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Requirements for inserting intercropping in aquaponics system for sustainability in agricultural production system

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Abstract. In recent years, the recirculating aquaponics system has gained high attention and significant popularity for organic vegetables and fruits production which contributes to the sustainable aquaculture for tropical regions. This review aims to summarize the possibility for practicing intercropping in aquaponics to produce high-quality fruits, vegetables and fish without any chemical fertilizer and minimum ecological impact for a sustainable agriculture. Although many studies have addressed about aquaponics for producing high-value crops such as tomato, cucumber, and lettuce, there is still a lack of complete information to support the development of intercropping in aquaponics and limited focus on its commercial implementation. Moreover, this study will focus first on the requirements for inserting intercropping in aquaponics and technical improvements needed to adapt as potential for sustainable food production system to increase productivity around the world, especially in countries have deficiency in water and land resources as well as soil problem like salinity and reduce environmental emissions. Secondly, the insertion of intercropping in aquaponics must be for crops with high value and for crops that can complement together such as tomato with basil and tomato with lettuce. Thirdly, in technical improvement in this study will summarize the strategies and factors that affect the intercropping in aquaponics system such as the nutrients needed for crops under intercropping aquaponics, stocking density and feeding rate which are important to know the concentration of ammonia that is produced and converted to nitrate so that the plants can uptake it. Studying the requirements for inserting and improving intercropping in aquaponics will increase our understanding of needed for new agriculture technique that contributes to the sustainable aquaponics for tropical regions.

Key words: Intercropping, Aquaponics, feeding rate, feeding frequency, high crop value.

INTRODUCTION

Aquaponics is the integration or/and interlinking of conventional aquaculture with hydroponic plant production (Diver & Rinehart, 2010). Aquaponics can be considered as a sustainable food production method since it bridges the gap between production and consumption of fish around the world without depleting the non-renewable resources. The important characteristic of aquaponics designing systems is that it has closed nutrient cycles (Nelson, 2008) and can be designing as decoupled system consists of 2 independent recirculation systems connected unidirectionally from the fish component to the plant component (Kloas et al., 2015) and enables sustainable agricultural production through complete biological processes among fish, bacteria and the plant (Nelson, 2008). Aquaponics can be implemented as the medium in a wide range of suitable fish species and plants at the same time in the system (Nelson, 2007; Diver & Rinehart, 2010; Resh, 2012). Moreover, Aquaponics is composed of three main components such as fish, plants and microbes. All the three components must be available for an aquaponics system to function since the nutrients, absorbed by plants, is a product of nitrification process of wastes excreted by fish. Moreover microbes bridge the process between the other two components (Nelson, 2008; Klinger & Naylor, 2012; Somerville et al., 2014).

In aquaponics, fish physiology and the composition of fish feed from protein are the main factors affecting nutrient availability in solution inside the system. Further other factors such as fish species, growth stage, stocking density and the rates of inside microbial nitrification also play a role here (Rakocy et al., 2006). Fish feed waste is the primary nutrient source for plants followed by fertilizers, periodically. While most of the required nutrients such as nitrogen, potassium and other elements for plant growth are available in the fertilizers (Tyson et al., 2004; Rakocy et al., 2006).

TYPES OF AQUAPONICS SYSTEMS

In an aquaponics system, three components work together such as fish tank (aquaculture), bio-filter (for nitrification) and grow bed (hydroponics). Aquaponics types are classified on the basis of grow bed designs according to hydroponics and can also be classified as closed (coupled) and decoupled systems (Kloas et al., 2015). The first type according to hydroponics, floating raft (RAFT, deep water culture – DWC) is widely used for lettuce. The second type, Nutrient Film Technique (NFT) is used widely for lettuce. NFT is not only used in Lettuce production, but also in Garlic as in (Abou-Hadid et al., 1986), Tomato, Cucumber, Strawberry and Beans (Chrissy, 2017). The final type is media-based bed that uses substrates media such as peatmoss, tuff and perlite in (flood and drain or ebb-and flow) (Diver, 2006; Lennard & Leonard, 2006; Rakocy et al., 2006; Nelson & Pade, 2007; Love et al., 2014).

