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ARAŞTIRMA MAKALESİ **RESEARCH PAPER**

Effects of Liquid Vermicompost Usage on System Operational Success in Aquaponic Systems

Abidin KÜÇÜKAĞTAŞ[1]* **İlker Zeki KURTOĞLU[1]***
[1] *Recep Tayyip Erdoğan University, Faculty of Fisheries, 53100 Rize, Türkiye*

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*: https://orcid.org/0000-0002-4214-7997
: https://orcid.org/0000-0002-4500-7009

***Corresponding author's:**
İlker Zeki KURTOĞLU
Recep Tayyip Erdoğan University, Faculty of Fisheries, 53100 Rize, Türkiye
✉: ilker.kurtoglu@erdogan.edu.tr

Abstract: In this study, it was aimed to supplement the insufficient plant nutrients in the system water and to develop healthier plants in the aquaponic system. For this purpose, liquid vermicompost, which is identical to nature and whose nutritional value has been proven in many studies, was used. In the experimental designed as indoor aquaponic system, the effects of liquid vermicompost sprayed on the leaf (VL) and directly added to the water (VW) on fish/plant/water quality were examined. Liquid vermicompost was not added to the control group (C). A total of 225 juvenile *Cyprinus carpio* were placed in 9 experimental systems with 25 fish in each tank, in this experiment. As the fish species, juvenile carp individuals were used with an average total length of 11.67±1.07 cm and an average weight of 22.82±7.97 g. A total of 11 plant seedlings were planted in each system, consisting of 5 peppers, 2 lettuce and 4 beans. Each system was illuminated with a light intensity of 171.25 μmol/m^2/s for activate plants growth. The 1 ml/L of liquid vermicompost was sprayed to water and leaves for the VW and VL groups, respectively. No additional supply was provided to the C groups. The system water quality parameters of oxygen saturation, temperature, pH, conductivity were measured daily, and parameters of ammonia, nitrite, nitrate, phosphate and turbidity were measured in 15-day periods for 90 days duration. The results showed that concentration of liquid vermicompost (VC) selected as sufficient amount for plants sprayed either on leaves or in water did not adversely affect water quality in aquaponic systems. Therefore, the use of vermicompost by adding VC to aquaponic system water has been supported to compensate essential plant nutrients.

Keywords: Indoor aquaponics; liquid vermicompost, plant cultivation; sustainable aquaculture.

Sıvı Solucan Gübresi Kullanımının Akuaponik Sistemlerde Sistem İşletim Başarısı Üzerine Etkileri

***Sorumlu yazar:**
İlker Zeki KURTOĞLU
Recep Tayyip Erdoğan University, Faculty of Fisheries, 53100 Rize, Türkiye
✉: ilker.kurtoglu@erdogan.edu.tr

Öz: Bu çalışmada, akuaponik sistem suyunda yetersiz olan bitki besin maddelerinin takviye edilmesi ve sistemde daha sağlıklı bitkilerin geliştirilmesi amaçlanmıştır. Bu amaçla doğayla özdeş, besin değeri birçok çalışma ile kanıtlanmış sıvı solucan gübresi kullanılmıştır. İç mekan akuaponik sistem olarak tasarlanan deney düzeneğinde, yaprağa püskürtülen sıvı solucan gübresinin (VL) ve suya doğrudan eklenen sıvı solucan gübresinin (VW) balık/bitki/su kalitesine etkileri incelenmiştir. Kontrol grubuna (C) sıvı solucan gübresi eklenmemiştir. Bu deneyde, her tankta 25 balık olacak şekilde toplam 225 adet yavru *Cyprinus carpio* 9 deney düzeneğine yerleştirilmiştir. Ortalama balık boyu 11,67±1,07 cm ve ortalama balık ağırlığı 22,82±7,97 g olan yavru sazan bireyleri kullanılmıştır. Her sisteme 5 adet biber, 2 adet marul ve 4 adet fasulye olmak üzere toplam 11 adet bitki fidesi dikilmiştir. Her sistem bitki büyümesini aktive etmek için 171,25 μmol/m^2/sn ışık yoğunluğuyla aydınlatılmıştır. 1 ml/L sıvı solucan gübresi VW ve VL grupları için sırasıyla suya ve yapraklara püskürtülmüştür. C tanklarına ek bir vermikompost takviyesi yapılmamıştır. 90 günlük süre boyunca, sistem su kalitesi parametrelerinden oksijen doygunluğu, sıcaklık, pH, iletkenlik günlük olarak ve amonyak, nitrit, nitrat, fosfat ve bulanıklık parametreleri 15 günlük periyotlarda ölçülmüştür. Sonuçlar, bitkiler için yeterli miktarda seçilen sıvı vermikompost VC konsantrasyonunun yapraklara veya suya püskürtülmesinin akuaponik sistemlerde su kalitesini olumsuz etkilemediğini göstermiştir. Bu nedenle, akuaponik sistem suyuna VC eklenerek solucan gübresi kullanımı, temel bitki besin maddelerini telafi etmek için desteklenmiştir.

