Development of Hydroponic Production Systems for Strawberry Production

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Background and Justification:

New York consumers have limited access to fresh, high quality, locally grown produce at competitive pricing with imported product. It is well known that consumers place an added value on locally produced products. This then provides an opportunity for the small-scale producer and that opportunity can be partially addressed through aquaponics and product diversification.

Strawberries are a highly favored fruit, yet almost all strawberries are imported into the New York State markets. NY ranked eighth in strawberry production in 2014 with 3.2 million pounds, but falls far behind the top five states (CA 2758 million lbs. per year, FL 207 M, OR 15, NC 15, WA 10, MI 4.5, WI 3.8, PA 3.3 M) (USDA, 2014). This domestic production comes from 56,000 acres of which only 22 acres are from greenhouse operations. This is in sharp contrast to Japan where 12,990 acres are greenhouse grown from a total country production of 14,876 acres. Historical production methods (field grown) need not prevent adaptation of new methods (greenhouse) as demonstrated in Mexico that had no history of strawberry production. As market opportunity presented itself, Mexico rapidly developed controlled environment agriculture (CEA, i.e. greenhouse production with climate control) capacity over the past 20 years. Today Mexico has the largest CEA area in North America, exceeding Canada and US. Tomato has historically been the major crop but due to the increasing competition in tomato as well as access to the technology, a diversity of crops are now grown in Mexico under controlled environments. In San Quintin Valley in Baja, out of its 3,230 ha of total agricultural area, strawberry now accounts for 65%, exceeding once-dominating field tomatoes (from cals.Arizona.edu/strawberry). Probably the most advanced country in terms of greenhouse production technology is the Netherlands. This is relevant to this project, since strawberry production in greenhouses is currently increasing in the Netherlands as evidence of economic viability.

Even during peak harvest months (July-August), only a small fraction of NYS residents have access to home-state strawberries. Most strawberries grown in NYS are sold within 50 miles of the farm, while residents of New York City never even see homegrown fruit, instead relying on strawberries imported from California, Florida, and Mexico. Even with the ready NY markets, New York experienced a 15% drop in production from 2011 to 2014. This drop has occurred even in spite of the market advantage that locally produced product has where quality and freshness are valued, since most consumers perceive local produce at farmers' markets to be of higher quality and lower price (Brown, 2009). Products presented to the market place must be competitive in price, since price still remains to be an important factor in consumers' food choice (Scheibehenne et al., 2007, Steptoe et al., 1995 and Van Birgelen et al., 2009).

Even if a product is locally produced and done so using sustainable and ecologically friendly methods, the product must still taste good. Tobler et al. (2011) reported that environmental motives alone might not be the strongest persuasion strategy to encourage ecological food consumption, while health or taste claims might have a stronger influence on consumers' willingness to consume in an environmentally friendly way (Tobler et al., 2011). One of our cooperators has had some experience with ponically (an inclusive term that includes hydroponics and aquaponics) produced strawberries and found them to not be as tasty as their field grown berries (personal communication, Silas Doyle-Burr, Last Resort Farm, Bristol VT). Gro-Moore Farms (Henrietta) is currently producing fresh strawberries using hydroponic drip-to-drain systems. Both taste and yield can be affected by manipulating the electrical conductivity (EC) of the nutrient solution (Sarooshi and Cresswell, 1994), and therefore using ponic systems

to produce strawberries should afford the opportunity to manage taste and quality via environmental (light and temperature) and nutrient management.
Strawberries must be price competitive with alternative sources even with the local, sustainable, and organic attributes. As a reference on price, the average monthly price received by growers in the U.S. for fresh strawberries in 2012 were the highest in December ($2.22/lb) and lowest in July ($0.74/lb) (USDA; http://www.agmrc.org/commodities__products/fruits/strawberries/commodity-strawberry-profile/). Local Wegmans price for strawberries December 5, 2016 was $4.99 for 16 oz (1 lb) pack. The University of Arizona (C. Kubota) estimated breakeven costs of greenhouse strawberry production as $2.96/lb based upon the following assumptions:

- 10,000 sq ft GH in Tucson, AZ, converted for strawberry production
- Owner + 40 h/week wages + 25% fringe
- Purchasing plug plants; 70% growing space in GH; 1 plant/ft^2 growing space
- Planting in September; Harvesting from November to April

Item Values

- Production Time 6 months; Benchmark Yield 1.8 lb/ft^2 (9 kg/m^2)
- Production Costs $3.81 /$ft^2$ GH; Labor: 40%; Materials: 23%
- Utilities: 20%; Amortized capital: 16%
- Breakeven price $2.96 /lb (@70% GH use)

The Arizona predicted cost is between the USDA price data for wintertime berries and Wegmans retail price, suggesting that NY farmers could be successful if the Arizona performance can be approached. Lighting and heating costs would be expected to be higher in NY and will be quantified before any recommendation is made. Summertime months would be used to prepare for fall plantings and not compete with field grown berries.

Hydroponic vs. Aquaponic:

Aquaponics is the combination of aquaculture (fish production) and hydroponic systems (plant production). Aquaponic systems make multiple uses of resources such as water and nutrients, and share infrastructure, management, and labor costs, as well as provide consumers with fresh high quality products (Rakocy 1999; Timmons et al. 2002; Diver and Rinehart 2010; Tyson et al. 2011). Plant nutrient requirements can be mostly supplied by the water taken from a fish recirculating aquaculture system (RAS). We have just concluded a series of experiments (Anderson et al. 2017) to compare production of butterhead lettuce grown using either reverse osmosis water with a standard nutrient solution vs. aquaponically grown lettuce where no nutrients were added except chelated iron. Surprisingly, production from the aquaponic condition (pH 7.0) was the same as the standard hydroponic conditions at pH 5.8, while hydroponic conditions at pH 7.0 were reduced significantly (~ 20% loss of production by fresh weight data). The aquaponic grown lettuce could also claim organically grown status. Whether similar success could be obtained with strawberries grown aquaponically or hydroponically is an objective of this research.

