# The agronomic potential of a new vertical growing farming system using biofertilizers and peat-based wood fibre growing medium: lettuce as a case study

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***Abstract***

**To offer a sustainable alternative to current food production models and contribute to urban food security, we studied the agronomic performance of an automated rotative growing system using LED lighting. We hypothesized that this vertical rotative growing system (VRGS) provides a higher yield per cultivated greenhouse area than a conventional horizontal growing system (HGS). We also studied the impact of three organic growing media (1 – peat-based medium, 2 – peat mix with wood fibre, and 3 – peat mix with coco fibre), two biofertilizers (1 – animal-based, 2 – plant-based fertilizers) and four biostimulant treatments (1 – bamboo vinegar in soil, 2 – spruce vinegar applied in soil or 3 – leaves, 4 – water as control) for plants cultivated in both systems (VRGS and HGS) within a randomized complete block design with 3 to 13 replicates. Lettuce (*Lactuca sativa* 'Salanova Red Batavia') cultivated in the VRGS had 48% and 29% higher dry and fresh shoot biomass, respectively, than HGS-grown plants, explained by a higher leaf number (+35%) and specific leaf area (+9%), while no significant difference was observed for leaf photosynthetic parameters. However, plant height of HGS-grown plants was 29% higher compared with the VRGS. Considering that the cultivated area per unit of greenhouse floor area in the VRGS is 2.25 times higher than the HGS, leafy-vegetable productivity could be increased by 2.9 times. For both systems, animal-based biofertilizers yielded up to 46% more compared with plant-based biofertilizers, partly due to a slower and lower mineralization rate. Biostimulant treatments had no significant impact on growth and plant photosynthetic performance. While no difference between the growing media for the HGS was observed, plants grown in peat-based growing medium with coco fibre had 9% and 6% lower fresh biomass than plants grown in peat-based with wood fibre and peat mix only, respectively. Our results showed that this VRGS resulted in a high potential of productivity compared with a traditional HGS and increased the use of cultivated land. As such, a VRGS is a promising sustainable technology that can also be used for indoor production within a completely automated multilevel growing facility, and for other plant species such as herbs, strawberries, and mini-vegetables.**

**Keywords:** organic farming, organic fertilizers, vertical farming, sustainable growing system, greenhouse horticulture, artificial lighting, biostimulants

## INTRODUCTION

For the last decades, climate change and the increase of the population worldwide are major concerns in terms of the resource accessibility and food security (FAO, 2020). In addition, agronomical issues like the decrease of arable land, soil salinity, soil contamination, water quality and shortage, the increasing cost of energy and greenhouse gas emissions, the environmental footprint of greenhouse products, and in some countries as Canada, worker shortage, constitute main barriers to sustainable food self-sufficiency. With those issues, numerous social movements appeared such as urban gardening (Eaves and Eaves, 2018) and circular horticulture farming (Duque-Acevedo et al., 2020). Organic agriculture is also expanding fast (Willer and al., 2022) due to the important consumer demand for free pesticide and GMO foods and environmental concerns (Bialais, 2020). However, organic farming is often

Acta Hortic. 1355. ISHS 2022. DOI 10.17660/ActaHortic.2022.1355.58
XXXI IHC – Proc. Int. Symp. on Agroecology and System Approach for Sustainable and Resilient Horticultural Production
Eds.: M.C. Dussi and S. Simon

seen as a less productive growing system due to suboptimal fertilization and pest control management (Dorais and Alsanius, 2015; Dorais, 2019). In order to propose a more efficient, automated and sustainable organic growing system, Virgo technologies has developed a vertical rotative growing system (VRGS) that aims to improve and optimize the use of water, nutrient and energy use resources per unit of food, while limiting the need of labor per cultivated area. We hypothesized that this VRGS provides a higher yield per cultivated greenhouse area than a traditional horizontal growing system (HGS), while plant-based organic fertilizers fulfil plant nutrient need as animal-based fertilizers, and the use of bamboo and wood vinegars promotes plant growth. Thus, the objective of this study was to compare the productivity of two growing systems (VRGS vs. HGS) as well as three organic growing media, two organic fertilization regimes and three biostimulant treatments on plant productivity and potential yield per cultivated area.

