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Reducing Greenhouse Energy Consumption By Bench-Top Root Zone Heating And Renewable Energy: Springhouse Farm Case Study (Vilas, North Carolina - POSTER)

By: **Hei-Young Kim, Dr. Ok-Youn Yu,** and **Dr. Jeremy Ferrell**

Abstract

Mountain farmers in Southern Appalachia often face challenges associated with terrain and climate such as a short growing season and size of farm, thus balancing economic feasibility. However, demand for locally grown produce exceeds current spending by 260%. This unmet demand indicates that the potential exists for increasing mountain farmers in the region. Growing season extension with greenhouse technology is a key strategy to increase the availability of local food and farmers' profits.

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Reducing Greenhouse Energy Consumption by bench-top root zone heating and renewable energy: Springhouse Farm Case Study (Vilas, North Carolina)

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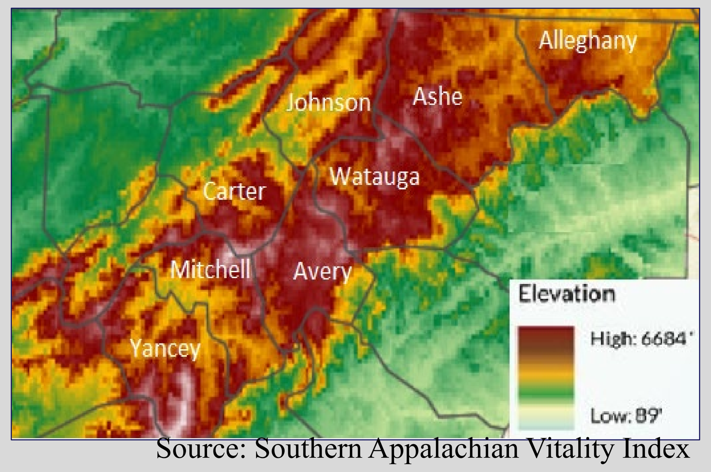
Problems and Background

Mountain farmers in Southern Appalachia often face challenges associated with terrain and climate such as a short growing season and size of farm, thus balancing economic feasibility. However, demand for locally grown produce exceeds current spending by 260%*. This unmet demand indicates that the potential exists for increasing mountain farmers in the region. Growing season extension with greenhouse technology is a key strategy to increase the availability of local food and farmers' profits. STBE department and Energy Center have collaborated to address regional challenges that mountain farmers in Southern Appalachia confront and to investigate technological solutions, focusing on the role of sustainable energy and synergetic productivity gains: **Nexus Project.**



Source: Southern Appalachian Vitality Index

	*Source: 2017 Census of US Agriculture	Number of operation	Median size per operation (Acres)	Net income per operation ($)
NC	Alleghany	448	70	19,730
	Ashe	864	62	9,648
	Avery	351	48	2,420
	Mitchell	250	34	-3,862
	Watauga	520	95	7,153
	Yancey	369	48	4,049
TN	Carter	469	35	372
	Johnson	517	45	-1,257

Source: 2017 Census of US Agriculture

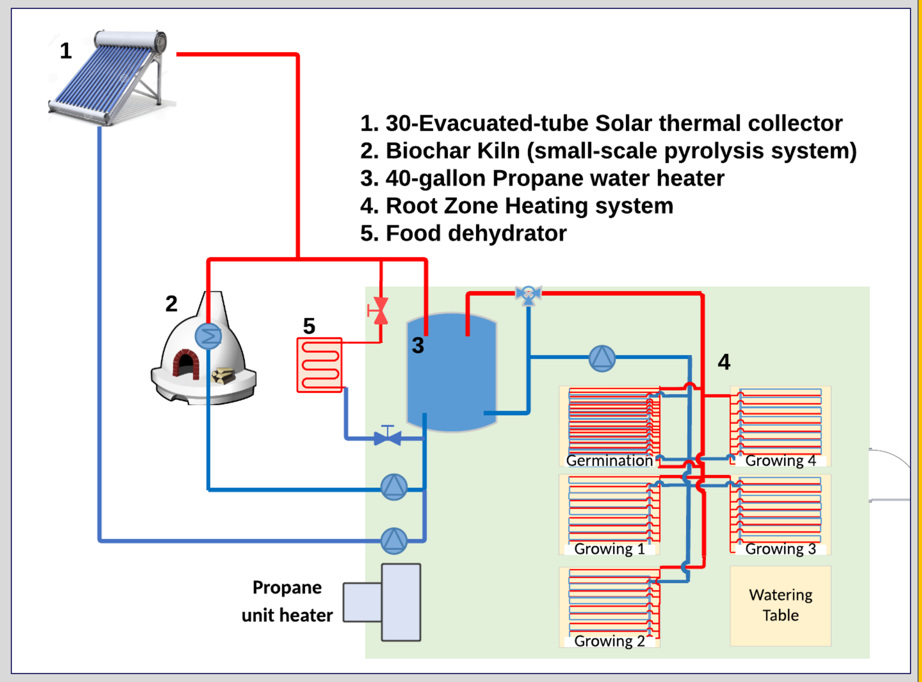
Springhouse Farm in Vilas, North Carolina has a 20-ft by 30-ft high tunnel greenhouse. Using an average of 194 gallons of propane each year, it was heated by a propane forced- air unit heater to start propagation as early as beginning of February. Funded by NCDA&CS, USDA-SARE, and Innovation Scholar's grant, we build a **pilot system** at Springhouse Farm to reduce fossil fuel use and carbon sequestration in late 2017.

