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Title: Growth Rates and Nutritional Composition of Basil Grown in Conventional, Organic, and Aquaponic Systems

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Growth Rates and Nutritional Composition of Basil Grown in Conventional, Organic, and Aquaponic Systems

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Departmental Distinction in Biology

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The growth rates and nutritional composition of basil grown in organic, conventional, and aquaponic systems

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Abstract

Agriculture accounts for the largest total land use on the planet, and the global food demand is expected to double by 2050 should the human population continue to grow as expected. Despite the high demand for agricultural products and the productivity of today's agricultural industry, agriculture is one of the leading producers of greenhouse gases, producing between 25-30% of annual global emissions. As a result, conventional agriculture is a main contributor to global climate change, an issue that will continue to cause massive environmental issues unless mitigation efforts are intensified. The interest in alternative farming systems as opposed to conventional systems is increasing, and alternative systems have distinct potential to remediate and mitigate global climate change. Conventional agriculture refers to the prevailing agricultural system which utilizes external inputs such as pesticides and nitrogenous fertilizers. Environmental issues such as soil erosion, eutrophication, and habitat degradation can be caused or exacerbated by conventional agricultural practices. These issues may be improved upon via furthered implementation of alternative means of agriculture, many of which minimize external inputs to the system. This study investigates the growth rates and nutritional composition of basil cultivars grown in conventional, sustainable, and aquaponic systems, as well as the composition of soil from each system. Results show that growth rates and nutritional differences in basil across all three systems were not significant, though significant differences were found in soil constituents between organic and conventional soil samples. This implies that despite differences in the soil, the crop itself does not vary greatly between conventional and alternative systems. More sustainable agricultural systems therefore offer viable alternatives to conventional agriculture and offer promising solutions for environmental issues. Combined with the growing

demand and interest in alternatively grown food products, alternative agriculture is a developing industry with great potential.

Introduction

Land-use practices in the name of food production have increased rapidly in recent history. In the past 40 years, there has been an approximate 70% increase in the global area of irrigated cropland, making modern agriculture the single largest land-use on the planet (Foley *et al.*, 2005). Such large increases in agricultural land usage are largely due to the Green Revolution in post-World War II America, which developed in response to food shortages that occurred in the 1940-1950s (Pimentel, 1996). During the Green Revolution, efforts were made to improve the productivity of many staple crops, such as grain, wheat, and rice in order to avoid further food shortages and satisfy the booming, post-war population's increasing demand for food. This was accomplished via the development of hybrid and selectively bred crop cultivars in tandem with the development of economically viable methods of producing synthetic nitrogenous fertilizers. The success of these developments resulted in the rampant usage of pesticides and synthetic fertilizers, which continues in the modern agricultural industry and has in part caused a multitude of environmental issues (Pimentel, 1996).

Synthetic nitrogenous fertilizer use in commercial farming has grown steadily since the Green Revolution, and has resulted in a corresponding increase in commercial crop yields per acre (Pimentel, 1996). Globally, the production of nitrogenous fertilizer has increased from less than 10 million metric tons in the 1950's to over 80 million metric tons by 1990, and is expected to increase along with the inevitable surge in the global populous (Smith *et al.*, 1999). The widespread use of synthetic fertilizers results in nutrient-laden runoff from agricultural areas that can cause severe issues with water quality (Withers and Lord, 2002). Nitrogen and phosphorus are important limiting nutrients in cropping systems, the concentrations of which are determinate factors in crop yield and health (Gregory, *et al.* 1997). Excess nitrogen and phosphorus from agricultural runoff can result in eutrophication of water bodies, which poses threats to aquatic ecosystems. An influx of nutrients from runoff can result in large algal blooms that subsequently die and sink to the bottom of the water body, where the dead algae are then processed by bacteria. The utilization of oxygen by bacteria in this process reduces the amount of oxygen in the system, and potentially renders the system anoxic. This reduction of oxygen causes remaining aquatic organisms to suffocate and die off, and results in anoxic zones. The process of eutrophication poses a large threat to the survival of aquatic populations in freshwater and saltwater systems and further reduces the amount of viable habitat in which survival is possible (Smith, *et al.* 1999). Pesticides also cause water quality issues, as presence of excess pesticides in agricultural runoff can pose serious threats to human health as well as the health of the ecosystem. (Pimentel, 1996).

In addition to contributing to the degradation of fresh and salt water resources, the agricultural sector is a major contributor to total global greenhouse gas emissions. Anthropogenic emissions resulting directly from agricultural practices make up for about 10-12% of annual carbon emissions, and land conversion such as slash and burn agriculture adds an additional 12% to that total. The loss of tree cover also subsequently results in decreased carbon sequestration capabilities and may therefore contribute more so to increased global emissions over time. The chemical synthesis of nitrogenous fertilizers accounts for another 1% of global carbon emissions, which totals to about 25% of annual global greenhouse gas emissions resulting from agriculture (Scialabba and Muller-Lindenlauf, 2010); some calculations have agriculture contributing as much as 30% of emissions (Rodale, 2014). Furthermore, as more land is converted due to agricultural intensification, natural soils will continue to be disturbed. Carbon is naturally sequestered in soils, and continued disturbance of natural soils results in more carbon emissions in addition to increases in nitrous oxide (Poulson *et al.*, 2011).

Though carbon dioxide is perhaps the most well-known and abundant greenhouse gas, nitrous oxide (N_2O) is roughly 200 times as potent a greenhouse gas as carbon dioxide. Agriculture is the largest contributor to the increasing concentration of N_2O in the atmosphere, accounting for 70% of global N_2O emissions, much of which comes from agricultural soils (Mosier, *et al.* 1998). N_2O emissions from agriculture are expected to increase from 6.4 Tg N_2O yr^{-1} in 2010 to 7.6 Tg N_2O yr^{-1} by 2030, largely due to projected increases in agricultural intensification and nitrogenous fertilizer use in areas such as Latin American, Africa, and Asia (Reay *et al.*, 2012).

Conventional Agriculture & Biodiversity

Continued growth in the agricultural industry not only poses issues in greenhouse gas emissions, but also has immense effects on biodiversity. Increased land use for agriculture has resulted in habitat fragmentation for countless species, and conventional practices such as mono-cropping contribute to decreased farmland biodiversity (Marja, *et al.* 2014). Habitat fragmentation is considered to be one of the greatest contributors to current and future species extinctions, which may lead to a decrease in biodiversity on a global scale (Buchmann *et al.*, 2013). For instance, the Amazon Rainforest is one of the most biodiverse areas in the world, and is expected to contain over 13% of the world's biota (Lewinsohn and Prado, 2005). Simultaneously, the Amazonian rainforest is experiencing some of the highest rates of deforestation globally (Barber *et al.*, 2014), as an average of 1.86 million hectares of forest has been cleared each year since the early 1990s (Rodrigues-Filho et al, 2015). About 70% of this forest depletion results from agricultural practices such as crop and livestock cultivation, and more recent years have seen a surge in soybean production. Agricultural progress is tightly linked with economic progress in the Amazon, and thus clearing forests for the sake of agricultural development acts as the impetus for significant biodiversity declines (Fearnside, 2005). Furthermore, domestic grassland in the Midwestern United States has decreased substantially as a result of agricultural intensification, and the probability of conversion of remaining grasslands to agricultural areas continues to increase (Rashford, *et al.*, 2010). Land conversion for agricultural intensification is a global issue that is not limited to one single locale or ecosystem. Habitat fragmentation and land conversion account for changes in soil carbon which can have large effects on soil properties. This can cause potential issues in future agricultural development and potential restoration projects in tandem with issues regarding greenhouse gas emission. Effectively, continued conversion of forests and other ecosystems for agricultural use results in degraded soil quality and health. Maintaining soil health is a key component in maintaining ecosystems services, mitigating carbon emissions, and maintaining sufficient crop yields (Poulson *et al.*, 2011).

