The influence of two different lights intensities on cleaning capacity and productivity in aquaponic filter part of biological filtration in recirculation aquaculture system

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Abstract. Aquaponics is sustainable technology where fish and plants are cultivated in integrated recirculation system. In this innovative technology the meaning of light on the cleaning capacity and plants productivity in aquaponic section is still remained not very well studied. In the current study we hypothesized that the higher light intensities would increase the cleaning capacity and plant productivity in aquaponic section of the system. The aim of current research was to retrace the effect of two light intensities (54.8±2.59 and 35.5±3.2 w m^{-2}), received respectively by the addition of artificial light (fluorescent tubes) and natural light condition on nitrogen and phosphate compounds in water, as well as on the plant's productivity in aquaponics raft system as a part of recirculation aquaculture system. The trial was conducted in greenhouse where temperature and humidity was controlled with air conditioner and fans. The aquaponic system consisted from 10 fish tanks followed by mechanical (sedimentation tank), biological filter (moving bed biofilter), sump and 8 raft aquaponics tanks. Three plant growth promoting lamps FLUORA T8 (18 w, Osram Fluorescent Fluora Tubular Linear Lamp) were used as a source of additional artificial light. The lamps were turned on at 6.30 am and stopped at 6.00 pm. For the second light regime natural light condition without additional artificial light was used. At the end of trial the growth of cultivated fish and lettuce was measured as well as hydrochemical parameters. The final weight in trout, cultivated in the system was higher with 52.8%, compared with the value in this parameter found out for the rainbow trout at the start of the trial. The average concentration of ammonium was lower with 11.6% compared with its value measured for aquaponic raft systems, where plants were exposed to natural light conditions and the difference was significant ($p < 0.05$). The artificial light positively affected also cleaning capacity of aquaponic filter, concerning average concentration of nitrates and phosphate and they were lower, respectively with 4.54% and 18.3% compared with the average concentration in these parameters found out for the aquaponics filter exposed to only natural light. The made measurement in the end of trial showed that the lettuce cultivated in aquaponics filter exposed to additional artificial light had higher yield and length of roots and they were higher, respectively with 2.29% and 5.7%, compared with the values in these parameters found for plants cultivated in aquaponics filter exposed only on natural light, but the differences were not statistically significant ($p \geq 0.05$).

Key Words: RAS, aquaponics, light intensities, hydrochemical parameters, lettuce and rainbow productivity.

Introduction. World aquaculture production increased from 31.1 to 44.1% of total production from capture fisheries and aquaculture (FAO 2016). The products produced from aquaculture are important source of protein for humans. Unfortunately together with the important role could play this industry in fight against hunger worldwide the aquafarm's effluent could be serious source of pollution for natural water basins (Valkova et al 2015; Valkova et al 2016).

The systems in which the water is partially reused after its treatment process are calling recirculation aquaculture systems (RAS). These systems could decrease the negative impact of aquaculture on natural ecosystem. Recirculation aquaculture systems are sometimes referred to as 'urban' aquaculture (Martins et al 2010) and could be organized directly in the cities, decreasing this way the costs and pollution due to the transportation of aquaculture products.

In most of the cases the water treatment process in RAS are sediment removal and nitrification process (Thanakitpairin et al 2014). The removal of solids includes mainly two possible processes - sedimentation and physical filtration (Timmons & Ebeling 2007).

The fish feed contains high level of protein (25-65%), considerable part of it is assured by the usage of different plants with high nutritional value according to the new tendencies in fish nutrition (Kirjakov & Velichkova 2016; Velichkova 2019). Unfortunately only 25% of protein nitrogen is assimilated in fish (Yogev et al 2017). The most amount of total ammonia nitrogen (TAN) is treated by aerobic nitrification. During this biological filtration the nitrate and phosphorus are only removed partially and non-toxic levels are supported in RAS by water exchange (20-40% system volume per day) (Hu et al 2012). One possible filter system which could decrease the nitrate and phosphorus quantities in RAS is aquaponics. Aquaponics is a sustainable technology where fish and plants are cultivated in integrated recirculation system (Graber & Junge 2009). In this innovative technology the water quality in the recirculation system is highly dependent from disposal capacity of plants.