Anahtar kelimeler: Bitki yetiştiriciliği; iç mekan akuaponik sistem; sıvı vermikompost; sürdürülebilir akuakültür.

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INTRODUCTION

Urban life is increasingly shifting towards city centers where vertical living, characterized by multi-story apartment buildings, is becoming more concentrated. In particular, aquaculture investments operate in terrestrial areas where water quality is much better and cleaner (Minaz&Kubilay, 2021; Minaz et al., 2024). Water quality in aquaculture tends to deteriorate where sources are close to densely populated urban areas. In areas where quality and quantity are limited, the use of recirculating systems, which aim to reuse water by passing it through mechanical, physical and chemical processes such as filtration and disinfection, has become widespread. Biological filtration units placed in such systems ensure the reduction of dissolved nitrogenous nutrient molecules coming from fish farming in the water. Toxic molecules reduced to less toxic molecules through bacterial activity in biofiltration and increased plant nutrients in the system offers a significant advantage for plant cultivation, as in hydroponic systems. To benefit from these valuable nutrients emerging in recirculating aquaculture systems, integrated aquaponic systems with plant cultivation have been popular over the last few decades. Aquaponic systems are an integrated recirculating system consisting of a combination of hydroponic system and aquaculture system. One of the most important basic purposes of plant cultivation in aquaponic systems is to ensure that the plant uses nutrients and minerals such as nitrogen and phosphorus compounds in the system water, thereby improving the bio-physical structure of the system water (Estim et al., 2019).

Aquaponic systems have become an increasingly favored environmentally friendly animal and plant production technology in Turkey, as well as globally (Hu et al., 2012; Diver, 2006). Fish and plant species with high economic value are preferred in aquaponics applications. Different species have been frequently observed in aquaponic systems in terms of both fish culture and plant cultivation (Tidwell, 2012).

In aquaponic systems monitored for 90 days, the group with the highest plant density exhibited the best removal of nitrogen compounds and the best plant and fish growth (Makhdom et al., 2017). The importance of oxygen supplementation in providing oxygen content to plants in deep water culture applications used as plant beds in aquaponic systems has been highlighted (Yiğit, 2019). The use of synthetic fertilizers in plant production has been reported to pose significant threat to the natural sustainability of the fish component of the system (Turhan, 2005). Instead, vermicompost obtained through the biotransformation of organic waste with a zero-waste approach is becoming increasingly widespread in plant production (Şahin et al., 2020). Liquid vermicompost obtained by composting of solid worm castings, is delivered to plants in plant production either through drip irrigation or foliar fertilization. It has been reported that the nutrient-rich mixture produced by the biotransformation of vermicompost with microorganisms originating from the worm's body cavity successfully nourishes plants and protects them against various plant pests (Kiliç & Saraçoğlu, 2022).

In the literature, the use of liquid vermicompost to support plant nutrition and its use in agricultural activities in Turkey and around the world due to its natural effects in addressing structural disturbances in soil for plant cultivation has been the subject of numerous studies. However, no study related to the application of liquid vermicompost to plant roots via water or direct foliar spraying in aquaponic systems has been found in the literature. In aquaponic systems, the distribution of plant nutrients is generally limited due to fish cultivation. In intensive aquaponic practices, synthetic plant nutrients are used. This study aims to test the effectiveness of liquid vermicompost, which has proven to be valuable for plant growth, in aquaponic systems.

MATERIAL AND METHOD

Experimental Design: The study was conducted at the Fisheries Application and Research Center of Recep Tayyip Erdoğan University. A total of nine aquaponic systems with similar system components were used. Each system consisted of 3 glass aquariums with dimensions of 57.5 cm in width, 111 cm in length, and 40 cm in height. Each aquarium had a total volume of 255.3 liters.

