# Barriers and incentives to engaging with aquaponics systems:

## Empirical Evidence from São Carlos, Brazil

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Abstract

This research presents the barriers and incentives faced by small-scale farmers in engaging in aquaponics systems in the São Carlos, Brazil community. Aquaponics is an agricultural system that combines hydroponics and aquaculture in a symbiotic arrangement to produce vegetables and protein simultaneously. Current research argues that aquaponics can help promote food security, community resiliency, and sustainable agriculture by integrating these versatile and necessarily organic systems into the urban environment. Despite historical use of aquaponics, there is currently a lack of research focused on the social dimensions of this emerging sustainable technology, including an assessment of barriers that may exist for local farmers to engage in aquaponics systems. During May 2018, 21 interviews were conducted with the owners of small farms (in Portuguese, "agriculturas familiares") within 30 kilometers of São Carlos, Brazil. The interviews revealed that there is interest in the potential profitability of aquaponics systems and an existing knowledge base of organics, hydroponics, and agriculture in the community. However, lack of initial financing and time to build the systems were also significant barriers to creating the systems. Cities could reduce this barrier through contracting with local farmers to increase farmer financial stability and reduce perceived risks. Knowledge-sharing workshops should also reduce technical barriers to engagement. These recommendations can be used to address these barriers in São Carlos and could be applied to cities throughout the world as they seek to promote the use of aquaponics and advance their local food security.

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## Introduction

This research presents the social factors that inhibit small-scale farmers from engaging with aquaponic systems, a promising sustainable farming technology. The barriers were determined through interviews in São Carlos, Brazil with small farmers, NGOs, and restaurant owners. The São Carlos context will serve as a case study that can be drawn upon with potential application for other cities that seek to develop their local food production.

Although an ancient technology, scholars and practitioners have recently studied aquaponics as a potential solution to global food insecurity (Goddeck et al. 2015). Aquaponics is a technology that allows fish production and vegetable production to occur simultaneously (see figure 1). It is the combination of hydroponics, the process of growing vegetables in water without soil, with aquaculture, fish raising (Kloas et al. 2015; Turcios and Papenbrock, 2014) This combination allows the production of both food products while minimizing water consumption, fertilizer use, and the environmental hazards associated with waste loading to local streams (Amosu et al. 2016; Kloas et al. 2015).

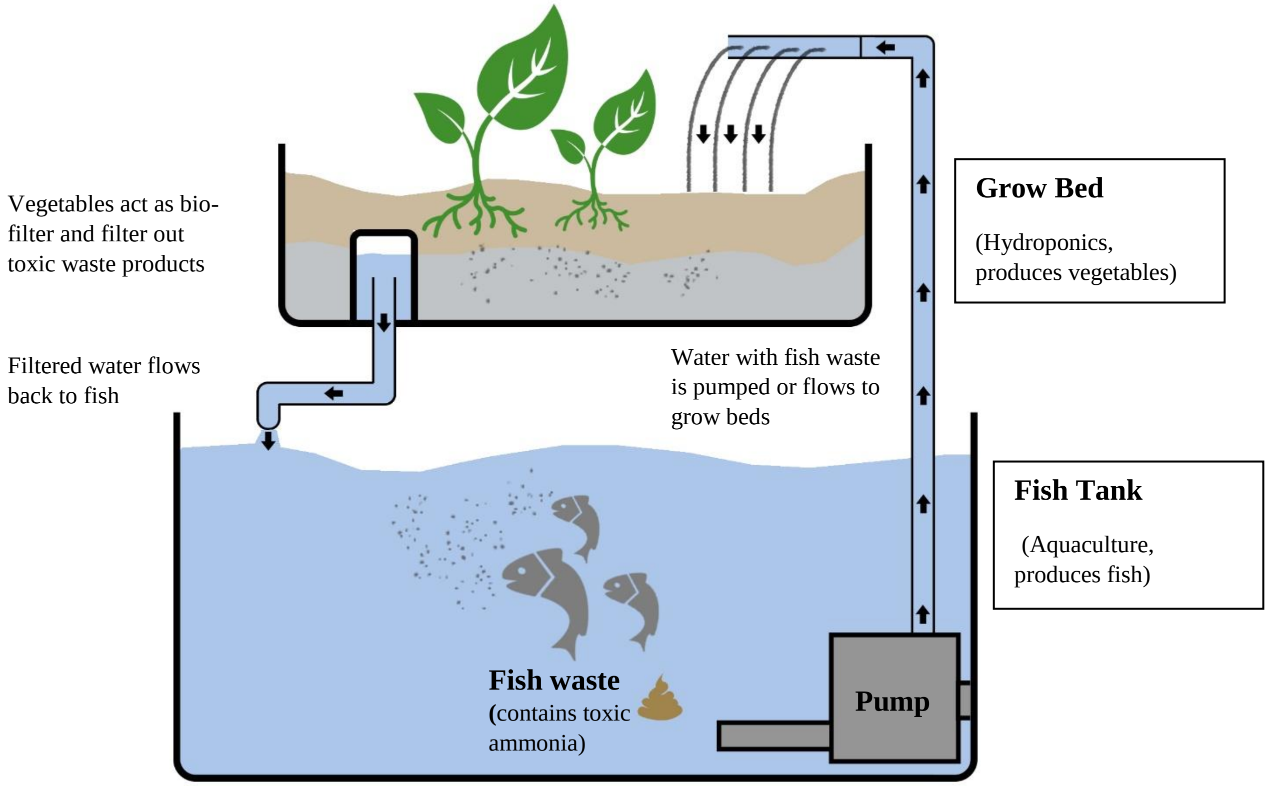


**Figure 1.** Diagram of an aquaponics system. The plants of the system function as a biofilter, filtering ammonia from the fish waste. This allows the water to be recirculated throughout the system and to reduce environmental pressures associated with loading aquaculture waste into local streams.

Aquaponic systems are also highly scalable and flexible (dos Santos, 2016); they can be designed to be used in a variety of indoor and outdoor environments and scaled to fit individual production needs. This flexibility could be particularly beneficial when applied to the urban context. As urbanization increases globally the demand for food sources will also increase. In many industrialized cities, previous sprawl can provide abandoned buildings and warehouses that can be repurposed as local food production centers. Aquaponics systems can fit into this context and help provide fresh, locally produced protein and vegetable sources, create new jobs in cities, and reduce food transportation costs and carbon emissions (dos Santos, 2016). Through integrating these versatile and necessarily organic systems into the urban environment, aquaponics can help promote food security, community resiliency, and sustainable urban agriculture.

Despite the perceived positive benefits of aquaponics, much of the current literature on aquaponics focuses on the technical aspects of the systems, such as system design, nutrient and water requirements, and on-going maintenance needs (Turcios and Papenbrock, 2014). There is currently a lack of research focused on the social dimensions of this emerging sustainable technology, including an assessment of barriers that may exist for local farmers to engage aquaponics systems (Laidlaw and Magee, 2014). Through understanding present barriers faced by small-scale farmers in engaging in aquaponics, local governments can be informed on how to best work with these farmers in order to promote the use of aquaponics and local food production.

