Leveraging carbon-based fertilizers and microbes mediated processes to move toward a circular citriculture

Deborah Pagliaccia

UC Riverside

&

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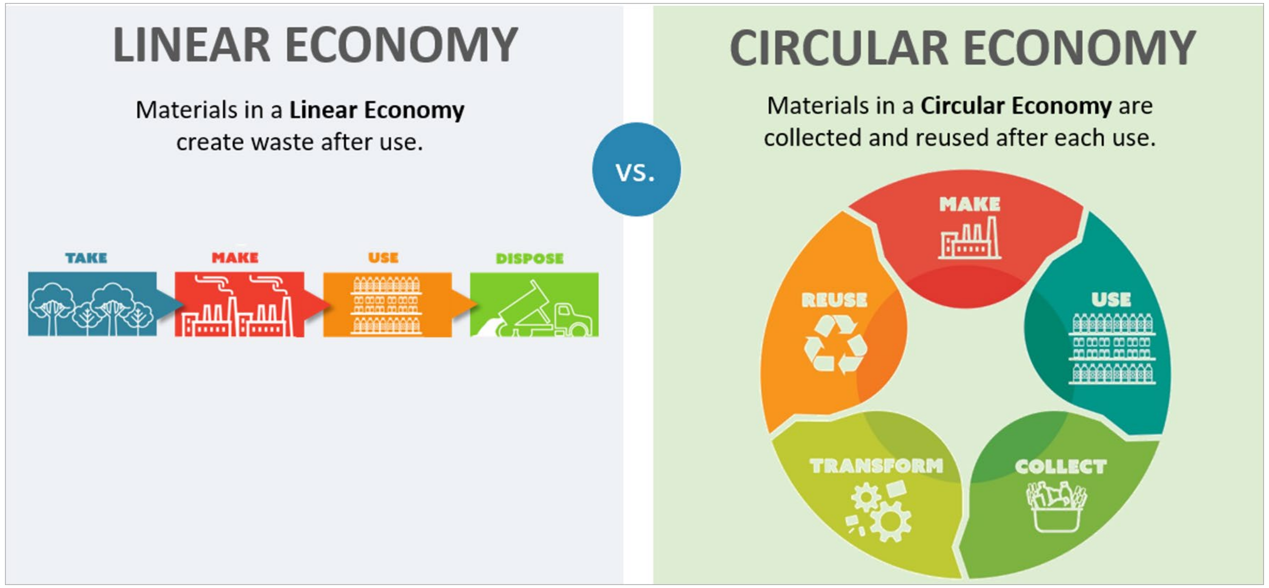

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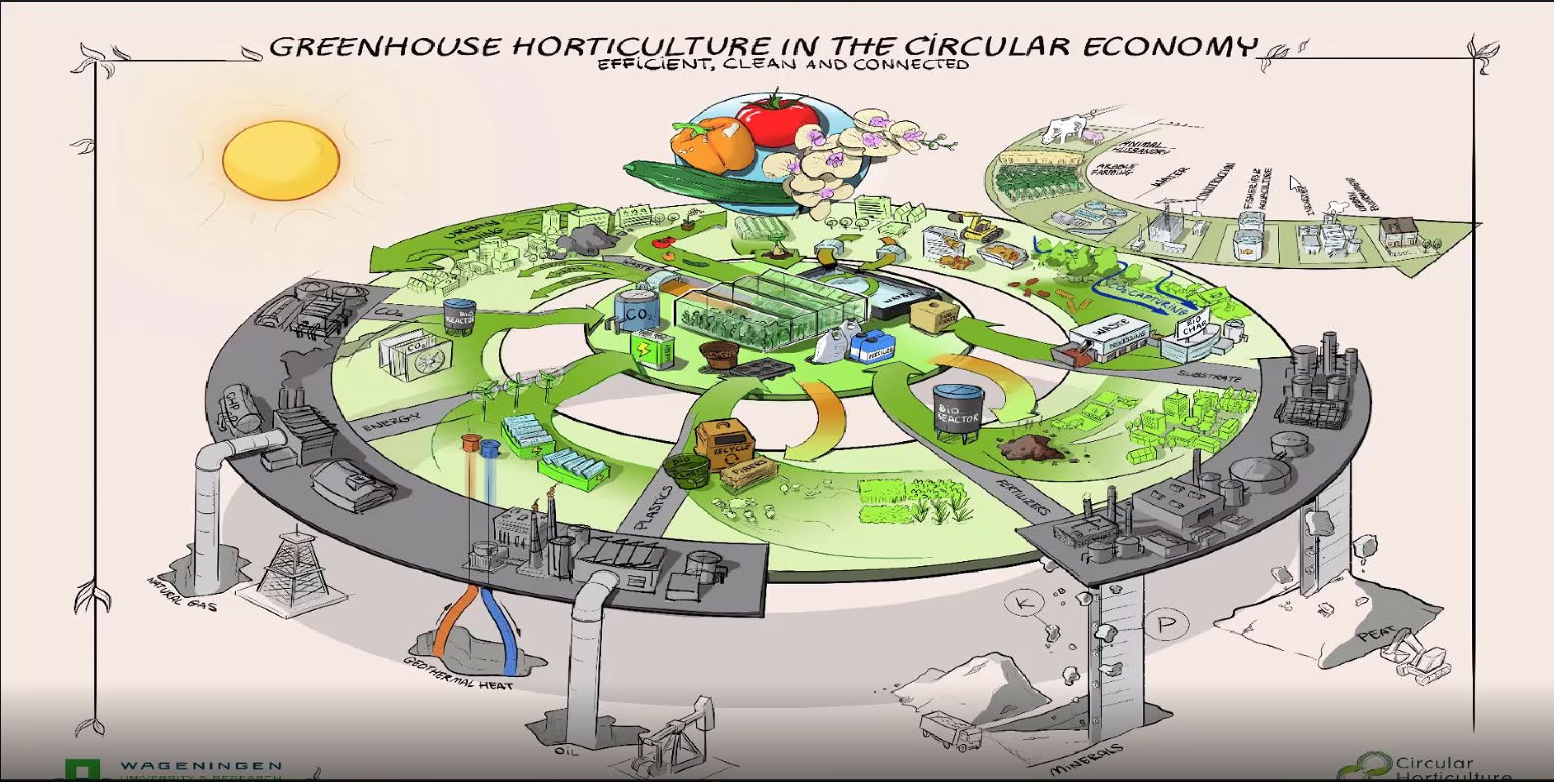

From https://www.wur.nl/en/product/circular-horticulture.htm

Today presentation summary

Brief introduction & Project Goals

Benefit for plant production

PHASE 1 Results– Anaerobic FERMENTATION of citrus waste – Day 1 to 14

- C & N
- MICROBIOME

PHASE 2 Results– Aerobic COMPOSTING of by-products with nursery soil – Day 15 to 28/42

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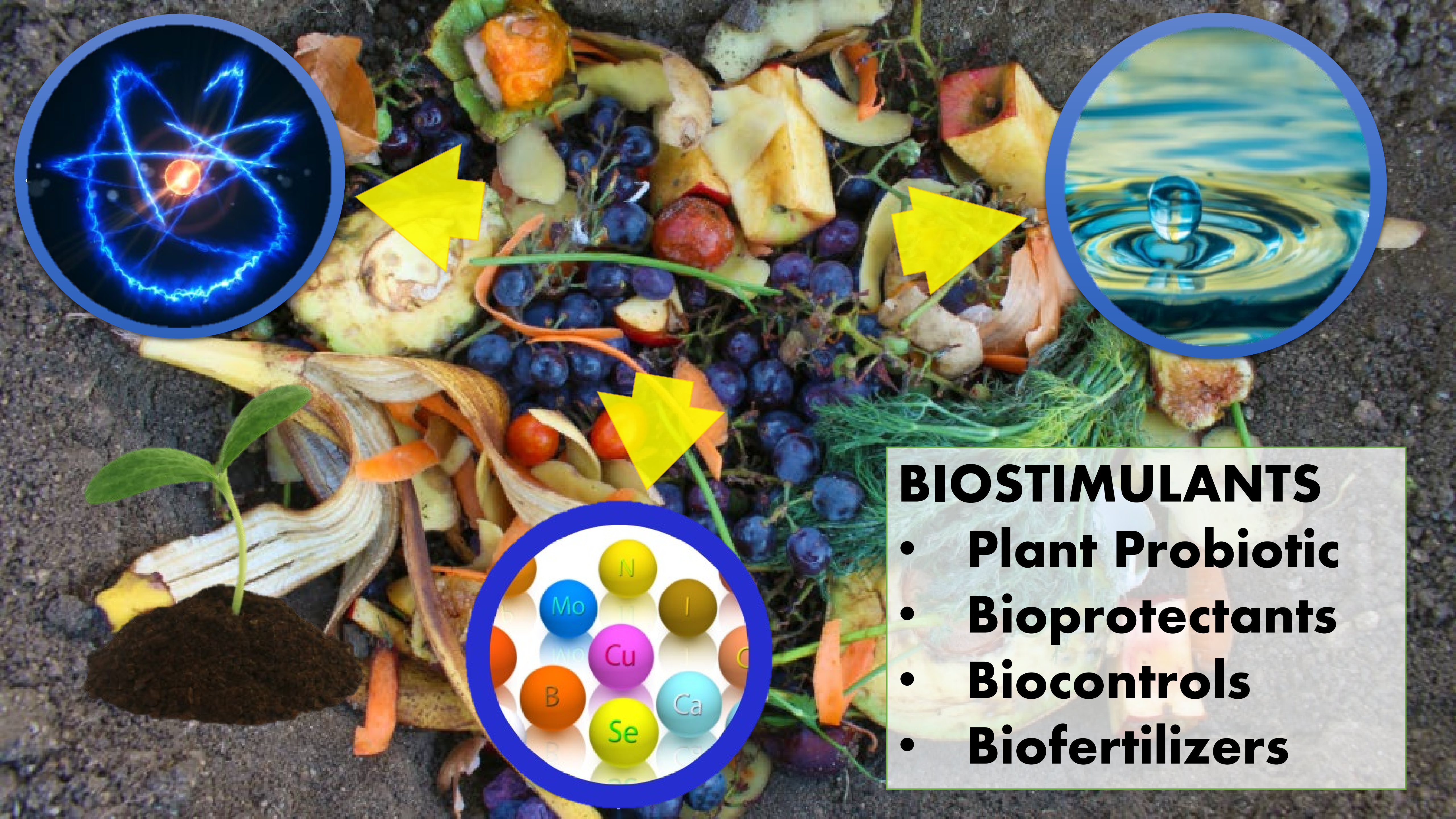
- Effect of **Solid Citrus waste derived Bokashi by-products** on soil mixes and plant

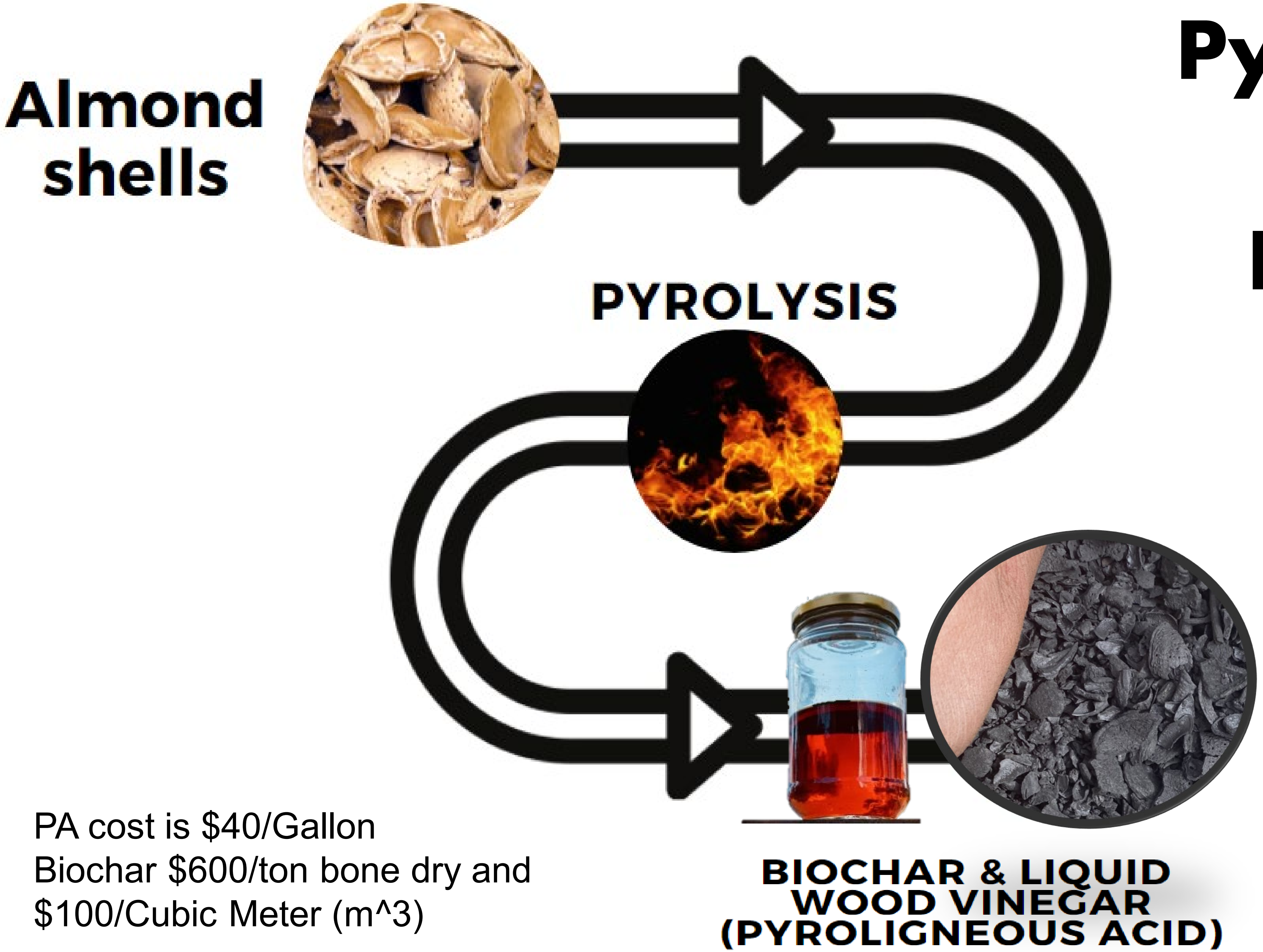
Drawbacks & Opportunities

Next step……scaling up

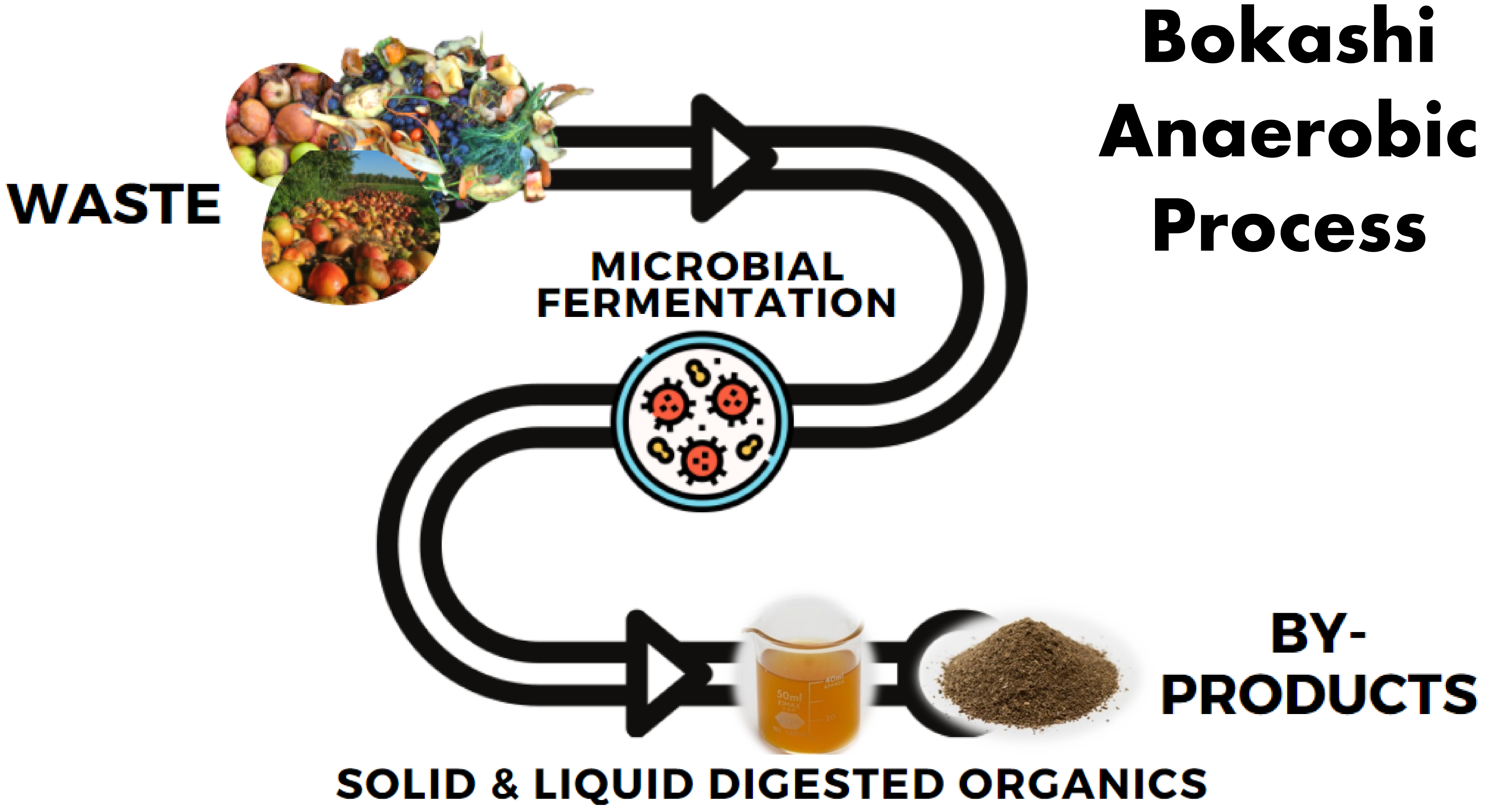
Air contamination
WASTE
Greenhouse gases
Soil & waster contamination
Human disease spread
Nutrient losses
Upcycling
Sustainable Production
Sustainable Consuption

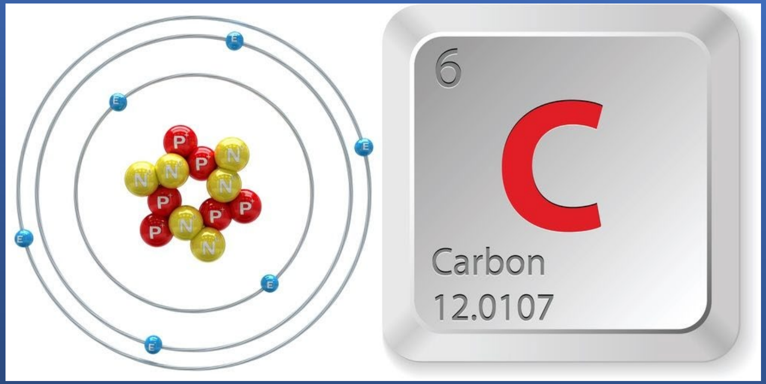

N
Mo
I
Cu
B
Ca
Se
BIOSTIMULANTS
• Plant Probiotic
• Bioprotectants
• Biocontrols
• Biofertilizers

Pyrolysis of Plant Biomass



- PA cost is $40/Gallon
- Biochar $600/ton bone dry and $100/Cubic Meter (m^3)


Bokashi Anaerobic Process
WASTE
MICROBIAL FERMENTATION
BY-PRODUCTS
SOLID & LIQUID DIGESTED ORGANICS



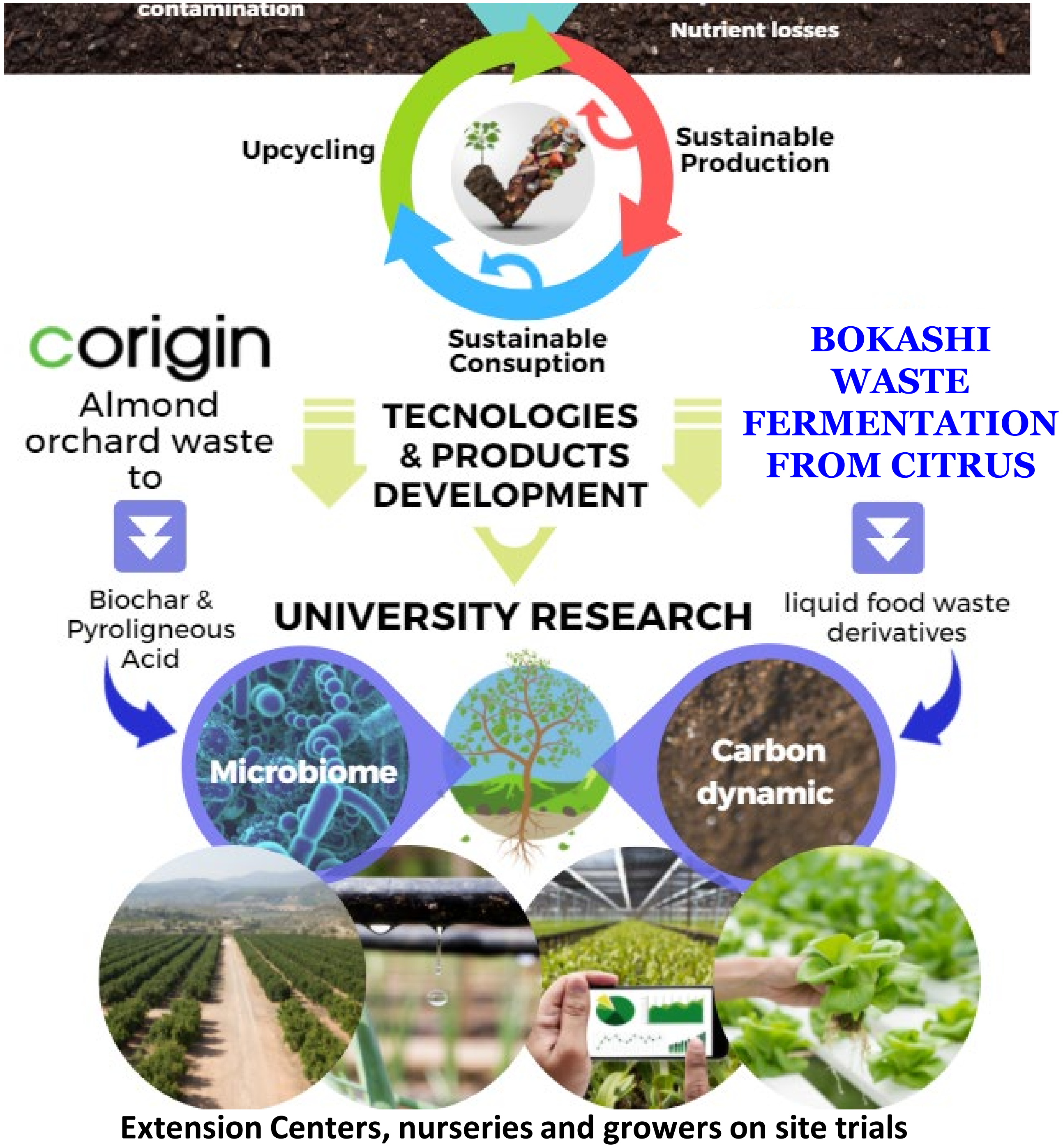
Johannes- Soil organic matter is one of the, if not the, foundation of soil functioning, soil fertility, soil everything. It's the foundation of soil health and how carbon and nutrients cycle in soil. So understanding soil organic matter is really fundamental to understanding soils.

