FERTILIZER AND CULTIVAR SELECTION OF DIFFERENT VEGETABLE CROPS AND EVALUATION OF DIFFERENT PH BUFFERS IN HYDROPONICS

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“It takes a village to raise a child” – African proverb

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Abstract:

During the last several decades, the primary objective of research work in soilless culture has been the composition of nutrient solutions and optimization of nutrition for commercial hydroponics. It is necessary that the nutrient solution provided for plants in hydroponic systems must be specific for a particular crop, the growth stage, the climatic conditions, and the substrate and hydroponic system used. Therefore, the objective of our study was to evaluate different one and two bag systems for fertilizers for the production of different types of vegetable crops (lettuce, basil, Swiss chard, sweet pepper, and eggplant). Crops are able to uptake nutrients from the nutrient solution only in a specific pH range (5.5-6.5). Therefore, various pH buffers are used to maintain nutrient solution pH in a specified range. The objective of one of our experiments was to evaluate the effect of alternative pH buffers (pH down, lime juice, and vinegar) on pH maintenance of the nutrient solution and growth and development of lettuce, basil, and Swiss chard. Results indicated that hydroponic producers should select lettuce and basil cultivars based on fertilizer used, while Swiss chard cultivars can be selected based on yield. Hydroponic producers should select fertilizer for sweet pepper cultivation in hydroponics based on yield, while for eggplant more cultivars and fertilizers need to be evaluated for yield differences. For alternative pH buffers, growers can use lime juice as an alternative for pH down for lettuce production but not for basil and Swiss chard.

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CHAPTER 1. LITERATURE REVIEW

HYDROPONICS

Soil is the most available growing medium for growing plants and provides anchorage, nutrients, air, water, and microbes essential for successful plant growth. There are some serious limitations of soil including soil compaction, poor drainage, low fertility, soil borne diseases, nematodes, and degradation due to erosion which leads to poor yield and quality. Other limitations which are faced in any conventional crop system is lack of space, labor, and water. The alternative for soil is the use of water as a medium. This technique is known as hydroponics.

Hydroponics is a word derived from Greek consisting of two words ‘hydro’ which means water and ‘ponos’ which means labor, i.e. working water. Thus, hydroponics or soilless culture is a system for growing plants in nutrient solutions that supply all the nutrient elements needed for optimum plant growth with or without the use of an inert medium such as gravel, vermiculite, rockwool, peat moss, saw dust, coir dust, and coconut fiber to provide mechanical support. Hydroponics has been practiced for centuries in the Amazon region, Egypt, Babylon, and India. The hanging gardens of Babylon and the floating gardens of the Aztecs in Mexico were prototypes of hydroponics systems. Later, plant physiologists began growing plants hydroponically for experimental purpose and named it ‘nutriculture’. Practical application of nutriculture flourished in 1925, due to problems such as soil fertility and pests faced in greenhouse soil. Therefore researchers were interested in replacing soil culture in the greenhouse with hydroponics. The soilless culture of plants was first practiced in the United States by American scientist, William

Frederick Gericke, in California in the 1930s. In the 1960s commercial hydroponic farms were established and in the 1980s automated and computerized hydroponics farms were establishedaround the world. Plants growing in hydroponics are physiologically similar to plants growing in soil. Both obtain essential elements in an inorganic form (Carpenter, 1994). But, the difference between both techniques is in the plant process of obtaining nutrients from the soil solution as opposed to hydroponic solution. In a hydroponics system dissolved nutrients are ready to be absorbed by the plants while in soil, minerals are released from soil collides. Due to this, hydroponics allows growers to manipulate the nutrient concentration of the solution according to species to be grown in hydroponics. There are many advantages of hydroponics over conventional crop growing systems. Plants grown in hydroponics systems are of higher quality and growth rate is also higher compared to conventional systems. For example, Resh (2001) found that using hydroponics systems production can be increased by 10 times as compared to conventional systems.

Hydroponics is profitable, more efficient, and a cleaner culture as compared to soil culture (Succop and Newman, 1998). Hydroponics is suitable for regions where soils are less fertile or have some toxicity or in regions which have high populations of people (Schoenstein, 1996). Due to decreased competition among roots of plants in hydroponics, the planting density of crops in hydroponics can be increased. Rate of growth is also faster in hydroponics and produce is high in vitamins and minerals as well. Skagg (1996) found that hydroponically grown plants are three times higher in vitamins and mineral content as compared to crops grown in soil. Plants grown hydroponically have a capacity to grow 25 percent faster as compared to plants grown in soil.

NUTRIENT MANAGEMENT

Nutrient management is a method of using crop nutrients as efficiently as possible to improve productivity without harming the environment. The main principle of crop nutrient management is to prevent over application of nutrients. Thefour R's of nutrient management are: application of the Right fertilizer source at the Right rate at the Right time and in the Right place. Nutrient management prevents losses in two ways: First is loss of money from purchasing fertilizers; Second is loss due to low yield from toxicities of some nutrients resulting from the unnecessary use of fertilizers. In hydroponics, nutrient management is a very necessary step. Total salt concentration, pH, and nutrient concentration ratio are three main characteristics aimed at nutrient management in soilless culture (Steiner, 1961; De Rijck and Schrevens, 1995).

In soilless culture, total salt concentration of a nutrient solution is the most important characteristic. If total salt concentration is too high, water nutrient level leads to salinity toxicity while low salt concentrations lead to nutrient deficiencies (Sonneveld, 1989). Electrical Conductivity (EC) is an easy and accurate method of measuring total salt concentration (Copper, 1977). Excessively high levels of nutrients induce osmotic stress, ion toxicity, and nutrient imbalance, while excessively low values are mostly accompanied by nutrient deficiencies and decreasing yield (Savvas and Passam, 2002).

The pH of a nutrient solution influences the availability of nutrients (Willumsen, 1980), therefore pH should be maintained in the optimum range. Nutrient solutions used for soilless culture should have a solution pH of between 5-6 (usually 5.5), so that the pH in the root environment is maintained between 6-6.5 (Jones, 1982). This is the pH range at which the nutrients are most readily available to plants (Skagg, 1996).

TYPES OF HYDROPONICS

There are many different types of hydroponic systems used for vegetable growing. On the basis of plumbing there are two types of systems: circulating systems and non-circulating systems which have further modifications. Circulating systems are those in which the nutrient solution is recirculated and nutrients levels are manipulated. Circulating systems are treated (heated or cooled) for the optimum growth of the plant in the system. A modification of the circulating systems is the Nutrient Film Technique (NFT). In this system the amount of nutrient solution is lower as compared to other modifications. Therefore, circulating systems conserve 20-40% of water and nutrients as compared to an open system, but due to ion accumulation during the recirculation of water maintaining nutrient level is very difficult (Lykas et al. 2006).

Non-recirculating systems are systems in which the nutrient solution is not recirculated and passes through the system only once, also known as a run-to-waste systems or open system. These systems have two advantages over the circulating system including no need for nutrient solution maintenance and reduced risk of disease infection (Jones Jr. 2005). The disadvantage of these systems is that large amounts of water and nutrients are wasted (Jensen, 1980; Massantini, 1976).

Several modifications of closed hydroponics systems are Nutrient Film Technique (NFT), Wick System, Ebb and Flow system, Drip system, Deep Water Culture, and Aeroponics. All these modifications are suitable for different types of crops. For example, NFT is good for lettuce (*Lactuca sativa* L.) and other herbs and a drip system is suitable for big plants like peppers (*Capsicum* spp. L.) and eggplants (*Solanum melongena* L.). NFT has various advantages over other systems of hydroponics. In NFT the volume of nutrient solution is reduced to lower levels which is easier to treat (heat or cool) as compared to the large volume of solution used in other hydroponics systems (Jensen and Collins, 1985; Orchard, 1980). Nutrient Film Technique (NFT) and its modifications are currently the most commonly used hydroponic systems (Jensen and Collins, 1985). This is due in large part to environmental concerns regarding ground water contamination, which means that all the water either used for hydroponics or pots should be collected and recycled (Blom, 1990).

Aeroponics is also one of the systems of hydroponics in which plant roots enclosed in a container absorb the nutrients from the mist of the nutrient solution periodically misted over them (Jensen and Collins, 1985). Aeroponics adequately supplies oxygen and water which are limiting factor in soil culture and hydroponics (Nir, 1981).

NUTRIENT FILM TECHNIQUE (N.F.T.)

Nutrient Film Technique is a modification of a closed system. It was developed in the late 1960s by Allen Cooper and his colleagues (Cooper, 1967; Windsor et al. 1979). It is believed to be a technique of the future (Spensley, 1978). This system consists of channels made up of plastic which is opaque and is UV protected (Graves, 1983). These channels are raised above the ground with the help of supports which provide a gentle slope to channels that provide effluent flow rate. The slope can also vary according to the crop to be grown in channels and total length of channels. As NFT is a closed system, regular monitoring of the nutrient solution is required to maintain nutrient composition.

The Nutrient Film Technique has several advantages and disadvantages over other hydroponics systems. Advantages include a more simple means of watering is employed by NFT and also greater control over the rooting environment (Graves, 1983). Another advantage is the needed volume of nutrient solution required relative to area of plant production is reduced so that energy required during cold weather for heating nutrient solution is also reduced (Thompson et al., 1998). Additionally, NFT is suitable for crops which require frequent cuttings like basil (*Ocimum basilicum* L.), lettuce, and Swiss chard (*Beta vulgaris* L.). This is because channels can be placed at comfortable heights above the ground making it more suitable for greenhouse employees for transplanting and harvesting. Disadvantages related to NFT include a high-installation cost similar to other hydroponics systems, the need for higher skilled growers due to need for proper monitoring of the nutrient solution. The risk in infection from one plant to another is greater in NFT as the same water is supplied to all plants (Spensley 1978; Graves 1983). Working with NFT can also lead to many other complications like higher nutrient levels at the front of the watering channel than at back of the system (Graves, 1983; Jones Jr., 2005). Another complication with NFT is that roots of plants increase in size with time, which may decrease the flow rate in the channel and again cause the problem of lowering the of nutrient gradient at the farthest end of the channel (Graves, 1983; Jones Jr., 2005). These complications can be reduced by decreasing channel length to 10 or 15 meter or by widening the channels (Jones Jr., 2005; Resh, 2013).

LETTUCE

Lactuca sativa, commonly known as lettuce belongs to the family Asteraceae (Ryder 1999). The popularity of lettuce has been rising since its domestication and today is the world's number one most cultivated vegetable used as salad (Ryder, 1999). Lettuce takes the largest proportion of area under hydroponics due to less skill required from growers for its cultivation in hydroponics and quick production cycle (Jones Jr., 2005).

There are numerous studies on lettuce grown in hydroponics such as the effect of EC of hydroponics solution and the effects of salinity on lettuce growth in NFT. In NFT, lettuce is sensitive to salt stress which results in poor growth and quality (Ahmed et al., 2010). Cresswell (1991), during his study on lettuce tip burn, revealed that irrigating hydroponics lettuce with water or a solution of calcium nitrate (100 mg Ca L^{-1}) can be an effective way to minimize loss due to tip burn. Lettuce grown hydroponically is also affected by the amount of carbon dioxide in the growth environment. Greenhouses with evaporative cooling systems and CO_2 augmentation allow for better yield and growth of lettuce. Air temperature and root temperature is required to be in specific limits for hydroponically grown lettuce. For lettuce production, air temperature should be 31°C and root temperature should be 24°C (Thompson and Langhans, 1998). Cooling the nutrient solution significantly reduced bolting and also reduced incidence of *Pythium aphanidermatum* (Jensen and Malter, 1995). The pH should be in optimal range for production of lettuce in hydroponics. Roosta (2011) looked for the effect of nutrient solution pH on vegetative growth of lettuce and concluded that safe acids should be used to reduce solution pH to 5 for commercial lettuce production.

BASIL

Basil belongs to genus *Ocimum* L. and originated in India (Paton, 1992). The genus *Ocimum* is very diverse having approximately 64 species identified and the number of basil cultivars is constantly increasing (Tucker and DeBaggio, 2009). Basil is cultivated for food, medicine, and religious purposes. Basil can be produced in the field, containers, or hydroponics. Research for basil production in hydroponics is still very limited, while there is significant amounts of research on basil production in field and container (Sifola and Barbieri, 2006). There are two systems of hydroponics for production of leafy crops: Deep Flow Technique (DFT) and Nutrient

Film Technique (NFT) (Al-Maskri et al., 2010; Jensen, 2002; Thompson et al., 1998). Each system has its own advantages and disadvantages. Research of basil in the field and container production, showed that with an increase in nitrogen concentration there was increase in shoot mass (Biesiada and Kuś, 2010; Golcz et al., 2006; Nurzyn´ska-Wierdak et al., 2012; Sifola and Barbieri, 2006). Suh and Park (1997) found that fresh mass per plant of basil grown hydroponically increased with decreasing EC value during his study on determining optimal EC for sweet, opal, and bush basil. Holbrook et al. (1993) found that with an elevated CO_2 concentration in the growth environment there was an increase in fresh weight of basil and spinach grown hydroponically. Maboko and Du Plooy (2013) during their study on high planting densities of basil in closed hydroponic system revealed that planting density of 40 plants m^{-2} can improve growth and yield significantly in the summer/fall season while for the spring/summer season planting density of 20 or 25 plants m^{-2} was recommended.

SWISS CHARD

Beta vulgaris commonly known as Swiss chard belongs to the family Amaranthaceae. It is also one of the leafy greens which are fast growing and gaining popularity in hydroponics production. Santamaria et al. (1999) during his study on comparison of fennel (*Foeniculum vulgare* Mill.), celery (*Apium* L.) and Swiss chard, found that Swiss chard did not tolerate NH_4 only nutrition, but accumulated less NO_3 than fennel and celery despite the higher uptake and specific absorption rates of nitrogen. Kaburagi et al. (2014) revealed that nitrogen uptake of Swiss chard grown hydroponically was not affected with increasing salinity of water during their study on barley (*Hordeum vulgare* L.) and Swiss chard. This study was focused on determining if sodium enhanced nitrate uptake while other crops showed a decrease in nitrate uptake with increasing salinity due to antagonistic effect of chlorine ions like in citrus (*Citrus* L.) (Cerezo et al. 1997), in maize (*Zea mays* L.) (Abd-El Baki et al. 2000) and in tomatoes (*Solanum lycopersicum* L.) (Debouba et al. 2006). Maboko and Du Plooy (2013) studied the effect of planting density and harvesting frequency on yield of hydroponically grown Swiss chard and concluded that planting density of 40 plants m^{-2} in combination with harvesting every 14 days was recommended for increased yield of Swiss chard.

