Vegetable Production in an Integrated Aquaponic System with Stellate Sturgeon and Spinach–*Matador* variety

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Abstract

This study aims to reveal the performances parameters, both in terms of quantity and quality, for spinach (*Spinacia oleracea*)-Matador variety, growth in an aquaponic integrated system, along with stellate sturgeons (*A. stellatus*) under three crops densities (V1-59 crops/m^2, V2–48 crops/m^2 and V3–39 crops/m^2), by using hydroton as growing substrate, under a continuous flow hydraulic regime. The experiment was run in triplicate for each one of the three variants. The water quality was monitored and a series of growth parameters were determined, as follows: leaf area index (LAI), relative growth rate (RGR), average net assimilation rate (NAR), mean leaf area ratio (LAR) and crop growth rate (CGR). Also the concentration of chlorophyll a, b, carotenoids, ash and dry matter for spinach leaf, from each of the three experimental variants was determined and compared with the one of marketable spinach, growth conventional, in soil. It can be concluded that statistical significant differences ($p<0.05$) were recorded in terms of growth performance and crops quality, between the experimental variants. Also the quality of spinach grown in aquaponic conditions, by using effluent derived from stellate sturgeon intensive aquaculture is similar to that of the marketable spinach, growth conventional.

Keywords: aquaponic system, chlorophyll, crop densities, relative growth rate, spinach, water quality

1. Introduction

It is well known that in the last decade many efforts have been paid to limit the impact of aquaculture on aquatic environments [1]. Also, Blidariu F. and Grozea A. (2011) [2] sustained that there is a possibility to increase economic efficiency of aquaculture by practicing aquaponics and selling the obtained crops as a certified organic crop, because it is produced entirely from natural manure (fish waste), noting that aquaponics presents an opportunity to rethink the indoor fish farming while having two profit sources: fish and plants. Various types of hydroponic media have been used for growing crops in freshwater aquaponic systems, including gravel bed ebb and flow systems, aeroponics, nutrient film technique (NFT), rock wool culture and sand beds. Graber A. and Junge R. (2009) [3] established an aquaponic system in Waedenswil, Zurich that has a new concept using light expanded clay aggregate (LECA), also known as hydroton, as filter medium for the trickling filter. Another technical problem raised by practicing aquaponics is regarding their hydrodynamics, more exactly regarding the type of flow that is better for being used: reciprocating flow, also called flow and drain regime or constant flow (continuous flow). Lennard W.A. and Leonard B. V (2004) [4] had made a comparison between reciprocating flow and constant flow, in an integrated, gravel bed, aquaponic test system and had discovered that lettuce growth was significantly better within a constant flow environment, most probably because of a greater nutrient assimilation.

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In the present study, we assessed the growth and productivity of spinach (*Spinacia oleracea*)-*Matador* variety, growth in an aquaponic integrated system, along with stellate sturgeons (*A. stellatus*) under three crops densities (V1-59 crops/m2, V2–48 crops/m2 and V3–39 crops/m2), by using hydroton (LECA) as growing substrate and a constant continuous flow hydraulic regime. Outside Dediu L. et al. (2012) [5], that had studied waste production and valorization in an integrated aquaponic system with bester and lettuce, no references have been found regarding the adaptation and performance of sturgeon species in integrated aquaponic systems. Thus, the compilation spinach (*Matador* variety)–stellate sturgeon was not found to be studied in integrated aquaponic system previous research.

2. Materials and methods

Integrated aquaponic system description

The present experiment took place between 20th February and 4th April 2013 at the main pilot recirculating system station of Aquaculture, Environmental Science and Cadastral Measurements Department of Food Science and Engineering Faculty–"*Dunarea de Jos*'' University of Galati. The configuration of the pilot recirculating main system was sized according to specific technology described by Cristea (2008) [6]. Figure1 describes for the first time, the new emplacement of the recirculating main pilot station as follows: 4 octagonal shape rearing units with a volume of approx. 2 m^3/unit–No.1, with water level sensors–No.3 and nitrogen compounds sensors-No.2; RAS monk–No.4; mechanical drum filter–No.5; sump–No.6; sand filter–No.8; ACLM 05 –ROMET Buzau type activated charcoal filter (10 m^3/h maximum filtering speed)–No.9; biological trickling filtration unit–No.10; sterilization UV filter (wavelength: 254 nm)–No.11; 3 pumps–No.7; oxygenation unit–No.12; growing units water outlet installation–No.15; growing units water inlet installation–No.14 and also automatically fresh water inlet–No.13. The hydraulic flow direction is indicated in figure1 by arrows.

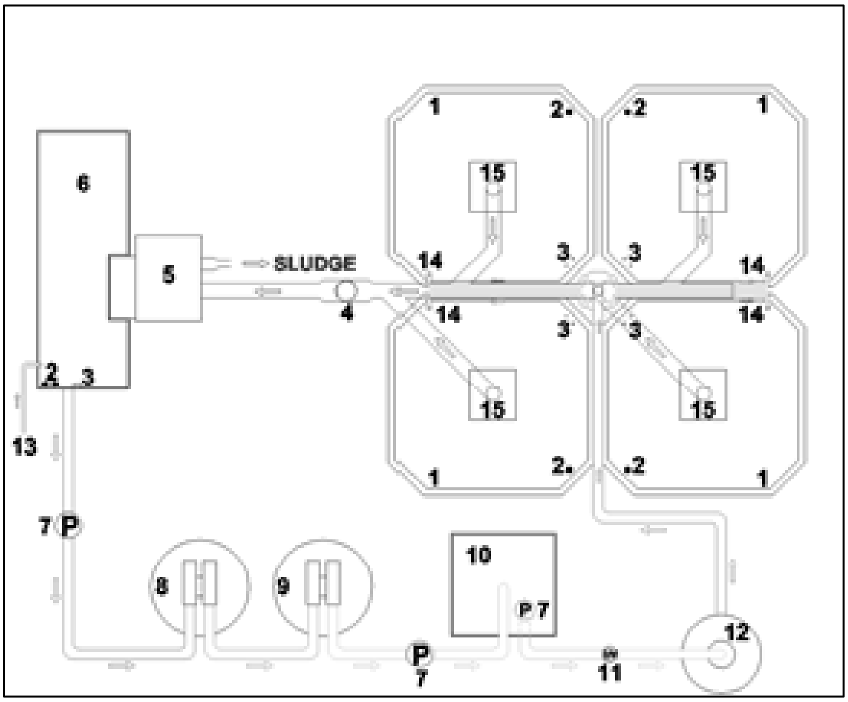


Figure.1. The configuration and emplacement of main pilot recirculating system station