Aquaponic systems, which have become widespread in recent years, are complex systems consisting of the combination of RAS (Recirculating Aquaculture Systems) systems, which aim to use much less water than flowthrough systems and "Hydroponic Systems". In this study, the basic components of aquaponic systems, which are fish tanks, plant beds, mechanical and biological filtration, pumping structure that provides water circulation, compressor ventilation to ensure that the oxygen needed for the living components of the system is absorbed from the air to the water, and to remove carbon dioxide from the water resulting from respiration, were created as basic components. Unlike other systems, artificial lighting with daylight quality was provided to the test setup carried out in indoor conditions.

The experimental setup included three groups of these systems, arranged in a three-tier configuration: a plant bed at the top, a fish tank in the middle, and a sump filter system at the bottom (Figure 1).

The water depths and volumes for each component were designed as follows:

•Plant Bed: Depth of 11 cm, water volume of 70 L.

•Deep Water Plant Bed (Floating System): Depth of 34 cm, water volume of 217 L.

•Fish Tank: Depth of 24 cm, water volume of 153 L.

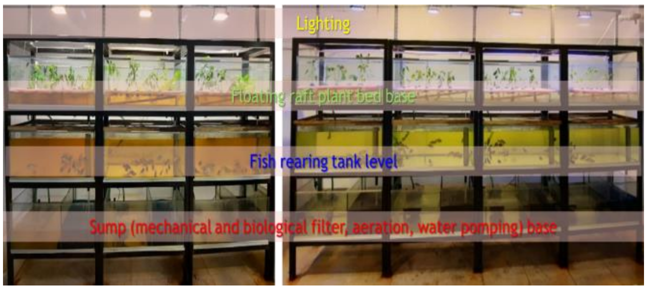

Figure 1. Control (C), Vermicompost from leaves (VL) and Vermicompost from water groups (VW) established in indoor conditions in this experiment.

The total water volume for each aquaponic system was 440 L. Well water was used as fresh water in the system. The water collected in a reservoir was thoroughly aerated and then added to the system as needed. Well water was used as fresh water in the system. Water collected in a reservoir was thoroughly aerated and then added to the system as needed. The quality of the aerated water ready to be given to the system is presented in Table 1.

Table 1. Measurements of aerated well water quality parameters used to compensate for water lost from evaporation and filter cleaning.

Measured Value	Measured Value
Water Temperature (°C)	17°C
pH	7.22
Nitrite (mg/L NO_2)	0.006
Nitrate (mg/L NO_3)	8.8
Phosphate (mg/L PO_4)	0.16
Ammonium (mg/L NH_4)	<0.03
Conductivity (µS/cm)	206.9
Salinity (‰)	0.10
Total Suspended Solids-TSS (mg/L)	2
Dissolved Oxygen (mg/L)	10.16
Dissolved Oxygen Saturation (%)	95.2
Total Hardness (mg/L $CaCO_3$)	89

Water circulation in the system was maintained using a VenusAqua P5200 circulation pump, while aeration was provided by a central blower system in the sump. The systems were supported by a central generator, ensuring no power outages during the 90-day experiment.

For filtration, a system consisting of aquarium filter sponges dimensions 50 × 50 × 5 cm was used, providing a total filtration volume of approximately 62.5 dm^3 with a surface area of 46.5 m^2 for mechanical and biological filtration. The lighting system was adjusted for indoor conditions, with a 16L:8D light/dark cycle corresponding to the region's longest daylight hours. ATLANTIS A3619 brand LED lamps were used, delivering useful light to the plants with a calculated Photosynthetic Photon Flux Density (PPFD) of 171.25 µmol/m²/s.

Fish and Plant Materials: The fish used in the study were common carp (*Cyprinus carpio*), sourced from the Amasya Yedikır Carp Reproduction Facility of the Ministry of Agriculture and Forestry, Turkey. Lettuce (*Lactuca sativa*) seedlings with edible leaves and pepper (*Capsicum annuum*) seedlings and bean seedling (*Phaseolus vulgaris*) with edible fruits were placed in the experimental aquaponic system. A total of 11 plants were planted in each system, consisting of 5 peppers, 2 lettuce and 4 beans.

Three different aquaponic system experimental groups consisting of three replications were created as follows:

•VW (Vermicompost to Water): Liquid vermicompost was added to the system water.

•VL (Vermicompost to Leaf): Liquid vermicompost was sprayed onto the plant leaves.

•C (Control): No liquid vermicompost was added to the system.

