Original scientific paper
DOI: /10.5513/JCEA01/21.3.2897
Journal of Central European Agriculture, 2020, 21(3), p.531-536

Potentials of indoor lettuce production in natural forest soil at limited watering

Beltéri saláta termesztés lehetőségének vizsgálata természetes erdőtalajon limitált öntözéssel

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Received: May 11, 2020; accepted: June 19, 2020

ABSTRACT

Indoor farming in the global vertical farming market has been growing by more than 8% annually since 2010 and 31.6% growth is expected by 2025. It promises to be a possible future form of agricultural practices producing local, fresh, high quality, lower-carbon food year-round. Indoor farming experiment was designed to using LED and neon lights and water source of a dehumidifier. Lettuce (*Lactuca sativa* L. var. *capitata*) was grown for 12 weeks in a naturally available forest surface soil, including its native biodiversity and biological activity. Two different levels of water supply were used, full- at 66%- and half- at 33% of the total water-holding capacity ($WHC_{100\%}$) of soil. Some of the physical-chemical, and soil-biological parameters, such as dehydrogenase- (DHA) and fluorescein diacetate (FDA) enzyme activities and the most probable number (MPN) of fungi and bacteria were assessed prior to and after lettuce cultivation. Although the abundance of countable microorganisms decreased appreciably by the end of the lettuce experiment, the growth of plants could result in an enhanced soil-biological enzyme activity of the used natural soil. DHA increased 4.2-fold at drought condition, and 2-fold at the optimal water supply. One can conclude that used natural forest soil with great fertility and biodiversity potential can provide a good facility for the indoor lettuce cultivation. Reduction of water supply can be further optimized with the required biomass-production of lettuce.

Keywords: natural soil, soil-enzymes, indoor gardening, vertical farming, sustainability

ABSZTRAKT

A beltéri termesztés a globális vertikális kertészeti ágazatban évente több mint 8%-os intenzitással növekszik 2010-óta és 2025-re már ehhez képest 31.6%-os növekedéssel számolhatunk. Ez a technológia a városiasodással párhuzamosan a jövő egyik mezőgazdasági megoldását ígéri az emberiség számára, melyet évszaktól és időjárástól függetlenül bárhol alkalmazhatunk, és ezek a rendszerek helyben szolgáltatnak friss, magas minőségű, kisebb karbonlábnyomú élelmiszert folyamatosan az év során. Az itt bemutatott beltéri termesztési kísérlethez LED- és neon-világítást, valamint páramentesítőből származó vizet használtunk. Termesztőközegként helyben elérhető erdei feltalajt alkalmaztunk amin salátát (*Lactuca sativa* L. var. *capitata*) termesztettünk 12 héten keresztül használva annak természetesen magas biodiverzitását és biológiai aktivitás-szintjét. Összehasonlítottuk két eltérő mértékű vízellátottság, a teljes- (66%-os) és a fél- (33%-os) teljes szárazföldi vízkapacitás ($WHC_{100\%}$) melletti termesztési eredményeket. Vizsgáltuk a termesztés során a talaj fiziko-kémiai és biológiai tulajdonságait. A talaj dehidrogenáz (DHA) és fluoreszcein-diacetát (FDA) enzimaktivitásértékeit a termesztés előtt és a termesztés végeztével mértük, a baktériumok és a gombák kitenyészthető legvalószínűbb számával (MPN) együtt. Eredményeink megnövekedett talajbiológiai aktivitást mutattak a termesztést követően. Habár a mikroorganizmusok száma csökkent, a DHA enzimaktivitás jelentős mértékű növekedést mutatott mindkét vízellátottsági szint mellett. A szárazság-stressznél 4.2-szeres, az optimális vízellátottság mellett 2-szeres mértékű növekedést tapasztaltunk. Eredményeink alapján a beltéri, organikus salátatermesztéshez az adott helyi erdőtalaj jól használható lehetőséget adott. A saláta biomassza-tömegét és a vízhasználatot azonban tovább szükséges optimalizálni.