The aquaponic modules consist in 12 rectangular plastic made units (650x470x340 mm), placed high above the fish growing units, on a special metal support (Figure 2B). Each growing unit corresponds with 3 aquaponic modules and inside the growing unit, a 2000L/h Hailea type pumps is placed in a protective casing made of mesh and steel frame, ensuring water recirculation from fish tank to hydroponic units and back. At a distance of 380 mm over each pump, a 25 mm diameter tap and 100 mm up, a non-return valve are placed (Figure 2A.). Over the hydroponic units level, the inlet installation splits in 4 parts, 3 of them for each hydroponic unit and one that goes again directly into growing units and gives the possibility of controlling the inlet flow, without negative effect to the pump (Figure 2A). The outlet of each hydroponic unit is placed in the middle of each one bottom and is ensure by a 25mm PVC pipe, with a bigger diameter (32 mm) on the entrance and a diameter narrowing (20 mm) length of 65 mm, placed 370 mm down the bottom of the unit (Figure 2C). The electric panel for the aquaponic modules ensures four Hailea type pumps (2000L/h each) and four Metal–Halide lamps (600W each), with a total luminous power of 5800 lm, placed above the hydroponic units. Each lamp has its own electronic ballast.

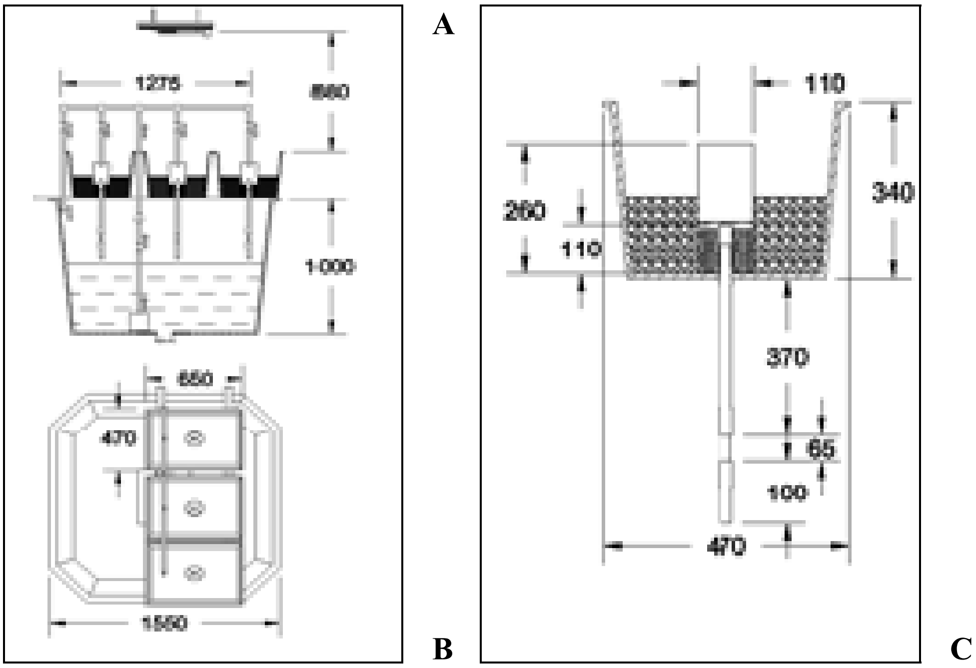


Figure 2. A. longitudinal section of aquaponic modules; B. Top view of aquaponic modules; C. Crossing section of aquaponic modules

Experimental design

Before starting the experiment, the activation of biological trickling filtration unit was made as described by Dediu et al. (2012) [5]. For the 44 days experiment, a total number of 184 stellate sturgeons (*A. stellatus*), with an average initial weight of 169.75 grams, was used in parallel with spinach (*Spinacia oleracea*), *Matador* variety, at an age of 25 days. The total fish biomass from the recirculating aquaculture system, at the beginning of the experiment, had 31.233 kg. Fish were divided in 4 groups and were fed with Clasic Extra 1P–41% brute protein, at an average feeding ratio of 1.75% of total biomass. A total amount of 25 877 grams of Clasic Extra 1P feed was administrated during all 44 experimental days. *Matador* variety spinach was placed in the hydroponic units with the following stocking densities: (V1–59 crops/m^2–12 crops/aquaponic unit, V2–48 crops/m^2–10 crops/aquaponic unit and V–39 crops/m^2–8 crops/aquaponic unit). The seedlings were obtained at Natural Sciences Museum Complex Galaţi-Botanical Garden. The growth support media of spinach, cultivated in the aquaponic system, consisted of hydroton medium (LECA). Plants were numbered each and then place in the the light expanded clay aggregate. The maximum capacity of an aquaponic unit is 12 plants. Plants biometric measurements were made and a set of growth performance indices were determined by formulas described by Petrea et al. (2013) [7]. The percentage of spinach ash, dry matter content, chlorophyll *a*, chlorophyll *b* and carotenoids were determined as described by Petrea et al. (2013) [7], for all three experimental variants and also for spinach derived from different markets located in Galati city, so that the comparison between aquaponic derived spinach and market spinach to be possible.

Water analysis

Technological water was analyzed in terms of temperature, pH, dissolved oxygen, electrical conductivity, turbidity, BOD5, NH_4^+, NO_2^-, NO_3^-, PO_4^{3-}, Fe^{3+}, Mn^{2+}, Mg^{2+}, Ca^{2+}, K^+, Cl^-, COD, TOC, total hardness and alkalinity as described by Petrea et al.(2013) [7]. The luminous intensity was measured with TESTO 545 light meter.

Statistical methods

Statistical analysis was performed using the IBM SPSS Statistics 20 for Windows. Statistical differences between treatments were tested using T test (α=0.05) after a normality test (Kolmogorov-Smirnov). Comparisons between variants were assessed using post-hoc Duncan test for multiple comparisons (ANOVA).