Preliminary trials were conducted to determine the concentration of liquid vermicompost that would not negatively affect fish and plants. At a concentration of 2 ml/L, slow swimming, reluctance to feed, and behavioral disturbances in vertical and horizontal water use were observed in the fish. This concentration also caused deterioration in lettuce leaves in the VL group. Although normal fish behavior was observed at a concentration of 1.5 ml/L, excessive turbidity in the tank water was noted. Therefore, a concentration of 1 ml/L, as recommended for hydroponic systems (Kiliç & Saraçoğlu, 2022), was deemed acceptable for fish behavior, system water turbidity, and plant growth. The composition of commercially available liquid vermicompost is given in Table 2.

Table 2. Content of SuperSol-Wormbomb brand liquid vermicompost approved label content (https://supersol.com.tr/wp-content/uploads/2023/09/WORMBOMB-ONAYLI-ETIKET.pdf).

Content Percentage	Ratio
Organic Matter (%)	15
TAN (Total Nitrogen) (%)	1.5
Organic Nitrogen (%)	1
Water-Soluble K_2O (%)	1
Total Humic+Fulvic Acid (%)	1.5
Maximum EC (dS/m)	5
pH	4.5-5.5

Monitoring of Water Quality Parameters: The surface of each aquarium is 63.8 dm^2, and the total surface area of three aquariums in a system is calculated as 1.9 m^2. The water evaporation from aquarium surfaces in the system was compensated with aerated fresh well water. It is calculated that an average of 0.68% of the system water loss is renewed daily. This low water replacement rate indicates that the system functions effectively as a Recirculating Aquaculture System (RAS), where more than 90% of the water is treated and reused (Bregnballe, 2022; Uğural et al., 2018).

System water quality parameters such as oxygen saturation, temperature, pH, conductivity were measured daily, and parameters such as ammonia, nitrite, nitrate, phosphate and turbidity were measured in 15-day periods. Oxygen saturation, temperature, pH and conductivity measurements were conducted using an Orion Star™ A329 multiprobe. Turbidity, dissolved metabolites such as ammonium, ammonia, nitrite, nitrate, and phosphate were analyzed using a HACH DR3900 spectrophotometer.

Statistical Analyzes: Water quality parameters were presented in mean ± standard deviation. Data obtained from the experiment were statistically interpreted and graphed using Excel and SigmaPlot 11.0 software packages. The normal distribution of groups was verified using the Kolmogorov–Smirnov test. Intra-group and inter-group differences were analyzed using t-tests and One-Way ANOVA tests. Results were considered significant at $p<0.05$. Through these methods, the study aimed to investigate the effects of liquid vermicompost application on the growth of fish and plants, as well as its impact on water quality parameters in aquaponic systems.

RESULTS AND DISCUSSION

Water Quality Monitoring

During the experiment, temporal measurements of ammonium, nitrate, nitrite, phosphate, temperature, pH, oxygen, conductivity (EC), and turbidity (NTU) values of the system waters were recorded. The averages of these measurements are presented in Table 3 ($p>0.05$). The nitrite values in the VW group were relatively higher than in the other groups, and the oxygen value in the C group was higher than in the other groups. However, in all three groups, nitrite and oxygen values did not reach levels that threaten fish welfare, similar to other water quality parameters ($p<0.05$).

Table 3. Water quality parameters according to experimental groups. VW: Liquid vermicompost sprayed to water, VL: Liquid vermicompost sprayed onto leaves, C: Control.

Groups	NH_4-N	NH_3-N	NO_2-N	NO_3-N	PO_4^{-3}-P	pH	O_2	EC µS cm^{-1}	Temperature(^{0}C)	Turbidity (NTU)
*VW	2.85±0.7	0.0019±0	0.03±0	38.4±2.1	3.9±0.1	6.03±0	7.45±0.1	672.62±43.3	23.51±0.3	3.07±0.6
*VL	3.25±0.8	0.0022±0	0.02±0	35.96±2.8	4.03±0.1	6.03±0	7.76±0.1	538.57±41.9	23.51±0.3	2.26±0.5
C	3.98±0.8	0.0027±0	0.02±0	37.56±3.9	3.93±0.2	6.05±0.1	7.49±0.1	622.07±52.2	23.51±0.3	2.30±0.3