Objectives:

Our hypothesis is that strawberries can be grown using common adapted controlled environment agriculture methods, on an economically competitive basis, by obtaining premium pricing for its local, sustainable, seasonal and taste attributes. We are conducting a series of experiments to test the above hypothesis through a specific set of defined objectives.

1. A. Determine the feasibility of raising strawberries using hydroponic and aquaponic growing techniques by constructing replica common commercial soilless production systems to contain three different cultivars of strawberry plants.
   B. Establish the feasibility of raising strawberries using methods that qualify for labeling the product as organically grown (Source/ availability/cost of propagative material and planting material will impact if the produce grown can be certified organic).
2. Identify if growing methods can enhance product yield and quality, in terms of nutrition and taste.
3. Transfer the technology designs to cooperator private farms as beta testing sites of research results.
4. Develop an economic model that evaluates returns from aquaponic or hydroponic systems used to grow strawberries. The economic model would include predictions of operating costs (costs of goods), labor cost, utilities, and depreciation and amortization. Model will include cost comparisons to these same crops that are traditionally grown.
5. Conduct a regional workshop focused on aquaponic and hydroponic growing procedures for strawberries and other targeted plant species.

Approach/Methods:

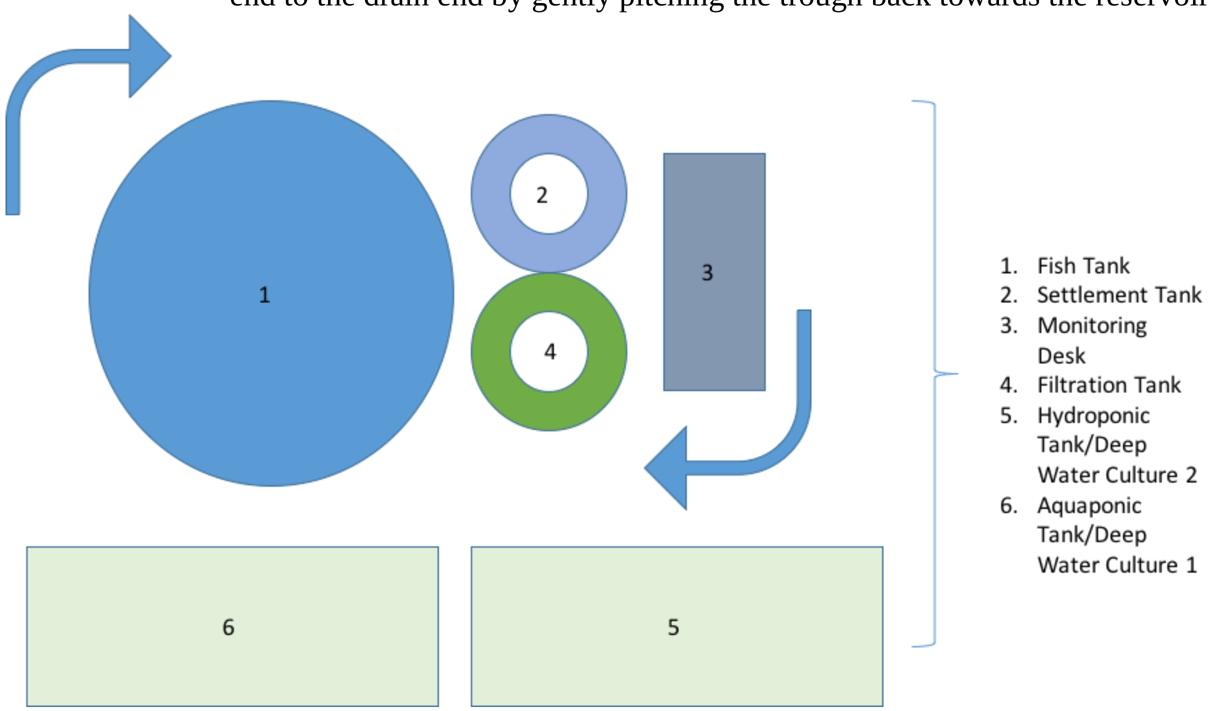
The research effort is conducted in the Ken Post Laboratory (KPL) greenhouses (Section 190C) on the Cornell campus in Ithaca, NY. Utilizing known and common recirculating soilless culture methodologies.

The three primary types of commercial production systems being evaluated are:

a) Deep Water Culture (DWC) ponds, which are constructed of 3'x 6' rectangular tubs 10" deep filled with nutrient solution (water and fertilizer) and covered with Styrofoam floats that are modified to accept bare-root plant stock and support the vegetation and fruit bearing trusses of the strawberry plant.

b) Drip irrigated (i.e. drip to drain pots) recirculating pots that are ~ 1.5 L individual 6" pots filled with a 50:50 blend of perlite:vermiculite to support the strawberry plant root structure and are irrigated on a cyclical basis.

c) Nutrient Film Technique (NFT) recirculating troughs, each fitted with lids that are modified to accept 15 bare root strawberry plants at 6" on center. In NFT systems the nutrient solution is pumped continuously and flows from the fill end to the drain end by gently pitching the trough back towards the reservoir.