Kulcsszavak: természetes talaj, talajenzimek, talajbiológia, beltéri kertészet, fenntarthatóság

INTRODUCTION

Indoor farming may represent the future of urban food-production. According to the Progressive Markets report the global vertical farming market was growing by over 8% each year since 2010 and a growth of 31,6% is expected by 2025. It promises to be a future form of agricultural production in strong relation with the fast urbanization. The real value of the technology is that it operates at any place with no or reduced pests and pathogens and is independent from weather conditions. One main advantage of the procedure is of producing local, fresh, high-quality, lower-carbon food year round with reduced water consumption (~23 times less) and on significantly smaller fields (15 times smaller) (Al-Kodmany, 2018; Despommier, 2010, Kozai et al., 2015). New economies and increasing urbanization ask for greater, better, safer, and more secure production capacity (Kocsis et al., 2018), while growing land and water shortages, climatic problems may lead to an increase of food crisis. Nowadays the intensified and centralized food production, with fertilizer supplied crops (Jakab, 2020) and highly degraded lands appears to be no longer sustainable (Shomana et al., 2020). It results in long and complicated supply chains, poor food quality, and enormous food losses of up to fifty percent. Nevertheless, this cultivation process is predominantly (~76%) soil-free, which has been aversive to many farmers and consumers because of the presumed depletion of nutrients and/ or the presence of nutrients from non-natural sources (Adema and Hensen, 1989). Therefore, there is a growing demand for healthy food production, avoiding the use of various chemicals and exclusively inorganic nutrients with limited essential element-composition. In this case, the good quality of soil with high biological activity and nutrient content could be essential (Dudás et al., 2017). With this idea in mind, an indoor lettuce experiment has been set up where local, natural forest soil was used (Orgiazzi et al., 2016) as the growing substrate, suggested by Vida et al. (2019). For growing, lettuce (*Lactuca sativa* L. var. *capitata*) was selected, which unfolds its leaf on soil surface. This allowed to test a considerably exposed plant for soil borne pathogens (Flint, 1985). After growing the aspiration was to return the growing soil substrate to the forest for regeneration and for regaining suppressivity to diseases – to conduce to decreasing the level of opportunist plant pathogens until the next use – as suggested by Albiach et al. (2014). The goal of the experiment was to test the possibility of producing indoor healthy vegetables with potentially avoiding pesticide-use or any industrial fertilizers, so that the production becomes the most sustainable possible. Considering these objectives, watering of lettuce plants was also considerably reduced.

MATERIALS AND METHODS

As the growing substrate, silty clay textured forest soil (SIC) was used, harvested from the soil surface (upper 1-3 cm strata) of a natural deciduous forest ecosystem (Jahn et al., 2006). After drying and sieving of soil grew lettuce (*Lactuca sativa* L. var. *capitata*) was used in two growing boxes. To secure optimal light supply, LED (red blue) was applied and neon-light tube (cold white) with a total of 12,000 lux (Figure 1). Water source was a dehumidifier with 2 different watering options. Among the two boxes the intensity of irrigation was 'Optimum' (=O), when 800 mL/plant daily water supply was used, and 'Drought stress' (=D), when only 400 mL/plant water was utilized (Figure 2).

Figure 1. White and red blue lights and drip irrigation of lettuce

Figure 2. On the left: plants exposed to drought-stress (D); On the right: plants receiving optimum (O) water supply

Soil biological activity was determined by the dehydrogenase (DHA) enzyme assay by using the method proposed by Veres et al. (2015) and the fluorescein-diacetate (FDA) method introduced by Villányi et al. (2006). Total cultivable aerobic bacterial and fungal counts were determined by the MPN (most probable number) method (Cochran, 1949). For physical-chemical parameters the samples were sent to an accredited soil analysis laboratory prior to and after growing lettuce. Results are shown as mean (Average) of the used six replicates and the standard deviation (SD) of Microsoft Office (2013 Standard) Excel program.

