REFEREED ARTICLE

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Using high tunnels to extend the growing season and improve crop quality and yield: assessing outcomes for organic and conventional growers in the U.S. Midwest

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ABSTRACT

High tunnels are a low-cost technology that can strengthen local and regional food systems by facilitating the production of high-quality fruits and vegetables during and beyond the frost-free growing season. The potential for high tunnels to improve crop quality and yield has been established with research trials, but there is a lack of research on the farm-level impacts of high tunnels, or comparisons between organic and conventional farming systems. This survey of high tunnel users in the U.S. Midwest state of Indiana finds that farmers have been successful with extending the growing season, as nearly half of the respondents are now harvesting in the cooler months and planting earlier in the spring. Farmers also reported significant increases in the productivity and quality of their crops year-round, and improvement in their farm's economic stability. Farm-level impacts were similar for farmers using organic and conventional farming practices, although farmers using organic practices were more likely to increase their off-season production than their conventional counterparts. Overall, high tunnels hold potential as a tool for increasing the availability of fresh vegetables and fruits for local food systems, thus increasing the viability of Midwest farms.

KEYWORDS: agricultural technology; high tunnels; hoophouses; organic farming; local food systems

Introduction

The use of high tunnels has increased immensely in the past decade, particularly among small-scale growers selling directly to consumers. High tunnels, also known as hoophouses, are plastic-covered structures used for growing plants that are constructed directly over the soil and heated by passive solar energy. The infrastructure protects plants from adverse weather conditions, such as heavy rains, winds, frosts, and sudden temperature fluctuations, as well as safeguarding crops for early planting and later harvesting (Carey *et al*., 2009; Knewtson *et al*., 2010). Research trials have shown great potential for high tunnels to increase the yield, quality, and shelf life of fresh fruits, vegetables, and flowers, in both organic and conventional systems (Carey *et al*., 2009; O'Connell *et al*., 2012). Growing under cover gives farmers greater control over growing conditions and crop nutrition, and a layer of protection from insects and diseases (Waldman *et al.,* 2012). High tunnels show potential to be an important technology as society works to create agricultural systems capable of meeting increased demand for healthy, sustainable crops.

While high tunnels have only received attention relatively recently in the U.S., they have been popular in parts of Asia and Europe since the 1970s (Enoch and Enoch, 1999; Lamont, 2009; Orzolek, 2011) and seem increasingly important to U.S operations.

High tunnel infrastructure is of interest to a wide international audience because it requires relatively little

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capital for construction and operation, even for small family farms with limited financial and human resources (U.S. Agency for International Development [USAID], 2008). They are also particularly well suited to maximizing income on small and marginal pieces of land (Huff, 2015; International Center for Agricultural Research in the Dry Areas [ICARDA], 2015). In the global south, high tunnels have been utilized to increase food security, and provide viable livelihood opportunities in rural communities as a low-cost alternative to greenhouses for smallholders to improve the quality and consistency of export crops (USAID, 2008; ICARDA, 2015). Growing crops in high tunnels also offers a strategy for dealing with adverse weather conditions posed by climate change, as they protect plants from excess moisture and damaging rains but maintain soil moisture and require less irrigation in drought conditions (Beckford and Norman 2016; Lawrence, Simpson, and Piggott, 2017).

High tunnel production allows farmers to even out the seasonality of production, balancing the highs and lows of the production year, to tackle the labor puzzle that poses a challenge for farmers (Waldman *et al*., 2012). Farmers are able to capture a premium for locally grown specialty crops, and in particular for produce grown late and early in the year (Conner *et al*., 2010; Orzolek, 2013; Waldman *et al*., 2012). The infrastructure addresses seasonal constraints, allowing for extended fruit and vegetable production in climates with a limited growing season, thus, presenting an opportunity to increase the availability of fresh produce for local markets. In addition, the capacity to offer fresh produce more consistently throughout the year supports farmers who use direct marketing to develop their customer base, thereby increasing the viability of farms that produce specialty crops for local food systems (Arnold and Arnold, 2003; Conner *et al*., 2009). The infrastructure also presents an opportunity to increase the availability of fresh produce for off season farmers' markets, restaurants, grocery stores, and food hubs, potentially expanding local and regional food systems in regions with a limited growing season, such as the U.S. Midwest.

The High Tunnel Initiative is a governmental program that has promoted and increased the adoption of high tunnels in the U.S. The High Tunnel Initiative (HTI) was established as a pilot program in 2009 by the U.S. Department of Agriculture (USDA) to assess the potential environmental benefits of high tunnels (NRCS 2016). After strong participation in the first three years, the initiative became a conservation practice standard in 2014 that made it available in all states. The HTI program is offered through the Natural Resources Conservation Service (NRCS) Environmental Quality Incentives Program (EQIP) (NRCS, 2014). The program provides a cost-share incentive of up to 90% or up to a dollar amount set by each state, whichever is less, that is paid out as a reimbursement to farmers who construct a new high tunnel. The goals of the EQIP HTI program are to reduce nutrient and pesticide runoff, improve plant and soil quality, reduce energy use through reduced transportation from farm to market, and increase the availability of fresh food for local food markets. Since 2016, NRCS allowed states to decide whether to offer high tunnels as a state initiative or a conservation practice that's available as part of the general EQIP program, giving states the option of keeping the initiative as a separate program to promote the practice and increase high tunnel use in their state (NSAC 2016).

The HTI was first piloted in 2009 as part of the Know Your Farmer, Know Your Food initiative of the USDA. The Know Your Farmer, Know Your Food initiative brought together staff from across the USDA to coordinate, share resources, and publicize USDA efforts related to local and regional food systems (Farm News, 2009; KYF, n.d.; NRCS, 2011). The initiative was designed to support diversified farms, ranches, and businesses in regional food networks, with the goal of strengthening the connection between farmers and consumers, reinvigorating rural economies, promoting job growth, and increasing healthy food access in America (KYF, n.d.). Thus, from its inception the high tunnel program was oriented towards small-scale and diversified farms that sell directly to consumers through local food systems. Exploratory research also indicates that high tunnels have been strongly utilized by small-scale, diverse farms that do direct marketing (Carey *et al.* 2009; Low *et al.* 2015). There is also an overlap between farms that sell into local food markets and small-scale, diversified farms that use organic or ecological practices (Ahearn and Newton 2009).