1.NFT 1
2.NFT 2
3. Drip 1
4.Drip 2
5.NFT 3
6.NFT 4
7. Drip 3
8.Drip 4
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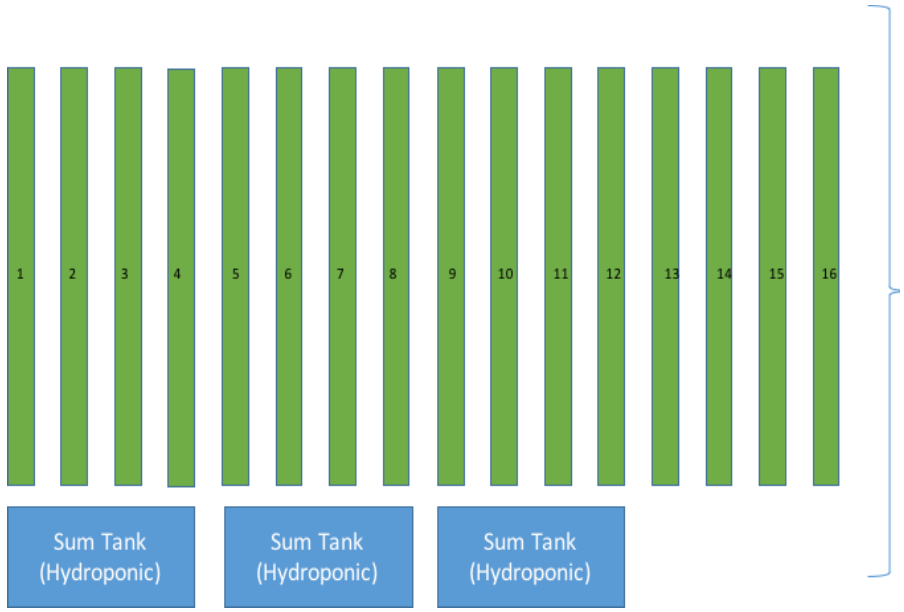
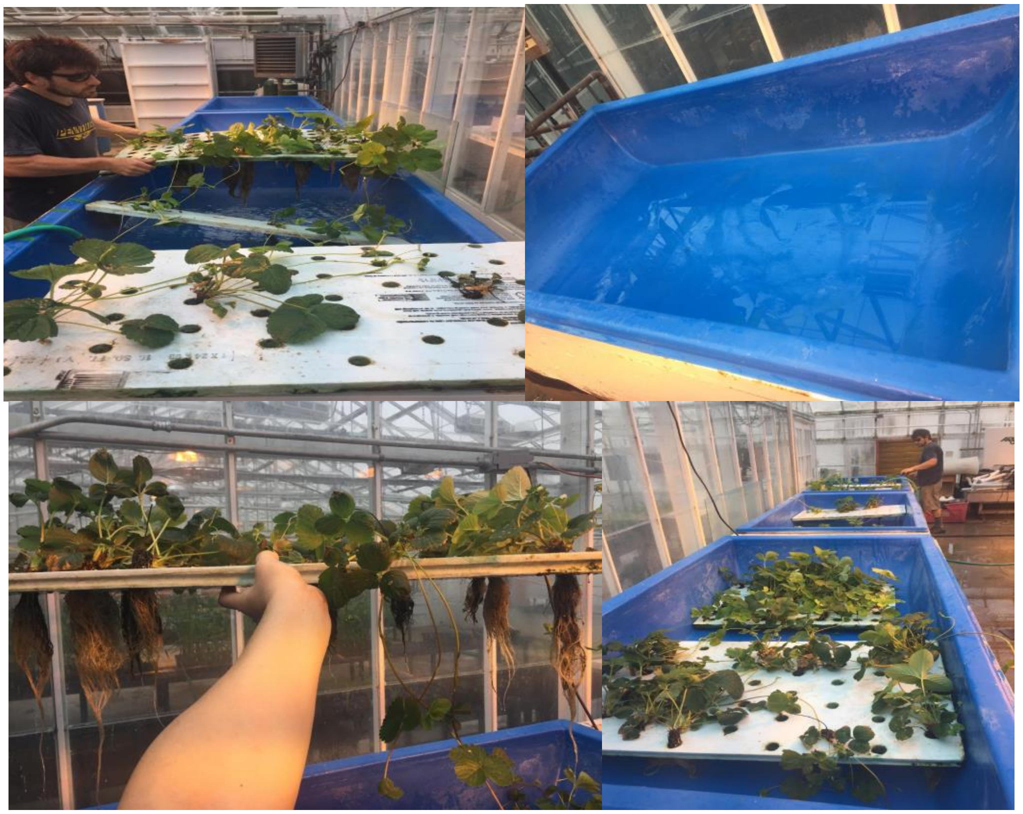