During May 2018, 21 interviews were conducted with the owners of small-scale farms ("agriculturas familiares") within 30 kilometers of São Carlos, Brazil. A comparison of the demographic information of this sample to the total population of 60 famers surrounding São Carlos demonstrated that this sample was representative of the entire population. These farmers were asked questions that assessed the major social, technical, economic, physical, and environmental factors involved in engaging in sustainable agriculture and aquaponics systems in São Carlos, Brazil. The remainder of this section will focus on the agriculture setting of Brazil, and São Carlos specifically. Section 2 will provide the methods and framework analysis for the interviews conducted. The results are then presented and analyzed in Section 3. The final section will conclude with a discussion of key findings and policy recommendations for municipalities that wish to promote urban sustainable agriculture practices in their community.

## Background

Brazil is one of the world's leading exporters of agricultural products (OECD/FAO, 2016). It is currently the world's largest sugar cane producer, with current projections for Brazil to replace India as the top global exporter of beef and to replace the United States as the top exporter of soy beans (OECD/FAO, 2016). Agriculture is also tremendously important to Brazil's economy. Agribusiness, including farming, processing, and agro-services accounted for 21.6 % of the total Brazilian Gross Domestic Product in 2017 (CEPEA, 2018), and nearly 50% of the country's total exports (Decerega, 2017). Some Brazilian farm lobbyists are even attributing the stabilization of the Brazilian currency, reais, to the growth of the agricultural sector (Mano, 2017).

Despite the economic benefits of production, agriculture can only exist if the ecosystems and natural resources that support these processes are used sustainability. Cultivated land currently accounts for 10.3% of the country's total land (FAO, 2016), with expansion every year. In 2010 agriculture was also responsible for 60 percent of the country's total water withdrawal (FAO 2016) and one-third of the national greenhouse gas emissions (Russell and Parsons, 2014). Large, typically monoculture, farms are also a major driver of land-use change as forests are cleared to increase arable land availability. While deforestation rates have decreased, forest loss still accounts for 22 percent of Brazil's carbon emissions (Russell and Parsons, 2014).

In recent years scholars and development organizations have argued that small-scale agriculture, production that occurs on small plots of land, typically without the use of "advanced" farming technologies, could help to reduce some of the environmental pressures contributed to larger, typically monoculture, farms (Kutya, 2012). These farms often exist within or on the periphery of urban areas and sell to local markets. The relatively smaller area of cultivation and support of local business is more sustainable than their large-scale counterparts in a variety of ways. Small local farms can promote food security, reduce carbon emissions associated with large machinery, large-scale tilling, and transportation, and reduce water use and loss through evaporation (Kutya, 2012). Furthermore, their products are often consumed by the farmers themselves, creating household food security as well as providing an income for multiple families.

Due to the perceived sustainable benefits of small-scale agriculture, there has been a push from development organizations to increase the growth and efficiency of these smaller farms to continue production while maintaining environmental sustainability. The Food and Agriculture Organization estimates that 50% of the required increase in food production by 2050 will have to come from smallholder farms (IFAD, 2011), and organizations worldwide are seeking to determine the best, most efficient, practices for these farmers.

This push is occurring on the local level as well. A semi-structured interview with the municipal Secretary of Agriculture of São Carlos, Brazil revealed that he and the city government are working with small-scale farmers[1], (in Portuguese, “agriculturas familiares” which translates to “familial agriculture”) to determine the ways in which the city can support them to increase local food production and provide a source of local food for municipal programs. The municipality manages social programs which include the provision of meals for schools and elderly care facilities. By contracting with the owners of small-scale farms and settlements[2], the city is able to

[1] In Brazil “agriculturas familiares” refers to farms that are owned and managed by a few individuals, typically one person and a close family member, such as a spouse, child, sibling, or parent. Within 100 km of São Carlos it is estimated that there are 60 of these types of farms.

[2] Settlements (“assentamento” in Portuguese) are typically comprised of a group of individuals that work on the same property. These properties are often former agricultural fields that have been abandoned and rendered unproductive by the National Government. Article 184 of the Brazilian Constitution of 1988, states that “unused farmland should be expropriated and used for redistribution” (McCowan, 2016). Supported by this article, the Landless Workers Movement (MST, Movimento dos Trabalhadores Rurais Sem Terra in Portuguse) has led nearly 400,000 families to occupy, work, and earn the right to live on over 20 million acres of land. By law, if the families are able to have productive use of the land for 6 years, they are granted rights to continue living and working on the land by INCRA, the national land reform institute (Instituto Nacional de Colonização e Reforma Agrária). It is often

request specific products for these programs, while farmers are benefitted by having a reliable buyer and stable income. The municipality has contracted with these small-scale farmers to support the city programs, local economy, and farmer livelihood.

São Carlos, Brazil is a town of 221,950 inhabitants (IBGE, 2010) located approximately 240 km northwest of the city of São Paulo. It is the largest city located within the the Feijão River watershed. All farmers interviewed drew their water from this watershed. The land use of the entire watershed can be seen in figure 2, which also illustrates that the São Carlos economy is predominately supported by agriculture and cattle raising. Currently the majority of land use surrounding São Carlos is dedicated to large-scale sugarcane, cattle raising, and citrus production. However, there is estimated to be 60 small-scale farmers within 30 kilometers of São Carlos that grow a variety of crops on their properties. In addition to selling to the city for the municipal program, farmers also sell their products at open-air markets, to local grocery stores, and others (see table 2).

difficult to make the land productive, which contributed to the original abandonment of the properties. As discussed further below, these lands often have acidic soils and a lack of reliable water sources, both of which require special care from the farmers.

