Elise Diestelhorst [1], Jan Lukas Storck [1], Bennet Brockhagen [1], Timo Grothe [1], Inken Blanca Post [2], Thorsten Bache [2], Rumen Korchev [2], Anke Rattenholl [1], Frank Gudermann [1], Andrea Ehrmann [1]
[1] Bielefeld University of Applied Sciences, Faculty of Engineering and Mathematics, Bielefeld, Germany
[2] Bache GmbH, Rheinberg, Germany

Necessary Parameters of Vertically Mounted Textile Substrates for Successful Cultivation of Cress for Low-Budget Vertical Farming

Lastnosti vertikalno nameščenih tekstilij, potrebne za uspešno gojenje kreše pri nizkocenovnem vertikalnem kmetovanju

Original scientific article/*Izvirni znanstveni članek*
Received/*Prispelo* 1-2021 • Accepted/*Sprejeto* 4-2021

Corresponding author/*Korespondenčna avtorica:*
Prof. Dr. Dr. Andrea Ehrmann
E-mail: andrea.ehrmann@fh-bielefeld
ORCID ID: 0000-0003-0695-3905

Abstract
A growing population needs an expansion of agriculture to ensure a reliable supply of nutritious food. As a variable concept, vertical farming, becoming increasingly popular, can allow plant growth for local food production in the vertical sense on, e.g. facades in addition to the classical layered structure in buildings. As substrates, textile fabrics can be used as a sustainable approach in terms of reusability. In our experiment, we investigated which properties a textile should possess in order to be suitable for an application in vertical farming by the example of cress seeds. To determine the best-fitted fabric, four different textiles were mounted vertically, and were provided with controlled irrigation and illumination. Our results showed that a hairy textile surface as provided by weft-knitted plush is advantageous. There, the rooting of cress plants used in this experiment is easier and less complicated than along tightly meshed, flat surfaces, as for woven linen fabrics.
Keywords: vertical farming, textile substrates, cress, cost-effectiveness, germination

Izvleček
Naraščajoče prebivalstvo potrebuje širitev kmetijstva, da bi si zagotovilo zanesljivo oskrbo s hranljivimi živili. Vertikalno kmetovanje, ki postaja čedalje bolj priljubljeno, lahko kot spremenljiv koncept omogoči rast rastlin za lokalno pridelavo hrane v navpični legi, na primer ob klasičnih večplastnih strukturah na fasadah stavb. Za podlago lahko uporabimo tekstilije, ki pomenijo trajnostni pristop v smislu njihove ponovne uporabe. Na primeru semen kreše v našem poskusu raziskujemo, katere lastnosti bi morala imeti tekstilija, da bi bila primerna za uporabo v vertikalnem kmetovanju. Za določitev najboljše tekstilije so bile štiri različne tekstilije nameščene vertikalno, z nadzorovanim namakanjem in osvetlitvijo. Naši rezultati kažejo, da ima prednost kosmatena tekstilna površina, ki jo zagotavlja votkovni pliš, pri katerem je ukoreninjenje rastlin kreše, uporabljenih v tem poskusu, lažje in manj zapleteno kot na tesno povezanih, ravnih površinah, kot so na primer lanene tkanine.
Ključne besede: vertikalno kmetovanje, tekstilni substrat, kreša, nizkocenovno, kalitev

1 Introduction

The system of vertical farming (VF) has generated increasing attention in recent years. This development is due to the many advantages of the system, when compared to conventional agriculture, as well as due to the flexibility of the structure, the components and materials used. In view of a growing population [1], the rising demand for nutritious food [2, 3] is expected to increase by about 70% until 2050 [4, 5], while the available arable land is decreasing in the face of growing cities and climate change [6]. One of the challenges to meet this demand lies in the phenomenon of urbanisation, which results in pushing green spaces further out of the city centre, thereby lengthening the transport routes of food products and significantly reducing their quality in terms of nutrients and freshness [7–9]. Furthermore, the carbon footprint caused by the transportation contributes to heavy air pollution and thus global warming [10, 11].

Apart from the insufficient quantity of land, conventional agriculture entails a variety of problems including the ongoing destruction of forests [7], which can lead to the loss of native plant and animal species [12], to a loss of biodiversity and degradation of ecosystems due to the use of fertilisers and pesticides [3], and to the intense utilisation of water [10, 13], to name just a few.

Another challenge of conventional agriculture lies in the invariable external factors such as weather conditions. In view of the changing climate due to global warming, the food supply can often not be ensured, as phenomena like droughts, heatwaves or floods can lead to crop failures [7, 10, 13] with agriculture itself contributing to those risks by using methods like intensive groundwater pumping [13].

These issues can partly be solved by transferring plant cultivation from the fields into buildings and utilising systems like VF as an alternative concept to conventional agriculture. This makes the supply of food more reliable for several reasons. The independence from weather and climate change prevents weather-related crop failures and production can be carried out regardless of the season [7], leading to a higher food security. In addition, no new areas need to be developed and production can be conducted centrally in existing buildings [7, 8, 14]. At the same time, by cultivating into the vertical plane, the productivity per unit area increases compared to conventional agriculture [4, 7, 15–17]. Local production can further reduce transport emissions, while the nutrient content can increase by shortening the storage time of plants. The overall environmental pollution is reduced since a local VF system offers a more sustainable solution in terms of used materials and the cultivation of plants regarding the usage of water and energy resources [7, 8, 18].