Since the quality of light affects the photosynthesis and plant growth, the different light's intensities may also affect the water quality in the system. The study made by Liang & Chien (2013) which retrace the effect of photoperiod in aquaponics system showed lower accumulation of all nitrogen and phosphate species in water, 2.4% higher fish growth, 12% higher plant growth at 24-h light regime compared with the values in these parameters received from 12-h light regime. The studies connected with the effect of different light intensities in aquaponics are missing up to now. We hypothesized that the higher light intensities would increase the cleaning capacity and plant productivity in aquaponic section of the system.

The aim of current research was to retrace the effect of two light intensities (54.8±2.59 and 35.5±3.2 w m^{-2}) received by the addition of artificial light (fluorescent tubes) and natural light condition on nitrogen and phosphate compounds in water as well as on the plant's productivity in aquaponics raft system as a part of recirculation aquaculture system.

Material and Method

Experimental fish. The trial was conducted from April to May 2018. One hundred rainbow trouts (*Oncorhynchus mykiss*) in good health condition without visible injuries were chosen and transferred from fish farm Ichtyo 2008 (Peshtera) to experimental aquaponics system situated at newly built greenhouse (Aquaculture experimental base, Trakia University, Stara Zagora, Bulgaria). The fish prior the starting of experiment were acclimated at aquaponic system for one week. The stocking density of rainbow trout was 33 pcs m^{-3}. The average initial trout's weight was 109.8±2.19. The fish weight was measured at start, middle and end of the experiment. The specific growth rate (SGR) of rainbow trout was calculated with the equation:

$$SGR = \left[\frac{lnBf - lnBi}{t}\right] * 100$$

where: SGR = specific growth rate of rainbow trout;
Bf = final biomass;
Bi = initial biomass;
t = time interval (days).

The rainbow trout were fed 3 times per day manually. The daily feed ratio was maintained at 2% from total fish biomass. The content of commercial feed which was used during the trial could be seen in Table 1. The size of granules used for feeding of trout during the trial was 3 mm.

Table 1

The content of commercial feed Aqua uni (according Aqua Garant®)

Ingredient	*Unit*	*Content*
1. Protein	%	45
2. Fat	%	16
3. Fibers	%	2.0
4. Phosphorus	%	1.0
5. Vit. A	I.U.	10000
6. Vit. D3	I.U.	1500
7. Vit. E	mg	200
8. Digestable energy	MJ	18.5

Experimental greenhouse. The continuation of the experiments was two months. The greenhouse with dimensions 10/3/2 m made from polycarbonate sheets was used in current experiment (Figure 1). The air circulation and reduction of humidity was assured by two fans, with capacity 1150 m^3 h^{-1}. The humidity in greenhouse was continuously maintained in range from 48.9 to 59.4% RH. The control of temperature condition in greenhouse was done by air conditioner (Fujitsu AOYG30LFT). The temperature in greenhouse was maintained at 21.1±1.1°C. The control of temperature and humidity was made by portable multiple environmental station (Voltcraft®).

Figure 1. The greenhouse, where experimental aquaponics system is situated.