Between 2010 and 2015, the high tunnel initiative has supported farmers in constructing over 14,000 high tunnels on farms in all 50 of the U.S. states (NRCS, 2016). The program has so far committed over $93 million in cost shares to support farmers in obtaining high tunnels. Between 2010 and 2013 the number of high tunnel contracts increased, with the most significant jump between 2011 and 2012, increasing by more than 70% (National Sustainable Agriculture Coalition [NSAC], 2014). In FY 2015 NRCS supported 1,830 high tunnel contracts, which is relatively consistent with the number of contracts in 2014, but a decline from 2012 and 2013 (NSAC 2016). This is likely due to the removal of a cap on the maximum high tunnel size in FY 2014 that likely contributed to larger contracts and a subsequent decline in the total number of contracts NRCS was able to fund (NSAC 2016).

In 2012, the Indiana division of the USDA NRCS implemented the cost-share program for high tunnels through EQIP that other states had been offering since 2009. Demand from specialty crop farmers in Indiana for this program has been overwhelming, according to the NRCS, with 169 tunnels constructed on farms in Indiana between 2012-2014. In this paper we present findings from a survey of 104 Indiana farmers who have used high tunnels on their farms, to understand farmers' success in using high tunnels to extend the growing season, increase produce quality and yield, and improve farm viability.

Broader significance

So far, most research on the potential of high tunnels to enhance specialty crop production comes from research trials and small case studies (Biernbaum, 2013; Carey *et al*., 2009; O'Connell *et al*., 2012; Waldman *et al*., 2012). To date, we found just one study that has assessed the benefits of high tunnels for local food systems, through GIS mapping of high tunnels obtained through the EQIP program, and a survey of 30 Virginia farms with high tunnels (Foust-Meyer and O'Rourke, 2015). There are no studies that we could identify that evaluate

the extent to which high tunnels are meeting the potential identified in research trials when they are integrated into existing farms. Given the federal funding dedicated to the high tunnel cost-share program as a conservation practice, policymakers will need to decide how much to continue to invest in high tunnels (NSAC, 2014). Thus our goal was to learn directly from farmers who have been using high tunnels to understand how well the technology is meeting its potential in the real world. Our findings will allow researchers, extension educators, policy makers, and farmers to better understand the potential impacts and benefits of high tunnels where research on the farm-level impacts of high tunnel use is limited (Conner *et al*., 2010).

High tunnels and organic growing

Because high tunnels have been popularized by influential organic farmers as a boon for organic and diversified farms (Coleman, 2009), we also compare farmers who use organic practices to those who do not, to understand if there are any differences in their experiences with using high tunnels. To date, there is a lack of research assessing how outcomes of high tunnel production are parallel or divergent between high tunnel users growing organically versus conventionally. This is important because organic practices contribute to preserving genetic diversity, building organic matter in the soil, reducing pesticide and nutrient runoff, and using less energy (Bengtsson, Ahnström, and Weibull, 2005; Gomiero, Pimentel, and Paoletti, 2011). Therefore it's possible that use of organic practices in high tunnels could support the environmental goals of the EQIP program. There is some evidence that high tunnels can support low input and organic production practices by limiting pest and weed pressures (Blomgren and Frisch, 2007; Carey *et al*., 2009; O'Connell *et al*., 2012). On the other hand, while high tunnels can enhance growing conditions, they can also create ideal conditions for diseases such as fluvia leaf mold of tomatoes if proper management is not implemented and may also increase certain pest pressures (Ingwell *et al*., 2017; Johnson, Grabowski, and Orshinsky, 2015; O'Connell *et al*., 2012). However, existing research on the benefits of high tunnels for organic production is mostly limited to field trials of specific crops.

Methods

Given that a composite listing of high tunnel growers does not exist, the project team developed a list of high tunnel users in Indiana for this exploratory study. We sought contact details through the Indiana NRCS office, garnering a list of 143 names (with city and county of residence). We then used online databases (whitepages.com and county GIS platforms) to garner mailing addresses. We also solicited mailing addresses for high tunnel users from Purdue University Extension and added names of our personal/professional contacts who have a high tunnel. This convenience sampling approach limits the generalizability of the study's results.

In total, the project team composed and administered a questionnaire to 178 farms with high tunnels, offering both paper and electronic options for responding. Every survey included a $5 incentive to support participation (Singer, 2002). Following a modified Dillman tailored-design survey method, the survey was mailed to 164 of the contacts using a four-phase contact approach (see Dillman, Smyth, and Christian, 2014).

The survey consisted of 6 sections. Section 1 (Introduction) included questions about farm location, number of high tunnels, EQIP funded high tunnels, and descriptive details on use of high tunnel. Section 2 (Value of high tunnel for your farm) included questions about the utility and impact of the high tunnel. Section 3 (Sales from the high tunnel) queried farmers about distribution mechanisms. Section 4 (High tunnel production) asked farmers the crops they produce in the high tunnels, production issues, research needs, and common practices. Section 5 (Your entire farm operation) asked about farm characteristics and economics. Finally, section 6 (Demographics and conclusion) asked about personal demographic characteristics and opportunities or challenges with the high tunnel (Bruce *et al.*, 2017).

Data were analyzed using SPSS 23.0. We used descriptive statistics to calculate general results for demographic variables, farm characteristics, and distribution type. Based on farmer response, we created a dichotomous variable for comparing farmers that (1) grow organically or are certified organic (n=65) vs. (2) farmers that use conventional methods for production (n=38). Chi-square analysis was used to explore the differences in categorical variables such as distribution method, gender, and education. Analysis of Variance (ANOVA) was used to compare results from the continuous variables and Likert-scales for high tunnel management practices and experience with high tunnels between those farming organically and conventionally.

Results

We distributed 178 surveys to Indiana high tunnel growers. A total of 118 were returned (6 were electronic), 9 with insufficient addresses, 4 noting their high tunnel was not yet erected, 1 person did not actually have a high tunnel, and 1 person reported the survey was too personal to complete. Thus, 103 were deemed usable from an adjusted sample of 164 (62.8% response rate).

First, we present general characteristics of the farmers that responded to our survey (see Table 1). The average respondents' age was 36.9, with the vast majority being the farm owner (92.2%), and male (72.8%). Nearly half of respondents had earned a bachelor's degree or higher (48.5%). The average respondent had been growing in a high tunnel for 5.3 years, with the median at 4 years. Generally speaking, respondents had been farming for nearly two decades in total (median 18.5), with 21.9% farming for 5 years or less. Most respondents had a gross farm income of less than $49,999 per year, with nearly 20% making less than $5,000 yearly from their farms. We also compared organic growers to conventional growers, finding that organic growers farmed significantly less acres (median 6) compared to their conventional counterparts (median 40) (see Table 1).