DUTCH BUCKET SYSTEM

The Dutch bucket system is also known as the Bato bucket system which is mainly used for growing big plants having massive root system like eggplants, sweet peppers (*Capsicum annuum* L.), cucumbers (*Cucumis sativus* L.), and tomatoes (*Solanum lycopersicum* L.). The Bato bucket system is a closed systems of hydroponics in which water is collected and reused. The plants grown in this system usually require support which is provided with some substrate placed in buckets like perlite, vermiculite, expanded clay pellets, gravel, and coconut coir. In this system, short irrigation times are scheduled throughout day and nutrients are injected into irrigation water. Nutrient solution distributed to plants in the buckets and can be recaptured and reused. Media to be used for this system should have specific properties including being clean, should hold roots, should not clog system, and should not give or take nutrients or change the pH of nutrient solution.

SWEET PEPPER

Capsicum annum commonly known as sweet pepper or bell pepper is a member of the Solanaceae family and originated in New Mexico and Central America. The phenolic compound capsaicin is present in peppers and is responsible for its pungency. Different cultivars differ in content of this chemical which results in different kinds of peppers like bell, jalapeno, cherry, and cayenne. The colored bell pepper is the most popular for greenhouse cultivation because of its high value as compared to other peppers.

Most hydroponic greenhouse production of bell pepper (especially for colored peppers) plants are fertigated with a low volume irrigation system at regular frequency to plants growing in soilless media with low cation exchange capacity. There are some studies about disease management of bell peppers growing in hydroponics especially for *Pythium* and *Phytophthora*. Schuerger and Hammer (2009) during their study on use of cross flow membrane filtration to suppress root rot deduced that filters with pore size of <5 µm were effective in removing infected propagules and protected pepper plants from root disease. Rubio et al. (2010) looked for response of calcium and potassium on yield and fruit quality of sweet pepper and found that adequate management of calcium and potassium fertilization could help in improving yield and fruit quality of sweet pepper in hydroponics. Savvas et al. (2007) during his research on interactions between salinity and irrigation frequency on greenhouse hydroponically grown peppers, revealed that high irrigation frequency was helpful in increasing pepper fruit yield and quality even with low water quality because frequent irrigation slowed down salt accumulation in the root zone and prevented issues with salinity. San-Francisco et al. (2004) studied the effect of IAA (Indole 3-Acetic Acid) and IAA precursors on development and mineral nutrition of pepper plants in hydroponics and deduced that two IAA precursors L-tryptophan (Trp) and indole (Ind) showed the same effect as IAA because of conversion into IAA within plants.

As there are two hydroponics systems; open and closed, so there are many studies related to different nutrition and irrigation methods within these different systems, similarly Gul et al. (2011) studied the effect of nutrition and irrigation on sweet pepper production in hydroponics. It was concluded that in closed system fertilization of nitrogen (N) 240, phosphorus (P) 60, potassium (K) 300, magnesium (Mg) 50, ferrous (Fe) 6, manganese (Mn) 3, boron (B) 1.6, zinc (Zn) 2, calcium (Ca) 90, copper (Cu) 0.8 and molybdenum (Mo) 0.12 (mg L^{-1}) combined with irrigation based on light sum levels of 4 MJ m^{-2} was recommendable, while for open system fertilization of N 120, P 30, K150, Mg 25, Fe 3, Mn 1.5, B 0.8, Zn 1, Ca 30, Cu 0.4 and Mo 0.06 (mg L^{-1}) combined with irrigation based on light sum levels of 1 MJ m^{-2} was recommendable.

EGGPLANT

Solanum melongena L. commonly known as aubergine (France), melanzana (Italy), brinjal (India) or eggplant belongs to the family Solanaceae. It is a native of the subtropical areas of south-eastern Asia and was introduced into Europe by early Arab traders. Barbuta et al. (2014) recommended growing of eggplant in polyethylene (PE) bags in conditions where soil is compact, deleterious, or problematic. Savvas and Lenz (2000) studied the response of eggplant to salinity in recirculating hydroponics systems. High salinity significantly affected osmotic potential due to water uptake by plant being reduced and therefore less water towards fruit. Savvas and Lenz (2000) recommended an EC of 1.5 dS m^{-1}, while Moazed et al. (2014) and Mahjoor et al. (2016) recommended an EC of 2.5 dS m^{-1}. Mahjoor et al. (2016) concluded that eggplant yield (fruit weight, fruit diameter, plant height, and shoot dry weight) decreased significantly as the salinity level of irrigation water increased.

pH MANAGEMENT

Steiner (1961) revealed that in nutrient management for hydroponics there are three main characteristics to consider and these are total pH, salt concentration, and nutrient concentration ratio. Solution pH is the most crucial characteristic which can be affected by various factors. Hochmuth (2001) recommended a nutrient solution pH of 5.5-6.5 for greenhouse hydroponic production and Resh (2001) recommended a pH of 5.8-6.4. Ahn and Ikeda (2004) also reported 5-7 as optimum pH for hydroponic cultivation of Chinese chive (*Allium tuberosum* Rottler ex Spreng.).

Various studies examining optimum pH for hydroponic lettuce production reported decreases in leaf area, shoot dry weight, leaf length and width, and stomatal conductance due to pH not being maintained in the specified range (Whipker et al., 1996). Bugbee (2003) also reported that available K and P is slightly reduced in high pH hydroponic nutrient solutions.

Various chemicals are used for stabilizing nutrient solution pH in hydroponics. Burleigh et al. (2008) recommended use of citric acid (lime juice), acetic acid (vinegar), nitric acid, phosphoric acid, and sulfuric acid for lowering the pH of water for plant cultivation. Furthermore, use of muriatic acid should be avoided as it contains chlorine which may damage the plants. Frick and Mitchell (1993) compared the use of 2-(N-morpholino) ethanesulfonic acid (MES) buffer and Amberlite DP-1 (cation-exchange resin beads) for stabilizing the pH of nutrient solution for production of brassicas and concluded that the greatest shoot harvest index and highest canopy seed yield rate were obtained when 6% resin bead treatment was used for stabilizing pH.

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CHAPTER 2: FERTILIZER AND CULTIVAR SELECTION FOR LETTUCE, BASIL, AND SWISS CHARD IN HYDROPONICS

ABSTRACT

Nutrient Film Technique trials were conducted to quantify the effect of different hydroponic fertilizers (Jack’s 5-12-26, Peter’s 5-11-26, and Dyna Gro 7-9-5) on different cultivars of lettuce, basil, and Swiss chard. Results indicate that Swiss chard yield was affected only by cultivars, with ‘Fordhooke Giant’ producing the greatest fresh weight across all fertilizer treatments. For lettuce production, interaction between fertilizers and cultivars was significant, indicating that ‘Mirlo’ and ‘Rubysky’ had greater growth in all three fertilizers, while ‘Dragoon’ performed well using Dyna Gro and Jacks but not in Peters. For basil, dry weight production showed significant interaction between fertilizers and cultivars indicating that ‘Largeleaf’ produced greater dry weight in Jacks, while ‘Lemon’ produced greater dry weight in Peters. ‘Dragoon’ and ‘Lemon’ grown with Dyna Gro showed tip burn. Therefore, hydroponic producers should select lettuce and basil cultivars based on fertilizer used, while Swiss chard cultivars can be selected based on yield.

INTRODUCTION

A very practical definition of “soilless culture” is growth of non-aquatic plants with roots in a complete inorganic medium, where plant nutrient needs are supplied using a nutrient solution. Soilless culture has various classification systems and methods like hydroponics, aeroponics, gravel culture, vermiculaponics, and rockwool culture (Maxwell, 1986). The term ‘Hydroponics’ was coined by Dr. William Frederick Gericke, and refers to plants being grown in water with or without a substrate. Hydroponic crop production has gained popularity in recent years worldwide due to its distinctive features like efficient use of fertilizers and water, greater control of growing climate, and pest control (Bradley and Marulanda, 2000).

There are many other essential attributes that lead to increased use of hydroponics to grow vegetables over field production. Maboko and Du Plooy (2009) reported that hydroponic cultivation of leafy vegetables leads to improved yield and quality. Resh (2001) reported that growth rate in hydroponics can be 10 times higher as compared to conventional field systems. Hydroponics is also a solution for regions with problematic soils (Schoenstein, 1996). Higher nutrient content of hydroponically produced plants increases the importance further. Skagg (1996) found that hydroponically grown plants are three times higher in vitamins and mineral content as compared to crops grown in soil. The other positive point of hydroponics over soil culture is that it is more profitable, efficient, and a cleaner culture (Succop and Newman, 1998).

Nutrient Film Technique (NFT) was developed by Allen Cooper and his colleagues in 1960s at the Glasshouse Crops Research Institute in Littlehampton, England (Resh, 1995). Nutrient Film Technique is a practice of growing plants in a shallow film of nutrient solution flowing near to bare roots in a water tight channel. According to Wilcox (1982), NFT provides a solution for problems of aeration faced in tank hydroponics and removes the inert media. Nutrient Film Technique is the preferred system of hydroponics for plants having rapid growth cycles like lettuce (*Lactuca sativa* L.), basil (*Ocimum basilicum* L.), Swiss chard (*Beta vulgaris* L.), and kale (*Kalmiopsis leachiana* (L.F. Hend.) Rehder). Nutrient Film Technique provides a greater control over the rooting environment (Graves, 1983), while the volume of nutrient solution used relative to area of plant production is reduced (Thompson et al., 1998). There are some problems also associated with NFT systems like high installation cost, and the need for higher skilled growers as proper monitoring of nutrient solution is required. Spensley (1978) reported that the risk of viral infection dispersal is also high in NFT system as the same water is supplied to all plants.

Selection of a suitable fertilizer is one of the main challenge in NFT. The fertilizer to be used in NFT should have balanced amount of essential elements and should not form any precipitate during its use. The plant should grow as a normal plant without facing any type of stress (Jones, 1982). As the nutrient solution in NFT system recirculates, macro nutrients as well as ions used in small quantity by plants accumulate in the nutrient solution. This necessitates frequent renewal of nutrient solution, which can lead to environmental pollution due to the release of mineral elements (Giuffrida et al., 2002). There are various hydroponic fertilizers available in market, but the selection may vary according to crop and the system used. In most studies, self-made nutrient recipes were used for growing leafy vegetables in hydroponics including Cooper's, Imai's, Massantini's, and Hoagland solution (Karimaei et al., 2001; Shah and Shah, 2009). This method of preparing nutrient recipes is also known as the made-from-scratch method (Mattson and Peters, 2014). While preparing a nutrient recipe precipitates may form. Mattson and Peters (2014) found that it is hard for small hydroponic growers to manage concentrations of nutrients while preparing of their own hydroponic recipes which has resulted in focusing towards commercially prepared water soluble fertilizers. This method is also known as one or two bag approach which include products like Jack's Hydroponic (5-12-26), Jack's Hydro-FeED (16-4-17), and Chem.-Grow 10-8-22 (Mattson and Peters, 2014; Shah and Shah, 2009). Draghici et al. (2016) compared the use of organic fertilizer with inorganic fertilizer for lettuce cultivation in a NFT system.

During the last decade, there have been various studies which discussed hydroponics nutrition topics related to various fertilizer compositions, major and minor elements, and effects of changing the ratios of various ions (Maxwell, 1986). Studies have also been reported on optimum pH and total salt concentration and nutrient concentration ratio, which are three main characteristics to focus on for nutrient management in hydroponics (Steiner, 1961; De Rijck and Schrevens, 1995). Different fertilizers may consist of nutrient elements in different forms which may or may not be accessible to plants in hydroponics. Fertilizer consisting of nitrogen in nitrate form is better for hydroponic cultivation (Guminska, 1987) because Guminska and Kobierzyñska-Golab (1976) revealed that the use of fertilizer with ammonium forms of nitrogen promoted the growth of bacteria which is harmful for plants. Guminska (1987) also reported that in hydroponics copper should be applied in sulfate form, manganese should be applied in chelated form, zinc can be applied in both sulfate and chelate forms while chelated form iron used in nutrient solution gave better results than the sulfate form. Recommendations of suitable fertilizer and cultivars of leafy greens suitable for hydroponics is lacking. The objectives of our research were to determine the effect of different hydroponic fertilizers in market on leafy greens production and evaluation of different species of leafy greens in a NFT system.

MATERIALS AND METHODS

Plant Material and Growth Conditions: Seeds of lettuce ‘Dragoon’ (Romaine type), ‘Mirlo’ (Butterhead type), ‘Panisse’ (Oakleaf type), ‘Ruby Sky’ (Leaf lettuce), ‘Rex’ (Butterhead type), ‘Oscarde’ (Oakleaf type) and for Swiss chard ‘Rainbow chard’, ‘Barese’, ‘Fordhooke Giant’ were obtained from Johnny’s Selected Seeds (Winslow, MN). Seeds of basil ‘Large leaf’, ‘Lemon’, ‘Sweet basil’ was obtained from Burpee seeds (Warminster, PA). Seeds were sown in rockwool starter cubes size 1.5 cm^3 (Gordan, Milton, ON) on 12 February, 2016 and transplanted into Hydrocycle Pro NFT series (Growers supply, Dyersville, IA) on 20 March, 2016 at the Department of Horticulture and Landscape Architecture Research Greenhouses in Stillwater, OK. Each table had 10 channels measuring 10 cm W x 5 cm D x 900 cm L. Channel lids had eighteen 2.5 cm site holes, spaced 20 cm on center. One plant was placed in each slot and 15 plants per cultivar per table were transplanted. The flood tables had a slope of 2.8% approximately between the irrigation and drainage end and the water flowing along this slope and was collected in the irrigation tank and recirculated by pump to the irrigation pipe.