Recirculation system connected with aquaponics raft system (RAS). The recirculation system consisted from 10 fish tanks, followed by mechanical (sedimentation tank), biological filter (moving bed biofilter) and sump, connected throughout the pump Initial Waste 14.9 (Wilo®) with the raft aquaponics tanks and the fish tanks (Figure 2). The volume of each fish tank was 300 L. The sedimentation tank was fulfilled with plastic lamellas which decrease the water's speed and assist the settling down of suspended solids. The moving bed biofilter was fulfilled with 0.08 m^3 media (plastic rings), which give 48 m^2. The volume of sedimentation tank, biological filter and sump was 1 m^{-3} each. The aquaponics raft system consisted from 8 raft tanks (Figure 2). Raft tanks were with dimensions 1/0.50/0.25 m. In each raft tanks polystyrene sheet with dimensions 0.95/0.45/0.05 m were floating on the water surface. The flow rates in fish and raft tanks were maintained respectively at 1.5 and 0.5 L min^{-1} and assured with the usage of spherical valves. The cultivation vessels as well as biological filter were aerated with two aerators. The favorable water temperature in fish tank and raft was assured by two heaters with 2000 w power submersed in the sump connected with controller with temperature probe. The 18°C water's temperature was assured during the trial.

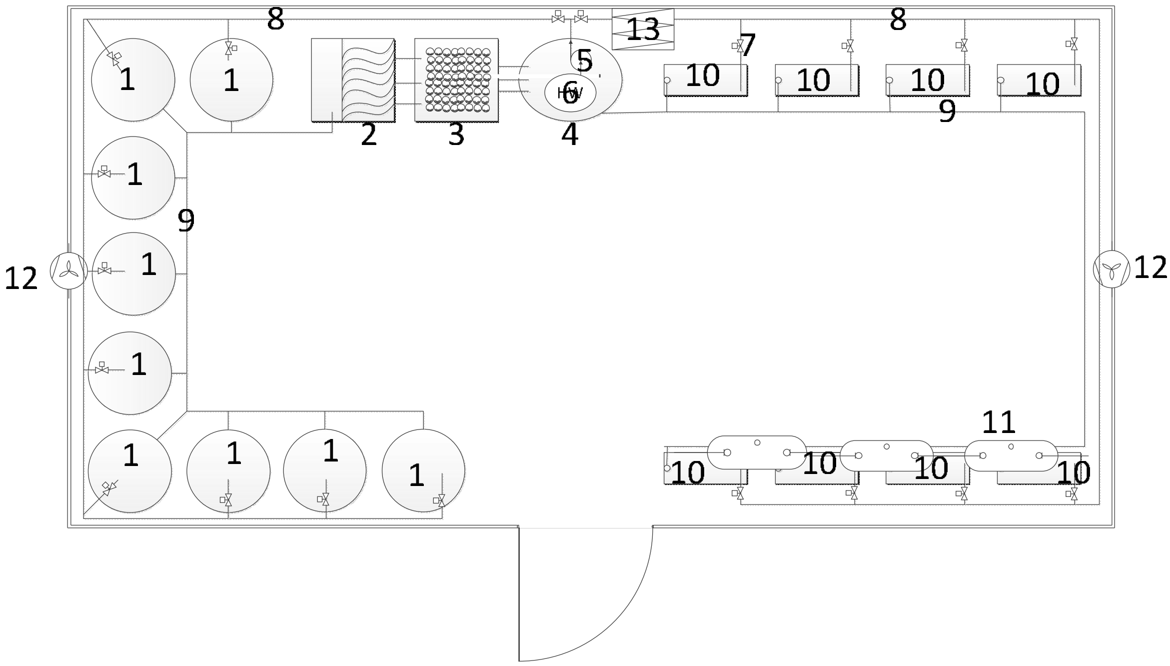

Figure 2. Experimental recirculation aquaponics system: 1) fish tanks; 2) sedimentation tank; 3) moving bed biofilter; 4) sump; 5) pump; 6) water heaters; 7) valve; 8) inlet water; 9) outlet water; 10) raft tanks; 11) fluorescent lamp; 12) fan; 3) air conditioner.