Farm characteristics

Over 81% of respondents are using their high tunnel in USDA Plant Hardiness zone 5, with 17.5% in Plant Hardiness Zone 6. The average proportion of specialty crop revenue to total farm revenue was 40.8% (26.25% median). The mean relative rurality score, which quantifies on a continuous scale how urban vs. rural a county

Table 1: Descriptive, ANOVA, and Chi-Square comparison results of demographic and farm characteristic data overall and between organic and conventional farmers

	All respondents	Organic Farmers	Conventional Farmers	
Group size (n)	103	65	38	
Mean age	36.9	36.5	37.7	
Gender (% male)	73.8	69.2	81.6	
Median Household income from farm (%)	25.0	20.0	35.0	
**Educational Attainment (%)*				*
Some high school	11.7	7.7	18.4	
High school/GED	15.5	13.9	18.4	
Some college	16.5	16.9	15.8	
Associates/Tech	7.8	7.7	7.9	
Bachelor's	33.0	35.4	28.9	
Grad	15.5	18.5	10.5	
Total	100.0	100.0	100.0	
***Farm*'s Gross Income (%)				**
Less than $5,000	20.0	23.8	13.5	
$5,000-$9,999	13.0	15.9	8.1	
$10,000-$49,999	32.0	34.9	27.0	
$50,000-$149,999	23.0	19.0	29.7	
$150,000-$349,999	2.0	1.6	2.7	
$350,000-$499,999	5.0	1.6	10.8	
$500,000-$999,999	4.0	3.2	5.4	
$1,000,000+	1.0	0.0	2.7	
Total	100.0	100.0	100.0	
****Acres farmed (%)*				***
Mean	62.8	32.0	115.6	
Median	17.00	6.00	40.00	

$P < .05$*; $p < .010$**; $p < .001$***.

is, was 0.35450 (<.1=most urban to >.9 = most rural) (Waldorf, 2007). Most farms were smaller than 30 acres (20.4%), with 41.7% being .5 to 10 acres in size. 18.4% of the farms were larger than 100 acres. The mean farm size was 62.8 acres (17 median acres). Respondents noted that on average they raise 9.7 acres in specialty crops (3 median acres). To put this in context, the average Indiana specialty crop farm had 21.5 acres in specialty crop production and produced $200,000 in market value of specialty crops (mean), according to the most recent USDA Ag Census (2015).

We also asked farmers about their distribution practices for their specialty crops. Most of the farmers participating in the survey sell 50% or more of their product directly to consumers (see Table 2). Table 2 describes the markets used by farmers, as well as the proportion of the specialty crops distributed through each distribution mechanism. Notably, 22% of farmers who responded to the survey also market at least some (between 1-50%) of their products through grocers, restaurants, or other institutions (see Table 2). The chi-square analysis did not reveal any statistically significant differences in marketing strategies between the organic and conventional growers.

High tunnel usage

Nearly half of the respondents had only one high tunnel (48.5%). The mean number of high tunnels owned was 3.07 per farm, with organic growers averaging 3.15 and conventional growers averaging 2.92 (see Table 3). Most (76.2%) respondents spent less than $5,000 out-of-pocket on constructing their new infrastructure. The average high tunnel size was 5,540 ft^2, with a median size of 2,880 ft^2. Based on the project's primary focus and methods for acquiring contact details for high tunnel users, we oversampled EQIP participants, which accounted for 73.8% (n=76) of our respondents. Among all respondents, 47% had only an EQIP funded high tunnel. Few respondents used Farm USDA Service Agency (FSA) financing to cover their portion of high tunnel costs: 6.8% of all respondents and 5.5% of EQIP participants.

We asked participants to list their top six most financially important high tunnel crops and thematically grouped them and calculated frequencies for the listed crops. Greens crops (salads, spinach, kale, micro greens, etc.; frequency (f)=126) were most often listed among the top six crops by Indiana high tunnel producers who responded to our survey, followed by tomatoes (f=87), peppers (f=28), root vegetables (f=28), cucumbers (f=25), beans (f=19), herbs (f=15), and raspberries (f=12). We also calculated the percentage of farmers in the survey who are growing greens, tomatoes, and both greens and tomatoes, because these were the two most financially important crops. Of the growers who responded to our survey, 78 grow tomatoes (75.0%), 56 grow greens (53.9%), and 42 grow both (40.4%). This selection of crops is broadly similar to international trends, with the following crops being produced most frequently in high tunnels in countries around the world: tomato (Solanum lycopersicum), pepper (Capsicum annuum Grossum group), cucumber (Cucumis sativus), muskmelon (Cucumis melo), and lettuce (Lactuca sativa) (Lamont 2009). The most notable difference with Indiana growers is the emphasis on growing a greater diversity of salad greens than just lettuce, although greens such as spinach and Swiss chard are also commonly grown in other countries.

We also asked about how their farm uses high tunnels, and farmers responded with a percentage of the high tunnel area dedicated to various crop types. Those who grow vegetable/melon/ herbs in tunnels use 86.7% of the high tunnel area to produce these crops. For those who grow berries or tree fruit, 38.8% of the high tunnel is used for those crops. Those growing flowers and bedding

Table 2: Cross-tabulations and Chi-square Results (no differences were detected) for Percent of High Tunnel Products Moved Through Various Distribution Mechanisms

	Overall (n=103)	Organic Farmers (n=65)	Conventional Farmers (n=38)
Sold direct to consumer			
0%	13.6%	15.4%	10.5%
1-50%	13.6%	13.8%	13.2%
50-99%	35.0%	38.5%	29.0%
100%	37.8%	32.3%	47.3%
Total	100.0%	100.0%	100.0%
Sold direct to grocer, restaurant, or institution			
0%	64.0%	60.0%	71.0%
1-50%	22.3%	26.1%	15.8%
50-99%	9.7%	10.8%	7.9%
100%	4.0%	3.1%	5.3%
Total	100.0%	100.0%	100.0%
Sold direct to aggregator, food hub, or other distributor			
0%	89.3%	90.8%	86.8%
1-50%	7.8%	7.7%	7.9%
50-99%	2.9%	1.5%	5.3%
100%	0.0%	0.0%	0.0%
Total	100.0%	100.0%	100.0%
Sold direct to food processor			
0%	97.1%	96.9%	97.4%
1-50%	2.9%	3.1%	2.6%
50-99%	0.0%	0.0%	0.0%
100%	0.0%	0.0%	0.0%
Total	100.0%	100.0%	100.0%
Sold/donated direct to food bank or similar initiative			
0%	62.1%	75.4%	65.8%
1-50%	34.0%	35.4%	31.6%
50-99%	2.9%	3.2%	0.0%
100%	1.0%	0.0%	2.6%
Total	100.0%	100.0%	100.0%