The study was conducted in an enclosed environment on the ground floor of the building under the indoor conditions, so there were no instantaneous fluctuations in water temperature. In all three systems, the water temperature remained similar, ranging from 21.5 to 25.2°C throughout the trial period (Figure 2A). The measured water and air temperature was within the recommended range for the living components of the system, including common carp, bell pepper, beans, and lettuce (Eşiyok, 2012; Özkaplan & Balkaya, 2021). The experimental groups operating in closed recirculating aquaponic systems were observed to show a continuous decrease in water pH. Initially, the pH in the three experimental groups decreased similarly from 6.60 to around 5.60 on days 5, 6 and 7. The rapid decline in pH was attributed to the metabolic activities of fish and the activation of the bio-filtration. To address this, 14 g of sodium hydroxide (NaOH) was dissolved in 5 L of well water and added to the system water via given to the system by a trickle from the reserve, targeting a total volume of 440 L in the experimental tanks. This addition buffered the system water, raised the pH value back to 6.60 (Figure 2B). In closed-loop systems, the pH of the water is a crucial parameter for the ammonium/ammonia balance. It is known that when the pH rises above neutral levels, the less toxic ammonium molecule in the water converts to the more toxic ammonia (Serezli, 2011; Serezli et al., 2016; Minaz et al., 2022). During the initial periods of the study, pH remained at neutral levels in all groups due to carbon dioxide release and biochemical reactions from biological filtration, depending on the size of the fish. However, in later stages, there was a radical tendency for pH to decrease. Daily measurements showed a noticeable decline in pH, reaching levels as low as 5.63 after the fifth day. For Common carp farming, it is reported that the optimum pH range should be between 7.5-8.0, with a range of 6.5-9.0 considered acceptable (Mohale et al., 2020). For hydroponic systems, it is reported that the suitable pH range for plant growth should be between 5.5-6.8 (Mohale et al., 2020). To bring closer the declining pH value to the reported neutral level, sodium hydroxide (NaOH) was regularly added to the water to neutralize the system water. Thus, the pH value of the aquaponic water was maintained just below the suitable level of 7 for both the aquaponic system components for fish (Mohale et al., 2020) and plants (Tyson et al., 2004). The dissolved oxygen values in groups VW, VL, and C were measured as 7.45±0.1, 7.76±0.1, and 7.49±0.1 mg/L, respectively (Figure 2C). Water temperature and dissolved oxygen content are vital parameters for the growth of both fish and plants. The dissolved oxygen content of the circulating water in the system ranged between 6.95-8.27 mg/L at the outlet of the fish tank. It has been reported that a decrease in the dissolved oxygen content to 3 mg/L in Common carp farming, along with a tendency for water temperature to drop below 19°C, leads to decreased feed intake and consequently slows down growth. Additionally, as the water temperature rises above the limit of 30°C, it weakens the water's gas-holding capacity, increases microbial activity in the water, leading to oxygen consumption by decomposing activities, and increases metabolic oxygen demand in fish, causing stress (Mohale, 2020).

The electrical conductivity (EC) in the aquaponic system, initially increased to approximately 191.28 µS/cm due to the addition of vermicompost to the water, gradually decreased to a difference of approximately 128.94 µS/cm by the end of the study (Figure 2D). For successful plant development in the system, it is recommended that the electrical conductivity (EC) of the system water should not exceed 3000 µS/cm (Soliman et al., 2022). In the preliminary trial of determining the amount that would not harm fish and plants in the group to which liquid vermicompost would be added from water, the addition of 1 ml/L increased the system water EC value of VW groups to 504 µS/cm, while the initial EC values of C groups and VL groups increased only to 300-323 µS/cm measured. At the end of the trial, the EC values reached 1,004 µS/cm in the control groups due to fish feeding, 927 µS/cm in the leaf group, and 1,095 µS/cm in the group with liquid vermicompost added to the water. It was concluded that the reason why EC values of C and CL groups approached the VW group values was fish excretions and limited water exchange. The EC values reached in all three groups did not exceed the specified limit values for both fish and plants. Although there was a numerical difference in the EC values between the groups at the end of the study, statistical analysis found that the difference between the groups was not significant ($p>0.05$).