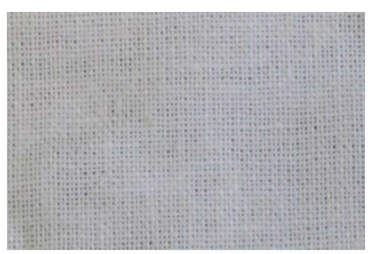
Initially, VF is often associated with constructions in the form of ceiling-high shelves in high-rise buildings with the use of hydroponics as an approach for a sustainable production of herbs and plants in general, and the ability of manipulating factors that mimic the natural growing environment, e.g. artificial light sources and heating [8, 16]. Although control over temperature and lighting brings many benefits in terms of plant growth, these are also the factors that can become problematic when it comes to sustainable crop production, depending on building characteristics and location. If outdoor temperature differs greatly from the required indoor temperature, or if the amount of daylight is extremely low or cannot be distributed sufficiently evenly, VF can have high-energy requirements. For example, in large cities with many surrounding high-rise buildings, this cannot be optimally met by renewable energy sources, e.g. solar panels, due to the shading from surrounding buildings [19]. Alternative concepts, e.g. living walls, utilise substrates like textile fabrics or nonwovens and attach them to walls vertically for city greening or for air improvement indoors [18, 21]. Apart from plants, another possibility is the cultivation of algae on textile substrates [22]. The term "agro textile" refers to a variety of textiles applied in areas like agriculture, landscaping and forestry [23] that are used, e.g. as mulch mats [24], hail protection or windshields, in agricultural contexts, all mainly with the purpose of crop protection [25]. Due to their numerous application possibilities, the textiles themselves differ considerably in their properties and can be woven, nonwoven or knitted [18, 23, 26]. Textiles, however, are usually not applied in VF [22], although they can be more sustainable than the often-used mineral wool. Thus, we are presenting here the findings on inherent textile fabric characteristics which enable successful plant growth. This form of farming can easily be adapted for home growth, e.g. herbs on a small scale in the kitchen, and thus generally enable a more widespread acceptance in the population for this relatively new form of soilless plant cultivation. In this context and with a low-budget system, the study aimed to investigate basic parameters of textile substrates for successful germination and cultivation of plants on the example of cress.

2 Experimental

The used textiles included woven linen, woven cotton (both plain weave), weft-knitted plush (from 5 threads 100% poly(ethylene terephthalate) (PET) 400 dtex, from Technofibres s.a., Wasserbillig, Luxembourg) and another weft-knitted fabric (1 thread merino wool 100%, Nm 30/2 (2 threads Nm 30), from Zegna Baruffa, Biella, Italy). The textiles were categorised according to their mass per unit area, thickness and capillary water height. An overview of fabric parameters can be found in Table 1.

These textiles were selected to allow a comparison of materials that differ significantly in their properties to find an indication which textiles are most suitable for a VF application. Another aspect was the reusability of textiles, which should be cleanable after the plants have been removed and reused to cultivate plants again, since their mechanical properties have not substantially changed after the cleaning.

Table 1: Parameters of fabrics used in investigation

Sample number	Composition	Mass per unit area (g/m^2)	Thickness (mm)	Capillary rise (cm)	Photograph
1	Weft-knitted merino wool	970	3.84	12.3	
2	PET weft-knitted plush	1020	6.91	2.6	
3	Cotton woven	85	0.22	5.8	
4	Linen woven	142	0.30	8.4	

The mass per unit area was determined according to DIN EN 12127 with an analytical balance SE-202 (VWR International GmbH, Darmstadt, Germany). Thickness was measured according to DIN EN ISO 5084 with a digital gauge J-40-T (Wolf-Messtechnik GmbH, Freiberg, Germany) and capillary rise according to DIN 53924 after 30 min, using 5 specimens per fabric. A digital microscope VHX-600D (Keyence, Neu-Isenburg, Germany) was utilised for the microscopic images of textiles with the roots of plants to see which fabric offers plants optimal growth conditions, e.g. secure attachment of roots in the meshes, pile and through the stitches.

Textiles (60 cm × 20 cm) were attached to a coated metal grid (45 cm in height, 180 cm in width) as shown in Figure 1, which is the same basic structure as in the previous experiment [27]; however, with larger pieces of fabric and a different irrigation rhythm.

The irrigation of textiles with supply water (water hardness level 16 °d, i.e. 16 degrees of hardness) took place every 15 minutes using a pump INDOOR P300-I (3.6 W) (Heissner, Lauterbach, Germany), which reuses dripping water and pumps it from a water reservoir under the textiles to the distribution tube above them. Zip ties allowed the water to exit the tube and to irrigate the grid in a well-directed flow, reducing splashes and thus the waste of water. The flow rate was measured per irrigation hole (cf. Figure 2). In the previous experiment, it was found that although water was distributed slightly unevenly throughout the openings, this had no measurable impact on the plant growth [27]. With this type of irrigation, one of the evaluation criteria for samples was the water storage capacity according to DIN 53923:1978-01.