Table 3: Descriptive, ANOVA, and Chi-Square comparison results of high tunnel management overall and between organic and conventional farmers

	All respondents	Organic Farmers	Conventional Farmers	Significance Level
Group size (n)	103	65	38	-
Acres owned (mean)	41.25	27.06	66.39	*
Acres in specialty crops	9.72	7.63	13.22	-
Years farming	21.61	20.31	24.00	-
Years using high tunnels	5.29	5.05	5.71	-
Gross farm Income of $50,000 or more (%)	35.0%	25.4%	51.4%	**
Total square feet of high tunnel space	5540.94	5138.44	6222.94	-
How many high tunnels on farm	3.07	3.15	2.92	-
Percentage of household income farm supplies (%)	36.3	32.2%	43.5%	-
Dollar value of farm's sales through high tunnels	$9852.86	$11,725.00	$7044.64	-
Growing more than 2 crops	77.7%	91.2%	56.8%	***
Growing more than 6 crops	51.1%	71.9%	18.9%	***
Winter harvesting (harvesting between Nov-March because of high tunnels)	68.0%	81.5%	44.7%	***

$P<.05$*; $p<.010$**; $p<.001$***.

plants use 17.6% of their high tunnel area for the ornamental crops. Notably, berries and tree fruit are also commonly grown in high tunnels elsewhere (Janke *et al.* 2017; Weber 2018). Of the farms participating in the survey, 6.1% of their high tunnel area was being used for storage. Among these planting priorities, a significant difference was found between organic and conventional growers, with conventional growers dedicating a higher percentage of their high tunnel space to berry and tree fruit production (X^2=0.003).

High tunnel management in conventional and organic systems

Of the farmers who responded to our survey, 52.4% are using organic practices but not certified organic, and 6.8% were certified organic. The fact that the majority of farmers using organic practices are not certified is not surprising because the majority of farmers included in this analysis are marketing their products directly to consumers, and thus are able to communicate about their practices without the added cost and record keeping requirements of certification (Veldstra *et al.* 2014). For the remainder of this paper we refer to farmers as using organic practices (N=65), whether certified or not. Organic farmers in this study generally owned less acres (X^2 = 0.012) and their farm income was lower (X^2 = 0.009), as just 25.4% had farm incomes of $50,000 or more, compared to 51.4% of conventional farmers in this study who earned over $50,000 from their farms (see Table 3). The farmers using organic practices were similar to their conventional counterparts in terms of the number of acres they managed in specialty crops, with conventional farmers managing slightly more acres (13.22 mean, compared to 7.63 mean acres for organic) (see Table 3). In addition, there was a statistically significant difference between the two groups in terms of their farm income level, with a greater percentage of conventional farmers reporting a farm income of $50,000 or more compared to organic farmers (see Table 3). In other ways the two groups were not significantly different. The groups were similar in terms of their farming experience and the number of years they had been using high tunnels, as well as the percentage of their household income that came from the farm and the dollar value of their high tunnel sales (see Table 3). There was not a significant difference between organic and conventional growers in the total square footage of high tunnel space or the number of high tunnels managed by each group (see Table 3).

The farming production systems that organic and conventional farmers used to manage their high tunnels differed in some important ways. The organic farmers used high tunnel production systems that emphasized crop diversity and utilized more complex crop rotations in their high tunnels. Our Chi-square analysis found a significant difference between what organic and conventional farmers were growing (X^2=0.000) with organic farmers planting a greater diversity of crops that include a variety of greens and other crops to complement tomato production. Specifically, 76.3% of conventional growers do not grow greens, while 72.3% of organic growers do grow greens (X^2= 0.000). Similarly, 65.8% of conventional growers grow just tomatoes and not greens, whereas 50.8% of organic growers grow tomatoes and greens (X^2= 0.000). In general, there were significant differences between the organic and conventional growers in terms of the level of crop diversity they maintained in their high tunnels. As shown in Table 3, 91.2% of organic farmers grow more than 2 kinds of crops (X^2= 0.000) and 81.5% grow more than 6 kinds of crops (X^2 = 0.000), such as kale, swiss chard, spinach, arugula, tomatoes, and peppers (see Table 3).

High tunnel economics

Among respondents to this survey, 27.2% grossed between $1,000 and $9,999 annually on specialty crop sales from their farm (field and high tunnel), with another 26.2% making between $10,000 and $49,999. The mean sales for specialty crops produced per high tunnel were $9,852.86 annually ($4,000 median). We did not find statistical differences between organic and conventional growers in gross specialty crop sales from their farms in general. Eighteen respondents made less than $999 annually on specialty crops sales. Almost a fourth (23.5%) of respondents made the majority of their specialty crop revenue through products grown in a high tunnel. The mean dollar per square foot of total revenue respondents received per year on their high tunnel was $1.70 ft^2 (median $1.00 ft^2). However, 32.0% of respondents indicated that they would not buy another high tunnel without NRCS funding (39% were somewhat likely or very likely and 29% were neutral on the idea) (Mean=3.05 / Median=3.00).

Season extension with high tunnels

One of the most important benefits of growing in high tunnels is the potential to extend the growing season, particularly in parts of the world with a limited growing season. In our survey we asked growers to report the months that they are now growing or harvesting crops, when they were not before, because of their high tunnels. Of the growers who responded to the survey, 46.6% and 35.9% of them said they are now growing crops in December and January, respectively, when they were not before using a high tunnel. In addition, 64.1% are now harvesting from their high tunnels in November, 45.6% in December, 35.9% in January, and 35.0% in February, when they did not harvest crops in those months before. Figure 1 illustrates the season extension potential of high tunnels by charting the frequency of increased production and harvesting by month because of high tunnels. It is important to note that while most definitions of high tunnels say they are not heated, in practice some are: 3.9% of respondents reported routinely heating the structure to keep the temperature optimum for crop growth; 6.8% keep it above freezing in winter; and 19.4% heat occasionally for frost or freeze protection.

