Soil steaming in high tunnels

New England Vegetable and Fruit Conference 2022

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12/15/22

The University of Vermont

Leafy greens are economically important

- Estimated $2-$5/ sq. foot gross sales value
- Provide winter labor
- Maintain markets

But chickweed can significantly reduce revenue

Chickweed biology makes it hard to control

Photos: https://aggie-horticulture.tamu.edu/galveston/Weeds/1200_x_800-JPGs/111-Fig_5--Common_Chickweed-GCMGA9999a.jp

Direct seeded spinach in unsteamed soil, November

Same unsteamed area, January

Left unchecked, handweeding is time intensive

Finding a use for it--cows love it

Kids don’t!

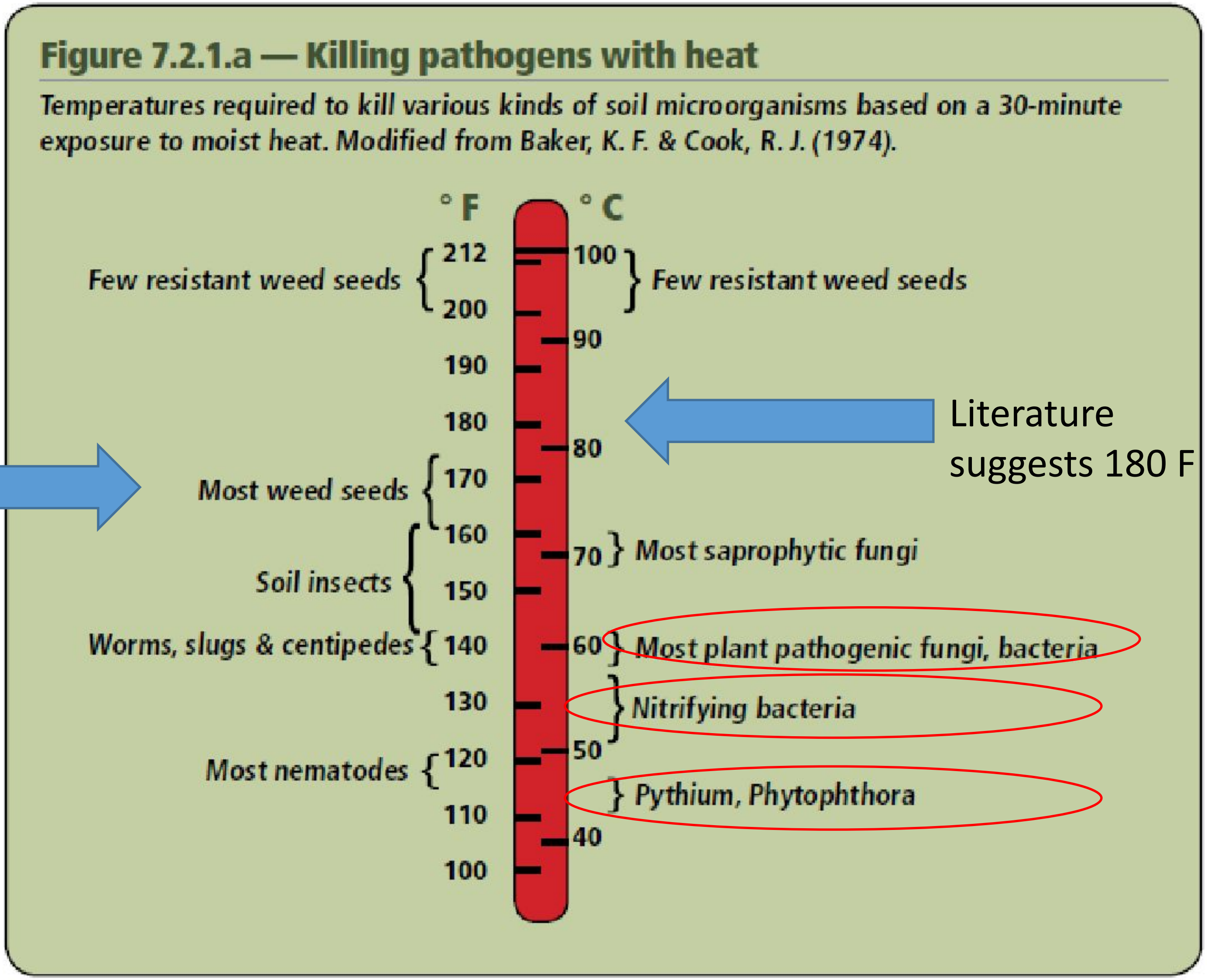
We have other challenges in high tunnels

Damping off in spinach

Soil borne pathogens and pests

Steaming has been used to kill many types of organisms

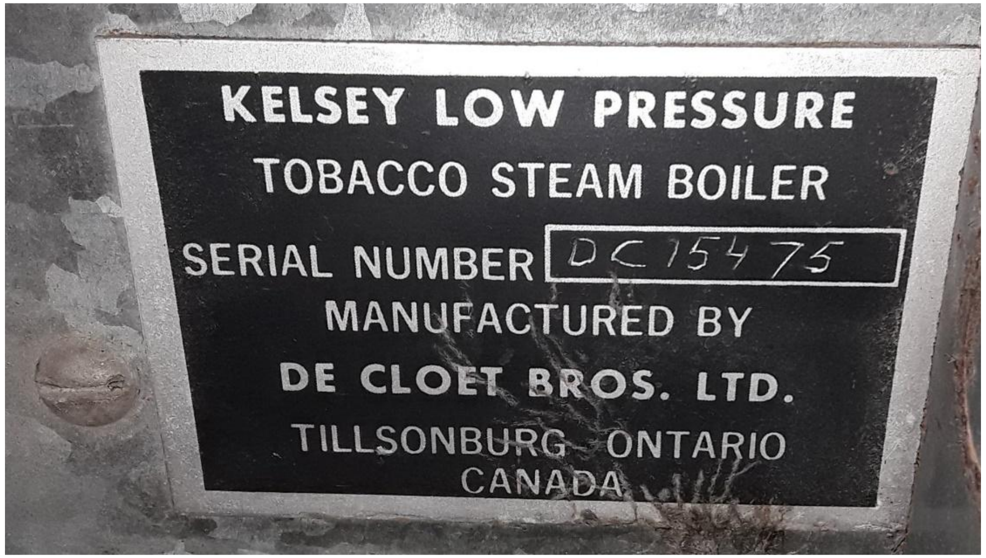
Can we control chickweed at a lower temp?



