Wyoming Department of Agriculture

Specialty Crop Block Grant Program – Farm Bill

Agreement No.

Final Performance Report

Feeding Laramie Valley 2018 Season Extension Trial & Education Project

Report written by Celeste Hefti, AmeriCorps VISTA Capacity Building, Feeding Laramie Valley
with
Dr. Cliff Riebe, Chemical Geologist, Associate Professor Dept. of Geology and Geophysics, University of Wyoming
Reece Owens, Food Production Coordinator, Feeding Laramie Valley
Gayle M. Woodsum, Founder, Feeding Laramie Valley; President/CEO Action Resources International
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Contact: Ted Craig
(307) 777-6651
Ted.craig@wyo.gov

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PROJECT SUMMARY

The purpose of this project was to determine what type of hoop house/high tunnel covering material (skin) contributes to the longest, most favorable combination of light, temperature, moisture, and generally controlled environment capable of extending the growing season. There are multiple geographic-related challenges to growing specialty crops in Wyoming. In Albany County in Southwest Wyoming where this research is taking place, the average growing season for the region is just 56 days without a frost. The semi-arid, high plains in the Laramie Valley, the high altitude sun and fierce winds that frequently batter the land, together with varying levels of soil quality and access to water, can test the most dedicated specialty crops producer. The use of hoop houses to grow fresh vegetables and fruit in Wyoming has increased substantially in recent years. The number of frost-free days in Wyoming varies dramatically across different locations due to elevation in addition to latitude. Hoop houses offer season extension benefits in all areas of the state. Three identical hoop houses had different covers installed. The first house was covered in a clear skin ("Clear"). The second hoop house was covered with a fiber-reinforced skin ("Tarp") in order to increase the resistance to tearing. The third unit was covered with a bubble-encapsulated skin ("Bubble") to increase resistance to heat loss. These modifications to the hoop houses provided information on the value of various cost effective techniques. These different skins were shown to have varying impacts on the amount of heat retained and, more importantly, on the production and variety of specialty crops available in the Wyoming food distribution channel. Winter markets are now common in three Wyoming communities due to hoop house production. An additional goal was to increase overall knowledge of specialty crop growing with season extension methods, specifically, through the use of hoop houses. Garden tours and presentations for student and community groups were conducted throughout the period of research. Continuing this research will build on the efforts that are presently being implemented.

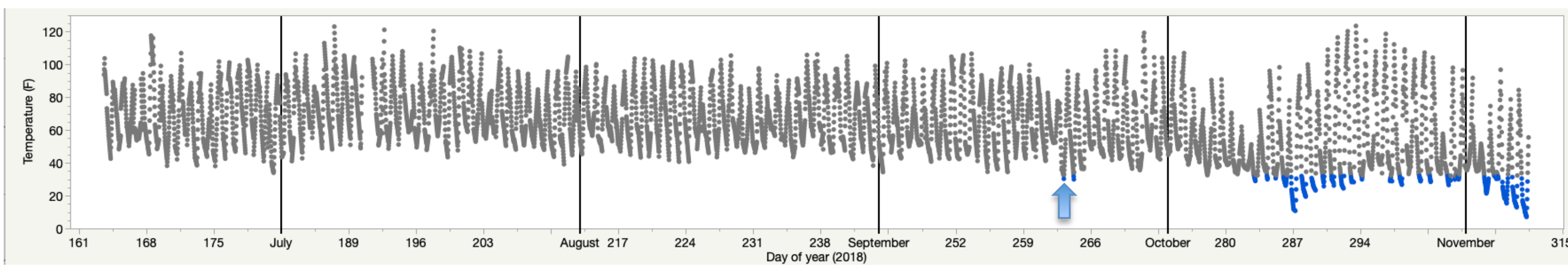
PROJECT APPROACH

Three identical hoop houses were constructed, each with a different material used to cover them (Clear, Tarp, and Bubble). Construction for the hoop houses, overseen by Reece Owens, the Food Production Coordinator, was completed mid-May and constructed with the aid of a team from an AmeriCorps National Civilian Community Corps (NCCC) and the Feeding Laramie Valley (FLV) Summer Shares Team. Identical types and amounts of specialty crops were planted in each hoop house on June 13, 2018. The specialty crops grown in each hoop house included cabbage, broccoli, cayenne peppers, jalapeño peppers, bell peppers, cucumbers, tomatoes, and okra. The growing procedure was identical for all hoop houses, including the use of the same soil type, time of watering, etc. The soil had been previously amended in 2017 for both the Bubble and the Tarp house, but not for the Clear house. The soil was amended for all three hoop houses in late May, 2018. Planting, watering, soil amendment, and harvesting all conducted by the FLV Summer Shares Team and overseen by Reece Owens.

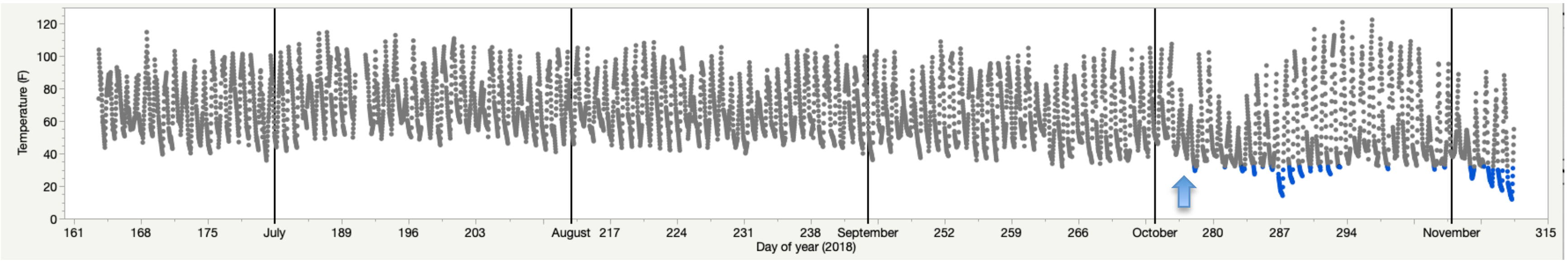
Seven Engbird IBS-TH1 sensors were used to record temperature and relative humidity; two in each hoop house, one measuring the air, the other the soil; one sensor was placed outside as a control for recording outside air temperature and relative humidity. The sensors measuring the air in the hoop houses were placed in the center of each house. The sensors measuring from the soil were placed 6 inches into in the soil and also in the center of the hoop houses. Relative humidity was calculated by taking the amount of moisture in the air and dividing it by the amount of moisture the air could hold. Monitoring range was 150 feet; temperature accuracy was ±0.5°F; humidity accuracy was ±3% relative humidity. Each sensor recorded both temperature and relative humidity every 30 minutes. Data was collected every 2 weeks.