That's

Johannes Lehmann I'm a professor of soil science at Cornell University.

Priming for production: A podcast on soil health

https://projects.sare.org/sare_project/one15-251/



Our research projects aims to demonstrate the beneficial use of Ag and food waste byproducts, to

- Enhance beneficial native citrus microbiome
- Impact soil/potting soil carbon, nitrogen, and improve nutrient dynamics

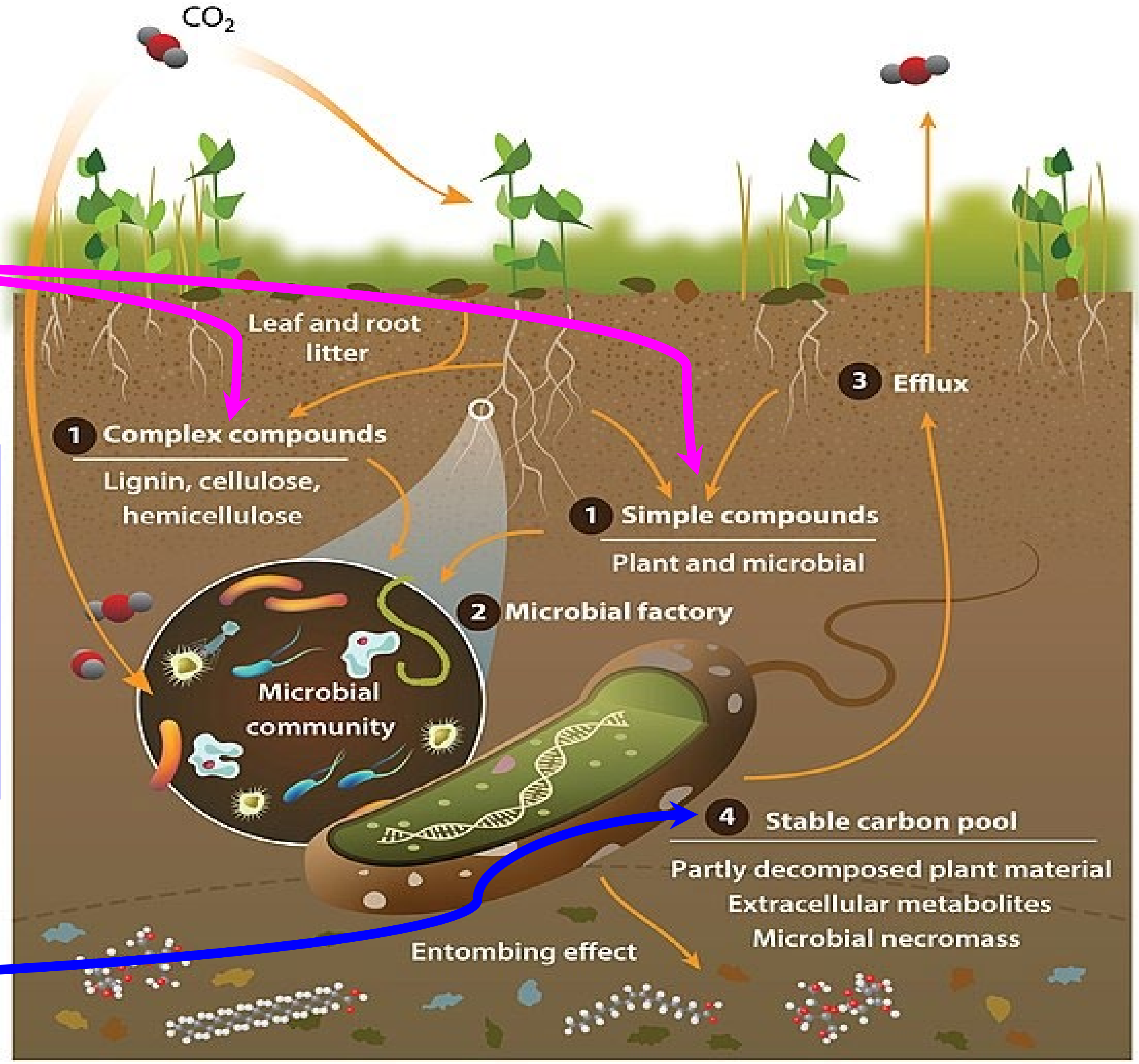
WHY? Because play a crucial role in plant growth, health, and stress resilience.

Summary

Nutrient-rich organic matter

Manage C to create a dynamics flow of nutrient availability and cycling to improve soil fertility, microbiome and plant health

Add stable CARBON



Naylor D, et al. 2020.
Annu. Rev. Environ. Resour. 45:29–59

Summary

Nutrient-rich organic matter

Manage C to create a dynamics flow of nutrient availability and cycling to improve soil fertility, microbiome and plant health

Add stable CARBON

BY-PRODUCTS

The liquid MAINTAIN

The solid BUILD

Biochar helps to BUILD & MAINTAIN!

Brief introduction & Project Goals

Benefit to the citrus nursery industry

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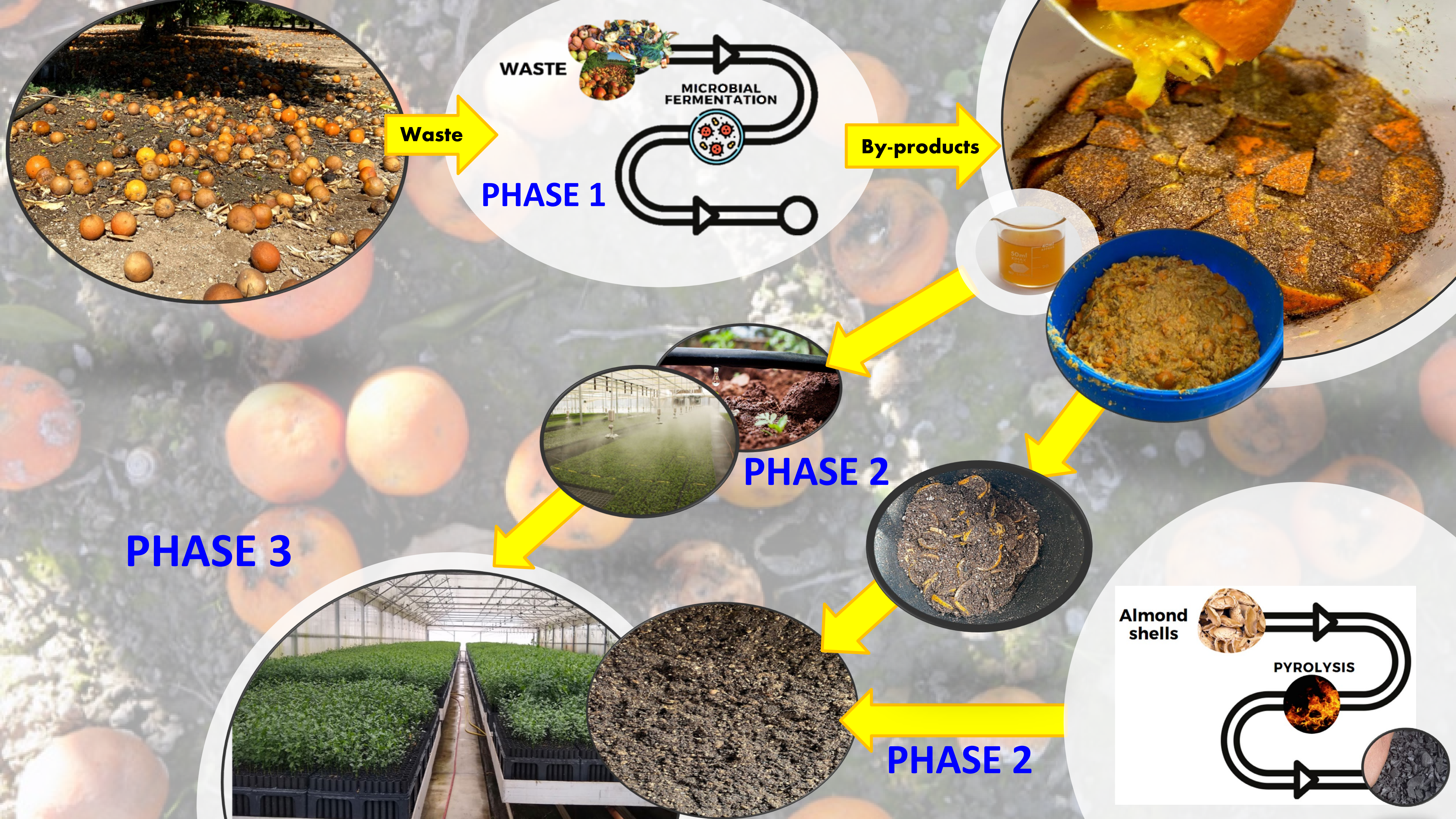
Drawbacks & Opportunities

Next step……



Waste
WASTE
MICROBIAL FERMENTATION
PHASE 1
By-products
PHASE 2
PHASE 3
Almond shells
PYROLYSIS
PHASE 2

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Drawbacks & Opportunities

Next step……

Waste

By-products

PHASE 1

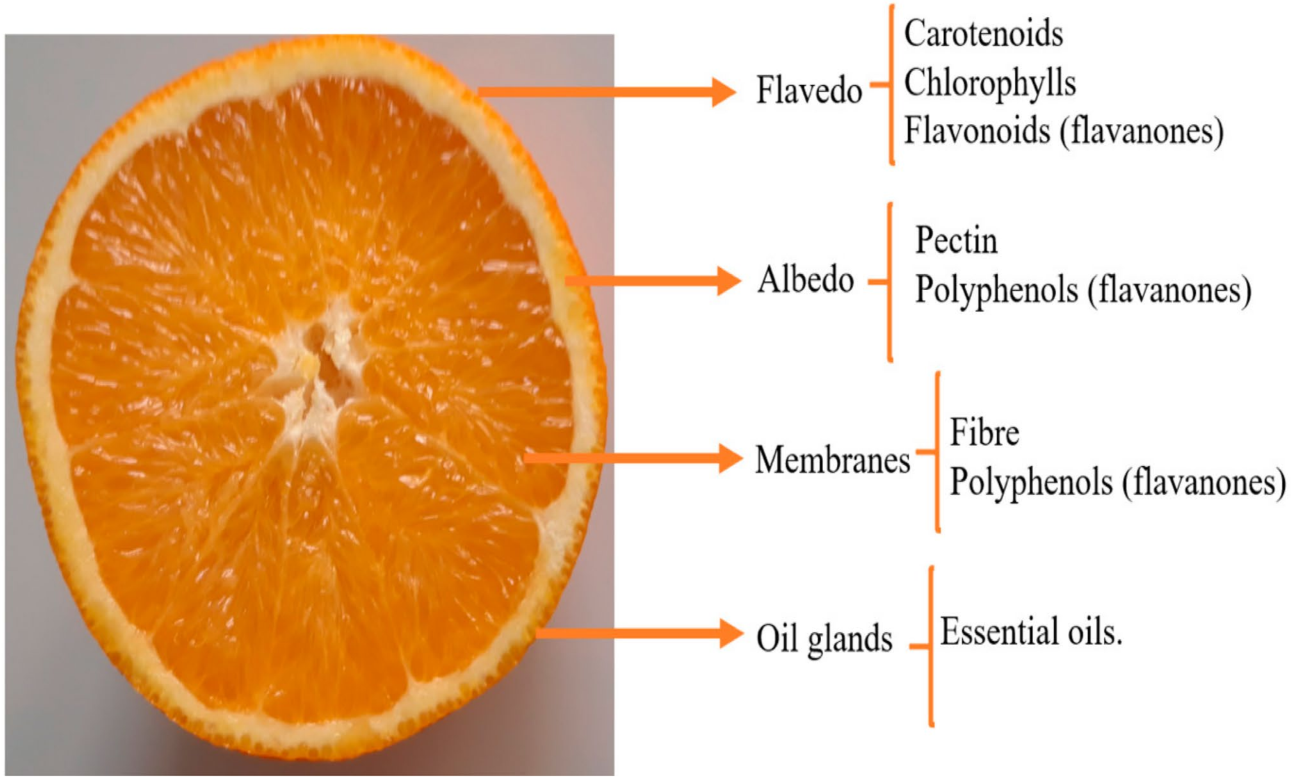
Time range - 0 to 14 days

For the **1st anaerobic phase** of the Bokashi fermentation process we are investigating:

1. A & B. Nutrient composition of row and bokashi by-product material
2. C, N, and C/N ratio changes during fermentation
3. Microbiome changes over time during the 1st phase.
4. Understand GHG reduction (carbon dioxide (CO_2), methane (CH_4), and Nitrous oxide (NO_2), during the 1st phase of the Bokashi fermentation process.

Soluble sugars (mainly fructose, glucose and sucrose), and structural polysaccharides, such as cellulose, hemicelluloses and pectin, including lignin-like compounds, such as flavonoids, and essential oils

1A. What's the nutrient composition of row citrus waste material?



Time 0

Citrus solid

pH 4.0-5.0

TC 40.3

TN 1.1

T C/N 36.85

https://www.frontiersin.org/articles/10.3389/fsufs.2020.593568/full

Two Food Waste By-Products Selectively Stimulate Beneficial Resident Citrus Host-Associated Microbes in a Zero-Runoff Indoor Plant Production System

	Amount	
Parameter	Beer Mash	Food Waste
Soluble Salts (Electrical Conductivity)	8.7 dS/m	29 dS/m
pH	3.8	5.7
Chloride (Cl)	0.05%	0.16%
Organic Matter	3.07%	2.16%
C:N Ratio	8:1	3:1
Nitrate-N	<0.02 %	<0.02 %
Ammonium-N	0.03%	0.22%
Organic N	0.19%	0.14%
Water Insoluble N	0.01%	0.01%
Water Insoluble Organic N	<0.01 %	0.01%
Total Nitrogen	0.22%	0.36%
Phosphorus (P)	823 ppm	323 ppm
Potassium (K)	446 ppm	3268 ppm
Sulfur (S)	137 ppm	231 ppm
Magnesium (Mg)	385 ppm	351 ppm
Calcium (Ca)	392 ppm	1215 ppm
Sodium (Na)	165 ppm	1661 ppm
Iron (Fe)	14 ppm	18 ppm
Aluminum (Al)	1 ppm	6 ppm
Manganese (Mn)	5 ppm	2 ppm
Copper (Cu)	0.01 ppm	0.42 ppm
Zinc (Zn)	9 ppm	8 ppm
Boron (B)	0.18 ppm	3 ppm

1B. What's the nutrient composition of the bokashi by-products material?

Time 14 - END

Citrus Solid Bokashi

pH 3.5
C 49
N 1.63
C/N 29
Nitrate-N 0.07
Ammonium-N 0.14

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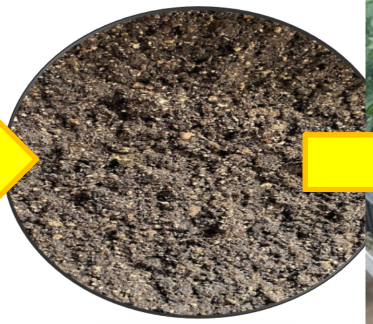
Drawbacks & Opportunities

Next step……

By-product

Improved soil mixes



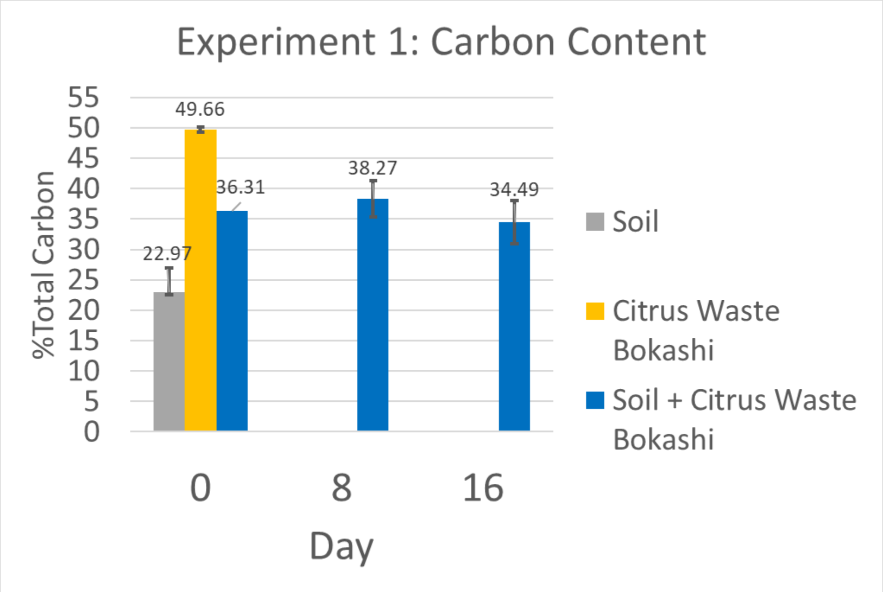
PHASE 2

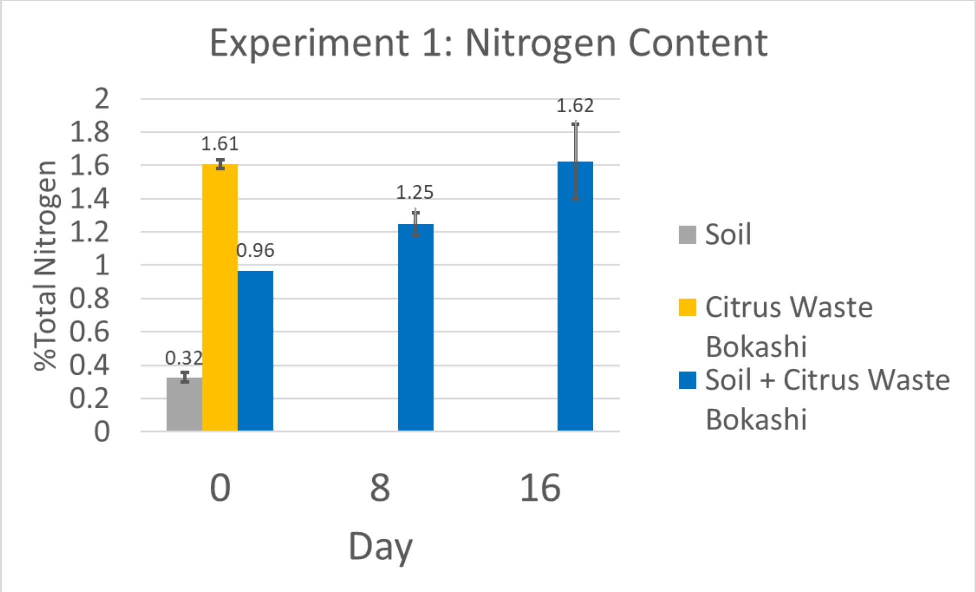
Time range - 14 to 28 days

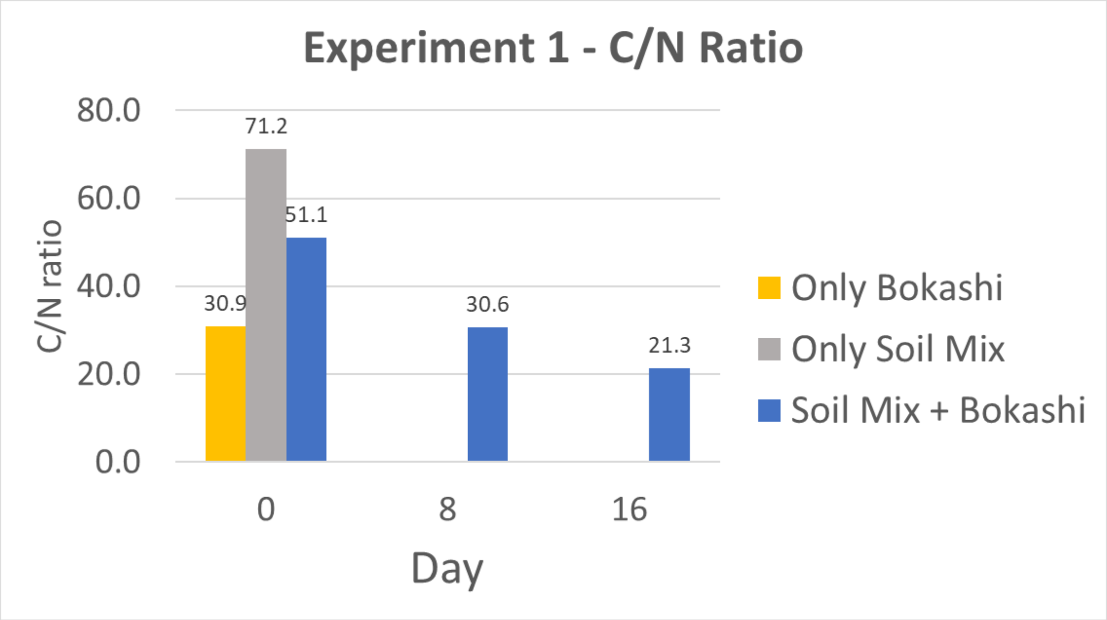
	In the 2nd **aerobic phase** of the process, we are investigating:
	1. C, N, and C/N ratio changes during 2nd PHASE
	2. Microbiome changes in soil mixes time during 2nd PHASE
	3. Understand GHG reduction (carbon dioxide (CO_2), methane (CH_4), and Nitrous oxide (NO_2), during the 1st phase of the Bokashi fermentation process.