Fertilizers: Three flood tables were used each supplied with either Jacks 5-12-26 (J.R. Peters, Allentown, PA), Peters 5-11-26 (J.R. Peters, Allentown, PA), or Dyna Gro 7-9-5 (Dyna Gro, Richmond, CA). Tap water was used to prepare the nutrient solution. Calcium nitrate (American Plant Products, Oklahoma City, OK) was used with the Jack's and Peter's due to lack of calcium in these fertilizers. Once tanks were at their 40-gallon capacity the 147.41 grams of Jacks and Peters and 97.52 grams of calcium nitrate were added initially according to recommended rates, while Dyna Gro 7-9-5 recommended the 9.8 ml per gallon of water so 392 ml were added to 40 gallon capacity tank.

EC, pH, and Data Collection: Each plant was scanned using SPAD-502 chlorophyll meter (SPAD-502, Konica Minolta, Japan) and atLEAF chlorophyll meter (FT Green LLC, Wilmington, DE) at the time of harvest. For each plant, SPAD and atLEAF reading were taken from three different mature leaves at base, middle, and top of the plant. The EC of all the nutrient solutions was maintained at 1.5-2.5 mm cm^{-1} and the pH was maintained at 5.5-6.5. The pH and EC of each solution was checked every 3 days. Two plant samples from the each treatment were sent for nutrient analysis after harvest. All essential nutrients and protein content was analyzed in this nutrient analysis test. At the end of the study, data was collected on dry weight (plants cut at base and dried for 2 days at 56°C) and fresh weight.

Data Analysis: The experimental was conducted as a split-plot arrangement in a design was split plot randomized complete block design replicated over time. Separate analyses were conducted for each species of plant. Factors were fertilizer (three levels) and cultivars (six levels for lettuce, three levels for basil, and three levels for Swiss chard). The experimental unit for fertilizer was 66 plants for lettuce and 33 plants for basil and Swiss chard. The experimental unit for cultivar was 11 plants of each crop. Tests of significance are reported at the 0.05, 0.001, and 0.0001 level. Protected least significance difference (LSD) method was used for comparing differences between treatment means. Data analysis were as conducted generated using SAS/STAT software, Version 9.4 (SAS Institute, Cary, NC). ANOVAs were conducted using PROC MIXED with an LSMEANS statement and a DIFF option.

RESULTS

No significant interaction was found between cultivar x fertilizer for Swiss chard. Fresh weight, SPAD, and atLEAF were affected by cultivar main effects, but no dry weight affects were observed in Swiss chard (Table 1). ‘Fordhooke Giant’ had the greatest fresh weight, which was different than ‘Barese’ and ‘Rainbow’, while atLEAF and SPAD reading were greater for ‘Barese’ (Table 2).

For lettuce, there was an interaction between cultivar x fertilizer for fresh weight and dry weight, while no interaction was found for atLEAF and SPAD readings, but both were affected by cultivar (Table 1). For Dyna Gro fertilizer, ‘Dragoon’, ‘Mirlo’, and ‘Rubysky’ lettuce had the greatest fresh weight, which was different than all other cultivars (Figure 1). For Peters fertilizer, ‘Mirlo’ had the greatest fresh weight, which was different than all other cultivars (Figure 1). For Jacks fertilizer, fresh weight of ‘Dragoon’, ‘Mirlo’, ‘Panisse’, and ‘Rubysky’ was greater than ‘Oscard’ and ‘Rex’ (Figure 1). All cultivars, except ‘Dragoon’, had greater fresh weight in Dyna

Gro and Peters, than Jacks. ‘Mirlo’ had the greatest dry weight, which was different than all other cultivars in Dyna Gro and Peters, while there was no significant difference for dry weight of different cultivars in Jacks (Figure 2). ‘Mirlo’ had a greater dry weight in Dyna Gro and Peters than in Jacks. ‘Rubysky’ and ‘Oscard’ had a greater dry weight in Dyna Gro and Peters, but dry weight in Jacks was not different than Peters. There were no differences in dry weight for ‘Panisse’, ‘Rex’, and ‘Dragoon’ among fertilizers (Figure 2).

For dry weight of basil, atLEAF and SPAD readings had a significant cultivar x fertilizer interaction (Table 1). For Jacks, ‘Largeleaf’ basil had a greater dry weight, which was significantly different than ‘Lemon’ and ‘Sweet’. ‘Lemon’ had a greater dry weight than ‘Largeleaf’ and ‘Sweet’ in Peters (Figure 3). ‘Largeleaf’ produced significantly greater dry weight in Jacks than in Dyna Gro and Peters. ‘Lemon’ produced greater dry weight in Jacks and Peters, which was significantly different than ‘Lemon’ in Dyna Gro (Figure 3).

For lettuce, basil, and Swiss chard, SPAD and atLEAF readings were correlated (Table 5). SPAD and atLEAF readings of Swiss chard varied as ‘Barese’ had the greatest and ‘Fordhooke Giant’ the lowest readings (Table 2). For lettuce, both chlorophyll meters were affected by cultivar. The SPAD and atLEAF readings were significantly greater for ‘Dragoon’, ‘Mirlo’, ‘Oscard’, and ‘Rubysky’ than ‘Panisse’ (Table 3). For basil, significant interaction was found for SPAD and atLEAF readings between cultivar x fertilizer. For Dyna Gro, ‘Largeleaf’ and ‘Sweet’ showed greater SPAD readings, which were significantly different than ‘Lemon’, while atLEAF readings were significantly greater for ‘Sweet’ than ‘Largeleaf’ and ‘Lemon’. In Jacks and Peters, ‘Sweet’ showed significantly greater SPAD and atLEAF readings as compared to ‘Largeleaf’ and ‘Lemon’ (Figure 4 and 5). For ‘Largeleaf’ and ‘Sweet’, SPAD and atLEAF readings were greater in Dyna

Gro, which were significantly different than in Jacks and Peters. ‘Sweet’ had a greater atLEAF and SPAD readings in Jacks and Peters as compared to Dyna Gro.

SPAD and atLEAF were not correlated with N, phosphorus (P), and potassium (K). In Swiss chard, SPAD and atLEAF were correlated with calcium (Ca) and ferrous (Fe) (Table 5). In lettuce, SPAD and atLEAF both were negatively correlated to sodium (Na) concentration in the leaf. In basil, SPAD was negatively correlated with Na, and positively correlated with sulfur (S) and Fe, while atLEAF was negatively correlated to Ca (Table 5).

DISCUSSION

Cultivar selection is one of the most important factors influencing growth characteristics, yield, and nutritional quality of Swiss chard (Gil et al. 1998). Some investigators recommended ‘Fordhooke Giant’ as being the best variety among green leaved varieties of Swiss chard for yield in different parts of the United States (Gorman et al., 2011; Herner and Taylor 1974; Weiss, 1983). The greater fresh weight of ‘Fordhooke Giant’ may due to genetic characteristics. Pokluda and Kuben (2002) reported a mean fresh weight of 248 g for ‘Fordhooke Giant’, which was slightly lower than ‘Bright Lights’. According to Maboko and Du Plooy (2013) yield of ‘Fordhooke Giant’ was also affected by planting density in a closed hydroponic system and recommended a planting density of 40 plants per meter square. Mattson and Peters (2014) recommended Jacks 5-12-26 fertilizer for lettuce, herbs, and leafy greens grown hydroponically. Soberg (2016) also recommended that Jacks Hydro-FeEd (16-4-17), Jacks Hydroponic (5-12-16), and modified Sonneveld’s solution can be used to grow lettuce, Swiss chard, and coriander (*Coriandrum sativum* L.) hydroponically. Burch and Chambers (2011) used Dyna Gro during experiment for establishment of *Cypripedium* L. ‘Lady Slipper’ orchids in Ebb and Flow system of hydroponics. Burke (2009) used Peters for hydroponic production of peanuts (*Arachis hypogaea* L.) and recommended that low temperature of rockwool pads lead to a reduction in pod development. Vital et al. (2003) also reported interaction between lettuce cultivars (‘Cinderella’, ‘Monica’, ‘Elizabeth’, and ‘Princess’) and hydroponic fertilizers for shoot weight, which corresponds to our results that there was an interaction between fertilizers and lettuce cultivars for fresh weight and dry weight (Table 1). For romaine lettuce, Boroujerdnia and Ansari (2007) also reported a significant interaction between nitrogen fertilizer and Iranian cultivars (‘Pich Awazi’ and ‘Pich Varamini’) for fresh weight and dry weight. Karimaei et al. (2001) compared the use of Hoagland solution and nutrient solution proposed by Massantini et al. (1988) for two romaine lettuce cultivars (‘Black Seeded’ and ‘White Seeded’) and two crisphead lettuce cultivars (‘Martha’ and ‘Olimpo’) and also reported interaction between cultivars and nutrient solution for leaf number, total dry weight and leaf dry weight. Maboko and Du Plooy (2008) recommended that ‘Lucy Brown’, ‘PF 1283’, ‘Robinson’, ‘Duke’, ‘Aviram’, and ‘Sahara’ for hydroponic cultivation of crisphead lettuce while using ‘Hygroponic’ fertilizer and calcium nitrate. For basil, Simon et al. (1999) recommended aroma of the cultivars as the first consideration in the selection, but the primary reason for cultivar selection should be growth and productivity. Walters and Currey (2015) recommended that ‘Largeleaf’ and ‘Lemon’ cultivars of basil were best suited for NFT system due to their morphological characteristics like short internodes, large sized leaves, and high branching which prevents lodging. This corresponds to current experiment results as ‘Largeleaf’ produced greater dry weight for Jacks and Dyna Gro, while ‘Lemon’ produced greater dry weight in Peters (Figure 3).

According to Ali et al. (2009) color is an influential trait for leafy greens as it affects preference, acceptability, and also is found to be an indicator of antioxidant properties of leafy vegetables. Vittum (1963) concluded that greenness of leafy vegetables is also an index for carotene content. Ferrante et al. (2004) also suggested that color of leafy vegetables can be considered as an indicator of antioxidant properties. Colonna et al. (2016) used SPAD readings as an indicator of greenness for 10 different green leafy vegetables, and concluded that SPAD readings were affected by the light intensity at time of harvest and recommended harvesting of leafy vegetables at low light intensity. In this experiment, atLEAF readings were greater than SPAD readings for all cultivar, which corresponds to finding by Dunn et al. (2015) that both sensors were correlated and had an average difference of 5.5 with reading of atLEAF higher than SPAD in ornamental cabbage (*Brassica oleracea* var. *capitata* L.).

Leaf chlorophyll concentration is directly correlated to N concentration (Shaahan et al. 1999), thus a chlorophyll meter can be used to estimate N concentration of a leaf. But, many investigators also reported no correlation between a chlorophyll meter reading and leaf N concentration. Altland et al. (2002) concluded that SPAD readings were not a good estimate of plant N status in vinca (*Catharanthus roseus* L.). Westerveld et al. (2003) reported that SPAD is not a suitable instrument for estimation of leaf N content in carrots (*Daucus carota* L.) and onions (*Allium* L.). Sibley et al. (1996) reported no significant relationship between leaf N concentration and SPAD readings in Red maple (*Acer rubrum* L.). Rodriguez and Miller (2000) reported limited use of SPAD for estimation of leaf N concentration in St. Augustine grass (*Stenotaphrum secundatum* (Walter) Kuntze). The reason behind this non-correlation of SPAD and atLEAF with N concentration can be that chlorophyll content in some crops may differ even due to deficiency of nutrients like Fe, S, magnesium (Mg), manganese (Mn) other that N (Masoni et al., 1996). Shaahan et al. (1999) also reported that iron deficiency in mandarin (*Citrus* x *limonia* Osbeck (pro sp.) (*limon* × *reticulate*)) and guava (*Psidium guajava* L.) can interfere with chlorophyll content, therefore can affect chlorophyll measurements.

Plants were also checked for physiological disorders which affect their appearance. Tip burn was detected in one cultivar of lettuce, ‘Dragoon’, and one cultivar of basil, ‘Lemon’ using Dyna Gro. Tip burn is a serious physiological disorder of lettuce because even small spots of tip burn on leaves make lettuce unacceptable by consumers (Hartz et al., 2007). There are many reasons suggested by various studies for the cause of tip burn in lettuce. Collier et al. (1982) suggested that various factors interact for causing tip burn in lettuce and calcium deficiency is the main reason behind tip burn. According to Collier and Tibbitts (1984), humidity and root temperature in the growing environment affects the calcium concentration in leaf tissue and therefore causes tip burn in lettuce. Calcium content of ‘Dragoon’ and ‘Lemon’ was significantly greater for leaves of plants in Dyna Gro than leaves of plants in Jacks and Peters (Table 4). These results supported the findings from the study by Hartz et al. (2007) who found that soil calcium content was unrelated to tip burn in romaine lettuce. Cox et al. (1976) suggested that tip burn in lettuce was related to growth rate of the cultivar and concluded that conditions favorable for high growth rate were conducive. Bres and Weston (1992) also concluded that tip burn in NFT grown lettuce in greenhouse was influenced by environmental conditions. Crisp et al. (1976) suggested that interaction of calcium content, boron content, and age of plant may be the causal reason behind tip burn of lettuce.

CONCLUSION

From the present experiment, ‘Fordhooke Giant’ is the greatest producing cultivar of Swiss chard on the basis of fresh weight produced for all three fertilizers in hydroponics. Fertilizer had no effect on Swiss chard indicating that other cultivars may perform well using these fertilizers as well. ‘Barese’ had greater sensor readings, as compared to other cultivars of Swiss chard and may have greater nutritional value. For lettuce, ‘Dragoon’, ‘Mirlo’ and ‘Rubysky’ are well suited for production in hydroponics based on growth and color. Thus, ‘Mirlo’ and ‘Rubysky’ can be recommended for Dyna Gro and Peters. ‘Dragoon’ in Dyna Gro would not be recommended because of tip burn. For basil, ‘Largeleaf’ and ‘Sweet’ can be recommended for Jacks while ‘Lemon’ can be recommended for both Jacks and Peters in hydroponics. Future research should investigate other cultivars suitable for hydroponics using these fertilizers or should evaluate other fertilizers for these cultivars.

