What Are the Barriers That Have Prevented Widespread Adoption of Hydroponics in the United States

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction

"O beautiful, for spacious skies, for amber waves of grain." An image so iconic of the United States, it has cemented itself within the first verse of one of the nation's most well-known anthems. This romanticization has unconsciously created what many believe to be the 'ideal' or most 'normal' form of agriculture. Yet here we are over a century after these lyrics were written and these wastefully homogenous fields are on the fast track to failing the needs of an ever-growing population. In 2021, the United States Census Bureau reported a national poverty rate of 11.6% comprised of 37.9 million people (Bureau, 2023). Such a staggering statistic goes largely unnoticed by most people, especially when compared with other countries, however the threat of food scarcity is quickly growing as population growth continues to exacerbate competition for land use (Dawson & Johnson, 2014; Manos & Xydis, 2019).

One of the proposed solutions is the integration of and/or transition to hydroponic technologies and cultivation methods. This is a farming technique in which the reliance on soil as a growing medium and delivery system for nutrients is replaced by water, thus eliminating many of the land requirements typically associated with farming. By replacing the soil with an inert substitute, hydroponics also eliminates the requirement for soil maintenance as well as the risk of runoff pollution. Most notably, although water takes on more roles outside just irrigation with this method, hydroponics allows for farmers to close the loop, greatly reducing water loss from evaporation, runoff, and groundwater infiltration and bringing total water consumption to a mere fraction of that of conventional methods.

In this paper, I argue that weaknesses in communication between researchers, produces, and consumers, as well as federal regulatory agencies and third-party certifications, have hindered the integration of hydroponic technologies. This begins first with a literature review of the development of hydroponic technologies over the last century leading up to the current state and its advantages over traditional, open-field cultivation. I will then use Pinch and Bijker's Social Construction of Technology (SCOT) framework as a lens through which to analyze how the interactions and perspectives of the aforementioned relevant social groups have either supported or stagnated the implementation of hydroponics (Pinch & Bijker, 1984). From this analysis, my project seeks to identify areas of weakness in regards to communication between these groups such that these misconceptions might be alleviated.

Literature Review

Research into hydroponic cultivation techniques began in the 1920's under the umbrella of closed environment farming (Walters et al., 2020). Here, hydroponics first demonstrated its effectiveness in conjunction with optimizations of environmental conditions by decreasing the amount of water consumed by agricultural production. Across the world, agriculture utilizing conventional methods consumes an average of 70% of a regions water usage. This is due to the incredible inefficiency of open-field techniques as they struggle with water loss through evaporation from indirect irrigation (Fussy & Papenbrock, 2022). Using hydroponics, water usage can be reduced to as little as 5% of what would normally be required by open-field methods (AlShrouf, 2017).

Additionally, by eliminating the reliance on arable land, hydroponics can be expanded in the vertical direction thus lowering the footprint of cultivation sites and allowing for integration within the built environment. By removing the requirement of arable land, hydroponics has removed the risk of soil degradation and allowed for the cultivation of climate locked crops to be expanded to areas previously deemed unsuitable when paired with controlled environments. This is becoming increasingly important as greater temperature anomalies have been reported year over year due to climate change (Czapiewska, 2020). As open-field methods have a great reliance on natural weather conditions, increasingly variable seasons have exacerbated the need to transition to a more resilient farming method.

Hydroponic cultivation also presents the advantage of significantly lowering, and even completely eliminating the use of chemical pesticides as hydroponic methods isolate the crop from many environmental risks, reducing the burden of environmental stewardship on producers (Fussy & Papenbrock, 2022). This allows for producers to shift investments away from preventative measures and into expansion of production or increases in the quality of the crop produced. Another advantage of hydroponic cultivation is the consistency that can be achieved, especially considering the accelerated production rates. In this cultivation technique, nutrients are delivered to crops through the water used for irrigation rather than the growth medium (Jan et al., 2020). This avoids potential loss from nutrient wash out into runoff during precipitous weather conditions and allows for greater control and monitoring of nutrient uptake into the crops being grown.

Research Question and Methods

In my analysis, I will first conduct a literature analysis which covers the research that has already been conducted, then the history of consumer perceptions of crops produced via hydroponics, and finally how both federal regulatory agencies and third-party certifications have metered and contoured the marketing of hydroponic crops. This will involve gathering academic journals to track the focus of research advancing hydroponic technologies and their use over time, as well as that documenting surveys of public reception and opinion of the crops produced. This will then be cross-referenced with how regulatory definitions have evolved over time to include or exclude hydroponics, along with the creation and proliferation of third-party certifications. By synthesizing this information, my analysis will identify potential points of correlations and how these have been reflected in the marketing tactics of hydroponic crop producers.