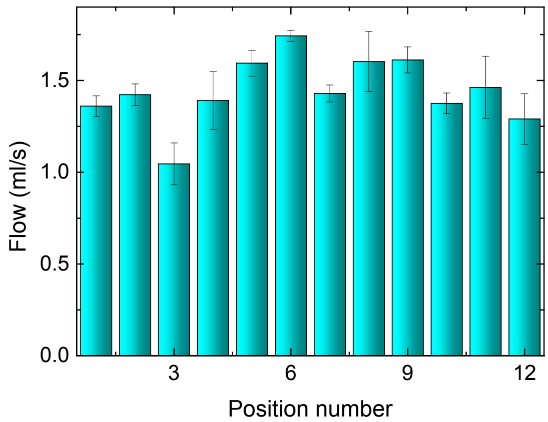


Figure 2: Flow rate through openings; samples were placed in positions 1–3, 4–6 etc. (cf. Figure 1)

Illumination was provided by an Osram lamp with the colour temperature of 3011 K, radiant flux of 6.25 W and luminous flux of 2.02 lm for 16 h per day (6 a.m.–10 p.m.). This lamp was chosen due to its wavelength peaks in the areas of chlorophyll A and B absorption, and its broad spectrum, which has been found to be suitable for plant cultivation in the context of VF [28]. Two of these lamps were placed one above the other in front of the test stand at the distance of 50 cm to illuminate it frontally. The resulting irradiance (in W/m^2) was measured with a KIMO SL-200.

The preparation of samples was the same as in the previous test, using a biodegradable Konjac Gum Powder (Special Ingredients, Chesterfield, UK)

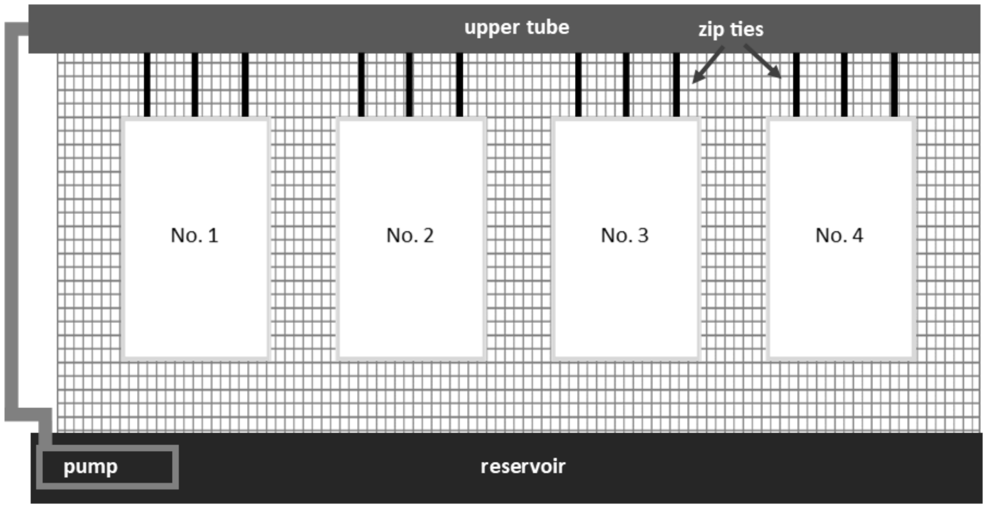


Figure 1: Schematic construction, showing fabrics numbered according to Table 1

hydrogel (2 g Konjac Gum Powder dissolved in 240 ml deionised water) to provide the seeds with a better hold and to prevent them from immediately falling [27]. One side of each textile was completely coated with the hydrogel and then the seeds were attached to the textiles. Subsequently, they were immediately attached vertically to the test stand.

Cress (Lepidium sativum L., Kiepenkerl, Everswinkel, Germany) was again used as a model organism. The reason was the easy handling due to the fast growth and the usability as food and potential for urban greening. On each piece of fabric, the seeds were arranged in 13 homogeneously spaced rows, each containing 5 seeds, i.e. overall 65 seeds per fabric.

In order to be able to make a statement about the quality of plant growth, the fresh mass was determined by cutting the plants above the textile at the end of the test and weighing them directly afterwards. Furthermore, the dry mass was determined to give a better indication of the biomass growth. The dry mass is the pure biomass without water, which is obtained by letting the plants dry in an oven for 48 h at 60 °C.

During the course of the experiment, which lasted over the period of 30 days, the main focus was on the water storage capacity of fabrics and the rooting of plants in the materials, which was investigated subjectively with microscopic images.

3 Results and discussion

The measured irradiance (W/m2) is presented in Figure 3.

The lamp was aligned in such a way that the illumination of fabrics was symmetrically distributed. As already stated in the previous paper [27], the slight varying intensity in the central area does not affect the comparability of plant development on different pieces of fabric as this low level of (varying) irradiance only triggers phototropism and the focus can be placed on the suitability of different textiles for the usage in VF [27, 29].