Air Temperature as a function of Time by House Type

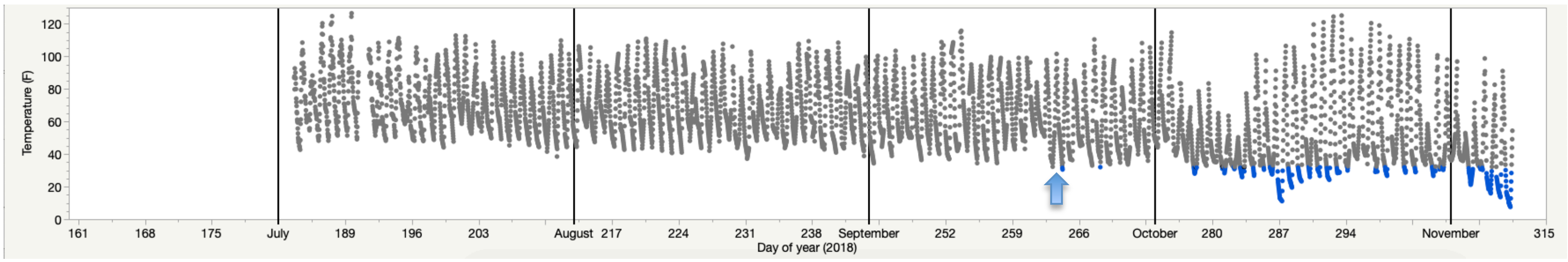
Clear



Bubble



Tarp



Control

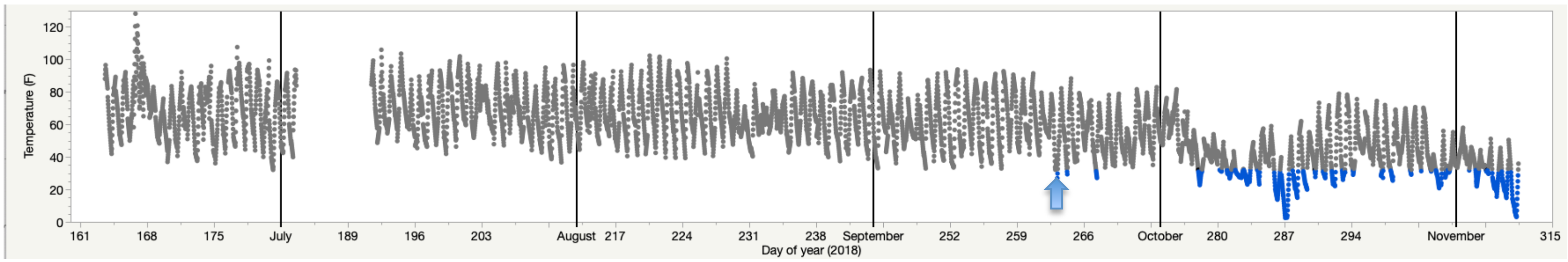


Figure 1. Temperature in degrees Fahrenheit as a function of time for three house types (Clear, Bubble, and Tarp) and Control, a probe that was placed outside the houses. The high-frequency variations are the "diurnal" changes in temperature that occur from

day-to-night-to-day as the sun rises, sets and rises again. Although there are some gaps in the data, all of the probes have near continuous temperature data from mid July to early November. Blue data points highlight measurements of temperature below 32°F, reflecting freezing conditions. Note that the Bubble house type kept temperatures above freezing until October 5, 2018, which is 15 days longer than the other house types and the Control (outside conditions).

Spline Fit to All Temp Data (lambda = 0.000001 – extremely flexible)

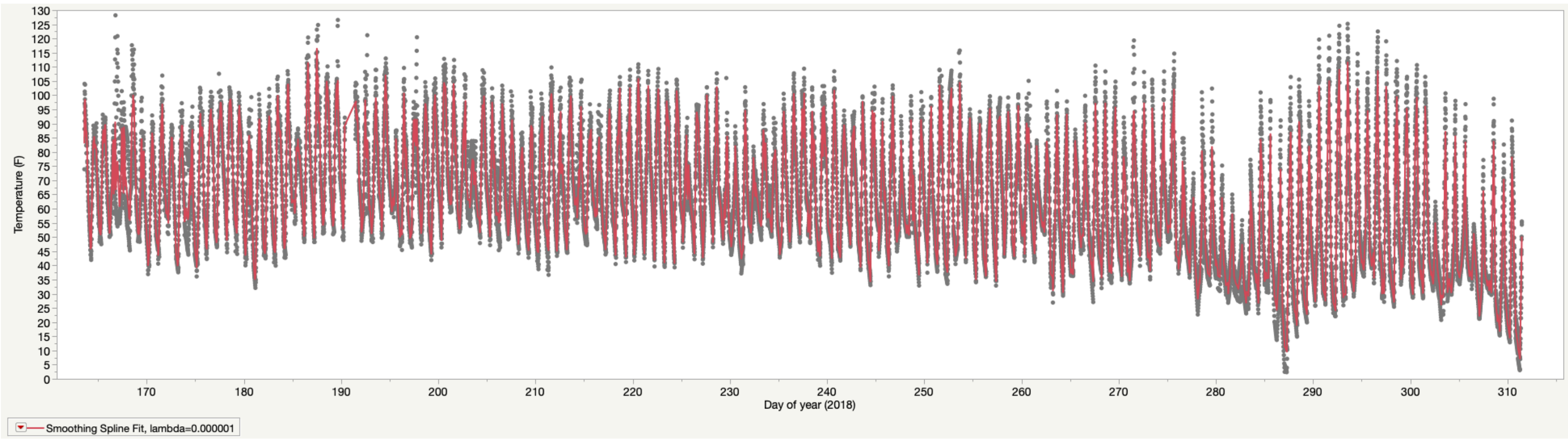


Figure 2. All air temperature data (from all four air probes) plotted against time. Red line shows best-fit spline (flexible, with lambda = 0.000001), which captures both the seasonal and diurnal fluctuations in temperature across the different house types.