Experimental light regimes. Two experimental regimes tested in current trial were with the average values 54.8±2.59 and 35.5±3.2 w m^{-2}. The first one was assured with additional artificial light. Three plant growth promoting lamps FLUORA T8 (18 w, Osram Fluorescent Fluora Tubular Linear Lamp) were used. The lamps were turned on at 6.30 am and stopped at 6.00 pm. For the second light regime natural light condition (approximately 13 h per day) without additional artificial light was used. The average light intensities were measured with light probe connected to portable multiple environmental station (Voltcraft®).

Hydrochemical parameters. The concentration of nitrogen (ammonium and nitrate) and phosphorus (ortho-phosphate-phosphorus) compounds were measured with spectrophotomer DR 2800 (Hach Lange®) every 10 days respectively with cuvette test LCK 304, LCK 339 and LCK 348 (Hach Lange, 2007).

Experimental plants. For the trial 96 lettuce seedlings (15 day old *Lactuca sativa* variety "Jylta krasavica") were chosen and transported from greenhouse situatetd at Plovdiv district. The plants were transplanted at hydroponic pots filled with expanded clay aggregate (LECA®). The micronutrients for plants were assured by foliar application of at the dosage according to producer (B-essentials®, General Hydoponics).

At the end of the trial the fresh weight of lettuce was measured on technical balance with 0.01 g accuracy. The length of roots (cm) in experimental plant was also measured.

Data analysis. The data received from the trial were statistically analysed by STATISTICA 6.0 software (StatSoft Inc., 2002).

Results and Discussion

Growth parameters of rainbow trout, cultivated in aquaponics recirculation system. The growth parameters of rainbow trout during the experiment were shown in Table 2. The survival of rainbow trout was high – 90%. The cases of mortality in experimental fish were observed in the first two weeks of the experiment probably due to the short period of acclimatization – one week. The weight of fish in the middle of the trial was higher with 1.32 times compared with the initial weight of rainbow trout. It was observed that intensity of growth decreased with 12.9% in the second part of trial compared with the value of this parameter found out for the first part of the trial. The influence of light in aquaponic filter on the fish during the trial was not possible to retrace, because the water from both experimental variants were mixed and pumped to fish tanks. Specific growth rate in experimental fish was 0.7 % body wt. gain day^{-1}.

We suggest that the registered mortality in rainbow trout did not result from the specific disease and conditions in tested aquaponics system but could be associated with high sensitivity of fish by handling and transportation. According to Möck & Peters (1990), in their experiment the activity of lysozyme returned to normal level within 2 weeks following confrontation with the stressor, which correspond to time in which the cases of mortality in rainbow trout were observed in the present study.

Table 2

Growth parameters in rainbow trout during the trial

Growth parameter	$x \pm Sx$
Survival (%)	90
Initial weight (g)	109.8±2.19
Fish weight in the middle of the trial (g)	145.8±4.11
Final weight (g)	167.8±2.77
Specific growth rate (% body wt.gain.day^{-1})	0.7±0.06

Cleaning capacity of aquaponics filters exposed to the different light conditions. The concentration of ammonium, nitrate and phosphate were used for determination of cleaning capacity of aquaponic filter exposed to the different light conditions (Figures 2, 3, 4). The average concentration of ammonium was lower with 11.6% compared with its value measured for aquaponic raft systems where plants were exposed to natural light conditions and the difference was significant ($p < 0.05$) (Figure 2).