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TABLES AND FIGURES

Table 1. Interaction and main effect for Swiss chard (‘Fordhooke Giant’, ‘Barese’, and ‘Rainbow’), lettuce (‘Dragoon’, ‘Mirlo’, ‘Rubysky’, ‘Oscard’, ‘Panisse’, and ‘Rex’), basil (‘Largeleaf’, ‘Lemon’, and ‘Sweet’), and hydroponic fertilizers.

	Cultivar	Fertilizer	C x F
		Swiss chard	
Fresh weight	***[z]	NS	NS
Dry weight	NS	NS	NS
atLEAF	***	NS	NS
SPAD	***	NS	NS
		Lettuce	
Fresh weight	***	***	*
Dry weight	***	***	*
atLEAF	***	NS	NS
SPAD	NS	NS	NS
		Basil	
Fresh weight	NS	NS	NS
Dry weight	*	*	**
atLEAF	***	NS	***
SPAD	***	*	**

[z] Indicates significant at or non-significant (NS) at *P ≤ 0.05, **P ≤ 0.001, or ***P ≤ 0.0001

Table 2. Main effect of cultivar on Swiss chard for fresh weight, atLEAF, and SPAD sensor readings. (n=33)

Cultivar	Fresh weight***[z] (g)	atLEAF*** (unitless)	SPAD*** (unitless)
Barese	168.2c[y]	54.8a	47.9a
Fordhooke Giant	296.6a	40.8b	38.2b
Rainbow	219.0b	41.4b	34.6c

[z] Indicates significant at or non-significant (NS) at *P ≤ 0.05, **P ≤ 0.001, or ***P ≤ 0.0001.

[y] Means within a column followed by same lowercase letter are not significantly different by pair wise comparison in mixed model (P ≤ 0.05).

Table 3. Main effect of lettuce cultivars for SPAD and atLEAF sensor readings. (n=33)

Cultivar	SPAD*[z] (unitless)	atLEAF*** (unitless)
Dragoon	27.1a[y]	33.4a
Mirlo	26.4a	34.7a
Rubysky	28.3a	34.1a
Oscard	27.2a	35.2a
Panisse	17.2c	27.8c
Rex	19.2b	30.4b

[z] Indicates significant at or non-significant (NS) at *$P \leq 0.05$, **$P \leq 0.001$, or ***$P \leq 0.0001$.

[y] Means within a column followed by same letter are not significantly different by pair wise comparison in mixed model ($P \leq 0.05$).

Table 4. Calcium content (%) of ‘Dragoon’ lettuce and ‘Lemon’ basil.

Cultivar	Dyna Gro	Jacks	Peters
Dragoon^{NSz}	1.4a^{y}	1.2a	1.2a
Lemon***	2.7a	2.1b	2.2b

^{z}Indicates significant at or non-significant (NS) at *P ≤ 0.05, **P ≤ 0.001, or ***P ≤ 0.0001.

^{y}Means within a row followed by same letter are not significantly different by pair wise comparison in mixed model (P ≤ 0.05).

Table 5. Linear correlation coefficients of different nutrient content with SPAD and atLEAF sensor readings. (n=18)

Nutrients	Basil SPAD	Basil atLEAF	Lettuce SPAD	Lettuce atLEAF	Swiss chard SPAD	Swiss chard atLEAF
Calcium	-0.356^{NS}[z]	-0.410*	-0.152^{NS}	-0.004^{NS}	0.568*	0.517*
Sodium	-0.632**	-0.690**	-0.604***	-0.452*	-0.331^{NS}	-0.347^{NS}
Sulfur	0.644**	0.6147**	-0.070^{NS}	-0.078^{NS}	0.104^{NS}	0.093^{NS}
Ferrous	0.695**	0.724***	0.069^{NS}	0.107^{NS}	0.444*	0.464*
SPAD	1.000	0.978***	1.000	0.721***	1.000	0.776***

[z] Indicates significant at or non-significant (NS) at *$P \le 0.05$, **$P \le 0.001$, or ***$P \le 0.0001$.

Figure 1. Interaction between lettuce cultivars and hydroponic fertilizers for fresh weight.

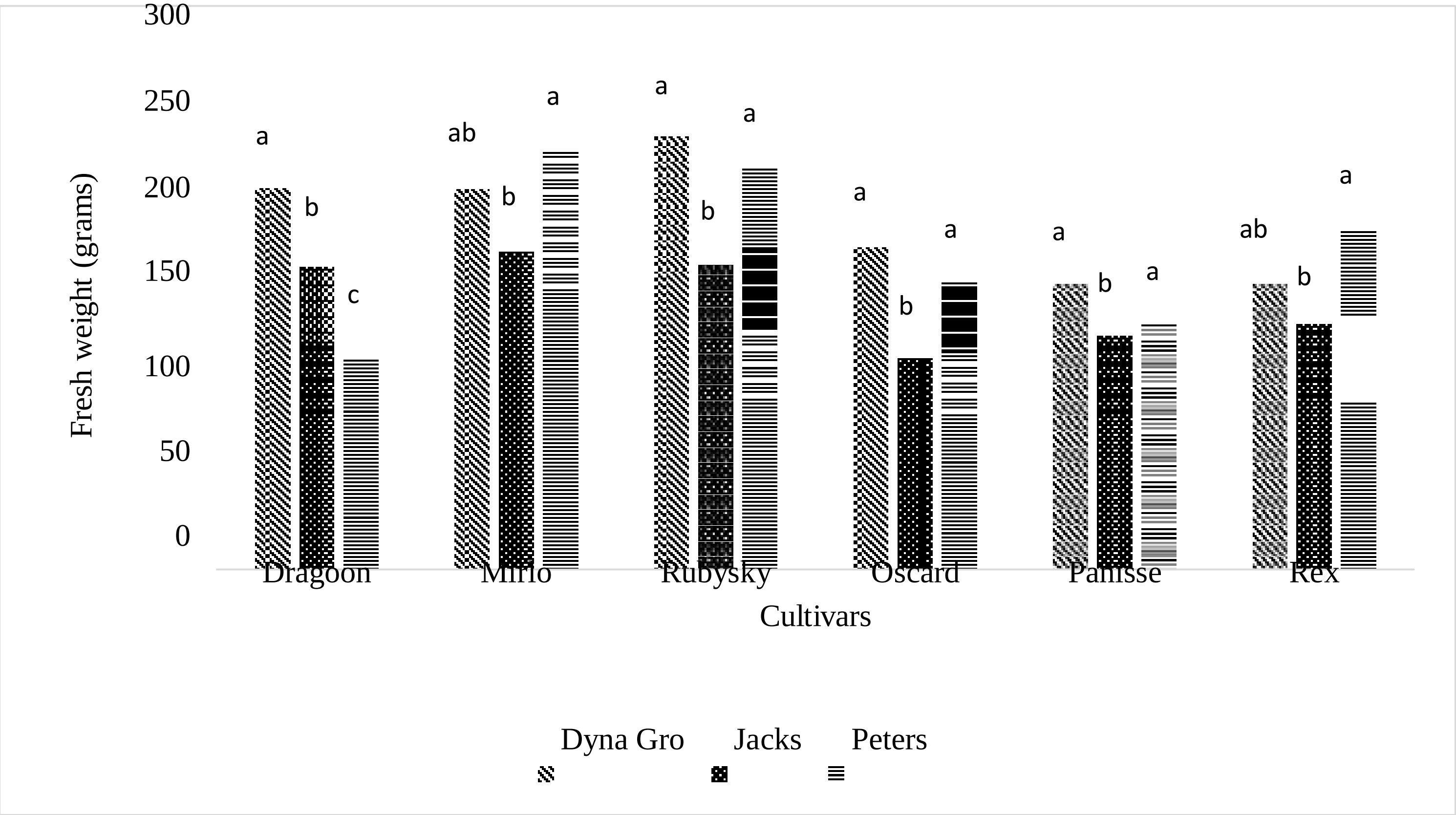


Figure 2. Interaction between lettuce cultivars and hydroponic fertilizers for dry weight.

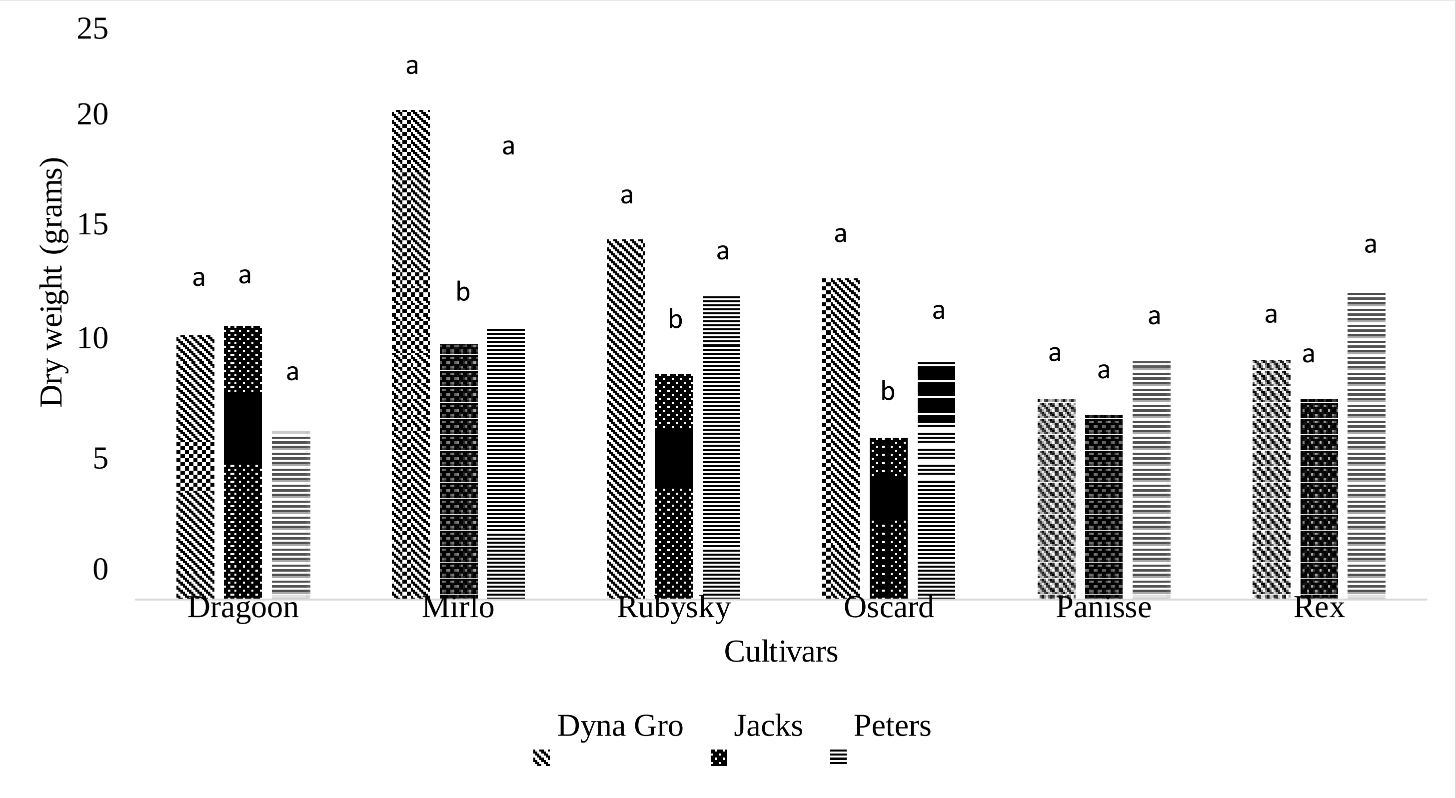


Figure 3. Interaction between basil cultivars and hydroponic fertilizers for dry weight.

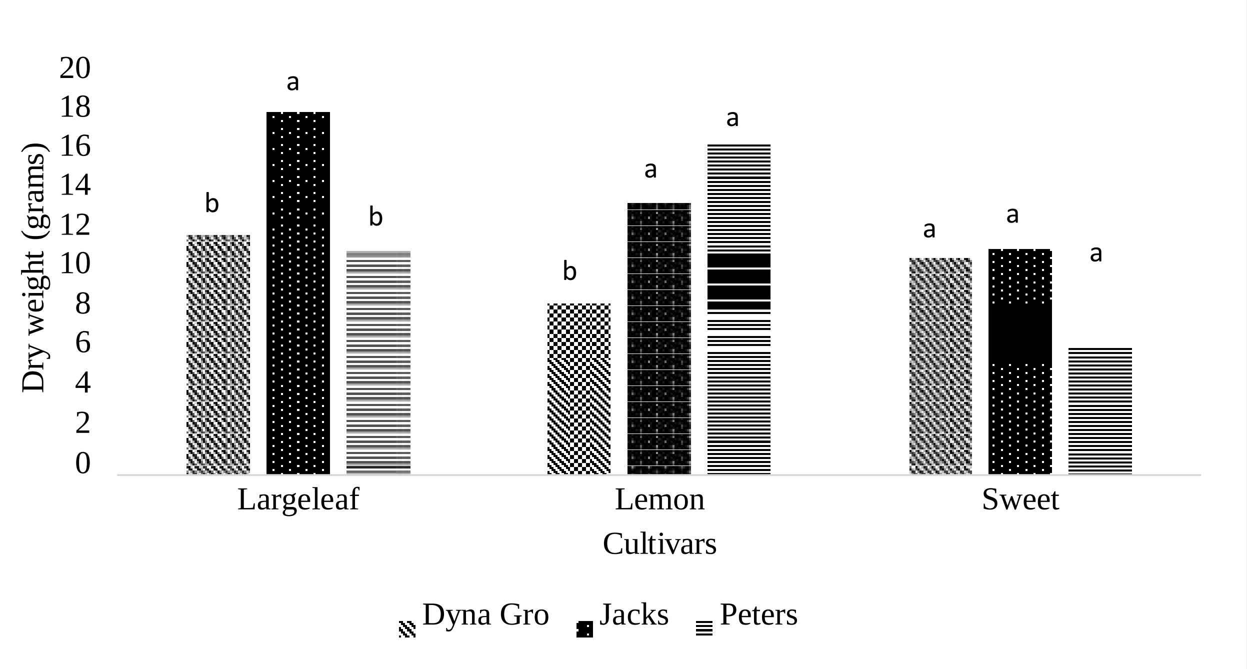


Figure 4. Interaction between basil cultivars and hydroponic fertilizers for SPAD readings.