Detrended Temperature Data

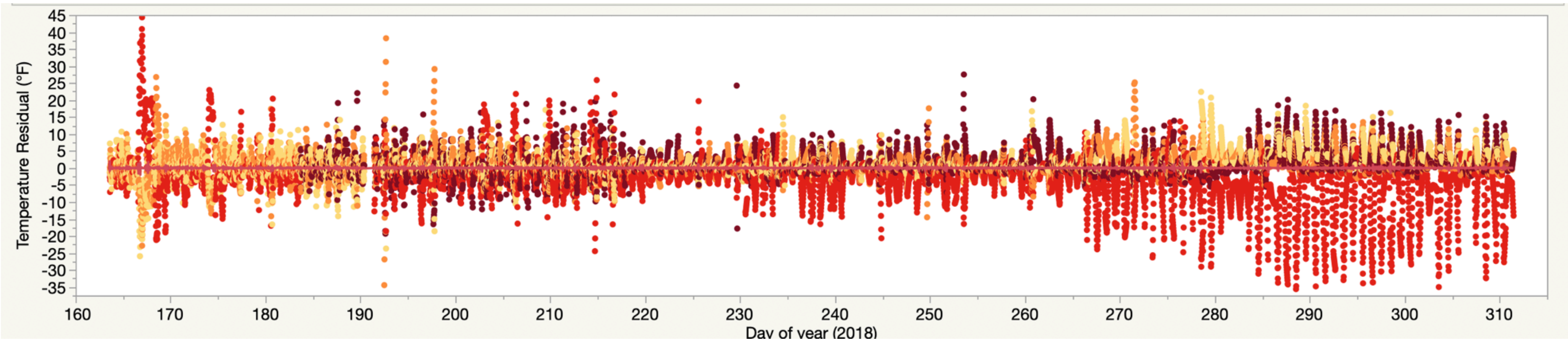


Figure 3. Detrended air temperature data. Colors represent different probes: Bright Red is Control; Yellow is Bubble; Orange is Clear; Dark Red is Tarp. This plot shows the difference between the measured temperature and the spline fit in Figure 2. In other words, this shows the data minus all of the seasonal and diurnal fluctuations, which dominate the variance in temperature in this data set. Thus, it should only contain information about the site-to-site differences in temperature, maximizing the chance to detect statistically significant differences in temperature across the site.

Figure 3 shows that there may be some substantial differences across the sites, particularly during the latter part of the record. These differences can be quantified using analysis of variance (ANOVA) coupled with a Tukey Honestly Significant Difference test.

ANOVA on Detrended Temperatures

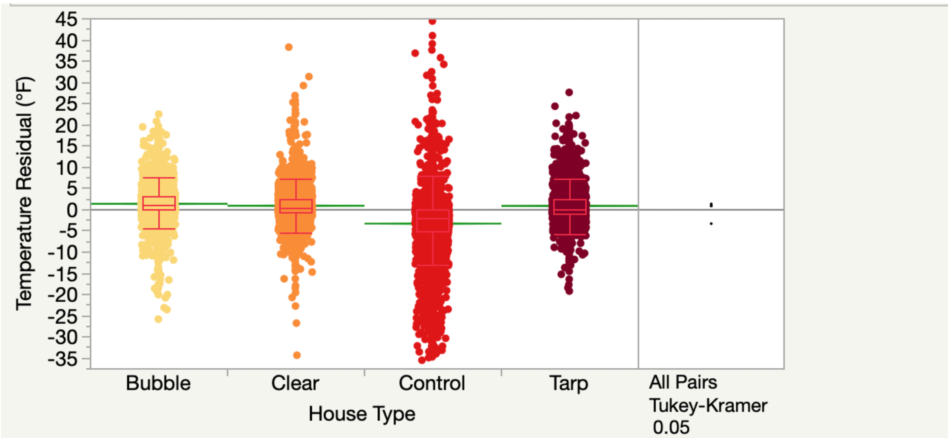


Figure 4. Temperature residual as a function of house type. Residuals are calculated by subtracting the spline-predicted temperature from the measured temperature (i.e., the difference between the gray points and the red line in Figure 2). Although there is substantial overlap between sites, analysis of variance (ANOVA) shows that the mean temperatures are markedly different: The mean residual Bubble temperature is 4.66±0.08 °F greater than the residual Control temperature; The mean residual Clear temperature is 4.22±0.08 °F greater than the residual Control temperature; The mean residual Tarp temperature is 4.18±0.08 °F greater than the residual Control temperature; The mean residual Bubble temperature is 0.49±0.08 °F greater than the residual Tarp temperature; The mean residual Bubble temperature is 0.45±0.08 °F greater than the residual Clear temperature. All of these differences are statistically significant, with $p<0.0001$. Only the Clear-Tarp comparison yields a difference that is not statistically significant (0.04±0.08, $p=0.95$).

The differences across the sites are large enough to be detected by ANOVA. In addition, the differences are particularly large during the latter part of the record, as temperatures dropped toward the onset of autumn. These differences can also be quantified using ANOVA coupled with a Tukey Honestly Significant Difference test.

Removing seasonal and diurnal variations (Figure 2) allowed us to easily detect divergences based on house type without the interference of seasonal and diurnal variations that dominate the data. Divergences are most apparent in the later months of

September, October and November, with all hoop house temperatures markedly higher than the outside air temperature as expected (see Figure 3). Analysis of data with ANOVA showed that the Bubble house was distinctly warmer than the Tarp and Clear, and that all three were markedly warmer than the Control (Figure 4).