RESULTS

Biomass production of lettuce at watered and drought condition

The growth production shows correlation with the used optimal and limited water treatments. Appreciably different, i.e., reduced growth parameters were found among the drought condition. Lettuce plants at $WHC_{33\%}$, could produce only about 50% less total biomass relative to the optimal, i.e., well-watered plants (Table 1).

Table 1. Biomass production of lettuce (g) and ratio of dry/fresh matter at drought stressed ($D=WHC_{33\%}$) and optimal ($O=WHC_{66\%}$) water supply

	Drought stressed (D)		Optimal water use (O)	
Sample				
	fresh weight (g)	dry weight (g)	fresh weight (g)	dry weight (g)
Average (g)	48.02+/-3.01	3.23+/-0.76	101.17+/-16.42	5.06+/-1.23
Dry/Total ratio (%)	100	6.73	100	5.12

Soil biological activities under watered and drought conditions

According to the test results, the bacterial count decreased appreciably by the end of cultivation in both treatments. A more great decrease could be achieved with the O treatment (Table 2). The number of fungi showed the opposite tendency; an increase of fungal abundance was found at both treatments.

Table 2. The Most Probable Number of the countable bacteria and fungi in forest soil before and at the end of the lettuce growth experiment at drought (D=$WHC_{33\%}$) and optimal (O=$WHC_{66\%}$) water treatment

	MPN – Bacteria × $10^{(3)}$ g soil		MPN – Fungi × $10^{(3)}$ g soil	
	Before growing	At harvest	Before growing	At harvest
D	2.300	1.500	23	93
O	2.300	930	75	93

Appreciable changes were also assessed in both DHA and FDA enzyme activities, which were found to increase in both treatments (Table 3).

Table 3. DHA and FDA enzyme activities in forest soil before and at the end of lettuce growth experiments, at drought-stressed (D=$WHC_{33\%}$) and optimal (O=$WHC_{66\%}$) water treatments

	DHA activity (TPF µg/g dry soil)		FDA activity (Fluorescein µg/g dry soil)	
	Before growing	At harvest	Before growing	At harvest
D	0.3768	6.4166	5.7544	15.2501
O	0.1019	2.6023	7.8874	11.7668

The macro and microelement content of the plants (Table 4) was different in the two treatments. Regarding the optimal water supply (O), there was a greater content of nitrogen (0.7%) and sodium (175 mg/kg) in the soil. By contrast, under drought (D) conditions, higher values of iron (249 mg/kg) and copper (2.9 mg/kg) were determined.

Table 4. Macro- and microelement content of dried biomass production of plants at drought-stressed (D=$WHC_{33\%}$) and optimal (O=$WHC_{66\%}$) water treatments

	D	O
Nitrogen (%)	2.15	2.85
Phosphorus (%)	0.23	0.23
Potassium (%)	5.01	4.67
Sodium (mg/kg)	551	726
Calcium (%)	1.51	1.54
Magnesium (%)	0.54	0.73
Iron (mg/kg)	888	639
Manganese (mg/kg)	68.1	64.3
Copper (mg/kg)	14.4	11.5
Zinc (mg/kg)	65.6	72.4

Water saving during experiments

During the duration of the experiment (12 weeks) with D treatment it was possible to save 201.6 L (33.6 L/plants) of water as compared to the O treatment.

DISCUSSION

Use of forest soil as growing substrate was found to be potentially applicable for the lettuce growth and nutrition. Growth of lettuce was not limited based on the weight of biomass, produced with optimal water supply.

A 50% reduction in water volume as a possible economic advance did not prove adequate, as revealed by the weight of plant biomass observed for D treatment, it is excessively reduced the amount of the crop.

The level of available Nitrogen was lower at D treatment and this can presumably be explained by the fact that the mineralization processes in the dry soil are hindered, thus also the amount of Nitrogen that can be absorbed (Berki, 1993).