Literature suggests 180 F

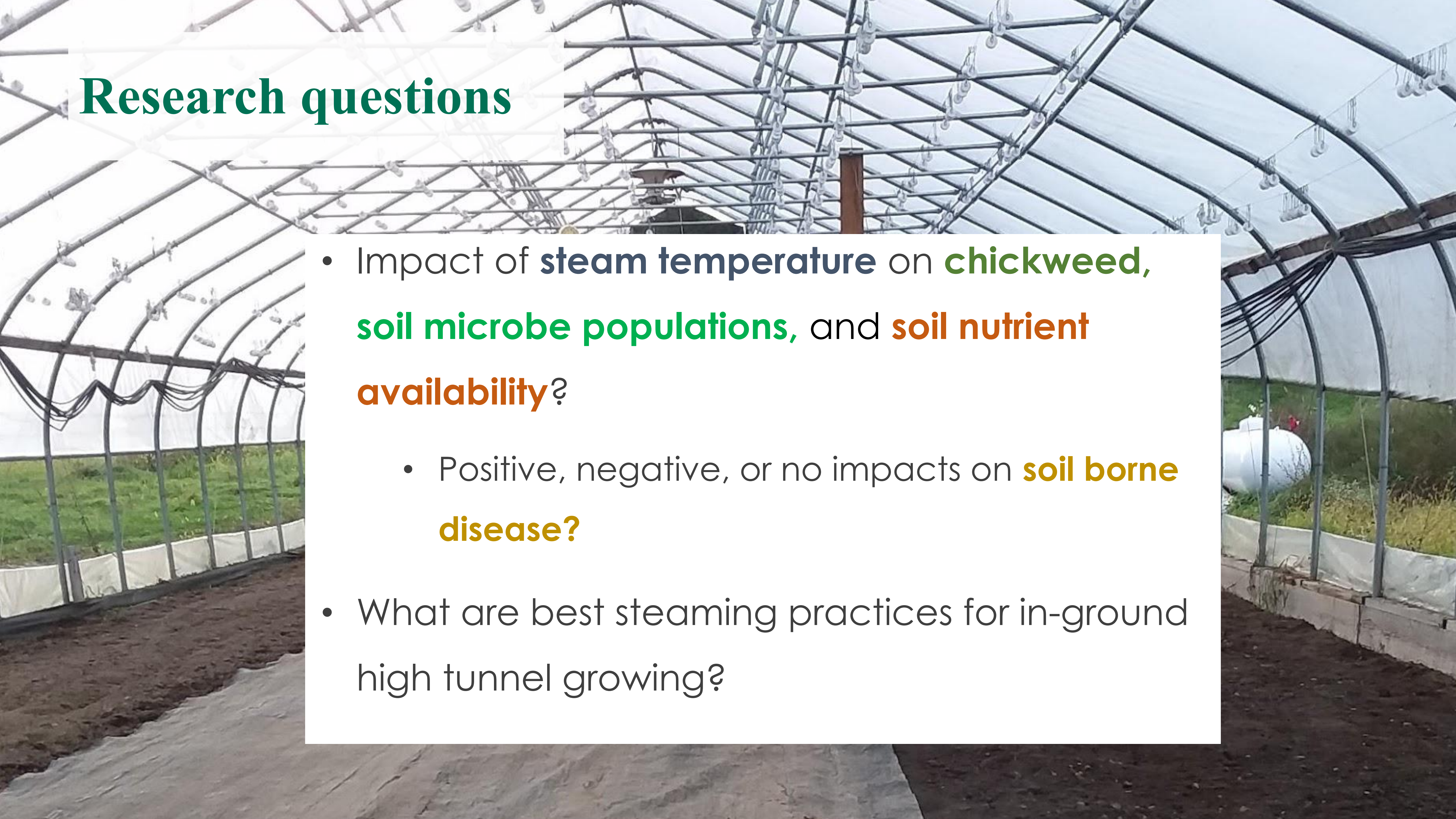
So let’s steam!