In comparing organic to conventional growers, organic growers were much more likely to use their high tunnels to extend harvest into the winter, as 81.5% of them reported harvesting during the winter months when they were not before, compared to 44.7% of conventional growers reporting winter harvesting (see Table 3). Winter harvesting was measured as harvesting during any month between November and March. It is likely that this difference in winter harvest is related to differences in crop choice: three-quarters of organic growers grow greens–nearly all of which are cool season crops– while only about one-quarter of conventional growers grow greens, focusing instead on tomatoes, which cannot tolerate winter conditions in high tunnels.

High tunnel experience

We asked a series of general likert style questions about farmers' experience with their high tunnels. When queried about the utility of the high tunnel, most respondents found them to be useful to extremely useful (on a 1-5 scale: 1=not at all useful; 2=somewhat useful; 3= useful; 4=very useful; 5= extremely useful). Increasing yields is another important potential benefit of high tunnel production, and we asked farmers to estimate yield in the high tunnel compared to yield in the field by

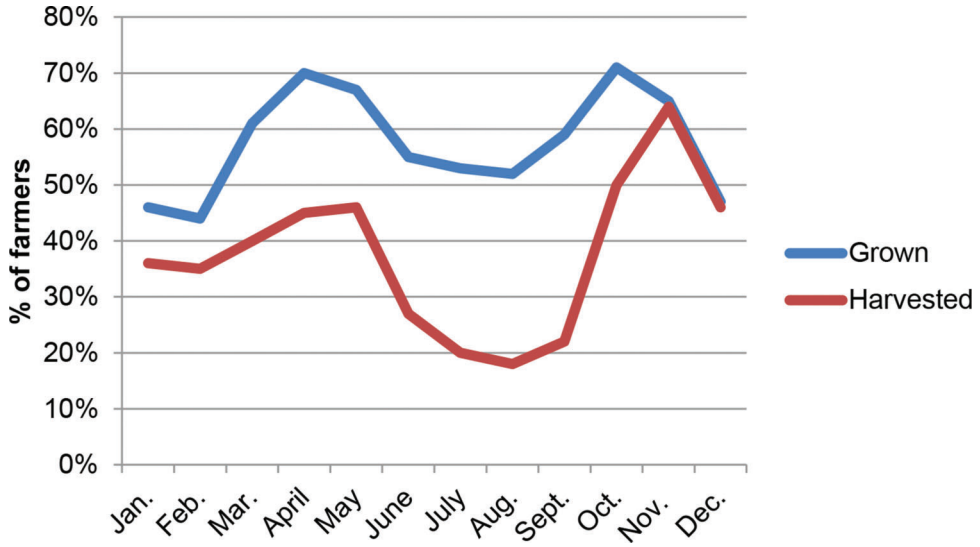

Figure 1: Months farmers are now growing more or now harvesting specialty crops, because of their high tunnels

selecting a response ranging from 'decreased 50% or more' to 'increased 50% or more', or 'do not know'. Just over 43% of the farmers in our survey reported that growing in a high tunnel increased their yields by 25-50%, a very significant increase. Furthermore, another 14.6% reported that growing in high tunnels increased their yields more than 50%. In addition, 16% noted an increase of 5-25%, 6.8% of respondents were neutral on the matter (suggesting they did not experience much change in yield), and 18.4% of respondents said they did not know.

We asked farmers to consider their overall experience in growing specialty crops and compare growing in the high tunnel to growing in the field in general (see Table 4, third set of items). Overall, farmers most noted the improvements to quality of harvested product (4.7/5), disease problems (e.g. fewer problems) (4.20/5), and weed problems (e.g. fewer problems) in the crop (4.19/5) by growing crops in high tunnels. Interestingly, conventional farmers reported that high tunnels aided in disease management more than organic farmers did (p = 0.024). Improving quality of harvested products also garnered a high mean score when farmers rated the ways the high tunnel is useful (see Table 4, first set of items; 3.89= very useful).

Similarly, farmers responded to a series of prompts about the potential of high tunnels for extending the growing season (on a 1-5 scale: 1=not at all useful; 2=somewhat useful; 3= useful; 4=very useful; 5= extremely useful, see Table 4). The mean score for the high tunnel usefulness in increasing fall/winter/spring production was 4.01 (very useful), which was statistically different between the two groups, with organic growers scoring it higher ($p > .001$). While respondent scores on harvesting warm season crops earlier in the season was at 3.89, harvesting warm season crops later in the season (3.62) and harvesting cool season crops in the coldest of months (3.26) received lower scores. Additionally, organic farmers were more apt to score the latter point significantly higher than their conventional counterparts ($p > 0.001$). Still, respondents indicated that high tunnels were between useful and very useful for increasing cash flow in fall/winter/spring (3.37).

In alignment with EQIP/NRCS goals, we queried farmers about how they perceive high tunnels affecting their farm's economic stability, improving their quality of life, increasing crop yields, and reducing negative environmental impacts (see Table 4). High tunnel user respondents agreed that growing in a high tunnel allowed them to significantly increase crop yields (4.80/6), improve the farm's economic stability (4.78), improve quality of life (4.52), and reduce negative environmental impacts (4.44) (see Table 4). The increase in yield documented by this response could reflect yield increase per unit area for a specific crop and/or increased production due to do double or triple cropping; the question was a general question about the whole farm impact of high tunnels. There were no significant differences between organic and conventional farmers on their assessment of these impacts (see Table 4).

Discussion

Based on our survey findings, farmers are able to offer fresh produce for an additional one to four months of the year, and significantly improve the quality and yield of their crops with high tunnels. Given that the majority of our survey respondents have been using high tunnels for less than 5 years, many in their first season, these results suggest that high tunnels can lead to relatively quick success. Given that many growers in our study reported income from their high tunnels that exceeded the cost of their out of pocket investment in just one growing season (not accounting for production costs), it shows economic potential for small farms. Analysis of the data for this study suggests three salient ideas worthy of discussion: (1) generally speaking, farmers are benefitting from high tunnel infrastructure investments, (2) high tunnels are not only supporting production during the cooler months, but also throughout the growing season, and (3) organic producers experience a similar level of benefits as conventional growers, except for disease problems in the crop (they reported less benefit), and season extension (they reported higher success). This section provides more depth on each of these points, as well as the study's limitations and directions for future research on specialty crop production in high tunnels.

