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University Research on Winter Growing of Container-Grown Strawberries Translates to Grower's Farm Trial

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Adams, Stacy A.; Paporozzi, Ellen T.; Pekarek, Ryan; Lambe, Dave P.; Meyer, George; Conley, M. Elizabeth; and Read, Paul, "University Research on Winter Growing of Container-Grown Strawberries Translates to Grower's Farm Trial" (2021). *Agronomy & Horticulture -- Faculty Publications*. 1514.

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University Research on Winter Growing of Container-Grown Strawberries Translates to Grower's Farm Trial

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ABSTRACT



Strawberries are only seasonally available in Nebraska (NE). If an affordable heated structure can be designed, then opportunity exists to increase on-farm income by producing strawberries off-season during high-value market periods. A series of university greenhouse trials were conducted from 2010 to 2012. The varieties Evie-2 and Seascape were identified as being most productive under a low technology growing scheme. A new research project, which ran from fall to late spring (2013–2014), was designed to determine if this production scheme would translate to a commercial grower. Varieties Seascape and Evie-2 (each at two grades indicated by +) and San Andreas plants were grown simultaneously at the university research greenhouse and a cooperative specialty crop grower greenhouse, similar structures and production timelines. Top performers for both experiment locations were 'Evie-2', and 'Evie-2+' plants, with average harvest berry weights (marketable) per plant (pp) of over 0.454 kg, and 'Seascape' with 0.390 kg. 'Seascape+' plants performed well at the cooperator location (0.399 kg pp), but not at the university location. 'San Andreas' plants performed well at the university location with 0.454 kg pp but not at the cooperator location. Productivity was greatest during the winter-spring season, which accounted for more than 82% of the total berry mass harvested at the cooperator site and 88% at the university site. The results support the concept that the growing system used within a controlled university research setting is representative of the crop productivity a specialty crop grower might expect, particularly when strawberries are grown in late winter and early spring. However, securing low fuel costs, eliminating delivery and having a secondary market for culls is key for profitability.

KEYWORDS

Day-neutral; capillary mat; return on investment; expenses; income

Introduction

Strawberries (*Fragaria x ananassa*) are one of America's favorite fruits and the US is one of the world's leaders with growers producing 1.4 to 1.6 billion pounds at a value of approximately \$3.5 billion dollars (Anonymous, 2019; Parton et al., 2007; Shahbendah, 2019). Fresh strawberry availability in Nebraska (NE) is seasonal. Locally grown berries are only available in June and July. Strawberries marketed in NE are harvested before full ripening and shipped to wholesalers/retailers and thus, often lack flavor due to early harvest. This increases firmness for shipping and lengthens postharvest shelf life, but sugars and other phytochemicals will not be at the highest levels. In addition, berries can be quite expensive when available during the winter months, being as much as \$11 to \$14.32 per kg.

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Nebraska's climate limits the production of most field grown food crops to one harvest per year. While typical commodity agricultural crop production has increased in the Great Plains region, the ratio of the farm net income to gross income has fallen, thus resulting in the need for more government payments (Paparozzi et al., 2018). In an effort to increase income (as government payments are unsure), some farmers have moved into the production of specialty food crops. Many have constructed high tunnels to lengthen their production and harvest period of high-value crops, principally tomato, pepper, and cucumber (Knewton et al., 2010).

A high tunnel is a single-layer plastic covered structure designed for the modification of the plant production environment. It typically is used to increase the number of growing days in the field and provide weather protection for the improvement of crop quality and yield (Knewton et al., 2010). With the addition of a second layer of plastic and installation of heating, ventilation, and automatic controls, an affordable greenhouse structure can be created that provides the opportunity for year-around plant production. Typical of field crop farming operations, many agricultural families have no farm income during the winter. In a review conducted by Goodwin and Mishra (2004) more than 38% of independent farm operators and 49% of their spouses worked outside of the farm to provide supplemental income.