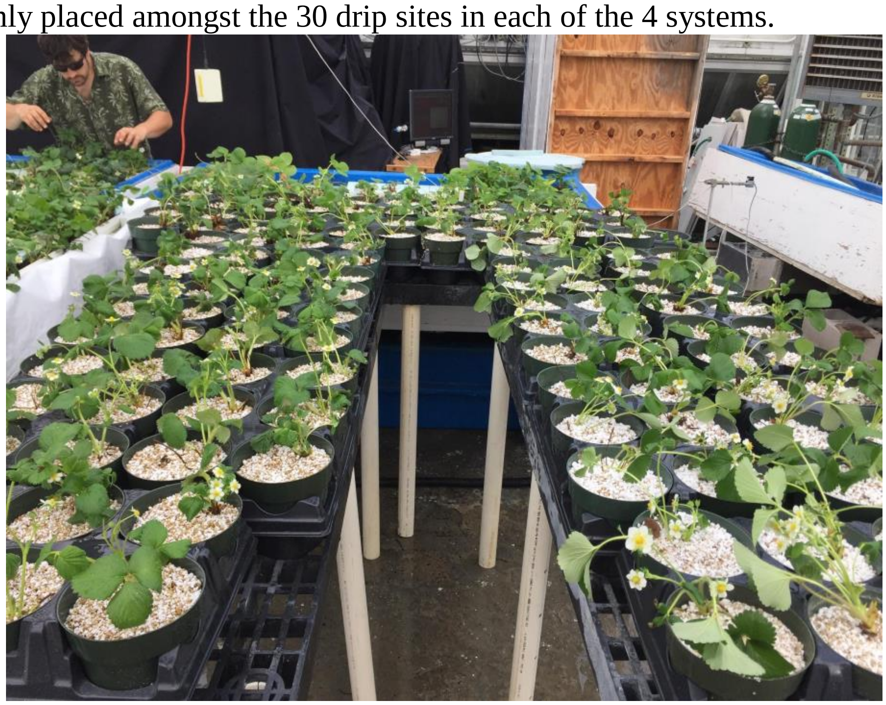
In all of these systems, water is conserved and recycled through catchment and return to a centralized reservoir or sump with the only water loss being from evapotranspiration, ambient evaporation and accidental loss. The hydroponic systems each consist of a 75 gallon capacity reservoir which is maintained with a complete mineral nutrient fertilizer mixed and measured from equal parts of a 2 part stock according to a modified Sonneveld solution for strawberries. The systems were maintained at an EC (electrical conductivity) of 1250 (± 50) $\mu S \cdot cm^{-1}$ at a pH (potential Hydrogen) of 6.0 ± 0.3)

The aquaculture (fish) system received high quality pelleted fish food and has been supplemented with chelated iron every two (2) weeks. The system is maintained at an EC of 1250 (± 50) $\mu S \cdot cm^{-1}$ at a pH of 7.0 (± 0.3)

The DWC system is constructed in duplicate to hold up to 30 plants per experiment (3 clusters of 10 plants each, placed in groups of 2 rows of 5). One system uses conventional mineral based nutrient solution the second receives nutrient solution form the recirculating aquaculture system.

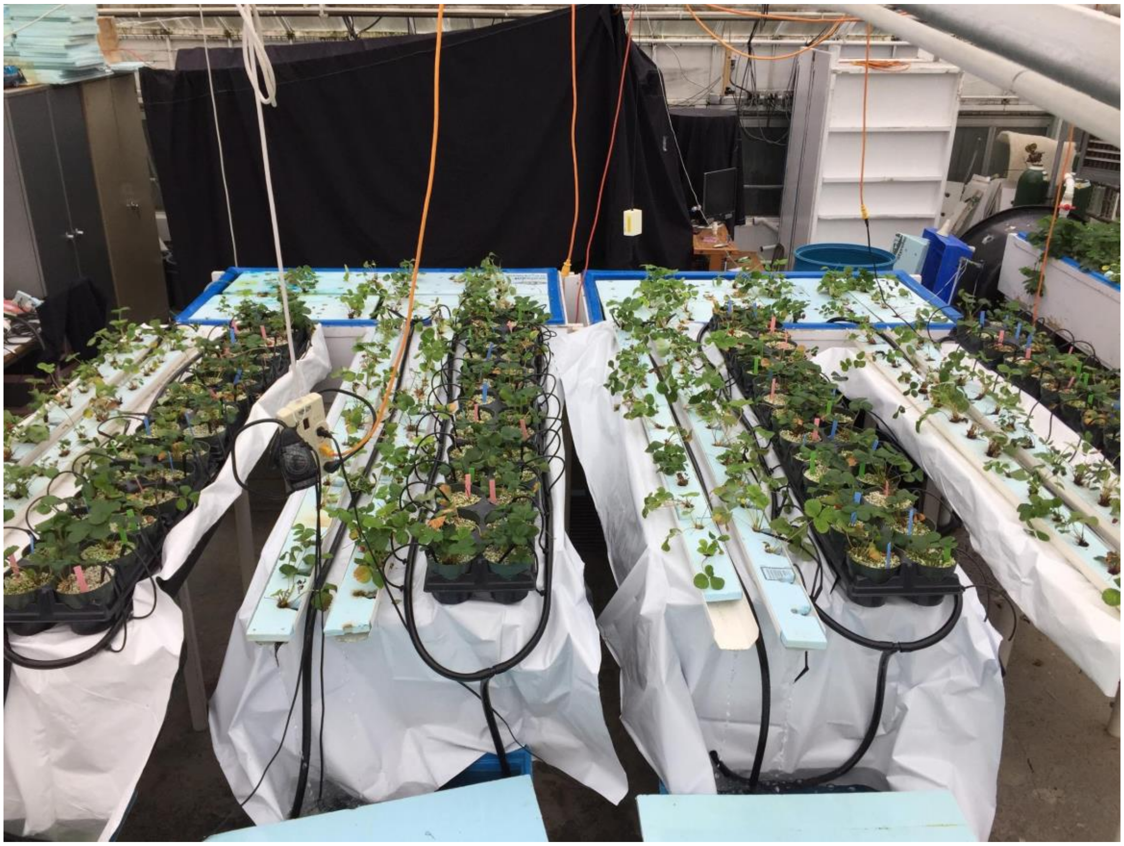


The drip system is constructed in triplicate for hydroponic plants and once for aquaponic conditions (plants with fish nutrients), so a total of 4 systems are constructed with accommodations for 30 plants per system (so that 3 cultivars, 10 plants of each, can be tested in each system concurrently for a total of 120 plants across the 4 systems). The plants were randomly placed amongst the 30 drip sites in each of the 4 systems.