The media-based bed is widely used in small scale aquaponics since not only that it could act as a filtration unit but also it does not require separate biofilters as it contains media (e.g., pumice stones or clay beads) in the grow bed for nitrification (Zou et al., 2016). In addition, the substrate which is used in media based bed provides high surface area for microbial growth during biological processes in aquaponics. This is the most popular grow bed design among home gardeners (Bernstein et al., 2014). Moreover, media-based bed is suitable for different kinds of vegetables and fruit species, because the grow bed can support high root density due to potential blockage of recirculating flow while NFT bed design is suitable only for small vegetable species such as lettuce because the grow bed cannot support a high quantity of roots due to potential blockage of recirculating flow (Engle, 2015). Thus, efficient solid removal is critical for NFT to prevent clogging in grow bed channel. Floating-raft is the commonly adopted type in aquaponics system since it allows the plant roots to freely absorb the nutrients in the water without clogging water channel (Liang & Chien, 2013; Engle, 2015). NFT and floating-raft aquaponics systems require a biofilter for nitrification and a sedimentation tank for solid removal (Nelson, 2008; Engle, 2015). Recently, many researchers conducted experiments to determine the efficiency of applied Nutrient film technique and deep water culture in large scale commercial operations (Bernstein et al., 2014).

COMPONENTS OF AQUAPONICS SYSTEM

Aquaponics system works on the principle of connection between the components, hydroponics and recirculating aquaculture elements. This can be otherwise described as, a combined culture of fish, bacteria and plants. For this reason, any aquaponics system must be composed of basic components such as fish tank, aerator, pipes, lights, pump, biofilter, hydroponics components-media beds, NFT, DWC, RAFT or deep water and sump tank. In addition to this, half barrels, PVC media, buckets, plastic containers etc. may be used (Rakocy et al., 2006). Devices of sedimentation cover plate separators, tube or settling basins. Each component in aquaponics system plays a specific role. Fish excretes organic wastes as ammonia in the fish tank while the biofilter component has two specific processes for converting fish waste metabolites such as ammonia into nitrite and then to nitrate through nitrification. The hydroponics component in aquaponics system provides the required nutrients to plants. Moreover, aquaponics system must ensure processes such as aeration, water movement and the biological process to produce nitrate in the final stage. Finally, aquaponics system is the culture for symbiosis between fish, bacteria and plants, and considered as sustainable agriculture system using water and nutrients in coupled recirculation (Rakocy et al., 2006; Somerville et al., 2014).

Positive effects of aquaponics

Today's competitive environment facing serious of issues includes changes of climate, degradation of soil, food security, and scarcity of water and rise of population. All these problems were possibly addressed by aquaponics through their closed loop system which consists of aquaculture and hydroponic elements (Goddek et al., 2015). It is the rapidly developing sector of agriculture which should be sustainable and also meet demands of biochemical aspect. Principally, aquaponics which is the combination of horticulture and aquaculture in a single recirculating aquaponic system (SRAPS) gives a sustainable approach (Kloas et al., 2015). Each part in aquaponics system can be controlled to maintain good environmental conditions through controlling water quality, temperature, pH, efficiency of the water used, improved waste management throw nitrification and nutrient recycling (Rakocy, 2007; McCarthy, 2011; Thorarinsdottir, 2015; Sallenave, 2016). Further water recirculation is the final outcome achieved (Lin et al., 2002; Hamlin et al., 2008; Endut et al., 2009; Martins et al., 2010). Moreover, aquaponics can protect crops from diseases and drought (Azad, 2015). Because of its unique, sustainable and environmental-friendly operational procedures, aquaponics has greater impact on sustainable food production (fish and vegetables), reduced environmental pollution and less water consumption which directly increases the profit of farmers in contrast to standalone RAS and hydroponics systems, aquaponics has a better economic benefit may include results from (McMurtry et al., 1997; Love et al., 2014; Love et al., 2015; Miličić et al., 2017).

IMPORTANT CRITERIA AND FACTORS THAT AFFECTS AQUAPONICS SYSTEMS

pH

In any aquatic system, pH stabilization is an important and critical phenomenon since the living organisms operate within a cycling system and it controls fish metabolism, microbial activities and affects the availability of nitrogen to plants (Kuhn et al., 2010; Zou et al., 2016). In aquaponics, it is important to know the optimal pH range for overall best performance from plant, bacteria and fish since it is necessary to achieve sustainability of all the biological interactions occurring in the system. The plant roots, bacteria, and fish must be able to absorb nutrients even at higher pH levels, because providing the optimal pH for every part in a system is challenging. The pH solution is the most important parameter in aquaponics systems because it controls fish metabolism, microbial activities and affects the availability of nitrogen to plants (Kuhn et al., 2010; Zou et al., 2016) and it must be balanced among fish, bacteria and plant demands at the same time. In general, the tolerance range for most plants is 5.5–7.5 (Somerville et al., 2014). So, during experiments period, ideal pH will be maintained for whole aquaponics system through adding calcium hydroxide and potassium hydroxide to the base of the addition tank, where it gets dissolved and slowly enters the system.