Table 4: Farmer perspective on (1) usefulness of high tunnels, (2) overall farm improvements, (3) growing in high tunnels compared to field production, and (4) likelihood of future investment in high tunnels. P values indicate significance levels between the two groups as determined by ANOVA

	Overall	Organic Growers	Non-Organic Growers	Significance Level
	Mean (SE)	Mean	Mean	
Usefulness 1-5 Likert-style scale(1=not at all useful; 2=somewhat useful; 3=useful; 4=very useful to 5=extremely useful)				
Increasing overall farm profit	3.8 (0.105)	3.9	3.6	-
Adding products/diversifying	3.3 (0.120)	3.4	3.2	-
Increasing fall/winter/spring production	4.0 (0.107)	4.3	3.6	***
Harvesting warm season crops earlier in the season	3.9 (0.103)	3.9	3.9	-
Harvesting warm season crops later in the season	3.6 (0.106)	3.6	3.6	-
Harvesting cool season crops earlier in the coldest of months	3.3 (0.154)	3.7	2.4	***
Increasing cash flow in fall/winter/spring	3.4 (0.136)	3.6	2.9	*
Shifting some of the summer workload to fall/winter/spring	2.8 (0.131)	2.9	2.6	-
Improving quality of harvest products	3.9 (0.103)	3.9	3.9	-
Reducing pest problems	3.3 (0.127)	3.3	3.3	-
Overall Farm Improvements 1-6 scale(1=strongly disagree; 2=disagree; 3=slightly disagree;4=slightly agree; 5=agree; 6=strongly agree)				
Improved farm's economic stability	4.8 (0.108)	4.9	4.6	-
Improved quality of life	4.5 (0.106)	4.6	4.3	-
Significantly increased crop yields	4.8 (0.096)	4.8	4.8	-
Significantly reduced negative environmental impacts	4.4 (0.115)	4.5	4.4	-
Production in High Tunnel vs in Field 1-5 Likert-style scale(1=extremely worse; 2=slightly worse; 3=no change;4=slightly improved; 5= extremely improved)				
Disease problems in the crop	4.2 (0.101)	4.0	4.5	*
Insect problems in the crop	3.8 (0.113)	3.9	3.9	-
Weed problems in the crop	4.2 (0.093)	4.2	4.2	-
Vertebrate pest problems	3.8 (0.123)	3.7	4.1	-
Maintaining soil quality	3.7 (0.120)	3.8	3.6	-
Quality of harvested product	4.7 (0.062)	4.7	4.7	-
Future Investment in High Tunnels 1-5 scale(1=not at all likely; 2=not very likely; 3=neutral; 4=somewhat likely; 5=very likely)				
Likelihood of your farm investing in a high tunnel without NRSC cost-share.	3.0	3.2	2.8	-

$p > .05$*; $p > .010$**; $p > .001$***.

General benefits from high tunnel infrastructure investment

The potential for high tunnels to improve specialty crop production and extend the growing season has been established with research trials and small case studies across varied locales (Blomgren & Frisch, 2007; Carey *et al.*, 2009; Conner *et al.*, 2010; Lamont, 2009). So far, there is a lack of research assessing the real-world application and benefits of high tunnels for specialty crop producers who integrate tunnels into their existing farms. This study provides evidence that in the state of Indiana, growers have had a positive experience with integrating high tunnels into their farm businesses.

Most survey respondents reported that their tunnels are useful or very useful for increasing production, extending the growing season and improving the quality of their products. The farmers who responded to the survey either slightly agreed or agreed that high tunnels improved their farm's economic stability and reported that high tunnels are between useful or very useful for increasing their overall farm profit. About half of our respondents are now harvesting from their high tunnels in the cooler months or planting earlier in the spring, when they were not able to previously. The farmers who provided information to this study, most of them operating small direct-market farms, clearly find the investment in a high tunnel to be beneficial.

High tunnel impacts on production

The signature benefit of high tunnels is their potential to extend the growing season. This is important because the lack of fresh local produce during the colder months is a major obstacle to the development of farm-to-institution programs and rebuilding year-round local and regional food systems in areas with a limited growing season (Martinez *et al.*, 2010). In Indiana, farmers are using high tunnels to extend the growing season into the colder months of October, November and December; thereby adding to the months their farms are earning revenue, and potentially capturing a premium at winter farmers markets or winter CSAs. Many farmers are also experiencing success with getting a head start in the spring, allowing them to offer high value crops such as tomatoes earlier in the summer that garner a premium price.

Another important benefit of growing in high tunnels is the improvement growers experienced with the quality and yield of their crops. In our study, over half of respondents have experienced improvements in their crop yields, some of them dramatic improvements. This finding coincides with research trials and field experiments that have found similar results (O'Connell *et al.*, 2012). In terms of quality improvements, farmers' responses ranged from a slight to significant improvement in the quality of their crops in the tunnel. In the write-in section where we asked about the opportunities from their perspective,

farmers also indicated the high tunnel led to improvements in produce quality, resulting from less insect and disease damage, the extended season for longer harvests, and utility of growing tomatoes in the high tunnel during the summer months.

Our finding that approximately half of respondents are not growing in the colder months indicates that for a major portion of those using the infrastructure, the focus is on bolstering production in the traditional growing season, including taking advantage of earlier planting dates and extended fall harvest possible in the high tunnel, as well as improved product quality. This in part explains why many of the write-in responses focused heavily on tomatoes, which a majority of farmers were planting in their high tunnels. Extending the growing season is an often-stated goal of high tunnels, but for farmers in Indiana that does not necessarily mean growing in the winter; extending the summer growing season proves valuable for many.

Organic vs. conventional growers' experience with high tunnels

The survey also provided some interesting findings regarding the extent to which high tunnels are complimentary to the use of organic farming systems. By comparing organic to conventional growers, our survey showed divergence in farmers' use of the season extension benefits of high tunnels by growing practices. The organic growers who responded to the survey were more likely to report benefits from harvesting cool season crops earlier in the coldest of months, increasing production in the fall, winter and spring, and in turn increasing cash flow during these months that are generally slower in sales. Given their emphasis on production and harvesting in the cold season, it is not surprising that the organic growers report growing a greater number of crops than their conventional counterparts, as they are growing crop types that do well in the cold season in addition to those that do well in the summer.

Both organic and conventional growers reported yield increases in high tunnels. This raises the question of whether high tunnels provide a bigger difference in improvement of yields of organic crops versus conventional, given that lower yields have historically been a challenge for organic producers (Seufert, Ramankutty, and Foley, 2012). While many of the organic farmers said their tunnels were helpful for dealing with pests and weeds, others are experiencing pest and disease problems specific to the tunnels that limit some of this benefit. In particular, the organic growers in the survey were less likely than their counterparts to report benefits in reducing disease problems (though the mean score on disease was still relatively high overall). It is possible that the organic growers simply have fewer options available for dealing with diseases that may be more problematic in high tunnels, or that they already experience superior disease control and hence are less likely to observe dramatic differences. Another possibility is that this difference is related to the preference of organic farmers in this study for growing greens. Reduction of some fungal diseases on tomatoes is commonly reported in high tunnels, thus tomato growers report needing fewer fungicide applications to manage these diseases in high tunnels compared to the field (Johnson, Grabowski, and Orshinsky 2015). In contrast, high humidity in winter tunnels promotes disease problems for leafy greens.