## MATERIALS AND METHODS

On March 15, 2021, a first trial was performed at Laval University greenhouses (Quebec, Qc, Canada 46°46'31.0"N, 71°16'51.6"W) where pelleted seeds of *Lactuca sativa* 'Salanova Red Batavia' (Johnny's Selected Seeds) were sown in multiple cell plug trays filled with an organic peat-based growing medium (OM2, Les Tourbières Berger, Saint-Modeste, QC, Canada). Twenty-one days after germination, seedlings were ready to be transplanted into the cultivation trays (61×23×5 cm; 6 L of growing media per tray) developed by Virgo technologies for the VRGS. Seedlings were transplanted in three growing media (GM) provided by Berger (2022) (Les Tourbières Berger, Saint-Modeste, QC, Canada; 1-OM6 HP with peat, perlite and compost; 2-OM5 HP/WF with peat, perlite, wood fibre and compost; 3-OM5 HP/COIR with peat, perlite, coir and compost), and two organic fertilization treatments (F) (animal- or plant-based fertilizers) for a total of 20 trays per GM × F treatments. The animal fertilization was based on composted poultry pellets (5-3-2 Actisol, Notre-Dame-du-Bon-Conseil, QC, Canada) at 6.36 g $L^{-1}$ and feather meal (13-0-0; McInnes, QC, Canada) at 0.10 g $L^{-1}$, where the plant fertilization was based on soybean protein hydrolysate (9-1.5-7, EZ-Gro, Kingston, ON, Canada) at 1.82 g $L^{-1}$, soy protein hydrolysate (18-0-0, EZ-Gro, Kingston, ON, Canada) at 0.92 g $L^{-1}$, Nature's Nectar Phosphorus Suspension (0-3-0, EZ-Gro, Kingston, ON, Canada) at 5.45 mL $L^{-1}$, Gypse (calcium sulfate) at 0.90 g $L^{-1}$ and Epson salt at 0.14 g $L^{-1}$. During the trial, we used a liquid organic fertilization based on marine residue (3-1-4, Biofert, Abbotsford, BC, Canada) at 0.6 mL $L^{-1}$, Epson salt at 40 g $L^{-1}$ and bore Etidot at 0.16 g $L^{-1}$. A volume of 700-850 mL $tray^{-1}$ was daily provided to all plants. The growing media and the solid organic fertilizers of each treatment were mixed with a potted machine where the moisture content, the volume and compaction of the trays were controlled. Ten seedlings per tray were transplanted for a plant population of 72 plants $m^{-2}$. A total of 120 trays of 10 lettuces $tray^{-1}$ were installed in the VRGS, while 72 trays were placed on a table in the same greenhouse compartment for the HGS (Figure 1). After the transplantation, four biostimulant treatments were applied in subplots: 1 – bamboo vinegar in drench (Seek, Minhang District, Shanghai, China) at 2 mL $L^{-1}$, 2 – spruce vinegar in drench (Biopterre, Sainte-Anne-de-la-Pocatière Québec, Canada) at 2 mL $L^{-1}$, 3 – spruce vinegar in spray at 2 mL $L^{-1}$ and 4 – water control at 2 mL $L^{-1}$. The factorial experiment was designed to compare 24 treatments. We had three (HGS) to five (VRGS) replicates of 10 plants per experimental unit (total of 30 or 50 plants $treatment^{-1}$).