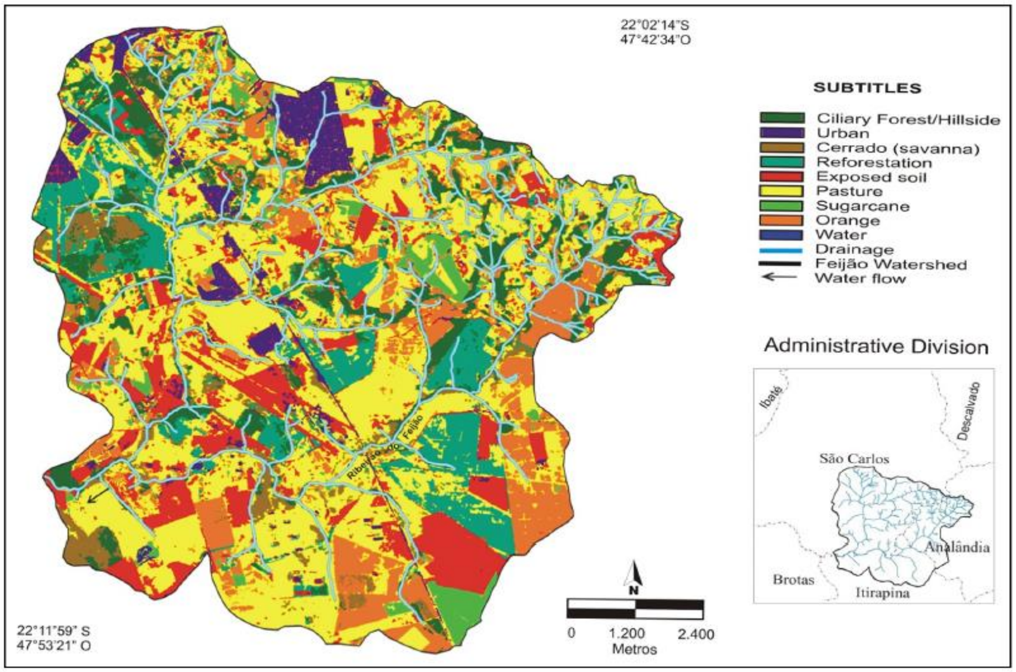


**Figure 2**. Land use of the Feijão River watershed. The Feijão River supplies the water of the city of São Carlos and the watershed provided water to all farmers interviewed. Created from ALOS satellite imagery November 2006. Adapted from Machado et al. 2016.

The farmers that sell to the city currently provide fresh citrus fruits, vegetables, and milk. However, the Secretary of Agriculture has a stated interest in expanding the program and procuring more locally produced protein sources. Due to its flexibility and scalability, aquaponics could be implemented on these small-scale farms and be used to provide for these programs. In this process the farmers would also expand the diversity of their products by producing protein and vegetable products simultaneously.

This research conducted interviews with the owners and workers of small-scale farms surrounding São Carlos to determine which factors would incentivize or inhibit their engagement with aquaponics systems.

## Methods

This research used structured interviews with local small-scale farmers in Sao Carlos Brazil in order to understand the social, technical, economic, physical, and environmental factors of the farm and how these factors influenced farmers engagement with aquaponics. The comments provided by farmers were supported by desktop research and semi-structured interviews with local government officials, local environmental non-profit owners, and members affiliated with the food supply chain in the region.

The structured interviews occurred during May and June 2018. Interviews were conducted with 21 owners or workers of small farms (in Portuguese, "agriculturas familiares") within 30 kilometers of São Carlos, Brazil. The local farmers were interviewed on their properties, in open air markets as they sold their products, and at the office of the municipal Secretary of Agriculture as the farmers dropped off the products purchased by the city. The properties visited included a farm-to-table restaurant, local farms, and two of the main settlements surrounding São Carlos.

The study population included all farmers that worked on small-scale farms within 30 kilometers of São Carlos, Brazil. For the sample population, efforts were made to interview every farmer that sold their products in the city. All open-air markets that occurred within a one-week period in São Carlos were visited and every farmer selling products was asked to voluntarily participate in the interview. In addition, farmers were chosen based on their partnership with the city and Secretary of Agriculture. These farmers were either interviewed in the office of Secretary of Agriculture or visited and interviewed on their farms. These methods are similar to Graber et al. (2018) in which known local contacts, events, and meetings were used to communicate with a broader set of respondents.

The interview was originally written in English and translated into Portuguese with help from the interview team comprised of Brazilian students at the University of São Paulo. The survey was first piloted with a local farmer on their property in São Carlos, and their responses or requests for clarification were used to revise the questions. The English version of the interview questions can be found in Appendix I, with the translated and administered Portuguese version in Appendix II. All interviews were conducted in Portuguese with responses translated back into English for the purposes of analysis.

Initial interview questions assessed the characteristics of the farm and prior knowledge of aquaponics. The farmers were then asked a series of questions concerning the technical, environmental, social, economic and physical factors that would incentivize or inhibit their engagement with aquaponics systems. The interview concluded with a series of open-ended questions the gauged barriers to aquaponics, knowledge and use of a farming technology to increase the productivity of the farm, and knowledge and use of technologies to protect the environment.

The description of each factor and the types of questions that were used to assess this factor are listed in table 1.

| Factor | Question topics | Purpose |
|---|---|---|
| Technical | Farmers' technical expertise and knowledge base of farming generally and aquaponics specifically, any challenges that the farm faced, and their ability and resources to handle those challenges. | These questions were used to understand the feasibility for the farmer to set up and maintain the aquaponics system. |
| Environmental | Farmers' nutrient and water availability, organic and pesticide practices, and any knowledge of farming technologies that could protect the environment. | Farmers that had low water and nutrient availability, as well as a desire to be organic and protect the environment, would be more likely to engage in aquaponics. |
| Social | The social dynamics of each farm: how the farmers currently work together, in what ways they would like to work with others, and what would influence them to do so. | By understanding these social factors, the city could develop the best strategies to successfully develop agricultural technologies throughout the community. |
| Economic | Farmers' land ownership, product selection, markets, and knowledge of technologies used to improve farm performance. | These questions were used to understand the general characteristics of the farm and how the farmers made decisions. These answers could be used to understand in what ways aquaponics systems could fit into these current models. |
| Physical | The amount of labor on each farm. | To determine if there is sufficient capacity to initiate and maintain new agricultural technologies, including aquaponics. |

**Table 1**. Description of factors. This table lists the topics within each factor that influenced engagement with aquaponics. Questions of the interview guide were used to understand how each factor would incentivize or be a barrier to the farmers' use of aquaponics.

## Results

All farmers interviewed either owned the farm or were a family member of the owner. Those interviewed worked on farms with a size ranging from 2.4 - 41 hectares (6 – 101 acres) with an average size of 12.3 hectares (30 acres). These farms had on average three employees, including the interviewee. The "employees" or farm workers always included family members, often a spouse and child or parent. Of the 21 farmers interviewed, 16 were males and 5 were female, with an age range of 26-62 years old.

## Aquaponics knowledge, interest, and barriers:

Of the farmers interviewed, 91 percent had not heard of aquaponics prior to the interview. Despite this, they were all highly interested in either learning more about or implementing the systems. When asked what would influence them to engage in aquaponics, 38 percent (8 of 21) responded that they would set up the systems if they knew that it would be successful and profitable. Others noted the need for more time, finances for purchasing equipment, or ownership of the land in order to modify the property. Two farmers were incentivized by the use of the system to produce its own fertilizer and water efficiency. Additionally, 47 percent of farmers did not think that the systems would be complicated to operate, but that their largest barrier would be the time and finances required to set up the system. Financial and time constraints were also revealed within the social and economic portion of the interview.

## Technical Factors

### Challenges:

The farmers were questioned about the general challenges that they face on their farm in order to understand the feasibility of initializing and maintaining the aquaponics systems during these challenges. The most frequently mentioned difficulty of their farm in general, mentioned by 30 percent of farmers, was water access, with water scarcity increasing during the dry season. Total costs of production were also a challenge mentioned by 24 percent of respondents. Aquaponics could be a solution to these challenges through its efficient use of water and ability to increase the productivity of land area. Two farmers also mentioned pests and fungi as being challenging, especially given that they had opted to eliminate pesticide use. While pests may still exist on an aquaponics system, one farmer stated that they had began aquaculture specifically with the intent for the fish to reduce mosquito reproduction.