1st Experiment - OUR SOIL MIX & Bokashi Living

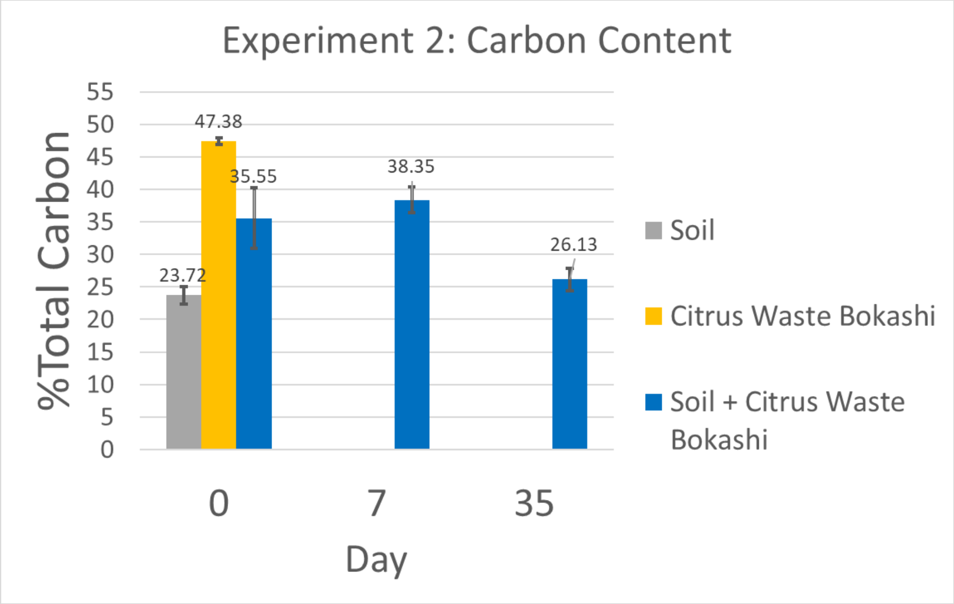
Mixed equal volume citrus solid bokashi with soil mix (made of equal parts perlite, peat moss and coco coir)

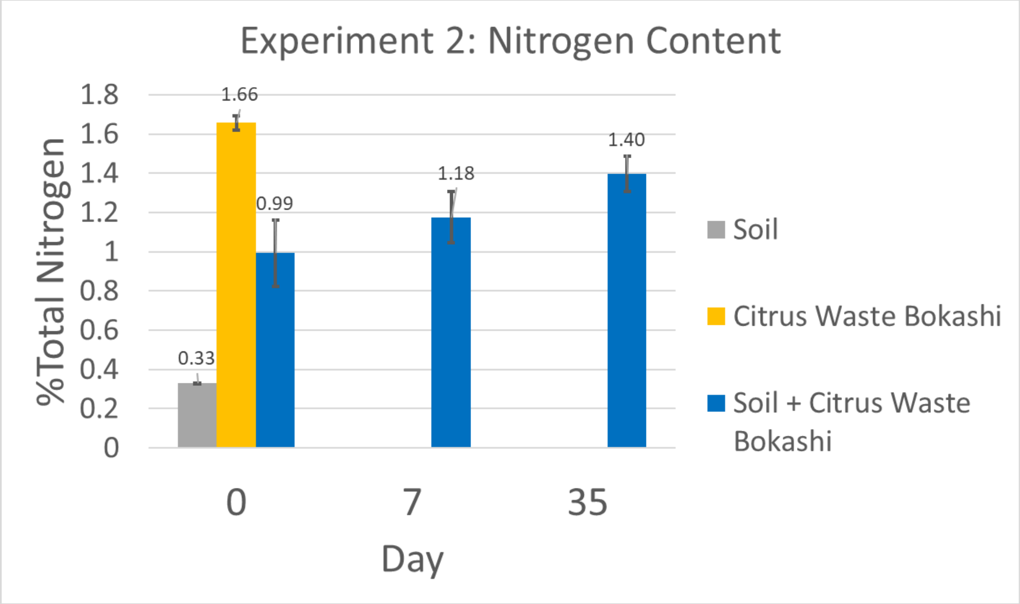


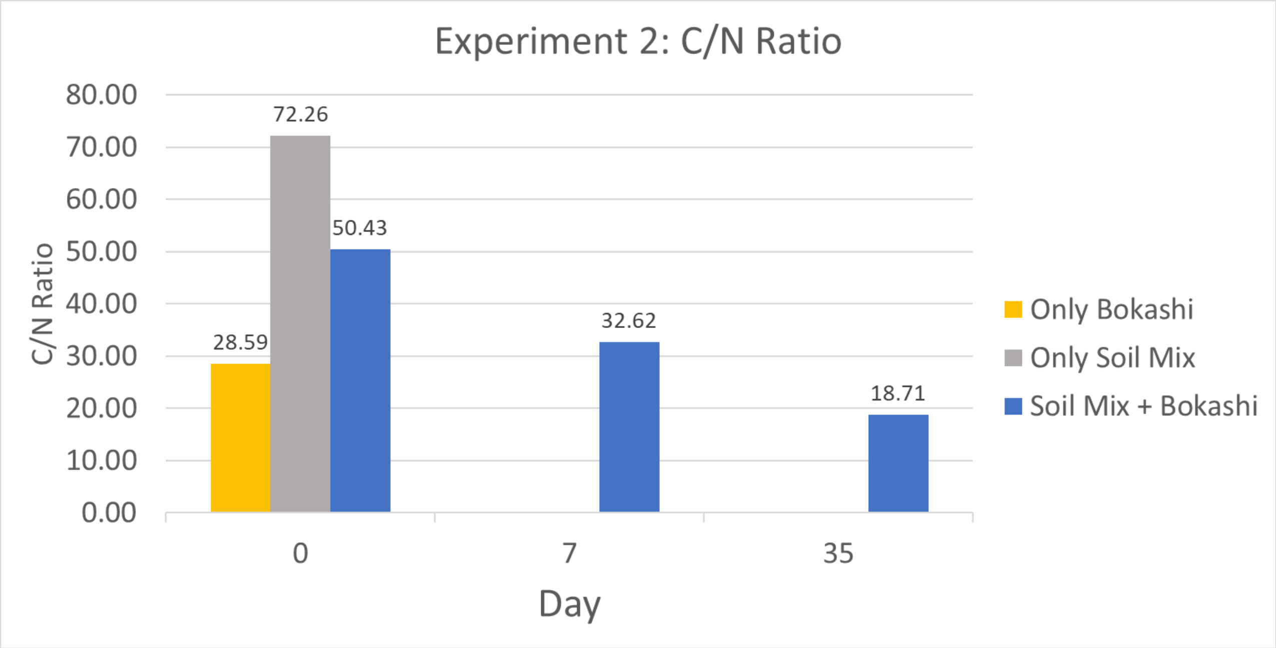




2nd Experiment - OUR SOIL MIX & Bokashi Living





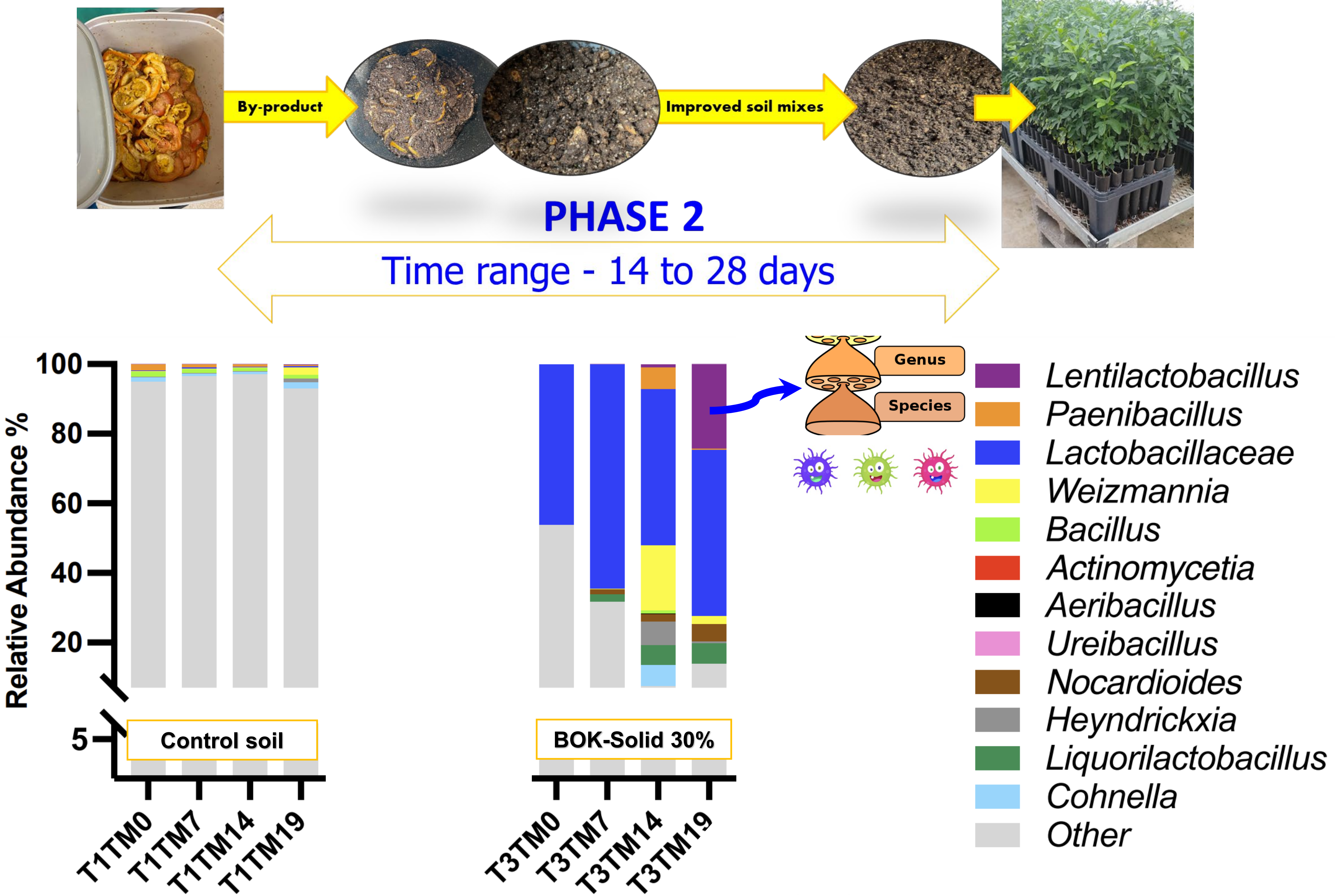


3rd Experiment - OUR SOIL MIX & Bokashi Living

We mixed 50% volume of citrus solid bokashi with 50% volume soil mix (made of equal parts perlite, peat moss and coco coir). We took the samples at TIME 0, 4, 7, 11, 14, 18, 21 up to 42 days and placed them in the -80c freezer for NGS microbiome and 4C for C/N sample processing.

		N Average	C Average	C/N
Time 0	Only Soil Mix	0.3	19.5	60.5
Time 0	Only Bokashi	1.5	43.0	29.1
Time 0	Soil Mix + Bokashi	0.9	31.2	44.8
Time 7	Soil Mix + Bokashi	1.0	29.5	28.6
Time 14	Soil Mix + Bokashi	1.1	29.1	25.4
Time 21	Soil Mix + Bokashi	1.1	26.4	24.5
Time 28	Soil Mix + Bokashi	1.2	26.6	22.4
Time 35	Soil Mix + Bokashi	1.1	24.1	21.0
Time 42	Soil Mix + Bokashi	1.2	25.0	21.3

Time 26	Only Soil Mix	0.4	23.5	58.1



By-product
Improved soil mixes
PHASE 2
Time range - 14 to 28 days
Relative Abundance %
100
80
60
40
20
5
Control soil
BOK-Solid 30%
T1TM0
T1TM7
T1TM14
T1TM19
T3TM0
T3TM7
T3TM14
T3TM19
Genus
Species
Lentilactobacillus
Paenibacillus
Lactobacillaceae
Weizmannia
Bacillus
Actinomycetia
Aeribacillus
Ureibacillus
Nocardioides
Heyndrickxia
Liquorilactobacillus
Cohnella
Other

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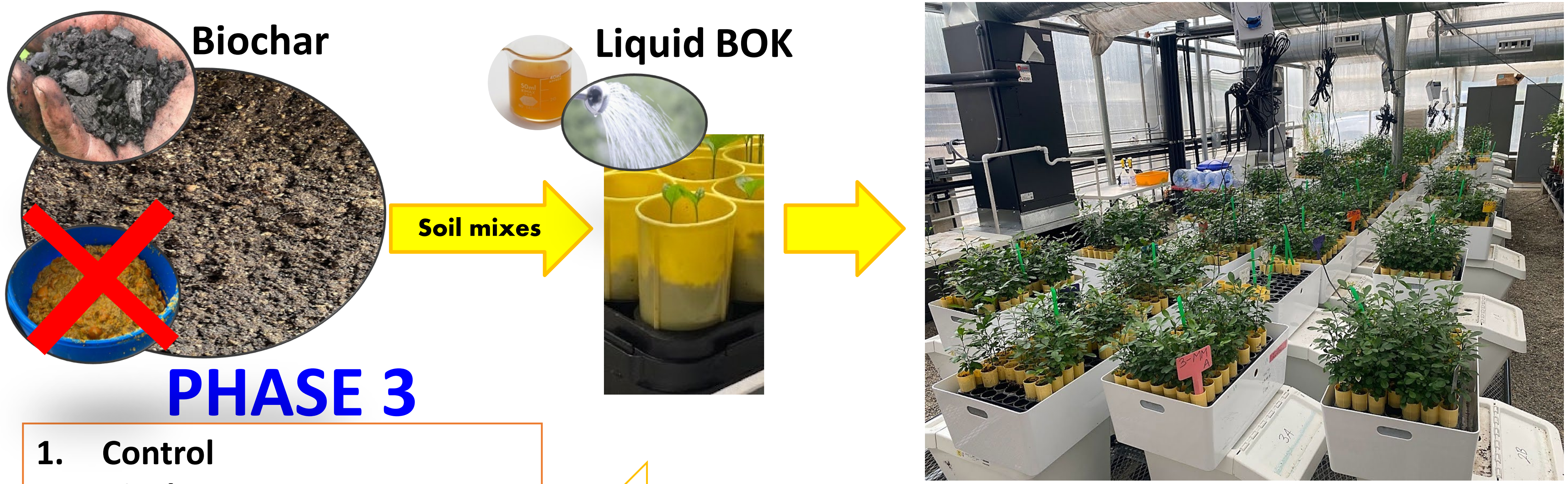
Drawbacks & Opportunities

Next step……



PHASE 3

1. Control
2. Biochar BC 10%
3. Liquid Bokashi L-BOK 0.5%
4. BC + L-BOK (0.5%)

Time range – From seeding to 5-6 months

For the 3rd **phase** we are investigating under greenhouse conditions:	
	1. C, N, and C/N ratio dynamics.
	2. Microbiome changes over time during in soil and root in the first 6 months.
	3. Impact on plant growth parameters, including plant height, seeds germinations, weight, and caliper.

Carbon, nutrients, and Bacterial dynamics in soil

Is soil C & N building up over time?

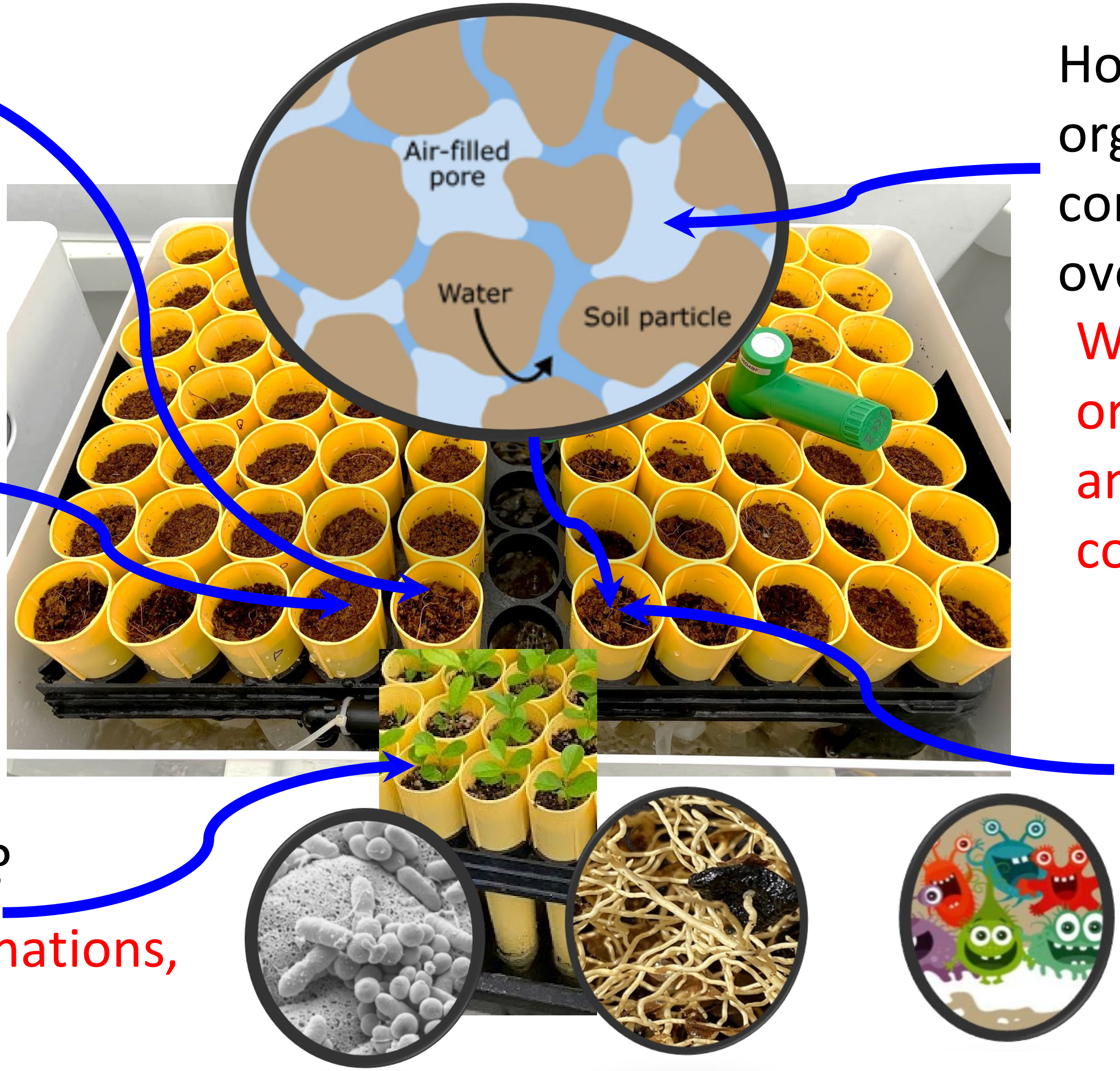
Costech ECS 4010 CHNSO elemental analyzer

Is there a change in total elemental composition in soils after repeat application?