In an effort to identify alternative high-value crops to supplement on-farm income, our specialty crops research team at the University of Nebraska-Lincoln (UNL) conducted winter greenhouse strawberry trials from 2010 through 2012. The trials included fourteen strawberry cultivars, nine of which were "June-bearing" (short day) and the remainder, day neutral. Strawberry productivity was determined based on berry mass, harvest number and nutraceutical characteristics (Paparozzi et al., 2018). Based on this research, we generated a winter growing production timeline for strawberries and a short list of cultivars which were both the most productive and had the highest nutritional value. However, in order to get growers to adopt winter growing of strawberries, a comparison study was needed to determine if this university research would translate to a commercial setting.

Thus, the purpose of this transfer technology research was to determine if the growing conditions and berry production at the university could be successfully replicated on a grower's farm. To accomplish this, startup and operational costs associated with the establishment of a heated high tunnel as well as the implementation of strawberry production were recorded. Yield data was collected weekly and barriers to technology transfer (e.g. costs, energy source, labor) were identified. Recommendations to surmount any barriers to implementation were the final step.

Materials and Methods

Growing Structures

The two experiments were conducted simultaneously from September 2013 through April 2014. The first experiment was conducted at the researchers on-campus production prototype located on UNL East Campus in Lincoln, NE (lat. 40°50'N, long. 96°45'W), which was used previously for the variety trials conducted from 2010 to 2012. The second experiment was conducted approximately 35 miles from the University campus at a cooperator grower site in Dwight, NE (lat. 41°08'N, long. 97°02'W). Both experiments (at UNL and the grower site) were completed in 7.93 × 23.2 m double polyethylene covered hoop style structures, having active greenhouse ventilation system and forced-air gas/propane furnace (Lambe et al., 2012). Both locations were monitored for temperature and light levels. Both were found to have the same DLI (daily light integral) range (October through February 4–5 to 9 mol; then increasing March–April 10–14 mol (Spectrum Technologies Aurora, IL, USA)). The university greenhouse environment was regulated by a Groton II control system (ACME Engineering and Manufacturing, Inc., Muskogee, OK) with the furnaces providing direct under-bench heating and the cooperator grower used a series of line-voltage mechanical thermostats to control individual equipment with supplemental axial fans redirecting heat to underneath the outside two growing benches. Both locations were set to maintain a day/night temperature differential of 21/17°C. Both the

university and cooperator growing structures were instrumented to monitor and record inside and outside temperatures, humidity, interior photosynthetically active radiation (PAR), heating and ventilation energy usage and water/fertilization events (Meyer et al., 2014). Supplemental lighting was not used given that the equipment, infrastructural and operational costs would negate the low technology production methods being employed.

The cooperator grower greenhouse was built to have a similar structure and capillary mat system. The heating system was slightly different in that the fuel was propane. The under bench poly-tube blower type distribution system was of blended air, not a direct connection to the unit heater blower as at the university location. In order to use space more efficiently and for the grower to have maximum productivity of the crop, there were more benches. The three benches (instead of two) were similarly constructed, measured 1.84×21.34 m and set 0.91 m above the floor surface.

The capillary mat system was covered with white top/black bottom polyethylene film (Panda Film™, Flora Hydroponics, Atlanta, GA) that served as a vapor barrier, enhanced light reflectance into the plant canopy, and prevented algae growth. Plants were grown in 15.2 cm, standard plastic pots with bottom holes to allow roots to interface with the capillary mat. This was done by cutting holes through the Panda Film™ reflective mulch using a jig and pivot cutter as described by Adams and Paparozzi (2014). The white reflective plastic mulch was selected based on light reflectance studies (Meyer et al., 2012). For both experiments, pots were spaced on 30 cm centers across the growing bench and 40.6 cm centers down the length of the growing bench.

Plant Production

Plants were container-grown on raised benches with forced air heat distributed through a convection tube system suspended under the growing benches. The benches were simply constructed block and fence benches with a capillary irrigation system (Adams and Paparozzi, 2014). Raised benches were used given the interior temperature stratification resulting from low outdoor winter temperatures, associated heat losses through infiltration, and covering conduction.