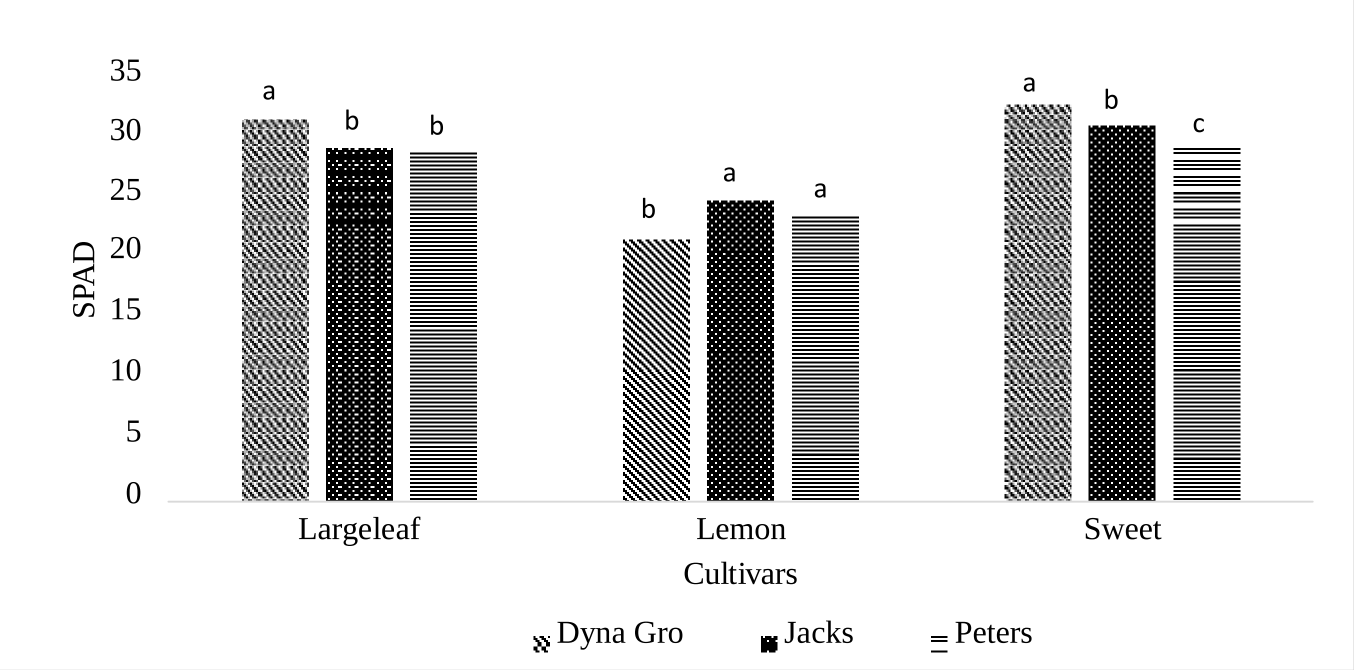
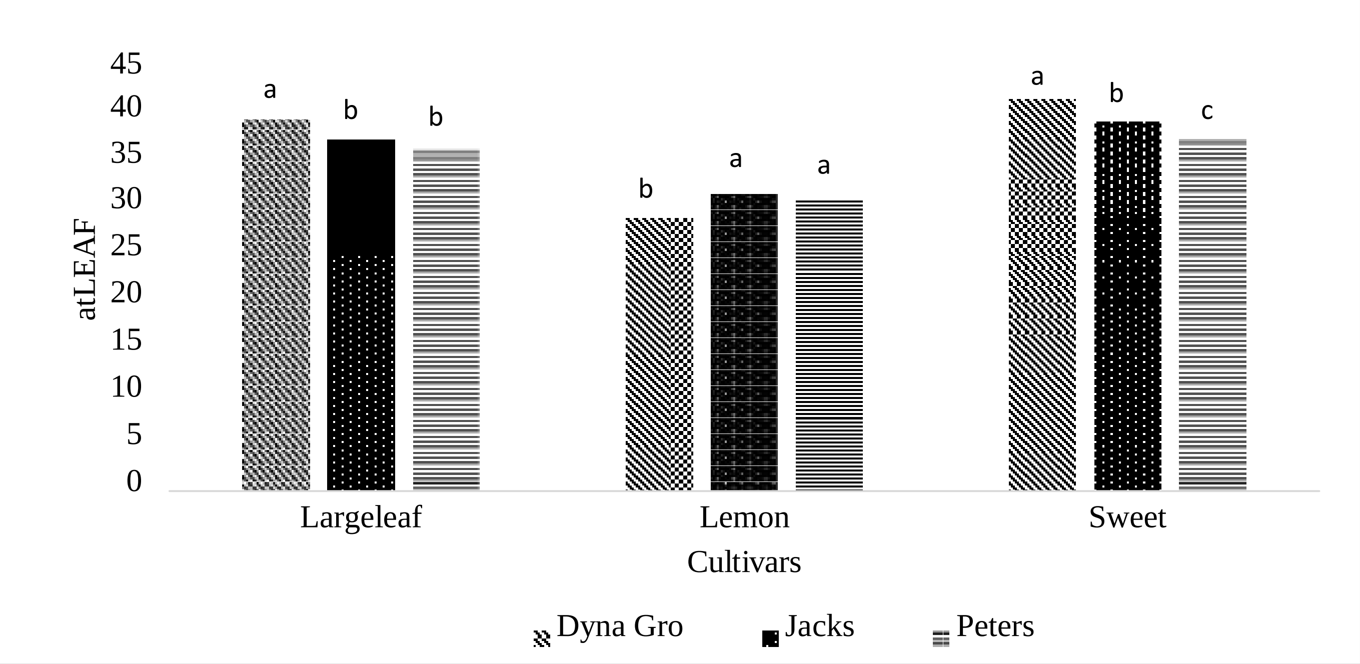


Figure 5. Interaction between basil cultivars and hydroponic fertilizers for atLEAF readings.



CHAPTER 3. FERTILIZER AND CULTIVAR SELECTION FOR SWEET PEPPER AND EGGPLANT IN HYDROPONICS.

ABSTRACT

Dutch Bucket System trials were conducted to quantify effect of different hydroponic fertilizers (Jacks 5-12-26, Peters 5-11-26, and Dyna Gro 7-9-5) on different cultivars of sweet pepper and eggplant. Results indicated that sweet pepper yield was affected only by the fertilizer, with Peters producing the greatest yield among both cultivars. For sweet pepper fresh and dry shoot weight, interaction between fertilizers and cultivars was significant, indicating that 'Orangella' had greater growth in Jacks and Peters fertilizers, while there was no difference among cultivars in Dyna Gro. Shape index was not effected with any factor. For eggplant yield, there was no main effect nor interaction between factors, while interaction between fertilizers and cultivars was significant for shoot fresh weight production. Shoot fresh weight was greatest for 'Angela' than 'Jaylo' in Jacks and Dyna Gro. Therefore, hydroponic producers should select a fertilizer for sweet pepper cultivation in hydroponics based on yield, while for eggplant more cultivars and fertilizers need to be evaluated for yield difference.

INTRODUCTION

Soilless culture, or growing plants without soil, is considered a sustainable method for cultivation of various greenhouse vegetable crops like tomatoes (*Solanum lycopersicum* L.), cucumbers (*Cucumis sativus* L.), peppers (*Capsicum* L.), lettuce (*Lactuca sativa* L.), Swiss chard (*Beta vulgaris* L.), and eggplant (*Solanum melongena* L.). According to Van Os et al. (2002) the reasons for initial development of soilless culture were problems with soil salinity, lack of fertile soil, and soil borne diseases, all of which can hinder field production. Recently, Bowe and Reinelt (1991) reported that soilless culture is gaining in popularity due to an increase in quality and quantity of vegetables that can be produced year round locally. In addition, soilless culture methods like hydroponics can result in 10 times greater growth rate of crops over conventional field production, can be more efficient and profitable, and has resulted in higher nutrient content (Succop and Newman, 1998; Resh, 2001, Skagg, 1996; Jensen and Malter, 1995). According to Albaho et al. (2008) soilless culture is a good idea for increasing the agriculture sustainability as well improving the environment health.

Long term crops like vine tomatoes, sweet peppers, cucumbers, and roses (*Rosa* L.) are often grown in Dutch or bato bucket type hydroponic systems (Jones, 1985; Roberto, 2003). This is a container type hydroponics system that was introduced in the early 1980s by Dutch and Belgian growers (Lieten, 2004). According to Love et al. (2015) Dutch bucket systems cover the fourth largest area under hydroponics after nutrient film technique, vertical towers, and wicking beds. The buckets are filled with substrates to provide support to the plant. According to Van Os et al. (2002) the commonly used substrates for Dutch bucket system are coconut coir, perlite, LECA (Lightweight Expanded Clay Aggregates), gravel, or sand. Perlite is the most common rooting medium used in this a bucket system (Gerhart and Gerhart, 1992). A nutrient solution is supplied to each bucket by one or two drip emitters, which drains through the bottom of the bucket. The drainage fitting is designed in such a way that a small amount of nutrient at bottom is retained and excess water is drained out and can be recycled through a drain tube (Roberto, 2003).

According to Latique et al. (2013) the most important factor affecting crop yield and quality in hydroponics is the nutrient solution. In most studies, nutrient solutions like Copper’s, Hoagland

and Arnon's, and Yamazaki's solution, which required self-preparation, have been evaluated in hydroponics production of various crops. Self-preparation of nutrient solution for hydroponic production is good for large scale growers, while small scale growers face difficulty in managing nutrient concentration (Mattson and Peters, 2014). Therefore, commercially prepared, also known as one or two bag approach, fertilizers are gaining in popularity. According to Mattson and Peters (2014) a single bag fertilizer performed well for production of peppers, cucumbers, and tomatoes at University of Arizona Controlled Agriculture Center greenhouse.

Soilless culture has been considered as easy and rapid method for screening of the cultivars of different crops for production, drought tolerance and some physiological disorders (Ogbonnaya et al., 2003). Some studies evaluated the performance of sweet pepper cultivars for different objectives. Won et al. (2009) evaluated 12 sweet pepper cultivars for hydroponic cultivation and concluded that 'Special' and 'Cupra' for red, 'Boogie', 'Fellini', and 'President' for orange, and 'Fiesta' and 'Derby' for yellow color had greater yield.

There are some studies which compare the use of different hydroponic fertilizers for cultivation of lettuce, basil, and Swiss chard (Singh et al., 2017). While studies related to selection of suitable fertilizer and cultivars of sweet pepper and eggplant for hydroponic production is lacking. The objectives of this study were to evaluate different commercially prepared hydroponic fertilizers available in market for sweet pepper and eggplant production and evaluation of different species of sweet pepper and eggplant in Dutch bucket system.

MATERIALS AND METHODS

Plant materials and growth conditions: Seeds of sweet pepper 'Bentley' and 'Orangella', eggplant 'Angela' and 'Jaylo' were obtained from Johnny's Selected Seeds (Winslow, ME) and sown on

12 February, 2016. Seeds were sown in rockwool starter cubes size 1.5 cm^3 (Gordan, Milton, ON) on 12 February, 2016 and transplanted into a PolyMax Dutch Bucket System (Growers Supply, Dyersville, IA) on 20 March, 2016 at the Department of Horticulture and Landscape Architecture Research Greenhouses in Stillwater, OK. Seeds for the second replication were sown on 15 February, 2017 and transplanted into the system on 23 March, 2017. A single plant was transplanted in each bucket. The Dutch buckets were placed 56 cm apart and the rows were 144 cm apart and arranged on opposite sides of the irrigation and drainage pipes. Water was provided to plants by one drip emitter, which supplied 1 gallon per hour of water. Buckets were filled with the Mother Earth Hydroton expanded clay pebbles (National Garden Wholesale Sunlight Supply, Vancouver, WA). Water that drained away was again recirculated from a 40-gallon capacity storage tank.

Fertilizers: Both crops were fertigated by Jacks 5-12-26 (J.R. Peters, Allentown, PA), Peters 5-11-26 (J.R. Peters, Allentown, PA) and Dyna Gro 7-9-5 (Dyna Gro, Richmond, CA). Tap water was used to prepare the nutrient solution. Calcium nitrate (American Plant Products, Oklahoma City, OK) was used with the Jacks and Peters because calcium was not supplied in the fertilizer. As our tanks were of 40-gallon capacity, the 147.41 grams of Jacks and Peters and 97.52 grams of calcium nitrate were added initially according to recommended rates, while Dyna Grow recommended an application rate of 9.8 ml per gallon of water, so 392 ml was added to the 40 gallon capacity tank.

EC, pH, and Data Collection: For the peppers the fruits were harvested when 80% color (yellow or orange) development occurred and eggplants were harvested when full size weighing 250-400 grams. Harvesting was done once a week. The EC of all the nutrient solutions was maintained at 2.5-3.5 mmhos cm^{-1} and the pH was maintained at 5.5-6.5 for eggplants and 5.5-6 for peppers. The pH and EC of the solution was checked every second day. At each harvest, data was collected on fruit fresh weight, size, and presence of blossom end rot. At the end of the study, data was collected on fresh shoot weight, dry shoot, and root weight (shoots and roots dried for 2 days at 56°C). Shape index and average fruit weight was recorded to know sweet pepper fruit quality. Shape index was defined by the equatorial to longitudinal length ratio. Height and width of each fruit was taken from randomly selected plant. Nutrient analysis was done for the leaves of eggplant.