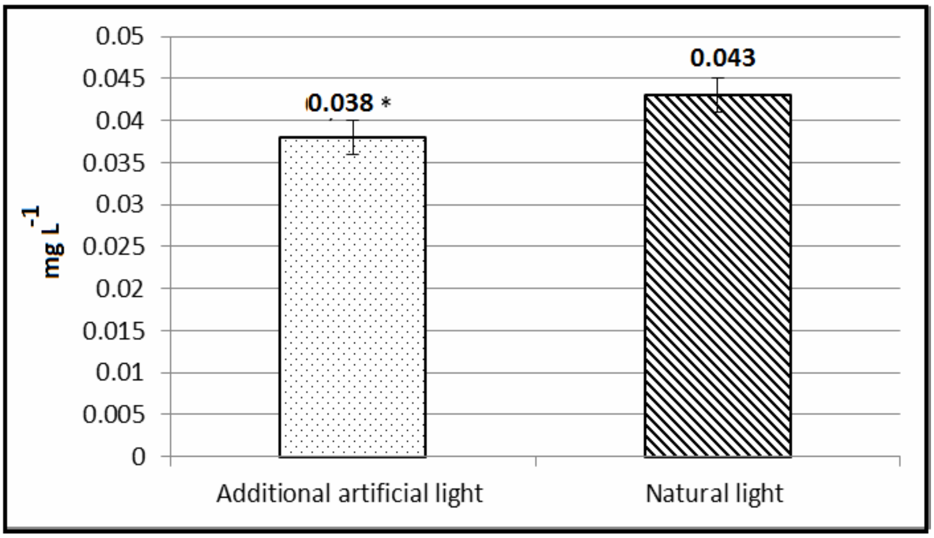

Figure 2. Concentration of ammonium in experimental aquaponic filters.

The artificial light positively affected also cleaning capacity of aquaponic filter, concerning average concentration of nitrates and phosphate and they were lower, respectively with 4.54% and 18.3%, compared with the values of these parameters found out for the aquaponics filter exposed to only natural light. The differences were statistically significant for nitrate concentrations ($p < 0.05$) and for phosphates quantities ($p < 0.01$) (Figures 3, 4).

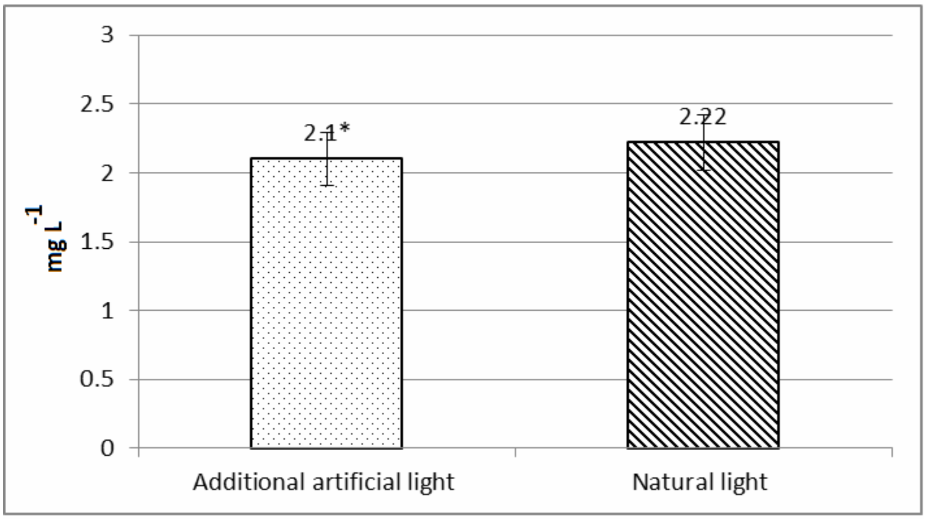

Figure 3. Concentration of nitrate in experimental aquaponics filters.