As a direct result of land conversion into agriculture space, species extinction rates are increasing and biodiversity is consequently decreasing. Populations of European bird species associated with agricultural areas are declining (Chamaberlain and Fuller, 2000). Honey bee and other pollinator populations continue to decline in North America, likely as a result of overexposure to pesticides and other conventional agricultural inputs (Potts *et al.*, 2010). Combined with the inevitable amplification of food demand in the near future (Green *et al.*, 2005), continued practice of conventional agriculture without minimization of environmental impacts, biodiversity can be expected to continue to decrease at alarming rates across the globe.

Despite the multitude and severity of environmental issues posed by the modern agricultural industry, there is potential for mitigation. N_2O emissions could be cut down by up to 20% annually by reducing field application of synthetic nitrogenous fertilizers (Mosier *et al.* 1998), and reducing human consumption of meat could reduce N_2O soil emissions 24% by 2055 (Reay *et al.*, 2012). Recent studies by the Rodale Institute claim that by switching to a sustainable and organic farming system on a global scale, over 100% of current carbon dioxide emissions could be sequestered (Rodale, 2014). Though this level of mitigation is unlikely in the immediate future, the potential for alternative farming systems to aid in mitigating climate change and reducing other environmental issues still remains. Furthermore, environmentally sound farm management has also decreased the impact of agriculture on biodiversity in certain areas, and has potential for broader implementation (Marja *et al.*, 2014).

Organic Agriculture

Organic farming constitutes a system in which the use of irradiation, sewage sludge, synthetic fertilizers, pesticides, and genetically modified organisms are prohibited (USDA, 2013). Though this is the definition used to receive a federal certification in organic farming in the United States, in reality there are distinct variations in how farmers, consumers, and local and global communities define organic farming (Rigby and Caceres, 2001). Typically, organic farming systems tend to utilize ecologically conscious practices and systems design in order to minimize impact on the ecosystem. This includes practices such as integrated pest management, composting, use of cover crops, minimal soil tillage, and crop rotation (Kontopoulou *et al.*, 2015). Instead of synthetic fertilizers and pesticides, organic agriculture relies on animal manure and composted materials to provide necessary nutrients such as phosphorus and nitrogen, which minimizes synthetic external inputs into the farming system (Rigby and Caceres 2001).

Sustainable agriculture typically encompasses a broader spectrum of farming practices, all of which are less rigidly defined than certified organic practices. Farming practices that conserve natural resources, minimize external input to the system, and generally are more environmentally conscious can be considered sustainable (Rigby and Caceres, 2001). Therefore, there is an overlap in organic and sustainable agriculture, as they both emphasize implementing ecologically sound practices, while minimizing external inputs. (Pacini *et al.*, 2003). Though organic agriculture is not inherently sustainable, the limitation of external inputs to organic systems results in organic agriculture generally being a more sustainable practice than conventional agriculture (Rigby and Caceres, 2001). Though the organic system utilized in this study is located in a Permaculture garden and is not certified organic, techniques such as cover cropping, composting, integrated pest management, and minimal tillage were applied in the system much as they are in other USDA certified organic systems. Therefore, the term “organic” is used to describe this system.

The greatest potential for mitigation in organic agriculture systems results from the carbon sequestration capacity of organic soils (Scialabba and Muller-Lindenlauf, 2010). In addition to the exclusion of mineral fertilizers that reduce greenhouse gas emissions in organic systems by up to 20%, organic practices also increase the potential for soils to maintain organic carbon stores and to reduce carbon emission through increasing soil carbon pools. Though this may not have long term effects on climate change mitigation, it does work to compensate for greenhouse gas emissions from traditional agriculture (Scialabba and Muller-Lindenlauf, 2010). Overall, due to significant contributions of global concentrations of greenhouse gases from the agricultural industry, the management of cropping systems provides great potential for mitigation and remediation of global climate change (Kontopoulou *et al.* 2015). Due to the recent rise in public concern for environmental issues, especially in younger generations, there has been an increased demand for organic agriculture. This demand is expected to continue to increase, and the growth of the organic food industry offers the potential to further aid the mitigation of environmental issues (Bourn and Prescott, 2002).

Yield Gaps

There are, however, distinct differences in crop yields between organic and conventional systems. On average, organic crop yields per acre are 80% that of conventional yields, with substantial variation of up to 21% (de Ponti *et al.*, 2012). This begs the question as to whether low-yielding organic systems could act as a reliable food system for a population expected to reach over 9 billion by 2050 (Connor, 2013). Despite distinct differences in yield, organic agriculture may in fact provide enough calories to support the human population's diet, and that the issue in food security lies far more on policies, prices, availability, and social issues rather than on the farming system itself (Badgley and Perfecto, 2007). Moreover, certain practices may further reduce the yield gap between organic and conventional farming systems. These methods include multi-species cropping instead of mono-cropping, along with additional crop rotations. In organic systems that utilized multi-cropping methods, the yield gap between conventional and organic crops dropped from 19.2% to 8%. In organic systems that utilized more crop rotations, differences in yield dropped from 19.2% to 9%. These methods may provide the possibility for organic systems to maintain sustainable practices without sacrificing yields, and may also provide more impetus for a changeover to a predominantly organic agriculture industry (Ponisio *et al.*, 2015).

Organic Agriculture & Biodiversity

Organic farms are typically higher in biodiversity than conventional farms, and implementation of environmentally friendly practices on farming systems of any type may have significant impacts on increasing the biodiversity of the area (Marja *et al.*, 2014). These practices include diversifying crop rotations, implementing permanent strips of grassland, limiting fertilizer inputs, and protecting landscape elements (Marja *et al.* 2014). Similarly, multi-cropping over mono-cropping has also resulted in maintaining farmland biodiversity, and is applicable regardless of farming system type (Ponisio *et al.*, 2015). Overall, implementation of more environmentally sensitive agricultural practices on existing conventional farming systems can act as an intermediate strategy between conventional and organic agriculture, or simply as the means of maintaining a more sustainable system (Marja *et al.* 2014). Though this is not an agriculture industry overhaul, it is certainly a step toward ensuring that the agriculture industry minimizes its impact on the environment while maintaining current quality and volume of crop production.

