Annals of Agricultural Science xxx (2016) xxx–xxx

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Annals of Agricultural Science

journal homepage:

Growth, yield, plant quality and nutrition of basil (*Ocimum basilicum* L.) under soilless agricultural systems

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ARTICLE INFO

Article history:
Received 20 July 2016
Received in revised form 4 September 2016
Accepted 13 October 2016
Available online xxxx

Keywords:
Aquaponic
Basil
Crayfish
Hydroponic
Nitrogen

ABSTRACT

Traditional agricultural systems are challenged by globally declining resources resulting from climate change and growing population. Alternative agricultural practices such as aquaponics (includes crop plant and aquatic species) and hydroponics (includes crop plant only) have the potential to generate high yield per unit area using limited land, water, and no soil. A soilless agricultural study was conducted at the Georgia Southern University, Statesboro, GA, USA from August to November, 2015. The growth, yield, quality, and nutrition of basil (*Ocimum basilicum* L.) cultivar *Aroma 2*, were compared between aquaponic and hydroponic systems using crayfish (*Procambarus* spp.) as the aquatic species. Non-circulating floating raft systems were designed using 95 L polyethylene tanks. Equal amounts of start-up fertilizer dose were applied to both systems. The objective was to understand how the additional nutritional dynamics associated with crayfish influence the basil crop. Both fresh and dry basil plant weights were collected after harvest, followed by leaf nutrient analysis. Leaf chlorophyll content, water pH, nitrogen and temperature were measured periodically. Aquaponic basil (AqB) showed 14%, 56%, and 65% more height, fresh weight, and dry weight, respectively, compared to hydroponic basil (HyB). It is logical to assume that crayfish waste (excreta and unconsumed feed) has supplied the additional nutrients to AqB, resulting in greater growth and yield. The chlorophyll content (plant quality) or leaf nutrients, however, did not differ between AqB and HyB. Further research is needed to investigate aquaponic crayfish yield, overall nutritional dynamics, cost-benefit ratio, and other plant characteristics under soilless systems.

Introduction

The human population worldwide currently exceeds 7 billion, and it is projected to reach 8.5 billion by 2030, and 9.7 billion by 2050 (UN, 2016). With a fast growing global population, the demand for soil and land for crop production is likely to increase, and more urban area development is projected to take place. Earth's arable land is finite and challenges such as soil degradation, water scarcity, and urban area development need to be addressed by developing new and modified agricultural systems (Lehman et al., 1993; Lal, 2013). Alternative food production systems that require limited land, soil, and water, and which can be developed in urban areas may play a major role in future agriculture.

Hydroponics and aquaponics are soilless agricultural systems that are highly productive, suitable for urban areas, and can address the shortage of land in relation to growing demand for food production (Medina et al., 2016). Hydroponics is the culture of plant crops in soilless water-based systems, where nutrients come only from formulated fertilizer (Liang and Chien, 2013). Aquaponics, is an integration of hydroponics and aquaculture, where crop plants and aquatic species can be grown together in a soilless water-based system (Seawright et al., 1998; Rakocy et al., 2006). Aquaculture is growing of aquatic animals/organisms in a designated water body (Boyd and Tucker, 1998). Large amounts of polluted water are produced in aquaculture systems with a potential for environmental pollution (Piedrahita, 2003), which can be reduced by techniques such as aquaponics (Schneider et al., 2005). Aquaponics, a combined culture of fish and plants has been proposed as a means to decrease waste accumulation from aquatic monoculture and to increase the productivity and profitability of the system (Rakocy and Hargreaves, 1993).

Soilless water-based systems are commonly set-up in vertical integration systems in indoor urban settings, which addresses the limitations of soil quality and space availability (Lal, 2013; Orsinsi et al., 2013). Being indoor practices, hydroponics and

Peer review under responsibility of Faculty of Agriculture, Ain-Shams University.
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http://dx.doi.org/10.1016/j.aoas.2016.10.001
0570-1783/

Please cite this article in press as: Saha, S., et al. Growth, yield, plant quality and nutrition of basil (*Ocimum basilicum* L.) under soilless agricultural systemsOcimum basilicum L.) –>. Ann. Agric. Sci. (2016), http://dx.doi.org/10.1016/j.aoas.2016.10.001

aquaponics are not directly affected by the changing climatic patterns and abrupt weather conditions, and hence could be effective adaptive strategies, as well. Aquaponics has several advantages over aquaculture and hydroponics. This system reduces the need for formulated fertilizers, eliminates the possibility of agricultural run-off, and cleanses the water through biofilter treatments (Rakocy et al., 2006). The nutrients released from fish excreta and microbial breakdown of organic wastes are used by plants in aquaponic systems (Roosta and Hamidpour, 2011). This way the plant component serves as a biofilter, and therefore a separate biofilter is not needed unlike aquacultural systems. In addition, this biofilter also generates income through the sale of the economic plant products (Rakocy and Hargreaves, 1993). Therefore, the aquaponic systems develop an economically advantageous symbiotic system, where aquatic species and the plant component benefit each other and the grower receives two marketable products. In contrast, the crop plant is the only marketable product in hydroponics and it is devoid of the commercial aquatic species and associated nutrient supply. Aquaponics can also be a strategy to combat water scarcity, as it has been shown to lower overall water consumption (McMurty et al., 1997) and prolong the useful life of water by reducing turnover rates and subsequently the environmental pollution, with improved economic return (Rakocy et al., 2006).