X-ray Fluorescence Spectrometry (XRF)

Is there a + impact on plant growth parameters?

Plant height, seeds germinations, weight, and caliper

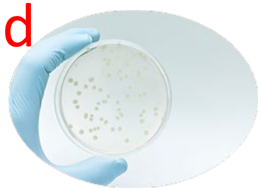


How do dissolved organic carbon concentrations change over time?

Water extractable organic carbon (WEOC) and nitrogen (WEON) concentrations

How does the microbial population changes in soil and root ?

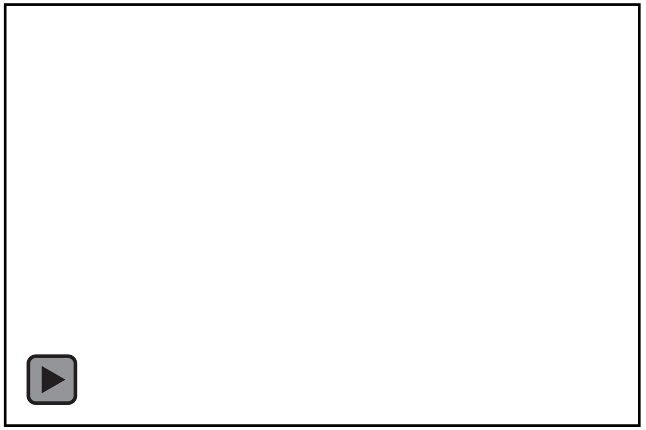
Plating and NGS

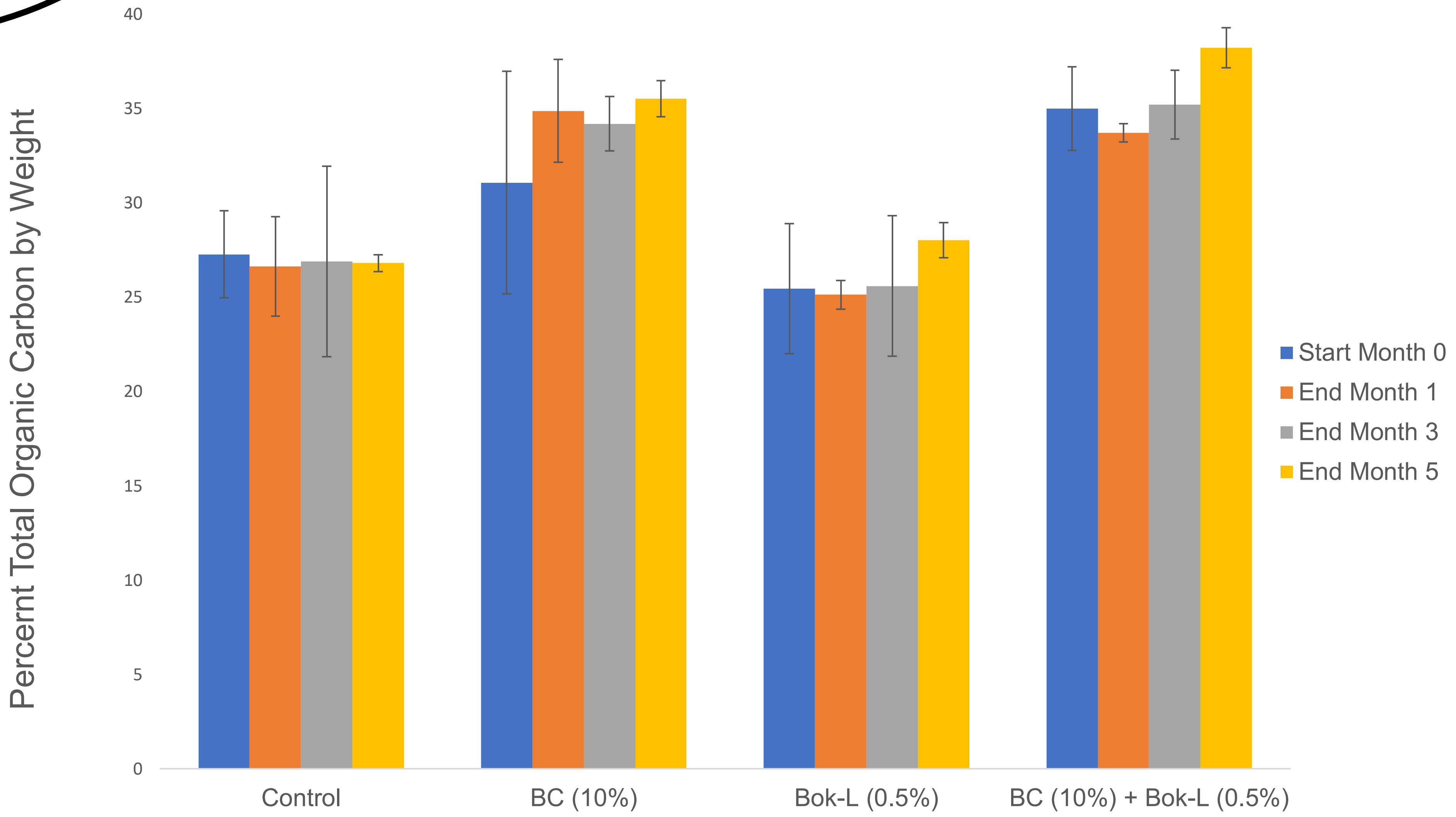


Results: Change in Total Organic Carbon Over Time

Is soil C & N building up over time?

Costech ECS 4010 CHNSO elemental analyzer

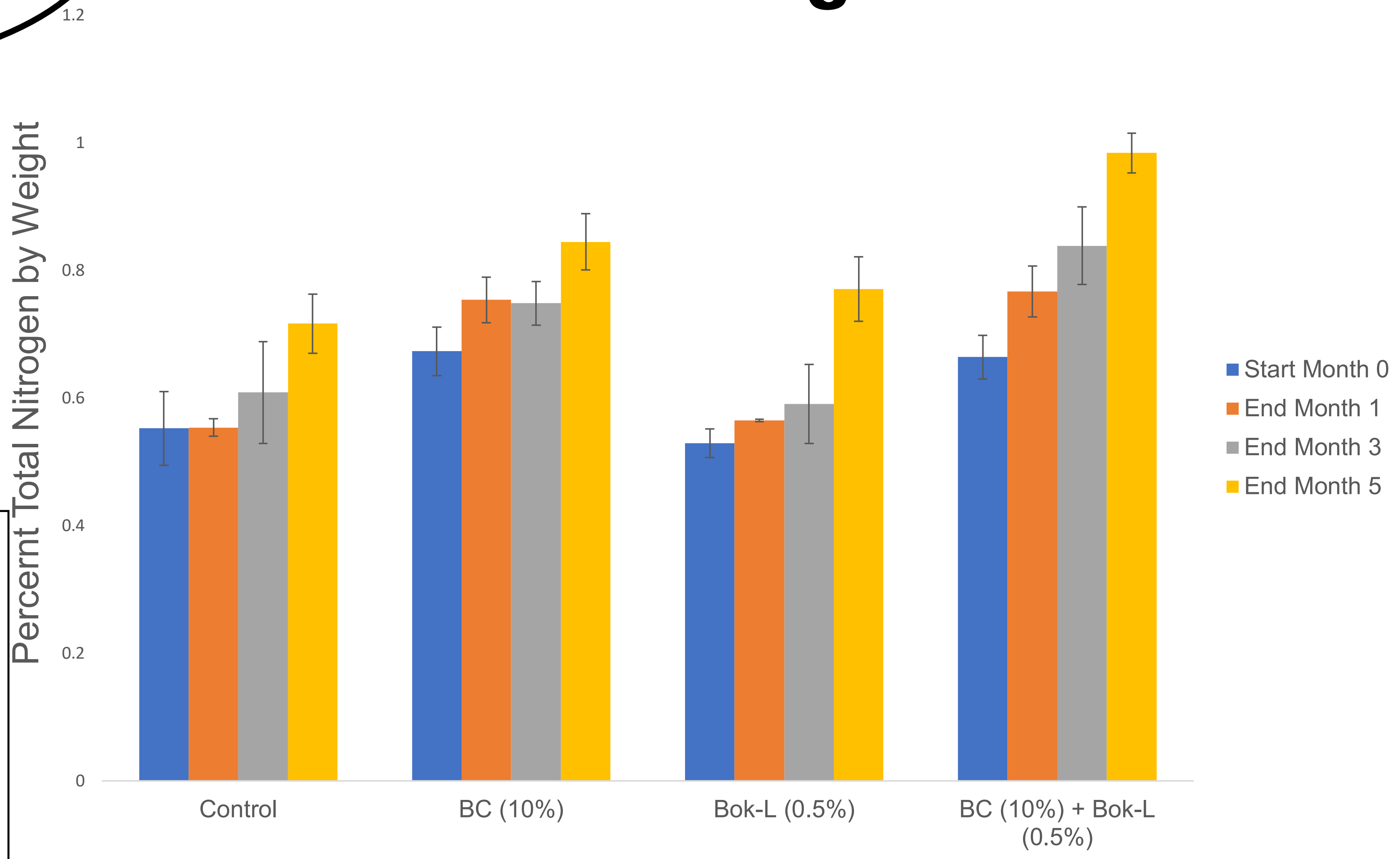




Results: Change in Total Nitrogen Over Time

Is soil C & N building up over time?

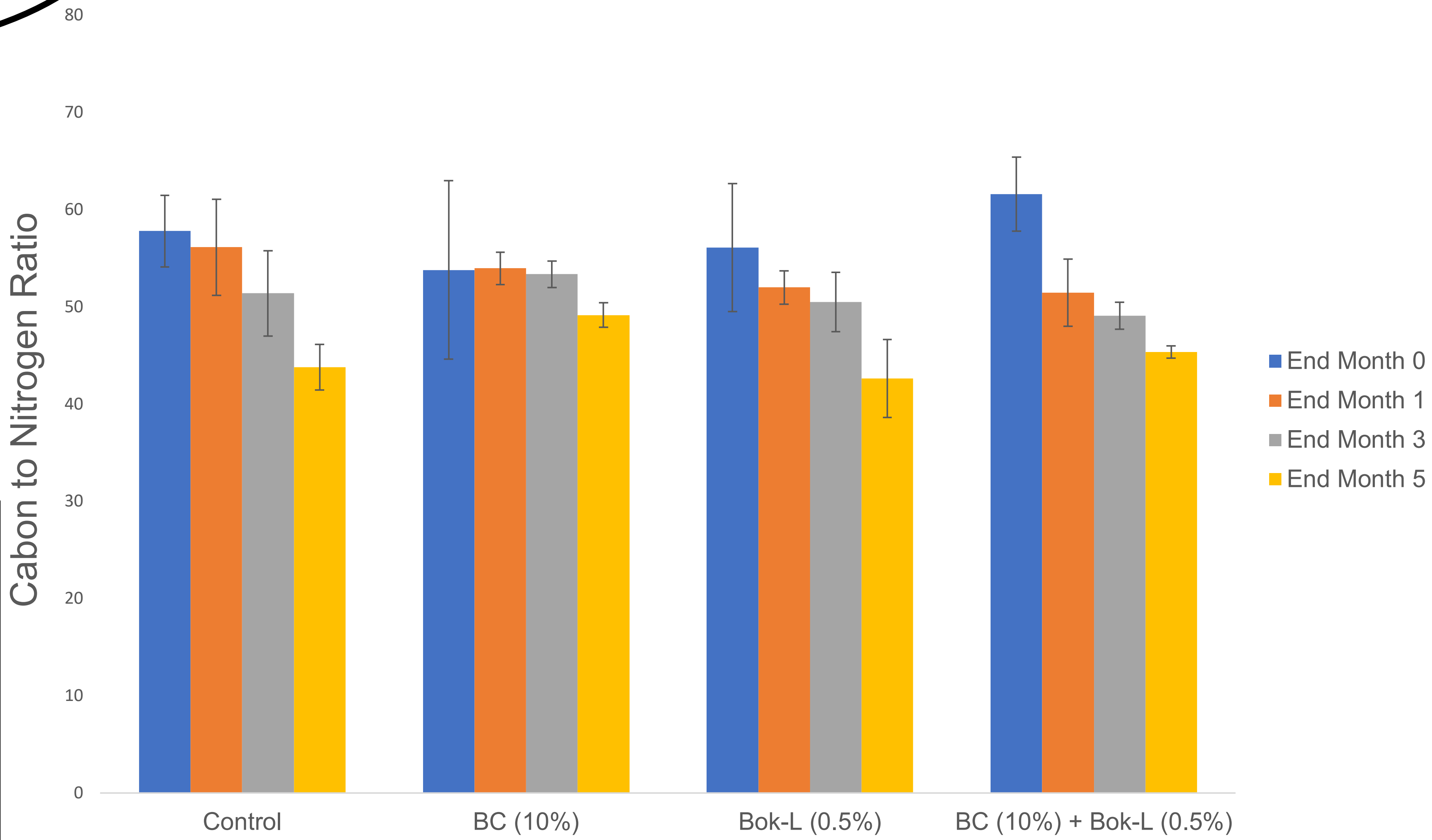
Costech ECS 4010 CHNSO elemental analyzer



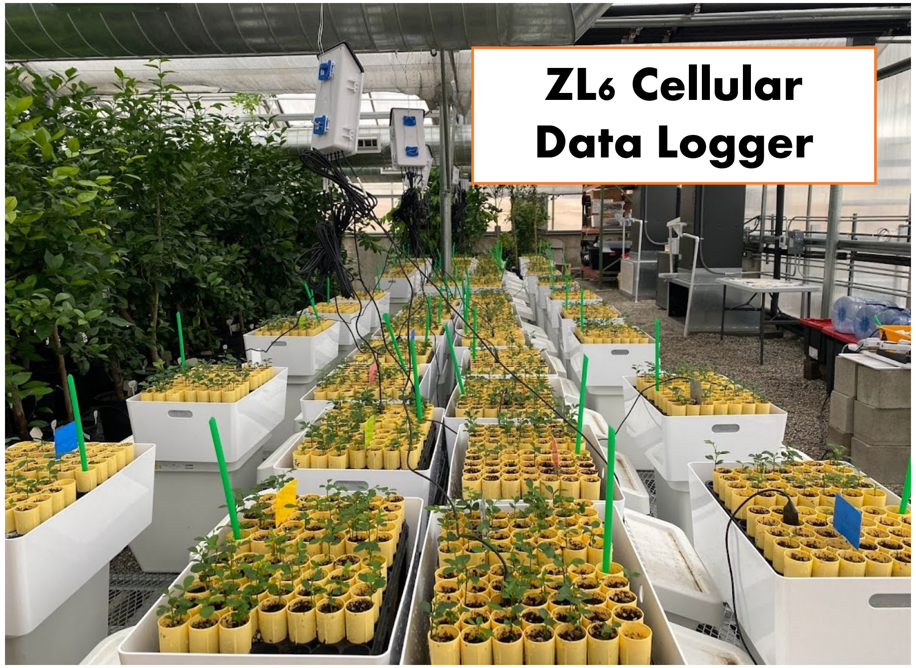
Results: Organic Carbon to Nitrogen Ratio Over Time

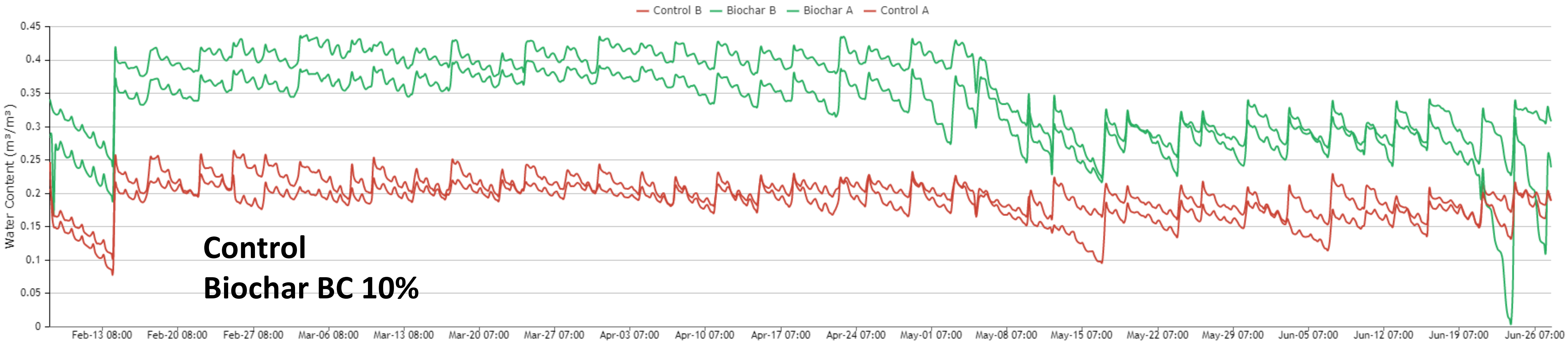
Is soil C & N building up over time?

Costech ECS 4010 CHNSO elemental analyzer

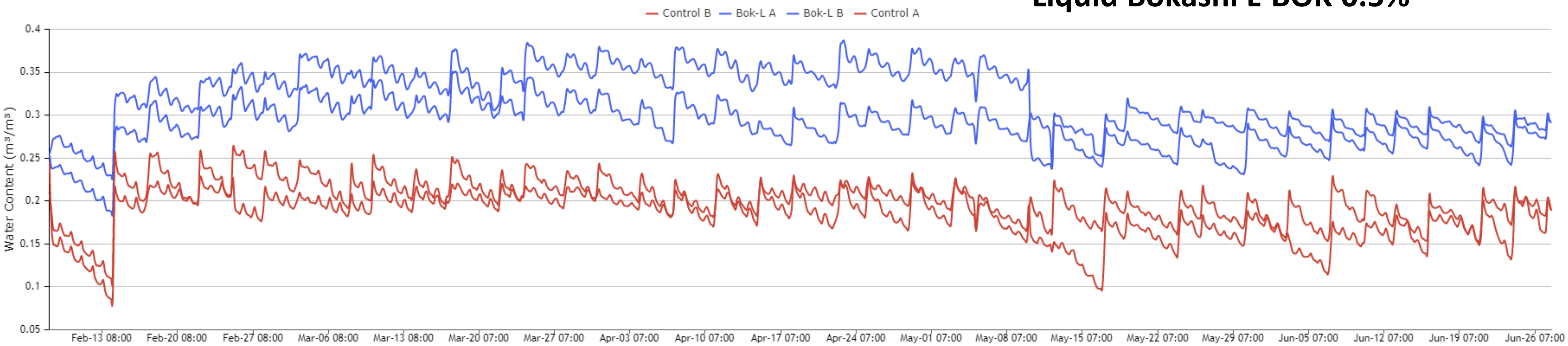



5TM Soil Moisture and Temp Sensor
METER
ZENTRA Cloud
ZENTRA Cloud

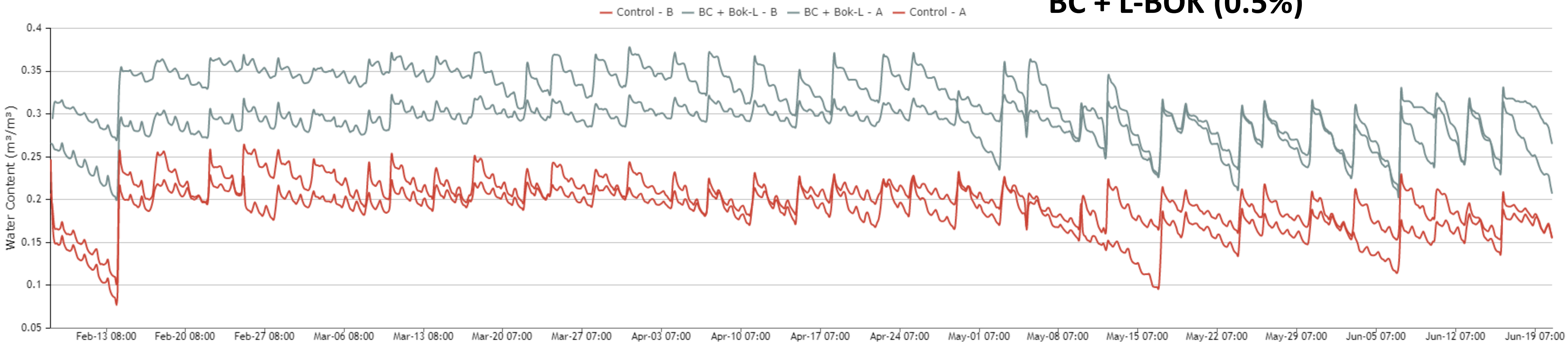

ZL6 Cellular Data Logger


Control B
Biochar B
Biochar A
Control A
Water Content (m³/m³)
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Feb-13 08:00
Feb-20 08:00
Feb-27 08:00
Mar-06 08:00
Mar-13 08:00
Mar-20 07:00
Mar-27 07:00
Apr-03 07:00
Apr-10 07:00
Apr-17 07:00
Apr-24 07:00
May-01 07:00
May-08 07:00
May-15 07:00
May-22 07:00
May-29 07:00
Jun-05 07:00
Jun-12 07:00
Jun-19 07:00
Jun-26 07:00
Control
Biochar BC 10%