Data Analysis: The experimental was conducted as a split-plot arrangement in a design was split plot randomized complete block design replicated over time. Separate analyses were conducted for each species of plant. Factors were fertilizers (three levels) and cultivars (two levels for each crop). The experimental unit for fertilizer was 18 plants while the experimental unit for cultivar was 9 plants of each crop. Tests of significance are reported at the 0.05, 0.001, and 0.0001 level. Protected least significance difference (LSD) method was used for comparing differences between treatment means. Data analysis were as conducted generated using SAS/STAT software, Version 9.4 (SAS Institute, Cary, NC). ANOVAs were conducted using PROC MIXED with an LSMEANS statement and a DIFF option.

RESULTS AND DISCUSSION

Fertilizer and cultivar effect and their interaction on yield, root weight, shoot fresh, and dry weight, average fruit weight and shape index of sweet pepper

Interaction between fertilizer and sweet pepper cultivars occurred for shoot fresh and dry weight, and average fruit weight. Shoot fresh weight and dry weight were significantly greater for ‘Orangella’ cultivar as compared to ‘Bentley’ when fertilized with Jacks and Peters (Figure 1 and 2). There was no significant difference between shoot fresh and dry weight of sweet pepper cultivars when fertilized with Dyna Gro (Figure 1 and 2). For average fruit weight, it was significantly greater for 'Orangella' as compared to 'Bentley' when fertilized with Jacks, while there was no significant difference between two cultivars when fertilized with Peters and Dyna Gro (Figure 3). Rubio et al. (2010) considered fruits weighing less than 100 grams to be unmarketable, while for our experiment average fruit weight ranged from 122- 172 grams which can assumed to be marketable. Rubio et al. (2010) looked for response of calcium and potassium on yield and fruit quality of sweet pepper and found that adequate management of calcium and potassium fertilization could help in improving yield and fruit quality of sweet pepper in hydroponics. Gul et al. (2011) studied the effect of nutrition and irrigation on sweet pepper production in hydroponics. It was concluded that in a closed system, fertilization of nitrogen (N) 240, phosphorus (P) 60, potassium (K) 300, magnesium (Mg) 50, ferrous (Fe) 6, manganese (Mn) 3, boron (B) 1.6, zinc (Zn) 2, calcium (Ca) 90, copper (Cu) 0.8 and molybdenum (Mo) 0.12 (mg L^{-1}) combined with irrigation based on light sum levels of 4 MJ m^{-2} was recommendable, while for open system fertilization of N 120, P 30, K150, Mg 25, Fe 3, Mn 1.5, B 0.8, Zn 1, Ca 30, Cu 0.4 and Mo 0.06 (mg L^{-1}) combined with irrigation based on light sum levels of 1 MJ m^{-2} was recommendable. Mattson and Peters (2014) compared the nutrient content of Jacks 5-12-26 with the hydroponic recipe prepared by university of Arizona, which worked well for hydroponic production of tomatoes, cucumbers, and peppers and found it to be similar in nutrient content.

For sweet pepper, fertilizer effect was found on the yield and root weight, while there was no significant effect for shoot dry weight, and shape index (Table 1). Yield of sweet pepper was significantly greater in Jacks and Peters as compared to Dyna Gro (Table 2). Urrestarazu and Mazuela (2005) reported that adding potassium peroxide at rate of 1 gm L^{-1} resulted in 20% increase in sweet pepper yield in hydroponics. According to Flores et al. (2004), supplementation of Ca^{2+} and NO_3^- in culture media helps to increase nutritional quality and commercial quality of sweet pepper in hydroponics. Xu et al. (2006) reported that type of nitrogen in nutrient solution may also affect fruit yield of sweet peppers in hydroponics and suggested that 0.9-1.8 mM NH_4^+-N in nutrient solution may help to increase yield while above this will limit absorption of K in sweet peppers and affect yield. The root weight of sweet pepper was significantly greater in Jacks as compared to Peters and Dyna Gro (Table 2). Cultivar main effect was not found for any of parameter for our experiment but there are some other factors also affecting sweet pepper cultivar selection in hydroponics. According to Cerkaukas (2017), susceptibility of cultivars to water borne pathogens also affect decision on cultivar selection. During a study on different cultivars for susceptibility to *Fusarium oxysporum*, Cerkaukas (2017) concluded that 50% of plants of cultivar 'Bentley' were affected with *F. oxysporum.* According to Savvas et al. (2007), in closed hydroponics frequent irrigation is recommended because it enhances yield, and improve fruit quality of sweet pepper due to delay in salt accumulation in root zone. Jovicich et al. (1999) reported that four plants per meter square pruned to four stems per plant increased yield for sweet pepper production in hydroponics.

Fertilizer and cultivar effect and their interaction on yield, root weight, shoot fresh, and dry weight of eggplant

Interaction between fertilizer and eggplant cultivars occurred for shoot fresh weight. Shoot fresh weight was significantly greater for 'Angela' cultivar as compared to 'Jaylo' when fertilized with Jacks and Dyna Gro. There was no significant difference between shoot fresh weights of eggplant cultivars when fertilized with Peters (Figure 3). Voogt (1986) recommended 16 mM of total N for eggplant production in rockwool, while Savvas et al. (2008) said that this concentration can be applied to eggplant grown in any inert material. For hydroponic eggplant production, the nitrate form of N should be dominating in the nutrient solution while ammonical form should have small part (Elia et al., 1996). There is very limited peer reviewed information regarding micronutrient requirement of eggplant in soilless culture. Voogt (1986) reported that eggplant needs 15, 10, 5, 0.75 and 0.5 µM of Fe, Mn, Zn, Cu, and Mo, respectively. According to de Kreij and Basar (1997) eggplant is susceptible to boron deficiency and young fully developed leaves turn yellow at the distal end.

For eggplant, fertilizer effect was found on the shoot dry weight, while cultivar effect was found only for the shoot dry weight of eggplant (Table 3). There was no significant difference for yield and root weight among different fertilizer treatments (Table 3). The shoot dry weight of eggplant was significantly greater in Jacks as compared to Peters and Dyna Gro (Table 4). The shoot dry weight of ‘Angela’ cultivar was significantly greater than ‘Jaylo’ (Table 4). Savvas and Lenz (2000) studied the response of eggplant to salinity in recirculating hydroponics system. They found that high salinity significantly affected osmotic potential due to which water uptake by plant is reduced and therefore less water towards fruit and recommended an EC of 1.5 dS m^{-1} while Moazed et al. (2014) and Mahjoor et al. (2016) recommended an EC of 2.5 dS m^{-1}. Mahjoor et al. (2016) concluded that eggplant yield (fruit weight, fruit diameter, plant height, and shoot dry weight) decreased significantly as the salinity level of irrigation water increased.

Eggplant fruits developed abnormal color after 2 months of production. Fruits of ‘Jaylo’ cultivar turned brownish purple in color, while ‘Angela’ cultivar fruits developed a yellow color. Foliar analysis found that the concentration of all nutrients was above the recommended limit except N (Table 5). Rouphael et al. (2003) also reported greater accumulation of macro and micro nutrients in closed system of hydroponics. According to Dorai (2001) ion toxicity in hydroponics may lead to decrease in fruit quality of tomato therefore proper nutrient levels in nutrient solution will help to produce high quality products.

CONCLUSION

From the results of the present experiment, Jacks and Peters can be recommended for sweet pepper production in hydroponics because yield and root weight was significantly greater in both. For cultivar selection, ‘Orangella’ can be recommended because plants produced significantly greater shoot fresh and dry weight in Jacks and Peters. However, some other studies reported ‘Bentley’ to be susceptible to *Fusarium*. For eggplant, there was no effect of cultivar or fertilizer, while ‘Jaylo’ can be recommended as yield was higher than ‘Angela’. Peters can be recommended fertilizer as yield was higher as compared to Jacks and Dyna Gro. By looking at interaction among fertilizers and eggplant cultivars for shoot fresh weight, Jacks and Dyna Gro can be recommended for cultivation of ‘Angela’ cultivar. Future, research should investigate causal reason behind the yellowing of eggplant fruits. Different recycling rates of nutrient solutions for eggplant production should be evaluated.

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TABLES AND FIGURES

Table 1. Interaction and main effect for sweet pepper (‘Orangella’ and ‘Bentley’) and hydroponic fertilizers (Jacks, Peters, and Dyna Gro).

	Cultivar	Fertilizer	Cultivar * Fertilizer
Yield	NS[z]	*	NS
Shoot fresh weight	***	NS	**
Root weight	NS	***	NS
Shoot dry weight	***	NS	*
Shape index	NS	NS	NS
Average fruit weight	NS	NS	*

[z] Indicates significant at or non-significant (NS) at *P ≤ 0.05, **P ≤ 0.001, or ***P ≤ 0.0001.

Table 2. Fertilizer main effect on yield and root weight of sweet pepper (‘Orangella’ and ‘Bentley’) (n=9).

	Yield	Root weight
Jacks	3697.76a[z]	104.47a
Peters	3080.97a	86.60b
Dyna Gro	1378.47b	39.11c

[z] Means within a column followed by same lowercase letter are not significantly different by pairwise comparison in mixed model ($P \leq 0.05$).

Table 3. Interaction and main effect for eggplant (‘Jaylo’ and ‘Angela’) and hydroponic fertilizers (Jacks, Peters, and Dyna Gro).

	Cultivar	Fertilizer	Cultivar* Fertilizer
Yield	NS[z]	NS	NS
Shoot fresh weight	**	***	*
Root weight	NS	NS	NS
Shoot dry weight	***	***	NS

[z] Indicates significant at or non-significant (NS) at *P ≤ 0.05, **P ≤ 0.001, or ***P ≤ 0.0001.

Table 4. Fertilizer and cultivar main effect on shoot dry weight of eggplant (n=9).

Fertilizer	Shoot dry weight
Jacks	204.07a[z]
Peters	191.26b
Dyna Gro	193.42b

Cultivar	Shoot dry weight
Jaylo	184.30b
Angela	248.20a

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[z] Means within a column followed by same lowercase letter are not significantly different by pairwise comparison in mixed model ($P \leq 0.05$).

Table 5. Foliar analysis of eggplant grown in Dutch bucket over 2 months using Jacks, Peters, and Dyna Gro along with recommended limits.

Nutrients	Recommended	Observed
Nitrogen (%)	4.20	3.62
Phosphorus (%)	0.30	0.38
Potassium (%)	3.50	3.83
Calcium (%)	0.80	4.00
Magnesium (%)	0.25	1.02
Manganese (ppm)	50	144.8
Iron (ppm)	50	158.1
Boron (ppm)	20	96.3
Zinc (ppm)	20	76.6

Figure 1. Interaction between sweet pepper cultivars and hydroponic fertilizers for shoot dry weight.

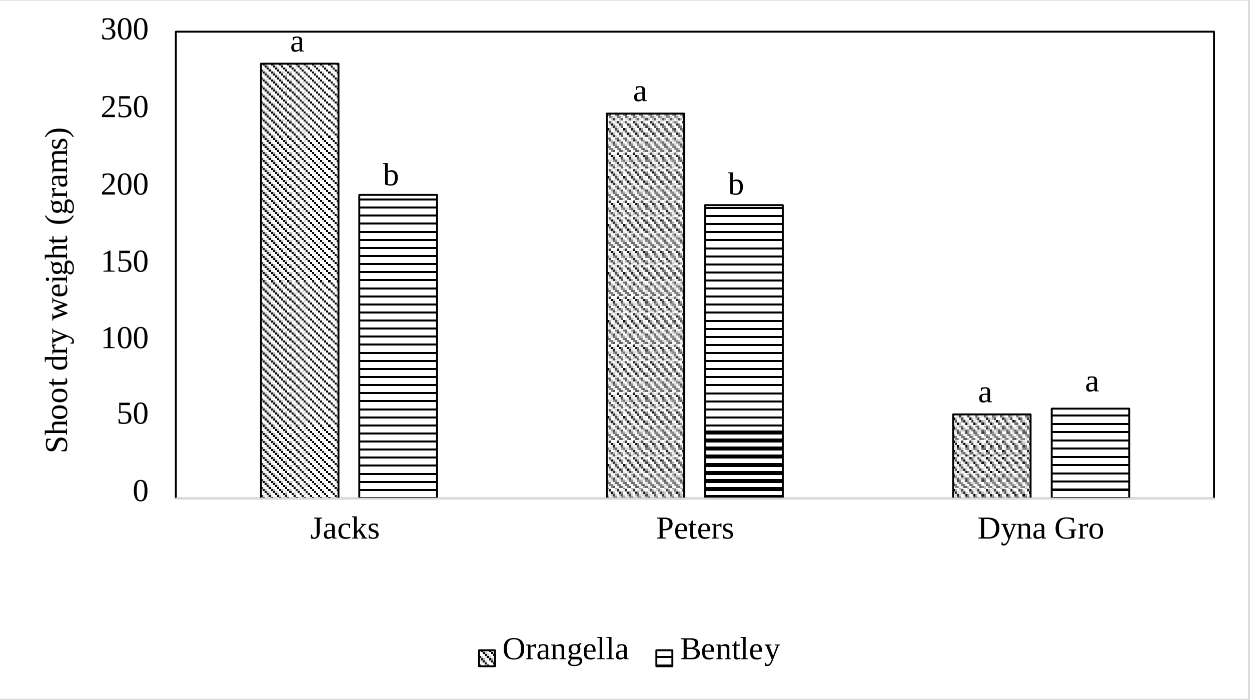


Figure 2. Interaction between sweet pepper cultivars and hydroponic fertilizers (Jacks, Peters, and Dyna Gro) for shoot fresh weight.