The described NFT system, similarly, is constructed in triplicate for hydroponic production and once for aquaponic conditions, so a total of 4 systems are constructed which holds 30 plants per system (so that 3 cultivars , 10 plants of each, can be tested in each system concurrently for a total of 120 plants across the 4 systems).

All three systems are populated with day-neutral varieties of strawberries; the cultivars are Albion, Monterey, and Sea Scape (University of California Davis cultivars).



The initial planting stock was purchased from a national supplier of disease-indexed field grown strawberry rootstock material in May of 2017. The plants had received several weeks to several months of cold storage before they were received for the experiment.

The crowns were graded by size and maintained in a recirculating trough of nutrient solution until they were transplanted to their final production system in July 2017. From July 2017 - September 2017 the plants were fed a nitrogen rich fertilizer regiment to encourage vegetative growth and sizeable crown development. All the flower buds as well as the vegetative runners developed during that period were removed to encourage the plant to further develop its crown and vegetative canopy. Beginning October 1 2017 the plants received fertilizer with decreased N and increased P K, to encourage fruit initiation and blooms were no longer removed from the plants. Beginning the 3rd week of October we began harvesting berries and have subsequently implemented protocols for collecting yield data, and fruit quality data. We have maintained twice a week harvests since mid-October 2017 and will continue to do so through April 2018.

All systems are being assessed concurrently to avoid seasonality effects when evaluating performance across system design. We began harvesting berries in October 2017 and have collected yield and fruit quality data from the resulting berries twice weekly (current data is through April 7). Berries are being counted for Total Yield and Marketable Yield, by number and by fresh weight and analyzed for Acidity by titration and Brix value by refractometer. We will continue to harvest and analyze the resulting crop from this planting through April 2018. Statistical analysis will be completed after data collection terminates on April 30. In this report we will provide mean comparisons of the various dependent performance variables.

Results and Discussion:

Using field-grown runners for soilless culture:

Initially the quality and consistency of the original planting stock was called into question as we had no way to verify the condition and duration that each variety was stored prior to our having received them. We also questioned if propagative materials from the field were more prone to damage/ disease due to differences in climatic conditions from field to greenhouse as well as cultural practices of cold storing field grown propagative material. Practices such as severing roots and vegetative shoots seemed to provide opportunities for excessive water, and therefor pathogens, to infiltrate the roots and crowns, especially in aqueous culture.

Feasibility of growing strawberries without medium:

Upon first planting the strawberry crowns to their various systems-- almost all broke dormancy and began producing new roots and fresh vegetative shoots. However, soon after planting the purely hydroponic cultures, both DWC and NFT, began to show symptoms of root rot (*Phytophthora*) and crown rot (anthracnose and *Botrytis*) with roots turning dark and mushy, crowns turning red, and leaves turning yellow with chlorosis eventually becoming necrotic and falling off the crown.

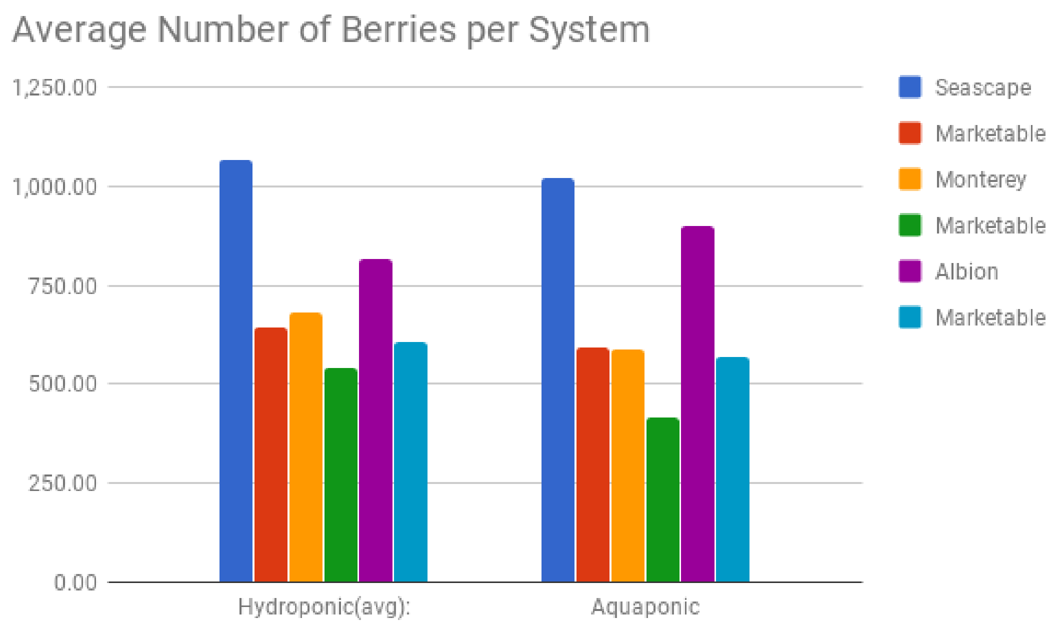
Strawberry plants/crowns in particular are susceptible to overwatering/super saturation as well as under watering/drying seemingly dependent on the depth that the roots are submerged in water. Plants that were resting directly on rafts, which were resting directly on the surface of nutrient solution, as in DWC, were prone to root rot. The plants that were elevated out of solution as in the NFT were unable to transport adequate water from the nutrient film to the crown of the plant. Only crowns that were set at an optimal depth in the NFT were able to grow without disease or desiccation. Over time, due to increasing root mass that created flow restriction in the NFT channel, water flooded deeper in the NFT trough and allowed water to infiltrate the crowns of the healthy plants that then invited disease and rot.