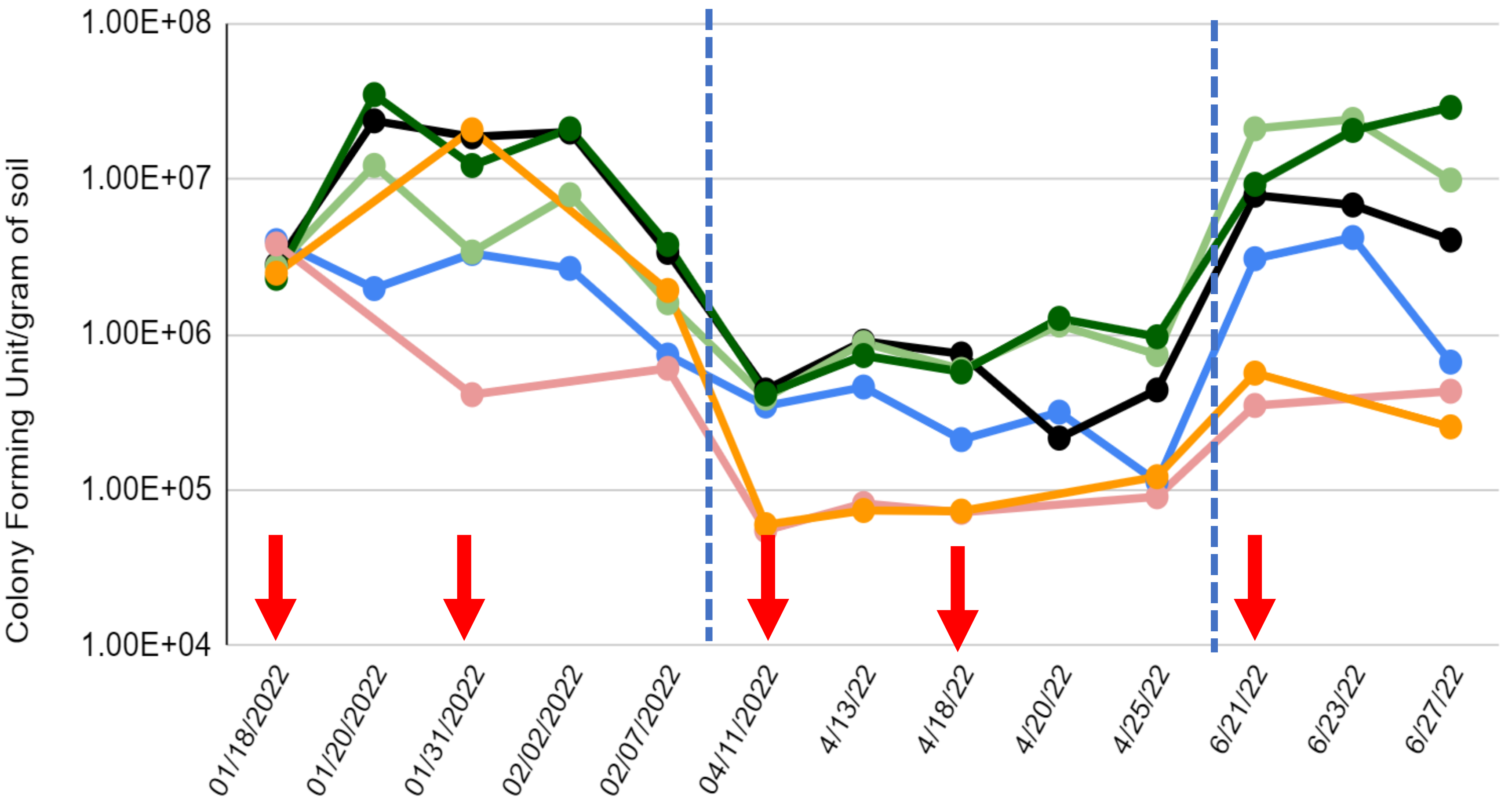
Control
Liquid Bokashi L-BOK 0.5%



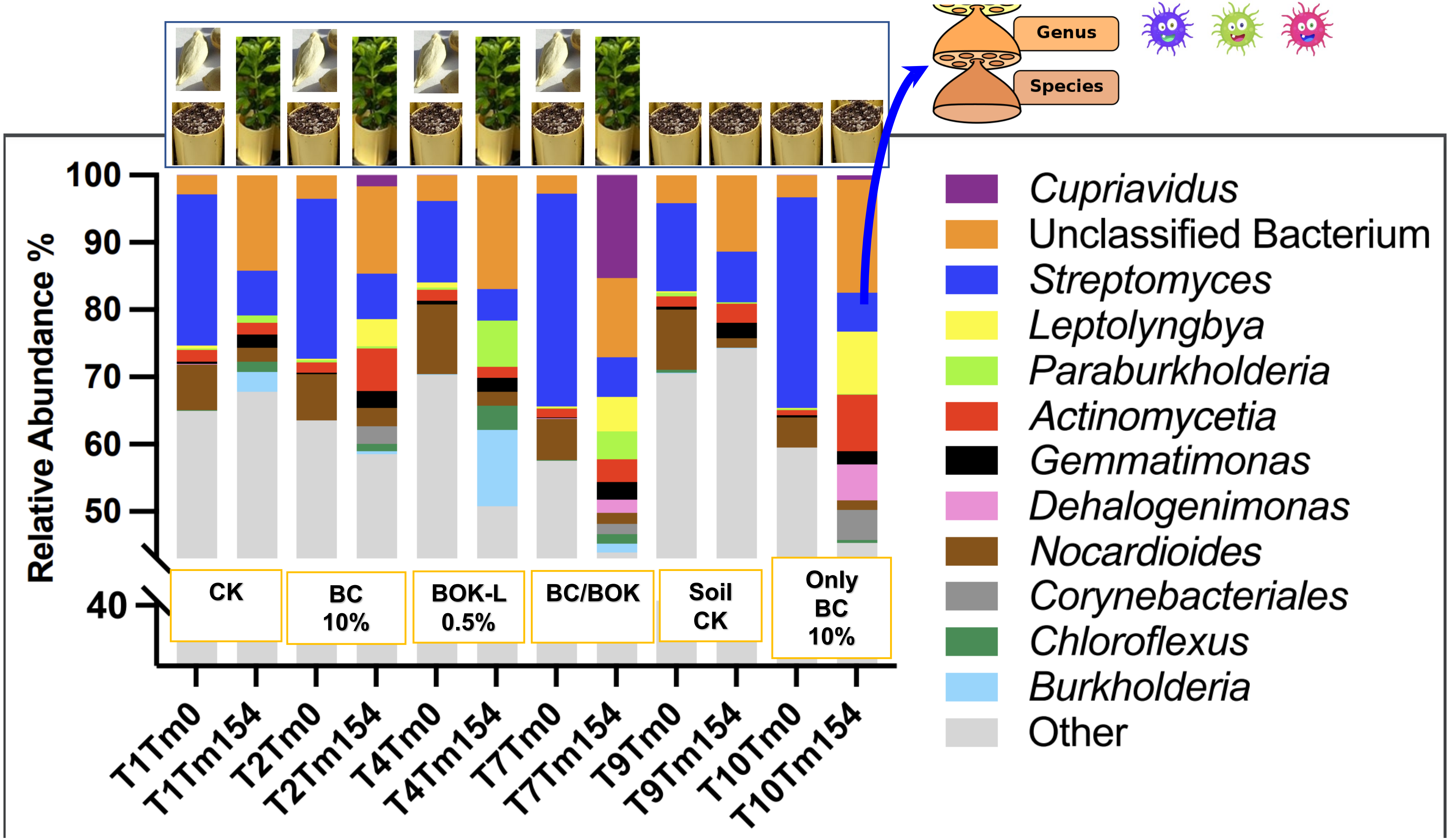
Control
BC + L-BOK (0.5%)

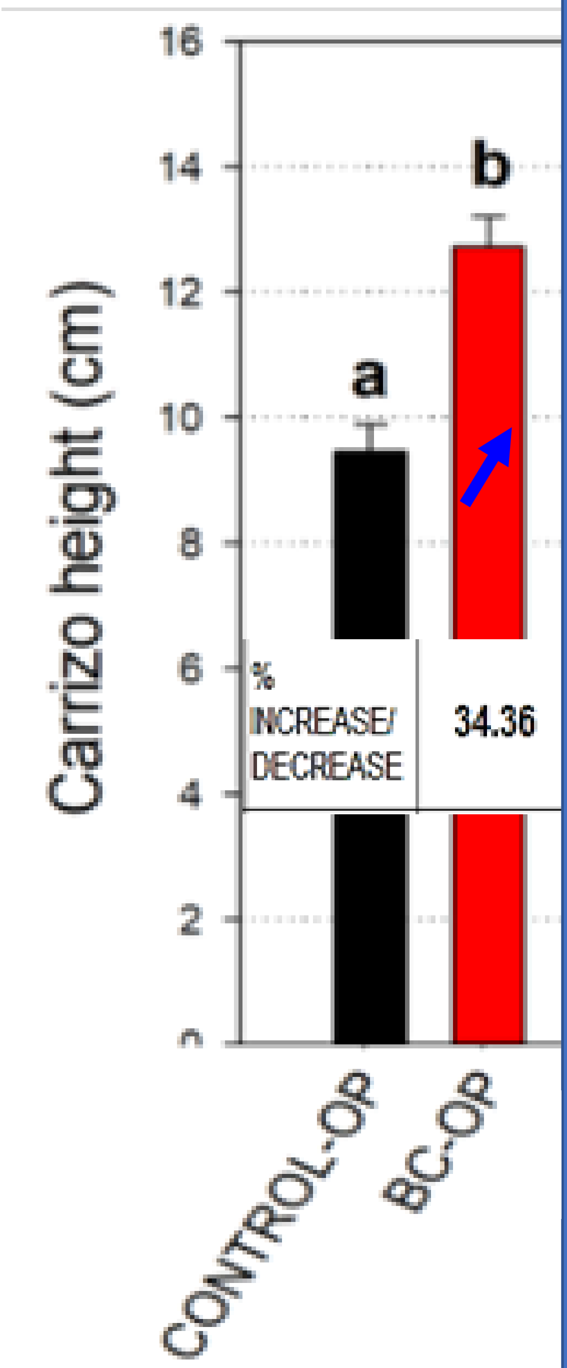


All CULTURABLE Soil Bacteria Experiment 1

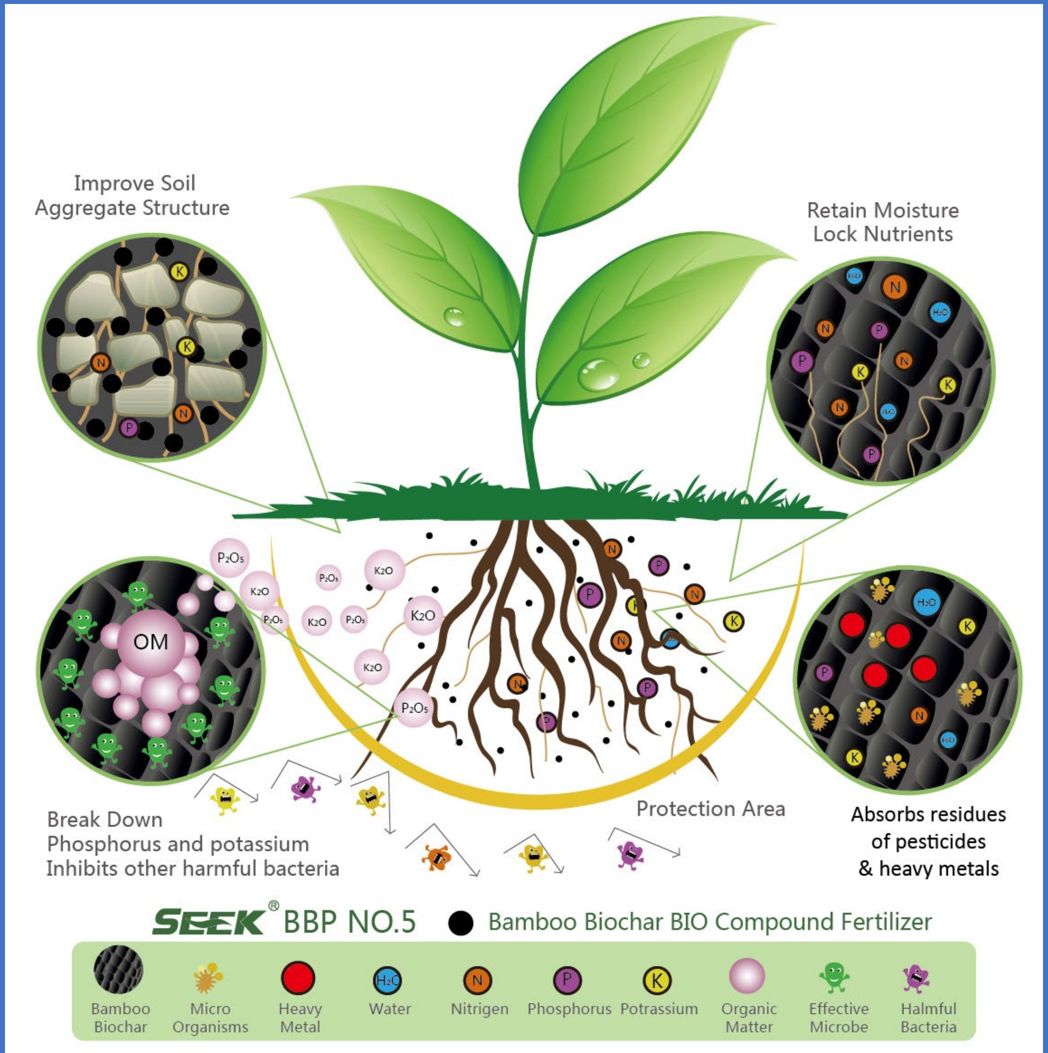


Bacterial dynamics on soil seeded with Carrizo

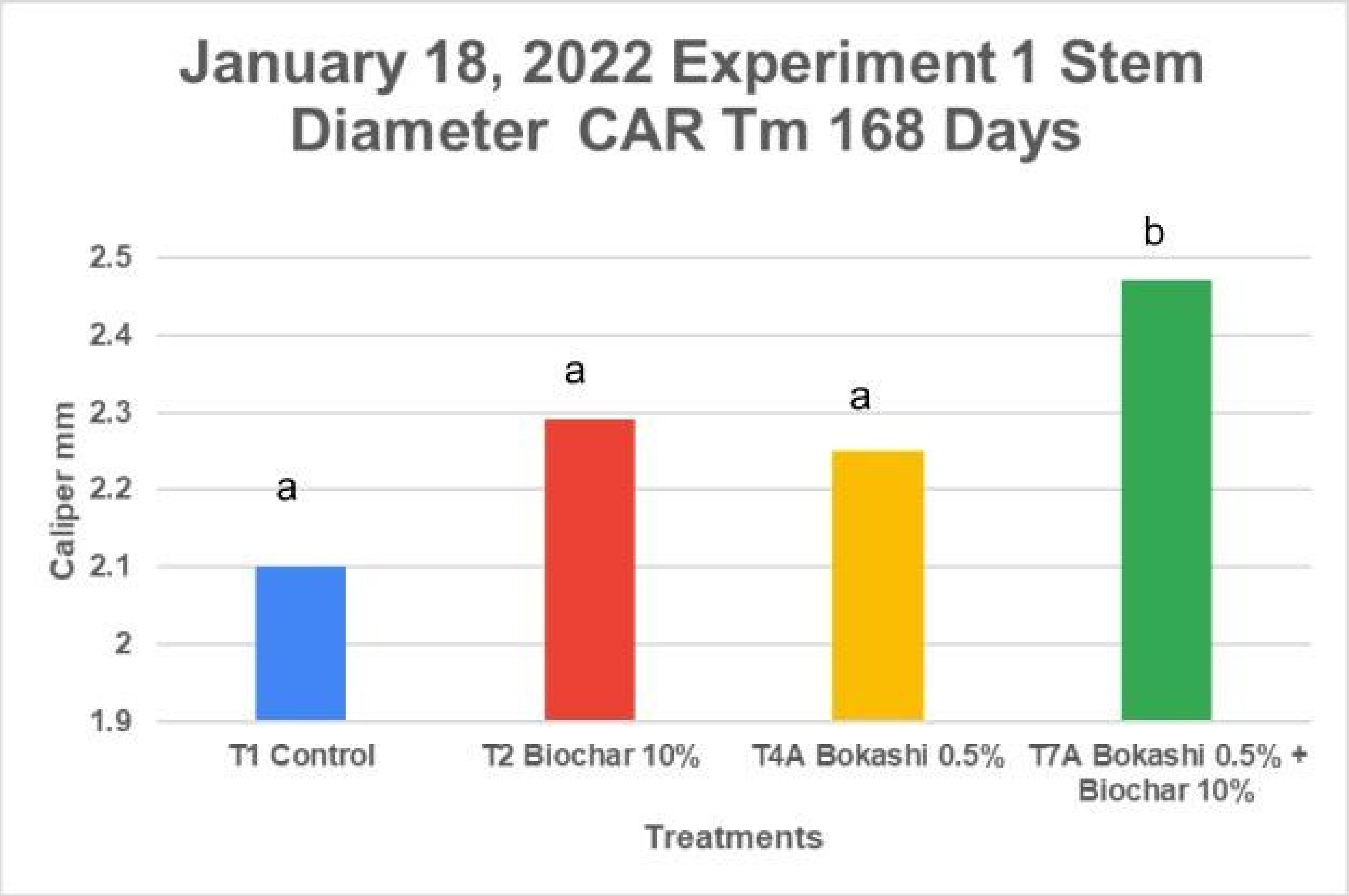




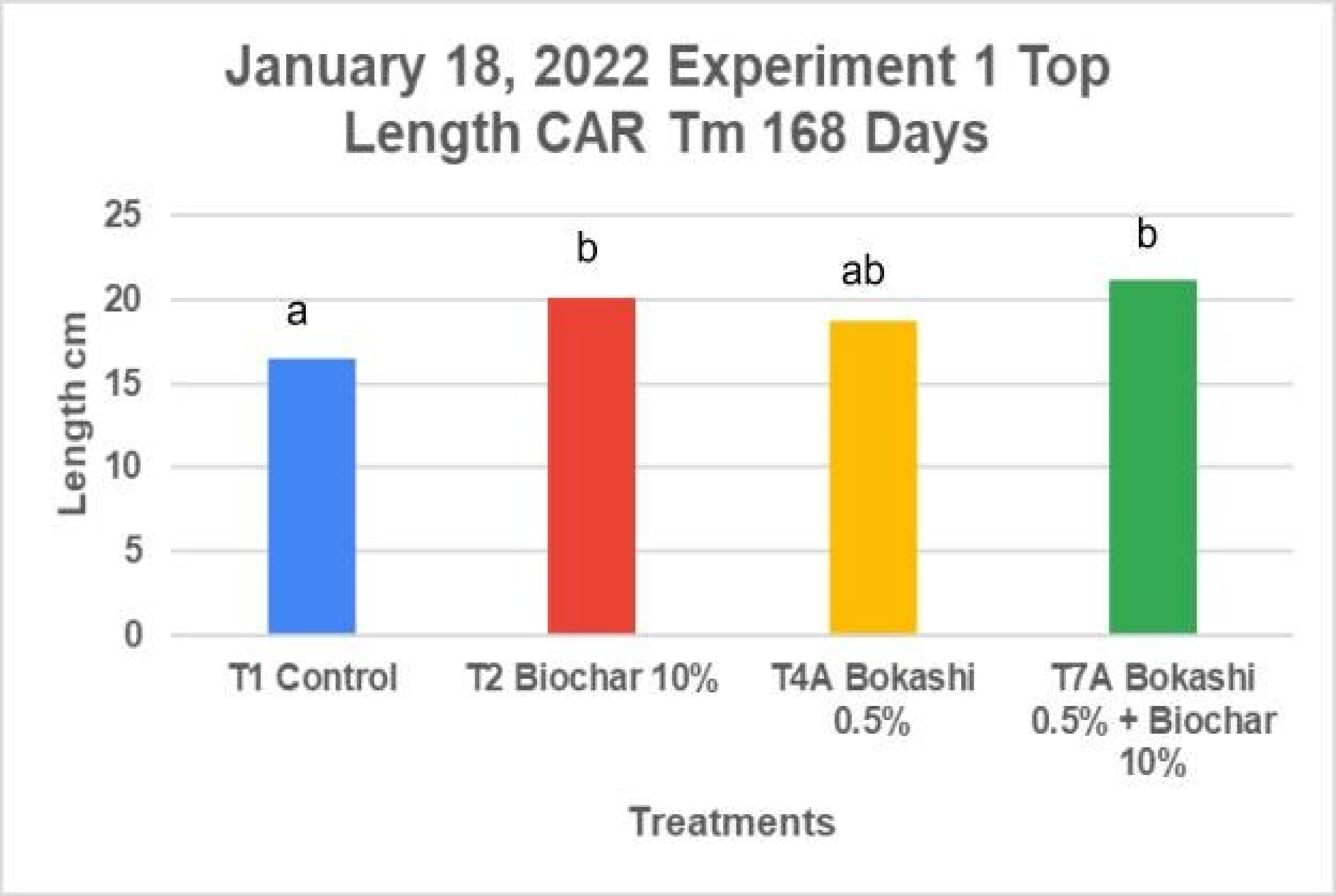
10% biochar alone has a significant positive effect on many plant growth parameters, including plant height, seeds germinations, and caliper