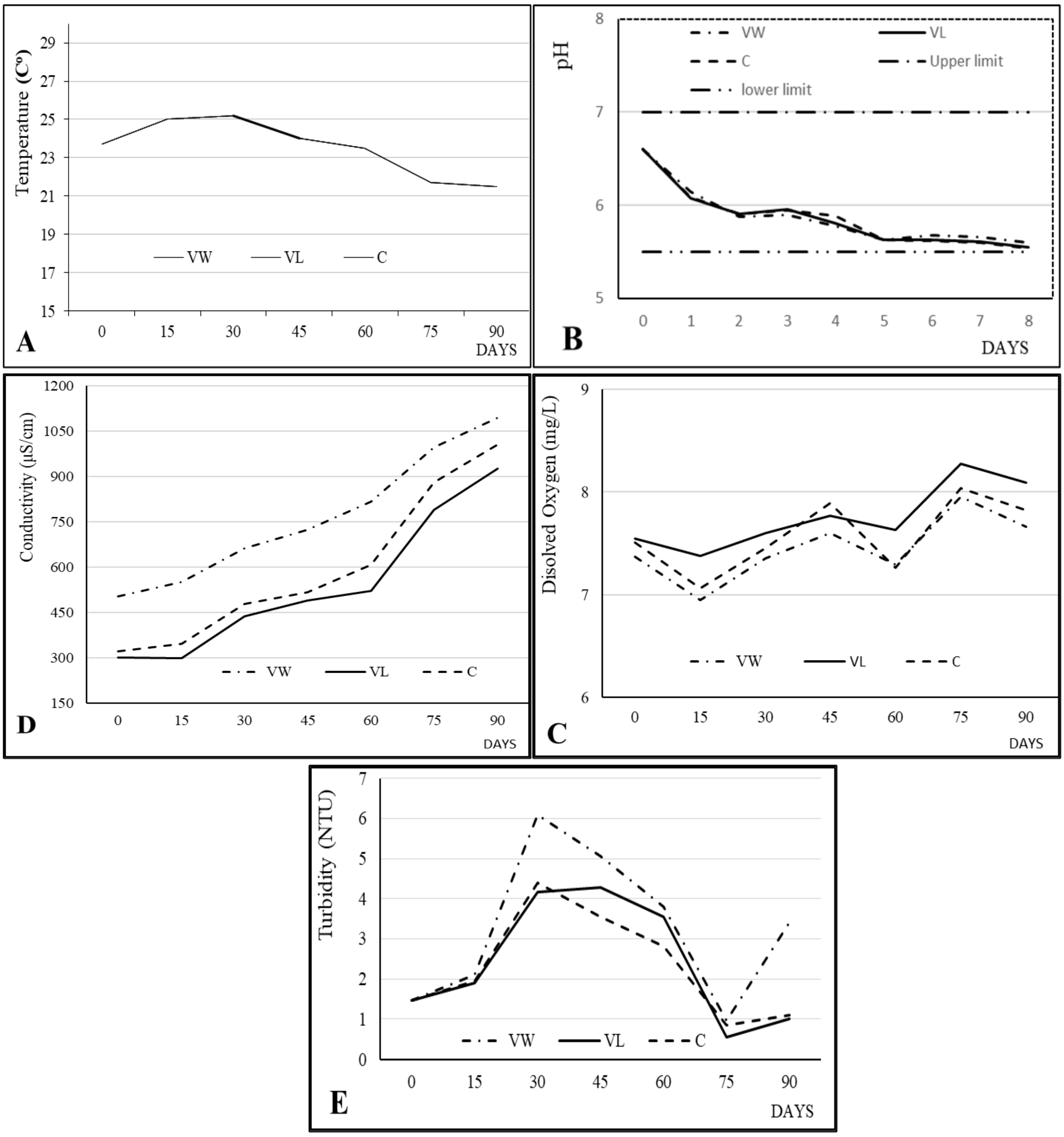

Figure 2. Water quality parameters changing depending on time. A: temperature, B: weekly pH, C: disolved oxygen, D: conductivity, E: turbidity.