Aquaponic Agriculture

Organic agriculture may be considered the most well-known type of alternative agricultural practice, but an alternate type of developing agricultural system is aquaponics, which combines principles from aquaculture and hydroponics (Love *et al.*, 2015) and integrates them into one recirculating system (Rakocy *et al.*, 2006). This type of system was first widely introduced in the 1970s and has grown in popularity and applications over time (Love *et al.*, 2015). As global aquaculture production has been expanding at an average rate of 6.2% since 2000, fish have become a major food industry crop and production is expected to continue to increase (Hu *et al.*, 2015). Similarly to agricultural intensification, aquaculture intensification has also lead to severe environmental issues, the largest of which is overutilization of freshwater and waste production. As fish waste contains large quantities of ammonia and other nitrogen bearing compounds, the discharge of this water can result in severe damage to freshwater systems via eutrophication induced hypoxia. However, the combined cultivation of fish and agricultural crops provides potential remediation for these issues posed by intensified aquaculture (Hu *et al.*, 2015).

In an aquaponic system, fish and crops are raised simultaneously and form a type of symbiotic relationship in which nitrogenous fish waste nourishes plants, while nutrient uptake and nitrogen fixation performed by the plants improves water quality for the fish. Fish waste contains concentrations of nitrogen and phosphorus, which are nutrients important for plant growth. Though the uptake of excess nutrients from the fish effluent acts to improve water quality and maintain health of the fish, excess solid waste that cannot be utilized by plants must be filtered out of the system to avoid toxic concentrations of ammonium. (Buzby and Lin, 2014). The central goal of the recirculating aquaponic system is to recycle and reuse the nutrients released from fish waste in order to grow crop plants, thereby maximizing the potential yield of the overall system. This process has applications in minimizing cost and environmental impacts of wastewater treatment (Graber and Junge, 2009), reducing the environmental impacts of traditional aquaculture (Buzby and Lin, 2014), as well as expanding the alternative agricultural industry (Love, et al 2015).

Aquaponic Design & Application

Though aquaponic practices date back to ancient China, recent increased interest in aquaponic systems has resulted in furthered growth and development of the classic aquaponic system design. The simplest and potentially most cost efficient design for an aquaponic system is raft aquaponics (Liang and Chien, 2013). The basic raft aquaponics components include fish-rearing tanks, a mechanical filtering system for removal of excess solid waste, and a raft that floats atop the fish-rearing tank in which crops are planted (Rakocy *et al.*, 2006). More complex aquaponic systems often involve the separation of fish and crops, in which aquaponic effluent is pumped from the fish-rearing tanks to the planting area to nourish crops (Graber and Junge, 2009). This process has applications in wastewater management, as wastewater often provides all necessary elements required for plant growth, and the uptake of these nutrients via crop production results in reclamation of domestic wastewater (Rana *et al.*, 2011). Though this results in cost efficient water treatment, crops grown utilizing wastewater have a higher probability of containing harmful heavy metals and harboring bacteria. In short, more research is necessary to provide safe fish and plant crops in the case of aquaponic wastewater treatment (Rana *et al.*, 2011).

Tilapia are the most commonly cultivated fish in aquaponic systems, as they grow quickly and are relatively adaptable to growing in captivity (Liang and Chien, 2013). In aquaponic systems, both herbaceous and fruiting plants have been successfully cultivated, though most aquaponic research has been implemented on leafy plants such as spinach, lettuce, and herbs, including basil (Hu, *et al.* 2015). This study utilizes tilapia in a raft aquaponic system, and basil (*Ocimum basilicum* L.) across all three experimental systems. Basil is an aromatic annual herb that has uses in food preparation, cosmetics, pharmaceuticals, and even pesticide production (Sifola and Barbieri, 2006), and has exhibited success in aquaponic (Love *et al.*, 2015) and organic cultivation (Kilmankova *et al.*, 2008).

Though organic and aquaponic systems may initially seem inherently different, both systems operate as alternative options to conventional agriculture. This study was implemented in order to practically investigate the differences between these three specific systems, in regards to their effect on the growth rates and nutritional components of basil grown in each system.

Growth rates as well as nutritional composition were both expected to differ across the three different systems. Experimental findings of this study are examined and implications for practical use of these systems in an effort to minimize further anthropogenic impacts on the earth in terms of agriculture are discussed.

Study Design and Methods

To evaluate the effects of various farming techniques on basil, two 0.75x1 m plots were constructed in Albright College's Permaculture Garden, located on the Albright College campus in Southeastern Pennsylvania. The organic plot was continuous with the rest of the Permaculture Garden, while the conventional plot was not continuous and was located directly adjacent to the Garden. The organic soil used in the Permaculture Garden consisted of compost and mushroom soil atop layers of cardboard and leaf litter. The conventional plot was not directly continuous with the Permaculture Garden, and was constructed by removing the sod, tilling the soil, and laying down conventional bagged topsoil containing added synthetic fertilizer.

In both the organic and conventional plots, Burpee brand sweet basil was planted in three rows of three and measured to a reference line 3cm above the soil. In the aquaponic system, basil was grown in individual cups containing rockwool fibers as a growing medium, and were placed in designated holders in the system which were partially submerged in the aquaponic water. All plantings were done during the first week of August, 2014.

From August until October 2014, weekly measurements of height and plant diameter measured from leaf tip to leaf tip at the plant’s widest point were made of each basil cultivar in all three systems. Height was measured to the reference line using a meter stick, and the diameter of cultivars was taken at their widest point utilizing calipers. Toward the end of the growing season on October 8th, leaf samples were removed from two of the basil cultivars in the conventional and aquaponic systems. The basil that was planted in the organic plot never germinated, and therefore a small leaf sample was extracted from a basil plant that was already established in the Permaculture garden's herb spiral structure to stand in as a comparison. Soil samples were also taken from the herb spiral structure.These samples are consequently referred to as herb spiral samples throughout this study. Three soil samples, each 3cm deep, were taken from each of the terrestrial plots using a core soil probe. The basil samples were then placed in a -80 C freezer and the soil samples were placed in a -20 C freezer until processing in January.

Basil samples from the aquaponic, conventional, and organic systems were tested for pH and nutrient concentrations. Using a YSI 9500 Photometer, a water sample from the aquaponic system was tested for ammonia, nitrate, nitrite, and phosphate concentrations. pH was measured with a probe. Subsamples from the conventional and organic system samples were tested for pH using a LaMotte Soil pH Kit, and organic matter of soil samples was determined utilizing the loss on ignitions method on 1g of each soil sample from the two separate terrestrial systems (Konen *et al.*, 2002). As the aquaponic system is soilless, soil data was not collected for the aquaponic system.

Remaining soil samples and all basil samples were placed in a lyophilizer for roughly 24 hours in order to remove all water from the samples. Approximately 3-4g of each soil sample was then homogenized within the sample bag and processed via the wet sieving and phi pipetting techniques (Plume, 1981). 2mg portions of each basil and soil sample were then prepared and run through a Perkin-Elmer Elemental Analyzer to determine carbon, hydrogen, and nitrogen concentrations as well as carob/nitrogen ratios.

All remaining basil samples were finally analyzed for their protein and carbohydrate content. Protein extraction was achieved in a nitrogen buffer utilizing the Pierce BCA technique for protein analysis, and samples were read on a microplate reader. Carbohydrate content of each sample was determined using a modified Anthrone method suitable for microplate use (Leyva *et al.*, 2008). Data analysis was carried using NCSS 2007 software. ANOVA tests were utilized to determine the significance of differences between basil and soil samples regarding growth rates and nutritional composition in all three systems.