Detrended Temperature Data by Month

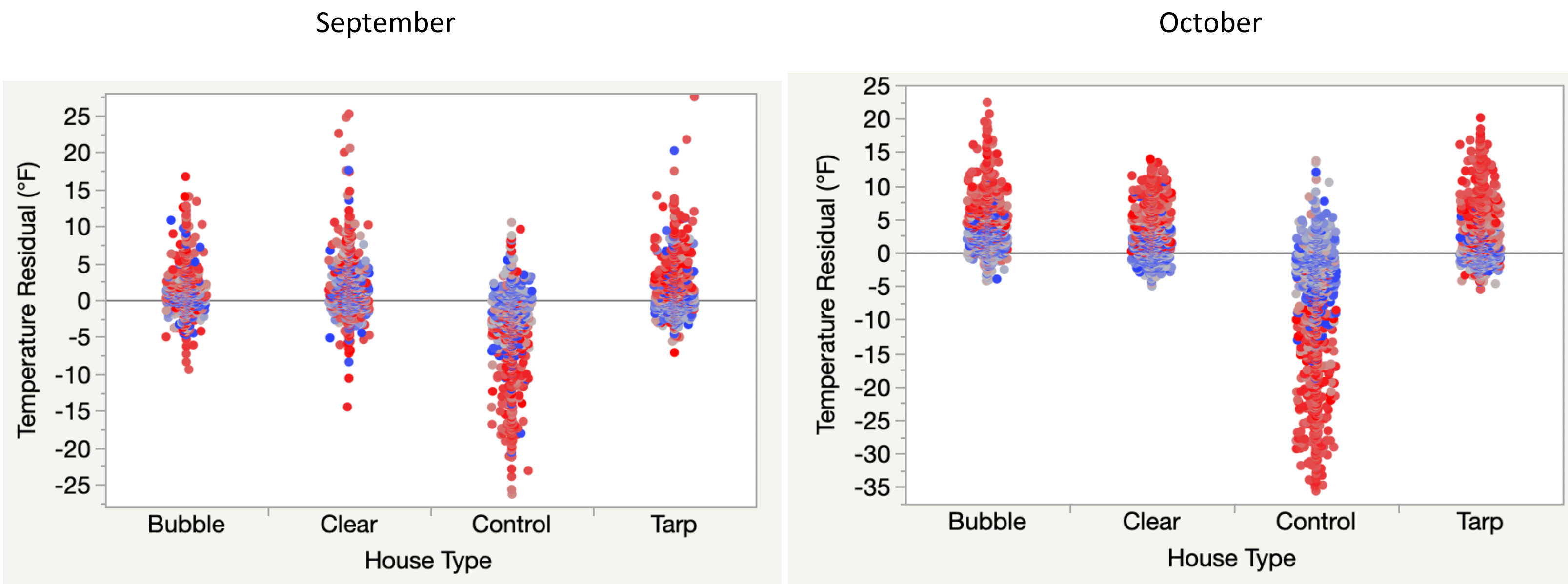


Figure 5. Differences in residual temperature across the different house types separated by month of year during harvest interval. November is not shown because freeze had already set in. Blue points highlight nighttime measurements and red points highlight daytime measurements. These plots show that differences between the Control and all of the house types are more pronounced during the day than during the night in these two months. Other months do not show this day-night dichotomy.

The data show a transition from largely overlapping residuals in June and July to August, September and October, when Control residuals are relatively much lower than the other residuals (Fig. 3) – especially during the day (Fig. 5). This highlights the importance of hoop houses in maintaining viable growing conditions into late summer and early autumn in Laramie, Wyoming. The data also indicate that the Bubble house type keeps temperatures higher than both of the other house types in addition to the Control (outside conditions) (Fig. 4). Finally, in summer 2018, the Bubble house type kept temperatures above freezing for more than two additional weeks, compared to both of the other house types and the Control.