The recirculating drip systems, using a 50/50 mix of perlite and vermiculite, grew bountifully as they were buffered by the nutrient and water holding capacity of the media without subjecting the plant roots or crowns to excessive moisture. The plants that performed poorly in the Drip system were those with drippers that were placed too close to the crown of the plant, which allowed irrigation solution to saturate the crown; or those where the plant was planted too deep in the media and again allowed water to infiltrate the crown. From the start of our experiment to date 23 plants from an initial number of 120 in the drip-to-drain systems have been lost to overwatering and associated disease.

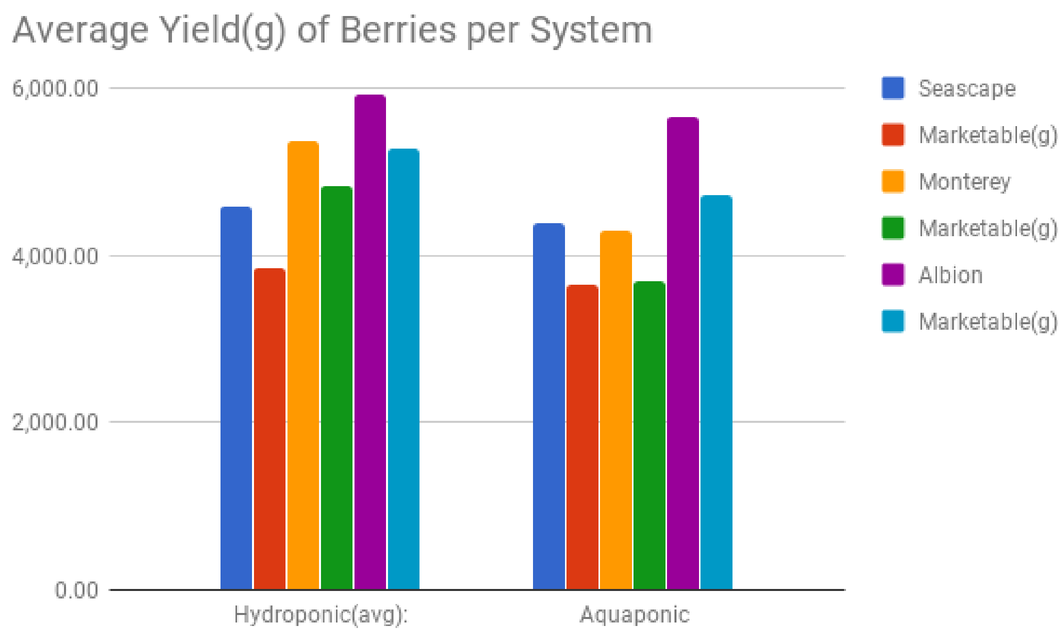
Cultivar effect on yield:

According to preliminary analysis of the data collected from October 15 2017 to March 31st amongst the 3 cultivars grown, we produced a total of 6,945 marketable berries with a total market weight of 53,906 grams from a total crop of 10,193 berries with a total weight of 61,916 grams in a canopy area of 64 ft^2 containing 120 plant sites.

Seascape has been the most productive variety with 2,522 marketable berries with market weight of 15,193 g. It performed consistently well when treated with hydroponic and aquaponic fertilizer sources averaging 643 marketable berries @ 3,846 grams across 9.66 plants (398.13g per plant) in hydroponics and 594 marketable berries 3655 g across 9 plants (406.11 g per plant) in aquaponics. We will determine if these differences are statistically significant once the last month of data is collected. Comparing the yield of our highest producer Seascape to the Kubota reference data for productivity (Production Time 6 months; Benchmark Yield 1.8 lb/ft^2 (9 kg/m^2); 1 plant/ft^2) our data = 15,193 g/38 plants = 399.81 g/plant (=0.88 lbs/plant or 2.08 lbs/ft^2) in ~ 5 months, so similar to Kubota in a much more dense plant setting (we have ~ 64 inch^2 vs. Kubota 144 in^2) if proportionally adjusted to 6 months (456 g/plant =1.0 lbs/plant) on 44% of the space (100%*64/144 = 44%).



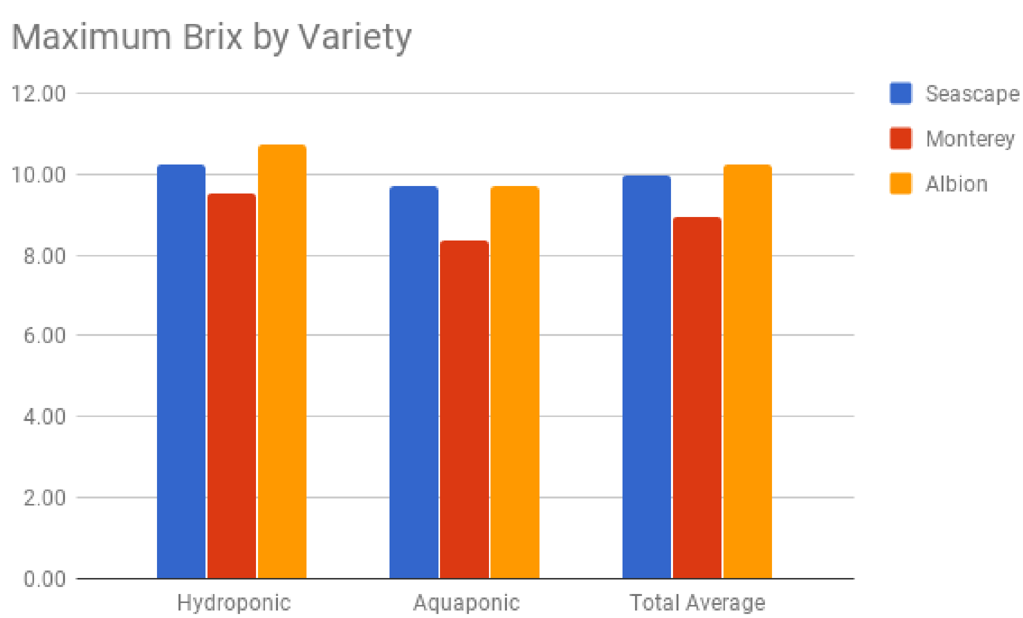
However, Albion produced the highest Market weight amongst all varieties with a total of 20,563 g with a total yield of 2,391 berries with an average of 5,281 g per system across the 3 hydroponic treatments, and 4,720 g from aquaponic production, or about a 12% reduction in yield (preliminary data).