Used tobacco steamer



Slide credit: David Paulk, Sassafras Creek Farm

Steam area: 600 sq feet maximum

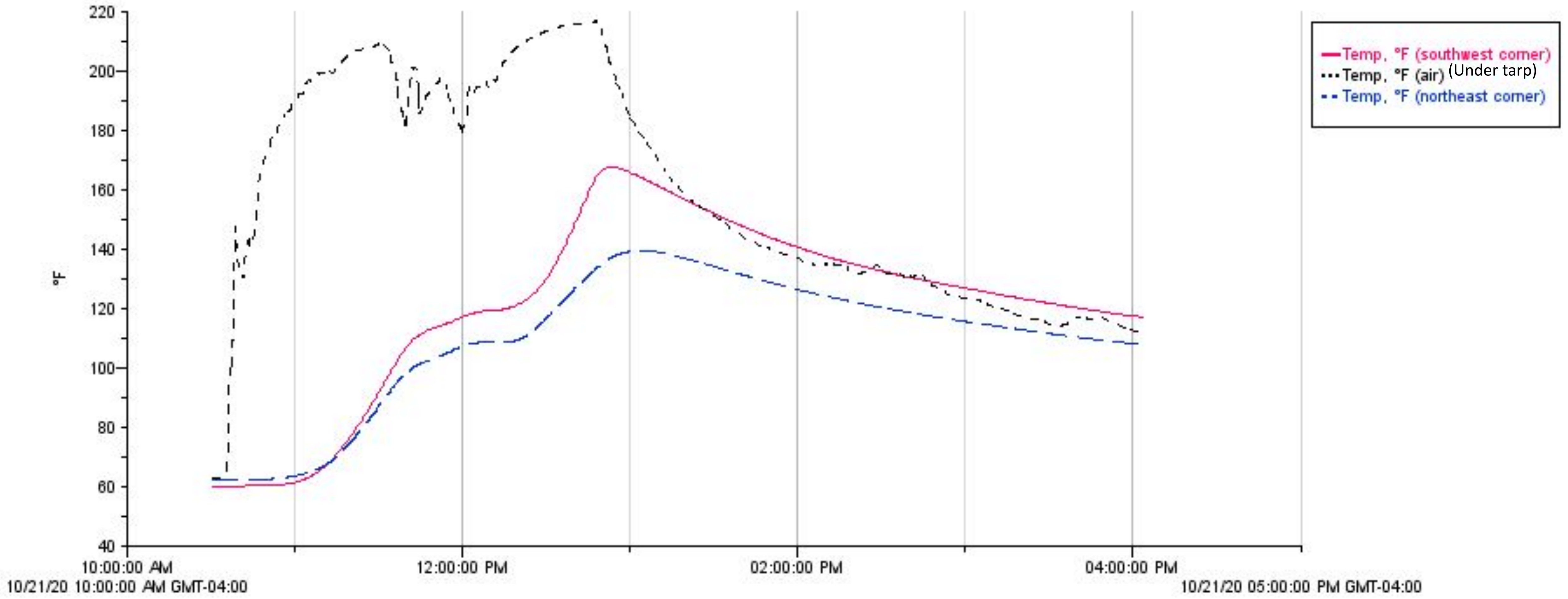


Research questions

- Impact of **steam temperature** on **chickweed, soil microbe populations,** and **soil nutrient availability**?
  - Positive, negative, or no impacts on **soil borne disease?**
- What are best steaming practices for in-ground high tunnel growing?

One challenge is achieving target temperatures with uneven steam distribution

air temperature and soil temperature in two corners of steam area before and after 1.5 hour steam duration



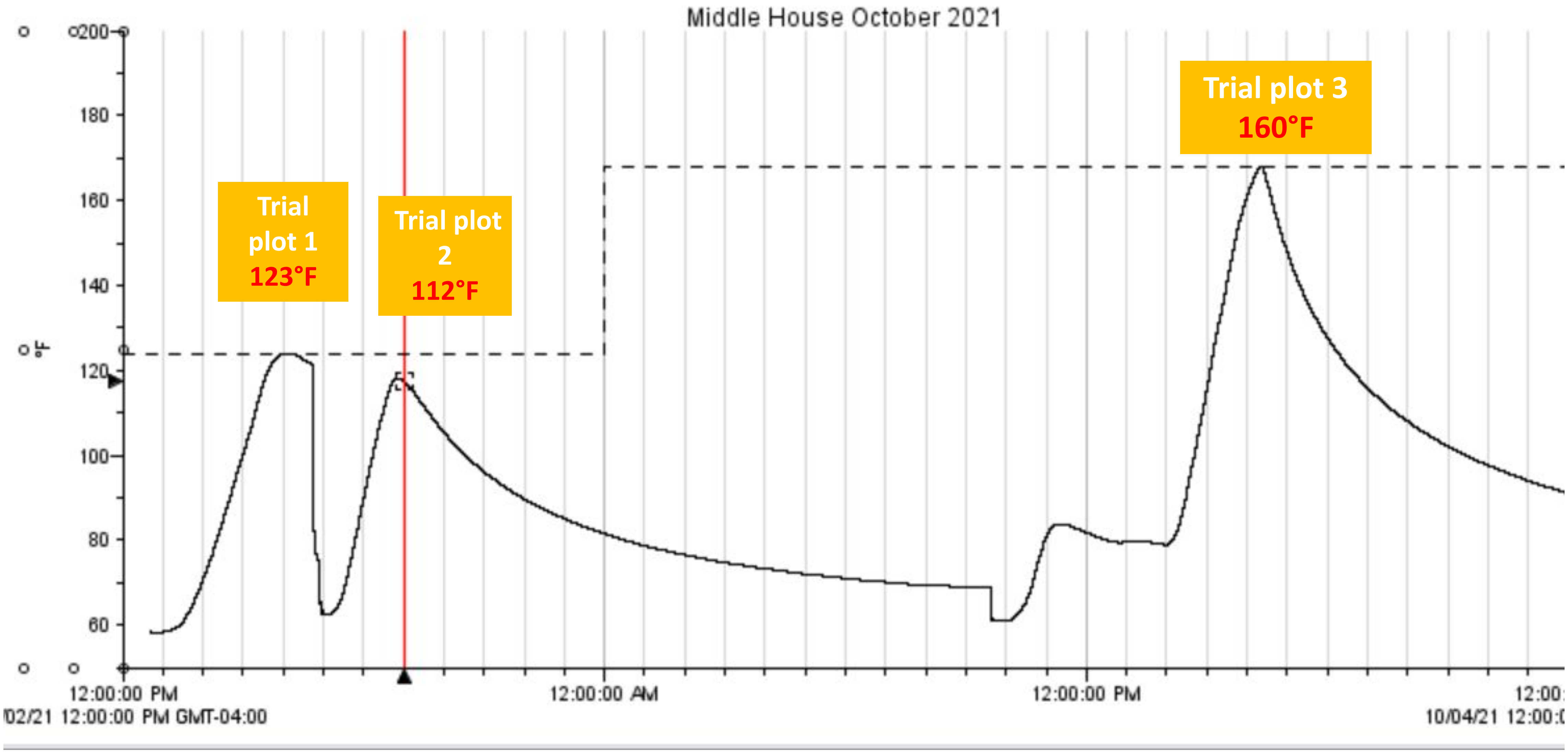
Newer steamer is easier to use

2021 Sioux Model SF-20 Steamer

Higher power machine

Thank you Cheshire County Conservation District (NH) for the rental!