3. Results and discussion

Water quality and fish growth performance

The mean values of main physico-chemical parameters of water, from the integrated recirculating system.

(Table 1) were within optimal range for both stellate sturgeon and spinach culture. Related to stellate sturgeon growth performance, a total weight gain of 14449 g was recorded at the end of experimental period. An average feed conversion ratio (FCR) of 1.77 g/g and an average specific growth rate (SGR) of 0.95%/day were recorded. The survival rate was 100%.

Plants growth parameters

At the beginning of the experiment, the total initial weight among triplicates at V1 (plant density of 59 crops/m^2) was: B_1H_1–9.5 g, B_1H_2–9.65 g and B_1H_3–9.31 g; in V2 (48 crops/m^2) case was: B_2H_1–6.85 g, B_2H_2–6.87 g and B_2H_3–7.25 g and at V3 (39 crops/m^2) was: B_3H_1–5.48 g, B_3H–5.58 g and B_3H_3–5.4 g. At the end of the experiment, a total plant weight of B_1H_1–151.03 g, B_1H_2–152.66 g and B_1H_3–156.6 g was recorded at V1; B_2H_1–174.36 g, B_2H_2–179.33 g and B_2H_3–177.48 g at V2 and B_3H_1–207.55 g, B_3H_2–206.6 g and B_3H_3–203.1g at V3. An average individual plant yield of B_1H_1–11.79 g/plant, B_1H_2–11.92 g/plant and B_1H_3–13.69 g/plant was registered in case of V1; B_2H_1–16.75 g/plant, B_2H_2–17.25 g/plant and B_2H –15.72 g/plant at V2 and B_3H_1–23.38 g/plant, B_3H_2–27.63 g/plant and B_3H_3–24.71 g/plant at V3. By using two multiple comparison test (Tukey and Duncan–ANOVA), it was observed that differences between V1-V2 were not statistically significant ($p>0.05$), comparing with the differences between V2-V3 and V-V3 that were statistically significant ($p<0.05$). Also, the differences between triplicates were not statistically significant ($p>0.05$). After applying Kolmogorov-Smirnov normality test on the final shoot height from all three experimental variants, we found a normal distribution ($p>0.05$), fct which allowed us to apply the parametric tests. Regarding the data series distribution of final shoot height, by analyzing skewness and kurtosis, it can be said that in case of all triplicates from V2 and especially V1, the mesokurtic distribution has a little platikurtic tendency, a bit flatter than a normal distribution, with the tendency of values scatting over a longer interval around the mean, a little tilted to the right, with more extreme values to the left. In case of V3 triplicates, the distribution almost the same, except that here the histogram is a little tilted to the right, with more extreme values to the left.

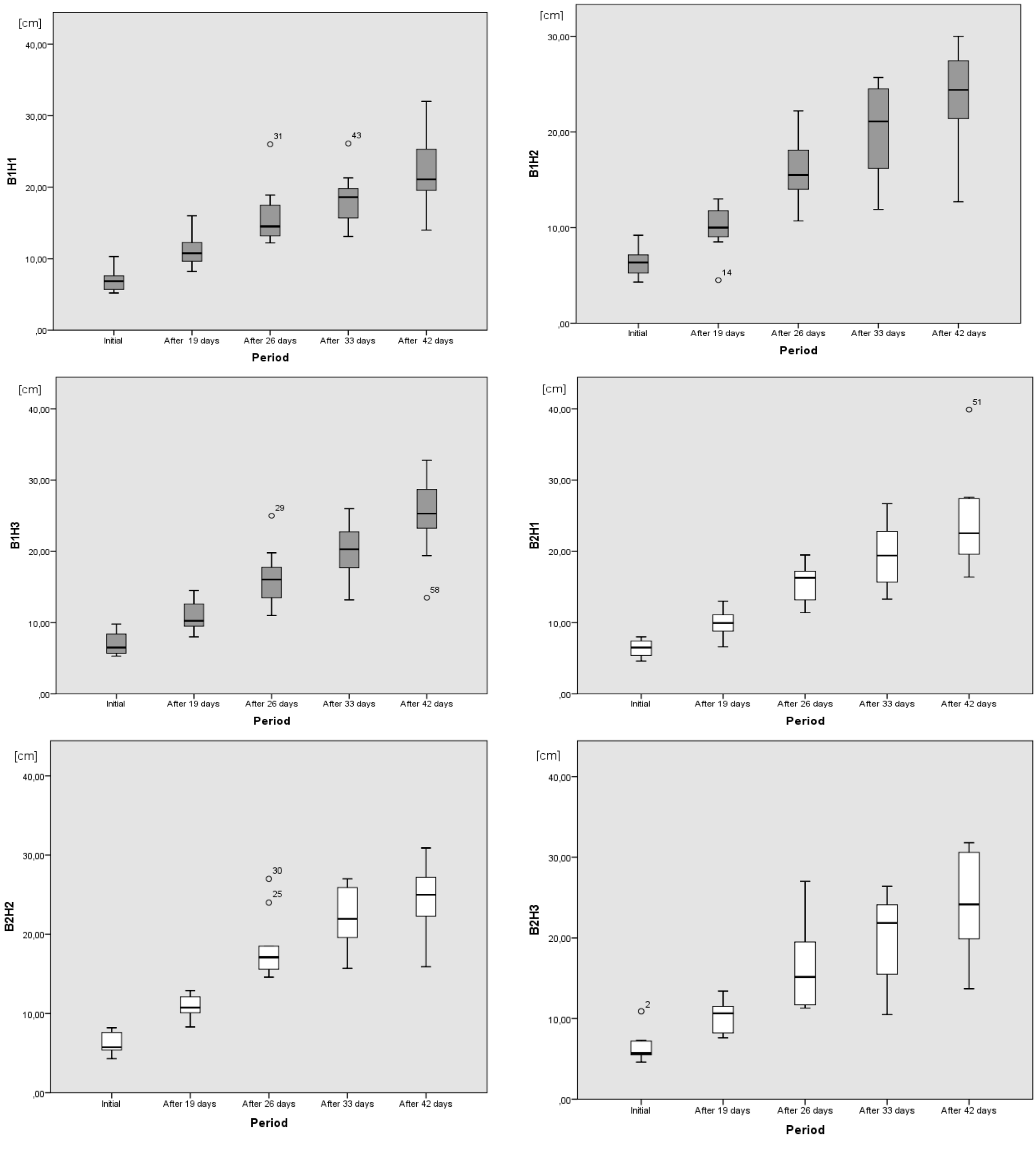
Table 1. The main physico-chemical parameters of water (mean±S.E.)*