Relative Humidity as a function of Time Separated by House Type

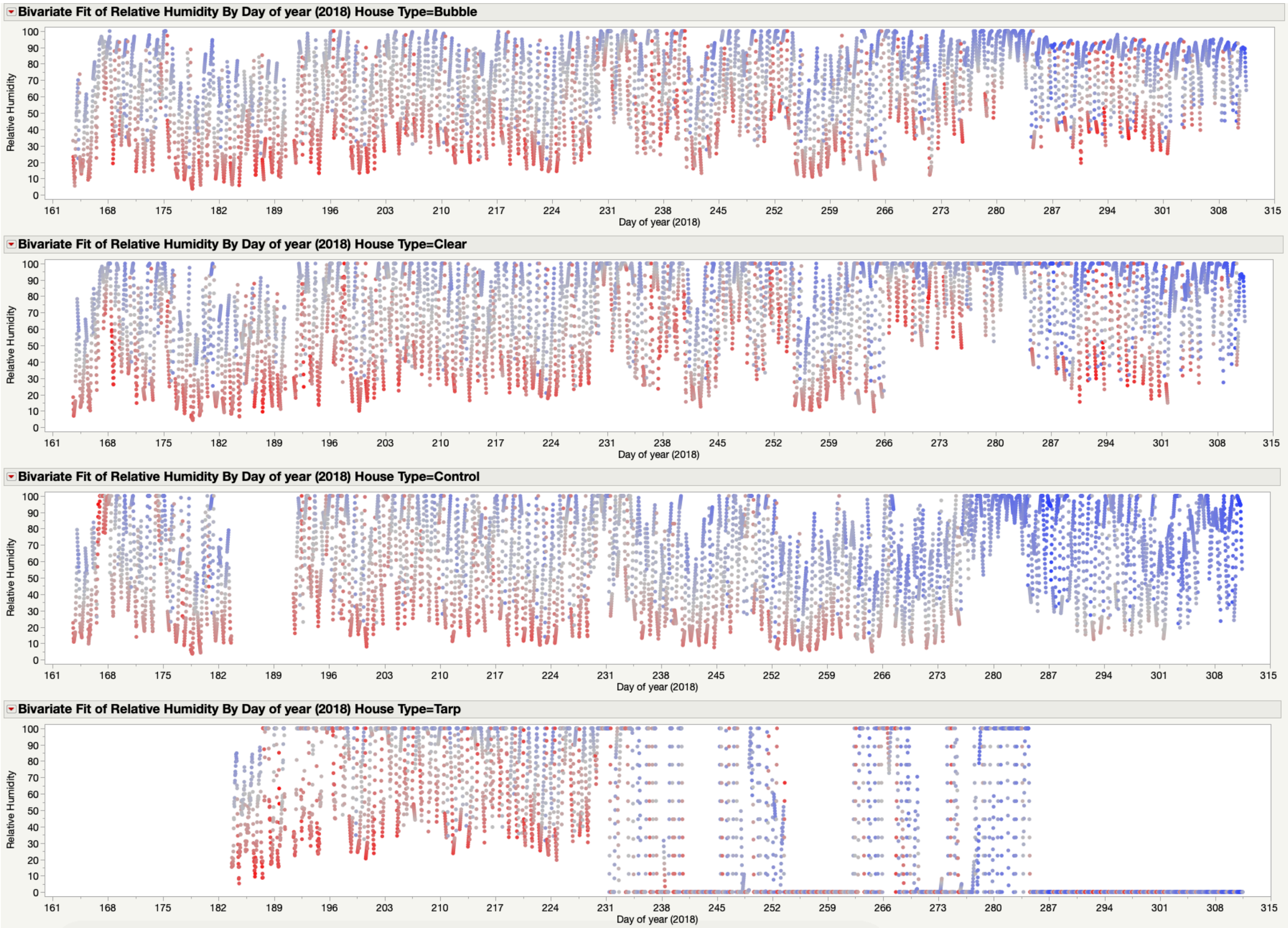


Figure 6. Relative humidity as a function of time for all four air probes. Colors represent temperature: Reds are relatively hot, and blues are relatively cold. Like the temperature data (Fig. 1), the relative humidity shows some data gaps. In particular, Tarp has a long period after day 230 where no reliable data was collected. However, the Bubble, Clear, and Control probes have near complete records from July through November. Relative humidity varies widely from nearly 0 to 100% in all of the probes. Relative humidity is generally higher in autumn when temperatures are also colder. This reflects the fact that cold air holds less moisture; for given moisture content in the atmosphere the relative humidity will be higher for colder air masses than for warm air masses. This same phenomenon explains why relative humidity is higher during the night when temperatures are generally lower. In addition, the hottest house (i.e., Bubble) has generally a relatively lower relative humidity because it is warmer. The extended period of high relative humidity around day 275 to 290 (October 1 through October 16, 2018) reflects the first cold snap that led to widespread freezing conditions (Figure 1).

Soil Temperature as a function of Time by House Type

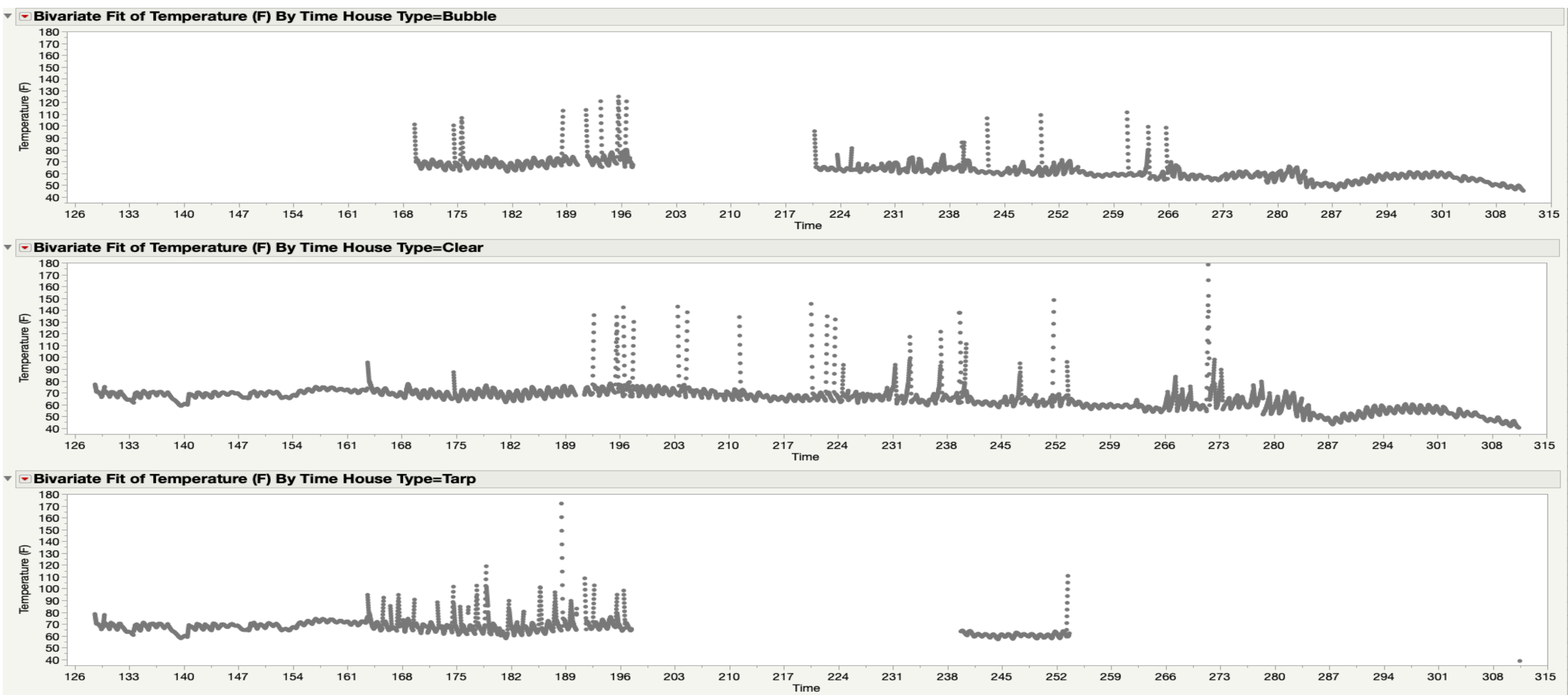


Figure 7. Soil temperature as a function of time for the three soil probes. Data from the Clear house are nearly continuous from May through November, in contrast, the Bubble house has a substantial gap in June and July, and very little data is available after end of July for the Tarp house. No Control data are available. The soil data has many more obvious outlier temperatures than the air temperatures. It is estimated that roughly 500 of the temperature measurements from the soil would need to be excluded from the analysis because they are unrealistically high. In contrast, only 18 of the air temperature measurements were excluded because they were unrealistic. The large number of outliers in the soil data and the large gaps, particularly for the Tarp house, suggest that cross-house comparisons would be fraught with uncertainty. It is therefore advisable to refrain from drawing conclusions from this data set.

