Short-term improvement of soil biological activity in biochar-amended organic greenhouse tomato crops – no effect on crop performance

BioGreenhouse

cost
EUROPEAN COOPERATION
IN SCIENCE AND TECHNOLOGY

COST is supported by
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Horizon 2020

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Challenge of organic greenhouse farming

Soil nutrient release that will perfectly match plant nutrient uptake, without any leaching or emissions into the environment

✓ Balanced fertilizers/amendments

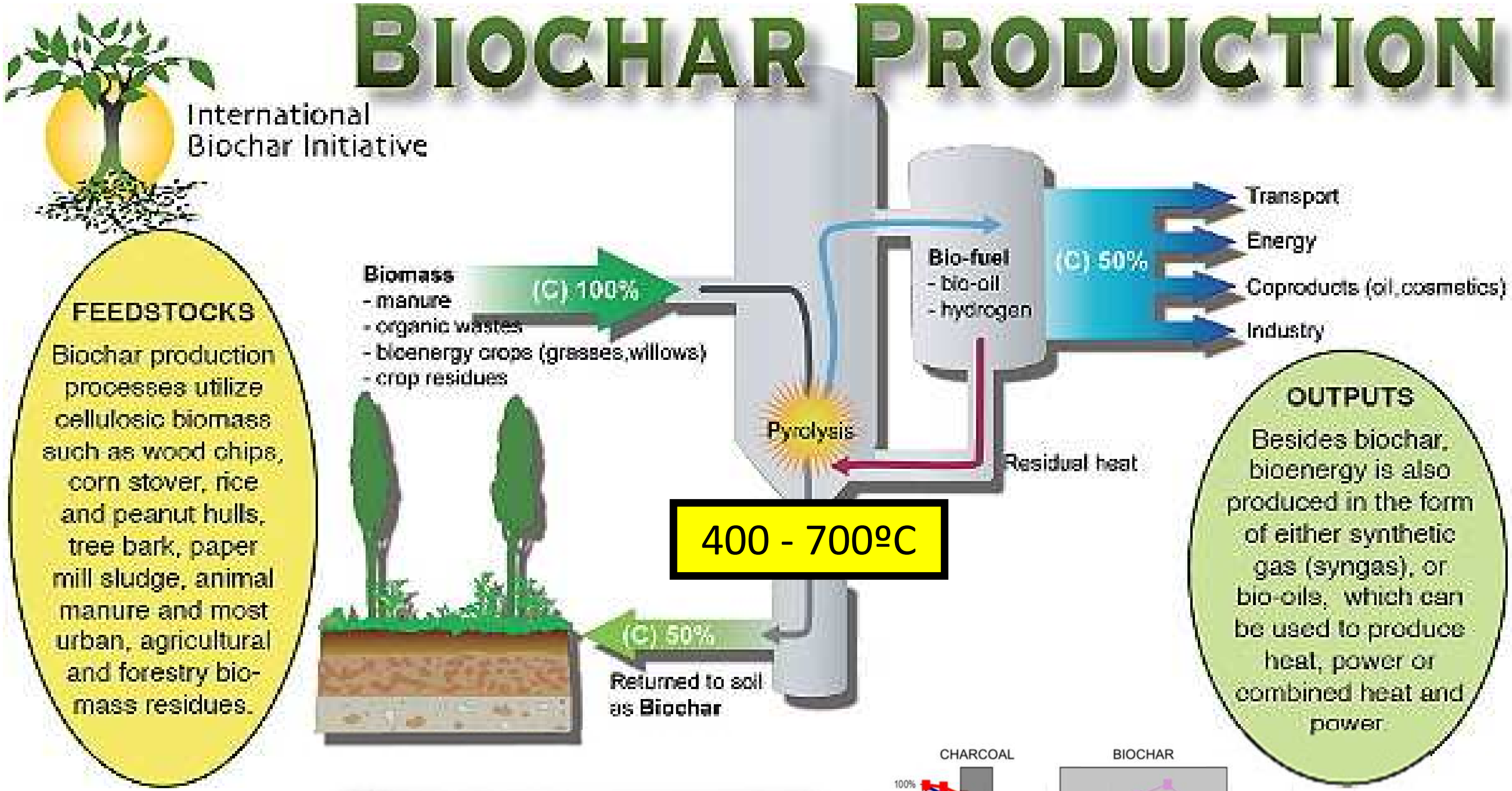
Plant nutrient uptake

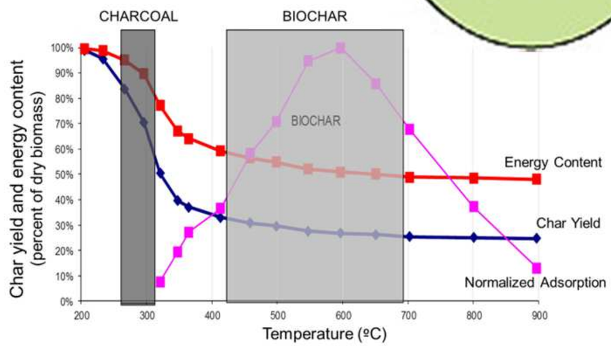
✓ High mineralization rate ➡ High nutrient plant demand

✓ Optimal fertilization ➡ minimize salinization + GHG

✓ Optimal irrigation ➡ No nutrient leaching (*e.g.* N, Ca, Mg)

Biochar as a soil amendment ⇨ ↑ Soil quality





Definition :

Charcoal from the thermal decomposition (pyrolysis) of C-rich biomass materials (Yao et al., 2012)

Source: www.energyrealist.com

Biochar effects on soil quality

Limiting Factor	Parameter	Problem	Role of biochar
Physical	Structure	Compaction	• Decreases bulk density
	Erosion	Erodibility	• Higher infiltration capacity
	Humidity	Soil drying	• Increases soil water retention