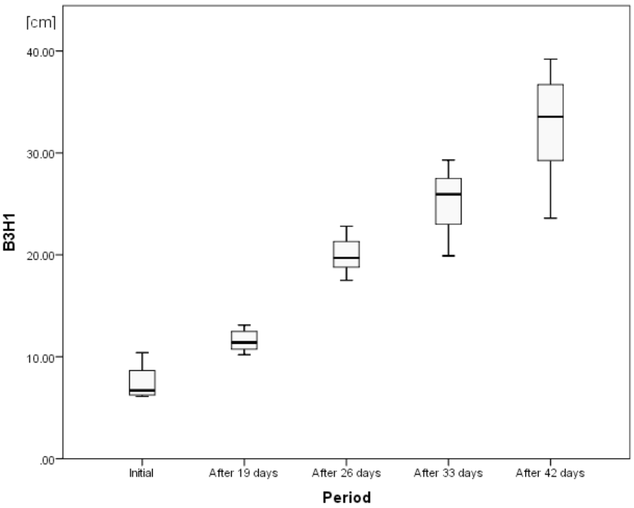
Physico-chemical parameter	Average	St DEV
N-NH_4^+ (mg/L)	0.13	±0.058
N-NO_2^- (mg/L)	0.18	±0.051
NO_3^- (mg/l)	176	±40.21
PO_4^{3-} (mg/L)	8.07	±3.04
Fe^{3+} (mg/L)*	0.65	±0.31
Mn^{2+} (mg/L)	0,54	±0.28
Mg^{2+} (mg/L)	30.38	±0.85
Ca^{2+} (mg/L)	102.28	±13.79
K^+ (mg/L)	28.21	±4.52
Cl^- (mg/L)	26.4	±2.61
COD (mg/L)	37.45	±17.56
TOC (mg/L)	39.54	±12.67
Total Hardness (mg $CaCO_3$/L)	130.52	±13
Alkalinity (mg/L)	52.95	±16.14
Electrical conductivity(μS/cm)	1166.96	±45.15
Turbidity (NTU)	2.41	±0.69
Temperature (^{o}C)	19.38	±1.25
pH	7.66	±0.16
Dissolved oxygen (mg/L)	7.3	±2.42
BOD5 (%)	42.15	±20.38

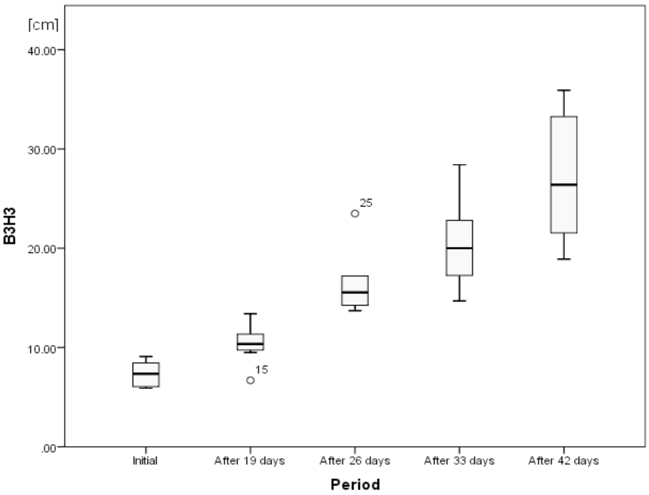
*a total of 112 g iron chelate was added in the technological water throughout the experimental period.

Regarding the evolution of shoot height (Figure 3), we can state that in case of V3 the evolution was a bit more symmetric comparing with V1 and

V2 that was less symmetric. The distribution of values in case of V3 (B3H1, B3H2, B3H3) had tended to the maximum value recorded at the last two measurements and also it can be seen a smaller distribution variation, comparing with the other two variants (Figure 3).







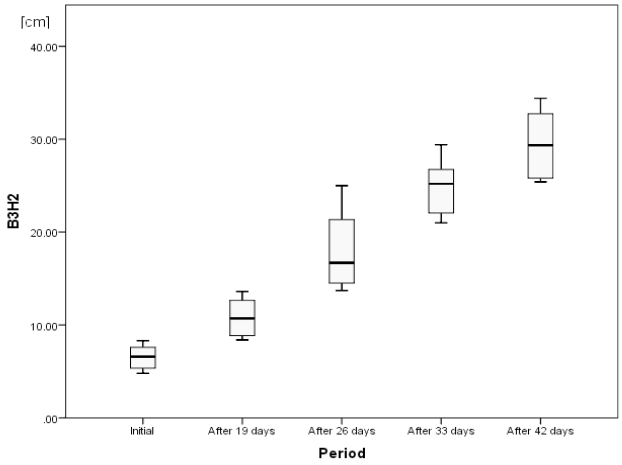


Figure 3. The evolution of shoot height among the experimental period
(V1: B1H1; B1H2; B1H3, V2: B2H1; B2H2; B2H3
V3: B3H1; B3H2; B3H3)

Thus, it is obvious that the differences between crop groups, among all the evolution stages, are more pronounced in case of V1 experimental variants, fact confirmed by all its triplicates. By analyzing the values of last two measurements of each variant, we can state that obvious differences between groups are observed and that plants from V3 had a more constant growth rate comparing to those from other two variants. It can be conclude that after 26 days of experiment, relatively close values are registered between crops shoot height of experimental groups, but immediately after this values are dissociating, plants from V3 having a significant increase of their growth rate in the last half of the experimental period. At the end of the experiment, at V1 mean individual plant heights of B1H1 22.73 cm; B1H2 23.66 cm; B1H3 25.15 cm were registered, at V2 the value were B2H1 24.07 cm; B2H2 24.74 cm and B2H3 23.91 cm and at V3 were B3H1 32.73 cm; B3H2 29.45 cm and B3H3 27.15 cm. Also, in case of V3, the values indicated by median are closer to average values, comparing with the other two variants tested. By using two multiple comparison test (Tukey and Duncan–ANOVA), it was observed that differences between plant height from V3, compare with other two experimental variants, at the end of experiment, were significant ($p<0.05$)– 2 data subsets: V1+V2 and V3. The differences of plant height between V1 and V2 were not significant ($p>0.05$).

