Outdoor vertical farming on textile substrates

L Dirkes, J D Massanés, R Böttjer, J I L Storck and A Ehrmann
Bielefeld University of Applied Sciences, Faculty of Engineering and Mathematics, Interaktion 1, 33619 Bielefeld, Germany
e-mail: andrea.ehrmann@fh-bielefeld.de

Abstract. Vertical farming may solve the problem that in many regions of the world, more area would be necessary to produce food, than it is available. Especially in large cities and other densely crowded areas, vertical farming can provide an efficient and eco-friendly way to feed people. While indoor vertical farming plants are usually highly automatized, outdoor approaches are usually less professionally setup and thus often prone to drying-out, in this way disturbing of even destroying the plants grown in such setups. Here we report on semi-automated irrigation systems, combined with different textile substrates to reduce the risk of fully dried substrates, in order to make inexpensive, successful vertical farming systems available for everybody.

1. Introduction
With more and more people to feed from a climatically more and more complicated world, alternatives to common agricultural techniques are necessary to provide enough food for everybody [1]. This is not only true for the poorest countries with highest expected population growth [2], but even for wealthier countries where often the total agricultural land area is insufficient to feed the population [3]. One approach to grow more crops etc. per unit area is based on vertical farming [4].

While vertical farming has several advantages, such as water recyclability, lower areal consumption and strongly reduced application of pesticides [5], there are also disadvantages, amongst others related to irrigation. A possible approach to overcome the problem of drying-out may be found in using textile fabrics instead of sand or bark to store water [6].

Textile fabrics can, on the one hand, be used for immobilisation and harvesting of macro- and microalgae. Kerrison et al. described growth of the macro-algae Saccharina latissimi on different textile fabrics [7], while Pellizaari et al. grew seaweed Gayralia sp. on polypropylene nets [8]. In a recent study, Sebök et al. found especially hairy, open-pore fabrics suitable for adhesion of the marine macroalgae Ectocarpus sp. [9]. Lee et al. suggested nylon meshes to harvest diverse microalgae [10].

Microalgae could adhere on some electrospun nanofiber mats, depending on the material [11,12].

Besides algae, macroscopic plants were also grown on textile fabrics. Here, however, not much research is yet available. Typical agroteciles are used to cover lettuce [13,14] or potatoes [15]. Knitted fabrics, on the other hand, were found suitable as substrates for growth of edible mushrooms [16] or plants in vertical or horizontal hydroponic systems [17,18]. Detailed examination of the drying of textile fabrics under different environmental conditions are not yet published.

Another solution to solve the problem of sufficient irrigation is an automated watering system. Here, a combination of both is described and tested under outdoor conditions in a hot summer.

2. Materials and Methods
Different substrates were used to investigate the water storage capability and as substrates: mineral wool, sponges, coco mats, and hemp fiber mats. Drying of these materials was tested by defined irrigation and constantly measuring the masses during the drying process.
The plants cultivated were cress (*Lepidium sativum*), salad “Attractie” (*Lactuca sativa*), broccoli (*Brassica oleracea var. italic*), basil (*Ocimum basilicum*), dill (*Anethum graveolens*), chive (*Allium schoenoprasum*), marjoram (*Origanum majorana*) and savory (*Satureja hortensis*).

Vertical farming stands were built and placed in gardens in Germany in the hot summer 2019 (Fig. 1). Generally, metal meshes were used to fix the textile fabrics, while a pump system was constructed for automatized interval irrigation systems using flexible tubes with regular holes.

Measurements were taken of the pH value of the nutrient solution which was found to be modified by some of the substrates (esp. in case of mineral wool). These undesired modifications were balanced by different fertilizers used as buffers.

The lengths of the plants were measured during four weeks to evaluate the growth success, depending on the combination of plant and substrate.

All experiments were performed in triplicates.

3. Results and Discussion

Figure 2 depicts the water mass uptake in relation to the original mass of the substrates after irrigating the samples completely, followed by allowing them to dry lying horizontally on a grid.

![Figure 2](image-url). Water uptake and drying process in different substrates.
The highest water storage capacity was found in mineral wool, whereas the artificial sponge unexpectedly lost water fastest. It should be mentioned that after approximately 1-2 hours, the curves show nearly parallel slopes, indicating identical relative mass loss per time. However, since the mineral wool could store the highest amount of water, relative to its own mass, it can be expected to dry completely after a significantly longer time than both other substrates.

Since all test stands were also equipped with a pump system, nevertheless different textile and other fabrics were investigated besides mineral wool. The following results refer to cultivation experiments using the outdoor vertical farming stand at a house wall (Fig. 1, left panel). As an example, Fig. 3 depicts germination and growth of cress on hemp and mineral wool, irrigated with pure water. As typical for cress, all seedlings germinated [17,18]. Unexpectedly, after a similar start during the first 6 days, the seedlings on hemp then grew faster before they died since the substrate was insufficiently irrigated. Basil, marjoram, and savory could not germinate on hemp since this substrate was too wet, being placed in a box filled few cm with water.

**Figure 3.** Average length of cress plants, grown on hemp and mineral wool. Measurements were taken for 3 samples with 9 seedlings each.

For larger plants with typically lower germination rates, here only the growth process after germination is investigated, starting from commercially available seedlings. Fig. 4 depicts the growth process during the 2.5 weeks, comparing broccoli and salad.

**Figure 4.** Average length of broccoli and salad plants, grown on sponges and a combination of mineral wool + hemp. Measurements were taken for 3 samples with 1 germinated seedling each.
In both cases, the combination of mineral wool + hemp fiber mats results in a slightly increased growth of the plants, however, without significant difference. Opposite to cress, no problems on the hemp fiber mats occurred, suggesting that for these plants the substrate does not influence the plant growth as strongly as it was found for cress.