* Source: Local Food Research Center, Food and Farm Assessment for a five-county region in the Southern Appalachians (2012)

Nexus Pilot System at Springhouse Farm

The heat (thermal energy) collected from (1) solar thermal collector and (2) biochar kiln is stored in (3) water tank installed inside the greenhouse during day time. The stored heat is distributed to the soil through (4) root zone heating system on cold nights when heating is needed.

In the pilot system, heat transfer fluid (50/50 propylene glycol/water-based solution) flows to transfer heat and deliver it to the plant root zone inside the greenhouse. During the warm season when heating is not needed in the greenhouse, the collected heat bypasses the heat storage and is dumped into (5) food dehydrator, which can use the heat to dry food.



Research Questions

1. How much propane can be saved while maintaining productive condition with Nexus pilot system?
2. How effective are bench covers and insulation with improved R-value?
3. How much thermal energy is gained from the system ?

Methodology

1. The greenhouse was heated with different conditions (see the table below) during the first-year (2018) and the second-year (2019) of the pilot system operation and compared the propane usages to those of previous years. The number of days below freezing and heating degree days (HDD) were considered as weather indicators of each year. The HDD of a day was obtained by subtracting the average temperature of the day from the base temperature (55degF) for each day of greenhouse usage, typically February through May. The sum of these HDDs provide an estimate of the seasonal heating need. In order to normalize the data across winters with varying intensity, the propane consumption/season was divided by the HDD/season.

Heating Source		2016	2017	2018	2019
Propane unit heater (forced-air)	On	V	V	V	
	Temperature setting (°F)	55	55	48	
Nexus pilot system	Solar collector			V	V
	Biochar kiln				V
	Propane water heater base temperature (°F)			86	86
Bench Insulation	Covers			old plastic	upgraded
	Bottom insulation			V	V

2. All the heat collected from solar collector and biochar kiln is stored in the 40 gallon water heater. Therefore, temperature increase of the water heater during daytime (or biochar kiln operation) indicates daily thermal energy collection. Temperature of the water heater was logged to compute the daily temperature increase. Overall thermal energy gain from the system's collection components (the solar thermal collector and the biochar kiln) were calculated in BTUs using temperature increase of the water and properties of 50% propylene glycol-water solution.

3. We installed different types (different R-values) of insulation under the RZH tubing on the growing benches and compared soil temperature of each bench.

The tubing on growing bench 1 is placed over both blue board and reflective bubble insulation, while bench 3 and bench 4 contain only reflective bubble insulation and blue board, respectively. Bench 2 has no insulation.

4. The bench covers were upgraded with higher R-value materials before the second-year operation and compared heat loss reduction indicators such as soil temperature and water heater ignition intervals.

The water heater run interval is the number of minutes that it took from one peak temperature to the next in the water heater between midnight and 8 a.m.

The covers used in 2018 were made of old greenhouse plastic (6 mil polyethylene film: 0.83 ft2·degF·h/BTU). New germination bench cover was made of 8mm double wall polycarbonate panel (1.6 ft2·degF·h/BTU) and new growing bench covers were made of new greenhouse plastic with zippers in it for tight closing.

Result 1: *Weather indicators and Propane usage*

Our system has reduced propane consumption by more than half compared to the previous years while maintaining productive growing conditions. This significant change was possible by reducing or eliminating inefficient forced-air space heating.

		2016	2017	2018	2019
Starting date of GH operation		2/16	1/31	2/15	2/8
Weather indicators	Heating Degree Days (Base: 55 °F) *Starting date ~ end of May*	688.4	856	792.4	875.8
	The number of days below freezing *Starting date ~ end of May*	62	68	63	69
Propane use	gallons	180.4	207.8	118.9	81.5
	gallons/HDD	*0.26*	*0.24*	*0.15*	*0.09*
Heating source	Pilot system			√	√
	Unit heater	√	√	√	