Plants growth indices

Growth, survival and reproduction are the three imperatives of any organism [7]. In plants, growth is particularly important because both survival and reproduction depend on plant size and therefore on growth rate [8]. The following plant growth indices were calculated: CGR, RGR, NAR, LAR, LAI and root-shoot ratio. The RGR evolution is influenced by NAR and LAR [7]. Analyzing spinach RGR makes possible to compare growth differences that arise between the experimental variants [7]. The photosynthetic efficiency of plants is indicated by NAR [7]. Individual NAR average values are greater in V3 (B3H1 0.81 g/m^2/day; B3H2 0.79 g/m^2/day; B3H3 0.88 g/m^2/day), comparing to V2 (B2H1 0.75 g/m^2/day; B2H2 0.75 g/m^2/day; B2H3 0.73 g/m^2/day) and V1 (B1H1 0.7 g/m^2/day; B1H2 0.62 g/m^2/day; B1H3 0.63 g/m^2/day). By using two multiple comparison test (Tukey and Duncan–ANOVA), it was observed that differences between variants V1 and V3 are statistically significant ($p<0.05$)–2 subsets: V1+V2 and V2+V3. From Figure 4 it can be observed that we encounter the most uniform distribution variation in case of V2.

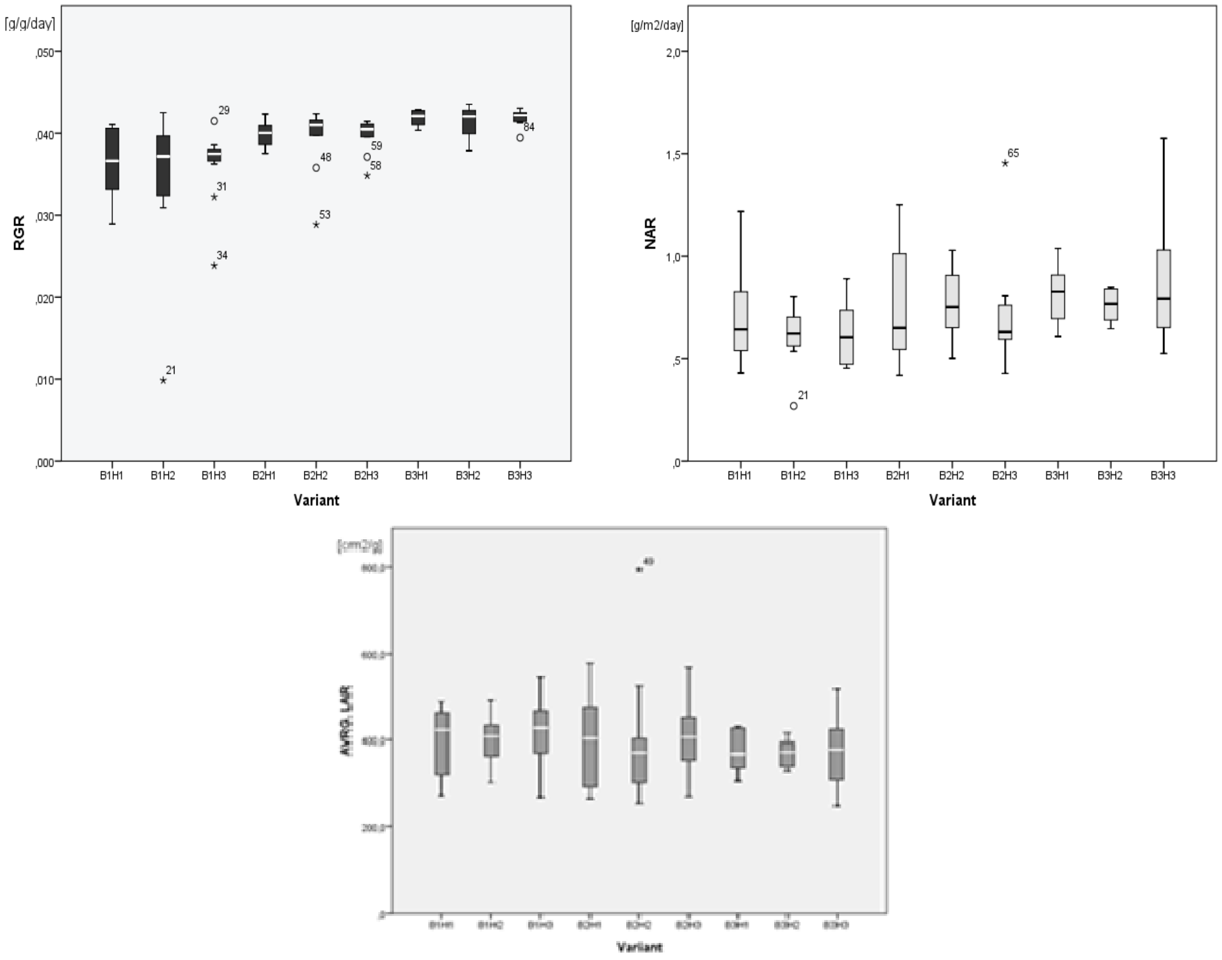


Figure 4. Plant RGR, NAR and LAR for each experimental variant
V1: B1H1; B1H2; B1H3, V2: B2H1; B2H2; B2H3, V3: B3H1; B3H2; B3H3

Slight NAR increase and the decrease in the values of the LAR indicate dry matter accumulation in leaves and stems [7]. LAR is characterized as a measure of payments balance between income and expenditure because it deals with the potentially photosynthesizing and potentially respiring components of the plant [9]. The mean individual average LAR values were as follows: B1H1 393.94 cm^2/g; B1H2 398.42 cm^2/g; B1H3 419.11 cm^2/g at V1, B2H1 400.39 cm^2/g; B2H2 406.17 cm^2/g; B2H3 408.32 cm^2/g at V2 and B3H1 374.69cm^2/g; B3H2 369.65 cm^2/g and B3H3 373.35 cm^2/g at V3. By using two multiple comparisons test (Tukey and Duncan–ANOVA), it was observed that differences between the variants were not statistically significant ($p>0.05$): 1 subset: V1+V2+V3. In Figure 4 it can be seen that average LAR in case of V2 has a higher distribution variation, significant differences being observed inside the group.