Limitations and future research

There are a number of limitations to this study. Our sample size of 103 (62.8% response rate) is relatively small and limits our ability to make broad generalizations about high tunnel users. However, the total number of growers using high tunnels in Indiana is relatively small, as NRCS reported funding the construction of just 160 tunnels on farms in Indiana since 2012 (NRCS, 2014). Considering the number of high tunnels in Indiana relative to our final sample of 103, our sample is a pretty strong representation of high tunnel users in Indiana. Our sample should not be considered representative, given that the compilation of the sample from the NRCS list and via extension contacts leaves out high tunnel users who we did not contact, and thus could change the results if we had access to the contact data of those individuals. Given that no such lists are available, research funding to support the creation of a more comprehensive database of potential respondents would enhance the sampling and in turn better capture any possible divergence in the high tunnel experience. Finally, while our research in Indiana (U.S.A.) is useful in the larger conversation on high tunnel research, the geographic locale and the climate zones in particular should be critically considered as experiences and outcomes of high tunnel usage will vary greatly across regions, in different ecological contexts, and with different soils.

Overall, while farmers reported that their high tunnels were either useful or very useful for increasing their cash flow in the off-season, the survey also indicates situations where the potential benefits of tunnels are not being realized, and these provide directions for future research. For instance, conventional growers are less likely to use high tunnels to increase cash flow in the off-season. The fact that around half of our respondents are not harvesting in the colder months raises some questions we hope to explore in future research. Farmers found tunnels valuable for harvesting warm season crops earlier in the season, but not quite as valuable for harvesting warm season crops later in the season. This finding probably reflects the fact that tomatoes are one of the most popular and successful crops grown in high tunnels, both among our respondents in Indiana, in other parts of the country, and around the world (Knewtson *et al.*, 2010; O'Connell *et al.*, 2012). The price premium for early season tomatoes, in addition to their value in attracting customers to a direct-marketer can explain the early season value; while harvesting later in the season doesn't provide those same benefits.

Future research is also warranted to investigate a larger sample of organic and conventional growers in order to offer a stronger comparison between management styles. This project was able to assess differences on a farm level, but could not document differences between organic and conventional high tunnel benefits for any particular crop, because the mix of crops grown in tunnels differed between the management styles. Thus, we could not conclude that the same differences between organic and conventional would be found if the same crops were produced in the two systems. A larger sample could allow for teasing out of differences by crop. In addition, it would be useful to explore the impacts of long-term high tunnel use on soil health in future research. For example, we are investigating whether

there is an increase in pest or disease pressure in the high tunnel over time because the soil is protected from freezing temperatures that would otherwise break pest life cycles, or a buildup of salts or other minerals because the soil is not flushed by heavy rains.

Conclusion

This survey indicates that high tunnels are strengthening specialty crop production on farms in the U.S. Midwest state of Indiana. Growers report a number of benefits from growing with high tunnels, including improvements to their crop harvests, quality, and overall farm viability. These grower reports provide the first survey-based confirmation that favorable results documented in research trials and small case studies carry through to the farm level when a high tunnel is integrated into an existing operation. Because the majority of these farmers have been using their high tunnels for less than 5 years, the results also serve as a baseline to which future responses can be compared. The positive outcomes suggest that although there is a learning curve to growing with high tunnels, benefits can be realized in a relatively short time period.

Although only Indiana farmers responded to the survey, it seems likely that similar results would be found in other U.S. Midwest states with comparable agricultural environments. In other parts of the world with differing agro-ecological contexts and differing markets, perceived economic and social benefits will likely differ. Some of the findings may be cautiously considered for other regions with the caveat that growing conditions and overall context is important to consider.

In this work we were able to identify farmer reported measurable impacts on one of the goals of the HTI: the availability of fresh produce. Our study shows that high tunnels assist growers in both increasing their crop yields and extending the growing season, thereby increasing the supply of fresh produce for local food markets where most respondents sell their products. Furthermore, our study finds that high tunnel usage improved these farms' economic stability and to a lesser extent their overall farm profit. This suggests the potential for continued increases in the supply of fresh food for local markets as some of these operations grow into larger enterprises. Assessing whether high tunnels are or are not meeting the other stated goals of the HTI–reducing nutrient and pesticide runoff, improving plant and soil quality, reducing energy use through reduced transportation from farm to market–is beyond the scope of the survey data.

Organic and conventional farmers for the most part agreed on the benefits of high tunnels. Differences were related to season of production (organic growers reported more production and harvest in the fall/winter/spring) and disease (organic growers did not see as much benefit in reducing disease as conventional growers). Recognizing the similarities and differences in these production systems will enable researchers and educators to more effectively address needs for new knowledge and production recommendations.

Overall, our survey provides evidence that high tunnels are enhancing specialty crop production in Indiana and increasing the viability of farms that supply local food systems.

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REFERENCES

Beckford, C.L. and Norman, A. (2016). Climate Change and Quality of Planting Materials for Domestic Food Production: Tissue Culture and Protected Agriculture. In *Globalization, Agriculture and Food in the Caribbean*, Palgrave Macmillan UK. pp. 189–215.

Bengtsson, J., Ahnström, J. and Weibull, A.C. (2005). The effects of organic agriculture on biodiversity and abundance: a meta-analysis. *Journal of Applied Ecology*, 42, pp. 261–269. doi: 10.1111/j.1365-2664.2005.01005.x

Biernbaum, J. (2013). Water, soil and fertility management in organic high tunnels. Available at: http://www.hrt.msu.edu/assets/PagePDFs/johnbiernbaum/HighTunnelWaterSoilFertility2013-10pgs.pdf [Accessed February 10, 2015].

Blomgren, T. A. and Frisch, T. (2007). *High Tunnels: Using Low Cost Technology to Increase Yields, Improve Quality, and Extend the Growing Season*. University of Vermont Center for Sustainable Agriculture. Available at: www.uvm.edu/sustainableagriculture.

Bruce, A.B., Farmer, J.R., Maynard, E.T. and Valliant, J.D. (2017). Assessing the impact of the EQIP High Tunnel Initiative. *Journal of Agriculture, Food Systems, and Community Development*, 7(3), pp. 159–180.