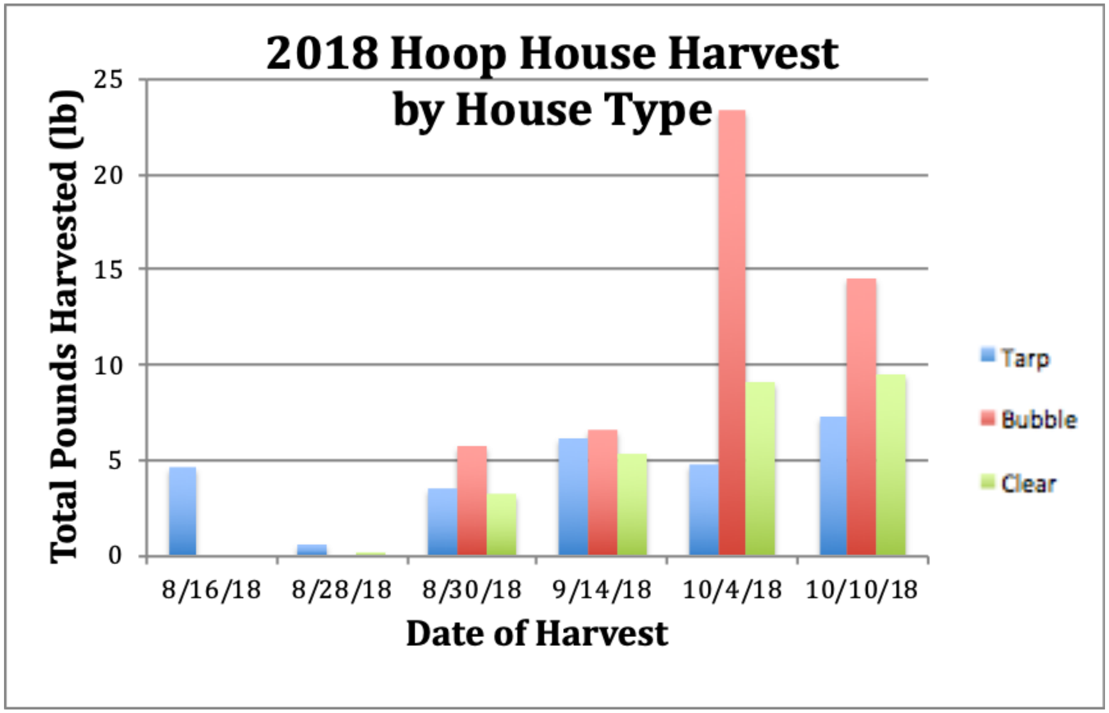


Figure 8. Total pounds of produce harvested in all three hoop houses. Identical varieties of each crop were planted in each of the hoop houses, in identical locations within the hoop house. Production from each hoop house was weighed and recorded according

to specific specialty crop. The total amount of produce for all hoop houses was 104.46lb. The Tarp house yielded 26.71lb (25.57% of total yield); the Bubble house yielded 50.43lb (48.28% of total yield); the Clear house yielded 27.32lb (26.15% of total yield). Note that while the Bubble house yielded a greater percentage of the overall harvest, additional data is needed in subsequent growing years before a degree of confidence can be given to the causation of greater yield in the Bubble house.

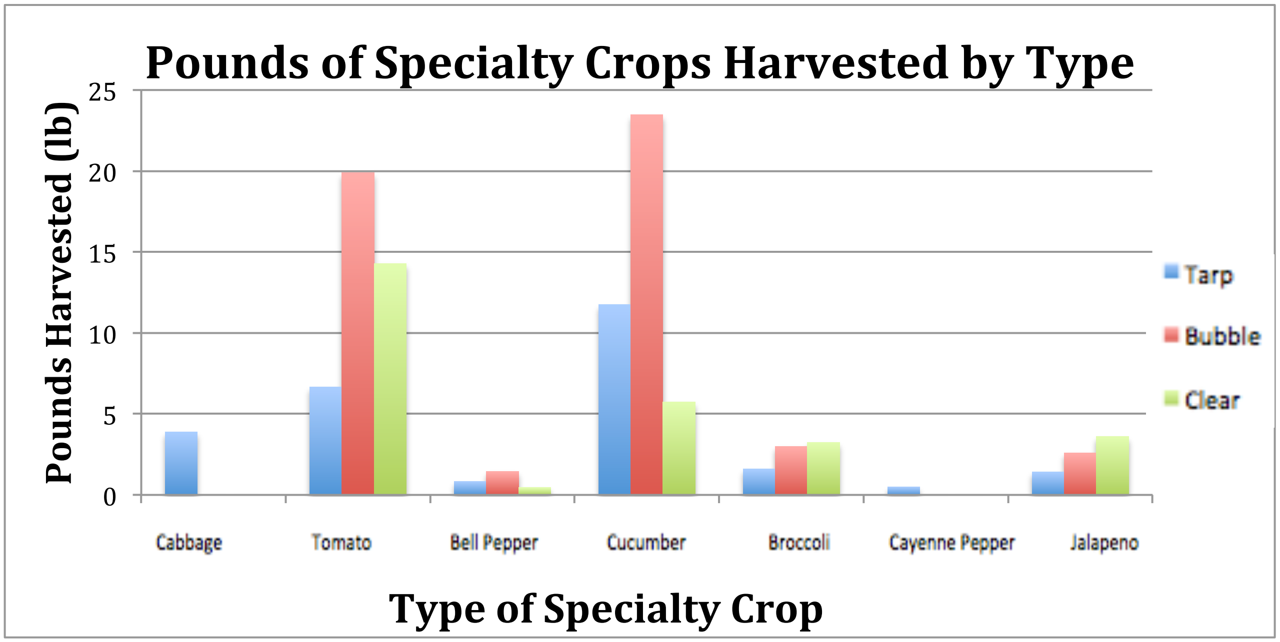


Figure 9. Amount of each specialty crop harvested in each hoop house per pound. The data show that tomatoes and cucumbers produced the highest amount per pound than the rest of the specialty crops (cabbage, bell pepper, broccoli, cayenne pepper, and jalapeños) combined. This observation is expected since tomatoes and cucumbers are of significantly larger weight than cayenne peppers, jalapeños, etc. The cabbage yield was successful in the Tarp, but unsuccessful in the Bubble and Clear houses. Cayenne Peppers were most successful in the Tarp, less so in the Bubble, and no harvest from the Clear. Jalapeños were most successful in the Clear, then the Bubble, and finally the Tarp. Okra was unsuccessful in all of the hoop houses, and not included in this histogram. Note that the broccoli had a narrow window of harvesting in the hoop houses. The flowering rate of broccoli in all three hoop

houses was very rapid (about 2-3 days), leading to much of the broccoli becoming inedible before it was able to be harvested. It is suggested that broccoli may not be an appropriate specialty crop to grow in hoop houses.

The variance in amount harvested, seen in Figure 9, is difficult to compare. However, when paired with amount harvested per house type (Figure 8), the Bubble appears to have had a higher success rate for crop production. Data was analyzed with the aid of Dr. Cliff Riebe, a University of Wyoming geology professor to ensure accuracy. Additional research is needed to establish which hoop house yields higher harvests over time.

Four educational signs were posted in the Feeding Laramie Valley farm at the Albany County Fairgrounds, one at the entrance of the farm, and the other three in front of each hoop house. Tours were prepared for the Albany County Fairgrounds Family Night and the Higher Ground Fair weekend.