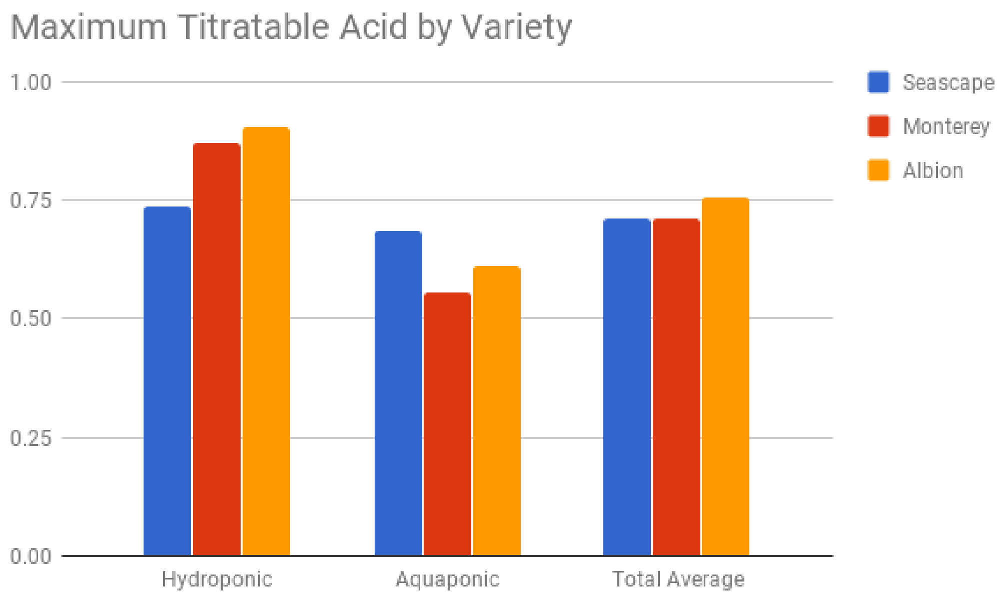
Cultivar effect on taste:

The flavor of strawberries is in part comprised from the interplay between sweetness (Total Soluble Solids expressed in Brix) and acidity (Titratable Acid expressed as grams of citric acid/100ml). Additionally, the TSS/TA ratio is often used as a measure of sweetness and consumer preference with a higher value being more desirable (more sugar/less acidity).

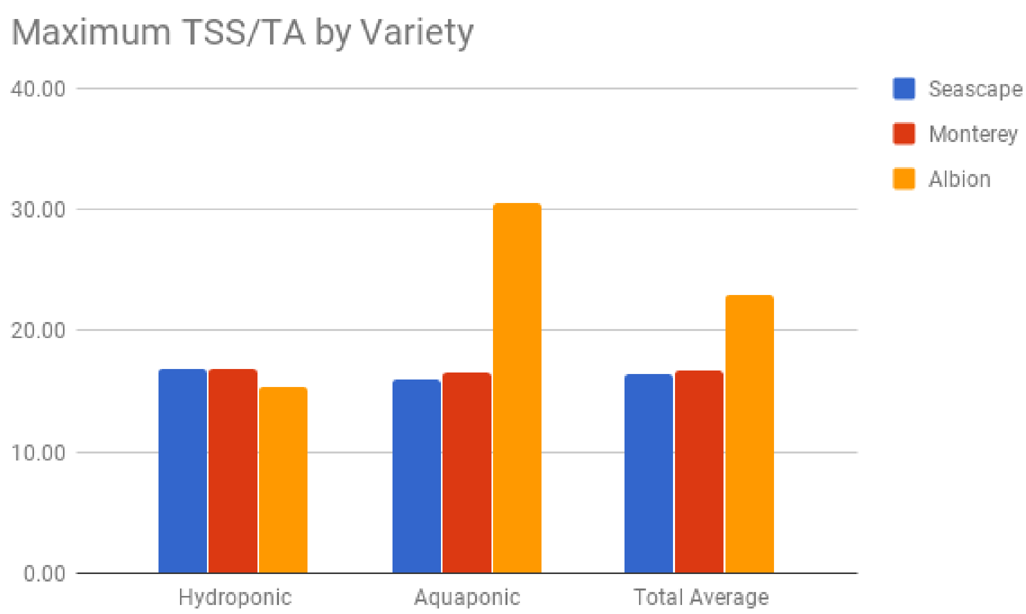
The variety that delivered the highest average maximum Brix value was Albion @ 10.22 Brix with hydroponic treatments averaging 10.73 Brix and aquaponic treatment averaging 9.70 Brix. Across all varieties hydroponic treatments had higher Brix values then aquaponic production.