Results

Organic basil did not germinate in the plot in Albright's Permaculture Garden, despite concurrent planting times with aquaponic and conventional basil. Thus, organic basil growth rates are not included in the results. Basil that had established in the herb spiral structure in Albright's Permaculture Garden earlier in the planting season were harvested and utilized as means of comparison in elemental, protein, and carbohydrate analyses to ascertain expected components of organic basil had the organic cultivars germinated. Soil samples were also taken from the herb spiral structure for comparative purposes against the organic and conventional soil samples. Although nine cultivars were initially planted in each of the three experimental plots, only seven cultivars survived to be measured in the conventional plot. All nine cultivars survived in the aquaponic plot, though some cultivars were far less successful than others.

Average growth rates for both total plant height and plant diameter between conventional and aquaponic basil cultivars were not significantly different (P=0.320607, F= 1.17). On average, conventional basil exhibited higher growth rates than aquaponic basil in regards to total plant height, as conventional basil reached an average of 14.17 cm by the end of the growing period. Aquaponic basil only reached 7.79 cm by the end of the growing period (Figure 1). Conventional and aquaponic growth rates were more similar in terms of total plant diameter. Average conventional basil diameter leveled off toward the end of the growing period at 10.76

cm, while aquaponic basil continued to increase in diameter and reached 13.52 cm at the end of the growing period (Figure 2). Aquaponic basil continued to grow well after the measurement period, whereas conventional basil began to die off soon after.

Soil elemental components were significantly different in regards to average percentages of carbon (P=0.0, F=369.37), hydrogen (P=0.0, F=228.73), and nitrogen (P=0.0, F=278.19) across the conventional, organic, and herb spiral systems. The C/N ratio was found to not be significantly different across all three systems (P=0.272326, F=1.45). Soil from the herb organic plot exhibited high percentages of carbon at 24.93%, and conventional soil only contained an average 4.49% carbon. Average percentages of hydrogen and nitrogen found in conventional soil were less than 1%, while average percentages in both the organic and herb spiral soil averaged around 2% in both hydrogen and nitrogen components. The carbon/nitrogen ratio was very similar across conventional, organic, and herb spiral systems (Figure 3).

Elemental components in basil samples did not differ significantly across the three systems in regard to carbon, hydrogen, or nitrogen percentages. Conventional and herb spiral basil samples contained far lower percentages of carbon as compared to aquaponic basil, though percentages of hydrogen and nitrogen were more similar across the three systems. The carbon/nitrogen ratio was significantly higher in conventionally grown basil samples as compared to organic or herb spiral basil samples (P=0.001859, F=15.24) (Figure 4).

Soil from the organic plot and soil from the herb spiral structure contained significantly higher percentages of sand as compared to conventional soil (P=0.009797, F=101.07). Organic soil averaged 69.9% sand, the herb spiral soil averaged 54.53% sand, and the conventional soil averaged only 18.6% sand. Differences in percent gravel across all three systems was not significant (0.847648, F=0.18).Percent silt was on average significantly higher in the conventional soil (P=0.000924, F=1080.77). Conventional soil exhibited an average of 68.2% silt, whereas organic and herb spiral soils exhibited an average of 17.3% and 27.2% respectively. Clay percentages were significantly different, with the conventional plot exhibited the highest average of 10.18%, and organic exhibiting the lowest average of 2.67%. (Figure 5).

Percent organic carbon in soil determined via the loss on ignition method varied greatly across conventional, organic, and herb spiral basil samples, with the conventional soil samples containing the highest average percent organic carbon. Conventional samples displayed an average of 16.45%, organic samples displayed an average of 8.82%, and the only herb spiral sample collected displayed 5.09% of organic carbon, though these differences were not significant (P=0.22687, F=2.20) (Figure 6).

Average carbohydrate concentration also varied greatly across basil samples, and conventional samples exhibited the highest average concentration of 25.60 mg/mL. Aquaponic and herb spiral concentrations were very similar, at 12.73 and 12.67 mg/mL, respectively, though these differences were not significant (P=0.469886, F=1.13) (Figure 7). Protein concentrations across basil samples also exhibited a varied range. Once again, conventional basil exhibited the highest concentration of protein at 1255.26 mg/mL, and aquaponic exhibited the lowest concentration at 249.62 mg/mL. Herb spiral basil samples on average had a protein concentration of 669.70 mg/mL, though differences in protein concentrations across all three systems were not significant (P=0.586134, F=0.71) (Figure 8).

Discussion

Organic basil did not germinate in the experimental organic plot, despite two attempts at transplanting greenhouse grown seedlings. The season in which this study was conducted was particularly rainy, and basil plantings occurred toward the end of the summer growing season.

Combined with the sandy conditions of the soil found in the organic plot, this may have prevented proper establishment of basil seedlings. Basil seedlings were far more successful in the conventional plot, and basil had already established in the herb spiral structure in the Permaculture Garden earlier in the growing season. Soil samples indicate that the conventional plot and the herb spiral structure contained significantly less sand as compared to the organic plot, which may have prohibited seedling establishment (Figure 5). Additionally, the herb spiral structure was a new construction in the Permaculture Garden at the time, with fresh soil layers having been added at the beginning of the season. Soil conditions were likely more optimal in the herb spiral structure than in the organic plot, due to potential loss of nutrients since the organic plot's creation three years prior.

Growth rates of aquaponic and conventional basil cultivars did not differ significantly, which implies that the farming system type may have minimal affect on the growth rate of basil in terms of height and total diameter. However, due to the lack of data on the growth rates of basil in organic soil in conjunction with the small sample size of this study, it is difficult to determine the effect that farming systems may have on growth rates overall. In order to determine whether conventional, aquaponic, and organic systems differ in their effect on basil growth rates, a larger sample size and more intensive study would be necessary.

Trends in the average growth rates for plant diameter imply that had the experimental measurement period continued, aquaponic basil may have continued to grow, whereas conventional basil would likely have leveled off and stopped growing. This is likely indicative of the end of the growing season, as the last growth measurements were taken in early October after the first frost. Conventional basil was grown outdoors, and the plateau effect of the growth rate data (Figures 1&2) was likely due to stress caused by dropping temperatures. The aquaponic system was located indoors in a climate controlled greenhouse, and thus the aquaponically grown cultivars remained relatively unaffected by temperature stress. The controlled environment and submerged growing habitat of the aquaponic basil may also explain the qualitative differences between conventional and aquaponic basil samples. Aquaponic basil exhibited a deeper green color, and the leaves were softer to the touch than that of conventional basil, despite being of the same species. This is likely due to the lack of environmental stress and increased water uptake resulting from a surplus of water present in the aquaponic system, which can consequently result in increased carbon uptake by plants (Alberto *et al.*, 2013).