Carey, E.E., Jett, L., Lamont, W.J., Nennich, T.T., Orzolek, M.D. and Williams, K.A. (2009). Horticultural crop production in high tunnels in the United States: A snapshot. *HortTechnology* 19, pp. 37–43.

Church, A. (1993). Estimating the effect of incentives on mail survey response rates: a meta-analysis. *Public Opinion Quarterly,* 57, pp. 62–79.

Coleman, E. (2009). *The winter harvest handbook: Year-round vegetable production using deep-organic techniques and*

unheated greenhouses. White River Junction, VT: Chelsea Green Publishing.

Conner, D.S., Montri, A.D., Montri, N. and Hamm, M.W. (2009). Consumer demand for local produce at extended season farmers' markets: guiding farmer marketing strategies. *Renewable Agriculture and Food Systems*, 24, pp. 251–259. https://doi.org/10.1017/S1742170509990044

Conner, D.S., Waldman, K.B., Montri, A.D., Hamm, M.W. and Biernbaum, J.A. (2010). Hoophouse contributions to economic viability: Nine Michigan case studies. *HortTechnology*, 20, pp. 877–884.

Dillman, D. A., Smyth, J. D. and Christian, L. M. (2014). *Internet, phone, mail, and mixed-mode surveys: the tailored design method*. John Wiley & Sons.

Foust-Meyer, N. and O'Rourke, M.E. (2015). High tunnels for local food systems: Subsidies, equity, and profitability. *Journal of Agriculture, Food Systems, and Community Development,* 5, pp. 27–38. doi.org/10.5304/jafscd.2015.052.015

Gomiero, T., Pimentel, D. and Paoletti, M.G. (2011). Environmental impact of different agricultural management practices: conventional vs. organic agriculture. *Critical Reviews in Plant Sciences*, 30, pp. 95–124. http://dx.doi.org/10.1080/07352689.2011.554355

Huff, P. (2015). *Extending the Growing Season*. Institute for Agriculture and Trade Policy. [Online]. Available at: http://www.iatp.org/files/2015_04_02_SeasonExtension_PH_0.pdf

ICARDA. (2015). Protected agriculture: productive use of marginal land. Available at: http://www.icarda.cgiar.org/tools/protected-agriculture

Ingwell, L.L., Thompson, S.L., Kaplan, I. and Foster, R.E. (2017). High tunnels: protection for rather than from insect pests? *Pest. Manag. Sci*, 73: 2439-2446. doi.org/10.1002/ps.4634

Janke, R.R., Alta-mimi, M.E. and Khan, M. (2017). The use of high tunnels to produce fruit and vegetable crops in North America. *Agri-cultural Sciences,* 8, 692–715. https://doi.org/10.4236/as.2017.87052

Johnson, A., Grabowski, M. and Orshinsky, A. (2015). *Leaf mold of tomato*. [online] University of Minnesota Extension. Available at: http://www.extension.umn.edu/garden/fruit-vegetable/plant-diseases/leaf-mold-tomato/index.html [Accessed November 21, 2016].

Lamont and William J (2009). Overview of the use of high tunnels worldwide. *HortTechnology*, 19, pp. 25–29.

Lawrence, J., Simpson, L. and Piggott, A. (2017). Protected Agriculture: A Climate Change Adaptation for. Natural Resources Management: Concepts, Methodologies, Tools, and Applications: Concepts, Methodologies, Tools, and Applications, 140.

Low, S.A., Adalja, A., Beaulieu, E., Key, N., Martinez, S., Melton, A., Perez, A., et al. (2015). Trends in U.S. local and regional food systems(AP-068). U.S. Department of Agriculture, Economic Research Service. Retrieved from Cornell School of Hospitality Administrationsite: http://scholarship.sha.cornell.edu/articles/1058

NRCS (2011, January 7). USDA provides update on seasonal high tunnel pilot [Press release]. Available at: http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/newsroom/?cid=STELPRDB1040764

NSAC. (2014, October). Environmental Quality Incentives Program; Helping farmers and ranchers share the costs of addressing natural resource concerns. [NSAC Blog]. Available at: http://sustainableagriculture.net/publications/grassrootsguide/conservation-environment/environmental-quality-incentives-program/

O'Connell, S., Rivard, C., Peet, M.M., Harlow, C. and Louws, F. (2012). High Tunnel and Field Production of Organic Heirloom Tomatoes: Yield, Fruit Quality, Disease, and Microclimate. *HortScience*, 47, pp. 1283–1290.

Orzolek, M.D. (2013). Increasing Economic Return to High Tunnel with Specialty Crops. Proc. On High Tunnel Horticultural Crop Production. Ed. L. Jett. *Acta Hort*, 987. ISHS 2013.

Seufert, V., Ramankutty, N. and Foley, J.A. (2012). Comparing the yields of organic and conventional agriculture. *Nature, 485*, pp. 229–232. doi:10.1038/nature11069

Singer, E. (2012, October 3-4). *The use and effects of incentives in surveys*. Presentation at the National Science Foundation. Retrieved November 2, 2014 from: https://iriss.stanford.edu/sites/all/files/EDGE/SingerOctober.pdf

United States Agency for International Development, USAID. (2008). *Protected Agriculture in Jamaica; A Reference Manual*. Available at: http://pdf.usaid.gov/pdf_docs/pnaeb744.pdf

USDA Ag Census. (2015). Results from 2012 Ag Census. Available at: http://www.agcensus.usda.gov/Publications/2012/Full_Report/Volume_1, Chapter_2_US_State_Level/

USDA Ag Census. (2015). Specialty Crops. Available at: https://www.agcensus.usda.gov/Publications/2012/Online_Resources/Specialty_Crops/SCROPS.pdf

Veldstra, M.D., Alexander, C.E. and Marshall, M.I., (2014). To certify or not to certify? Separating the organic production and certification decisions. *Food Policy*, 49, pp. 429–436.

Waldman, K.B., Conner, D.S., Biernbaum, J.A., Hamm, M.A. and Montri, A.D. (2012). Determinants of Hoophouse Profitability: A Case Study of 12 Novice Michigan Farmers. *HortTechnology*, 22, pp. 215–223.

Waldorf, B., (2007). What is rural and what is urban in Indiana Purdue Center for Regional Development Report, 4.

Weber, C.A. (2018). High tunnel performance of seven floricane red raspberry cultivars in western NY. *Journal of the American Pomological Society*, 72(4), pp. 251–259.