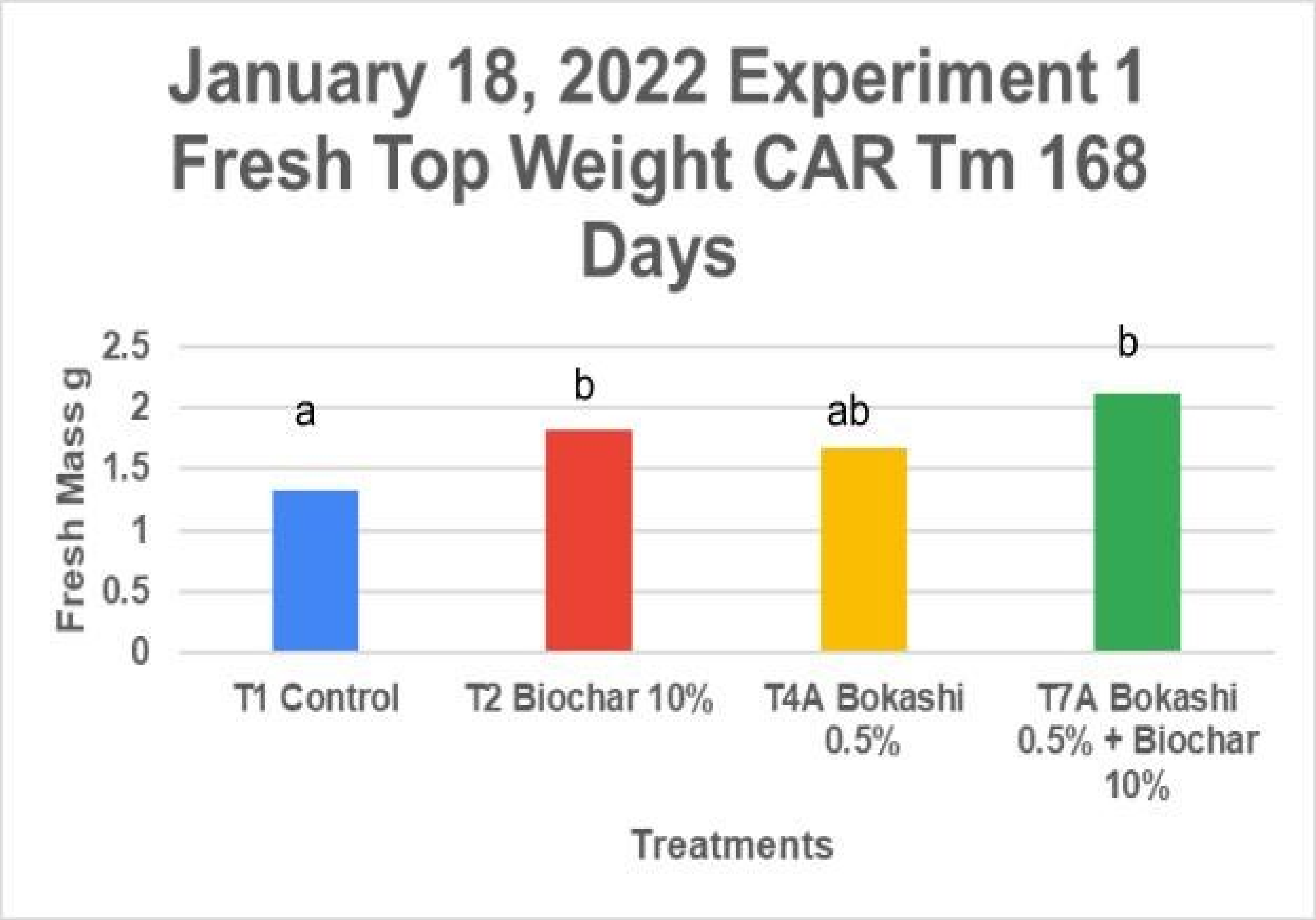
https://biochar.co.nz/images/BBP-NO.5-Diagram.pdf

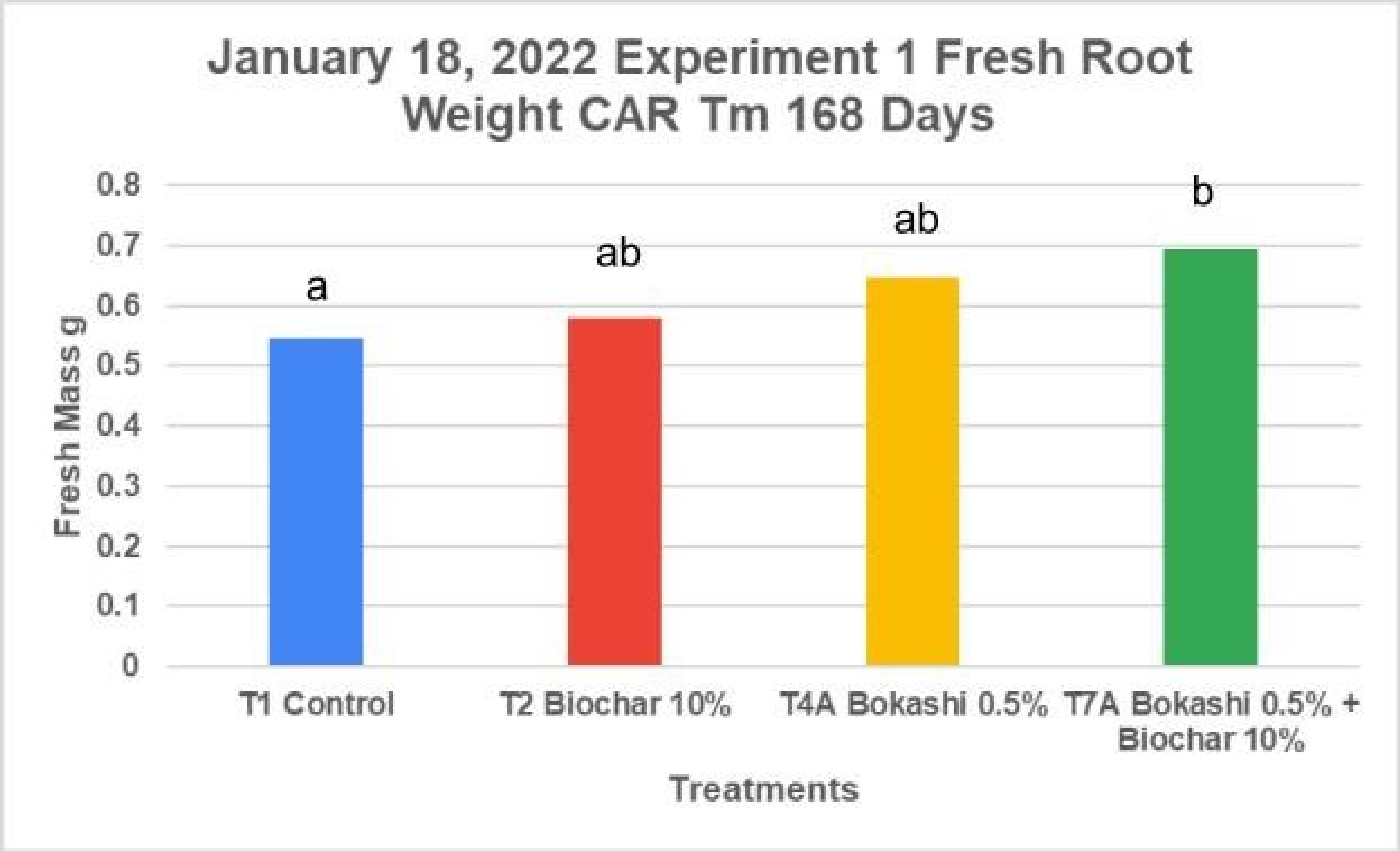


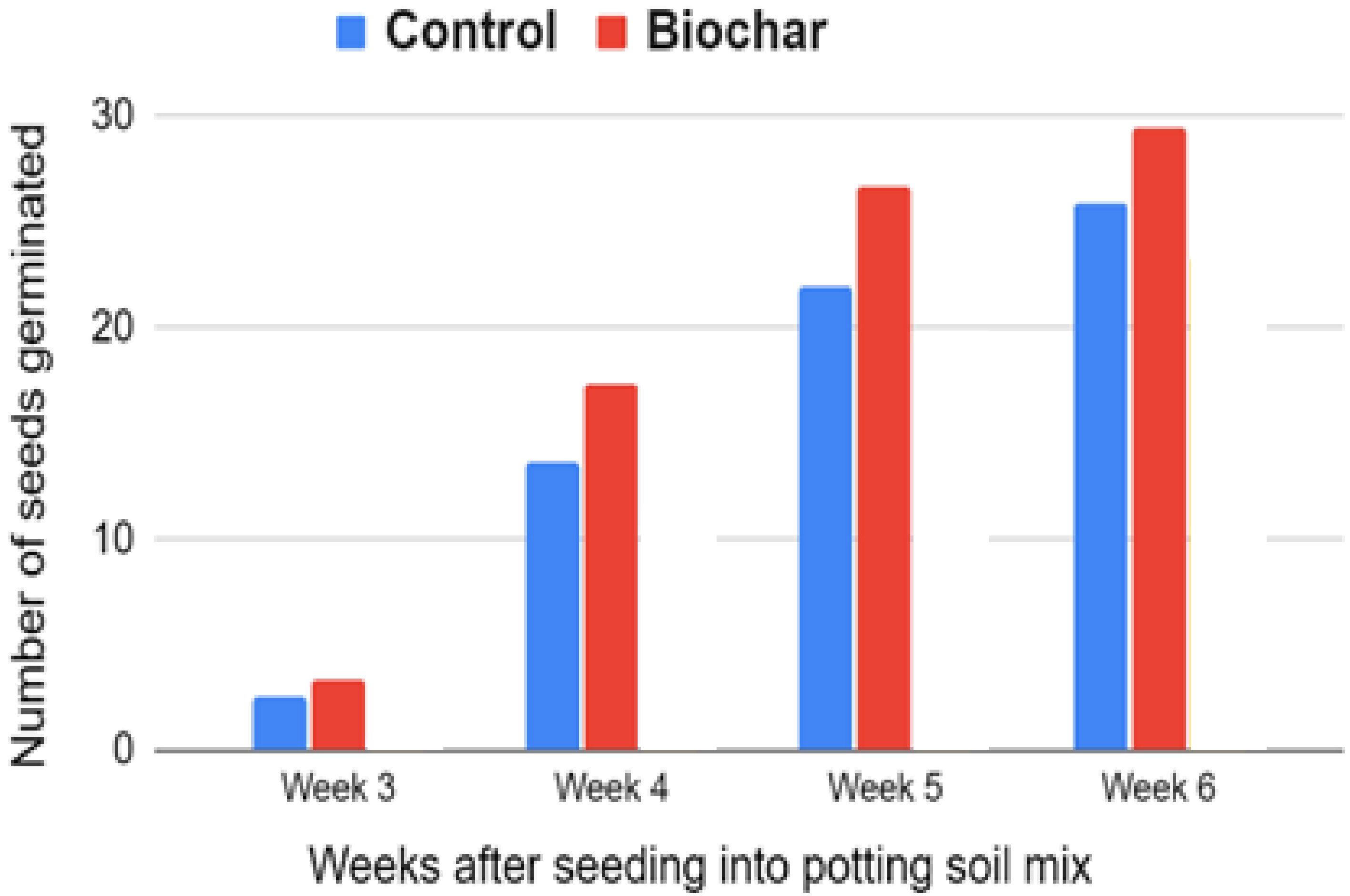
January 18, 2022 Experiment 1 Stem Diameter CAR Tm 168 Days
Caliper mm
2.5
2.4
2.3
2.2
2.1
2
1.9
a
a
a
b
T1 Control
T2 Biochar 10%
T4A Bokashi 0.5%
T7A Bokashi 0.5% + Biochar 10%
Treatments



January 18, 2022 Experiment 1 Top Length CAR Tm 168 Days
Length cm
25
20
15
10
5
0
a
b
ab
b
T1 Control
T2 Biochar 10%
T4A Bokashi 0.5%
T7A Bokashi 0.5% + Biochar 10%
Treatments


January 18, 2022 Experiment 1
Fresh Top Weight CAR Tm 168
Days
Fresh Mass g
2.5
2
1.5
1
0.5
0
a
b
ab
b
T1 Control
T2 Biochar 10%
T4A Bokashi 0.5%
T7A Bokashi 0.5% + Biochar 10%
Treatments


January 18, 2022 Experiment 1 Fresh Root Weight CAR Tm 168 Days
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Fresh Mass g
a
ab
ab
b
T1 Control
T2 Biochar 10%
T4A Bokashi 0.5%
T7A Bokashi 0.5% + Biochar 10%
Treatments



10% biochar has a positive effect on many plant growth parameters including seeds germinations

Liquid BOK

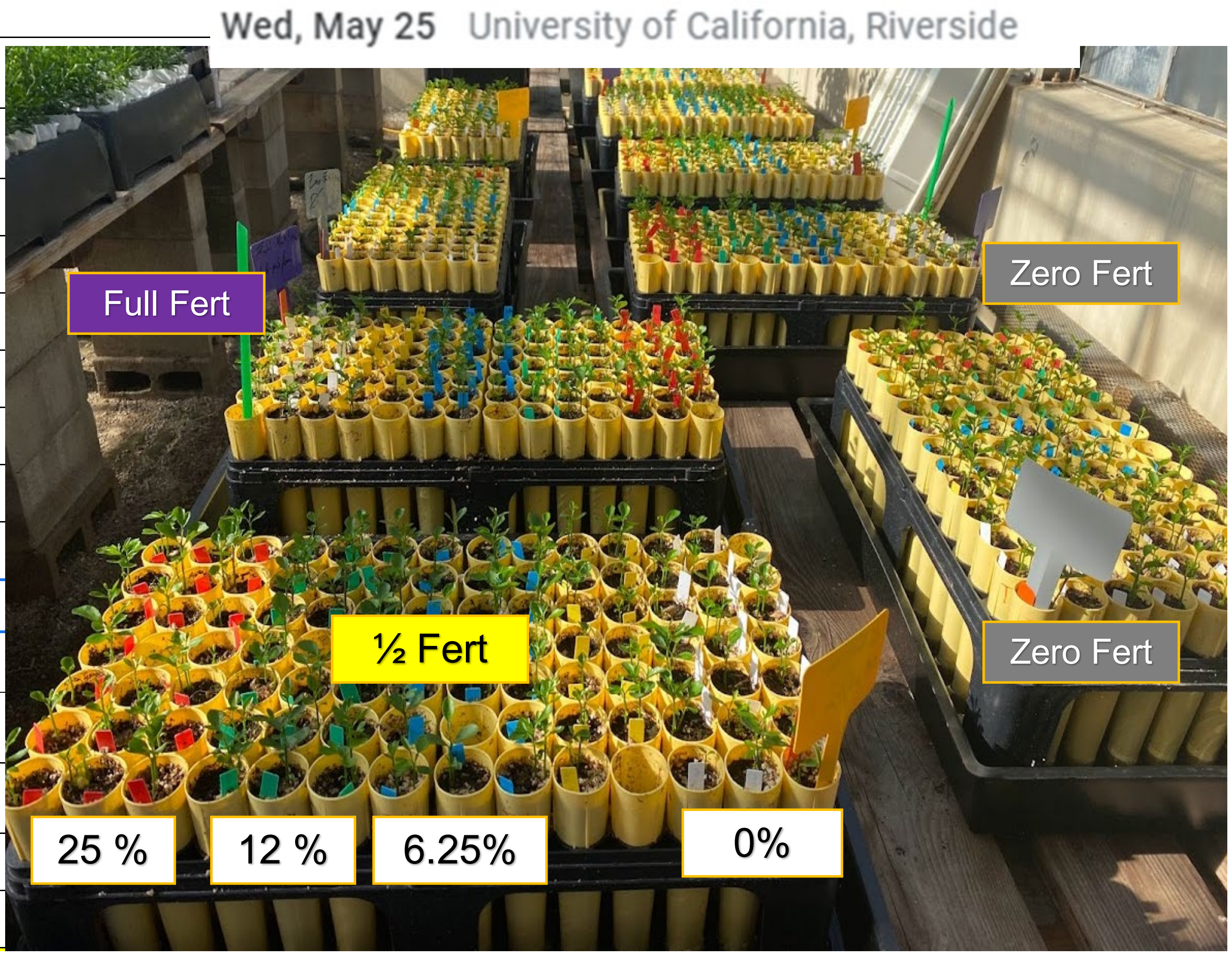
Soil mixes

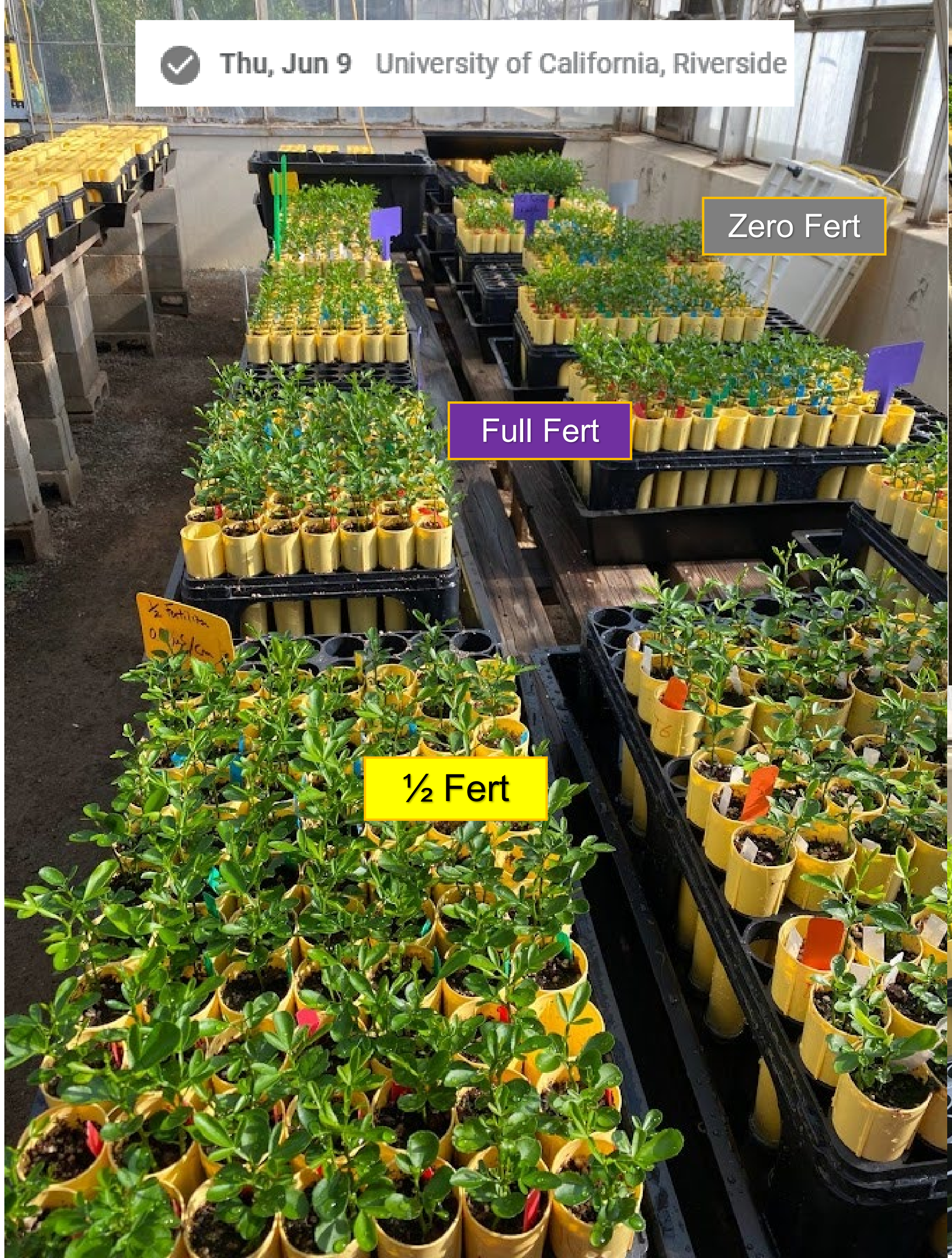
PHASE 3

Time range – From seeding to 5-6 months

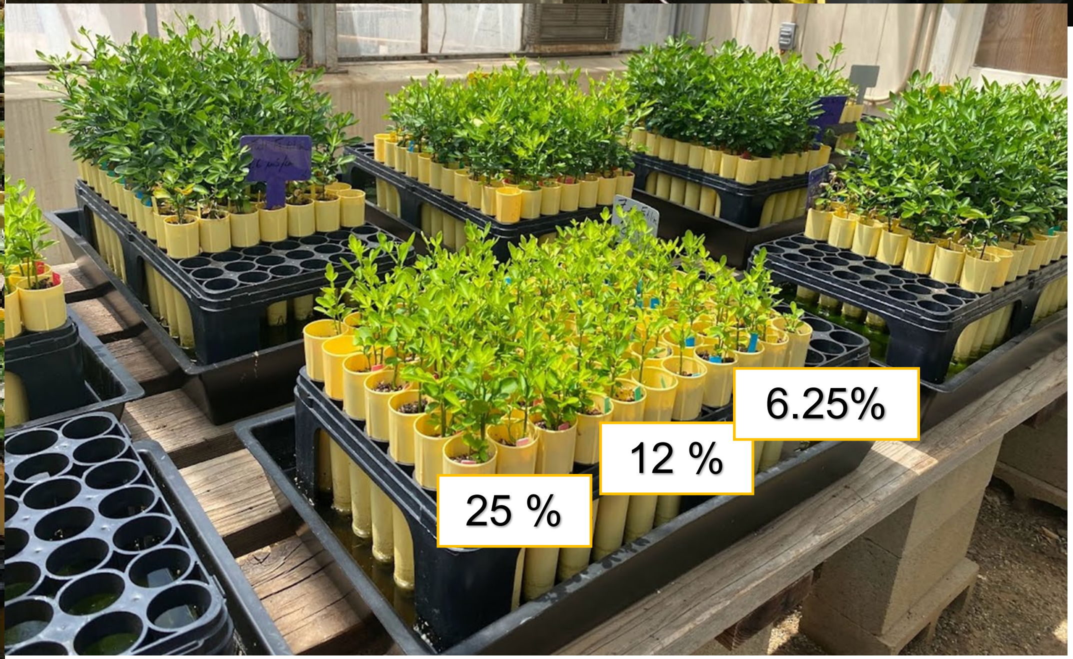
	For the 3rd **phase** we are investigating under greenhouse conditions:
	1. C, N, and C/N ratio dynamics.
	2. Microbiome changes over time during in soil and root in the first 3 months.
	3. Impact on plant growth parameters and stress resilience