Though differences in protein and carbohydrate concentrations did not differ significantly across conventional, aquaponic, or herb spiral basil samples, on average conventional basil exhibited higher concentrations of both proteins (Figure 7) and carbohydrates (Figure 8). These results reflect many other studies conducted upon different crop varieties in which protein concentrations are often lower in organic cultivars as compared to conventional, or they exhibit no significant differences. However, studies on carbohydrate concentrations indicate that organically grown crops tend to exhibit higher carbohydrate concentrations (Bourn and Prescott, 2002). As the differences observed in this study were not significant, this indicates that the type of farming system in which basil is grown does not affect the nutritional composition of basil crops in terms of protein and carbohydrate concentrations. However, this study was relatively small and did not have a large enough sample size to confidently determine the effect of farming system on nutritional aspects of basil. Additionally, further nutritional components of basil such as essential oils were not taken into account, which have been shown to change significantly due to farming system type (Kimankova et al, 2008; Lu et al, 2014).

Significant differences in elemental constituents of soil between conventional, organic, and herb spiral samples are likely due to the differences in the construction of each plot. The organic plot soil was comprised of mainly composted materials and leaf waste, both of which are high in carbon. The conventional plot was constructed via removing the sod and adding a layer of bagged topsoil with added fertilizer, which contains more nitrogen than the compost. Furthermore, the organic plot utilized was constructed approximately three growing seasons prior to the construction of the herb spiral, resulting in significantly different levels of carbon, nitrogen, and hydrogen in the soil between the systems. C/N ratio did not differ significantly across systems due to low levels of carbon in the conventional system, and high levels of carbon in the organic system and the herb spiral structure. In tandem with higher levels of percent nitrogen in organic and herb spiral samples, the low levels of nitrogen and carbon in the conventional systems balances out the C/N ratio across all systems (Figure 3).

The opposite situation is apparent in elemental constituents of basil tissue from each system. There were not significant differences in carbon, hydrogen, or nitrogen across the three systems, though there was a significant difference in C/N ratios. The conventionally grown basil exhibited the greatest C/N ratio (Figure 3), which is consistent with low nitrogen levels found in the conventional soil (Figure 4). However, conventional soil was also significantly greater in silt and clay as compared to organic and herb spiral soil (Figure 5). Silt and clay-based soils tend to have greater water holding capacity due the smaller particle size of silt and clay aggregates. This results in reduced nutrient leaching in silt and clay soils as compared to sand and gravel based soils, which demonstrate greater water drainage due to larger soil particles (Piedallu *et al.*, 2011). Therefore, conventional soil would be expected to exhibit greater percent nitrogen content due to significantly greater concentration of silt particles, which would in turn result in greater uptake of nitrogen in conventionally grown basil. However, this process is not reflected in the data, indicating that conventional soil may have experienced losses in percent nitrogen. This may have been caused by increased nutrient runoff due to excessive rain and the slope of the experimental site, or perhaps by the loss of nitrogen from the system in the form of nitrous oxide. Regardless, a greater sample size and measurements of nitrous oxide emissions would be needed to precisely indicate reasons for decreased percent nitrogen in the conventional system.

The relative similarities in growth rates and nutritional composition across the three systems indicates that conventional, aquaponic, and organic systems have minimal effect on the growth rates of basil, despite significant differences across the systems in soil particle and elemental composition present in the soil. Though this study was not all inclusive, and far more aspects of nutritional qualities of basil and other crops can be investigated, the results of this study implies that the farming system can be altered with minimal impact on the nutritional quality of the crops themselves. Ultimately, alternative agricultural methods may therefore have the potential to compete with conventional methods on a larger scale, while simultaneously minimizing environmental impacts of conventional industrialized agriculture.

Works Cited

Alberto, C.R., Bureshe, R.J., hirano, T., Miyata, A., Wassmann, R., Quilty, J.R., Correa, T.Q., Sandro, J. 2013. Carbon uptake and water productivity for dry-seeded rice and hybrid maize grown with overhead sprinkler irrigation. Field Crops Research 146: 51-65.

Badgley, C., Perfecto, I. 2007. Can organic agriculture feed the world? Agronomy & Hortiulture—Faculty Publications. 110.

Bourn,D., Prescott, J. 2002. A comparison of the nutritional value, sensory qualities, and food safety of organically and conventionally produced foods. Critical Reviews in Food Science and Nutrition 42(1): 1-34.

Buchmann, C.M., Schurr, F.M., Nathan, R., Jeltsch, F. 2013. Habitat loss and fragmentation affecting mammal and bird communities- The role of interspecific competition and individual space use. Ecological informatics 14: 90-98.

Buzby, K.M., Lin, L.S. 2014. Scaling aquaponic systems: balancing plant uptake with fish output. Aquacultural Engineering 63: 39-44.

Chamberlain, D.E., Fuller, R.J. 2000. Local extinctions and changes in species richness of lowland farmland birds in England and Wales in relation to recent changes in agricultural land-use. Agriculture, Ecosystems, & Environment 78(1): 1-17.

Conti, S., Villari, G., Faugno, S., Melchionna, G., Somma, S., Caruso, G. 2014. Effects of organic vs. conventional farming system on yield and quality of strawberry grown as an annual or biennial crop in sounther Italy. Sciencia Horticulturae 180:63-71.

Connor, D.J. 2013. Organically grown crops do not a cropping systems make and nor can organic agriculture nearly feed the world. Field Crops Research 144:145-147.

De Ponti, T., Rijk, B., van Ittersum, M.K.2012. The crop yield gap between organic and conventional agriculture. Agricultural Systems. 108:1-9.

Foley, J., DeFries, R., Asner, G., Barford, C., Bonan, G., Carpenter, S., Chapin, F., Coe, M., Daily, G., Gibbs, H., Helkowski, J., Holloway, T., Howard, E., Kucharik, C. Monfreda, C. Patz, J. Prentice, I. Ramankutty, N. Snyder, P. 2005. Global consequences of land use. Science 309:570-574

Graber, A. Junge, R. 2009. Aquaponic systems: nutrient recycling from fish wastewater by vegetable production. Desalination 246: 147-156.

Gregory, P.J., Simmonds, L.P., Warren, G.P. 1997. Interactions between plants nutrients, water and carbon dioxide as factors limiting crop yields. Physiological Transactions B . 352(1356).

Hu, Z., Lee, J.W., Chandran, K., Kim, S., Brotto, A.C., Khanal, S.K. 2015. Effect of plant species on nitrogen recovery in aquaponics. Bioresource Technology, In Press.

Kilmankova, E., Holadova, K., Hajslova, J., Cajka, T., Poustka, J., Koudela, M. 2008. Aroma profiles of five basil (*Ocimum basilicum* L.) cultivars grown under conventional and organic conditions. Food Chemistry 107: 464-472.

Kontopoulou, C.K., Bialis, D., Pappa, V.A., Rees, R.M., Savvas, D. 2015. Effects of organic farming practices and salinity on yield and greenhouse gas emissions from a common bean crop. Scientia Horticulturae 183:48-57.

Leyva, A., Quintana, A., Sanchez, M., Rodriguez, E.N., Cremata, J., Sanchez, J.C. 2008. Rapid and sensitive anthrone-sulfuric acid assay in microplate format to quantify carbohydrate in biopharmaceutical products: Method development and validation. Biologicals 36:134 141.

Liang, J.Y., Chien, Y.H. 2013. Effects of feeding frequency and photoperiod on water quality and crop production in a tilapia-water spinach raft aquaponics system. International Biodeterioration & Biodegredation 85:693-700.