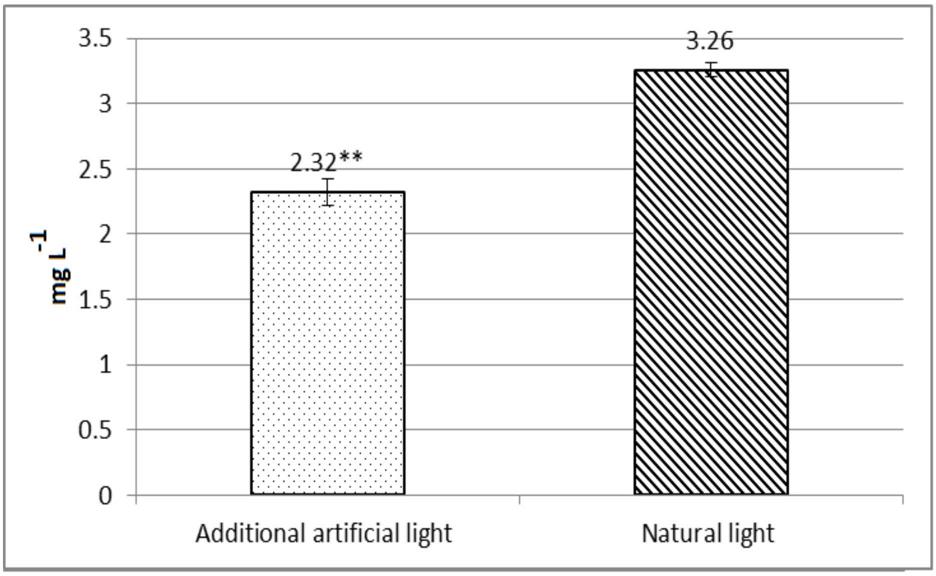

Figure 4. Concentration of phosphate in experimental aquaponics filters.

The concentration of ammonium was retraced because the fish are highly sensitive to this hydrochemical parameters and even minimal quantity of this compound could cause decrease of growth in fish. The content of nitrogen compounds are increasing with the time in classical recirculation system (Hu et al 2012).

The plant growth and development are affected from intensity of light and spectral composition because they impact a number of different processes, also including nutrient uptake (Hogewoning et al 2010). Photosynthesis is a biochemical process where light energy is using to produce ATP and NADPH, ultimately consumed in the assembly of carbon atoms in organic molecules. The photons from light are accumulated by protein-chlorophyll (Chl)-carotenoid complexes and then transferred to the photosystem reaction centre, where electrons are generated. These processes take place in the chloroplast (Darko et al 2014). According to Solymosi & Schoefs (2010) if lighting is too weak, photosynthesis cannot work efficiently and etiolation symptoms appear. From other side, high level of light could generate oxygen radicals that could cause photoinhibition. Both phenomena strongly limit primary productivity (Barber & Anderson 1992).

***Plant's productivity of aquaponics filters exposed to the different light conditions*.** The additional artificial light in current study did not affect the productivity of cultivated plants in aquaponics filter in term of lettuce growth (Figures 5, 6). The made measurement in the end of trial showed that the lettuce, cultivated in filter exposed to additional artificial light had higher yield and length of roots and they were higher, respectively with 2.29% and 5.7% compared with the values in these parameters found for plants cultivated in aquaponics filter exposed only on natural light, but the differences were not statistically significant ($p \geq 0.05$) (Figures 5, 6).