All plants at both locations were grown in Grower Select® M1 Professional Grower Mix (BFG Supply, Burton, OH) that was comprised of equal parts composted bark, peat, perlite and vermiculite with a wetting agent and nutrient charge. Soluble fertilizer applications were made using 100 mg nitrogen (N) L⁻¹ Jack's Professional™ 20 N-8.8P-16.6 K general purpose fertilizer (J.R. Peters, Inc., Allentown, PA) alternated with calcium nitrate at 100 mg N L⁻¹ (15.5 N-0P-0 K) (YaraLiva™ CALCINIT™ greenhouse grade, Tampa, FL), or tap water as determined from plant observations. Soluble fertilizer was proportioned 1:100 into irrigation water through a SuperDos 30 Model 2.5% Professional injector (Dosmatic U.S.A., Carrollton, TX). Daily watering was automatically controlled using an irrigation controller by Rainbird (Azusa, CA) having schedules adjusted according to crop and environmental conditions that would minimize nighttime humidity levels and thus, reduce plant disease and pest pressure.

Dormant strawberry crowns were received for both experiments on calendar week 37 (September 9) in 2013 and all were potted at the university location using like supplies. The plants were monitored for two weeks to assure growth initiation following the extended dormancy period associated with receipt of late summer propagates. Plants were then distributed to their respective experimental locations during week 40 (approximately September 24). Bumblebees, *Bombus impatiens* NATUPOL™ (Koppert Biological Systems, Inc., Howell, MI) were released into both growing structures to enhance flower pollination. It is important to note that by supplying bumblebees pollination and subsequent berry production was probably assured.

Three day-neutral cultivars were used in both experiments, Evie-2, Seascape and San Andreas (Nourse Farms, South Deerfield, MA). Evie-2 and Seascape cultivars were also evaluated as premium size rootstocks (supplier graded) and treated as separately for data purposes, being noted as: Evie-2 + and Seascape+. 'San Andreas' had not been trialed before by our researchers but was recommended for our production system based on research done using high tunnels in Kansas which was later published by (Gude et al., 2018).

Experimental Designs

The university study had four plants of each of the five varieties in each block, arranged in a randomized complete block design (RCBD) with twelve replications for a total of 240 plants. The blocking criteria were light and temperature. Each plant was the experimental unit. The experiment was arranged across two benches that were 1.83×18.3 m and set above the floor 0.91 m. At the grower's site, the same five cultivars were also arranged in a RCBD with the goal of 20 plants per each of the five cultivars in each block. However, due to supply issues, cultivar San Andreas had nine plants per block and cultivars Seascape and Seascape+ had nineteen, for a total of 1044 plants. Again, each plant was the experimental unit (the unit on which data were taken).

Data Collection and Statistical Analysis

Berries were deemed ripe by comparison of color to those available at grocers and standardized using the *RHS Color Chart* (Red Group 46) (Royal Horticulture Society, 1995). Harvest began on calendar week 43 (end of October) at both locations and data were collected on a weekly basis for the number of marketable fruit harvested per plant and the individual fruit weights.

Total berry mass and number data, as well as on a per pot basis, were analyzed using a repeated measures analysis implemented using the GLIMMIX procedure of SAS (Gbur et al., 2012; Littell et al., 2006). Given that the week each cultivar produced fruit was different and was sometimes zero, data were transformed to a log scale so that it approximated a normal (Gaussian) distribution. The resulting LSMeans were evaluated using pairwise t-comparisons ($\alpha = 0.05$).

Associated Costs

The grower built the high tunnel and growing system from barren ground to full operation and recorded all costs associated with greenhouse construction and installation of equipment. The grower additionally collected costs associated with production, marketing and distribution of the harvested product, allowing for projected return on investment (ROI). The project was continued through calendar week 15 (April 12) of 2014 and terminated in correlation to increase on-farm field activities.

Results and Discussion

Technology Transfer Experiment-University Results

The first harvest occurred five weeks after planting, beginning calendar week 42 (ending October 14), with a combined cultivar harvest weight (all plants bearing marketable fruit) of 0.519 kg. Productivity increased to 0.865 kg the following week and remained relatively stable throughout the fall season, with greater productivity (1.82 kg) during the week ending November 23 and the week following (2.21 kg) (Figure 1). Total harvest during the period of October 14 through December 28 was 13.54 kg.