The VRGS was calibrated and programed in order that each experimental unit had the same light intensity, photoperiod, temperature, humidity, air flow velocity and irrigation. The greenhouse climatic conditions were maintained at a water deficit of 7.9 g $m^{-3}$ and day and night temperatures of 24 and 19°C. Supplemental lighting was provided to both growing systems. For the VRGS, Fluence LED lamps (Ray 44 model) located at 1 m from the plants provided 404 µmol $m^{-2}$ $s^{-1}$ during 18 h for a daylight integral (DLI) of 26.18 mol $m^{-2}$ $d^{-1}$, while 1000 W HPS lamps located at 3 m from the plants provided 296 µmol $m^{-2}$ $s^{-1}$ during 18 h (DLI of 19.18 mol $m^{-2}$ $d^{-1}$) for the HGS. The irrigation was similar for both systems and was adjusted according to the solar radiation. Multiple parameters were evaluated such as the fitness of the plant, the growing medium microbial activity, the growth parameters, and the lettuce quality.

As plant photosynthetic performance indicators, we measured the chlorophyll content (SPAD) and chlorophyll fluorescence (PEA) parameters on at least three plants per experimental unit. The following plant growth parameters were measured three times during the experiment: plant diameter and height, number of leaves per plant, specific leaf area (SLA), fresh and dry shoot biomass. The saturated media extract was performed for the mineral analysis ("Saturated Media Extract | Soil Testing Laboratory" s.d.) (SME, 2022) of the growing media and the microbial activities was expressed by the FDA method (Adam and Duncan, 2001). Measurements were performed at the beginning of the growth cycle (transplantation), 14 days after the transplantation and at harvest (after 21 days for the physiological parameters or 25 days for the other studied parameters). Data were analyzed by using Proc Mixed (SAS v. 9.4, SAS Institute). Data normality was checked using the Shapiro-Wilk statistic, and homogeneity of variance was assessed visually by examining the graphic distribution of residuals. When significant ($P \leq 0.05$), means were compared using LSD Fisher protected range test.

Figure 1. The experimental design of the studied vertical rotative growing system (VRGS) and the traditional table growing system (HGS).

## RESULTS AND DISCUSSION

### Fertilization

After 14 days of growth and for both growing systems, plants grown with animal-based fertilizers incorporated to the growing media were larger than plants treated with the plant-based fertilizers. Indeed, the fresh and dry shoot biomass of animal-based fertilizers grown plants were 109 and 78% higher, respectively, for the VRGS and 65 and 47% higher for the HGS compared with the biomass of plants grown with plant-based fertilizers (data not shown). However, at harvest (25 days after plantation), this biomass gap between the animal- and plant-based fertilizers was respectively reduced to 25 and 30% for the VRGS, and by 46-24% for the HGS (Table 1). For both growing systems, plants grown with solid animal-based fertilizers incorporated to the growing media had 12-14% more leaves than plant-based fertilizers grown plants, with a 30% higher specific leaf area. These differences may be related to a slower nitrogen mineralization of the plant-based fertilizers that have limited plant growth (data not shown) and/or by a negative impact of the soybean hydrolysate when incorporated in the growing media as N base supply. Indeed, the use of a high soy protein hydrolysate concentration may promote plant defense mechanisms to the detriment of plant growth (Barrada et al., 2022). Although the pH decreased during the growth cycle, no substantial difference between treatments was observed, although the EC of the growing media of plants grown on the HGS was in general higher (data not shown). It was reported from an in vitro experiment that the mineralization rate of feather meal was 39 and 75% after

1 week and 4 weeks, respectively, while it was only 12 and 39%, respectively, for the alfalfa meal (Dion et al., 2019). Under similar experimental conditions than Dion et al. (2019), lower mineralization rate of the soybean hydrolysates was also observed compared with animal-based fertilizers (P. Vezina, pers. commun.). On the other hand, by using organic fertilizers with similar chemical properties, no significant difference was observed for the N mineralization of animal or plant-based organic fertilizers (Cannavo et al., 2019; Paillat et al., 2020). The mineralization rate of organic amendments was rather related to the microbiota activities in the soil and other chemical and physical properties such as the pH, the electrical conductivity (Qi et al., 2018), the C:N ratio (Dion et al., 2019) as well as soil components (Schreiter et al., 2014).