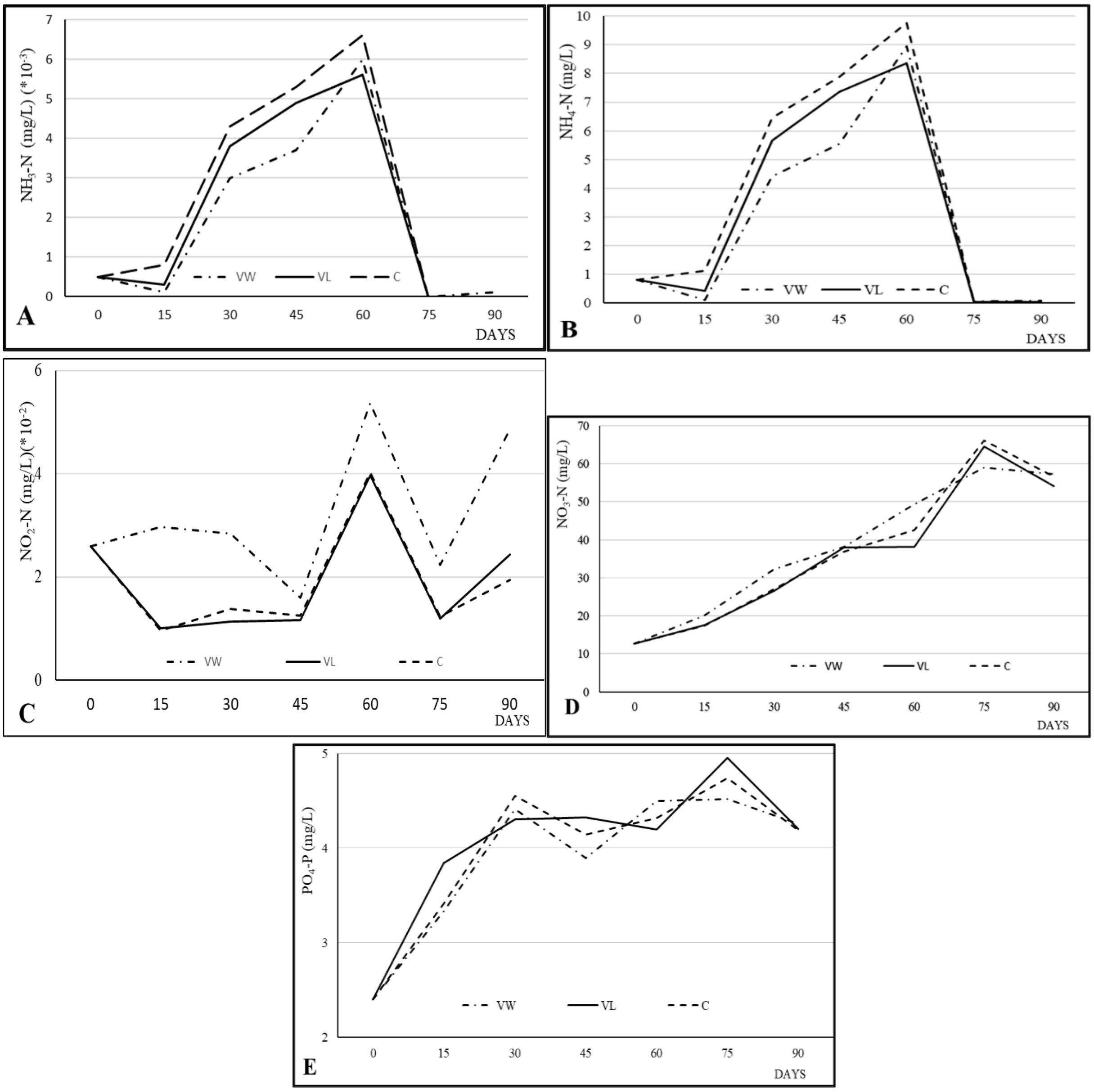

Figure 3. Water quality parameters changing depending on time. A: ammonia nitrogen, B: ammonium nitrogen, C: nitrite nitrogen, D: nitrate nitrogen, E: phosphate.

Throughout the study, the turbidity of the group with vermicompost addition was relatively higher compared to the other groups (Figure 2E). In all groups, the suspended solids (NTU) values measured during the study period were below the limit value of 10 mg/L (Çelikkale, 1988; Mohale et al., 2020) specified for aquaculture. The highest suspended load value was measured in the VW group as 6.09 mg/L NTU. In the VL and C groups, the change was lower than in the VW group, with similar changes in both groups during the study period. It was evaluated that the main reason for the relatively higher suspended solids in the VW group than the other two groups was the liquid vermicompost added to the system water.

Soluble metabolites in water are typically converted through the process of biofiltration, first into nitrites, and then into nitrates. This process is important to monitor the changes in nitrite and nitrate levels in water and ensure proper management. The temporal changes in the levels of ammonium, ammonia, nitrite, nitrate, and phosphate across groups VW, VL, and C are provided in Figures 3 A-E. The amount of toxic metabolites released into the aquaponic system as a result of digestion metabolism could limit the growth of fish. Although in fish farming, the parameters of ammonia and nitrite with high toxicity should ideally be below limit values of 0.02 mg/L for high fish welfare, it has been reported that tolerable values for both parameters in Common carp are <0.6 mg/L and <1-2 mg/L, respectively (Mohale et al., 2020). Under acute conditions, it has been reported that ammonia at a concentration of 2.33 mg/L can cause mortality within 96 hours, while under chronic conditions, concentrations ranging from 1.03-1.74 mg/L can lead to death in Common carp (Ebeling & Miller, 1995; Guan et al., 1986).