Love, D.C., Fry, J.P., Li, X., Hill, E.S., Genello, L., Semmens, K., Thompson, R.E. 2015. Commercial aquaponics production and profitability: Findings from an international survey. Aquaculture 435: 67-74.

Lu, Y., Gao, B., Chem, P., Charles, D., Yu, L. 2014. Characterization of organic and conventional sweet basil leaves using chromatographic an flow-injection mass spectrometric (FIMS) fingerprints combined with principle component analysis. Food Chemistry 154: 262-268.

Marja, R., Herzon, I., Viik, E., Elts, J., Mand, M., Tscharntke, T., Batary, P. 2014. Environmentally friendly management as an intermediate strategy between organic and conventional agriculture to support biodiversity. Biological Conservation 178: 146-154.

Pacnini, C., Wossink, A., Giesen, G., Vazzana, C., Huirne, R. 2003. Evaluation of sustainability of organic, integrated and conventional farming systems: a farm and field-scale analysis. Agriculture, Ecosystems, and Environment 95:273-288.

Palmer, M., Bernhardt, E., Chornesky, E., Collins, S., Dobson, A., Duke, C., Gold, B., Jacobson, R., Kingsland, S., Kranz, R., Mappin, M., Matinez, M.L., Micheli, F., Morse, J., Pace, M., Pascucal, M., Palumbi, S., Reichman, O.J., Simons, A., Townsend, A., Turner, M. 2004. Ecology for a crowded planet. Science 304.

Piedallu, C., Gégout, J.C., Bruand, A., Seynave, I. 2011. Mapping soil holding capacity over large areas to predict potential production of forest stands. Geoderma 160(3-4): 355-366.

Pimentel, D. 1996. Green revolution agriculture and chemical hazards. The Science of the Total Environment 188: S86-S89

Pimentel, D., Hepperly, P, hanson, J., Douds, D., Seidel, R. 2005. Environmental, energetic, and economic comparisons of organic and conventional farming systems. BioScience 55(7): 573-582.

Plumb, R.H. Jr. 1981. Procedures for handling and chemical analysis of sediment and water samples. US Army Waterways Experiment Station, Vicksburg, MS. 403.

Ponisio, L.C., M'Conigle, L.K., Mace, K.C., Palomino, J., de Valpine, P., Kremen, C. 2015. Diversification practices reduce organic to conventional yield gap. Proc. R. Soc. B 282: 20141396.

Potts, S.G., Biesmeijer, J.C., Kremen, C., Neumann, P., Schweiger, O., Kunin, W.E. 2010. Global pollinator declines: trends, impacts, and drivers. Trends in Ecology & Evolution 25(6): 345-353.

Poulson, D.S., Gregory, P.J., Whalley, W.R., Quinton, J.N., Hopkins, D.W., Whitmore, A.P., Hirsch, P.R., Goulding, K.W.T. 2001. Soil management in relation to sustainable agriculture and ecosystem services. Food policy 36:S72-S87.

Rakocy, J.E., Shultz, R.C., Bailey, D.S., Thoman, E.S. 2006. Aquaponic production of tilapia and basil: comparing a basil and staggered cropping system. University of the Virgin Islands.

Rana, S., Bag, S.K., Golder, D., Mukherjee, S., Pradhan, C., Jana, B.B. 2011. Reclamation of municipal domestic wastewater by aquaponics of tomato plants. Ecological Engineering 37: 981-988.

Rashfor, B.S., Walker, J.A., Bastian, C.S. 2001. Economics of grassland conversion to cropland in the prairie pothole region. Conservation Biology 25(2): 276-284.

Reay, D.S., Davidson, E.A., Smith, K.A., Smith, P., Melillo, J.M., Dentener, F., Crutzen, P.J. 2012. Global agriculture and nitrous oxide emissions. Nature Climate Change 2: 410-416.

Rigby, D., Caceres, D. 2001. Organic farming and the sustainability of agricultural systems. Agricultural Systems 68:21-40.

Rodale Institute. 2014. Regenerative organic agriculture and climate change.

Rodrigues-Filho, S., Verburg, R., Bursztyn, M., Lindoso, D., Debortoli, N., Vilhena, A. 2015. Election-driven weakening of deforestation control in the Brazilian Amazon. Land Use Policy 43:111-118.

Scialabba, N.E., Muller-Lindenlauf, M. 2010. Organic agriculture and climate change. Renewable Agriculture and Food Systems 25(2):158-169.

Sifola, M.I., Barbieri, G. 2006. Growth, yield and essential oil content of three cultivars of basil grown under different levels of nitrogen in the field. Scientia Horticulturae 108: 408-413.

Smith, V.H., Tilman, G.D., Nekola, J.C. 1999. Eutrophication: impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems. Environmental Pollution 100: 179-196

USDA Agricultural Marketing Service. 2013. Organic Standards.

Vitousek, P., Mooney, H., Lubchenco, J., Melillo, J. 1997. Human Domination of Earth's Ecosystems. Science 277: 494-499

Withers, P.J.A., Lord, E.I. 2002. Agricultural nutrient inputs to rivers and groundwaters in the UK: policy, environmental management and research needs. Science o the Total Environment 283-284: 9-24.

Tables and Figures

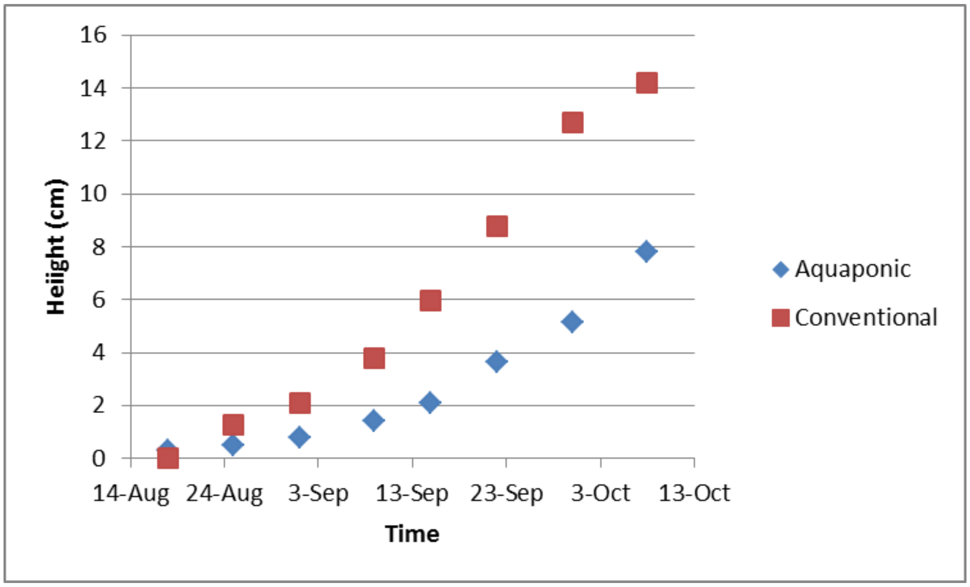

Figure 1. Average change in height of aquaponic and conventional basil cultivars over time.