Changes in bacterial counts can be explained by plant-physiological changes, occurred during cultivation.

After growth, the lettuce can reduce the soil-biological parameters in its rhizosphere (Pabar et al., 2019). Bacteria are the fastest responders to changes in root system characteristics. There was less decrease in bacterial count with the O treatment, than with D treatment. Drought probably could result in a more stress-adapted microbial community, which was less affected by rhizosphere disturbance. There was a slight increase in the number of fungi, demonstrating that due to the drought-stress, the plant had improved the fungal connections in the soil, which is considered to be a typical mechanism under environmental stress conditions (Kohler et al., 2010; Ruiz-Lozano et al., 2015).

CONCLUSIONS

Indoor organic lettuce growing is one of the possibilities of future food production. Available soils have potential, indeed, for lettuce growing. Soil biological activity can be improved in soil-plant systems under environmental stress conditions (i.e., drought), which can be used for safe and economically appropriate lettuce production. Water usage can be further optimized to reach the most favorable biomass-production of lettuce in indoor conditions. Subsequently to optimization the method can be appropriate and well-applicable for producing healthy, economic, and also ecologically supported indoor food.

ACKNOWLEDGEMENTS

The research is supported by the EFOP-3.6.3-VEKOP-16-2017-00008 project. The projects are co-financed by the European Union and the European Social Fund. The study is considering of EU Horizon 2020 Mission Board of “Soil Health and Food” aspects.

REFERENCES

Adema, D.M.M., Henzen, L. (1989): A comparison of plant toxicities of some industrial chemicals in soil culture and soilless culture. Ecotoxicology and Environmental Safety, 18:, 219-229. DOI: https://doi.org/10.1016/0147-6513(89)90083-3

Albiach, R., Pérez-Piqueres, A., Domínguez, A., Pomares, F., Canet, R. (2014): Short-term effects of different techniques to prepare an organic citrus soil for replanting on its microbiological and biochemical properties. In: Proc. of 4th ISOFAR ‘Building Organic Bridges’ Organic World Congress, Istanbul, Turkey. [Online] Available at: https://orgprints.org/23593/c [Accessed 24 April 2020]

Al-Kodmany, K. (2018): The vertical farm: A review of developments and implications for the vertical city. Buildings, 8 (24), 1-36. DOI: https://doi.org/10.3390/buildings8020024

Berki I. (1993): Az aszály szerepe a magyarországi tölgypusztulásban. Debreceni Szemle, 1, :103-108.

Cochran, W.G. (1949): Estimation of bacterial densities by means of the "Most Probable Number”. Biometrics, 6 (2):,105-116. DOI: https://doi.org/10.2307/3001491

Despommier, D. (2010): The vertical farm: Feeding the World in the 21st century. New York: Picador USA.

Dudás, A., Szalai, Z., Vidéki, E., Wass-Matics, H., Kocsis, T., Végvári, Gy., Kotroczó, Zs., Biró, B. (2017): Sporeforming *Bacillus* bioeffectors for healthier fruit quality of tomato in pots and field. Applied Ecology and Environmental Research, 15, 1399-1418. [Online] Available at: http://www.aloki.hu/pdf/1504_13991418.pdf [24 April 2020]

Jahn, R., Blume, H. P., Asio, V. B., Spaargaren, O., Schad, P. (2006): Guidelines for soil description, 4th edition. Rome: FAO. [Online] Available at: https://library.wur.nl/WebQuery/wurpubs/355777 [Accessed 24 April 2020]

Jakab, A. (2020): The ammonium lactate soluble potassium and phosphorus content of the soils of north-east Hungary region: a quantifying study. DRC Sustainable Future. 1 (1):, 7-13.