Additionally, it is known that ammonium, which is non-toxic below a pH value of 7 and has a significantly higher toxic threshold, rapidly converts to highly toxic ammonia as the water pH rises above the threshold of 7 (Hasan & Macintosh, 1986). While the measured ammonia levels were quite low in all groups at the beginning of the study, ammonia values began to rise from the second period onwards due to feeding. By the 90th day of the study, the highest concentration reached was 6.5×10^{-3} mg/L. Ammonium nitrogen, which is much less toxic, remained below toxic levels in all groups despite repeated measurements, with concentrations ranging from 8.0-9.7 mg/L on the 90th day of the trial. The consistent levels of nitrite values among the groups from the beginning of the study have been attributed to the success of the activated biofiltration system in biological conversion. The nitrate value reached its highest level on the 75th day of the study, reaching 66.4 mg/L.

In the study, the nitrite nitrogen (NO_2-N) concentration, which was at levels of 0.025 ppm in all groups at the beginning of the study, remained relatively higher in the VW group compared to the control group and VL groups until the end of the study. The relatively high nitrite value measured in the VW group was attributed to the Liquid Vermicompost added to the water. However, statistical analysis found that the difference in measured nitrite concentrations among the groups at the end of the trial was not significant ($p>0.05$). It was observed that the measured NO_2-N values in all groups were not at a level that could negatively affect fish welfare (Çelikkale, 1988; Mohale et al., 2020). Despite fish feeding in the groups and the additional supply of liquid vermicompost to the VW group, the reason for the measured nutrient values being quite low was considered the success of the biofiltration system in operation.

It has been reported that 182 mg/L nitrate nitrogen in temperate freshwater fish results in 50% mortality within 24-96 hours (Lewis & Morris, 1986; Mohale et al., 2020). Nitrate levels were 12 mg/L at the start of the study, reached similar levels of 58-65 mg/L in all groups on day 75, and began to decline to levels of 55-57 mg/L on day 90. While these levels may not adversely affect fish development, nitrate nitrogen, which is the form of nitrogen used by plants, was considered to be an effective level.

The phosphate content of the system water, which started at levels of 2.3 mg/L at the beginning of the study, reached its highest level like nitrate, on day 75 and ranged from 4.5 mg/L to 4.9 mg/L. When compared with previous studies regarding fish and plant development, phosphate levels were not found to be at levels that could cause stress (Çelikkale, 1988).

CONCLUSIONS

This study showed that adding enough liquid vermicompost to the aquaponic system water does not affect survival and development of the fish. Liquid vermicompost is known for its high nutritional value and high microorganism content. It has been observed that this characteristic makes it highly effective in promoting plant growth and health in aquaponic systems. Because of the addition of liquid vermicompost at a concentration of 1 mg/L did not exceed the threshold values for the physicochemical parameters of especially VW aquaponic systems water used in common carp rearing, it also did not cause significant changes in the physiological parameters of juvenile *C. carpio*, at a level that may adversely affect fish welfare. The addition of liquid vermicompost at 1.5 mg/L did not threaten the survival of the fish stock. However, it increased the turbidity of the system water, which reduced its visual appeal of the rearing tank water. This result showed that the use of liquid vermicompost in an aquaponic system to improve plant growth should not exceed a concentration of 1.5 mg/L.

Additionally, the development of lettuce plants, which represent leafy vegetables, yielded more positive results compared to pepper plants, which represent fruit-bearing plants. It was concluded that fruit-bearing plants, which require higher light intensities, need to meet elevated light requirements in indoor systems.

Adding liquid vermicompost directly to the aquaponic system water at a rate of 1 mg/L was found to be more successful in terms of plant growth. However, conducting the study under indoor conditions required artificial lighting. The use of aquaponic systems indoors has prevented reaching the level of industrial plant growth due to insufficient sunlight. It is highly likely that more successful plant development will be achieved in applications conducted directly under sunlight in a greenhouse environments.

In this study, Floating Raft Aquaponics plant beds were used in indoor conditions. In order to test the success of nutrients released by fish and artificially added enrichers in aquaponic systems in further studies, Flood and Drain Aquaponics, Gravel Bucket Aquaponics and Nutrient film technique (NFT) plant bed techniques should be investigated in outdoor greenhouse environments. Thus, the effect of liquid vermicompost on plant development will be revealed with different methods.

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