But still challenging to reach target temps with Sioux steamer



Challenges

- Learning curve/ achieving temps.
- Critical time window for establishing greens.
- Scientific study vs. on farm study.
- Fuel use and long term sustainability

On-line tool helps determine steam area, timing, inputs, etc.

Chris Callahan's steam calculator

Soil steaming calculation

C. Callahan & B. Maden, 2020 10 12, UVM Extension

Values in blue are adjustable, values in **black** are calculated

Bed width	180	inches	Assumptions		
Bed length	95	feet	1. Assumes perfect steam distribtution in hood / under plastic		
Heating depth	2	inches	2. Does not account for boiler recovery due to makeup water		
Starting temp	65	°F	3. Does not account for any steam super heat, only assumes ambient pressure steam		
Target temp	140	°F	4. Assumes fuel oil as heating fuel.		
Soil texture / type	Silt Loam		5. Does not account for heat transfer within the soil (yet).		
Soil moisture	Moist				
Dry soil density	1.48	g/cm3			
	92.3	lb/ft3			
Actual soil density	2.21	g/cm3			
	138.5	lb/ft3			
Soil heat capacity	0.4	BTU/lb/F			
Thermal conductivity	0.74	BTU/hr/ft2/F			
I know how long I have, but need to know my nozzle sizing.			**I know my nozzle sizing, but want to know how long it will take.**		
Time to heat	180	minutes	Burner nozzle size	5	GPH
Heated soil mass	32884	lb	Boiler efficiency	75	%
Energy input required	986524	BTU	Fuel heating value	140000	BTU/gal for oil
Energy rate (steam)	328841	BTU/hr			
	329	lb/hr	Burner firing rate	700000	BTU/hr
			Energy rate (steam)	525000	BTU/hr
Boiler efficiency	84	%	Heated soil mass	32884	lb
Fuel heating value	140000	BTU/gal for oil			
			Time to heat	**113**	minutes
Burner firing rate	391478	BTU/hr		1.9	hours
Burner nozzle size	**2.8**	**GPH oil**			

Research results

1. Chickweed control
2. Microbes
3. Nitrate
4. Costs
5. Disease control

Chickweed control at 140° F

STEAMED 140° F—6 weeks after planting

UNSTEAMED—6 weeks after planting

Comparing temperatures -- 6 weeks after steaming

STEAMED 120 ° F

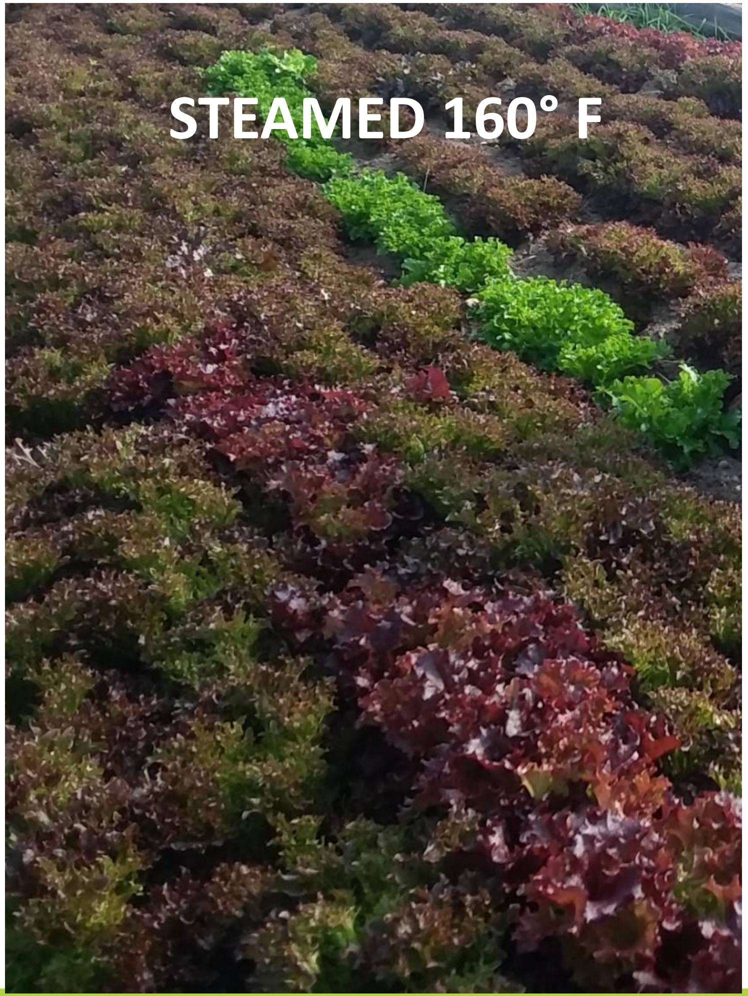
STEAMED 140 ° F

Soil disturbance after steaming increases chickweed emergence

Soil disturbance during transplanting

Tilling after steaming

2021 results: >*140° achieves chickweed control*



One year after steaming—chickweed returns!