**Growing media**

For both growing systems, no significant impact of the growing media was observed after 14 days of growth on all measured parameters (data not shown). However, after 25 days of cultivation, plants grown in the peat-based growing medium with coir had a 6 and 9% lower fresh biomass compared with plants grown in the peat-based medium with wood fibre and peat mix, respectively, while the other measured parameters were generally not impacted by the growing media (data not shown). Although wood fibre has a lower resistance to degradation than peat and coir due to its higher hemicellulose content and is subject to nitrogen immobilization if insufficient nitrogen is provided (Carlile et al., 2019; Harris et al., 2020; Jackson et al., 2008), it has a hydrophilic character that improves the wettability of growing media (Durand et al., 2021), and can act as a suppressive medium against pathogens such as *Pythium* (Pascual et al., 2018). Adding wood fibre to peat-based growing media may thus constitute a sustainable alternative to unsustainable components of the growing media. Regarding the interaction between the growing medium and the mineralization rate of different organic fertilizers, Paillat et al. (2020) reported that the components of the growing media had more impact on the enzymatic activity and mineralization than the type of fertilizer itself, which was related to the C/N ratio and pH. On the other hand, it was observed that the use of wood material such as bark allowed a greater mineralization of nitrogen, but a lower quantity of genes coding for the enzyme ammonia mono-oxygenase (Cannavo et al., 2019). In addition, Grunert et al. (2016) observed differences in microbial respiration rates between components of the growing media, which can be explained by the different C/N ratios as well as physical parameters, which also differ between the components.

**Biostimulants**

After 2 weks of growth, the fresh and dry biomass of lettuce treated with the bamboo vinegar treatment in drench were 19% higher than control plants cultivated within the HGS (data not shown), while no significative effect was observed after 25 days of growth (Table 1). On the other hand, the height of plants grown within the VRGS and treated in drench with the bamboo wood vinegar was 9% higher than the control plants. For young seedlings treated with foliar application of chestnut wood distillates, leaf chlorophyll content (+1.54 times) and plant biomass (+1.38 times) were increased after one week of treatment compared with the control plants (Vannini et al., 2021). Similarly, bamboo vinegar increased growth, development and yield of lettuce and other vegetables such as cucumber (Grewal et al., 2018).

**Growing systems**

Regardless of the fertilizer, growing medium and biostimulant treatments, the growth parameters of the plants grown in the VRGS after 14 and 25 days of cultivation were higher than the HGS; after 14 days of growth, the fresh and dry biomass of lettuce was 56 and 73% higher, respectively, compared with the HGS (data not shown). After 25 days of growth, lettuce cultivated in the VRGS had 48% higher dry shoot biomass, 29% higher fresh shoot biomass, 35% higher number of leaves, and 9% higher SLA compared with HGS-grown plants (Table 1). These differences may be explained by the light spectral quality of the lamps and the higher supplemental DLI received by the plants grown in the VRGS compared with the HGS. As shown in Figure 2, the proportion of red light for the VRGS was much higher than the HGS (60 vs.

35%), while the proportion of UV, blue and green light were lower (0.23 vs. 2.02% UV; 15 vs. 29% B; 26 vs. 36% G). In addition, far-red light was provided for the VRGS (10 vs. 0% FR).

Table 1. Growth parameters of lettuce cultivated for 25 days in vertical rotative or horizontal growing systems (VRGS), two fertilizer and four biostimulant treatments, and three growing media. Data are means of *n*=30-50 plants.