In addition to these property challenges, the farmers on settlements (see footnote two above for description of settlement properties), which comprised of 5 of the 21 farmers interviewed, also mentioned their transportation issues during the rainy season. With their properties being located on a dirt road, they are often unable to drive to town to sell their products when roadways are washed out by seasonal rains. This is not a problem that is unique to settlement workers, and transportation logistics are a large barrier known to the city of São Carlos and to farmers throughout Brazil, especially those located in inland regions. The lack of reliable roadways and transportation impacts the livelihood of all Brazilians and the productivity of the entire agricultural sector. However, the Brazilian government launched an infrastructure investment program, known as a Growth Acceleration Program (PAC) in 2007 that should help to alleviate these issues (Dahr, 2012).

## Knowledge and expertise:

The interviewees were asked how many years they had worked on the farm in order to gauge the extent of their agricultural knowledge. These responses were varied, ranging from 1-40 years with an average of 14 years of farming experience. The farmers that were younger with fewer years of experience were often the children of parents that had owned and worked the land for generations, demonstrating that the agricultural knowledge base would still exist on the property and a lack of knowledge would not be a barrier. Additionally, two farmers had previously worked with aquaponics, three farmers were currently engaged in aquaculture, and nearly half of the respondents were "very knowledgeable" of hydroponics, with either having their own hydroponics system or knowing someone with a system. The extensive knowledge of farming, aquaculture, and hydroponics that exists throughout the São Carlos farming community could facilitate farmer engagement with aquaponics.

## Environmental Factors

### Water access and availability:

All farmers not living in settlements reported having sufficient water for their crops. In general, farmers received their water from a well (57 percent), a river (20 percent), or a reservoir (14 percent), and all farmers lived within the Feijão River watershed. The average distance between the water source and the farm was 300 meters. Having reliable water access on each property should enable the farmers to easily set up and maintain the aquaponics systems.

### Nutrient availability:

Of the farmers interviewed, 72 percent (15 of 21) used fertilizer, with fertilizer accounting for on average 15 percent of the farmer's total expenses. Nearly all farmers felt that they had a sufficient amount of fertilizer or was able to buy more or use the manure from their farm to meet their needs. Knowing that farmers are purchasing fertilizer, the farmers will likely be incentivized to increase their profits by using the nutrients that are generated from the fish in aquaponics systems to grow their produce.

### Organic practices:

Since aquaponics systems continuously circulate the same water through fish ponds, it is essential that the entire system is organic to prevent any adverse toxic effects to the fish. Organic practices were also very important to the São Carlos farming community, with 62 percent of farmers stating that their farm is completely organic and nearly all farmers stating that they try to be as organic as possible. Most farmers spoke of their desire to have as healthy and as high-quality produce as possible, and so used synthetic pesticides only when necessary, if at all. All farmers said that they consumed the food that they grew at nearly every meal, so organic practices and pesticide reduction was an important consideration to their personal health as well as the health of the community. With organics being a known priority to these farmers, the necessarily organic aquaponics systems would fit well into their current farming techniques and the need for the systems to be organic should not be a barrier.

### Sustainable farming technologies:

When asked, “are you familiar with any environmentally friendly farming technique or technology?” thirty percent of farmers discussed organic practices and how they have already implemented them. Fifteen percent of farmers had also implemented agroforestry and permaculture practices, and several had active reforestation projects and vegetative waterway buffers on their properties. These practices illustrate a concern for the environment and these considerations could influence the farmers to engage with environmentally-friendly aquaponics systems.

## Social Factors

Of the farmers that believed that there are barriers to working together, 62 percent of respondents, 54 percent felt that the largest barrier to working together was that each farmer had “cabezas diferentes”, which translates to different ways of thinking. These respondents explained that farmers tend to have strong opinions about the ways that a farm should be managed and operated, and therefore it would be difficult, if not impossible, for the same farmers to work together on the same land. Another barrier that was often mentioned was time; the farmers did not feel that they could meet the demands of their property while also working with others. However, those interviewed responded that on average they would be 8 on a scale of 10 interested in working with others. When asked in what way they would like to work together, most were interested in a co-operative that allowed farmers to meet and share technics, methods, knowledge and experiences. Many also expressed interest in a partnership where products were exchanged so that each individual farmer could have a larger variety to sell when they went to the market without having to grow each product themselves.

## Economic Factors

### Land ownership:

Ownership was common among the farmers interviewed, with 80 percent of farmers either owning the land or were members of the family that did. This includes settlement owners who owned the rights to work on the land. Less than ten percent of those interviewed were employees of the farm only without any ownership rights or familial ties to the land. Through owning the land, the farmers would have the ability to make decisions about the land use; they have the right to dig holes to create the fish ponds for the aquaponics systems.

### Product selection:

The interviewees were asked about the types of products that they grow on their farm and why they selected these products. While there was a large variety of products, (appendix V), nearly 72 percent of those interviewed already grow "leaf vegetables" including lettuce and cabbage, vegetables traditionally grown in many hydroponics and aquaponics systems. Other popular products included various citrus fruits, broccoli, and milk. The majority of respondents selected their products based on market demand; they grew and sold products that were known to sell reliably. Sometimes farmers would select products that could be sold at a premium price because they were either processed products (such as cheese) or they were less common and unique from their competitors. Other times the farmer was limited in their product selection, because of the climate, poor soil quality, or a lack of a workforce required to grow other produce. The prominence of leaf vegetables in these markets illustrates both that the farmers tend to have agricultural knowledge to successfully produce them and that there is a market demand for these products.

## Market:

All farmers interviewed, except one, considered their farm to be commercial, meaning that they sold their farm products for a profit. However, the farmers also relied heavily on their farm for their own sustenance, with every respondent saying that they consumed the food that they grew for nearly every meal.

Everyone interviewed sold their products locally, either to the city, at open markets, or to local grocery stores directly (see table 2). The average distance that the farmers traveled ranged from 0 (on their property) to 100 km, with an average distance traveled of 24 km. When asked why they sold their products locally, they noted that selling local was easiest and cheapest for them in terms of transportation. There is also a demand at the local level, so they could grow products specific to meet the demand of individual customers and their contracts with the city. Table two illustrates that the local farmers heavily rely on the municipality and the open-air markets for an outlet of their products, while only a few sell directly to grocery stores or restaurants.

| | |
|---|---|
| Municipal government | 11 |
| Open-air market | 11 |
| Local grocery store | 5 |
| Local University cafeterias | 3 |
| On property | 3 |
| Neighboring city | 2 |
| Restaurants | 2 |

**Table 2.** Markets for small-scale farmers in São Carlos. Results are taken from the 21 farmers interviewed in response to the question, "Where do you sell your products?"