November 3, 2021

December 14, 2021

Two years of steaming: chickweed hot spots become long term problems

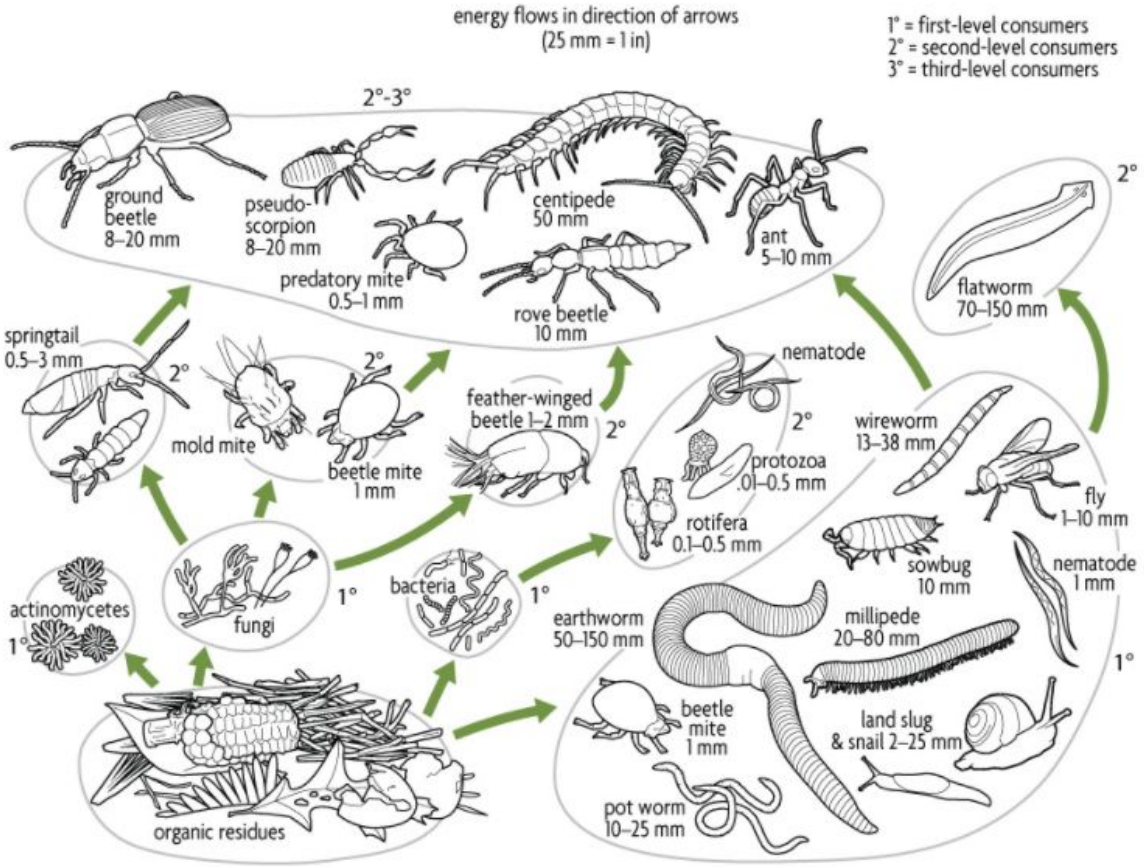
Unsteamed "control" in 2020

Same area after steaming in 2021 and 2022. Chickweed seed bank is high, emerging where soil is disturbed.

Edges and corners hard to steam

Fluffy texture immediately after steam, then algal crust forms

Measuring soil microbes



https://www.sare.org/publications/building-soils-for-better-crops/the-living-soil/

Using Biolog EcoPlates

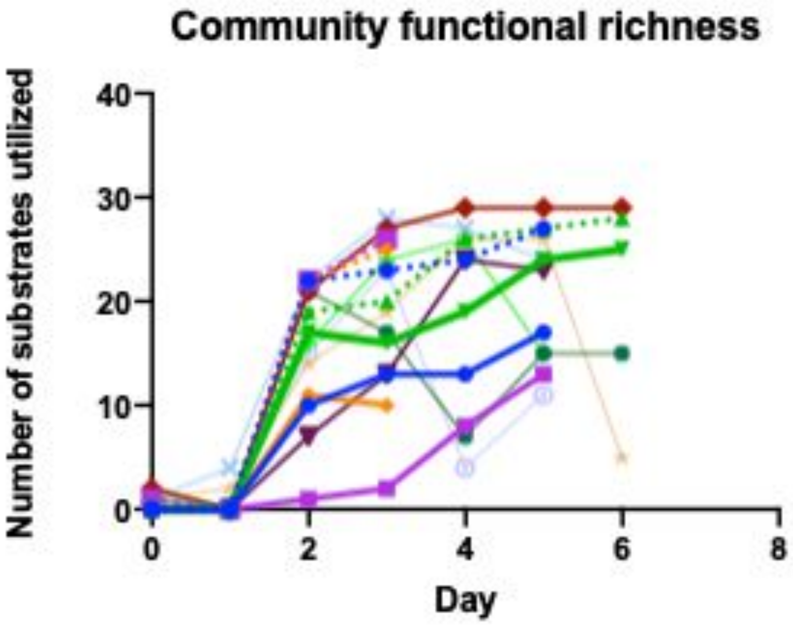
Community Level Physiological Profiling (CLPP)

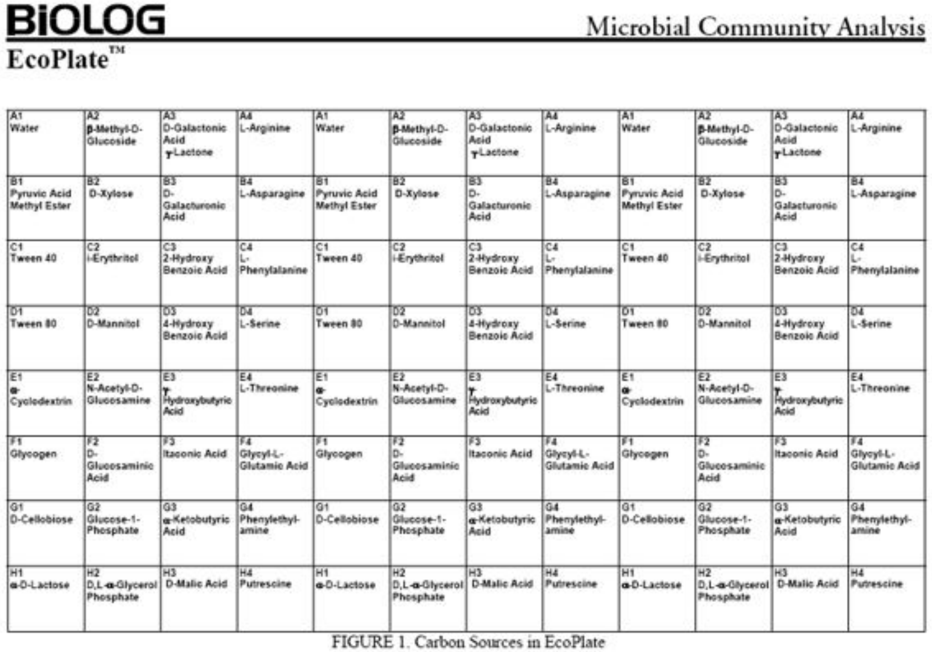
Example of a BIOLOG plate inoculated with a dilution of soil and incubated for 48 hours. The purple wells contain carbon sources that were used by the microbial community. The intensity of the purple coloration indicates the degree of carbon source usage by the community.