The suitability of textiles for the application in VF was first evaluated on the basis of lost seeds (cf. Figure 4). The reason for some seeds falling off from the textiles was the rinsing away of the Konjac Gum hydrogel, which inevitably happens after a certain period of time due to its water solubility in combination with late germination of the seeds. A large number of lost seeds on Sample 3 is the indication that, despite the Konjac Gum Powder and formed roots, it was not possible for the roots to adhere to the surface of this fabric. This can clearly be attributed to Sample 3 being the thinnest fabric with the smallest pores between the neighbouring warp and weft threads, which does not enable the plant roots to penetrate through these pores to get fixed. Sample 2 is considered the most suitable regarding the rooting or the adherence of roots to the substrate as the low number of lost seeds (cf. Figure 4) suggests.

It should be mentioned that this is in contrast to Khandaker and Kotzen [20] where a "living wall" with vertically mounted pots was applied, using soil and different substrates, hence showing another way to implement the vertical approach without the danger of losing seeds since the substrates inside these vertically mounted pots were only slightly tilted with respect to the ground and not fully vertical.

Focusing on the amount of germinated and growing plants (cf. Figure 5), Samples 1 and 2 are advantageous, i.e. relatively thick weft-knitted fabrics. Sample 4 had the lowest percentage of grown plants, followed by Sample 3, which can be explained by the poor possibility of rooting in these thin fabrics.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
5	7	9	9	10	10	10	10	10	10	10	9	8	6	5
5	7	9	9	10	10	11	10	10	10	11	9	9	7	6
5	7	8	9	9	10	10	10	10	11	10	9	9	6	6
5	6	8	8	8	8	8	10	9	10	9	8	8	6	6
5	5	7	7	7	8	8	8	8	9	8	6	7	5	5

Figure 3: Measured irradiance in W/m²; samples were placed in positions 1–3, 4–6, 7–9 and 10–12.

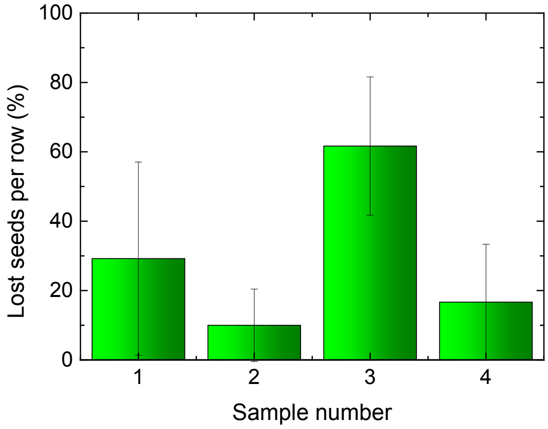


Figure 4: Lost seeds on different samples; error bars show standard deviations, calculated from percentage of lost seeds in each of 13 rows.

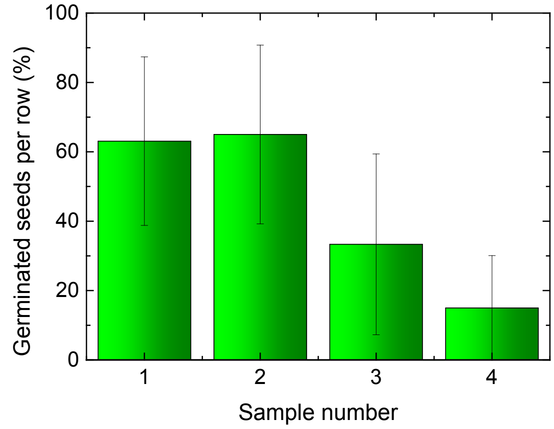


Figure 5: Germinated seeds; error bars show standard deviations, calculated from percentage of lost seeds in each of 13 rows.

It should be mentioned that some of the seeds were stuck on the fabric without germination; therefore, adding the percentages in Figures 3 and 4 does not result in 100%.

When observing the rooting of plants under a microscope, it is noticeable that the roots in Samples 3 and 4 could not find a hold through the interaction with meshes (cf. Figure 6c), but instead developed along the surface with the aid of small root hairs (cf. Figure 6d). Looking at the microscopic pictures of knitted Samples 1 and 2 (cf. Figures 6a, b), a good rooting through the hairy surface and plush threads, respectively, can be seen. In addition, a less intensive formation of root hairs is visible, which