## Product expansion:

Every farmer interviewed was interested in expanding their production, either through producing more or having equipment to produce more or process their products, but most noted that they were limited by their lack of workforce. Of the farmers that noted that they were interested in a technology for improving the performance of their farm, 20 percent mentioned interest in aquaculture, and 20 percent were interested in technologies that saved energy. These energy technologies included using biodigesters to use farm waste to create energy or implementing a water wheel to irrigate crops and save time, money, and energy.

These economic results indicate that the farmers have great flexibility in selecting their products and modifying their land to grow new products to meet the local demand. Product selection, then, is driven by local demand. These results also demonstrate that farmers are interested in expanding their production but are limited by their time, finances, and workforce capacity.

### Physical Factors

The farmers indicated that one of their largest challenges on the farm was their lack of workforce. While they felt confident in their ability to complete their daily tasks on their own, they also discussed the desire to expand production, which was limited by their capacity of physical labor. The farmers worked an average of 11 hours every day, including weekends when they sold their products at open-air markets.

These physical factors are a potential major barrier to farmer engagement in emerging agricultural technologies and aquaponics, and the lack of time was explicitly mentioned as a barrier to engaging in aquaponics in the results of the aquaponics knowledge section. If aquaponic systems are to be developed on these farms, there must be special consideration to reduce the time and financial burdens that are born by the farmers.

## Discussion

There are many factors that would support the diffusion of aquaponics systems as a sustainable agricultural technology in the São Carlos community. However, some barriers to developing these sustainable technologies also exist that would need to be addressed by community officials for these systems to be successfully adopted. In this section the factors that would incentivize the development and diffusion of aquaponics systems in the São Carlos community will first be discussed, followed by current barriers to the success of aquaponics. A brief set of policy suggestions are then presented for the city officials of São Carlos and any that wish to implement aquaponics or other sustainable agriculture technologies in their own communities.

## Incentives:

*Technical:* Though the farmers were not familiar with aquaponics, most were highly interested in the systems after a brief explanation of the system and did not believe that they would be difficult to operate. The farmers also had extensive agricultural knowledge, as evident through the respondents having an average of 14 years of farming experience. Most farmers were very knowledgeable about hydroponics and had already implemented organic practices. The extensive knowledge base of organics, hydroponics, and agriculture, as well as interest in aquaponics should incentivize engagement with aquaponics systems.

*Economic:* Interview responses indicate that local agricultural production is driven by local demand, and that the farmers have a high capacity to meet this demand. These small-scale farmers typically own their properties and can modify them to grow the products that the customers desire. Their flexibility and ability to meet demand has been demonstrated repeatedly through the successful programs and city contracts initialized by the municipal Secretary of Agriculture. Knowing that local production is driven by local demand, the Secretary of Agriculture can work with the farmers to establish contracts for fish production and hydroponics vegetables. The farmers know also that there is a market demand for vegetables that are typically grown in hydroponics systems, as illustrated by the majority of farmers growing and selling leaf vegetables (see appendix V). If the city contracts with the farmers to purchase their fish products, the farmers are more likely to be incentivized to engage in aquaponics. The contracts with the city reduce the barrier of the farmers not knowing initially if their products will be profitable, reducing perceived risks by the farmer to initializing new products. Once the farmers can comfortably produce and sell their fish to the city, they can then develop the capacity to sell their fish and hydroponics vegetables at the open-market to local consumers directly.

*Environment:* The São Carlos farming community has already engaged in environmentally-friendly practices, reduced their pesticide use, and many have implemented organic practices. Additionally, many farmers expressed the need to protect the watershed and their water resources through the use of permaculture and vegetative buffers that reduce soil erosion. These trends are also being seen around Brazil, with "22.5 percent of Brazilian municipalities already engaging in some sort of organic production" (Decerega, 2017). The interview results surrounding environmental factors illustrate that there is a desire in the community to promote healthy products, communities, and ecosystems. The necessarily organic aquaponics systems and its ability to reduce fertilizer inputs, naturally filter water, and conserve water consumption should incentivize many farmers to engage in these systems.

## Barriers:

*Economic:* A more nuanced discussion of economic barriers is necessary. The results demonstrate that farmers are interested in expanding their production but are limited by their time, finances, and workforce capacity. This response is particularly interesting because when asked if the farmers had sufficient labor capacity all farmers felt that their labor capacity was sufficient to meet the needs of their farm. After further analysis, the comments included in responses indicate that the farmers feel that as individuals and with the help of family members they are able to meet the current demands of their farm. This requires them to work long hours, often 12-14-hour days, nearly every day. While the lack of labor appears to be a barrier to engaging in aquaponics systems initially, these systems could actually benefit the farmers by producing two types of products simultaneously. Additionally, aside from fish feeding, the systems do not require daily irrigation or time for maintenance in the ways that traditional crops do. In this way, aquaponics could help to reduce the workload of farmers by allowing them to expand their production without adding, or perhaps reducing, time to total working hours.

*Social:* “Agriculturas familiares” are by definition small-scale farms which contain few workers. The farmers interviewed had on average 3 employees that worked on farms less than 12 hectares. These farms are classified as “agriculturas familiares” because they are individual families that live and work on the same property. Having multiple families work on the same property would require working against culture and tradition, and it is not apparent that this is necessary for aquaponics to be successful. As the social results indicated, the farmers are most interested in working in a co-operative that allowed farmers to share knowledge and expertise. When working to develop an emerging technology in a community, co-operatives and workshops would be highly beneficial to reduce costs associated with a lack of expertise of the system. Through working together in this capacity, farmers could collectively learn and trouble-shoot issues with the systems. A few farmers also expressed interests in exchanging products with other farmers. In this way, they could concentrate on producing one product, and a product exchange would allow them to diversify the products that they sell at the market without increasing their work load by producing each unique product individually. Applying this concept to aquaponics systems, a sales partnership would allow a fewer number of farmers to engage with aquaponics while potentially increasing the number of markets that these products can enter, potentially increasing the local demand for aquaponics products overtime.

Many farmers also knew the owner of Sitio São Joao, a farmer in São Carlos with a functional aquaponics system who regularly hosts educational workshops as part of a co-operative. The popularity of this farmer in the São Carlos community and his ability to host workshops could help to remove technical barriers and increase knowledge about the systems through information sharing.

*Environment:* Every farmer, except for those on settlements, had reliable access to water on their properties, though some noted the need to conserve water during the dry season. Since settlements occur on land that was originally abandoned due to farming challenges, including soil acidity and a lack of water, challenges with reliable water sources on settlements will likely always be a barrier to any productive use of the land. Settlement owners also often had to “fix” the soil through the addition of minerals that reduced its acidity. The low-quality soils present special financial and environmental challenges to settlements that should be taken into consideration when working with these farming communities.

*Technical challenges:* The challenging road infrastructure system throughout the inland regions of Brazil has been a known concern for farmers for many years (Schaffer and Ray, 2015). As previously stated, the Brazilian government launched a program known as the “Growth Acceleration Program” in 2007 that should improve the road systems to allow farmers to more easily transport their goods to the market. These results indicate that while dirt roads did present a challenge for transportation during the rainy seasons, these adverse conditions only impacted the farmers on settlement properties that are often on the outer periphery of the city.