Use deionized water	TREATMENTS	OPEN IRRIGATION	Cones per Rep	# Replicates (i.e. RACKS A, B, C)
Full Fertilizer dose 1400 uS/cm	Control	T1		
Full Fertilizer dose uS/cm	Bokashi sprinkles directly	T2		
Full Fertilizer dose uS/cm	Bok Solid 6.25%	T3		
Full Fertilizer dose uS/cm	Bok Solid 12.5%	T4		
Full Fertilizer dose uS/cm	Bok Solid 25%	T5		
Half fertilizer dose 700 uS/cm	Control	T6		
Half fertilizer dose uS/cm	Bokashi sprinkles directly	T7		
Half fertilizer dose uS/cm	Bok Solid 6.25%	T8		
Half fertilizer dose uS/cm	Bok Solid 12.5%	T9		
Half fertilizer dose uS/cm	Bok Solid 25%	T10		
Zero fertilizer dose 0 uS/cm	Control	T11		
Zero fertilizer dose 0 uS/cm	Bokashi sprinkles directly	T12		
Zero fertilizer dose 0 uS/cm	Bok Solid 6.25%	T13		
Zero fertilizer dose 0 uS/cm	Bok Solid 12.5%	T14		
Zero fertilizer dose 0 uS/cm	Bok Solid 25%	T15		



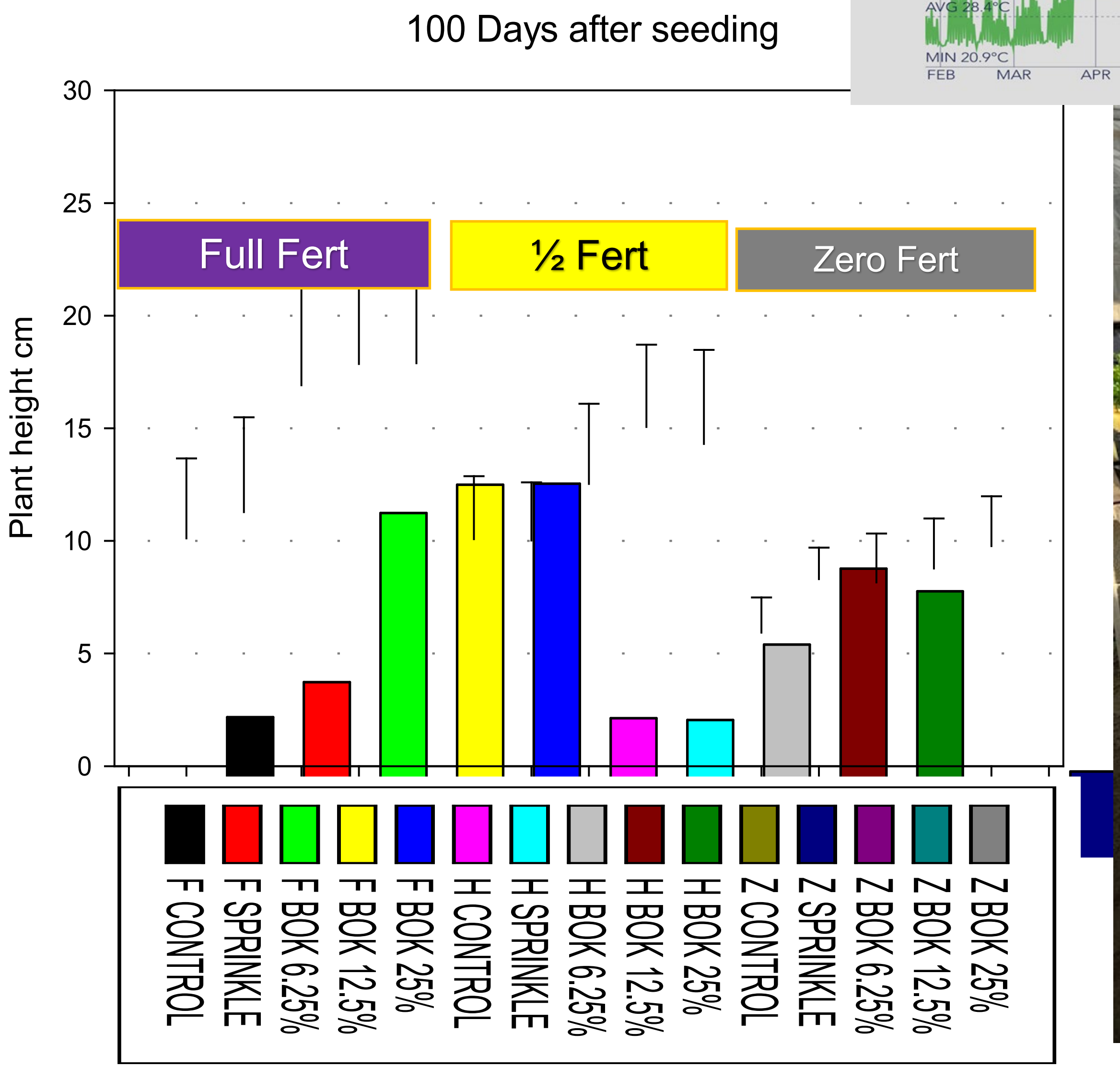

Thu, Jun 9 University of California, Riverside
Zero Fert
Full Fert
½ Fert

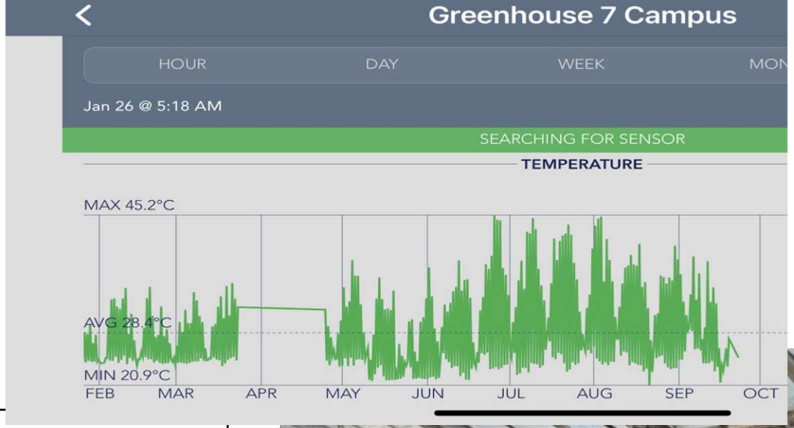

Full Fert
Zero Fert
Full Fert
0%
½ Fert
Mon, Jul 18 Riverside, CA


6.25%
12 %
25 %

Bokashi improved

1. plant stress resilience
2. Plant growth compared to control
3. ½ fertilizer with Bok 12.5% +++

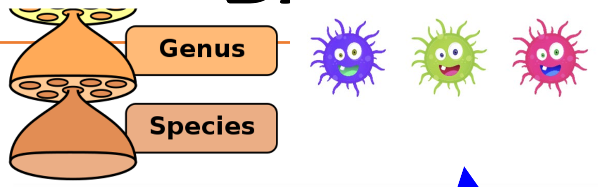


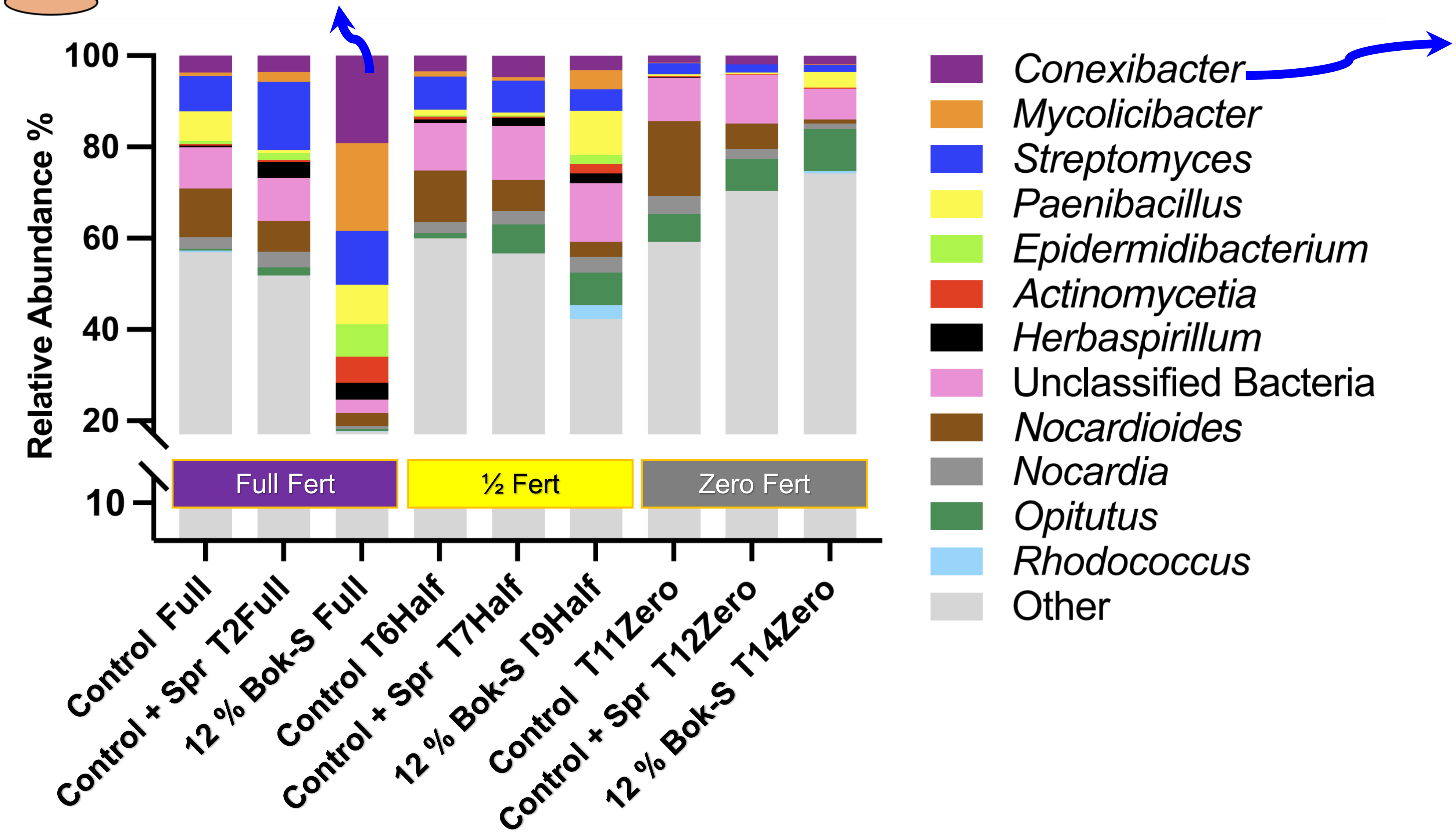


Bokashi improved plant growth

- For at least the first 2 months
- After that additional carbon sources needs to be amended.

BACTERIAL DYNAMICS ON SOIL SEEDED WITH CARRIZO



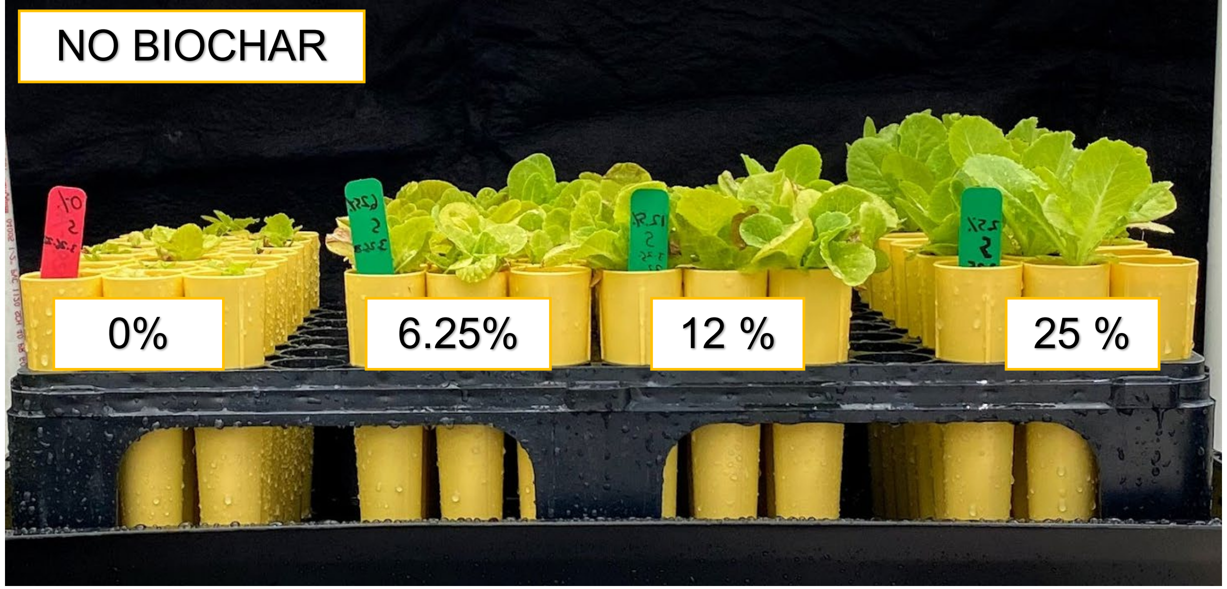


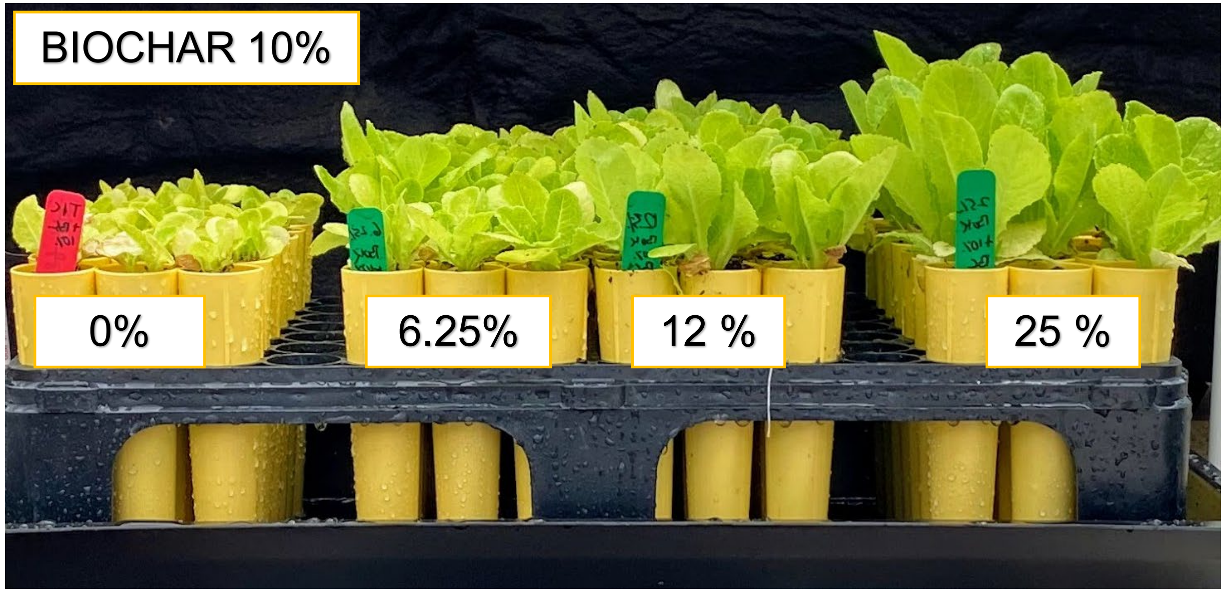
They contribute to carbon cycling in soil environments and have the potential to also be contributing to nitrogen cycling.

Bacterial dynamics on Carrizo Root

edgeRootCarSolid
Treatments3rdPhasePL2
Congress

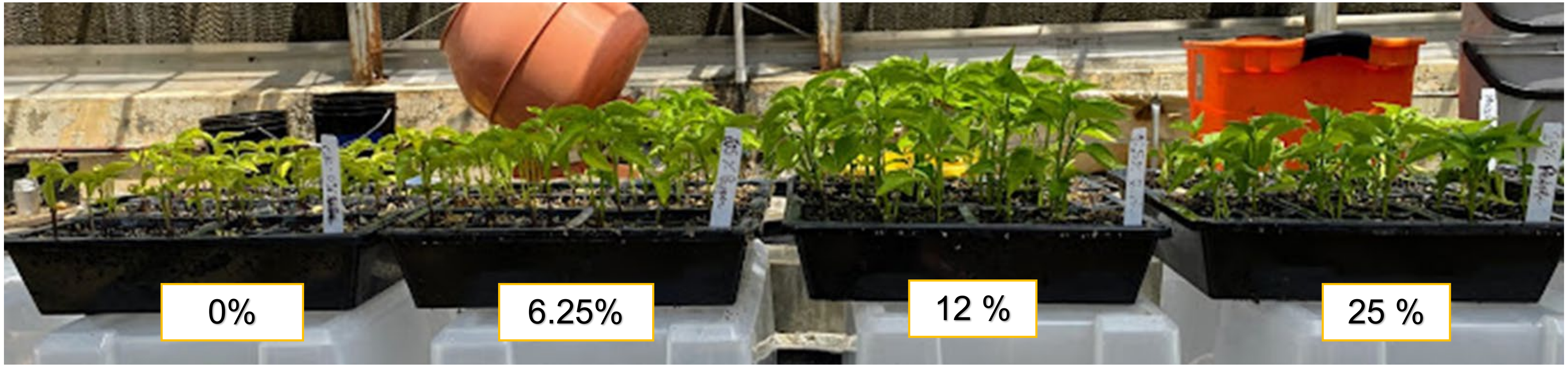
COMING SOON!





Same results on other crops where Bokashi improved plant growth

- BIOCHAR has synergistic effect
- Amendment at around 10-12% seems to have best results.



Going in the right direction….