Moreover, the pH level for crops must be within the optimal range because if pH exceeds this range, plants are unable to absorb nutrients such as iron, calcium, and magnesium available in the water which becomes deficient in plants (Rakocy et al., 2006; Somerville et al., 2014). On the other hand, the optimal pH for nitrification in biological processes is in the range of 7.5–8.5 (Kim et al., 2007). The ideal pH for the nitrification process is 8.5 (Wortman & Dawson, 2015). Recent studies inferred that pH 6.0 is optimal for plant growth and efficient nitrogen utilization in aquaponics at the expense of increased N_2O emission due to high denitrification (Zou et al., 2016). In aquaponics systems, pH was usually managed in the range of 6–7.0 because this range is optimal for bacteria to function to its fullest capacity and the plant roots have full access to absorb all the essential micro and macronutrients (Wortman & Dawson, 2015). Tilapia can tolerate wide pH ranges and each tilapia species has different optimal pH (Lemarié et al., 2004; Arimoro, 2006). Due to higher pH, fish is usually affected due to toxicity of ammonia. Further, higher pH levels lead to higher toxicity in tilapia, but best performance can be achieved in the range of 6.5–8.5. Therefore, it is important to keep the pH value at possible stable level from (6–7.0) (Rakocy et al., 2006).

Dissolved Oxygen

Dissolved oxygen (DO) is one of the most important parameters in fish culture. This is also critical to the beneficial nitrifying bacteria that convert fish waste into nutrients so that the plants can absorb (Somerville et al., 2014). Dissolved oxygen (DO) level describes the amount of molecular oxygen within water in the aquaponics system. This is essential component for plants, fish and nitrifying bacteria to live and flourish in aquaponics system and measured in terms of milligrams per liter. In new aquaponics system, continuous monitoring of DO amount should be done until the system is standardized by determined feeding and stocking rate to provide sufficient aeration (Stark, 1996; Timmons & Ebeling, 2013; Somerville et al., 2014). In aquaponics, the addition of excess oxygen do not show any negative effects or risks because when the water gets saturated, the additional oxygen is simply dispersed into the atmosphere.

The water temperature must be taken care and checked frequently because it is strongly related to dissolved oxygen and when DO is insufficient at high water temperatures, the root rot symptoms may appear (Rakocy, 2007). Most plants need high levels of DO (> 3 mg L^{-1}), while for biofilters, it is recommended above 1.7 mg L^{-1} to maintain the activity of nitrifiers (Ruiz et al., 2003). On the other hand, tilapia is tolerant when the DO concentration is low, but growth rates will be affected. Tilapia, when there is low level of dissolved oxygen (1 mg L^{-1}), it comes to the surface for oxygen-rich surface water. Moreover, it is recommended that DO levels should be maintained at 5 mg L^{-1} or higher in aquaponics systems to prevent from stress to fish and plants (Bernstein, 2011; Rakocy, 2007).

Tank water temperature

Water temperature is a major influence factor on organisms inside the aquaponics culture systems. The water temperature not only affects the organisms in it but also show effects on growth of fish, feeding rate and fish size (Gardeur et al., 2007). Moreover, the water tank temperature influences the behavior and physiological process of fish in the aquaponics system and the performance of biofilter (Xia & Li, 2010). In addition, high temperature has a direct effect system processes in terms of reduced dissolved oxygen, increased unionized (toxic) ammonia and restricted absorption of calcium (Somerville et al., 2014). Several studies have been reported that each fish species has ideal range of water temperature as because it is affected directly by maximum growth (Person-Le Ruyet et al., 2006; Björnsson et al., 2007; Oyugi et al., 2011; Somerville et al., 2014). Tilapia in aquaponics system require warm temperatures (25–27 °C) (DeLong et al., 2009) for maximum growth (Rakocy et al., 2006; Savidov et al., 2007). When the ideal temperature is not maintained in fish tanks, the growth is drastically reduced and cause diseases which results in other criticalities such as reduced reproduction, sluggishness due to retarded digestion capacity of fishes (Bailey & Alanärä, 2006). The ideal temperature for vegetable growth is 20–25 °C and for biofilters (nitrifying bacteria) it ranges from 25 to 30 °C while tilapia dies when the temperature drops below 10 °C.