This will then be followed by a policy analysis focused on the United States Department of Agriculture's (USDA) approach to regulating the marketing and sale of crops produced using hydroponic technologies. By examining the limitations imposed by these guidelines as well as the potentially more open or inclusive approaches of third-party certifications, I will abstract the marketing strategies used by hydroponic producers to attempt to garner interest in their alternatively produced crops. Investigation into these requirements will also illustrate how over complexity and poor communication has led to an ill-informed consumer base whose understanding is greatly varied and fragmented.

STS Framework

My analysis will be conducted utilizing the SCOT framework. This describes the development of technology as a reflection of the different groups united around a common understanding of the desired use case or potential benefits to be had (Pinch & Bijker, 1984). From this it can be extrapolated that little interest from the concerned parties will lead to stalling of the developmental process as resources are redirected and results go unnoticed. Thus, this framework involves the identification of a core set of social groups and stakeholders whose perspectives play a key role in the design process. Not only do these perspectives shape the developmental process and direction, these perspectives themselves are guided by the choices made during the developmental process and how results are communicated between parties.

The shaping of perspectives can take the form of rhetorical closure by redefining the problem the technology seeks to solve. This can be both good and bad as it may allow for a technology to push past overemphasized weak points in pursuit of the overall benefits provided, however it may also serve to silence the critique of specific social groups. Doing so can limit the inclusion of less effected groups in favor or benefitting another party and potentially creating an unbalanced power dynamic.

Another framework which will be incorporated into this analysis is the immovable nature of infrastructure. As described by Susan Leigh Star, infrastructures are characterized by several qualities that lead to resistance to change and limit the speed of transition (Star, 1999). Of these, most relevant to this discussion are embeddedness, links with convention, limitations of an installed base, and incremental progression. The interconnectedness imposed by these characteristics increases both the complexity of addressing the problems of infrastructures while also magnifying these problems as they become increasingly complex over time, drawing in more remote social groups and creating a wider base of stakeholders.

Results and Discussions

While much research has been conducted on hydroponics, up until recent years this research has maintained a focus on integration into only the largest scales of production. As discussed earlier, hydroponics are largely included among a suite of technologies and methodologies that surround cultivation within a controlled environment (Walters et al., 2020). While this integration compounds the benefits of all these technologies, it has led to the characterization of hydroponics as expensive and complex. Although this grouping is not unwarranted as this research is devoted to addressing the imminent threat of climate change and its effects of agriculture, it has led to integration running aground against the resistive nature of infrastructures as described by Star. This overcomplexity of hydroponics has also made it appear less approachable to producers of small scale as it implies a necessity of specialized higher education (Arakkal Thaiparambil & Radhakrishnan, 2022). This approach by researchers has presented hydroponics not as a standalone technology, but a component of a much more involved process, overshadowing the low barrier to entry of the simplest variations. As a result, this has led to hydroponics being perceived as accessible to only the largest of producers.

Upon its introduction to the masses, hydroponics has previously failed to garner the attention of consumers due to preconceptions around what is seen as “natural.” While the classification of crops as organic has become popular, this is largely due to the organic label’s ability to resonate with consumers’ already established understandings of crop cultivation (Nithya et al., 2022). Additionally, the organic label drew greater appeal as it included the humane treatment of livestock. Much of the success of organic produce is due to consumer motivations focusing on the health benefits of buying organic (Davies et al., 1995). By appealing to the individual efforts of consumers and the benefits that they might experience personally, organic produce rapidly grew a consumer base that were willing to pay a premium for a more ‘natural,’ sustainably produced product. It is here that hydroponics failed, unable to find the same engagement as it placed greater emphasis on the environmental benefits and was attempting to redefine the image consumers had of the agricultural sector. While organics pushed consumers to move away from chemical usage, be it pesticides or supplemental nutrients, hydroponics appeared to be the exact opposite, proposing that all nutrients be delivered in chemical form. The focus on the larger-scale environmental benefits also had less impact on consumers as these were benefits where progress would be slow and hardly felt at the individual scale (Gilmour et al., 2019). Research pairing hydroponics with controlled environments also served as a detriment as it further cemented consumer perceptions of hydroponics as clinical laboratory settings.