Microbe population data

Average metabolic response (AMR) average respiration of the C sources by the microbial community. Communities can be compared.

Community metabolic diversity (CMD) is number of substrates utilized by the community. Functional richness or diversity.



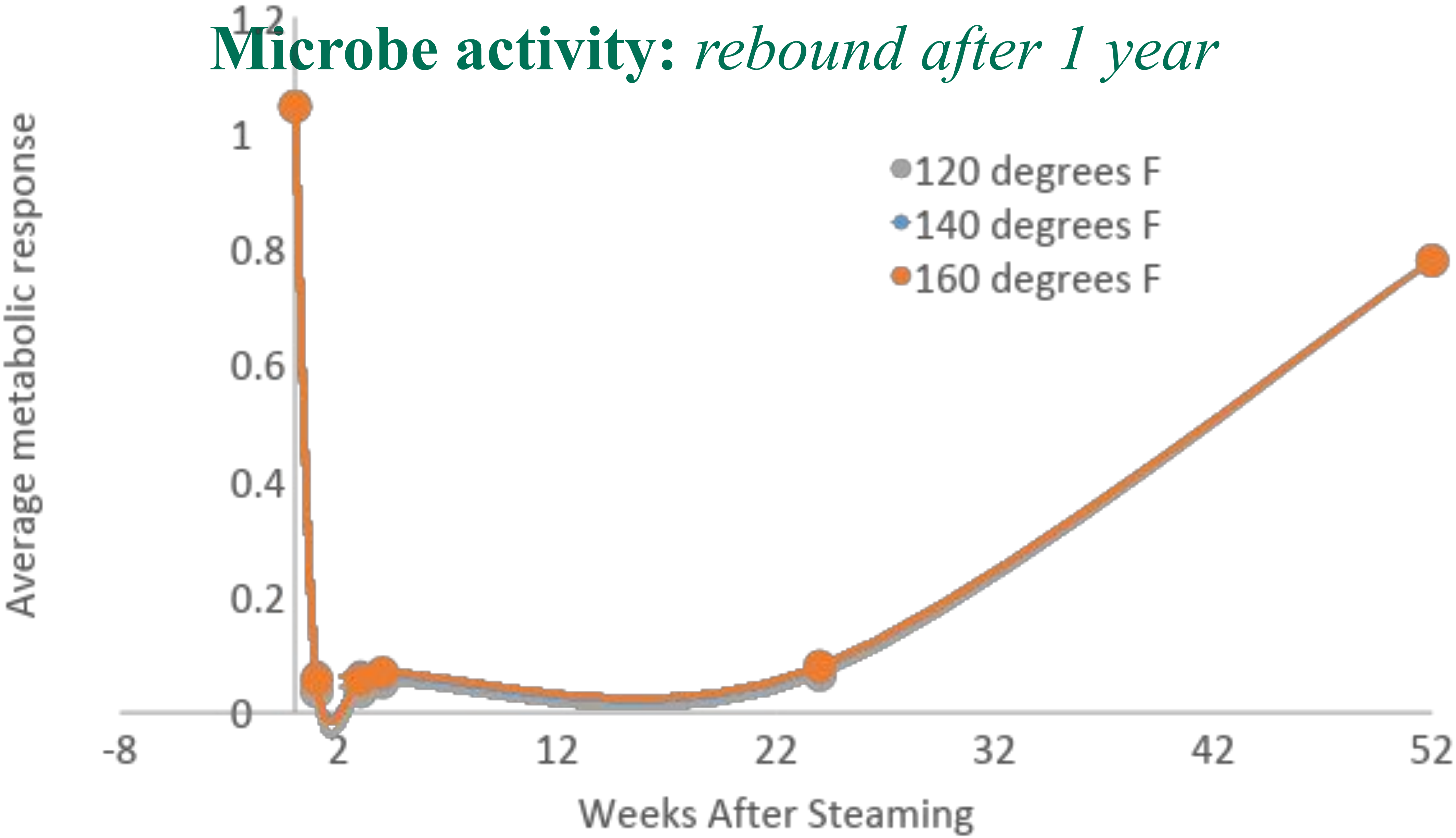


A1 Water	A2 β-Methyl-D-Glucoside	A3 D-Galactonic Acid γ-Lactone	A4 L-Arginine	A1 Water	A2 β-Methyl-D-Glucoside	A3 D-Galactonic Acid γ-Lactone	A4 L-Arginine	A1 Water	A2 β-Methyl-D-Glucoside	A3 D-Galactonic Acid γ-Lactone	A4 L-Arginine
B1 Pyruvic Acid Methyl Ester	B2 D-Xylose	B3 D-Galacturonic Acid	B4 L-Asparagine	B1 Pyruvic Acid Methyl Ester	B2 D-Xylose	B3 D-Galacturonic Acid	B4 L-Asparagine	B1 Pyruvic Acid Methyl Ester	B2 D-Xylose	B3 D-Galacturonic Acid	B4 L-Asparagine
C1 Tween 40	C2 i-Erythritol	C3 2-Hydroxy Benzoic Acid	C4 L-Phenylalanine	C1 Tween 40	C2 i-Erythritol	C3 2-Hydroxy Benzoic Acid	C4 L-Phenylalanine	C1 Tween 40	C2 i-Erythritol	C3 2-Hydroxy Benzoic Acid	C4 L-Phenylalanine
D1 Tween 80	D2 D-Mannitol	D3 4-Hydroxy Benzoic Acid	D4 L-Serine	D1 Tween 80	D2 D-Mannitol	D3 4-Hydroxy Benzoic Acid	D4 L-Serine	D1 Tween 80	D2 D-Mannitol	D3 4-Hydroxy Benzoic Acid	D4 L-Serine