| | | Fresh biomass (g FM plant$^{-1}$) | Dry biomass (g DM plant$^{-1}$) | Specific leaf area (cm$^2$ g$^{-1}$ DM) | Number of leaves (Nb plant$^{-1}$) | Height (cm) |
|---|---|---|---|---|---|---|
| | | | | Rotative growing system | | |
| Fertilizers | Animal | 58.8 a | 3.57 a | 263.5 a | 44.4 a | 9.7 |
| | Vegetal | 45.0 b | 2.86 b | 253.0 b | 39.5 b | 9.4 |
| Biostimulant | Bamboo vinegar (growing media) | 51.8 | 3.25 | 261.5 | 43.2 | 10.0 a |
| | Spruce vinegar (leaves) | 51.7 | 3.16 | 258.5 | 41.1 | 9.3 b |
| | Spruce vinegar (growing media) | 53.1 | 3.18 | 253.0 | 41.4 | 9.8 ab |
| | Control (water) | 51.0 | 3.26 | 260.0 | 42.0 | 9.2 b |
| Growing medium | Peat & wood fibre | 52.4 a | 3.29 | 256.4 | 42.2 | 9.3 b |
| | Peat & coco fibre | 49.4 b | 3.11 | 253.4 | 42.2 | 9.4 b |
| | Peat-based medium | 53.9 a | 3.23 | 265.0 | 41.4 | 10.0 a |
| | | | | Horizontal growing system | | |
| Fertilizer | Animal | 47.6 a | 2.41 a | 356.3 | 33.0 a | 13.1 a |
| | Vegetal | 32.5 b | 1.95 b | 340.2 | 29.0 b | 11.9 b |
| Biostimulant | Bamboo vinegar (growing media) | 38.0 | 2.12 | 341.2 | 30.0 | 12.1 |
| | Spruce vinegar (leaves) | 39.2 | 2.19 | 352.1 | 31.0 | 12.3 |
| | Spruce vinegar (growing media) | 40.4 | 2.17 | 346.8 | 31.0 | 12.3 |
| | Control (water) | 42.7 | 2.23 | 352.9 | 30.0 | 13.1 |
| Growth medium | Peat & wood fibre | 41.2 | 2.25 | 353.1 | 31.0 | 12.1 |
| | Peat & coco fibre | 39.5 | 2.11 | 346.2 | 30.0 | 12.8 |
| | Peat-based medium | 39.6 | 2.17 | 345.4 | 31.0 | 12.4 |

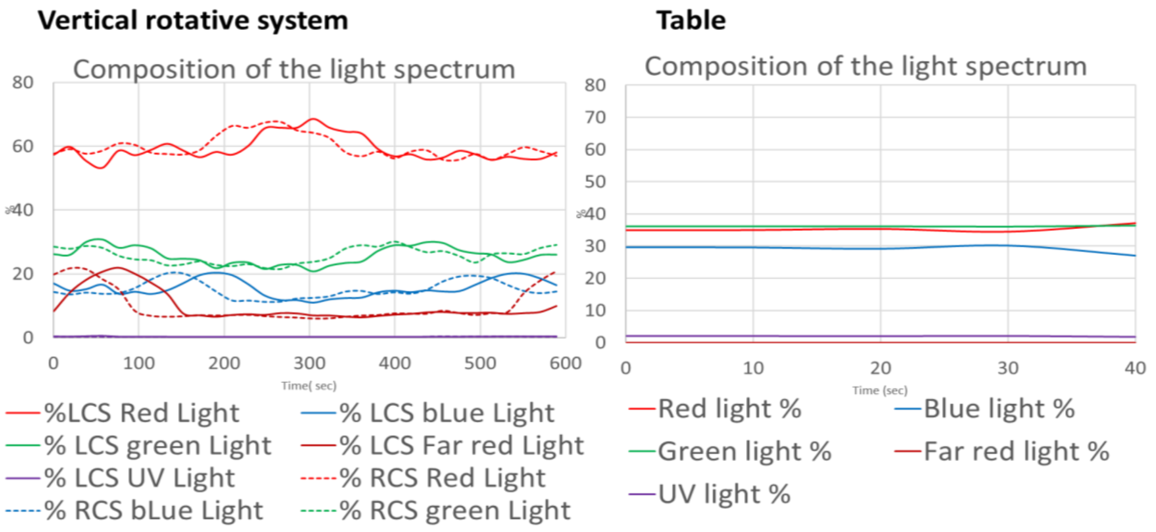


Figure 2. Composition (%) of the light spectrum of the supplemental lighting provided to the vertical rotative growing system (VRGS) and the horizontal table growing system, HGS. LCS stand for left center side and RCS stand for right center side.