TYPES OF TILAPIA USED IN AQUAPONICS

Tilapia is one of the most popular fish species in aquaponics systems (Rakocy et al., 2006) and the basic requirements for successful biological process the aquaponics system (Love et al., 2014). Tilapia has a great attention because of its high availability, easily cultivable nature, fast growing, stress and disease-resistant and highly adaptable to a wide range of environmental conditions such as pH, water temperature, dissolved oxygen (DO), salinity, light intensity and photoperiods (El-Sayed & Kawanna, 2004; Hussain, 2004). Due to these characteristics, tilapia culture is being practiced in most of the tropical, subtropical and temperate regions to reduce the global rising demands for protein sources (Ng & Romano, 2013). Fish is important to produce ammonia which is the major end product in the breakdown of proteins which is converted to nitrate in next stage by bacteria (Rakocy et al., 2006). There are many species of tilapia such as Blue tilapia (Oreochromis aureus), Nile tilapia (*Oreochromis niloticus*), hybrid tilapia (*Oreochromis mossambicus* x *Oreochromis* *niloticus*), Nile tilapia ‘red strain’ hybrid (*Oreochromis niloticus* x *O. aureus*) and red tilapia (*Oreochromis* sp.) which are being used successfully in aquaponics system. In a study conducted by Palm et al. (2014), *Oreochromis niloticus* is used for better growth of lettuce (*Lactuca sativa*) and cucumber fruits (*Cucumis sativus*) in aquaponics system. Further, another study conducted by Knaus & Palm (2017) recorded better growth in basil (*Ocimum basilicum*) and parsley (*Petroselinum crispum*) when used *O. niloticus* in aquaponics system. Consequently, under identical aquaponics system design, optimal fish and plant choice govern the growth performance of the cultivated plants (Knaus & Palm, 2017).

BACTERIA IN AQUAPONICS

Bacteria is one of the three basic requirements to complete the biological processes (nitrification) in aquaponics system. Nitrification process is a major biological process in biofilter aquaponics and forms the basic process for removing ammonia, a metabolic waste excreted by fish. Ammonia is toxic to fish at concentrations above 0.05 mg L^{-1} (Rakocy et al., 2006; Reed et al., 2009). Nitrification process in aquaponics system provides elements for the plants which eliminates ammonia and nitrite (Gutierrez-Wing & Malone, 2006) through two types of bacteria of which the first type is composed of <u>*Nitrobacter*</u>, <u>*Nitrospina*</u> and <u>*Nitrococcus*</u>, a group of nitrifying bacteria that oxidize ammonia(NH_3 or NH_4^+) convert into nitrite (NO_2^-) which is also toxic to fish. The second type of nitrifying bacteria composed of <u>*Nitrosomonas*</u> and <u>*Nitrosococcus*</u> that oxidize nitrite converts the nitrite into nitrate (NO_3^-) (Somerville et al., 2014). In aquaponics, biofilters use sand, gravel, shells or various plastic media with large surface areas which is optimal to develop extensive colonies of nitrifying bacteria (Rakocy et al., 2006). The nitrification process results in the transformation of 93% to 96% of ammonia-nitrogen to nitrate, an end product of nitrification, in infiltration units (Prinsloo et al., 1999). Nitrate is the primary source of nitrogen for plants (Resh, 2012). Nitrite is the intermediate product of nitrification and toxic to both fish as well as plants while nitrate is not toxic to fish. The nitrifying bacteria in aquaponics system is affected by pH. The optimum pH range for nitrification is 7.0 to 9.0 although most studies indicate that the ideal pH for efficient activity of *Nitrosomonas* spec. is 7.8–8.0 and for *Nitrobacter* spec. it is 7.2–8.2. On the other hand, the optimal temperature range for nitrifying bacteria is 17–34 °C while the optimum levels of DO for nitrification process at 4–8 mg L^{-1}. (Somerville et al., 2014) This is the level required in the case of fish and the plants. Nitrification is affected negatively if the DO level is less than 2 mg L^{-1}. So it is mandatory to ensure adequate pH, water temperature and DO for successful biofiltration process (Rakocy et al., 2006).

INTERCROPPING IN AQUAPONICS CONDITIONS

Recently, intercropping has been recognized as cropping system and beneficial system for the production of two or more crops such as vegetables under greenhouse conditions in the same location and must be at least a part of production cycles. Intercropping has played important role in most countries in Asia, Africa and Latin America for food security under conventional conditions (soil conditions). Soil degradation, desertification and water pollution (Gregory et al., 2002) are the main reasons for innovation and adapting to intercropping techniques combined with new technologies such as hydroponics and aquaponics. Nowadays, it is urgent to study and develop the practices for applying intercropping under hydroponics and aquaponics systems, because it remains the potential strategy in sustainable food systems (Malézieux et al., 2009; Li, 2011; Lithourgidis et al., 2011).