## Recommendations to communities and policy makers:

This section will now present five recommendations to citizens and policy makers on how to promote aquaponics systems in their communities based on the results of this research. First, it is recommended that if cities hold current contracts between the city and farmers that the contracts are maintained, and the contracts could be expanded to other farmers if resources allow. Second, the city could use the contracts to purchase fish, or the product not currently being sold at markets, directly from the farmers to increase demand for that product and be a reliable buyer for the farmer. Third, the city could work with farmers to reduce the financial and time constraints associated with initializing the systems, potentially through the diffusion of aquaponics kits. Fourth, the city could work with the community to create aquaponics workshops and encourage knowledge sharing. Finally, if the city desires to work with settlement properties, they could seek to understand the unique challenges that are presented on the properties, and work with those farmers to overcome them.

Other than selling directly to the city, many small-scale farmers will sell at open air farmer's markets ("ferias"), universities for use in their cafeterias, or to local grocery stores (see table 2). Many farmers in this study noted that producing and selling first to the city allowed them to reliably increase their income to expand their production and sell to other markets. The contracts with the city enabled farmers to ensure that they would have a buyer and make a profit on the products that they sold. The farmers then have been able to grow more products with their excess income and expand their sales to open-air markets and local grocery stores. Through the creation of contracts with the farmers, the municipality has provided a livelihood to the farmers, successfully increased local procurement of produce for their city and improved the local economy.

To support the development of aquaponics systems in the community the city could create contracts with farmers specifically requesting fish produced from aquaponics systems. The results demonstrate that if the farmers have a known buyer, they are more likely to engage in new technologies and the development of a new product. If it is not known how the market will react to new products or if there will be a demand for them, the farmers are hesitant to invest time and finances to develop new products that may not necessarily be profitable. Since the farmers know that leaf vegetables and hydroponics will be successful, the city should create contracts to purchase the fish products and address this barrier.

The city could work with farmers to reduce the initial start-up barriers to aquaponics systems, including financing and time constraints. One potential way that this could be done would be the development and distribution of “kits” or pre-made aquaponics systems that can be easily and quickly set up. There are some companies based in São Paulo that have already begun to create flexible and scalable aquaponics kits. If communities wish to reduce the time and financial barriers of initializing aquaponics, then the community could determine how the company would either sell directly to the city or the community could create and distribute their own kits.

The city could work with the local farmers to support aquaponics workshops. A few of these workshops have already occurred at Sitio São Joao, where a functional aquaponics system exists. Hosting the workshops here would allow the farmers to see the successful operation of the system, as well as build a community network that would allow information and best practices sharing to occur. The city could partner with this farmer or a similar farm to support the workshops, encourage local farmers to participate, and promote the diffusion of sustainable agriculture technology throughout the community by facilitating the transfer of knowledge about the systems.

There are two special concerns for settlement properties that cities could seek to address if they wish to work with these communities: road infrastructure and water access. While transportation and water availability were not a concern for the majority of farmers, those that lived on settlements did express concern with water access during the dry season, and the inability to transport their produce to the markets during the rainy season due to washed-out dirt roads. Cities that seek to work with settlements should understand these challenges and work with these communities to overcome them.

The hope of these recommendations is that they can be applied to the city of São Carlos and other communities alike as they seek to promote aquaponics or other developing sustainable agriculture technologies in their communities. Of course, every city is unique and will have their own cultures, challenges, and opportunities and policy makes should seek to understand these unique aspects as they work with their local farmers.

## Limitations

While every effort was made to ensure that all information was translated exactly, there are likely nuances that did not translate between conducting the interview in Portuguese and translating and transcribing the responses in English.

Every effort was also made to reach every farmer within 30 kilometers of São Carlos, Brazil. Farmers were contacted via phone and in person, and interviews were conducted on the properties of farmers, at every open-market in the city open within a week period, and at the Office of the Secretary of Agriculture. Despite this, only 21 farmers of the known 60 small-scale farmers surrounding São Carlos were reached. A sample-size calculator was used and illustrated that this this sample is not representative at the 95 percent confidence level. To compensate, sample demographics were compared to population demographics, demonstrating that the sample collected is similar to that of the entire population of small-scale farmers. Future studies should attempt to interview at least 52 farmers of the population in order to be representative with 95 percent confidence and should further seek to reach as many farmers as possible.

To address these short comings, future studies should ensure that all interviewers speak fluent Portuguese in order to effectively conduct, translate, and transcribe the interviews. Every farmer, if possible, should also be contacted in person with a request to participate in the interview. In this way, the study can ensure that the entire São Carlos population is being reached and their opinions represented.

## Conclusion

Aquaponics is a potential viable solution to increasing food security and promoting local economies throughout the world (Goddeck et al. 2015).  However, barriers and incentives will always exist when adopting any new technology and creating societal changes. Efforts should be made to understand the barriers within each community to these changes, and how the local government or businesses can respond to these challenges with solutions.

This research indicates that one major solution to the challenge of promoting aquaponics and local food security is through the implementation of municipal contracts with farmers. The economic results of the interviews demonstrated that farmers grow their products to meet local demand, and their small-scale and ability to make decisions of their farm gave them great flexibility to meet this demand. Despite this, farmers frequently discussed the high costs of farming and the need to ensure that there was a demand for their products to maintain profits. Through a partnership with farmers, municipal contracts increased farmer financial security and reduced the perceived risk of unknown profitability from new production. The application of these findings indicate that partnerships could also be leveraged to reduce or eliminate risk aversion to new products and technologies. Cities that wish to promote a new technology or produce could specify their intent to purchase the products from these systems in contracts. To promote aquaponics systems cities could directly purchase the fish that the systems produce. This research shows that this partnership and security provided to the farmer has the added benefit of allowing the farmer to have a stable market and demand, increase their profits, and eventually use those profits to expand their production and increase their sales throughout the rest of the community. For aquaponics, once the farmers can comfortably produce and sell their fish to the city, they can then develop the capacity to sell their fish and hydroponics vegetables at the open-market to local consumers directly. Through developing the capacity of the farmers to implement aquaponics systems in a financially secure way, the city will indirectly allow these farmers to increase their production and sell aquaponics products throughout the entire community. Municipal governments could promote local food security and the promotion of new through direct purchases from local farmers. These contracts will increase the demand for and prevalence of the specific products that they wish to develop in their city.

Despite the benefits of municipal contracts, barriers to initializing aquaponics, or any new technology, in a community remain. The results demonstrate that major barriers to engagement include the lack of time, finances, and knowledge to initiate the farming technology. These barriers could be addressed through the distribution of prefabricated aquaponics “kits” and the support of community-based knowledge-sharing workshops. Additionally, the results indicated that every farm will present its unique challenges that should be understood, and low-quality soils and dirt roads present special financial and environmental challenges to settlement properties that should be taken into consideration when working with these farming communities.

This research, results, and discussion provide a template and guidelines for understanding the barriers and incentives found to engaging in aquaponics systems in the São Carlos, Brazil community. These recommendations can be used to address the barriers in the São Carlos community and could be applied to cities throughout the world as they seek to promote the use of aquaponics and advance their local food security.