E1 α-Cyclodextrin	E2 N-Acetyl-D-Glucosamine	E3 γ-Hydroxybutyric Acid	E4 L-Threonine	E1 α-Cyclodextrin	E2 N-Acetyl-D-Glucosamine	E3 γ-Hydroxybutyric Acid	E4 L-Threonine	E1 α-Cyclodextrin	E2 N-Acetyl-D-Glucosamine	E3 γ-Hydroxybutyric Acid	E4 L-Threonine
F1 Glycogen	F2 D-Glucosaminic Acid	F3 Itaconic Acid	F4 Glycyl-L-Glutamic Acid	F1 Glycogen	F2 D-Glucosaminic Acid	F3 Itaconic Acid	F4 Glycyl-L-Glutamic Acid	F1 Glycogen	F2 D-Glucosaminic Acid	F3 Itaconic Acid	F4 Glycyl-L-Glutamic Acid
G1 D-Cellobiose	G2 Glucose-1-Phosphate	G3 α-Ketobutyric Acid	G4 Phenylethyl-amine	G1 D-Cellobiose	G2 Glucose-1-Phosphate	G3 α-Ketobutyric Acid	G4 Phenylethyl-amine	G1 D-Cellobiose	G2 Glucose-1-Phosphate	G3 α-Ketobutyric Acid	G4 Phenylethyl-amine
H1 α-D-Lactose	H2 D,L-α-Glycerol Phosphate	H3 D-Malic Acid	H4 Putrescine	H1 α-D-Lactose	H2 D,L-α-Glycerol Phosphate	H3 D-Malic Acid	H4 Putrescine	H1 α-D-Lactose	H2 D,L-α-Glycerol Phosphate	H3 D-Malic Acid	H4 Putrescine

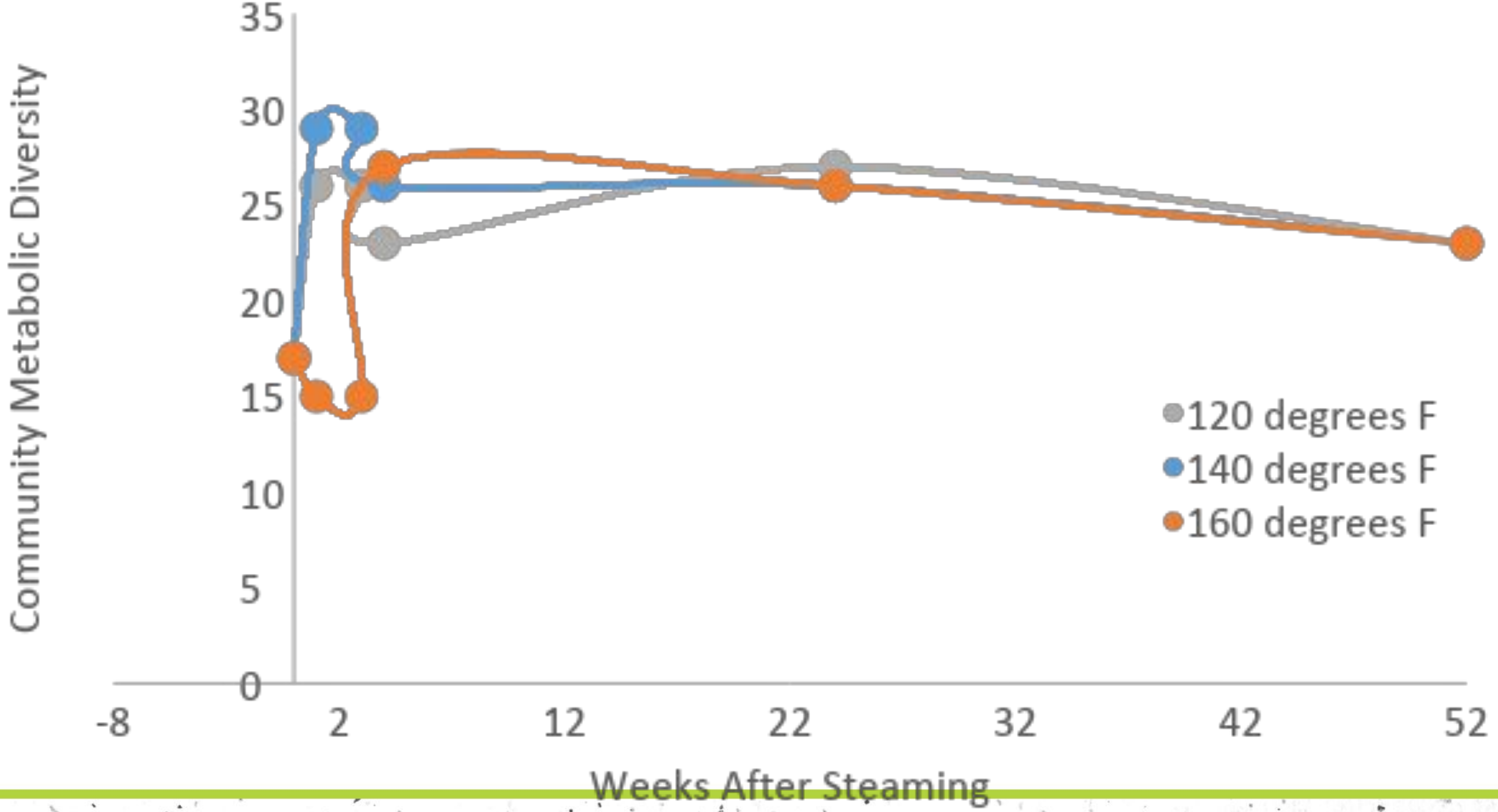
FIGURE 1. Carbon Sources in EcoPlate

Distribution of carbon sources in the BIOLOG EcoPlate.