Advantages and disadvantages of intercropping

Intercropping has many advantages over single crop cultivation according to recent and past studies. Most of the studies about intercropping application are under soil conditions. Inserted or combined intercropping in aquaponics will bring greater attention for many reasons such as production of vegetables in a biological way meeting high quality standard without compromising the quantity. The main reason to adopt intercropping, besides these advantages is that food security can be achieved through sustainable agriculture system. As mentioned above, intercropping has many advantages over single cropping (Gebru, 2015) such as efficient water usage, increased total productivity per unit land, per unit time, and increased efficiency in using space among different species and thus reducing the cost of production, labor and environmental impacts (Anitha et al., 2001; Li, 2011; Bedoussac et al., 2015).

Yu et al. (2015) reported that intercropping uses land up to 22% more efficiently than corresponding sole crops with same growth duration. In addition, intercropping can increase profitability, especially when the basic requirements such as water, light and nutrients are efficiently and effectively used than single cropping systems which leads in less time and energy consumption in food production (Barros Júnior et al., 2009; Filho et al., 2010).

FACTORS AFFECTING INTERCROPPING IN AQUAPONICS SYSTEMS

Crop properties and aquaponics types

Various researchers have proved that wide varieties of crops especially vegetables such as lettuce and tomato (Rakocy et al., 1993) or basil (Adler et al., 2003), cucumber and other herbs (Savidov et al., 2007) have been grown in the different types of aquaponics systems. However, crop properties varied on the basis of types of aquaponics. For instance, Cormier (2016) reported that tomatoes and other fruiting plants are not better in floating raft systems. Likewise, deep flow technique (DFT) is generally utilized for herbs (oregano, thyme and basil) and salad greens (include arugula, chicory, spinach and lettuce). Lettuce grow in raft and other media with the ideal temperature of 15–27 °C and temperature tolerate over 27 °C lettuce bolts; tomatoes grow in only very popular hydroponic varieties and aquaponics with the ideal temperature of 26 °C and temperature tolerate over 7.2 °C (Sawyer, 2013). Richard Tyson (2012) examined that the aquaponics fish called tilapia was commonly grown in good quality water with yellow perch, largemouth bass, rainbow trout, koi and bluegills. Brook (2017) reported that salad greens, lettuce, peppers, tomatoes and herbs like low-water thyme and basil grown in media bed.

It was recommended by the researchers to practice intercropping of two or more crops in aquaponics. But prior to implementing dual crops, in this instance, tomato and lettuce, care must be taken with aquaponics system since there are many factors that could possible affect the success of intercropping.

First, the crop's complete characteristics, properties and suitable type of aquaponics system must be studied followed by the investigation of factors that affect each crop over the other in terms of botanical characteristics (Beets, 1982). The other agronomic factors, especially population density must be studied because it is very important to know the optimal density for each crop and size of the bed to ensure that each crop has optimal aeration and light to complete photosynthesis process. For example, tomato and lettuce can be intercropped in aquaponics but it is must to know the planting density for both crops and crops arrangement is critical such that the crops have no effect over each other. Further nutrient availability is a critical factor because the study must ensure that aquaponics can produce efficient amount of nitrate and other macro and micro elements which the crop needed to grow. In addition, researchers such as (Alves et al., 2010; Filho et al., 2013) reported that strategy for managing the time for intercropping is important because, the competition between the crops for nutrient uptake needs to be minimized and the period of coexistence of species influenced the crop productivities, for example, tomato and lettuce, and cucumber and lettuce, respectively.

Nutrients needed for crops under intercropping aquaponics

The main challenge for success in intercropping under aquaponics is how to achieve and assess the optimum amount of elements needed from nutrient concentration for both crops from transplant stage to growth until the harvesting period by calculating the nutrients needed for both crops in intercropping to prevent nutrient deficiency. A deeper understanding of needs from the nutrient solution for both crops in intercropping is important to manage fish stocking density, feeding rate, frequency of fish, feed composition and bacterial surface area to achieve the elements needed. Moreover, it is important to determine the ratio of elements uptake by both crops in each stage in order to manage the fish culture composed of the above factors. The other factors that are to be considered are pH, water temperature for both crops and all other elements of the aquaponics system such as the fish tank, bacteria tank and beds. In addition, management of fruit crops like tomato is difficult than leafy crops such as lettuce, because tomato has different nutrient demands based on the different developmental stages from first flower to start setting fruits. Fruit crops, when start setting fruits, need more specific nutrients such as Ca, Mg and K (Nelson, 2008). It denotes that knowledge on both the crops and its stage of growth is a must and its timely application is mandated. Most intercropping crops are chosen as fruits and leafy crops because it is highly profitable and has value.