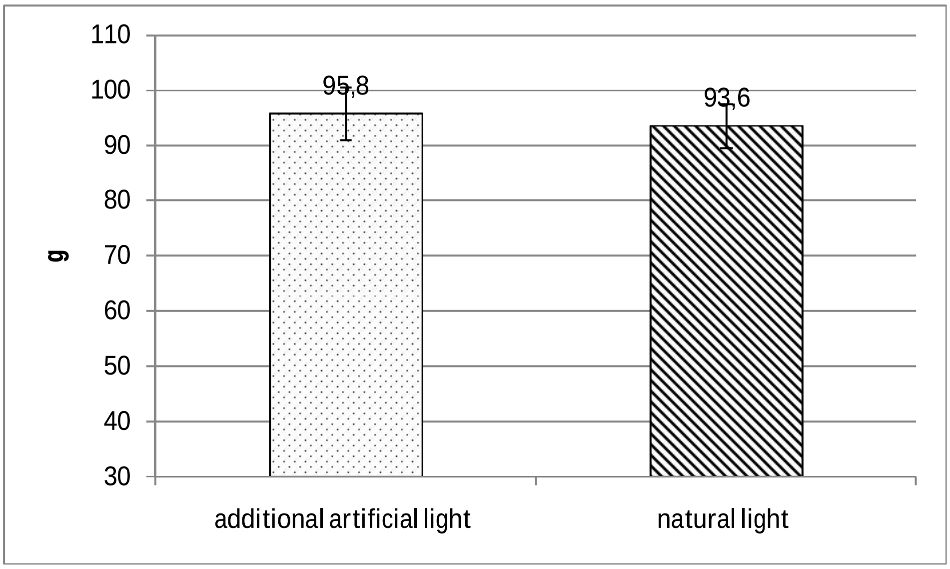

Figure 5. Yield of lettuce in the end of the trial.

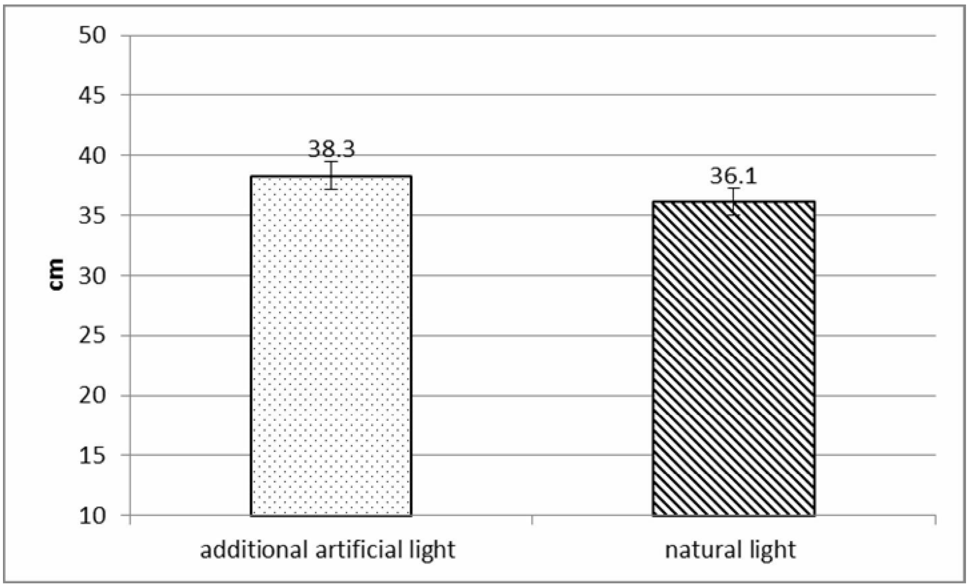

Figure 6. Length of lettuce's roots in the end of the trial.

Lettuce is used very often as a model plant in studies investigating the influence of light, because this plant is sensitive to different light intensities and vegetation period is short as well as it is one of the most cultivated plants in greenhouses worldwide (Dougher & Bugbee 2001). Johkan et al (2010) stated that development of plant is strongly influenced by the light quality, which is depending of color or wavelength reaching a plant's surface. Liang & Chien (2013) showed that increased photoperiod positively affect spinach productivity when this plant was cultivated in aquaponics. Our results did not confirm that higher intensity of light during the cultivation of lettuce in aquaponic increase its productivity, mostly possible because the trial was conducted during the period of April-May 2018. During this period the quality of natural light conditions was good enough for the development of cultivated culture. The number of cloudy days during the trial period was also minimal. Other trials should be conducted during the late autumn and winter when the light conditions are worse and the number of cloudy days is higher.

Conclusions. Additional artificial light assuring light intensity of 54.8±2.59 $w.m^{-2}$ on the plant surface affected significantly cleaning capacity of aquaponic filter in relation of its removing capacity of ammonium, nitrates and phosphate compounds but did not influenced yield and length of roots in lettuce (*Lactuca sativa*) cultivated in aquaponics.

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