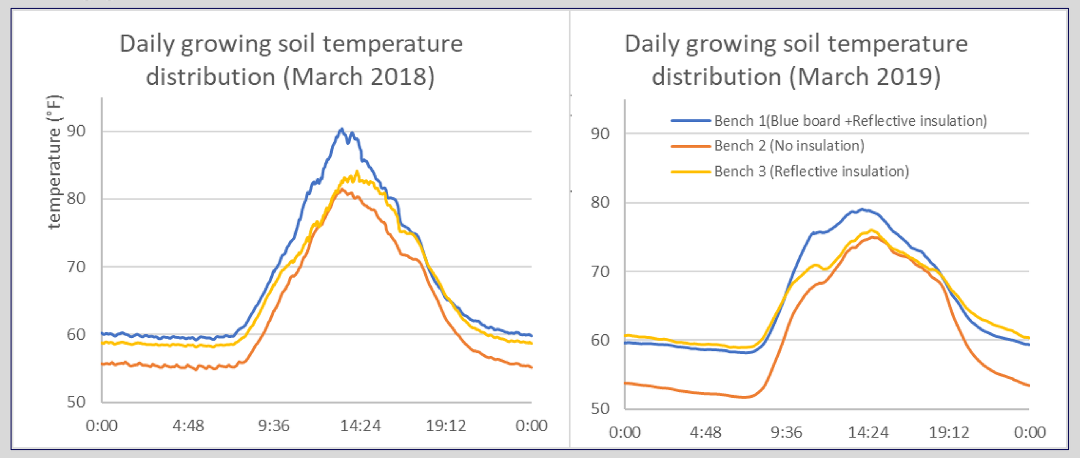
Result 2: *Thermal energy gained from Pilot system*

Of the total thermal energy use to heat the greenhouse in 2018 and 2019, about 10% and 13% was renewable energy, respectively, generated by the pilot system.

	2018	2019
Days of RZH system operation	117	122
Total Dgrees gained from system (°F)	3,837	3,921
Thermal Energy from system (BTUs)	1,131,021	1,154,703
Total thermal energy use (BTUs)	11,950,921	8,571,203

Result 3: *Different insulation*

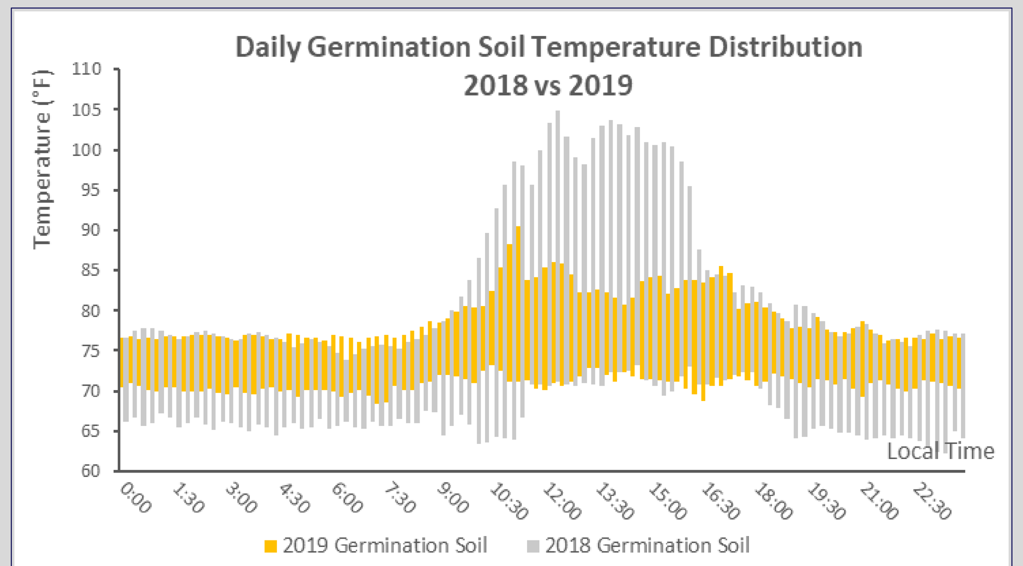
Bench 2 without insulation presented the lowest average soil temperature compared to the benches with insulation. However, Bench 1 and 3 with different insulation did not present much difference in night time soil temperature.



Result 4: *Bench Covers upgrade*

The improved insulation resulted in two outcomes: (1) stable soil temperature at cold nights and (2) longer water heater running intervals (time between each propane combustion in water heater).

Overall germination soil temperature maintained mostly above 70°F with upgraded in 2019 while it frequently dropped below 70°F by heat loss through the cover in 2018. Compared to 2018, the average intervals are longer in 2019 despite lower outside temperature. This means a decrease in propane consumption.



Cold nights	2018				2019			
	3/2	3/3	3/4	3/5	3/17	3/18	3/19	3/20
Low temp (outside, °F)	34.5	25.5	20.1	22.0	19.7	20.4	15.0	18.9
Average WT running Interval (min)	54	47	46	47	54	57	54	55

Conclusion

Propane consumption was reduced 58% in 2019 by eliminating inefficient space heating and improving insulation around benches, which reduced GHG emissions of about 1,186 lbs. CO2-equivalent annually.* The GHG emissions avoided by renewable energy generation is estimated at 306 lbs. CO2-equivalent during the two years of operation*.

The Nexus pilot system has received positive feedback from our partner farmer for energy savings and its user-friendly remote-monitoring system.

Future projects include (1) increasing renewable energy production by separating heat storage and supplemental heating source and (2) conducting an economic analysis of the system.

* source: Emission factors from US-EPA (2018)