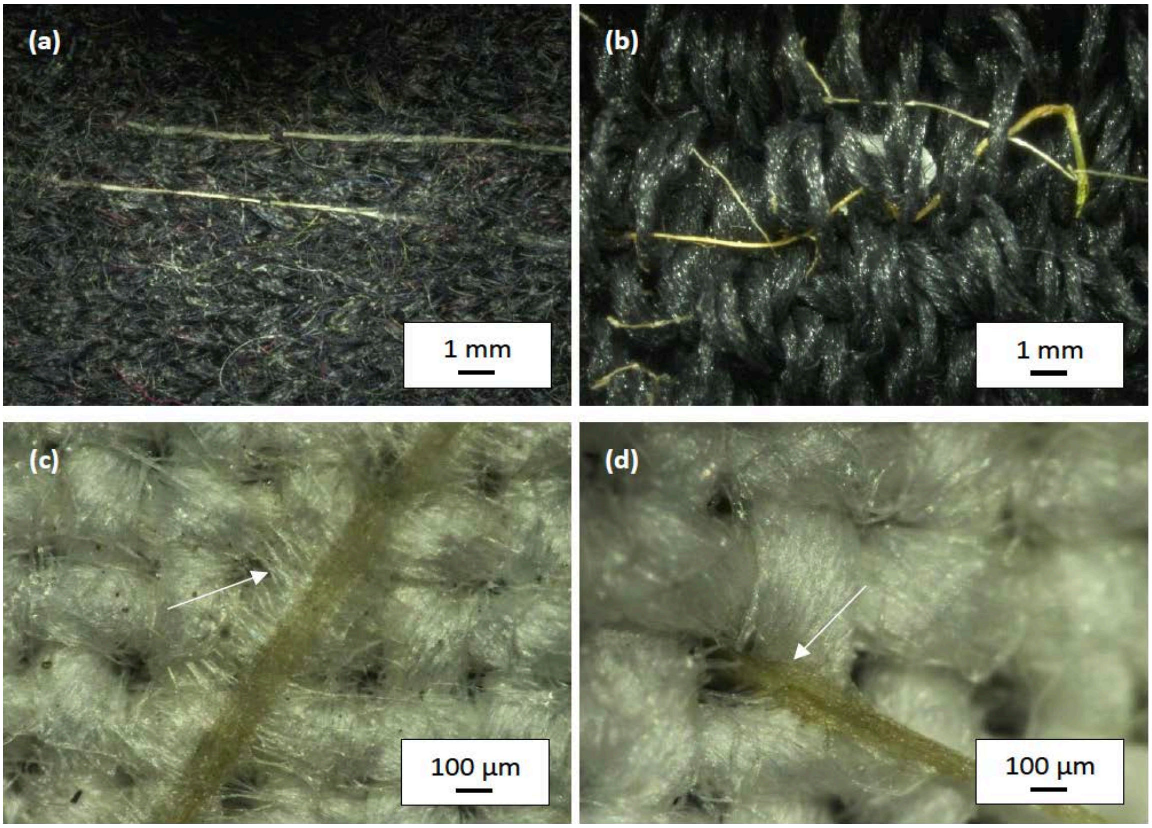


Figure 6: Roots on (a) Sample 1, (b) Sample 2, (c) Sample 3 and (d) Sample 4; arrows indicate root hairs

also supports the thesis that the fixation in the textile is a prerequisite for better plant growth due to the reduced requirement of an intensive root development. Due to a small amount of textile fabrics, it can be assumed that textile substrates should have for successful plant growth high porosity with a hairy surface for the seeds not to fall down before the formation of their germ roots, and to take root in the meshes and the pile without difficulty in further growth. These parameters are interestingly identical to those found for the growth of micro- and macro-algae [30, 31].

The fact that the surfaces of Samples 3 and 4 require a more intensive formation of root hairs to prevent the plant from falling down may result from the plants on Samples 3 and 4 being shorter than those of Samples 1 and 2 (cf. Figure 7).

The latter is also supported by the previous experiment [27] which indicated that the water solubility of the Konjac Gum Powder hydrogel can be problematic if it dissolves before the root could anchor in the textile. This makes a high porosity fabric with large pores or a raised surface the roots can grow easily in more advantageous for the application in VF. Nevertheless, it must be mentioned that the differences among all four samples are not significant, as it is directly visible from the large error bars. Thus, there is only a tendency of plants growing on Samples 1 and 2 to have larger stem lengths.

Another factor that is beneficial in promoting growth is the material's ability to distribute and store water. Samples 1 and 2 have the best water storage properties (cf. Figure 8) and can therefore provide plants with a constant supply of water over a longer period of time. The capillary height, as a measure for water distribution inside the fabric, is less important here due to the irrigation with relatively small spaces between the irrigation holes, so that all fabrics were fully wetted.

The harvested aboveground fresh mass per plant of each textile is shown in Figure 9a. Sample 2 produced the highest yield, which is also reflected in the amount of dry mass (cf. Figure 9b).

Again, a strong difference can be seen between Samples 2 and 4, obtaining by more than 50% less dry mass at Sample 4 compared to Sample 2. However, it must be mentioned again that most differences are not significant, i.e. standard deviations overlap.

Furthermore, while a large number of seeds (65 seeds per sample) was used, especially for Sample 4 where less than 20% germinated (cf. Figure 5), the statistical significance based on standard deviations is lower than it could be expected at first glance.

Finally, it must be mentioned that the results presented here are valid for a certain period during the year (in this case end of July until the end of August in Western Europe) and may be different in other seasons. This effect is well known from indoor plant growth experiments, even inside climate rooms, which is why such experiments are usually repeated subsequently [32–34]. In consequence, the results obtained in this study can only serve to choose textile fabrics for future experiments where objective, time-independent findings can be reported, i.e. for the differentiation between the two thin-woven

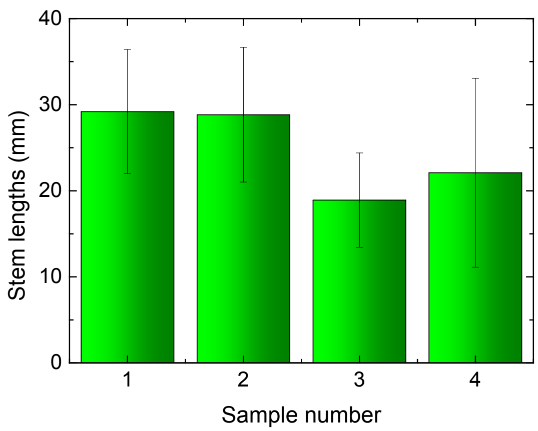


Figure 7: Plant lengths; error bars show standard deviations, calculated from all germinated seeds with grown stems (depending on germination rate, 10–42 plants per sample)