The spring season was when plants were most productive, notably the week ending February 15 with combined harvest weight of 5.33 kg and peaking the week ending March 15 with 20.98 kg (Figure 1). The total fruit harvest for the spring period was 101.71 kg and for the entire thirty week project was 115.25 kg. Productivity was highest for cultivars Evie-2+ and Evie-2, each plant producing 0.662 kg and 0.590 kg of berries respectively. This was significantly more than the other cultivars (Table 1). 'San Andreas' and 'Seascape' plants were not significantly different in production, having average per plant (pp) harvests of 0.454 kg and 0.395 kg, respectively. 'Seascape+' was the least productive with an average of 0.304 kg pp during the project.

University Harvest Weights 2013 - 2014

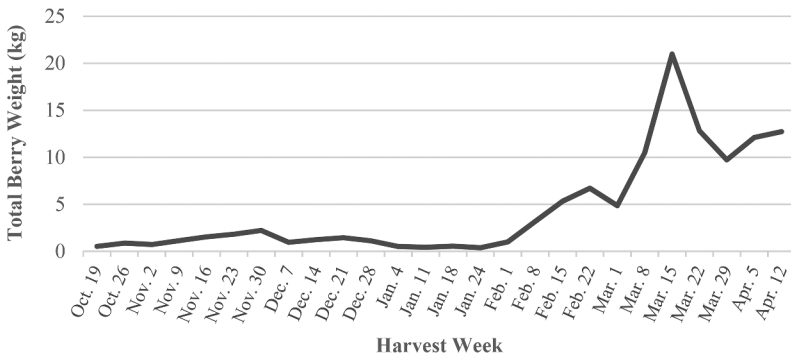


Figure 1. Total weekly marketable strawberry weight for all cultivars evaluated at the University location. There were 240 plants total in this experiment.

Table 1. LSMeans for marketable berry weight per plant (per pot) per cultivar for the entire 30-week project and partitioned for fall and spring at the University greenhouse experiment. There were 240 plants total in this experiment.

Cultivar	Harvest weight for duration of project	Fall only (WK 37–52) harvest weight	Spring only (WK 1–15) harvest weight
Evie-2+	0.299 ± 0.036 a	0.090 ± 0.009 a	0.567 ± 0.036 a
Evie-2	0.268 ± 0.036 a	0.082 ± 0.009 a	0.508 ± 0.036 a
San Andreas	0.454 ± 0.036 b	0.045 ± 0.009 b	0.413 ± 0.036 b
Seascape	0.395 ± 0.036 b	0.018 ± 0.009 c	0.376 ± 0.036 b
Seascape+	0.304 ± 0.036 c	0.045 ± 0.009 b	0.259 ± 0.036 c

LSMeans in columns followed by the same letters are not significantly different at $P < 0.05$.

Productivity data were then analyzed separately for fall 2013 (calendar weeks 37–52) and spring 2014 (weeks 01–15) (Table 1). For the fall season, ‘Evie-2+’ and ‘Evie-2’ plants were top producers, having per plant harvests of 0.09 kg and 0.082 kg respectively. Both ‘Seascape+’ and ‘San Andreas’ plants produced 0.045 kg pp with ‘Seascape’ plants having the least amount of fruit harvest, with only 0.018 kg pp during this period.

Spring 2014 (calendar weeks 01–15) strawberry fruit productivity was much higher for all cultivars evaluated (Table 1). Top performers were ‘Evie-2+’ at 0.567 kg and ‘Evie-2’ at 0.508 kg pp. The next most productive cultivars were San Andreas with 0.413 kg and Seascape with 0.376 kg pp, which produced lower yield than the top performers, but more fruit than ‘Seascape+’ plants, which produced only 0.259 kg during the spring harvest.

Technology Transfer – Grower Cooperator Results

The harvest pattern for the strawberry mass (marketable) were the same for the grower cooperator as for the university trial (Figure 2). Productivity was highest for ‘Evie-2’, with 0.485 kg over the duration of the project (Table 2). ‘Evie-2+’ produced slightly less, having an estimated total per plant of 0.481 kg. This was not significantly different than ‘Evie-2’. ‘Seascape +’ produced 0.399 kg pp and was not significantly different than ‘Seascape,’ having a harvest of 0.390 kg pp. The lowest producing cultivar was San Andreas, with a total harvest mass of 0.295 kg pp.