Following this marketing blunder, hydroponic producers have since attempted pairing with the organic label as hydroponic techniques technically adhered to the requirements, however, this was met with intense backlash from established organic producers. While the USDA did permit hydroponic producers to use the label, many of the larger producers utilizing the organic label on traditionally farmed crops believed that hydroponics should be excluded (Morath, 2018). The requirements in order to use the USDA organic labels were put into place not only to restrict the use of chemical pesticides and genetic modification, but also to promote practices in environmental stewardship and the remediation of depleted soils. As hydroponics bypass the need for soil as a growing medium entirely, many of the established organic producers felt that hydroponics had an unfair advantage as they essentially were not held to the same environmental improvement standards. Additionally, precedents set outside the US for banning the labelling of hydroponic crop as organic has also been citied in arguments against their inclusion (Fruscella et al., 2021). Though the USDA has held firm on hydroponics' ability to obtain their organic certifications, this decision was only maintained with a vote of eight to seven by the National Organic Standards Board (NOSB) in 2017 (Morath, 2018). Although hydroponics has maintained its marketability under the organic label, this controversy has placed its produce into a grey zone for many customers.

As argued by these organic producers utilizing traditional methods, the current definitions provided by federal regulatory agencies like the USDA do not provide clear communication as to whether or not hydroponics specifically are immediately recognizable as organic. What with hydroponics' burgeoning integration into the agricultural sector, the requirements for the different organic certifications that can be obtained from the USDA have not been clearly updated to reflect hydroponics inclusion. Furthermore, the variety of labels to be obtained create greater confusion among consumers as to what information these are trying to relay. There exist three organic classifications from the USDA: organic, made with organic, and 100% organic (McEvoy, 2016). While these labels are meant to provide less stringent classifications for producers to transition to organic practices while communicating to consumers about the product with greater specificity, they have instead created more confusion about the products they categorize. Many people are unaware of criteria associated with each label or even that the labels are different from one another, thus they ignore every other part except for where it says "organic" (Grebitus et al., 2018). Even when consumers recognize that these labels are different, the lack of communication from the USDA to the public about the distinctions between these labels has contributed to the confusion among consumers.

With so many complications surrounding the use of the organic label on hydroponic produce, many producers have instead relied on third-party certifications in their marketing. Rather than attempting to remedy the confusion regarding whether or not hydroponic crops are or aren't organically cultivated, producers have instead placed greater emphasis on what their products are not, similar to the tactics used by the organic label. This includes obtaining certification labels such as Non-GMO from groups like the Non-GMO Project (Grebitus et al., 2018). Already, the USDA organic labels included that certification demands producers to exclude genetic modification in their cultivation; however, by explicitly labelling products as such, producers have seen a more positive reception from consumers. Producers have found products are much more approachable with these kinds of labels as consumers are much more capable or identifying what they do not want, rather than that which they do (Grebitus et al., 2018). These voluntary labels have provided a means for hydroponics to rebrand and steer consumers away from the original perceptions of laboratory conditions.

Changes to the landscape of consumer mindsets in recent years have also contributed to the recent growth in the hydroponic market. As we have grown more environmentally conscious and have felt the impacts of climate change on daily life, people have placed greater importance on the resource conservation hydroponics originally touted (Lin & Niu, 2018). This shift in mindset was not motivated just by recognition of environmental impacts at the individual scale but also by larger governing bodies emphasizing the looming irreversible impacts that we may experience within this century. International consensus such as the 2015 Paris Agreement have generated mass calls to action by putting numbers to the climate problems we are facing, as well as highlighting sustainability as a problem that extends past national borders (Rhodes, 2016). With a much more environmentally motivated consumer base, hydroponics has garnered more interest in recent years, moving past those earlier preconceptions, however we've yet to reconcile those established misconceptions of economic viability between researchers and producers, thus hydroponics has yet to establish itself as a selling point.

Conclusion

The original focus of hydroponic integration at the largest scales and in only the most monitored and environmentally regulated of environments has stalled what would already have been a slow integration processes as it appeared to call for a complete overhaul of the systems already in place. Failing to appeal in both economic requirement as well as consumer demand, integration of hydroponic technologies and methods came to a standstill despite the advantages it presented over conventional methods. While this is largely a failure of communication, hydroponics also faced opposition from the competing market and fell victim to precedents outside the US. In recent years, hydroponics has successfully found a niche through which to begin establishing a consumer base and eventually expand to a larger market, though we are still far from seeing widespread adoption of such technologies.

This analysis was limited in scope to the interactions of the relevant social groups as described by the sociotechnical framework, however that has left many other contributing factors to be investigated. Future investigations may include how the role automation or the lack thereof may have played a role in halting hydroponics' integration, as well as consideration for the generational investments producers have already made towards improving the efficiency of conventional farming methods. Though we may not see hydroponics full integration for some time, it has already gotten its foot in the door and looks to make greater strides into smaller scales of production.

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