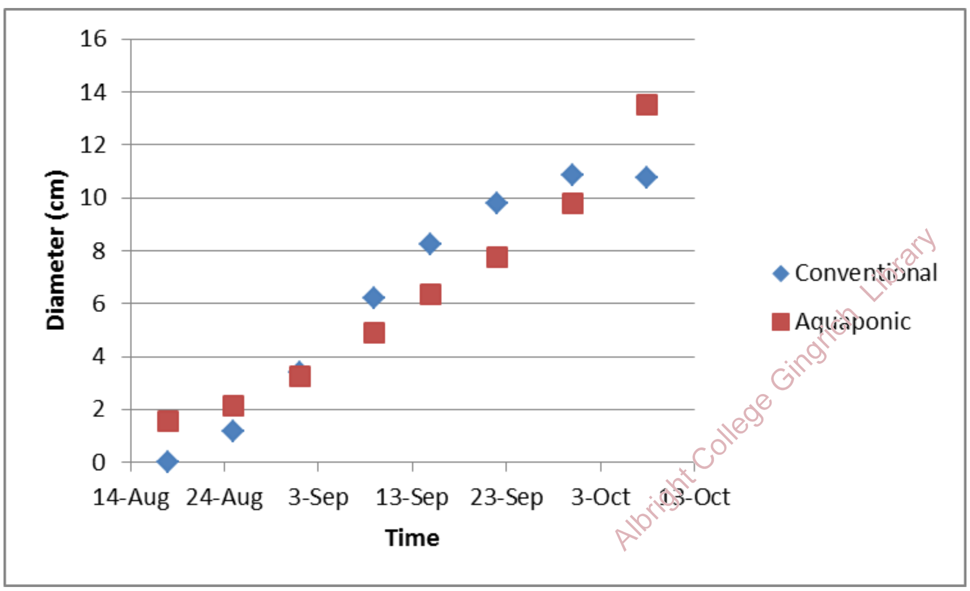

Figure 2. Average change in diameter of aquaponic and conventional basil cultivars over time.

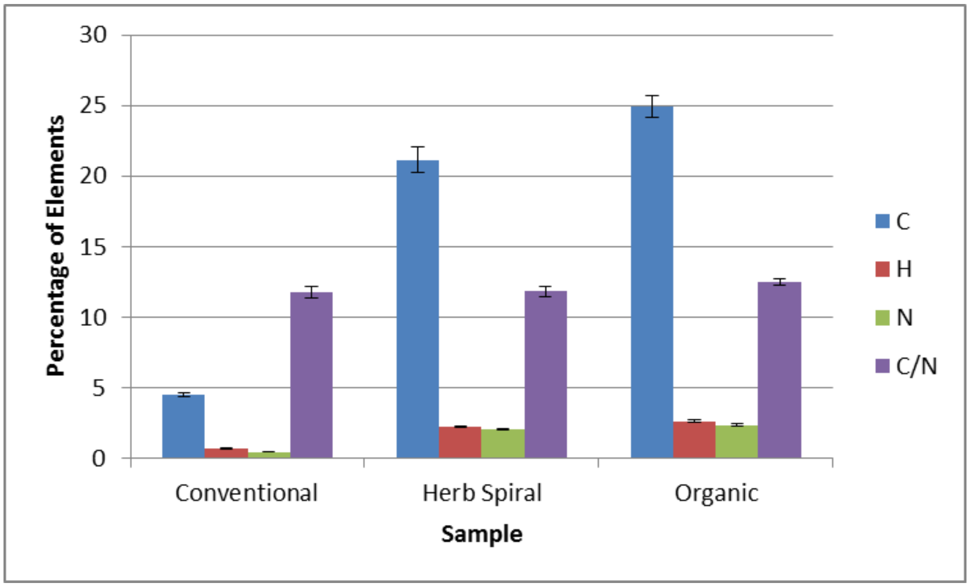

Figure 3. Percentages of carbon, hydrogen, nitrogen, and the carbon to nitrogen ratio found in the soil of the conventional and organic systems, with inclusion of soil from the herb spiral for comparison.

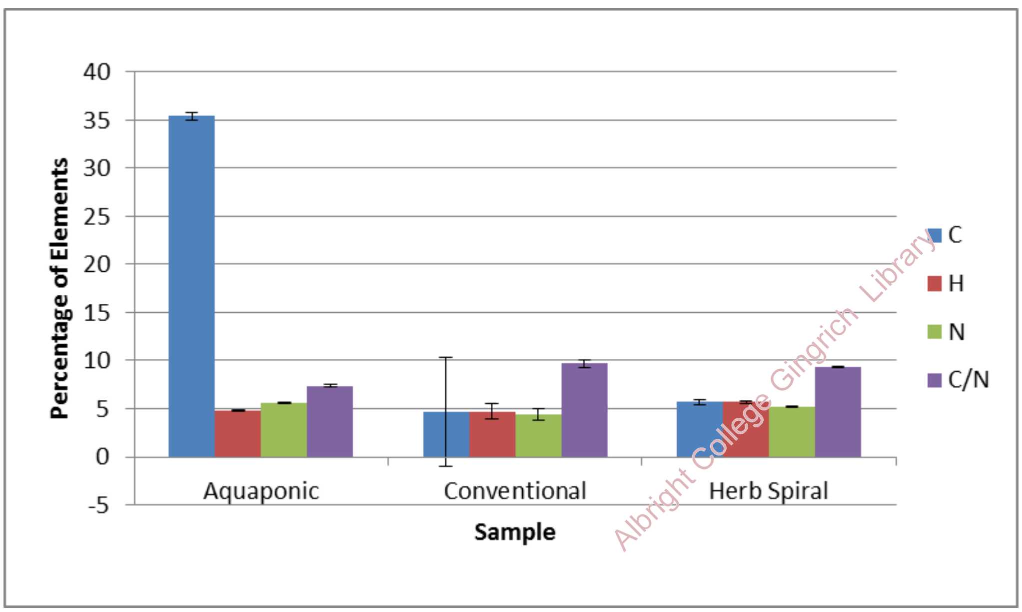

Figure 4. Percentage of carbon, hydrogen, nitrogen, and the carbon and nitrogen ratio found in basil grown in the aquaponic and conventional systems, with inclusion of the basil sample from the herb spiral for comparison.