Next, Fig. 5 shows different plants grown on mineral wool or sponges, respectively, this time with hydroculture fertilizer “Mairol Hydropflege” (Mairol GmbH, Gussenstadt, Germany) added to the water in a ratio of 1:1000 as suggested by the producer, as a buffer to avoid the undesired increase of the pH value which was found in samples with mineral wool.

**Figure 5.** Average length of diverse plants, grown on mineral wool or sponges. Measurements were taken for 3 samples with 1 germinated seedling each.

On mineral wool, savory and especially chive grew very well, while marjoram and basil stayed much smaller. Dill died completely after less than two weeks. On the sponges, oppositely dill and savory grew well, while basil again stayed very small, and marjoram and chive died. The fact that different plants preferred different substrates was also pointed out by Khandaker and Kotzen who suggested, e.g., mineral wool for spinach, but found nearly equal growth of lettuce on diverse substrates and maximum growth of basil on vermiculite [19].

The pH value increased in spite of the hydroculture fertilizer; the buffer properties of the strongly diluted fertilizer were apparently insufficient in the large hydroponic system. An additional problem occurred in the form of undesired microalgae which grew strongly in the system and used the available nutrition which could thus not reach the higher plants. Besides, in the hot summer time in June 2019 when this experiment was performed, the water evaporated fast from the open system, disturbing a regular irrigation.

This is why an additional experiment was performed using a setup in a pond (Fig. 1 right panel), using the water from the pond which had sufficient nutrients, did not change its pH value due to the large enough volume and did not dry out so that irrigation was guaranteed. In addition, the vertical farming stand was placed outside the direct sun to avoid burning the young plants.

While the plants firstly grew faster after germination (not shown), under the modified environmental conditions they were irrigated too strongly, after some time the plants started fouling. This result clearly shows that not only plants and substrates must be correlated, as visible in Fig. 5, but also the artificial environmental parameters must be fitted to the natural ones, especially regarding irrigation which must differ in sunny or shadowed areas, for different environmental temperatures and depending on the wind which dries the fabrics. These findings already show that outdoor vertical farming under undefined environmental conditions necessitates a higher level of control of the pumps, the fertilizer content in the water and other possible parts of the system.
4. Conclusion

Vertical farming experiments were performed under hot summer conditions outdoor, in the direct sun as well as in shaded areas, using many different vegetables and herbs, grown on different fibrous substrates. In general, the mineral wool was found to be superior in terms of water retention and plant growth. Besides salads, different herbs grew well under heavy conditions. On the other hand, some plants were found to grow better on sponges, suggesting that substrates should be chosen according to the requirements of the respective plants.

Acknowledgments

The project was partly funded by the Federal Ministry for Economic Affairs and Energy in the scope of the ZIM project ZF4036107.

References

[1] Janusziewicz K and Jarmusz M 2017 IOP Conf. Ser. Mater. Sci. Eng. 245 052094
[2] Global Hunger Index Results – Global, Regional, and National Trends (accessed 18-09-2020) Available at http://www.globalhungerindex.org/results
[3] Mayer H, Schuh M, Flachmann C 2018 Statistisches Bundesamt (Destatis) no 5385101-16900-4.
[4] Despommier D 2013 Trends Biotechnol. 31 388–389
[5] Flachmann C 2017 Glob. Food Secur. 17 233–235
[6] Ehrmann A 2019 Tekstilec 62 34–41
[7] Kerrison P D, Stanley M S, Hughes A D 2018 Algal Research 33 352–357
[8] Pellizzari FM, Absher T, Yokoya NS, Oliveira EC 2007 Journal of Applied Phycology 19 63–69
[9] Sebök S, Brockhagen B, Storck J L, Post I B, Bache T, Korchev R, Böttjer R, Grothe T, Ehrmann A 2020 Environmental Technology online first
[10] Lee S H, Oh H M, Jo B H, Lee S A, Shin S Y, Kim H S, Lee S H, Ahn C Y 2014 Journal of Microbiology and Biotechnology 24 1566–1573
[11] Großerhode C, Wehlage D, Grothe T, Grimmelsmann N, Fuchs S, Hartmann J, Mazur P, Reschke V, Siemens H, Rattenholl A, Homburg S V, Ehrmann A 2017 AIMS Bioengineering 4 376−685
[12] Keskin N O S, Celebioglu A, Uyar T, Tekinay T 2015 Industrial and Engineering Chemistry Research 54 5802–5809
[13] Govedarica-Lucic A, Mojovic M, Perkovic G, Govedarica B 2014 Genetika 46 1027–1036
[14] Ponjican O, Bajkin A, Dimitrijevic A, Mileusnic Z, Miodragovic R 2011 In 39th International Symposium on Agricultural Engineering, Actual Tasks on Agricultural Engineering: book of proceedings 39 393–401
[15] Rebarz K, Borowczak F, Gaj R, Frieske T 2015 American Journal of Potato Research 92 359–366
[16] Helberg J, Klöcker M, Sabantina L, Storck J L, Böttjer R, Brockhagen B, Kinzel F, Rattenholl A, Ehrmann A 2019 Materials 12 2270
[17] Böttjer R, Storck J L, Vahle D, Brockhagen B, Grothe T, Herbst S, Dietz K J, Rattenholl A, Gudermann F, Ehrmann A 2019 Tekstilec 62 200–207.
[18] Storck J L, Böttjer R, Vahle D, Brockhagen B, Grothe T, Dietz K J, Rattenholl A, Gudermann F, Ehrmann A 2019 Horticulturae 5 73
[19] Khandaker M, Kotzen B 2018 Aquaculture Research 0 1-15