Over the course of the season 205 people had educational exposure to the project. Educational exposure is defined here as having an in-depth tour and/or presentation of the research project. Those who had educational exposure include: 1 member of the Wind River Development Fund, 1 County Commissioner, 5 University of Wyoming professors, 87 University of Wyoming students, 14 Higher Ground Fair attendees, 12 members of the American Baptist Women's Group, 45 FLV volunteers, 1 Action Resources International (ARI) board member, 4 permanent FLV staff, 5 AmeriCorps VISTA members, 4 FLV interns, 4 AmeriCorps VISTA Summer Associates, 2 Food Production Supervisors, 18 AmeriCorps NCCC members, and 2 AmeriCorps NCCC Field Advisors.

Surveys, in the form of oral exit interviews, were conducted with the intent to determine degree of increased knowledge of hoop houses and different skin covers. Of those who received educational exposure, approximately 18.05% completed a survey. Interviews revealed an increased interest and understanding of knowledge as opposed to a specific quantifiable pre- or post-measurement. Dissemination of information on this project was limited to the findings to date, using the ongoing information to engage and inspire the community's future growing efforts. As a result, disseminating the information will also be ongoing as the findings increase. Additional time and research will be needed to establish a structure to more reliably measure knowledge base.

GOALS AND OUTCOMES ACHIEVED

Goal 1: Determine the effects of greenhouse covers on season extension.

Benchmark: The rule of thumb in Wyoming is that a covered hoop house in 11mm clear plastic will extend the growing season one month on either side of frost-free days.

Target: By comparing the 3 covers, we hoped to see if an additional 20 growing days are possible before frost damage occurs.

Outcome:

- Soil was amended in 2018 for all hoop houses with a 4-6" layer of aged llama manure prior to planting. The location of both the Tarp and the Bubble overlapped with soil from previous garden plots. This meant that the soil in both houses had been previously amended prior to 2018. The soil in the Clear house had not been amended prior to 2018.
- Crops were planted on June 13, 2018. All crops were transplanted to the hoop houses with the exception of okra and cucumber (half transplanted, half planted by seed). There were no replants. The crops were watered daily and weeded as needed (typically semi-weekly). Harvesting was done as needed.
- While air temperatures varied wildly in a given day, we were able to detect tiny differences between each hoop house because of an abundance of air temperature data by fitting an extremely flexible spline to the air temperature data.
- Analyzing temperature as a function of time by each house type (see Figure 1) it became clear that the Bubble house was generally better at retaining heat. As seen in Figure 1 the Bubble house kept air temperatures above freezing until October 5, 2018, approximately 15 days longer than the ambient temperature (Control) or Clear house, and roughly 14 days longer than the Tarp house.
- While the Bubble did not reach our target of 20 added growing days, it was able to protect the crops for approximately 2 extra weeks.
- Further analysis using ANOVA (see Figure 4 and 5) confirmed that hoop houses have a markedly significant effect on air temperature, particularly during September and October, and was especially prominent during the day. The Bubble house contained the most marked difference, compared to the ambient temperature, the Bubble house was able to maintain approximately 5°F higher temperatures in the hoop house than the ambient air (Control).
- The Tarp and Clear hoop houses were not statistically different from each other with regards to maintaining air temperature.
- After analyzing the relative humidity in the air, the Bubble house, as expected, was able to hold more moisture than the Tarp and the Clear, and significantly more than the Control.

- The total crop yield from the hoop houses in 2018 was 104.46lb. The Bubble house generated the highest amount of harvested produce (50.43lb or 48.28% of total yield), despite a severe bug infestation mid-July. The Clear house generated 27.32lb (26.15%) of produce and the Tarp generated 26.71lb (25.57%).
- Tomatoes and cucumbers yielded the most harvest (in pounds) across all three hoop houses.
- Soil temperatures and relative humidity measurements were insufficient and unreliable.
- Additional data will be needed to confirm this year's findings.

Goal 2: Increase knowledge of specialty crop growers on season extension.
Benchmark: Growers indicate that cost of cover is the determining factor in skin cover purchases.
Target: We hope to increase the knowledge of 100 growers as to the relative season extension value of the three different covers.
Outcome:

- The hoop houses were on display with detailed, educational signage during the Albany County Fairgrounds Family Night and the Higher Ground Fair. Approximately 2,000 people attended Family Night and 2,500 people attended the Higher Ground Fair. Feeding Laramie Valley staff and volunteers were on-hand for more in-depth tours and education, in which about a dozen people participated.
- Approximately 205 people directly received educational exposure to the hoop houses including volunteers, students, professors, community groups, FLV staff (temporary and permanent), and other miscellaneous members of the community and around Wyoming.
- 100% of people exposed to the project provided feedback of having increased their knowledge of how different hoop house skin covers have a different effect on growing specialty crops.
- Oral surveys were conducted with the intent to determine degree of increased knowledge of hoop houses and different skin covers during exit interviews for approximately 18% of people who received educational exposure.
- There was no tool in place to measure baseline knowledge, however, those interviewed expressed interest in learning more about season extension and growing specialty crops in Laramie, Wyoming. Many also expressed having a more clear sense of which covering they would use for personal gardening. Many cited cost as the determining factor, particularly citing costs of replacing the hoop house skins.

- A blog post and an informational brochure with the aforementioned results will be extended for broad pubic distribution. The blog post is scheduled to be posted on the FLV website December 24, 2018.
- Additionally, the results and continual performance measures will be posted on the Feeding Laramie Valley and Higher Ground Fair website beginning January 2, 2019, as well as on the associated social media pages (Facebook, Instagram, and Twitter).
- Dr. Cliff Riebe will utilize the analysis and results of this research as real-life examples for future students in geology and environmental analysis labs (typically 30-40 students per class per semester).
- Finally, inquiries are being developed for potential publication of this research in food systems related journals.

BENEFICIARIES

Beneficiaries include Laramie residents who were in the Feeding Laramie Valley Summer Shares Program, where individuals and families receive a weekly bag of fresh produce at no cost. The majority of specialty crops harvested went directly into the weekly Summer Shares bags. As of October 13, 2018 there were over 200 community members each week in the Shares Program. Specialty crops that were not distributed for the Summer Shares participants were donated to Laramie Interfaith Good Samaritan, and used the Feeding Laramie Valley Summer Food Program, Kids Out to Lunch. Using the Laramie Farmers Market average pricing of $3.22 per pound produce (based on a study conducted by Feeding Laramie Valley in 2015), the hoop houses produced approximately $336.36 worth of food.