Kocsis T., Biró B., Kotroczó Zs. (2018): Time-lapse effect of ancient plant coal biochar on some soil agrochemical parameters and soil characteristics. Environmental Science and Pollution Research, 25 (2),: 990-999. DOI: https://doi.org/10.1007/s11356-017-8707-0

Kohler, J., Knapp, B. A., Waldhuber, S., Caravaca, F., Roldán, A., Insam, H. (2010): Effects of elevated CO_2, water stress, and inoculation with *Glomus intraradices* or *Pseudomonas mendocina* on lettuce dry matter and rhizosphere microbial and functional diversity under growth chamber conditions. Journal of soils and sediments, 10 (8), 1585-1597.

Kozai, T., Niu, G., Takagaki, M. (2015): Plant factory: an indoor vertical farming system for efficient quality food production. Elsevier, Academic Press. DOI: https://doi.org/10.1016/C2014-0-01039-8

Orgiazzi, A., Bardgett, R.D., Barrios, E., Behan-Pelletier, V., Briones, M.J.I., Chotte, J.L., De Deyn, G.B., Eggleton, P., Fierer, N., Fraser, T., Hedlund, K., Jeffery, S., Johnson, N.C., Jones, A., Kandeler, E., Kaneko, N., Lavelle, P., Lemanceau, P., Miko, L., Montanarella, L., Moreira, F.M.S., Ramirez, K.S., Scheu, S., Singh, B.K., Six, J., van der Putten, W.H. Wall, D.H. (Eds.) (2016): Global Soil Biodiversity Atlas. Luxembourg: European Commission, Publications Office of the European Union. [Online] Available at: https://www.cabdirect.org/cabdirect/abstract/20173130918 [Accessed 24 April 2020]

Pabar S. A., Mónok D., Kotroczó Zs., Biró B. (2019): Soil microbial parameters and synergies between bean growth and microbial inoculums as a dependence of five soils with different characteristics. SYNERGY - VI. International Conference of CIGR. Gödöllő, Hungary, 4-6 November 2019 (Electronical issue).

Progressive Markets (2017): Global Vertical Farming Market - Size, Trend, Share, Opportunity Analysis and Forecast, 2014-2025. 4/2017. [Online] Available at: https://www.progressivemarkets.com/industry-research/vertical-farming-market [Accessed 7 May 2020].

Ruiz-Lozano, J.M., Gómez, M., Azcón, R. (1995): Influence of different *Glomus* species on the time-course of physiological plant responses of lettuce to progressive drought stress periods. Plant Science, 110 (1), 37-44. DOI: https://doi.org/10.1016/0168-9452(95)04184-V

Shomana, T., Botha, D.E., Agachi, P.S. (2020): The water retention properties of biochar derived from broiler poultry litter as applied to the Botswana soil. DRC Sustainable Future. 1 (1),: 67-72. DOI: https://doi.org/10.37281/DRCSF/1.1.9

Flint, M. L. (1985): Integrated pest management for cole crops and lettuce. Oakland: Univ. of California,.

Veres, Zs., Kotroczó, Zs., Fekete, I., Tóth, J.A., Lajtha, K., Townsend, K., Tóthmérész, B. (2015): Soil extracellular enzyme activities are sensitive indicators of detrital inputs and carbon availability. Applied Soil Ecology, 92, :18-23. DOI: https://doi.org/10.1016/j.apsoil.2015.03.006

Vida, V., Vicente, A., Cazorla, F.M. (2019): The role of organic amendments to soil for crop protection: induction of suppression of soil-borne pathogens. Annals of Applied Biology. 176 (1), -1-15. DOI: https://doi.org/10.1111/aab.12555

Villányi, I., Füzy, A., Angerer, I., Biró, B. (2006): Total catabolic enzyme activity of microbial communities. The fluorescein diacetate analysis (FDA). In:. D. L. Jones, ed. Understanding and modelling plant-soil interactions. Handbook of methods used in rhizosphere research. Birmensdorf, Swiss Federal Research Institute WSL. Chapter 4.2, 441-442.