Cooperator Harvest Weights 2013 - 2014

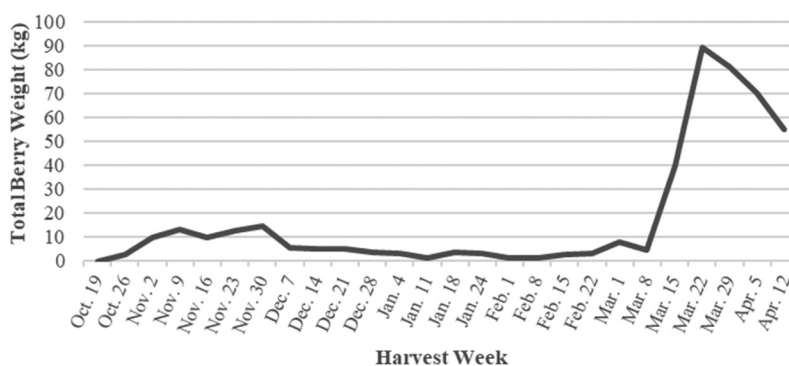


Figure 2. Total weekly marketable strawberry weight for all cultivars evaluated at the grower cooperator location. There were 1044 plants total in this experiment.

Table 2. LSMeans for marketable berry weight per plant (per pot) per cultivar for the entire 30-week project and partitioned for fall and spring at the grower cooperator experiment. There were 1044 plants in this experiment.

Mean Berry Weight Per Plant (kg)			
Cultivar	Harvest weight for duration of the project	Fall only (WK 37–52) harvest weight	Spring only (WK 1–15) harvest weight
Evie-2	0.485 ± 0.032 a	0.091 ± 0.005 b	0.395 ± 0.032 a
Evie-2+	0.481 ± 0.027 a	0.122 ± 0.005 a	0.358 ± 0.027 a
Seascape+	0.399 ± 0.027 b	0.073 ± 0.005 c	0.323 ± 0.027 ab
Seascape	0.390 ± 0.032 b	0.041 ± 0.005 d	0.349 ± 0.032 a
San Andreas	0.295 ± 0.036 c	0.036 ± 0.005 d	0.263 ± 0.036 b

LSMeans in columns followed by the same letters are not significantly different at $P < 0.05$.

Analysis of productivity for the grower cooperator trial was also completed separately for fall 2013 (calendar weeks 37–52) and spring 2014 (weeks 01–15) (Table 2). Estimated harvest mass per plant for each cultivar in the fall season were, 'Evie-2+' with 0.122 kg, 'Evie-2' of 0.091 kg, 'Seascape+' of 0.073 kg, 'Seascape' of 0.041 kg and 'San Andreas' with 0.036 kg pp.

Heavier yields were noted during the spring period of January 1 through April 12, having average per plant harvests of; 'Evie-2' 0.395 kg, 'Evie-2+' 0.358 kg, 'Seascape' 0.349 kg, 'Seascape+' 0.350 kg, and 'San Andreas' with 0.263 kg.

Strawberry harvest for the collective cultivars over the entire thirty-week project at the cooperator site was 450.09 kg. During the fall harvest period from October 19 through December 31, 2013, a total of 78.36 kg of salable strawberries were harvested (Figure 2). The harvests were greater from January 1 through April 12, 2014, having a total harvest of 371.73 kg with the highest productivity from March 8 to termination of the experiment.

Growing Comparison between the Two Sites

The cultivars Evie-2 and Evie-2+ (two grades) were top performers at both locations, having harvests over 0.454 kg per plant at their respective locations. 'San Andreas' plants performed well in the university experiment with harvests averaging 0.454 kg per plant, but produced only 0.295 kg per plant at the cooperator location. Though plant health was good at both locations, the majority of fruit harvest from this cultivar occurred in the spring season. Productivity was likely delayed at the cooperator site as lower temperatures were used to conserve on heating fuel and many strawberries

flower better at temperatures above 40–85°F (Pritts and Handley, 1998). Thus, ‘San Andreas’ plants would not be a suitable cultivar for fall production but shows promise for spring production in this growing scheme. ‘Seascape’ plants performed nearly identically at both experimental locations with average per plant harvests of 0.390 kg. ‘Seascape+’ plants responded similarly to ‘Seascape’ plants at the cooperator site, but production was less at the university location. This was attributed primarily to diminished plant health from spider mite damage.