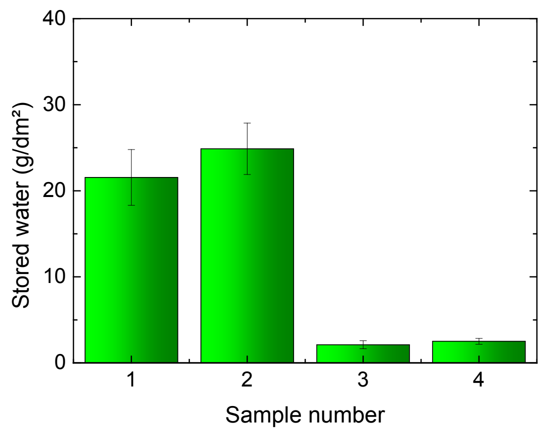


Figure 8: Water storage capacity

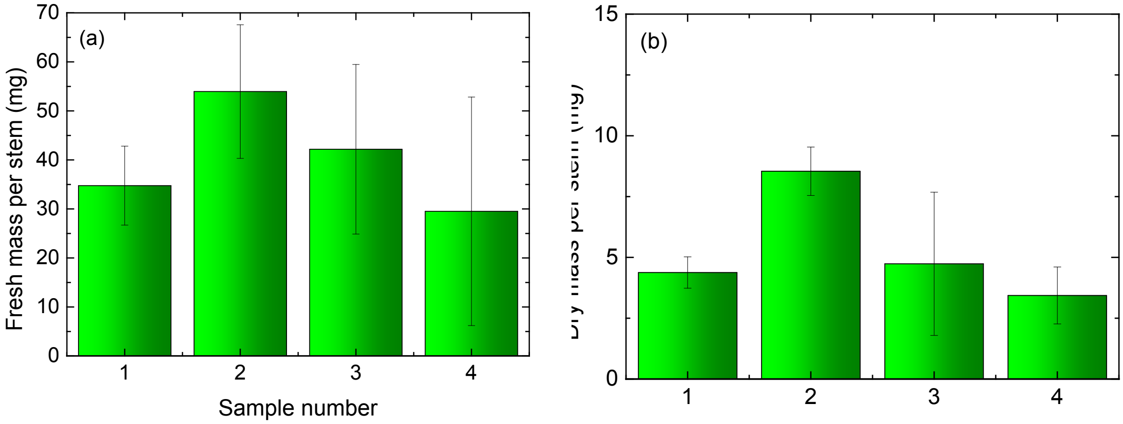


Figure 9: (a) Total aboveground fresh mass per plant, (b) total dry mass per stem; error bars show standard deviations, calculated from all germinated seeds with grown stems.

fabrics (Samples 3 and 4), which are clearly not suitable for root fixation, and different thicker knitted fabrics (Samples 1 and 2) which allowed the penetration by plant roots and will thus be investigated in further studies.

4 Conclusion and outlook

In this experiment, four different fabrics were compared regarding their applicability in vertical farming, i.e. vertically positioned substrates, with cress as a test plant over the course of 30 days.

In general, it was found that textile substrates should have for successful plant growth high porosity with a hairy surface to enable the penetration of roots into the fabric. Furthermore, a correlation between the water absorption capacity and biomass growth can be assumed. Overall, Sample 2 (weft-knitted plush) showed the best combination of good rooting properties, high germination rate, good water storage capacity, and high fresh and dry matter.

For future trials, considering water usage and sustainability, we will investigate these and other relatively thick, open-pore materials with different water-storage properties, and change the duration and frequency of irrigation to see if the amount of used water can be reduced by less frequent irrigation. Additionally, other more agronomically important plants should be in the scope of future research.

Funding

The project was partly funded by the Federal Ministry for Economic Affairs and Energy in the scope of the ZIM project ZF4036107 and by the HiF fund of the Bielefeld University of Applied Sciences.

Acknowledgments

We thank Martina Holt and Karl-Josef Dietz for their constructive criticism of the manuscript, lending laboratory equipment and for advice on the implementation of the experiments.

References

1. Selected Results of the 2019 UN World Population Projections. *Population and Development Review,* 2019, **45**(3), 689–694, doi: 10.1111/padr.12288.
2. ICKOWITZ, A., POWELL, B., ROWLAND, D., JONES, A., SUNDERLAND, T. Agricultural intensification, dietary diversity, and markets in the global food security narrative. *Global Food Security,* 2019, **20**, 9–16, doi: 10.1016/j.gfs.2018.11.002.
3. HUNTER, Mitchell C., SMITH, Richard G., SCHIPANSKI, Meagan E., ATWOOD, Lesley W., MORTENSEN, David A. Agriculture in 2050: recalibrating targets for sustainable intensification. *BioScience*, 2017, **67**(4), 386–391, doi: 10.1093/biosci/bix010.
4. TOULIATOS, Dionysios, DODD, Ian C., MCAINSH, Martin. Vertical farming increases

lettuce yield per unit area compared to conventional horizontal hydroponics. *Food Energy Security*, 2016, **5**(3), 184–191, doi:10.1002/fes3.83.