Role of foliar application in intercropping aquaponics

A crucial point for aquaponics in general, and for intercropping in specific, is the nutrient balance in system culture, as it is critical for both crops during growth until harvesting stage. According to previous studies (Adler et al., 1996; Seawright et al., 1998; Graber & Junge, 2009), it is reported that aquaponics system produces lower levels of potassium (K), iron (Fe), manganese (Mn) and sulfur (S). Therefore, the optimal nutrient balance, during the growth cycle for both crops, can be achieved by considering all the factors inserted in the above title (i.e., nutrients needed for crops under intercropping aquaponics) and by supplementation of the required elements throw foliar application such as potassium and iron, because these elements are not released from fish feeds (Rakocy et al., 1997; Rakocy et al., 2006; Roosta & Hamidpour, 2011). Foliar application is one of the efficient methods of plant nutrition in case of nutrient deficiency for Mg, Zn, and Mn during growth stage (Roosta & Hamidpour, 2011).

Stocking density of tilapia under intercropping aquaponics

Stocking density is considered as one of the important factors in aquaponics, besides feeding rate and frequency since it varies according to fish type. In aquaponics systems, especially for intercropping, stocking density must be ideal and optimum to ensure that the waste is converted to ammonia and nitrate in the final phase. Through optimum stocking density, one can obtain maximum production without effects on environment, optimum health, economic benefits (Rahman & Marimuthu, 2010) and minimum occurrence of physiological and behavioral disorders (Ashley, 2007; Ayyat et al., 2011). Tilapia is the fish species which is commonly cultured in aquaponics system. In order to recover the operating expenses and huge capital cost of aquaponics systems and earn a profit, both the hydroponic vegetable components and fish rearing should be continuously operated near maximum production capacity (Rakocy et al., 2006). Working a framework close to its critical standing crop utilizes space proficiently, expands production and decreases variation in the daily feed input to the system, a critical factor in estimating the hydroponic segment.

There are three stocking methods that can keep up fish biomass close to the critical standing crop: multiple rearing units, stock splitting, and sequential rearing. Sequential rearing includes the culture of various age groups of fish in a similar rearing tank. When one age group achieves marketable size, it is specifically collected with nets and a grading system, and an equivalent number of fingerlings are quickly restocked in a similar tank. Stock splitting includes stocking high densities of fingerlings and intermittently splitting the populace in half as the critical standing crop of the rearing tank is attained. This technique keeps away from the vestige issue of stunted fish and enhances stock inventory. With different rearing units, the whole populace is moved to bigger rearing tanks when the critical standing crop of the underlying rearing tank is reached. Multiple rearing units, for the most part, come in modules of two to four tanks and are associated with a typical filtration framework. After the biggest tank is gathered, the greater part of the rest of the gatherings of fish is moved to the following biggest tank and the smallest tank is restocked with fingerlings. A variety of the idea of multiple rearing units is the division of a long raceway into compartments with portable screens. As the fish develop, their compartment is expanded in size and drew nearer to one end of the raceway where they will, in the long run, be collected. Each rearing tank contains an alternate age group of fish, yet they are not moved amid the production cycle. This system does not utilize space proficiently in the beginning periods of development, however, the fish are never exasperated and the work associated with moving the fish is killed. Cropping systems showed that batch and staggered production of basil in an aquaponic system were comparable and both were approximately three times more productive than field production.

In addition, stocking density has direct effects on growth, survival, water quality and fish behavior (de Oliveira et al., 2012). On the other hand, if a farmer stock fishes in the fish tank at less optimal conditions, the efficiency and profitability of the culture system gets reduced. For this reason, Ahmed & Hamad (2013) reported that increasing stocking density from 100 to 200 fish m^{-3} in the fish tank results in negative impact by reduced survival, growth and benefits. On the other hand, another study conducted by

El-Saidy & Hussein (2015) about an effect of low stocking density (50 fish m^{-3}) inferred that there is a positive effect on growth performance and feed utilization parameters. However farmers and commercial producers always look for the optimum stocking density to achieve maximum profits. Finally, according to (El-Salam et al., 2014), it could be concluded that the optimum stocking density is 100 fish m^{-3} and the dietary protein levels is 25%, so that the maximum growth is achieved with highest profit analysis.

Feeding rate of tilapia in intercropping aquaponics

Feeding rate is an important factor that affects fish growth as well as the crops in intercropping system under aquaponics. Optimized feeding rate is important for a fish to growth healthy and this can be determined measuring correct balance of composition of feeding like proteins, vitamins, carbohydrates, fats, and minerals. The amount of feeding rate for each aquaponics system will be g m^{-1} per square meter of plant growing area and this feeding rate will be calculated for daily amount of feed per square meter of plant growing area. Table 1 composition (%) of the fish feed in aquaponics systems especially tilapia fish.

