blue LED lights on resource use efficiency and nutritional properties of indoor grown sweet basil. Front. Plant Sci. 10, 305.

Pennisi, G., Orsini, F., Blasioli, S., Cellini, A., Crepaldi, A., Braschi, I., Spinelli, F., Nicola., S., Fernandez., J.A., Stanghellini, C., Gianquinto, G., and Marcellis, L.M.F. (2019b) Resource use efficiency of indoor lettuce (*Lactuca sativa* L.) cultivation as affected by red:blue ratio provided by LED lighting. Sci. Rep. 9, 14127.

Pennisi, G., Orsini, F., Landolfo, M., Pistillo, A., Crepaldi, A., Nicola, S., Fernandez, J.A., Marcelis, L.F.M,. and Gianquinto, G. (2020a). Optimal photoperiod for indoor cultivation of leafy vegetables and herbs. Eur. J. Hortic. Sci. 85, 5.

Pennisi, G., Pistillo, A., Orsini, F., Cellini, A., Spinelli, F., Nicola, S., Fernandez, J.A., Crepaldi, A., Gianquinto, G., and Marcelis, L.F.M. (2020b). Optimal light intensity for sustainable water and energy use in indoor cultivation of lettuce and basil under red and blue LEDs. Sci. Hortic., 272, 109508.

Pietola, K., Myyrä, S., and Heikkilä, A. M. (2011). The penetration of financial instability in agricultural credit and leveraging. Brussels, Belgium: Centre for European Policy Studies (CEPS), pp.19.

Raaphorst, M., Benninga, J., and Eveleens, B.A. (2019). Quantitative information on Dutc h greenhouse horticulture 2019. Report WPR-898. Wageningen University and Research, The Netherlands.

Van Delden S.H., SharathKumar, M., Butturini, M., Graamans, L.J.A., Heuvelink, E., Kacira, M., Kaiser, E., Klamer, R.S., Klerkx., L., Kootstra, A., et al., 2021 Current status and future challenges in implementing and upscaling vertical farming systems. Nat. Food *2(12)*, 944-956.

Yokoyama, R. (2019). Energy Consumption and Heat Sources. In Plant Factories Using Artificial Lights: adapting to environmental disruption and clues to agricultural innovation. Anpo, M., Fukuda, H., and Wada, T. eds. (Elsevier), pp. 177-184.