Average yields for field-grown strawberries using plastic mulch-covered raised ground beds (termed plasticulture) in the US Mid-South region were 1.30 lbs. (0.812 kg) and 1.79 lbs. (0.812 kg) per plant (Ballington et al., 2008). According to Safley et al. (2014) a minimum harvest of one pound (0.454 kg) of berries per plant is needed to make a profit in field production. When grown using nutrient film technique (NFT) in a greenhouse, the variety Chandler averaged 0.74 lbs. (0.336 kg) per plant for a December through May production period (Takeda, 1999). However, per plant productivity varied greatly given their proximity on the stacked NFT production system used. This may be correlated to light availability. In comparison to Takeda (1999) during a similar production period, our cooperator project had average per plant harvests of 0.323 kg to 0.395 kg for ‘Evie-2’, ‘Evie-2+’, ‘Seascape’ and ‘Seascape+’ plants and at the university experiment, all cultivars except ‘Seascape+’ averaged between 0.376 kg and 0.567 kg pp. This indicates that our production system for growing strawberries is a suitable method for specialty crop growers.

Harvest weights on a per plant basis were generally greater at the university location and likely the result of heating consistency from two under bench heating units as opposed to the cooperators single furnace during the coldest part of the winter. The cooperator project was hampered by a regional heating fuel shortage resulting from an unusual number of continuously cold days where fuel deliveries were delayed and costs increased by more than 400% during a four-week period in February and March 2014. The grower conserved heating fuel by operating with lower temperatures. Once fuel became available and more affordable, the grower increased the temperatures to that set forth by the project and strawberry productivity greatly increased, as seen by a sharp increase in harvests beginning the week of March 8.

Grower Cooperator Development Costs

The cost to build the 26' × 76' double polyethylene, hoop style greenhouse, including site preparation, utility connections, and equipment and installation costs was \$26,377 (Table 3).

Additional information on the construction specifics can be found at: <https://agronomy.unl.edu/cea>. See particularly the sections on high tunnel and greenhouse, benching, and irrigation/fertigation.

Table 3. Costs associated with construction of the hoop style greenhouse at the cooperator site.

Site Preparation	Excavation	\$600
	Fill	\$180
	Ground Cover	\$556
	Utilities (water, gas, electric)	\$4,570
	Sub-total	\$5,906
Greenhouse	Structure	\$4,932
	Covering and Fastening	\$4,744
	Hardware	\$1,417
	Concrete	\$150
	Installation Labor	\$2,075
	Sub-total	\$13,318
Equipment	Heating and Controls	\$2,150
	Cooling and Controls	\$1,825
	Benches	\$1,440
	Installation Labor	\$1,738
	Sub-total	\$7,153
TOTAL COST		\$26,377

Strawberry Production Expense and Income

Final bench space allowed 1044 plants to be grown at the cooperator site. Startup production costs calculated to be \$1.56 per pot, for a total of \$1,628 and included the plant start (dormant crowns), pot, media, fungicide and labor (Table 4). There was a total of \$11,844 operation costs over the 30-week project, with a large amount (\$7,488) directly related to heating fuel expenses. This was due to a propane shortage due to unprecedented cold weather. Together with low inventories, propane costs were elevated by as much as 400%. In addition, there was another \$2,004 in marketing and delivery of the final product (Table 4). In total, 2,076 pints and quarts of strawberries were sold wholesale for an income of \$5,580. Per package prices varied from \$2.75 to \$5.00 each (similar to retail prices), depending upon packaging (weight) and time of year. Only berries that were grocery store quality were packed for the fresh market.