Although plants grown on the table system received a higher proportion of UV and B, and no FR light, plant height was 29% higher for HGS-grown plants compared with the VRGS. On the other hand, we did not observe any significant difference between leaf photosynthetic parameters such as the chlorophyll content (SPAD) or the chlorophyll fluorescence parameters (PIndex and FV/FM ratio) (data not shown). Despite small differences in the SLA between both growing systems, lettuce plants cultivated on the HGS had a more fragile appearance compared with the ones grown in the VRGS. This could be explained by a higher airflow at the plant level compared with the plants grown in the HGS and the impact of the gravity on plant morphology.

In order to compare the potential productivity of the two studied growing systems, based on our results, we calculated the square meter productivity by greenhouse floor area. The VRGS occupied eight square meters of greenhouse floor area for 18 $m^2$ of cultivated areas. In other terms, this system provides 2.25 times more cultivated area for a same greenhouse floor unit used. Thus, the productivity of fresh lettuce by square meter of greenhouse floor unit (kg $m^{-2}$) for the VRGS was 7.785 kg compared to 2.675 kg for a traditional HGS, which was 2.9 times more productive. Assuming a growth cycle of 21-25 days, it is then possible to produce 15-18 growth cycles per year, producing around 62 kg lettuce $cycle^{-1}$. With those results, the VRGS could produce 934-1,121 kg lettuce $year^{-1}$ with only 8 $m^2$ of greenhouse floor area. Figure 3 shows the potential productivity of fresh lettuce per ha per year, assuming 18 growth cycles per year, of both systems per greenhouse floor area.

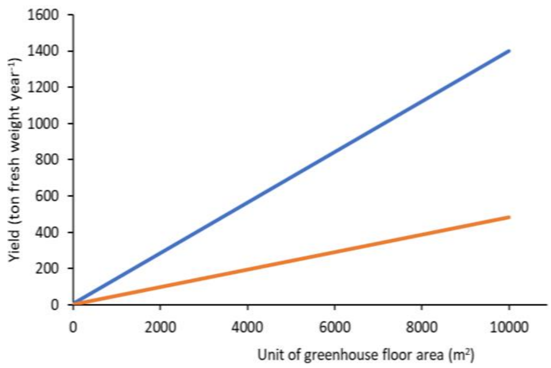


Figure 3. The potential yield of fresh biomass per square meter of greenhouse floor area and per year for a vertical rotative (blue line) and traditional horizontal (red line) growing systems.

**CONCLUSIONS**

Our results showed that a VRGS has a high productivity potential compared to a traditional HGS. It also showed that the VRGS could considerably increase the use of cultivated land and facilitate the resource management for the greenhouse industry. As such, a VRGS is a promising sustainable technology that can also be used for indoor production within a completely automated multilevel growing facility. Our results also showed that the animal-based fertilization incorporated to the growing medium before plantation was better than the studied plant-based fertilization, which may be related to a low mineralization rate as well as the components per se. Replacing part of the peat and perlite with wood fibre had no negative impact of plant performance and had a positive impact of soil microbial activity (data not shown). Although the use of bamboo vinegar used in drench as biostimulant may promote plant growth at the early stage, further investigation will be needed to show its benefits at the end of the growth cycle. Further assays also need to be conducted to improve and adapt that innovative growing system to different crop species. This system has the advantageous of producing uniform and high-quality products year-round and may be suitable for regions with harsh climatic conditions and limited resources that make agriculture difficult such as Arctic or desertic countries. This vertical rotative growing system may also contribute to food security by proving vegetables or fruits of high quality on a limited use of urban land.

**ACKNOWLEDGEMENTS**

The authors sincerely thank the *Ministère de l'Agriculture, des Pêcheries et de* *l'Alimentation* of Quebec and the partners of the research Chair in Organic Horticulture in Greenhouse and controlled environment for their financial support: Berger, Les Serres Frank Zyromski, Industries Harnois, Hydroserre Mirabel, Redsunfarms, Inno-3B and Virgo Technologie.

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