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Appendix I: Interview Questions (English)

*Informed Consent:*

In this research, I seek to determine the major social, technical, economic, physical, and environmental factors involved in engaging in sustainable agriculture and aquaponics systems. This research will be used to assess how cities and communities can adopt sustainable food practices to promote food security and community resilience. Your participation is completely voluntary. At any time you can refuse to answer any question or you can choose to stop participating in the survey. Your time is greatly appreciated but you will not be compensated. Your identity will be protected, is not connected with your response, and will not be captured or used in any way.

1. Do you consent to participate in this interview?
2. Do you consent to be recorded? The recording is only for accuracy purposes.

Survey:

*(Background)*

**A. Your farm:**

*Size, productivity, challenges:*

3. Do you own this farm?
4. *If yes,* How many years have you owned this farm?
5. *If employee,* how many years have you worked here?
6. What products do you sell on your farm?
7. Why were these products selected?
8. What percentage of your products are organic?
9. What is the size of your farm (hectares)?
10. What percentage of the farm is currently being used (hectares)?
11. What difficulties do you face with your farm?
12. Do these difficulties vary with the time of year?
13. How do you get water to your farm?
14. What is the distance from that water source to the farm (meters)?

*(Physical / Labor force at your farm:)*

15. How many workers work on the farm?
16. How many total hours overall do you feel go into the farm per week (physical labor and operating procedures)?
17. Do you feel like you have sufficient labor to complete the tasks required for the farm? (Yes = all tasks are completed or No = maintaining the farm requires more assistance)

*(Social / Community Networking):*

18. Do you know Flavio at SSJ?

19. On a scale of 1-10, where 1 = no interest, and 10 = Greatest interest, how interested are you in working with other local farmers?
20. *If greater than 1*, in what way would you like to work with other local farmers?
21. Are there any barriers to working with other local farmers?

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*B. Economics and Distribution*

22. Do you consider your farm to be commercial (do you sell you farm products for a profit)?
23. How often are the products from your farm a part of your diet? (1-10, where 1 = never eat them and 10 = eat them for all meals)
24. Are your products sold locally?
25. Why or why not?
26. Where do you currently sell your farm products?
27. What is the distance between your farm and where your products are sold?
28. Are you interested in expanding the market of your products?
29. *If so*, how?
30. What percentage of your total farm expenditures are spent on fertilizer?
31. How often do you purchase fertilizer for your crops?

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*C. Environment*

What percentage of the time do you have sufficient amounts of the following:

32. Water for your farm
33. Labor on the farm
34. Nutrients for your crops

***D. Farming technologies:***

On a scale of 1-10, how familiar are you with … (1 = no knowledge, 10 = very knowledgeable)

35. Aquaponics
36. Aquaculture
37. Hydroponics

*38.* On a scale of 1-10, where 1 = no interest and 10 = greatest interested, how interested are you in working with aquaponics?
*39.* Have you worked with aquaponics before?
*40. If yes*, How many years have you worked with aquaponics?
41. Would you be interested in being a part of a group that shares experiences and helps other farmers to develop aquaponics systems?
42. What may influence you to create an aquaponics system?

43. On a scale of 1-10, where 1 = impossible to operate, and 10 = not complicated at all, in your opinion, how complex do you consider aquaponics to be to operate?

*(Sustainable agriculture)*

44. Are you familiar with any environmentally friendly farming technique or technology?
45. If so, which?
46. How likely are you to adopt this technique or technology? (Scale of 1-10, 1 = not at all likely, 10 = have already adopted).
47. Are you familiar with any farming technique or technology that is used to protect the watershed?
48. If so, which?
49. How likely are you to adopt this technique or technology? (Scale of 1-10, 1 = not at all likely, 10 = have already adopted).
50. Are you interested in any particular technology for improving the performance of the farm?
51. If so, which?
52. How likely are you to adopt this technique or technology? (Scale of 1-10, 1 = not at all likely, 10 = have already adopted).

E. Conclusion (Answers on a separate sheet than recorded responses)

53. Do you know of any other local farmers that would be interested in participating in the interview?
54. Are you interested in attending our workshop on aquaponics on June 5th? (Yes/No)
    a. What is the best way to contact you to remind you about the workshop?
    b. Do you need transportation to the workshop?
    c. Do you need transportation to SSJ?
55. Do you have any further comments?
56. Would you like a copy of the report?
57. If yes, how can we contact you?

Appendix II: Interview Questions (Translated to Portuguese)

**QUESTIONÁRIO**

Informação para ser consentida:

Nessa pesquisa, eu procuro determinar os maiores fatores sociais, técnicos, econômicos, físicos e ambientais envolvidos no engajamento em agricultura sustentável e sistemas aquapônicos. Essa pesquisa será usada para avaliar como cidades e comunidades podem adotar práticas sustentáveis relacionadas à alimentos para promover segurança alimentar e resiliência de comunidades. Sua participação é completamente voluntária. À qualquer momento você pode se recusar a responder qualquer questão ou pode decidir parar o questionário. Agradecemos muito pelo seu tempo, mas não será recompensado. Sua identidade será protegida, não será ligada às suas respostas e não será capturada ou usada de nenhuma forma.

1. Você consente em participar da entrevista?
2. Você consente em ser gravado? A gravação é somente para questões de precisão nas respostas.

Questionário:

A. **Sua fazenda:**

*Tamanho, produtividade, dificuldades:*

3. Você é o dono desta propriedade?
4. Se sim, quantos anos faz que você é dono?
5. Se for um empregado, por quantos anos você tem trabalhado aqui?
6. Quais produtos são vendidos na propriedade?
7. Porque esses produtos foram escolhidos?
8. Qual porcentagem dos produtos são orgânicos?
9. Qual é o tamanho da propriedade (hectares)?
10. Qual porcentagem da fazenda está sendo utilizada atualmente (hectares)?
11. Quais dificuldades você encontra na propriedade?
12. Essas dificuldades mudam com a época do ano?
13. Como você consegue água para a propriedade?
14. Qual a distância desta fonte de água até a propriedade (metros)?

*(Mão de obra e força física na fazenda):*

15. Quantos trabalhadores têm a propriedade?
16. Quantas horas, no total, você gasta em relação à propriedade por semana (tanto em trabalho físico, quanto em procedimentos mais operacionais, à distância)?

17. Você sente que tem suficiente mão de obra para completar as tarefas requeridas pela fazenda? (Sim = todas as tarefas são completadas ou Não = manter a fazenda requer mais assistência)

*(Rede com a comunidade e social ):*

18. Você conhece Flavio do Sítio São João?
19. Numa escala de 1-10, onde 1 = sem interesse e 10 = máximo de interesse, quão interessado você estaria em trabalhar com outros produtores?
20. *Se maior do que 1*, como você gostaria de trabalhar com outros proprietários?
21. Existe alguma barreira para trabalhar com outros proprietários locais?