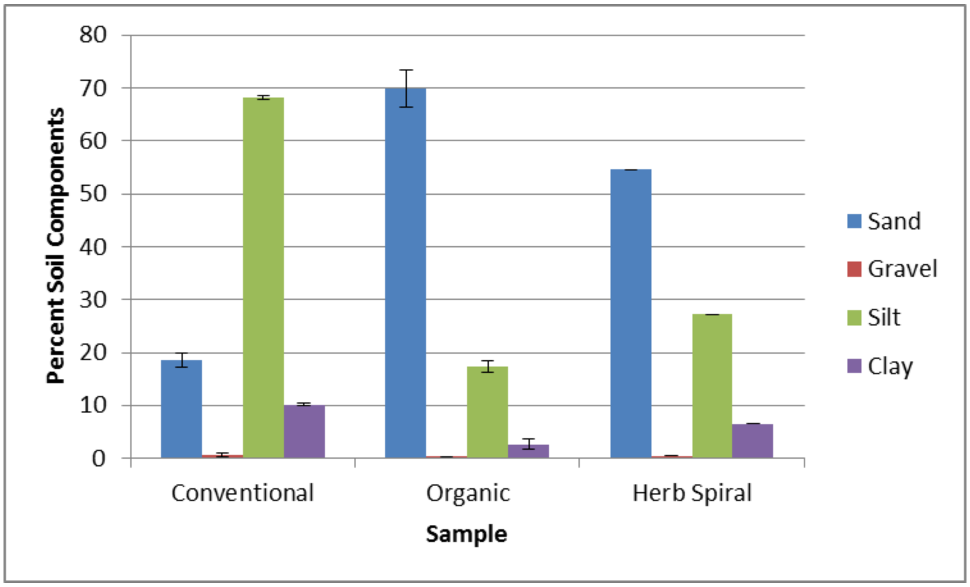

Figure 5. Average percentage of soil components as a result of the wet sieve method. Percentage of the main constituents of soil (sand, gravel, silt, and clay) found in the conventional and organic systems, as well as the herb spiral structure are reflected.

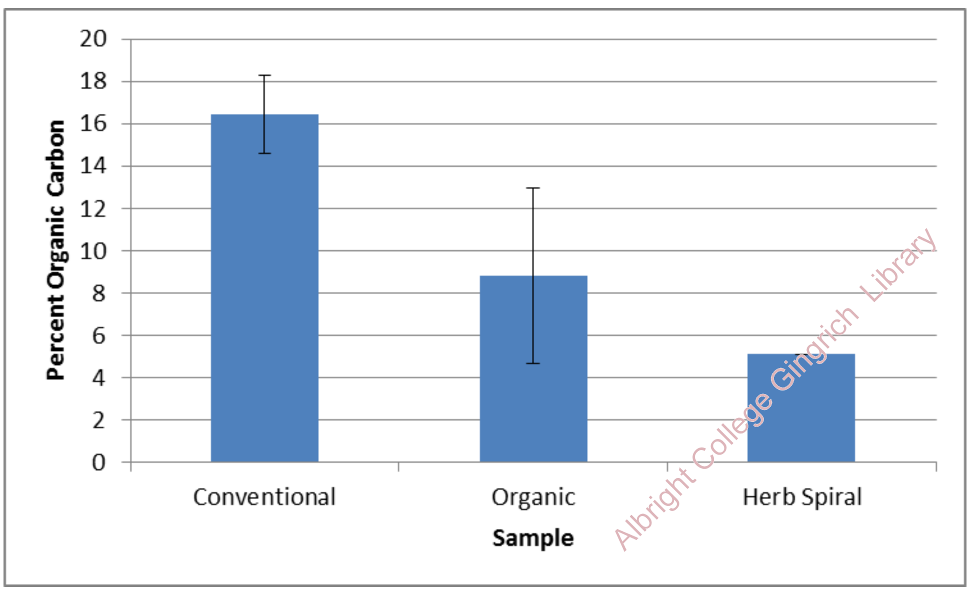

Figure 6. Average percentage of organic carbon in soil samples determined by loss on ignition methods. Percent carbon found in soil samples from the conventional and organic systems, as well as the herb spiral structure are reflected.

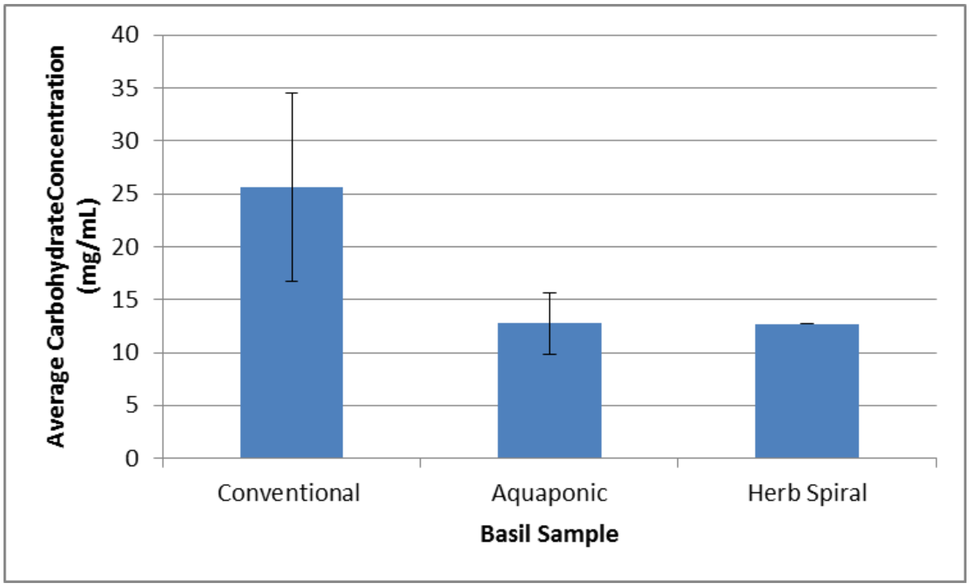

Figure 7. Average carbohydrate concentration (mg/mL) found in basil samples grown in aquaponic and conventional systems, as well as the herb spiral structure.

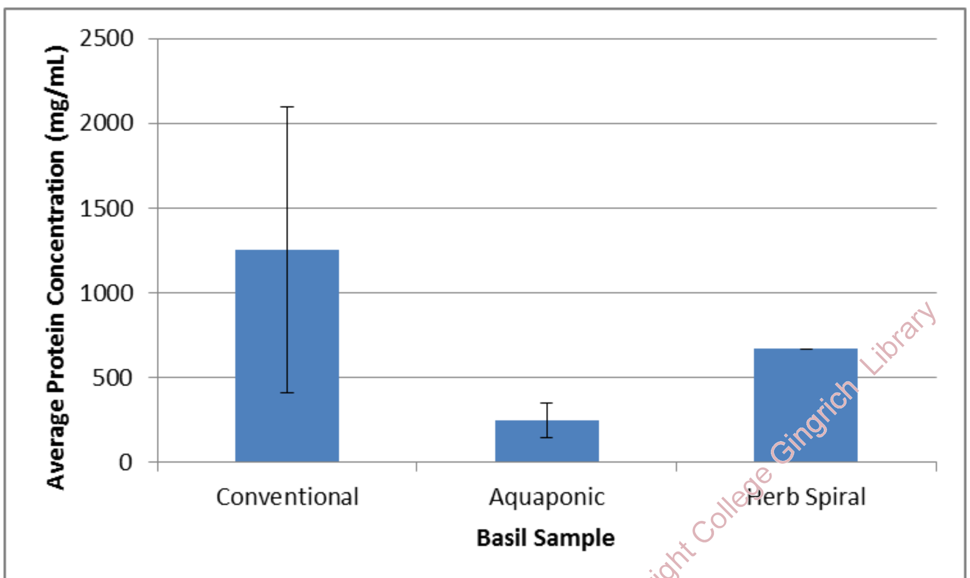

Figure 8. Average protein concentration (mg/mL) found in basil samples grown in the aquaponic and conventional systems, as well as the herb spiral structure.