Table 1. Proximate composition (%) of the fish feed

Nutrient	(%Content)
Crude Protein	Around 30%
Fat	4%–6%
Cellulose	5%–20%
Mixed Inorganic	3%–5%
Phosphorous	0.54%–1.14

Feeding rate calculation

The feeding rate will be ranged for example between 50–80 g of fish feed per square meter per day. If the plant growing area is 1.125 m^2 per replicate and the total area will be (3*1.125 m^2) and then the total area for one treatment 3.375 m^2 and the feed ration would be 60 g per day per m^2

80 g $\longrightarrow$ day per m^2

x g $\longrightarrow$ day per 3.375 m^2

The amount of feed must be 270 g per day per 3.375 m^2 of area of growing plant whereas the fish biomass of tilapia in a system eats 1–2% from the total weight of body fish per day. i.e., the mean value of feed for fish is that, for each 100 g fish, 2 g must be fed.

Protein is the basic composition in fish meal as it is the building block in fish body and it is also necessary for muscle formation, enzymatic functions, and partially helps in energy maintenance (Bahnasawy, 2009). Further, proteins form the basic structures and enzymes in all living organisms. The optimum protein requirement of tilapia depends on size, age, and water temperature. In general, younger fish (fry and fingerlings) require a diet which is richer than what is fed during the grow-out stage. In their grow-out stage, tilapia needs 25–35 percent of protein in its diet for optimal growth using essential and non-essential amino acids. Several studies estimated that the protein requirement for juvenile tilapia varies from 32 to 50% whereas, for larger tilapia it is between 25 to 30% (Hafedh, 1999; El-Saidy & Gaber, 2005; Ali, Al-Ogaily et al., 2007; Nguyen, Davis & Saoud, 2009; Abdel-Tawwab et al., 2010). In aquaponic system, the feeding fish type it is one of the largest variable costs (Naylor et al., 2009). Feeding rate of tilapia does not treat the possible feeding rate of tilapia in coupled aquaponics but only the protein requirement. However, since the feeding rate ratio of Rakocy et al. (2006) is an important factor in coupled aquaponics. Rakocy pointed out the NFT and gravel systems must have a feed ratio is approximately 25 percent of suggested ratio for Raft hydroponics. Some factors which determine the optimum feeding ratio are the exchange rate of water, level of nutrient in source water, type of plant and degree etc. Decreasing rate of exchange of water, increasing source-water nutrient levels, slow solids removal (as a result in release of more dissolved nutrients) and slow growing plants would permit a lesser feeding rate ratio. Floating and sinking pellet these are the two types of commercial fish feed that can be classified into floating (extruded) or traditional sinking (pressure-pelleted) pellets. Both floating and sinking feed can produce satisfactory growth, but some fish species prefer floating and others sinking (Craig & Helfrich, 2009). Tilapia can utilize both the floating pellets and sinking pellets very efficiently (Santiago, 1987). Kawser et al. (2016) reported that tilapia O. niloticus fed with floating pellet was better than sinking pellet in terms of growth response, feed utilization and nutrient retention. Feeding must be done by hand very slowly and carefully to ensure ingestion of feed completely.

Avoid overfeeding in aquaponics system

In aquaponics system, it is important and advantageous to determine the optimal feeding rate to avoid overfeeding. Moreover, overfeeding has negative effects on the success of aquaponics since overfeeding overloads fish stomach and intestine, leading to decreased digestive efficiency and reduced feed utilization. In biofilter process, heterotrophic bacteria feeds extreme waste from overfeeding which consumes substantial amounts of oxygen. As a result of food decomposition, the level of ammonia and nitrite rise to toxic levels in a relatively short period. In addition, the unconsumed feed pellets can block the mechanical filters, leading to decreased water flow and anoxic areas. Finally, protein is the most expensive component in a diet (Somerville et al., 2014). Therefore, the quantity of protein in the diet should be ideal for fish growth where the excess protein in fish diets may turn unused and cause unnecessary expenses (Ahmad et al., 2004).