BY-PRODUCTS

The liquid
MAINTAIN

The solid
BUILD

Nutrient-rich
organic matter

Manage C to create a dynamics flow of nutrient availability and cycling to improve soil fertility, microbiome and plant health

Add stable
CARBON

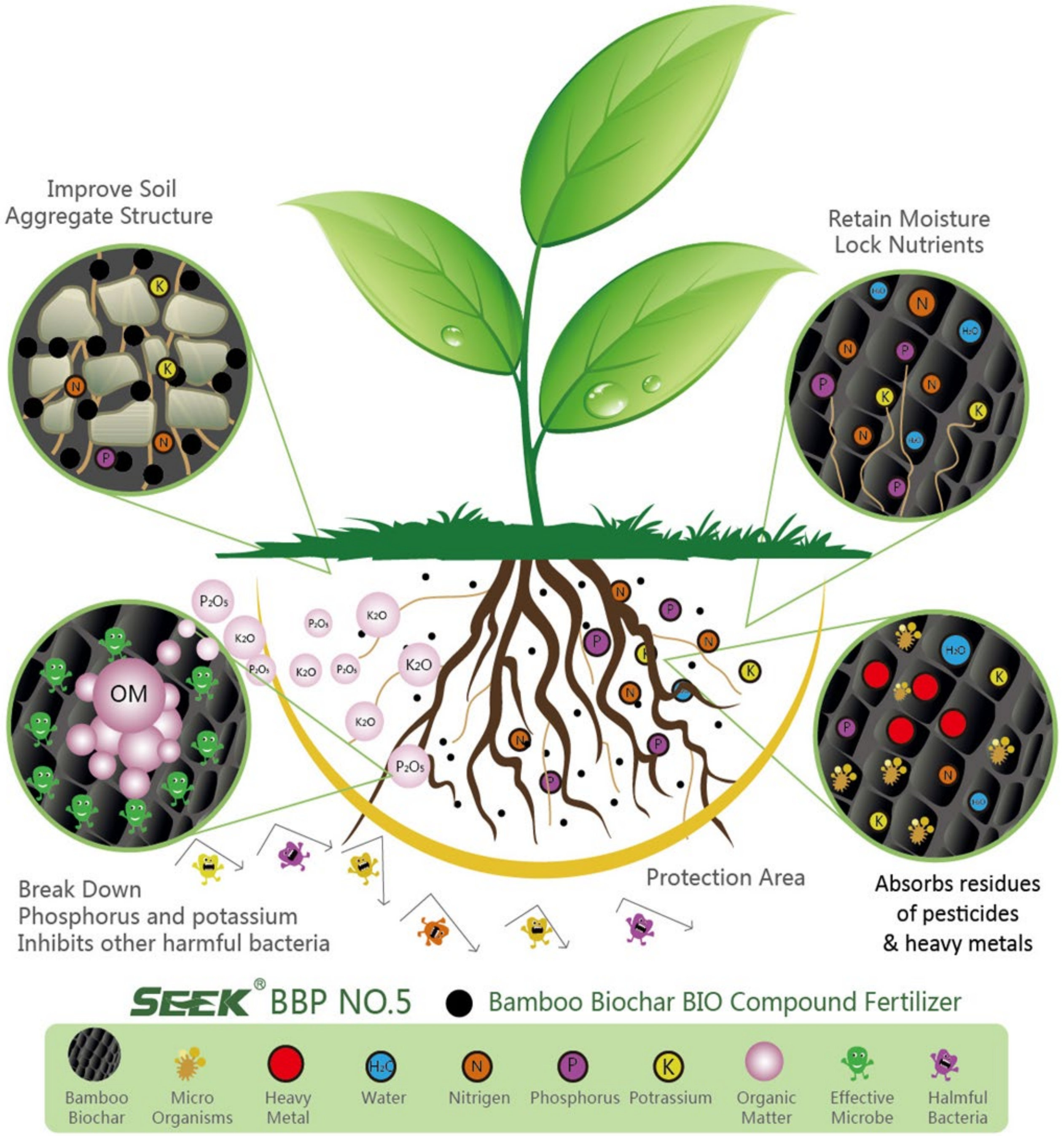
Biochar helps to BUILD & MAINTAIN!

Drawbacks & Opportunity

- Very promising use of
  - **Biochar at 10% &**
  - **Bokashi at around 10-15%**
- **However, both % can be reduced!**
- **Co-composting**
  - Composting substantially increases the concentration of nutrients in biochar
  - Organic carbon (OC)
  - Microbial biomass carbon (C_{mic})
  - Cation exchange capacity (CEC)

Cleaner Run-Off

Greater Fertilizer Utilization Efficiency

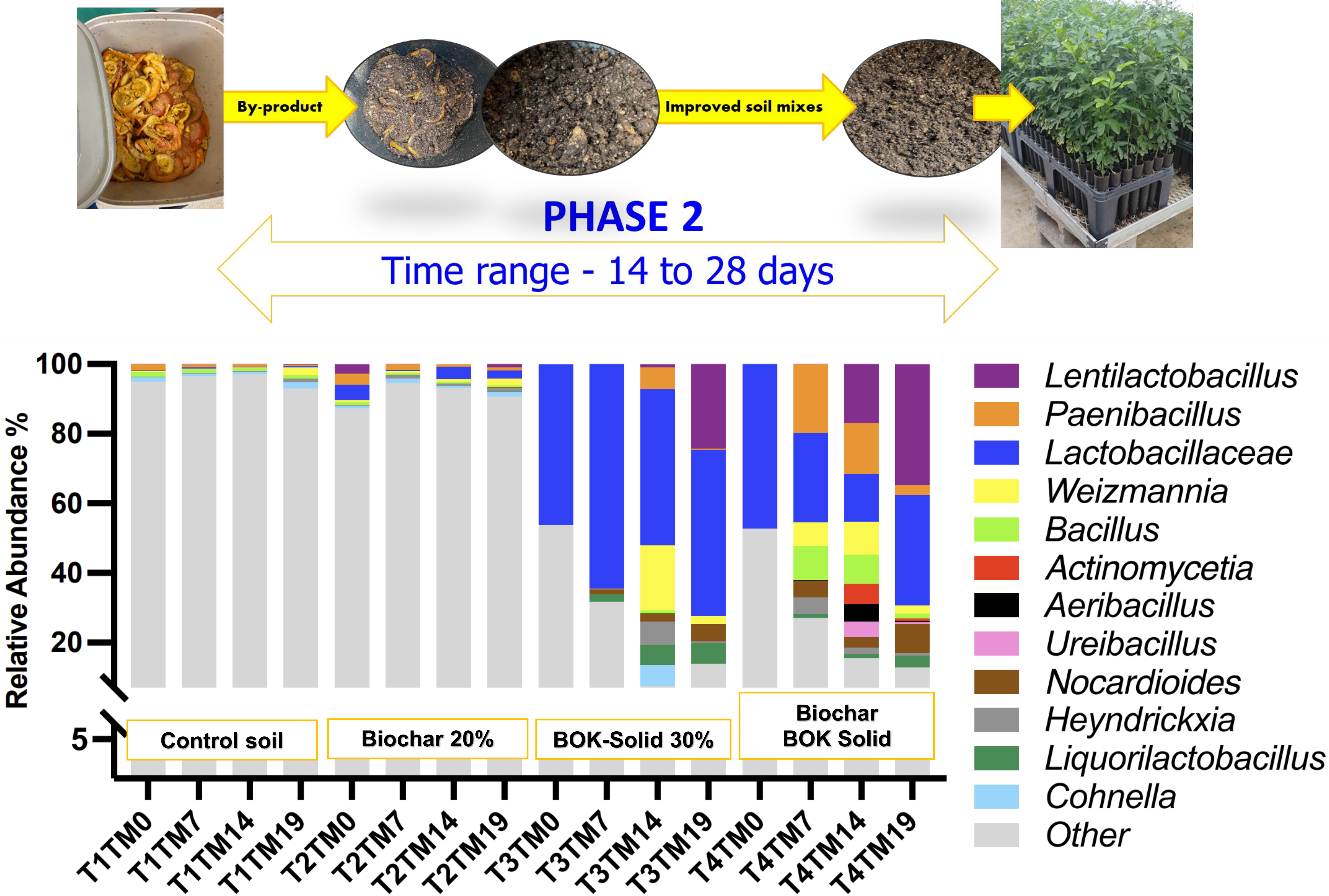


https://biochar.co.nz/images/BBP-NO.5-Diagram.pdf

Review

The roles of co-composted biochar (COMBI) in improving soil quality, crop productivity, and toxic metal amelioration ☆

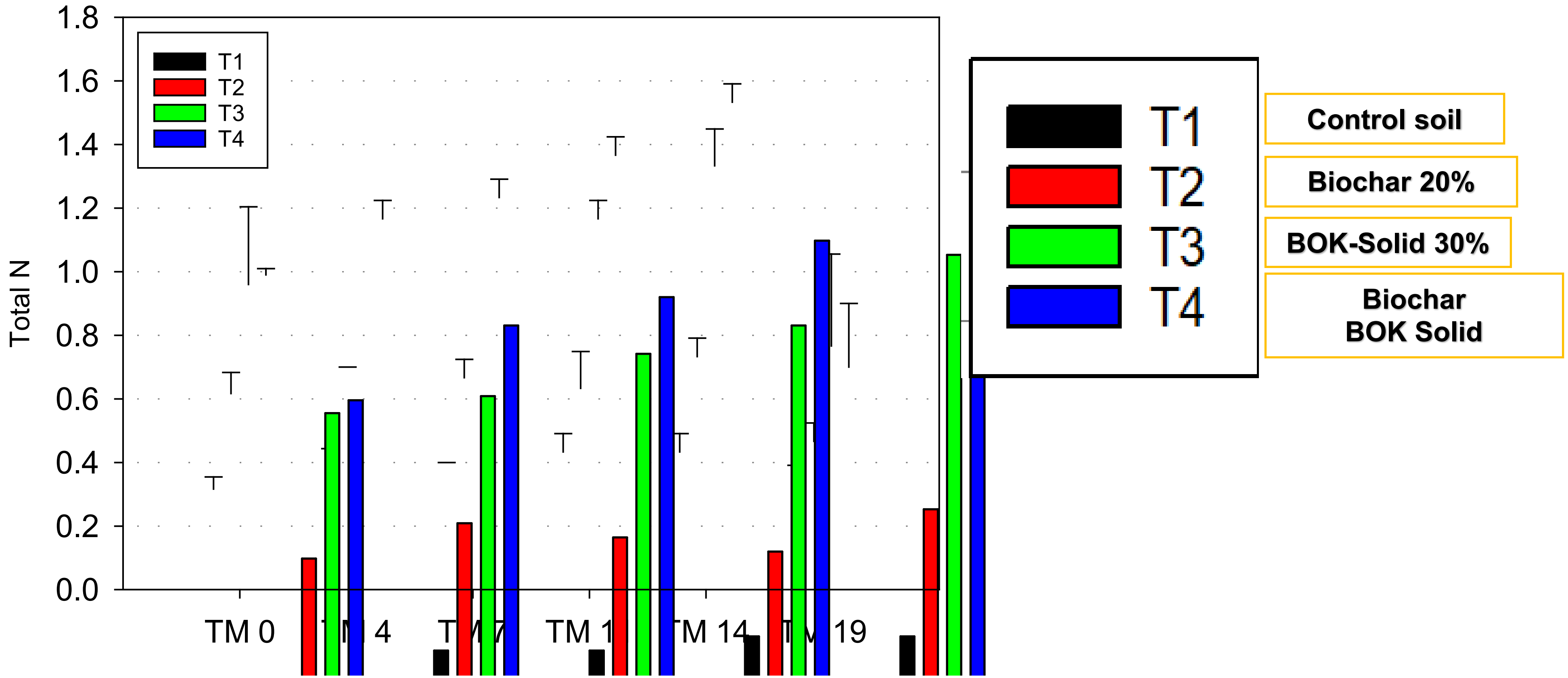
João A. Antonangelo [a], Xiao Sun [b], Hailin Zhang [a]



By-product
Improved soil mixes
PHASE 2
Time range - 14 to 28 days
Relative Abundance %
100
80
60
40
20
5
Control soil
Biochar 20%
BOK-Solid 30%
Biochar
BOK Solid
T1TM0
T1TM7
T1TM14
T1TM19
T2TM0
T2TM7
T2TM14
T2TM19
T3TM0
T3TM7
T3TM14
T3TM19
T4TM0
T4TM7
T4TM14
T4TM19
Lentilactobacillus
Paenibacillus
Lactobacillaceae
Weizmannia
Bacillus
Actinomycetia
Aeribacillus
Ureibacillus
Nocardioides
Heyndrickxia
Liquorilactobacillus
Cohnella
Other

PHASE 2

Time range - 14 to 28 days



Review

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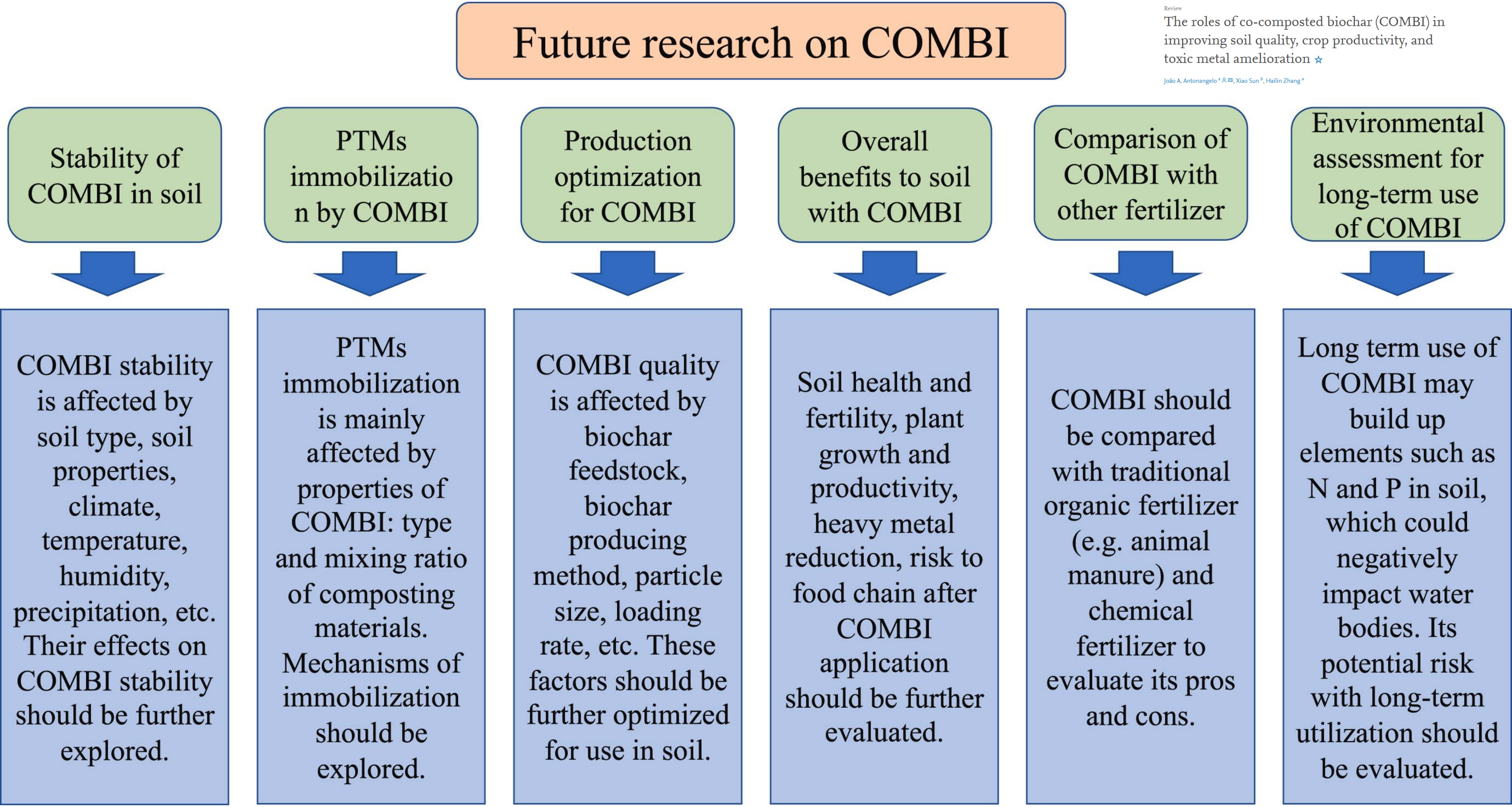
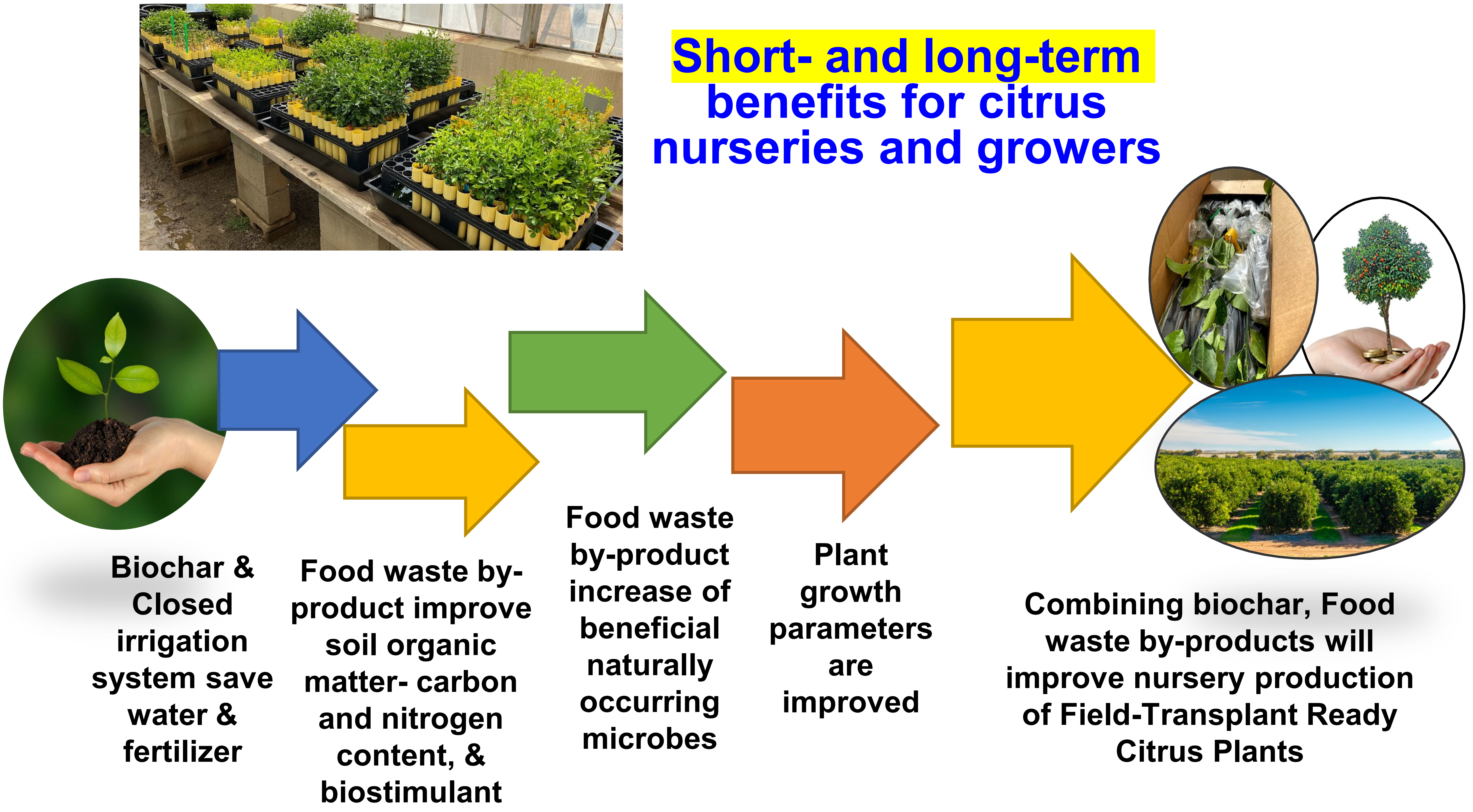


Scaling up


Short- and long-term benefits for citrus nurseries and growers
Biochar & Closed irrigation system save water & fertilizer
Food waste by-product improve soil organic matter- carbon and nitrogen content, & biostimulant
Food waste by-product increase of beneficial naturally occurring microbes
Plant growth parameters are improved
Combining biochar, Food waste by-products will improve nursery production of Field-Transplant Ready Citrus Plants

Thank You

James Borneman
Samantha Ying
Ashraf El-Kereamy
Georgios Vidalakis
Jonathan D. Kaplan
Mike Woelk
Francesca Hopkins

Sohrab Bodaghi
Michelle Ortiz
Sohrab Bodaghi
Benjamin Maki
Michael Rodriguez
Norman Ellstrand

Research project supported by funding from

CCNB

cdfa
CALIFORNIA DEPARTMENT OF FOOD & AGRICULTURE

corigin

Thank You!

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Wonderful citrus

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University of California Cooperative Extension

Thomas A Delfino

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