5. TILMAN, David, BALZER, Christian, HILL, Jason, BEFORT, Belinda L. Global food demand and the sustainable intensification of agriculture. *Proceedings of the National Academy of Sciences*, 2011, **108**(50), 20260–20264, doi: 10.1073/pnas.1116437108.
6. ZHANG, Xioa, CAI, Ximing. Climate change impacts on global agricultural land availability. *Environmental Research Letter,* 2011, **6**, 014014, doi: 10.1088/1748-9326/6/1/014014.
7. KALANTARI, Fatemeh, NOCHIAN, Ashkan, DARKHANI, Faiza, ASIF, Nayeem. The significance of vertical farming concept in ensuring food security for high-density urban areas. *Jurnal Kejuruteraan*, 2020, **32**(1), 105–111, doi: 10.17576/jkukm-2020-32(1)-13.
8. AVGOUSTAKI, Dafni Despoina, XYDIS, George. Indoor vertical farming in the urban nexus context: business growth and resource savings. *Sustainability*, 2020, **12**(5), 1965, doi: 10.3390/su12051965.
9. FAO [accessible online]. Nutrition-sensitive agriculture and food systems in practice. 2017. [accessed 8.10.2021]. Available on World Wide Web: <http://www.fao.org/publications/card/en/c/9ca3cf89-6109-4a38-855f-6e218eae543b/>
10. MANOS, Dimitrios-Panagiotis, XYDIS, George. Hydroponics: are we moving towards that direction only because of the environment? A discussion on forecasting and a systems review. *Environmental Science and Pollution Research*, 2019, **26**, 12662–12672, doi: 10.1007/s11356-019-04933-5.
11. PANDEY, Divya, AGRAWAL, Madhoolika, PANDEY, Jai Shanker. Carbon footprint: current methods of estimation. *Environmental Monitoring and Assessment*, 2011, **178**(1-4), 135–160, doi: 10.1007/s10661-010-1678-y.
12. JALETA, Olani Ganfure, JEBESSA DEBELLA, Habte. The impact of large scale agriculture on forest and wildlife in Diga Woreda, Western Ethiopia. *Asian Journal of Agriculture*, 2017, **1**(02), 100–113, doi: 10.13057/asianjagric/g010207.
13. GRUÈRE, Guillaume, LE BOËDEC, Hélène. Navigating pathways to reform water policies in agriculture. *OECD Food, Agriculture and Fisheries Papers*, 2019, **128**, 63 p., doi: 10.1787/906cea2b-en.
14. DESPOMMIER, Dickson D. The vertical farm: Controlled environment agriculture carried out in tall buildings would create greater food safety and security for large urban populations. *Journal für Verbraucherschutz und Lebensmittelsicherheit*, 2011, **6**(2), 233–236, doi: 10.1007/s00003-010-0654-3.
15. PENNISI, Giuseppina, ORSINI, Francesco, BLASIOLI, Sonia, CELLINI, Antonio, CREPALDI, Andrea, BRASCHI, Ilaria, SPINELLI, Francesco, NICOLA, Silvana, FERNANDEZ, Juan A., STANGHELLINI, Cecilia, GIANQUINTO, Giorgio, MARCELIS, L. F. M. Resource use efficiency of indoor lettuce (*Lactuca sativa L.*) cultivation as affected by red:blue ratio provided by LED lighting. *Scientific Reports*, 2019, **9**(1), doi: 10.1038/s41598-019-50783-z.
16. MOLIN, Elvira, MARTIN, Michael Alan. Assessing the energy and environmental performance of vertical hydroponic farming. Report number: C299.IVL. Swedish Environmental Research Institute, 2018. Available online: <https://www.researchgate.net/publication/324088096_Assessing_the_energy_and_environmental_performance_of_vertical_hydroponic_farming>.
17. TOULIATOS, Dionysios, BREYNON-DAVIES, Rhydian, MCAINSH, Martin. Vertical farming. *eLS*, 2020, 1–8, doi: 10.1002/9780470015902.a0028908.
18. SHARATHKUMAR, Malleshaiah, HEUVELINK, Ep, MARCELIS, Leo F.M. Vertical farming: moving from genetic to environmental modification. *Trends in Plant Science*, 2020, **25**(8), 724–727, doi: 10.1016/j.tplants.2020.05.012.
19. KALANTARI, Fatemeh, TAHIR, Osman Mohd, JONI, Raheleh Akbari, FATEMI, Ezaz. Opportunities and challenges in sustainability of vertical farming: a review. *Journal of Landscape Ecology*, 2018, **11**(1), 35–60, doi: 10.1515/jlecol-2017-0016.
20. KHANDAKER, Mohammed, KOTZEN, Benz. The potential for combining living wall and vertical farming systems with aquaponics with special emphasis on substrates. *Aquaculture Research*, 2018, **49**(2), 1454–1468, doi: 10.1111/are.13601.
21. FERNÁNDEZ-CAÑERO, Rafael, URRESTARAZU, Luis Pérez, PERINI, Katia. Vertical greening systems: classifications, plant species, substrates. In *Nature Based*

Strategies for Urban and Building Sustainability. Edited by Gabriel PÉREZ and Katia PERINI. Elsevier, 2018, pp. 45–54, doi: 10.1016/B978-0-12-812150-4.00004-5.