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***B. Economia e distribuição:***

22. Você considera a propriedade como comercial (ou seja, vocês vendem os produtos em busca de um lucro)?
23. Quão frequente os produtos da propriedade fazem parte da alimentação? (1-10, onde 1 = nunca fazem e 10 = comem em todas as refeições)
24. Os produtos são vendidos localmente?
25. Porque ou por que não?
26. Onde se vende os produtos atualmente?
27. Qual a distância entre a sua propriedade e onde os produtos são vendidos?
28. Vocês estariam interessados em expandir o mercado dos seus produtos?
29. Se sim, como?
30. Qual porcentagem dos gastos da propriedade é voltada para fertilizantes?
31. Quão frequentemente se compra fertilizante para as culturas?

***C.* Qual porcentagem do tempo você tem quantidade suficiente desses próximos itens:**

32. Água suficiente
33. Trabalho suficiente
34. Nutrientes suficientes para as culturas

**D. Tecnologias da fazenda:**

Numa escala de 1-10, quão familiar você é com (1 = sem conhecimento, 10 = bem conhecido) :

35. Aquaponia
36. Aquicultura / Piscicultura

37. Hidroponia

38. Numa escala de 1-10, onde 1 = sem interesse e 10 = máximo de interesse, quão interessado você estaria em trabalhar com aquaponia?
39. Você já trabalhou com aquaponia antes?
40. Caso sim, quantos anos você trabalhou com aquaponia?
41. Você estaria interessado em ser parte de um grupo que compartilhe experiências e ajude outros fazendeiros a desenvolverem sistemas aquapônicos?
42. O que pode te influenciar a criar um sistema aquapônico?
43. Em uma escala de 1-10, onde 1 = impossível de operar, e 10 = sem complicação nenhuma, na sua opinião, quão complexo você considera a operação da aquaponia?

*(Agricultura sustentável)*

44. Você conhece alguma técnica ou tecnologia referente à fazenda que seja ambientalmente boa?
45. Se sim, qual?
46. Quão possível seria para você adotar essa técnica? (Escala de 1-10, 1 = impossível, 10 = já adotada).
47. Você conhece alguma técnica ou tecnologia referente à fazenda que seja adequada à proteção da água?
48. Se sim, qual?
49. Quão possível seria para você adotar essa técnica? (Escala de 1-10, 1 = impossível, 10 = já adotada).
50. Você estaria interessado em alguma tecnologia em particular para melhorar a performance da sua fazenda?
51. Se sim, qual?
52. Quão possível seria para você adotar esta técnica ou tecnologia? (Escala de 1-10, 1 = impossível, 10 = já adotada).

***E. (Conclusão)***

53. Você conhece algum outro fazendeira que estaria interessado em participar da entrevista?
54. Você estaria interessado em comparecer ao nosso workshop sobre aquaponia no dia 5 de Junho? (Sim/Não)
    a. Qual o melhor jeito de contratarmos você para lembrar do workshop?
    b. Precisaría de transporte para o workshop?
    c. Precisaría de transporte do workshop para a sitio?
55. Você tem algum comentário?
56. Você gostaria de receber o relatório sobre a pesquisa? (Sim/Não)

Appendix III: Consent form for UM Records (Portuguese)

EESC · USP
São Carlos School of Engineering
University of São Paulo

M | SEAS SCHOOL FOR ENVIRONMENT AND SUSTAINABILITY
UNIVERSITY OF MICHIGAN

TERMO DE COMPROMETIMENTO

Eu, _________________________________________, aceito participar da pesquisa para a qual fui convidado(a), contribuindo com a preenchimento de um questionário, como parte da pesquisa da Escola de Ambiente e Sustentabilidade da Universidade de Michigan e Escola de Engenharia de São Carlos, da Universidade de São Paulo. A pesquisa é coordenada pelos professores Tadeu Malheiros, da EESC-USP, e Jose Alfaro, da Universidade de Michigan, e é de responsabilidade da pesquisadora Lexi Brewer, e avaliará os principais fatores sociais, técnicos, econômicos, físicos e ambientais envolvidos no engajamento em agricultura sustentável e sistemas aquapônicos. Assim, será usada também para avaliar como cidades e comunidades podem adotar práticas sustentáveis relacionadas à alimentos para promover segurança alimentar e como comunidades reagem a problemas.

Sua participação é completamente voluntária. A qualquer momento você pode se recusar a responder qualquer questão ou pode decidir parar o questionário. Agradecemos muito pelo seu tempo, mas não será recompensado. Sua identidade será protegida, não será ligada às suas respostas e não será capturada ou usada de nenhuma forma.

Assinatura: ___________________________________________ Data: __________________

Appendix IV: Consent form for participants to keep (Portuguese)

TERMO DE COMPROMETIMENTO

Essa pesquisa, é coordenada pelos professores Tadeu Malheiros, da EESC-USP, e Jose Alfaro, da Universidade de Michigan. Nela, nós procuramos determinar os maiores fatores sociais, técnicos, econômicos, físicos e ambientais envolvidos no engajamento em agricultura sustentável e sistemas aquapônicos. Essa pesquisa será usada para avaliar como cidades e comunidades podem adotar práticas sustentáveis relacionadas a alimentos para promover segurança alimentar e como comunidades resistem aos problemas.

Desse modo, nos comprometemos a devolver os resultados obtidos ao final da pesquisa e garantimos o anonimato associado ao conteúdo do questionário. Para qualquer informação adicional temos disponível para contato o celular 16-982663933 (Artur Malheiros) e o e-mail albrewer@umich.edu (Lexi Brewer).

Assinatura: ________________________________________ Data: _________________

Appendix V: Products sold by small-scale farmers in São Carlos, Brazil

Raw responses from the question, “What products do you sell on your farm?

| **Product** | **Count** |
|---|---|
| legumes | 7 |
| leaf vegetables | 13 |
| arugula | 2 |
| avocado | 2 |
| banana | 2 |
| beets | 3 |
| broccoli | 4 |
| cabbage | 5 |
| carrots | 3 |
| tomatoes | 2 |
| cassava | 7 |
| Chicken | 3 |
| corn | 2 |
| cows | 3 |
| eggplant | 3 |
| eucalyptus | 1 |
| fish | 2 |
| fruit | 2 |
| Cauliflower | 1 |
| Gourd | 1 |
| guava | 2 |
| Jackfruit | 1 |
| lettuce | 10 |
| lime | 2 |
| mango | 7 |
| Milk | 5 |
| mint | 1 |
| okra | 3 |
| orange | 2 |
| passionfruit | 2 |
| pineapple | 4 |
| Sugarcane | 2 |
| sweet potatoes | 2 |
| watercress | 3 |
| Citrus fruits | 1 |
| Papaya | 1 |

Responses when grouped by category:

| Product | Count |
|---|---|
| Legumes | 7 |
| Leaf vegetables | 15 |
| Vegetables | 9 |
| Broccoli | 4 |
| Cassava | 7 |
| Animal products | 7 |
| Fruit (citrus) | 20 |