Profit potential is a major consideration when determining cropping season. It is important to note that productivity was greatest during the spring season and accounted for more than 82% of the total berry mass harvested at the cooperator site and 88% at the university site. It appears the lull of berries harvested between late November and early February is directly related to critical day length and available light since temperatures were carefully maintained at both locations during this period. If supplemental lighting will not be incorporated into the production scheme, late winter and early spring strawberry production appears to result in the quickest and largest fruit harvest. This schedule implies less operational costs (heating in particular) than presented here, thus, allowing for highest returns.

The initial purpose of our project was to attempt to grow fresh strawberries that could be marketed during the high-value winter period, targeting the holiday season. Our cooperator was able to sell all the strawberries harvested throughout the winter for as much as \$11 per kg wholesale and demand was greater than productivity. To increase productivity, a grower would need to incorporate supplemental lighting in the fall, which could increase infrastructural and operational costs significantly. That aside, a major consideration is heating a greenhouse during the coldest months of the year and the impact weather has on fuel costs (over 50% in this project). It is possible that profitability could be increased by utilizing an existing greenhouse structure that was retrofitted to grow this crop, locking in propane cost prior to the season, or the use of a different energy source (such as wood pellets or natural gas).

Strawberry packaging/marketing was also a large expense associated with the cooperator project. The packaging was for retail (pint and quart plastic clamshells) whereas using large wooden or cardboard crates would have saved money. Given the remote farm location (approximately 100 miles round trip from the two major cities) and that this was the only product being distributed during the winter, delivery was costly. If a grower pursued direct marketing at markets or customer site pick up only, then delivery and packaging costs could be reduced. Additionally, the grower cooperator only marketed fresh perfect strawberries and threw out culls. This was a missed

Table 4. Strawberry expenses and income at the cooperator site.

Revenue	Pints	\$4,280
	Quarts	\$1,300
	Total Income	\$5,580
Production Expenses	Starts, pots, media and planting labor	\$1,644
	Production labor	\$1,910
	Heating and Utilities	\$7,488
	Fertilizer	\$68
	Beneficials and pollinators	\$734
	Sub-total	\$11,844
Marketing	Packaging	\$364
	Delivery (Mileage and labor)	\$1,640
	Sub-total	\$2,004
TOTAL INCOME	LOSS	(\$8,268)

opportunity for multiple-level marketing in that the culls could have been sold to processors for manufacturing ice cream, jams and jellies or fragrance products. While this may have added some expense (a refrigerator), this still would have increased income potential.

Conclusions

The results from this project support our hypothesis that the growing system used within a controlled university greenhouse research setting is representative and comparable to that of a specialty crop grower for producing strawberries during winter in Nebraska. The timing of flowering and fruiting and the average per plant harvest mass for 'Evie-2', 'Evie-2+' and 'Seascape' plants were similar at both experiment locations. Plant health affected 'Seascape+' plants at the university experiment but they performed well at the cooperator site, indicating potential for success. 'San Andreas' plants did not do well at either location in the fall production period, but did well for both locations in the spring.

There is a potential to make a profit growing strawberries if this production scheme occurs during the winter-spring season. A grower could start strawberry plants in the greenhouse in early January and harvest through mid-April or possibly May, depending on air temperature. This would complement field strawberry harvest, which begins locally in June. This strategy could increase field production sales since customers are already used to buying strawberries early from a grower who incorporates heated high tunnel growing methods into his operation. Thus, setting up a marketing opportunity as well as a product opportunity.

The container grown strawberry production system used in this experiment is also a low-cost venture that allows for flexible greenhouse usage unlike a hydroponic growing system. The greenhouse could also be used off-season for other purposes, such as growing plant liners for field production and/or set idle during the coldest part of winter. The keys to successful winter production include securing low fuel costs, customer pickup rather than delivery and having a secondary market for culls. Using existing facilities retrofitted to this low-technology system could be an added benefit. If supplemental lighting will not be used, late winter and early spring strawberry production results in the quickest and largest fruit harvest with highest returns to coincide with high wholesale prices.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This project was funded by a grant from the Walmart Foundation, administered by the University of Arkansas System Division of Agricultural Center for Agricultural and Rural Sustainability, and additionally supported in part by the Agricultural Research Division of the Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln. Mention of specific trade names is for reference only and not to imply exclusion of others that may be suitable.

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