MANAGEMENT OF THE NUTRIENT SOLUTION IN INTERCROPPING UNDER AQUAPONICS VS. HYDROPONICS

In hydroponics system, nutrient solution is prepared according to the plant needs and growth stages. Moreover, the pH, Electrical conductivity (EC) and nutrient composition solution can be modified during the life cycle of crops. Intercropping in hydroponics system is easier to apply when compared to aquaponics, because in hydroponics, nutrients can be applied to tank nutrient solution with ideal concentration, while in aquaponics, the nutrients are produced only from the fish waste through nitrification process i.e., conversion of ammonia to nitrate to nitrite along with the production of a low amount of potassium and calcium. According to Table 2, the total nitrogen needs for intercropping between tomato and lettuce is 341 mg L^{-1}, while in aquaponics, the total nitrogen for intercropping the same crops is 172 mg L^{-1}. In addition, the total calcium (300 mg L^{-1}) required for intercropping under hydroponics for tomato and lettuce is higher than aquaponics (214 mg L^{-1}). Moreover, the total concentration of

Table 2. The differences between total nutrient concentrations in intercropping in aquaponics and hydroponics for lettuce and tomato, all nutrients reported in mg L^{-1}

Plant species	System	NO3-N	Ca	PO4-P	Mg	SO4S	Na	K	CL	Fe	Mn	Cu	Zn	B	Mo	Source
Lettuce (*Lactuca sativa*)	Hydroponics	190	200	50	50	66	50–90	210	65–235	5	0.5	0.15	0.15	0.3	0.05	Resh, 2012
Tomato (*Solanum lycopersicum*)	Hydroponics	151	110	39	24	48	–	254	–	0.8	0.6	0.05	0.3	0.2	0.05	Sonneveld & Voogt, 2009
Total Nutrient concentrations		341	300	89	74	114	50	464	65	5.8	1.1	0.2	0.45	0.5	0.1	
Lettuce (*Lactuca sativa*)	Aquaponic	137	180	9	44	–	17	106	–	–	–	–	–	–	–	Pantanella et al., 2012
Tomato (*Solanum lycopersicum*)	Aquaponic	35	34	8	–	–		27	–	0.2	–	0.04	0.37	–	–	Roosta & Hamidpour, 2011
Total Nutrient concentrations		172	214	17	44	–	17	133		0.2	–	0.04	0.37	–	–	

Mg, P, Na, K and microelements under hydroponics for intercropping is higher than in aquaponics for the same crops. According to the information mentioned above, it can be concluded that the aquaponics concentration for macro and micro elements are below the recommended hydroponics level. Also, the other differences between the nutrient solutions between both the systems is the total dissolved solid. In aquaponics, the dissolved solid is organic molecules, while in hydroponics, it is mineral compounds.

CONCLUSION AND RECOMMENDATIONS

The current study provided some valid insights in terms of how to choose crops for intercropping in aquaponics in specific and how to execute aquaponics successfully in general. In aquaponics, the most important point to achieve success is to understand the characteristics of individual living and non-living components such as fish, crop, nitrification biofilter systems and how to combine all the above. The study would like to recommend the future researchers to obtain complete information about the systems being used before venturing into aquaponics since managing aquaponics system is critical and care must be taken to avoid any mistakes during the production cycle in getting the expected output. Prior to adapting intercropping under aquaponics, more knowledge should be gained in various areas such as follows:

- While selecting crops for intercropping in aquaponics, care must be taken such that one crop is leafy and other is a fruit type (for example, tomato and lettuce; tomato and parsley; cucumber and lettuce; strawberry and lettuce, etc.);
- It is important to determine the planting density of both crops (tomato and lettuce) in order to increase the efficiency in using space and also the growing area for beds;
- Selection of aquaponics system for plants that suits and meets the requirements For example, NFT bed design is suitable only for small vegetable species such as lettuce (Engle, 2015);
- The stocking density of fish needs to be determined since this is important for the plant to be provided with nutrients required by both crops, thus integrating the nutrient flow;
- The fish feed composition and the response of fish to the feed are important to be determined prior to beginning the aquaponics process;
- It is important to determine the amount of ammonia that could possibly be produced by feed;
- The amount of biofilter media needed for nitrifying bacteria is critical to be measured prior to beginning the setup;
- The dissolved oxygen and the temperature in tank must be daily checked whereas the pH should be checked frequently;
- Plants selected for aquaponics must have the ability to act as biofilter that takes up waste generated in the system.

The success of intercropping under aquaponics will reduce the gap between crop consumption and fish needs that are grown under organic conditions. There are practical challenges in intercropping high value crops such as tomato and lettuce under aquaponics. According to report Statista (2014), 24.98 Million metric tons of Lettuce was produced globally in the year 2014. It is especially important as a commercial crop in Asia, North and Central America, and Europe. These challenges need to be resolved to increase the production of crops under organic conditions and reduce the usage of fertilizers. For the above to happen, the current study suggests the future researchers to develop full information about the crops of high economical value in terms of its growth under controlled and standardized aquaponics systems so that it becomes possible to achieve the sustainable agricultural production that is viable both in terms of quality and quantity.

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