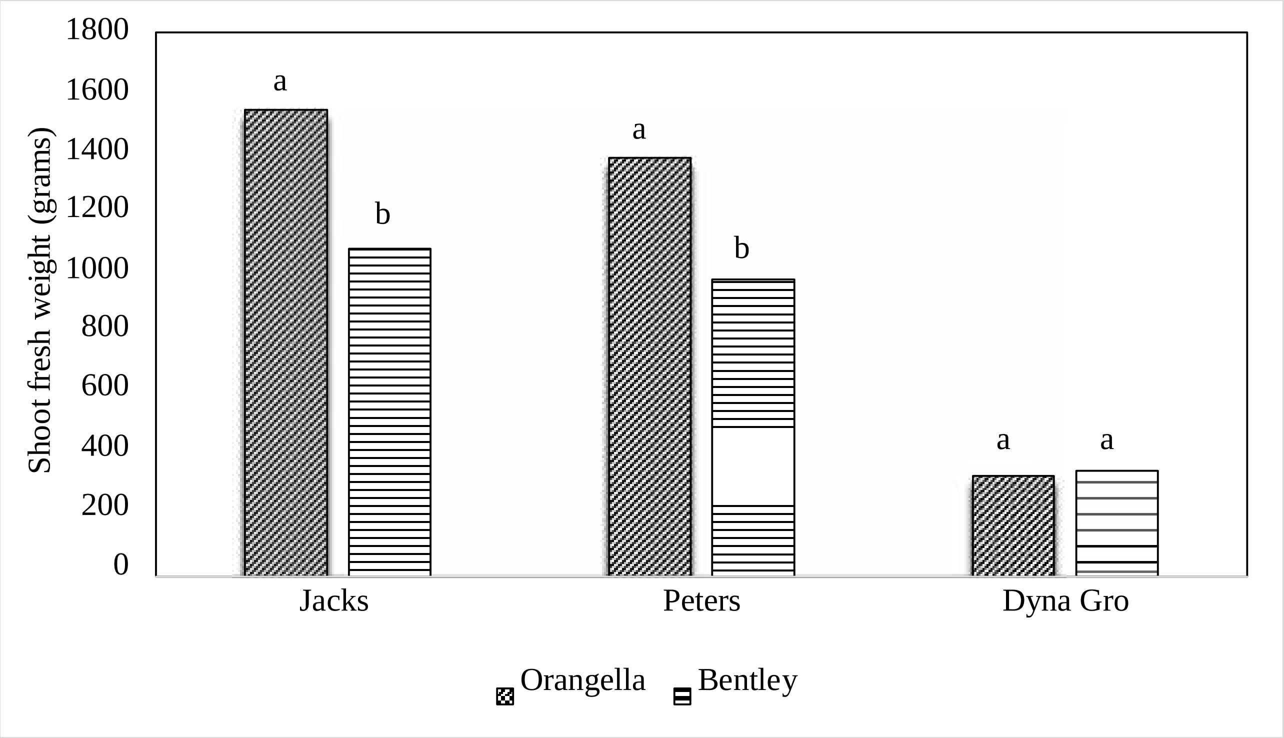


Fig 3. Interaction between sweet pepper cultivars and hydroponic fertilizers (Jacks, Peters, and Dyna Gro) for average fruit weight (grams).

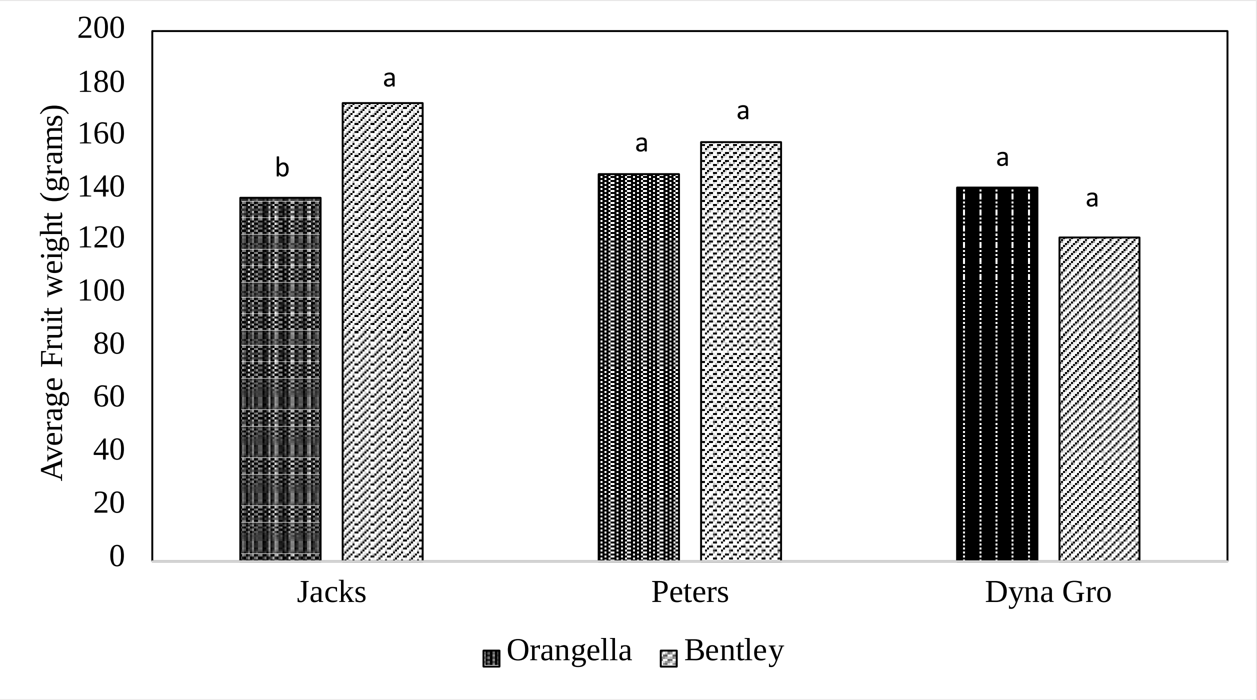
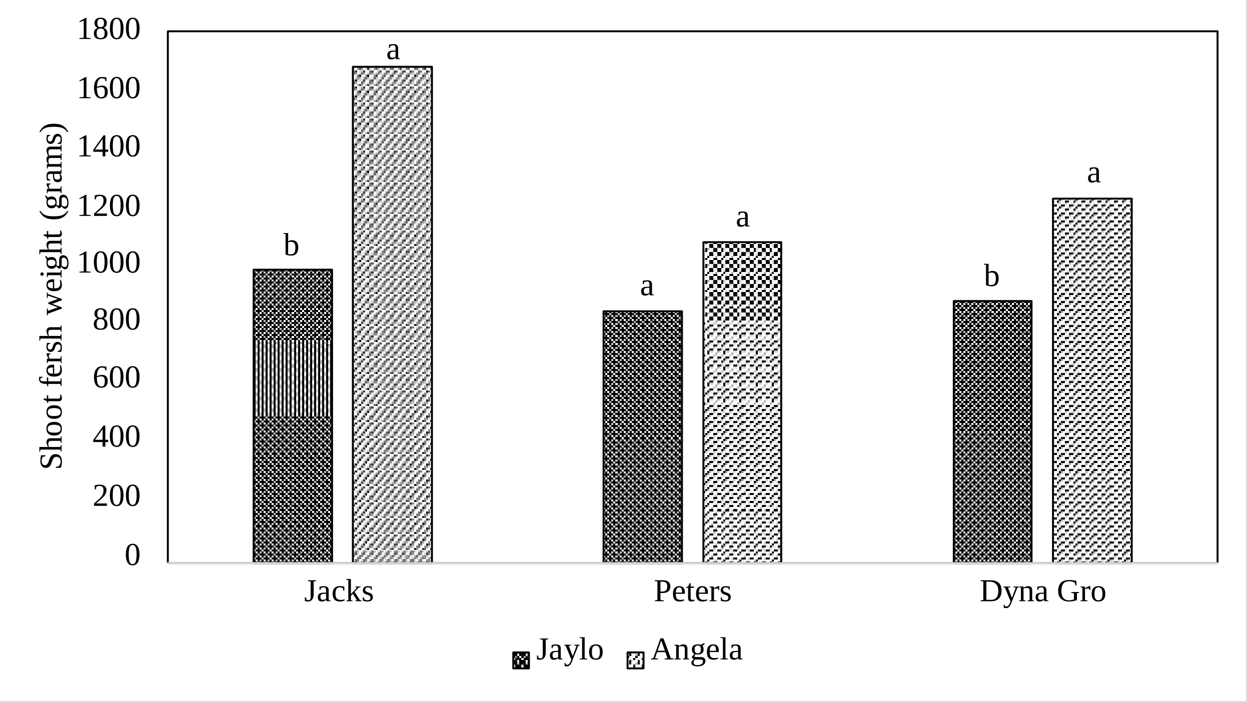


Figure 4. Interaction between eggplant cultivars and hydroponic fertilizers (Jacks, Peters, and Dyna Gro) for shoot fresh weight.



CHAPTER 4: EVALUATION OF ALTERNATIVE PH BUFFERS IN HYDROPONIC SYSTEMS AND THEIR EFFECT ON GROWTH AND DEVELOPMENT OF DIFFERENT LEAFY GREENS

ABSTRACT

Use of hydroponics is increasing due to its ability to produce food needed for increasing population in future years. There are various problems associated with hydroponic production and pH maintenance is one of them. Our objective was to quantify the effect of different alternative pH buffers on growth of different leafy greens and stability of nutrient solution pH. Lettuce, basil, and Swiss chard were transplanted into Ebb and Flow system of hydroponics and nutrient solution pH was maintained using different pH buffers (pH down, lime juice, vinegar). The nutrient solution pH was maintained between 5.5 and6.5. The pH was most stable using pH down and amount used was also less as compared to lime juice and vinegar. The cost was significantly greater for pH down and lime juice as compared to vinegar. The yield of lettuce was not significantly different for pH down and lime juice while for basil and Swiss chard yield decreased significantly in lime juice. Therefore, growers can use lime juice as alternative for pH down for lettuce production but not for basil and Swiss chard.

INTRODUCTION

By 2050, the human population is assumed to reach 8.9 billion (USAID, 2004) and a major challenge for the increased population will be food security. The supply of fresh produce will be necessary for maintaining human health. Hydroponic or soilless techniques for production is the best solution for this problem due to higher production rates and more nutritious food (Skagg, 1996). Hydroponics can be defined as a technique of growing non-aquatic plants without soil in a nutrient solution with or without soilless substrate (Arancon et al., 2015). Hydroponics also helps to overcome problems faced in field crop cultivation like soil-borne diseases, disease and pest infestations, and environmental stresses. Therefore, new growers of edible crops are interested in hydroponic cultivation. Maintaining an adequate nutrient solution is often cited as a major obstacle to hydroponic production. Steiner (1961) indicated that for nutrient management in hydroponics, three main characteristics including pH, salt concentration, and nutrient concentration ratio need to be monitored. Solution pH is the most crucial characteristic, which can be affected by various factors. Frick and Mitchell (1993) indicated that pH of a hydroponic nutrient solutions fluctuate due to the unbalanced anion and cation exchange reaction. According to Hershey (1992) the type of nitrogen available in the hydroponic fertilizer also affects the pH of the nutrient solution.

Several studies on hydroponic production have concluded that plant nutrients are available at specific pH ranges. According to Resh (2004) slightly acidic pH is optimum for hydroponic production as iron (Fe), manganese (Mn), calcium (Ca), and magnesium (Mg) may form precipitates and become unavailable at pH above 7. Islam et al. (1980) reported that at higher pH, the amount of Fe, Mn, Mg, potassium (K), and Ca increased in the plants, but these ions were not translocated to the shoot but instead remain stored in the roots. Bugbee (2003) also reported that availability of K and phosphorus (P) is slightly reduced in a high pH nutrient solution. Hochmuth (2001) recommended a nutrient solution pH of 5.5-6.5 for greenhouse hydroponic production while Resh (2004) recommended a pH of 5.8-6.4. Ahn and Ikeda (2004) also reported a pH of 5 to 7 as optimum for hydroponic cultivation of Chinese chive (*Allium tuberosum* Rottler ex

Spreng.). Various studies examining optimum pH for hydroponic lettuce (*Lactuca sativa* L.) production reported a decrease in leaf area, shoot dry weight, leaf length and width, and stomatal conductance due to the pH not being in a specified range (Whipker et al., 1996).

There are various chemicals which can be used to stabilize the pH of a nutrient solution in hydroponics. Burleigh et al. (2008) recommended use of citric acid (lime juice), acetic acid (vinegar), nitric acid, phosphoric acid, and sulfuric acid for lowering the water pH for plant cultivation. Furthermore, use of muriatic acid should be avoided due to chlorine which may damage the plants. Chen et al. (2015) also reported that wood vinegar can be used for hydroponic cultivation of lettuce at a rate of 0.25 ml L^{-1}. Frick and Mitchell (1993) compared use of 2-(N-morpholino) ethanesulfonic acid (MES) buffer and Amberlite DP-1 (cation-exchange resin beads) for stabilizing the pH of nutrient solution for production of mustard (*Brassica L.*). Others have reported using phosphoric acid for control of the pH in hydroponics and has the added benefit of not acting as an additional source of phosphorus (Bruning et al., 2012). The concentration of chemicals used for pH stabilization can also affect plant growth. Stahl et al. (2008) used different concentrations of MES for hydroponic culture of cucumber (*Cucumis sativus* L.) and concluded that plant growth was affected with increasing concentrations.

Stabilizing the pH of a nutrient solution is necessary for optimum crop productivity in hydroponics (Frick and Mitchell, 1993). Using a safe, natural, and cheap acidic material will have greater significance on plant growth as well as food quality than using inorganic acids (Kirimura and Inden, 2005). Therefore, the objective of present study was to evaluate use of lime juice, vinegar, and a commercial pH down product as organic pH stabilization methods for production of leafy greens in an Ebb and Flow hydroponics system.

MATERIALS AND METHODS

Plant Material and Growth Conditions: Seeds of lettuce ‘Oscard’, basil (*Ocimum basilicum* L.) ‘Citrus’ and Swiss chard (*Beta vulgaris* L. *var*. cycla) ‘Magenta Sunset’, were obtained from Johnny’s Selected Seeds (Winslow, ME). Seeds were sown in 1.5 cm^3 rockwool starter cubes (Gordan, Milton, ON) on 2 February, 2017. A styrofoam sheet was used to support the plants and 5 cm diameter slots were drilled with holes spaced 28 x 28 cm apart. Plants were transplanted individually into 5 cm net pots placed in each slot of the Styrofoam sheet on an Ebb and Flow table (Gro Master, Maple Park (Virgil), IL) after attaining two true leaves on 6 March, 2017. Tables were located at the Department of Horticulture and Landscape Architecture Research Greenhouses in Stillwater, OK. Each table had 30 net pots and three tables were used with 10 plants of each cultivar per table. The experiment was replicated three times with plants being completely randomized. In each table, different pH solutions including white vinegar (Target Brands, Minneapolis, MN) with a pH of 2.5, lime juice (Dr. Pepper Snapple Group, Plano, TX) which was diluted to 2.5 pH), and pH down (General Hydroponics, Santa Rosa, CA) which has a pH of 2.5 and acting as control. The plants were harvested after 30 days, when marketable size was obtained.