The final mean leaf area at V1 is B1H1 603.13 cm^2; B1H2 625.01 cm^2; B1H3 674.74 cm^2, at V2 is B2H1 952.87 cm^2; B2H2 965.95 cm^2; B2H3 971.5 cm^2 and for V3 we registered values of B3H1 1239.61 cm^2; B3H2 1284.91 cm^2 and B3H3 1239.29 cm^2. From both final mean leaf area and

LAR values, it can be concluded that spinach leaves are thinner in case of V2, comparing to V1 and V3 leaves are significant ($p<0.05$) thicker comparing to other two variants. This particular fact can be given on account of the plant adaptability to new growth conditions [7]. The current data tendency confirms the one obtained by Petrea et al. (2013) for *Nores* variety spinach, growth in aquaponic conditions, in a floating rafts system, with effluent derived from rainbow trout aquaculture. Mean individual value for RGR registered at V1 were B1H1 0.037 g/g/day–24.29% from initial DW/day; B1H2 0.035 g/g/day–23.29%; B1H3 0.036 g/g/day–21.49%, at V2 was B2H1 0.04 g/g/day –35.72%; B2H2 0.04 g/g/day–39.17%; B2H3 0.04 g/g/day–34.75% and in case of V3, the RGR value was B3H1 0.042 g/g/day–56.82%; B3H2 0.041 g/g/day–56.62% and B3H3 0.042 g/g/day–56.58%. By using two multiple comparison test (Tukey and Duncan–ANOVA), it was observed that differences between variant V1 and the other two were statistically significant ($p<0.05$)-2 subsets: V1 and V2+V3. From figure 4 it can be observed that in case of V1 we encounter a higher distribution variation, comparing with the other variants and also the differences between the groups are evident expose. Also, in case of all variants, the values indicated by median are closer to average values.

A plant with optimum LAI and NAR may produce higher biological yield as well as seed yield [10]. In our case, mean individual CGR registered the following values: B1H1 0.102 g/m^2/day; B1H2 0.103 g/m^2/day; B1H3 0.106 g/m^2/day at V1, for V2 the values were B2H1 0.154 g/m^2/day; B2H2 0.159 g/m^2/day; B2H3 0.156 g/m^2/day and for V3 were B3H1 0.246 g/m^2/day; B3H2 0.243 g/m^2/day and B3H3 0.241 g/m^2/day. By using two multiple comparison test (Tukey and Duncan–ANOVA), it was observed that differences between variant V1 and the other two were statistically significant ($p<0.05$)-2 subsets: V1 and V2+V3. It can be seen from figure 5 that the highest distribution variation is encountered in case of V3. Also, LAI evolution in time shows that 26 days after the start of the experiment the values in case of V3 detach from one of V1 and V2 by getting higher while after another 7 days the same thing happens with V2 (Figure 5). Regarding mean individual root-shoot ratio, at the end of experiment, the following results were obtained: B1H1 0.09; B1H2 0.1; B1H3 0.08 at V1, B2H1 0.11; B2H2 0.11; B2H3 0.12 at V2 and B3H1 0.14; B3H2 0.13; B3H3 0.13 at V3. The root-shoot ratio helps to assess the overall health of plants [7]. The root-shoot ratio high values from V3 could be as well an indication of a healthier plant, given that the increase came from a greater root weight and not from a decrease in shoot weight. By using two multiple comparison test (Tukey and Duncan–ANOVA), it was observed that differences between variants V1 and V3 were statistically significant ($p<0.05$)-2 subsets: V1+V2 and V2+V3. Also, in case of all variants, the values indicated by median are closer to average values (Figure 5).

For measuring the correlation intensity between leaf area, plant weight and shoot lenght numerical variables, Pearson correlation was used. The values of Pearson correlation coefficient are as follows: for V1 0.844 for leaf are (LA)–plant weight (PW) correlation, 0.695 for leaf area (LA)-shoot lenght (SL) and 0.677 for SL–PW; for V2 0.793 for LA–PW, 0.629 for LA–SL and 0.446 for SL–PW; for V3 0.810 for LA–PW, 0.44 for LA–SL and 0.348 for SL–PW. As a conclusion, it can be stated that there is a strong direct correlation only between leaf area and plant weight.

Plant quality parameters

Spinach ash and dry weight were determined from all three variants and also from market spinach–*Matador* variety. As a conclusion it can be said that shoot dry matter percentage of V1 recorded the following mean values: B1H1 8.12%; B1H2 8.11%; B1H3 8.1%; at V2 variant B2H1 8.41%; B2H2 8.45% and B2H3 8.42% and for V3 variants B3H1 8.82%; B3H2 8.79% and B3H3 8.84%. The values were significant higher ($p<0.05$) comparing with the average value obtained for market *Matador* variety spinach, which was 7.82%. The values were near the ones obtained by Petrea et al. (2013) by practicing the same spinach–*Nores* variety growth densities, but by using floating rafts as growth substrate and rainbow trout (7.1%–7.82%) and higher than those of Roe et al. (2013) [11] that reported 6.5% shoot dry matter for spinach growth in field, but lower than the values reported by Hannatu et al. (2011) [12] who registered a shoot dry matter content of 18.25 for spinach growth also in field. Ash content of spinach growth in aquaponic condition registered lower percentages (V1:

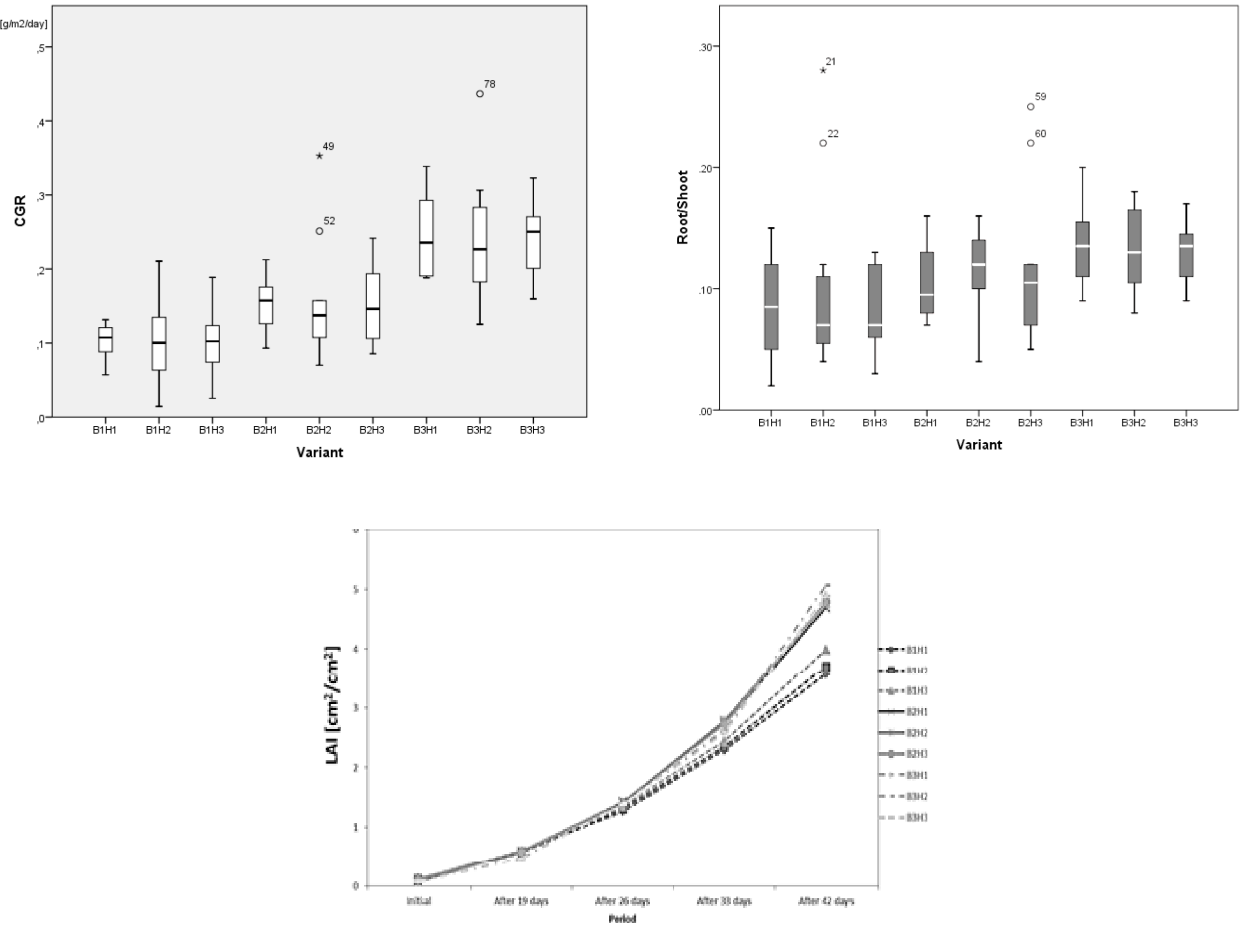


Figure 5. Plant CGR, root-shoot ratio and LAI for each experimental variant
V1: B1H1; B1H2; B1H3, V2: B2H1; B2H2; B2H3, V3: B3H1; B3H2; B3H3

B1H1-1.77%, B1H2–1.75%, B1H3–1.65%; V2: B2H1–2.03%, B2H2–2.05%, B2H–2.01% and V3: B3H1–2.19%; B3H2–2.14% and B3H3–2.21%), compared with market spinach ash percentage with was 2.23% (Figure 5). The ash content was higher than the one mentioned by Akhter et al. (2013) [13] 1.26%, Petrea et al. (2013) [7] 1.24-1.63%, Hannatu et al (2011) [12] 1.62%, Umar et al. (2007) [14] 1.08% and near the ash content reported by Roe et al. (2013) [11] 2% for spinach growth in field. Both ash and dry matter content differences between experimental variant V1 and V3 were statistically significant ($p<0.05$). The values of chlorophyll *a* and *b* from aquaponic cultured spinach were measured both as mg/dm^2 and also mg/g and compared with one of market spinach. Also carotenoid content was determined for aquaponic cultured spinach. The final mean values of chlorophyll *a* at V1 were B1H1 0.93 mg/g; 0.22 mg/dm^2, B1H2 1.08 mg/g; 0.21 mg/dm^2, B1H3 1.02 mg/g; 0.23 mg/dm^2; at V2 the values were B2H1 1.27 mg/g; 0.31 mg/dm^2, B2H2 1.29 mg/g; 0.31 mg/dm^2, B2H3 1.29 mg/g; 0.32 mg/dm^2 and at V3 the values were B3H11.41 mg/g, 0.48 mg/dm^2, B3H2 1.39 mg/g, 0.45 mg/dm^2 and B3H3 1.38 mg/g; 0.47 mg/dm^2. The chlorophyll *b* final values for V1 were: B1H1 0.14 mg/dm^2, 0.46 mg/g; B1H2 0.1 mg/dm^2, 0.48 mg/g; B1H3 0.12 mg/dm^2, 0.48 mg/g, for V2 the values were B2H1 0.2 mg/dm^2, 0.54 mg/g; B2H2 0.21 mg/dm^2, 0.55 mg/g; B2H3 0.24 mg/dm^2, 0.58 mg/g and for V3 the values were B3H1 0.28 mg/dm^2, 0.82 mg/g; B3H2 0.27 mg/dm^2, 0.86 mg/g and B3H3 0.26 mg/dm^2, 0.85 mg/g. The carotenoid values at the end of experiment were B1H10.16 mg/dm^2, B1H2 0.14 mg/dm^2, B1H3 0.15 mg/dm^2; at V2 the values were B2H1 0.20 mg/dm^2, B2H2 0.22 mg/dm^2, B2H3 0.22 mg/dm^2 and at V3 the values were B3H1 0.3 mg/dm^2, B3H2 0.28 mg/dm^2 and B3H3 0.29 mg/dm^2. The values were higher than those registered by Petrea et al. (2013) for aquaponic growth spinach–*Nores* variety (chlorophyll *a:* 0.18 mg/dm^2, 0.35 mg/g-0.2 mg/dm^2 and 1.24 mg/g; chlorophyll *b:* 0.12 mg/dm^2, 0.17 mg/g-0.21 mg/dm^2 and 0.24 mg/g; carotenoids*:* 0.09 mg/dm^2–0.14 mg/dm^2). Both chlorophyll *a* and *b* values for market spinach (1.08 mg/g and 0.49 mg/g) were lower than values registered at V2 and V3 and higher than those recorded at V1 (Figure 6).