Primarily, fishes are used as the aquatic species in aquaponic studies and the potential for other commercial species such as crayfish (*Procambarus* spp.) are little known. Crayfishes have high economic importance globally, including southern United States and Southeast Asia (FAO, 2014). However, very few aquaponic studies have incorporated crayfishes and observed plant animal interaction effects. Effendi et al. (2015) observed that spinach-aquaponic systems resulted 5% higher crayfish survival rates than crayfish monoculture. They concluded that plant biofilters such as spinach, is very effective in cleansing the water resulting better crayfish survival. Crayfish can also be grown together with common fishes under aquaponic systems. In Louisiana, cultivation of crayfish (*Procambarus clarkii*) and rice (*Oryza sativa*) together increased yield for both (Chiena and Avault, 1980). Gallardo-Collí et al. (2014) reported that tilapia cohabited with crayfish (*Procambarus acanthophorus*) in an aquaponic system that produced 9.4% higher green corn fodder (*Zea mays*) compared to hydroponics.

Selection of plants for soilless systems is critical. Basil (*Ocimum basilicum* L.) is an annual herb that is commercially important and both fresh and dried leaves are used for culinary purposes (Chalchat and Ozcan, 2008). Basil is considered a medicinal herb (Ahmed et al., 2014) for its diuretic and stimulating properties and also used in perfume compositions (Nguyen et al., 2010). Basil is suitable for soilless production, and several studies have used basil as aquaponic or hydroponic crop (Rakocy et al., 2004; Roosta, 2014; Mangmang et al. (2016)). Basil responds with better yield under soilless systems than conventional systems. Rakocy et al. (2004) reported that aquaponic basil produced higher yield (1.8 kg m^{-2}) than field basil (0.6 kg m^{-2}). However, no studies have compared aquaponics and hydroponics systems for basil production.

Hydroponics and aquaponics are emerging fields of alternative agriculture with the potential to address the contemporary challenges faced by traditional agriculture. However, of the few studies that have compared these two systems, mostly focused on the commercial aquaponic species and little information is available on the plant production dynamics. In addition, little is known about the potential for non-fish aquatic species such as crayfish. We conducted a greenhouse study comparing crayfish-based aquaponic systems to hydroponic systems with a focus on the basil plant. The parameters under study included basil plant growth, yield, quality, and nutrition.

Materials and methods

Study location and components

A greenhouse experiment on soilless crop production was conducted from August to November, 2015 at the biology department of Georgia Southern University, Statesboro, GA, USA (32°26′43″N, 81°46′45″W). The growth, yield, plant quality, and nutrition of basil (*Ocimum basilicum* L.) cultivar *Aroma 2* were evaluated under hydroponic and crayfish-aquaponic systems. Red crayfish (*Procambarus clarkii*) and White River crayfish (*Procambarus zonangulus*) were used as the commercial aquatic species. The basil seedlings were collected from a local nursery in Newington, GA and the crayfishes were purchased from Carolina Biological Supply Company, Burlington, NC and Duluth, GA.

Study set-up

Dark polyethylene containers ($16.88 \times 18.75 \times 27$ cm^3 – $h \times w \times d$) of 95 L (25 Gal) capacity were used as study tanks. Four tanks each for aquaponics and hydroponics were allotted. Tanks were filled with 83 L (22 Gal) of tap water with a neutral pH. Two air stones (30 mm round) and double air pump (75–225 L capacity) were placed in all tanks. Four mature crayfishes were released in each aquaponic tank. Crayfishes are territorial, so to prevent aggression and increase their survival, assorted pieces of polyvinyl chloride (PVC) pipe shelters were placed in each tank. A similar strategy of using PVC shelters was adopted by Gallardo-Collí et al. (2014) that resulted better crayfish survival. The surface area of each container lid was 506.25 cm^2 (18.75 cm $\times$ 27 cm). The lids were given five circular cuts, one in each corner and one in the center, for inserting the net pots holding the seedlings. The planting density was 5 basil seedlings per 506.25 cm^2 (100 plants m^{-2}). Slotted net pots with 12.7 cm (5 in) diameter were used in this study. Pots were prepared with coconut coir lining and vermiculite (60:40) to hold the basil seedlings. Three week old seedlings were planted in the net pots and were transplanted to tanks on August 14, 2015. The net pots containing seedlings were set down into the circular holes of the lids, so that the lower half of each pot containing the roots remained submerged in the water. Each lid holding five submerged basil seedlings in each tank developed a non-circulating floating raft system, which is a common design used in soilless studies (Lennard and Leonard, 2006; Roosta and Hamidpour, 2011). Water loss due to evaporation and transpiration was replenished with tap water.

Chemical treatments and applications

Low potassium (K), sulfur (S), iron (Fe), and manganese (Mn) have been reported in aquaponic plants that received nutrition only from fish waste (Adler et al., 1996; Seawright et al., 1998). Thus, to provide a complete plant nutrition, supply of external nutrients is necessary (Rakocy et al., 2006). Both aquaponic and hydroponic tanks received a one-time basic start-up nutritional dose. Hydroponic liquid fertilizer Floranova Grow (7:4:10) (General Hydroponics Inc., Sebastopol, CA) was applied at the rate of 1.25 ml L^{-1} and each tank received 104 ml of fertilizer. Floranova Grow had 7% N, 4% P_2O_5, 10% K_2O, 4% Ca, 2% S, 1.5% Mg, and 0.1% Fe and less than 0.1% of each micronutrient (B, Cl, Co, Mn, Mo, Zn) (General Hydroponics Inc., Sebastopol, CA). A dechlorinator (AquaSafe) was applied to all tanks at the rate of 10 ml per 37.85 L (10 Gal) with each tank receiving 22 ml. To promote the nitrification process, 260 ml of Zym-Bac (Home Grown Ponics, Wilbraham, MA), a source of nitrifying bacteria, was applied to each

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