Fertilizers and EC: Each Ebb and Flow bench was supplied with Peters 5-11-26 (J.R. Peters, Allentown, PA) fertilizer and tap water with EC of 0.5 and a pH of 7.8 was used to prepare the nutrient solution. Tanks had a 40-gallon capacity, so 147.41 g of Peters and 97.52 g of calcium nitrate (American Plant Products, OKC, OK) was added initially according to recommended rates. Calcium nitrate was added separately because Peters does not supply calcium. The EC of the nutrient solution was checked every other day to maintain the EC at 1.5 to 2.5 mmhos cm^{-1} and the pH at 5.5 to 6.5 by adding fertilizer and pH buffer solution.

Data Collection: At the end of the study, data was collected on fresh weight and shoot and root dry weight (plants cut and dried for 2 days at 55.66°C). Each plant was scanned using a SPAD-502 chlorophyll meter (SPAD-502, Konica Minolta, Japan) at the time of harvest. Three SPAD readings were taken from each plant, which consisted of taking a reading from top, middle, and bottom leaf within the canopy and then averaged. For each treatment, the fluctuation of pH as well the amount of solution used for maintaining pH in specified range was noted every 2 days.

Data Analysis: The experimental was conducted as a split-plot arrangement in a design was split plot randomized complete block design replicated over time. Separate analyses were conducted for each species of plant. The factors were different pH buffers (three levels). The experimental unit was 11 plants of each crop. Tests of significance are reported at the 0.05, 0.001, and 0.0001 level. Protected least significance difference (LSD) method was used for comparing differences between treatment means. Data analysis were as conducted generated using SAS/STAT software, Version 9.4 (SAS Institute, Cary, NC). ANOVAs were conducted using PROC MIXED with an LSMEANS statement and a DIFF option.

RESULTS

Effect of different pH products on nutrient solution pH

Initially, there was little change in the nutrient solution pH during the first week then there was a steady rise in all treatments until about 18 days (Fig 1). The pH was in the required range (5.5-6.5) throughout the growth cycle for treatments using phosphoric acid, while for treatments using lime juice and vinegar the pH went up to 7.5 (Fig.1). The amount of lime juice and vinegar used for lowering the pH to a suitable range was also higher as compared to phosphoric acid. Average amounts of lime, vinegar, and phosphoric acid used per replication was 6000 ml, 8000 ml, and 600 ml respectively. There was a great difference in their prices as lime juice and pH down cost \$4.40 l^{-1}, vinegar cost \$1.00 l^{-1}.

Effect of different pH products on growth and chlorophyll content of lettuce, basil, and Swiss chard

The fresh and dry shoot weight of lettuce were significantly lower for the treatment using vinegar than the other treatments, while there was no significant difference between lime juice and pH down (Table 1). There was no significant difference for dry weight of lettuce roots among treatment groups. The SPAD values were significantly lower for lime juice and there was no significant difference between vinegar and pH down (Table 1).

The fresh and dry shoot weight of basil was significantly greater for phosphoric acid. The dry root weight of basil was significantly lower for vinegar than other treatments, while there was no significant difference between lime juice and pH down. The SPAD values were also significantly greater for pH down than lime juice and vinegar (Table 2).

The fresh and dry shoot weight of Swiss chard was significantly greater for plants grown with pH down (Table 3). The dry weight of the Swiss chard roots was significantly lower using vinegar, while there was no significant difference among lime juice and pH down. No significant difference was observed for SPAD values among all three treatments of Swiss chard (Table 3).

DISCUSSION

In the present study, pH of the nutrient solution was stable for the first week, then increased starting the second week. The authors hypothesize that this may be because the nutrient absorption was less during the first week due to the small size of the plant as well as a smaller leaf surface area for transpiration of water. During the second week as plants grew, more nutrients and water was taken up. This may have led to an uneven absorption of anions and cations which is one of the causes of pH changes in a nutrient solution (Frick and Mitchell, 1993). Chen et al. (2016) also reported that pH was more stable during the first week of the growth cycle but increased thereafter. In contrast to our results, Li and Li (2006) reported that due to balanced nutrient absorption during the growth cycle, the nutrient solution pH remained stable during hydroponic production of leafy greens.

Chlorophyll meters can be used to estimate the greenness of leafy green vegetables as Colonna et al. (2016) used a SPAD meter to estimate nitrogen (N) content of leaves as a non-destructive method. Furthermore, average SPAD value for red lettuce was 30.1 which was higher than the SPAD value in the present study at time of harvest, while the average SPAD value reported for Swiss chard was 40.0 which was similar to the SPAD values in the present study. Color of leafy greens is an important attribute, which affects consumer preference (Ali et al., 2009). In the present study, SPAD was used as an indicator of greenness and N content in leafy vegetables. According to Liu et al. (2006), SPAD can also be used to determine harvest time in spinach (*Spinacia oleracea* L.). The SPAD values were significantly lower for basil treated with lime juice and vinegar, which corresponded to the visual observations as the leaves of basil showed chlorosis in these treatments. Chen et al. (2015) found that use of wood vinegar at high concentrations in hydroponic production may lead to a decrease in absorption of nitrates. Furthermore, high concentrations of wood vinegar also lead to decreases in photosynthesis because the amount of photosynthesis is directly proportional to the amount of chlorophyll content present in a leaf. The shoot fresh and dry weight was also lower in both of these treatments because as chlorophyll content is lower, photosynthesis is also less. The SPAD values were also significantly lower for lettuce plants produced using lemon juice. However, no chlorosis was observed which may be the result of using a red colored cultivar.

Generally, inorganic acids like nitric acid, sulfuric acid, and phosphoric acid are used for stabilizing the nutrient solution pH in hydroponic production. Because these acids are considered strong acids, damage to hydroponic equipment from corrosion, damaging adhesive used to the build system may develop overtime. This may also affect the nutrient load of the fertilizer solution as nitric acid may contribute to the nitrate form of nitrogen and sulfuric acid may contribute to sulfate ions (Chen et al., 2015), but phosphoric acid does not act as a source of phosphorus (Burning et al., 2012). Lei et al. (2004) reported hydroponic vegetables to be higher in nitrate concentration as compared to soil grown vegetables, which is harmful for human consumption. Therefore, use of nitric acid in hydroponics and can cause higher nitrate concentrations and is not good for the nutritive value of vegetables. Kirimura and Inden (2005) reported that using safe, natural, and less expensive acidic material is more beneficial for hydroponic production as compared to inorganic acids. According to Sinclair and Eny (1946) juices like lemon juice consisting of citric acid can also be used as organic buffers to resist changes in the pH when hydrogen or hydroxyl ions are added. Zhou and Zhang (2011) reported an increase in growth and chlorophyll content of hydroponic lettuce using humic acid (0.116% or 0.348%) in the nutrient solution. Bast et al. (2003) reported the use of lemon extract for control of pathogenic microorganisms and spores, and therefore may also help in controlling water borne pathogens in hydroponics.

CONCLUSION

From the results of the present experiment, lime juice or pH down can be used as a pH buffer for hydroponic production of lettuce. For hydroponic production of basil, only phosphoric acid can be recommended as a pH buffer, because use of lime juice and vinegar lead to lower SPAD values (chlorosis) and reduced growth in basil. For Swiss chard, pH down would be recommended as the best pH buffer for shoot growth but there was no effect on SPAD values when lime juice and vinegar were used. The effect of lime and vinegar on basil and Swiss chard may be due to use of too high concentrations or related to cultivar effects. So, future research should investigate the use of different concentrations of lime and vinegar for hydroponic basil and Swiss chard production. Because lime and vinegar are organic alternatives, other cultivars and crops should be evaluated.

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Tables and Figures

Table 1. Effect of different pH lowering solutions on ‘Oscard’ lettuce growth and quality after 30 days (n=11).

Treatment	Shoot fresh wt ***[z]	Shoot dry wt **	Root dry wt [NS]	SPAD *
pH Down	235.9a[y]	7.7a	0.68a	22.2a
Lime	210.8a	7.8a	0.79a	20.5b
Vinegar	116.7b	5.7b	0.73a	22.6a

[z] Indicates significant at or non-significant (NS) at *P ≤ 0.05, **P ≤ 0.001, or ***P ≤ 0.0001.

[y] Means within a column followed by same lowercase letter are not significantly different by pairwise comparison in mixed model (P ≤ 0.05).

Table 2. Effect of different pH lowering solutions on ‘Citrus’ basil growth and quality after 30 days (n=11).

Treatment	Shoot fresh wt *** [z]	Shoot dry wt ***	Root dry wt *	SPAD *
pH Down	293.0a[y]	24.6a	4.17a	26.0a
Lime	213.6b	19.1b	4.32a	24.5b
Vinegar	151.8c	13.4c	3.31b	23.6b

[z] Indicates significant at or non-significant (NS) at $*P \leq 0.05$, $**P \leq 0.001$, or $***P \leq 0.0001$.

[y] Means within a column followed by same lowercase letter are not significantly different by pairwise comparison in mixed model ($P \leq 0.05$).

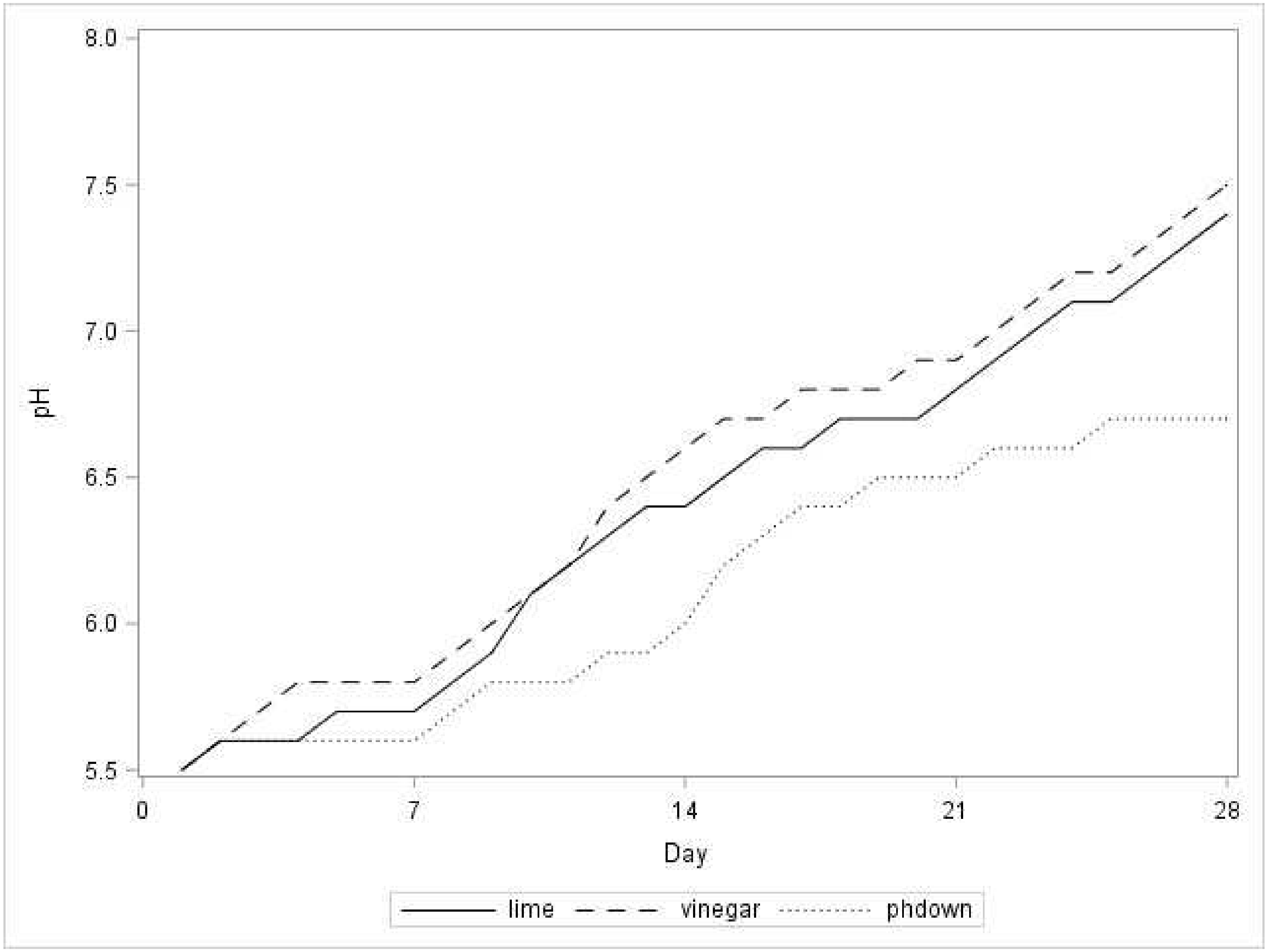
Table 3. Effect of different pH down solutions on ‘Magenta Sunset’ Swiss chard growth and quality after 30 days (n=11).

Treatment	Shoot fresh wt ** [z]	Shoot dry wt **	Root dry wt *	SPAD [NS]
pH Down	187.7a[y]	10.9a	1.41a	42.6a
Lime	118.8b	7.6b	0.99a	42.1a
Vinegar	50.1c	4.3c	0.32b	42.0a

[z] Indicates significant at or non-significant (NS) at *P ≤ 0.05, **P ≤ 0.001, or ***P ≤ 0.0001.

[y] Means within a column followed by same lowercase letter are not significantly different by pairwise comparison in mixed model (P ≤ 0.05).

Figure 1. Nutrient solution pH before adjustment during production of lettuce, basil, and Swiss chard.


8.0
7.5
7.0
6.5
6.0
5.5
pH
0
7
14
21
28
Day
lime
vinegar
phdown

VITA Hardeep

Singh

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Master of Science

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