The variety that imparted the highest average Acid density was also Albion @ 0.76 g citric acid per 100ml with hydroponic treatments averaging 0.93 g citric acid per 100ml and the aquaponic treatment producing an average maximum value of 0.61g citric acid per 100ml. across all varieties hydroponic treatments had higher TA values then aquaponic production. Interestingly Albion also displayed the lowest average acid density @ 0.44 g citric acid/100ml with 0.54 g/100 ml in hydroponics and 0.29 g/100ml in aquaponics



The variety that displayed the highest Total Suspended Solids/Titratable Acids Ratio, and therefore imparted the best theoretical flavor was Albion with an average of 19.14 across all systems. The hydroponic treatments averaged a maximum TSS/TA ratio of 15.35 while the aquaponic treatment imparted a maximum value of 30.5. Other varieties tested did not produce such a disparity but instead displayed similar TSS/TA ratios across both hydroponic and aquaponic conditions.



Outcomes and Impacts:

Strawberries are of particular interest to the controlled environment agriculture industry in North America due to their out of season price volatility, lack of common or localized production outside of California, and evolving regulations concerning field grown berries and the use of pesticides and soil fumigants. Our study is the first comparative assessment of the performance of the aforementioned day neutral strawberry varieties in both hydroponic and aquaponic conditions. It is also the first to assess cultivar performance across three different hydroponic methodologies.

This project led to improved understanding around the particular conditions required to successfully cultivate healthy and productive strawberry plants in soilless crop production systems.

Within the nascent CEA strawberry industry, drip to drain irrigation methodology is almost exclusively utilized, which, due to our experience, is commensurate with the methodologies ease of production, resilience and performance. The Drip to drain methodology was the only system of the three that was able to produce results for both hydroponic and aquaponic conditions.

However, the Drip to drain systems were not without flaw. We regularly encountered clogged drip emitters across all systems, which accounted for a majority of the plant loss over the course of the experiment, and added significantly to the day-to-day maintenance of the systems. This coupled with the use of synthesized substrates called to question the sustainability of such a practice.

As noted previously, from our initial planting, implementations of the bare-root Deep Water Culture methodology seemed prone to root and crown rot, to which strawberry plants are particularly susceptible.

The hydroponic DWC system succumbed to rot and failed before data collection even began while simultaneously the aquaponic plantings were also experiencing significant decline.

In an effort to reverse the adverse conditions, we elevated the floating rafts populated with strawberry plants from direct contact with the aquaponic effluent by floating the rafts on strips of 1" thick insulation foam. After elevating the rafts (and associated plants) out of direct contact with the solution we noted the propagation of fresh, healthy, white roots, improved vigor and prolific vegetative growth. The plants were maintained in the aquaponic system for the remainder of the trial period and did produce viable and marketable fruit; offering promise for future commercial application. More research will be conducted on this in the immediate future.

Similarly, both the hydroponic and aquaponic bare-root Nutrient Film Technique systems were particularly sensitive to overwatering (and rot) and under watering (and drought) depending on whether the plants were placed on the drain end or the fill end of the NFT trough. We suspect that the lack of media, to provide a consistent root zone environment across all plant sites contributed significantly to this effect.

Outreach:

Based upon experimental findings, commercial scale systems will be designed and an economic model created to predict total costs of production including system capitalization costs. Our model will be compared to the economic model created by University Arizona CEAC (see http://ag.arizona.edu/ceac/). Outreach will be further extended by conducting a regional workshop on hydroponic and aquaponic production of vegetables and berries. At the conclusion of the project, a 1-day extension workshop would be held at Cornell Cooperative Extension, Orange County. Findings and practical applications for small-scale hydroponic/aquaponic systems will be presented.

Student Activities:

The experimental hydroponic systems at Cornell also serve as a base for the Cornell Ponics Club, which consists of 15 students who test ideas and gain first-hand experience of running ponic systems. The club was created 4 years ago. Additionally, the availability of operational ponic systems is of great utility to show people what such a system is actually like and whether it is something that they might be interested in for their own application. Having a working production system with crops present is a very effective outreach tool. People really like to look at an operating system rather than just text and pictures on a page or screen.

Cooperators and Commercial Testing:

This project is integrated with the Cornell Controlled Environment Agriculture (CEA) who is already working actively with the commercial CEA community. Once, prototype systems have been demonstrated, our two cooperators (Main Street Farms and Last Resort Farm) will beta test these designs and operational methods. Project leader has previously worked with both of these identified cooperators.

Future Work:

Fertilizer inputs and nutritional outputs-

Evaluation will include performing mass balances of macro and micro elements between aquaponic and hydroponic systems compared against the nutritional qualities of the resulting berries.

Supplemented aquaponics to match hydroponic solution composition-

Testing will consider the performance of a supplemented aquaponics system to match the nutrient composition of an optimized hydroponics system; Manipulations of EC will be used to evaluate effects on taste. Strawberry yield and taste characteristics will be quantified.

Hydroponic system engineering for strawberry production-

Implement modifications to DWC and NFT systems that consider the specificities of strawberry cultivation (i.e. requirement for proper balance of water supply and drainage, and susceptibility of crown to rot when in contact with water).

If the project directly or indirectly led to other grant funding being received please list the source and amount of funds here.

We have submitted other grants in cooperation with the University of New Hampshire specifically on aquaponic production of strawberries.

If the project resulted in presentations please list here as well as the number of participants reached.

We are currently planning an extension and outreach event for summer/fall of 2018 targeted at academic researchers and commercial practitioners to share the findings of our research in alternative strawberry production systems as well as compiled research from other academic bodies concerning out of season and localized CEA production of strawberries and the integration of remote sensing and data logging devices to increase on farm productivity and profitability.

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