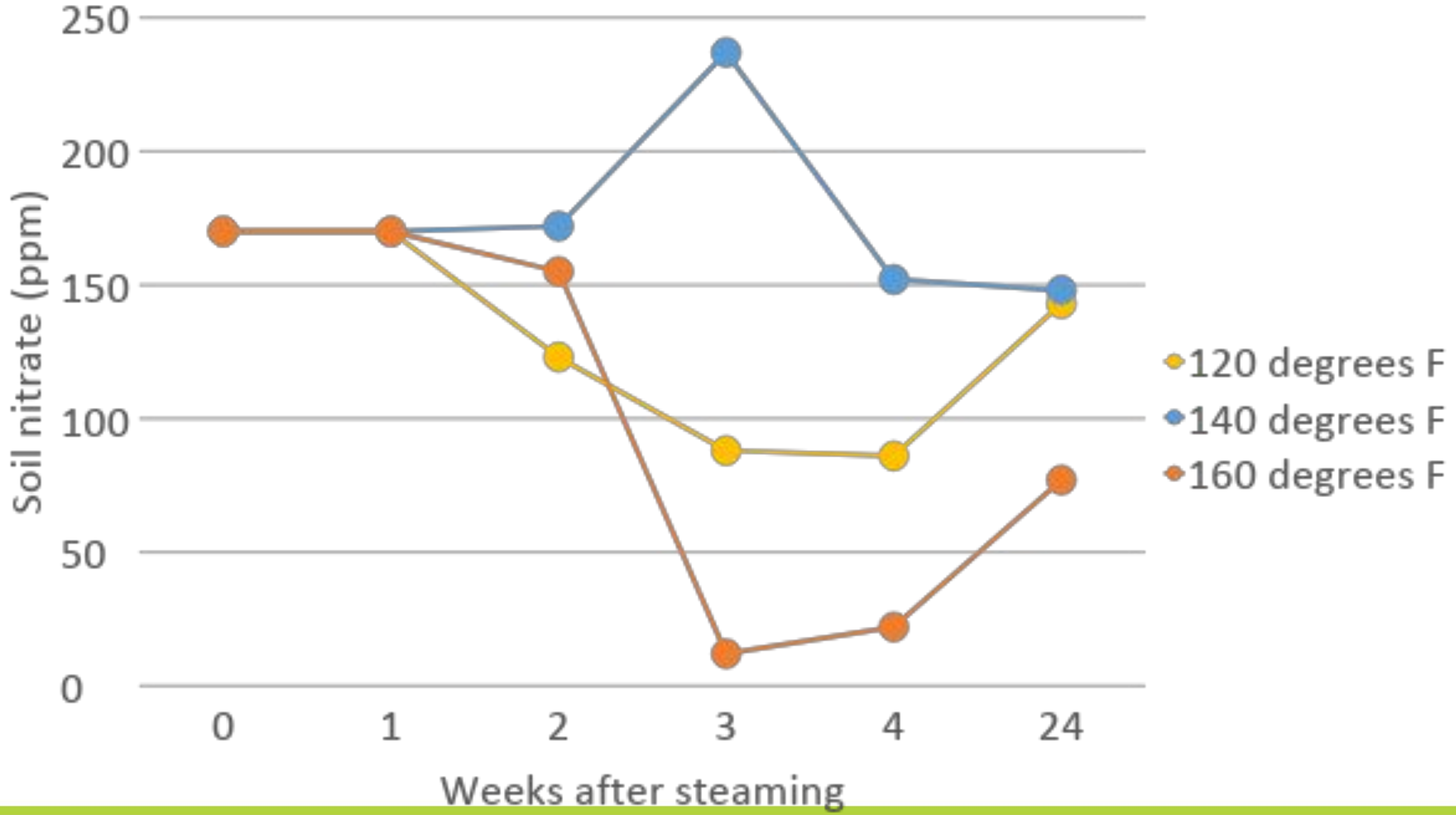
Microbe activity: *rebound after 1 year*



Microbe diversity: *doesn't decrease after steaming*



Soil nitrate: *steaming impact unclear*



Steaming reduces damping off

STEAMED –great germination

Unsteamed-->40% loss to damping off

Costs & yield

What happens in 1 square foot?

Not weeded

Hand weeded

11/11/20

$3.15 / sq. ft. income after hand weeding costs

Weeding time for 1 sq ft = 5.4 minutes
@ $15/ hr = ***$1.35 weeding labor***

1 lb/ sq ft expected yield
Crop loss due to lower density @ 50% = 0.5 lb @ $9/ lb =
$4.50 crop value

$7.78 / sq. ft. income after soil steaming costs

Steaming costs for 1 sq ft =
$0.22

1 lb/ sq ft expected yield
@ $9/ lb = ***$9 crop value***

Est. annual steaming cost per 2700 sq ft tunnel: $513

Steamer purchase (2020), accessories, & delivery	$6,500
Annual cost per tunnel if used for 10 years, 3 tunnels/ year	**$217**
Fuel (diesel or kerosene) per 30x96 ft tunnel	
55 gallons @$5/ gallon	$ 275
Person time	
(8 hours per tunnel @ $18/ person hr)	$ 144
total cost per 30x96 sq foot tunnel	**$ 636**
cost per square ft	**$ 0.22**

Conclusions

- Steaming can increase net revenue by reducing yield losses to chickweed
- Chickweed control is not long term with high weed population
- Steaming appears to reduce damping off in spinach
- Microbial activity and diversity appear to rebound within a year after steaming
- Crop growth appears enhanced after steaming, nitrate availability??
- It can be challenging to achieve/maintain optimal soil temperatures with steaming
- New steamers are much easier to maintain and use, but basic functions are equal

Thank You!

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