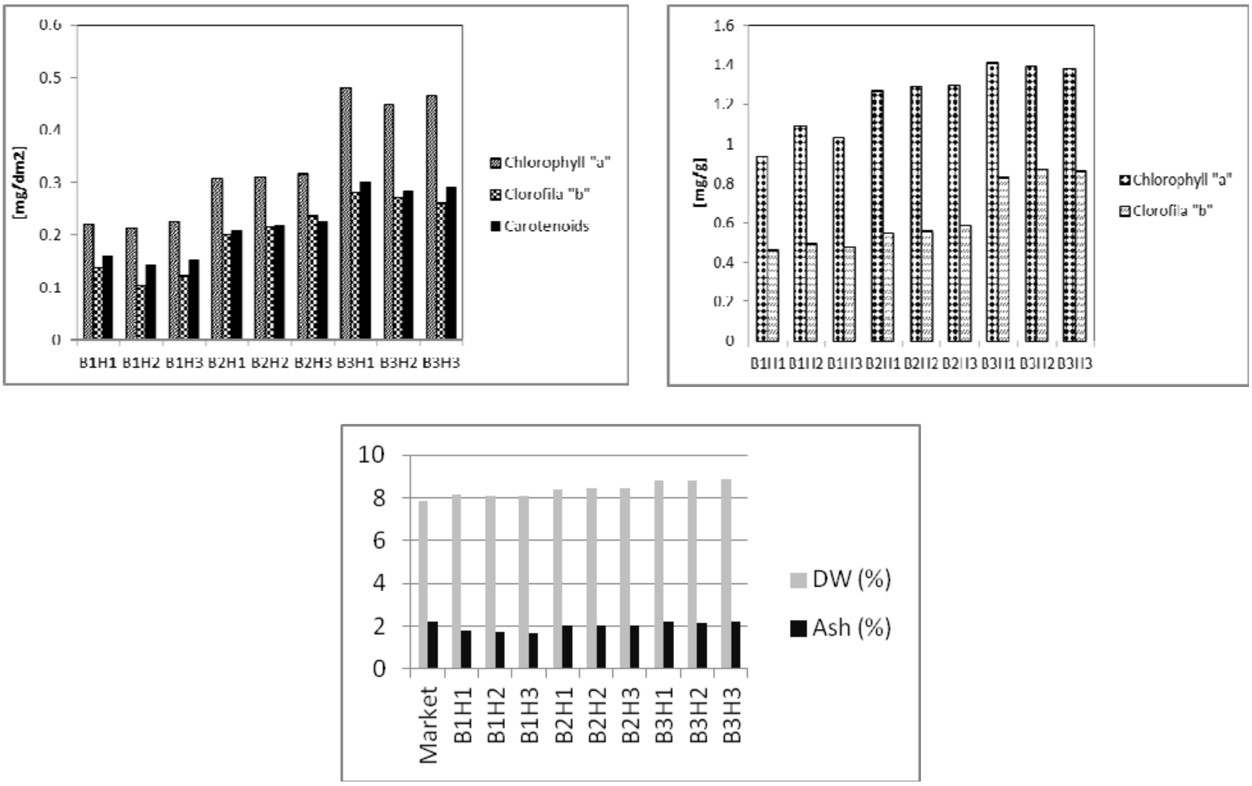


Figure 6. Chlorophyll a, b and carotenoid, ash and dry matter for each experimental variant V1: B1H1; B1H2; B1H3, V2: B2H1; B2H2; B2H3, V3: B3H1; B3H2; B3H3

4. Conclusions

The present study shows that significant differences were recorded in terms of growth performance between the three experimental variants. Both final height of plants and leaf area were influenced by plant stocking density and therefore by water nutrients availability. It was also observed that spinach–*Matador* variety, growth in aquaponic integrated systems, has a better growth performance and also a better quality than spinach–*Nores* variety, from other similar studies. No signs of stress were observed among the experimental variants. Also, it can be concluded that hydroton used as media support for growing spinach in aquaponic conditions gives better results than floating rafts techniques, used in previous studies, by improving plants growth and quality parameters and as a consequence, their suitability for being cultured in integrated aquaponic systems.

Crops from V3 had an accelerated leaf area growth rate, fact revealed by LAI values. Regarding health condition, better results were found in V3 experimental variant, by taking into consideration the root–shoot ratio.

Regarding plants quality, ash and dry matter percentage emphasizes the fact that the content of fats, proteins, vitamins, minerals and antioxidants from all the experimental variants are higher than those of market spinach, except V1, the variant with the highest crop density, where ash values were smaller. Regarding chlorophyll *a* and *b* content, the highest values were observed at V3 variant, the one with the smallest crop density. Also, the chlorophyll values for spinach growth in aquaponic conditions, in current experiment, were higher than those of market spinach, except V1 experimental variant, where the values were nearly the same with those of market spinach.

Therefore, it can be concluded that plants growth in aquaponic condition are similar, or even better if proper densities are used, in terms of quality to those growth in field. Also, the constant continuous flow hydraulics technique, collaborated with using hydroton media as support for plant grow and a proper effluent physico-chemical parameters, derived from stellate sturgeons aquaculture activity, leads to a better growth and quality of spinach–*Matador* variety, comparing with market spinach, obtain in classical soil culture conditions. In case of our integrated aquaponic system, all three tested plant stocking densities give good results, assuring a marketable quality of final products. Also, it must be mentioned that, comparing all three stocking densities, the best growth and quality results for crops were obtained at 39 plants/m^2.

These findings will be useful in the build-up of an artificial equilibrium aquaponics ecosystem, in balancing the specific ratios for plant/fish/feed and in integrating aquaponic system based on hydroton media support technique.

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