LESSONS LEARNED

There were several unexpected outcomes from this preliminary research, mainly the performance of the fiber reinforced skin, or Tarp house. The Tarp house, which had been built in 2017, had had soil amendments twice prior to this research. The resistance to tearing made the Tarp an ideal match for the high Laramie winds, and came highly recommended. The additional years of soil amendment was expected to give the Tarp house an advantage. The clear skinned unit or Clear house, performed as anticipated, and is predicted to have to be repaired in less than a year. While the 2018 data reflects that the bubble encapsulated skin, or Bubble house, was more effective at retaining higher temperatures and had a higher yield than the other houses, at this time we cannot make a definitive decision as to what type of hoop house would contribute to the longest, most favorable growing environment as well as being cost effective without follow-up research in subsequent years.

There were several challenges throughout the course of this research including pest infestations, temperamental crops, and irregular and suspect sensor records. Mid-July saw an outbreak of gnats in the Bubble house that spread rapidly and was not resolved for several weeks. As a result, this may have reduced the amount of harvest that was available throughout the rest of the season. Since pests can spread easily in a confined space such as a hoop house and can become a large problem, we must remain vigilant about pest control. As aforementioned, broccoli was not ideal for growing in the hoop houses. The rapid flowering rate of the broccoli (about 2-3 days) made it difficult to harvest in time before flowering. The biggest challenge we faced, however, was the sensors themselves. As seen in the charts above, there were several gaps in the data where sensors had stopped working for several weeks causing the analysis to be less robust than would be preferred, particularly for any analysis on soil temperatures. The high degree of outliers, as seen in extreme hot temperatures (120°F and up) in the air and particularly the soil temperature measurements leads to uncertainty in the degree of accuracy of the sensors. Additionally, there was a high degree of uncertainty in the reliability of relative humidity measurements, particularly seen in the Tarp house. In the future, the sensors should be tested prior to their placement in the hoop houses. For a more robust analysis of the soil temperature, there should be an additional sensor that records soil temperature outside of the hoop houses. Finally, to increase certainty in the harvest yield, an additional plot of identical size should be planted without a covering to act as a control for production.

Determining a specific hoop house type after one year of research is difficult to establish. Broadly, this research confirmed that having any hoop house, regardless of the type of covering, is more beneficial for growing warm-weather specialty crops. The rapidly changing weather in Laramie means that any cover of a hoop house will help prevent weather-caused damages such as hail, heavy rain, and high winds. However, with regard to cost effectiveness, the fiber reinforced covering, or Tarp, is recommended above the clear skin and the bubble encapsulated covering. This is due to the relatively low cost ($350) compared with the Bubble house type ($700), and the high resistance to tearing. This recommendation also takes into account the cost of less frequent skin replacement, as compared to the Bubble and Clear skins. Subsequent research will need to be recorded and analyzed over several years before a conclusion is established.

Assessing the degree of increased knowledge of season extension was also challenging to measure. There was no easy way to establish baseline knowledge of participants prior to or after tours and/or presentations about the research project. For future research, it is recommended to establish an optional written survey for those who are directly exposed to the research. Surveys could be disseminated in person or sent out in an email. We will need additional time and research to better determine the degree of increased knowledge on season extension, particularly with the new findings established in the research project. Ongoing efforts of disseminating the information and results gained from this research through the Feeding Laramie Valley websites, blog and social media posts, publication, and other efforts, will significantly increase the number of people aware of season extension options in the Laramie Valley. Continued efforts and research will also increase the robustness and confidence of our results.

Figure 10. Photos of hoop house construction at the Albany County Fairgrounds Feeding Laramie Valley Farm. AmeriCorps NCCC and FLV Summer Shares Team pictured aiding in construction. Note the far hoop house (Tarp house) had been previously constructed in 2017.

Figure 11. Photos of sensors used to record temperature and relative humidity. Left-most photo shows the sensor recording outside temperatures (Control). Note the probes in the soil are not shown.

Figure 12. Left – Two AmeriCorps VISTA members admire the newly transplanted crops inside the Clear hoop house. Right – Full view of all three completed hoop houses at the Feeding Laramie Valley Farm.

Figure 13. Left – Close up of 2 of the 4 educational signs at the FLV Farm. Right – Founder Gayle M. Woodsum gives a tour to a new team of AmeriCorps NCCC members July 13, 2018.

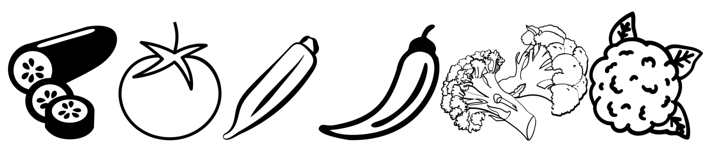
Figure 14. Left - Tomatoes from the Bubble house. Right – Clear house specialty crops. Note the broccoli has already flowered.

Information on educational signs:

Sign #1

Hoop Houses

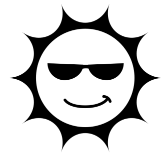
The Wyoming Department of Agriculture Specialty Grant is funding our Hoop House Project! We are measuring 3 different types of plastic to see which is best for growing in this region. The materials used for the hoop houses are lumber, PVC pipe and rebar. We are recording the air temperature, soil temperature, relative humidity, and production in each hoop house. We have planted cabbage, cucumbers, tomatoes, okra, bell peppers, broccoli, jalapeño peppers, and cayenne peppers in identical locations in each hoop house.



Sign #2

1st Hoop House

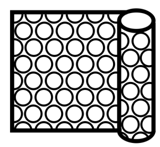
This hoop house has an 8-mil plastic cover with UV protection. This plastic is the cheapest of the three. ***Fun fact: Plastic covers need UV protection; otherwise the sunlight will break through the hoop house and affect the growing process.***



Sign #3

2nd Hoop House

This hoop house has a plastic cover that is similar to bubble wrap. The plastic has a layer of air for insulation. It has a higher UV protection than the other hoop houses, so the plastic lets in less UV light. Out of the three plastics, this one is the most expensive.



Sign #4

3rd Hoop House

This hoop house, built in 2017, has a woven poly plastic cover, which is similar to a tarp. It is much stronger than the other two plastic coverings. This type of plastic is most commonly used in hoop houses partly because the price is more affordable.