22. EHRMANN, Andrea. On the possible use of textile fabrics for vertical farming. *Tekstilec*, 2019, **62**(1), 34–41, doi: 10.14502/tekstilec2019.62.34-41.
23. CHOWDHURY, Md Jonayet, NASRIN, Shamima, AL FARUQUE, Md Abdullah. Significance of agro-textiles and future prospects in Bangladesh. *European Scientific Journal*, 2017, **13**(21), 1857–7881, doi: 10.19044/esj.2017.v13n21p139.
24. ABIDI, Houcine, RANA, Sohel, CHAOUCH, Walid, AZOUZ, Bechir, AISSA, Imed Ben, HASSEN, Mohamed Ben, FANGUEIRO, Raul. Accelerated Weathering of textile waste nonwovens used as sustainable agricultural mulching. *Journal of Industrial Textiles*, 2019, **50**(7), 1079–1110, doi: 10.1177/1528083719855326.
25. BHAVANI, K., MALLIKARJUN, Ningdalli, SUNILKUMAR, N.M. Agro textiles - their applications in agriculture and scope for utilizing natural fibers in agro tech sector. *International Journal of Applied Home Science*, 2017, **4**(7&8), 653–662.
26. STORCK, Jan Lukas, BÖTTJER, Robin, VAHLE, Dominik, BROCKHAGEN, Bennet, GROTHE, Timo, DIETZ, Karl-Josef, RATTENHOLL, Anke, GUDERMANN, Frank, EHRMANN, Andrea. Seed germination and seedling growth on knitted fabrics as new substrates for hydroponic systems. *Horticulturae***,** 2019, **5**(4), 1–9, doi: 10.3390/horticulturae5040073.
27. BÖTTJER, Robin, STORCK, Jan Lukas, VAHLE, Dominik, BROCKHAGEN, Bennet, GROTHE, Timo, HERBST, Sabine, DIETZ, Karl-Josef, RATTENHOLL, Anke, GUDERMANN, Frank, EHRMANN, Andrea. Influence of textile and environmental parameters on plant growth on vertically mounted knitted fabrics. *Tekstilec*, 2019, **62**(3), 200–207, doi: 10.14502/Tekstilec2019.62.200-207.
28. HICKEM, Taylor, O'MARA, Colin. THE FOOD WALL - open source engineering design software for vertical farming greenhouse. *HELVA PTE,* 2019. Available online: https://www.researchgate.net/publication/335543711_THE_FOOD_WALL_Open_source_Engineering_Design_Software_for_Vertical_Farming_Greenhouse.
29. CHRISTIE, John Mackie. Phototropin blue-light receptors. *Annual Review of Plant Biology*, 2007, **58**(1), 21–45, doi: 10.1146/annurev.arplant.58.032806.103951.
30. BROCKHAGEN, Bennet, STORCK, Jan Lukas, GROTHE, Timo, BÖTTJER, Robin, EHRMANN, Andrea. Improved growth and harvesting of microalgae *Chlorella vulgaris* on textile fabrics as 2.5D substrates. *AIMS Bioengineering*, 2021, **8**(1), 16–24, doi: 10.3934/bioeng.2021003.
31. SEBÖK, Stefan, BROCKHAGEN, Bennet, STORCK, Jan Lukas, POST, Inken Blanca, BACHE, Thorsten, KORCHEV, Rumen, BÖTTJER, Robin, GROTHE, Timo, EHRMANN, Andrea. Growth of marine macroalgae *Ectocarpus sp.* on various textile substrates. *Environmental Technology*, 2020, online first, doi: 10.1080/09593330.2020.1829086.
32. HORLING, Frank, LAMKEMEYER, Petra, KÖNIG, Janine, FINKEMEIER, Iris, KANDLBINDER, Andrea, BAIER, Margarete, DIETZ, Karl-Josef. Divergent light-, ascorbate-, and oxidative stress-dependent regulation of expression of the peroxiredoxin gene family in Arabidopsis. *Plant Physiology*, 2003, **131**(1), 317–325, doi: 10.1104/pp.010017.
33. POORTER, Hendrik, FIORANI, Fabio, STITT, Mark, SCHURR, Uli, FINCK, Alex, GIBON, Yves, USADEL, Björn, MUNNS, Rana, ATKIN, Owen K., TARDIEU, Francois, PONS, Thijs L. The art of growing plants for experimental purposes: a practical guide for the plant biologist. *Functional Plant Biology*, 2012**, 39**(11), 821–838, doi: 10.1071/FP12028.
34. POORTER, Hendrik, FIORANI, Fabio, PIERUSCHKA, Roland, WOJCIECHOWSKI, Tobias, VAN DER PUTTEN, Wim H., KLEYER, Michael, SCHURR, Uli, POSTMA, Johannes. Pampered inside, pestered outside? Differences and similarities between plants growing in controlled conditions and in the field. *New Phytologist,* 2016, **212**(4), 838–855, doi: 10.1111/nph.14243.