(adapted from Shrestha & Lal, 2006)

Hypothesis – organic greenhouse tomato

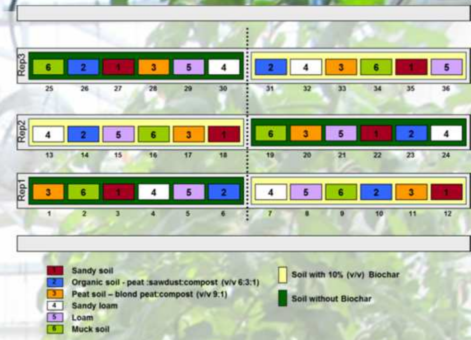
Biochar amendment to different types of organic soil can:

(1) Increase soil microbial activity, mycorrhizal colonization and plant nutrient availability

(2) Decrease CO_2 and N_2O emissions and nutrient leaching

(3) Improve plant growth, yield and fruit quality of organic greenhouse tomato

- 150 m^2 greenhouse
- Cv Trust grafted on Beaufort
- 0.62 m^3 container (2.4 plants/m^2)



- Six types of soil
  Sand
  Sandy loam
  Loam
  Muck soil
  Peat - sawdust
  Peat mix

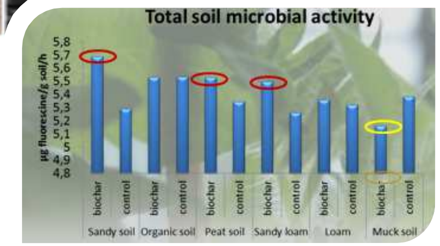
A three-year experiment

and 2-week (mid-Aug. to end of Oct.) intervals

- Irrigation : ψ_m –20 to –40 kPa
- Split plot with 3 replicates - ANOVA using the MIXED procedure + Tukey's test ($P \leq 0.05$)

Biochar soil amendment (10% v/v) – after 1 year

Biochar	Significant effect ($p<0.05$)	↓ GHG Emission
Biochar	No significant effect ($p<0.05$)	Soil mineral content CO_2 & light Ph saturation curves Fluorescence Fv/Fm ratio Plant growth parameters Yield and fruit quality
Soil type	Significant effect ($p<0.05$)	Soil mineral content Fluorescence Fv/Fm ratio Plant growth parameters Yield
Biochar*soil	Significant effect ($p<0.05$)	Soil microbial activity (FDA



+ Sandy
+ Sandy loam
+ Peat mix

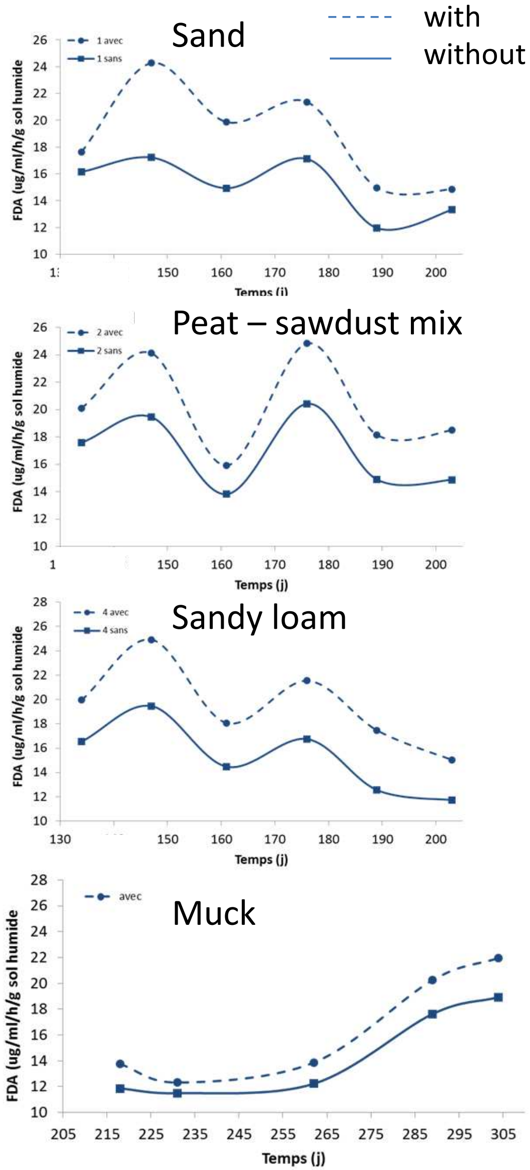
Biochar soil amendment (10% v/v) – after 2 years

Microbial activity

(FDA; ug fluorescein /ml/h/g soil)

May-July 2013 (4-wk interval)		Biochar with	Biochar without	*P value*
Sand	**↑ 25%**	**18.8**	**15.1**	***0.0001***
Peat sawdust mix	**↑ 21%**	**20.3**	**16.8**	***0.0002***
Peat mix		19.7	18.8	*0.2440*
Sandy loam	**↑ 27%**	**19.5**	**15.3**	***<0.0001***
Loam		15.6	14.6	*0.2253*
Muck	**↑ 17%**	**18.2**	**15.5**	***0.0029***

August to October 2013 (2-wk interval)		Biochar with	Biochar without	*P value*
FDA (ug/ml/h/g sol humide)	**↑ 14%**	**16.4**	**14.4**	***0.0047***



Biochar soil amendment (after 2 years) – Flux of CO_2

May-July 2013 (4-wk interval)		Biochar with	Biochar without	*P value*
Flux of CO_2 (mg CO_2 m^{-2} s^{-1})	↓ 15%	**17.6**	**20.8**	***0.05***

August to October 2013 (2-wk interval)		Biochar with	Biochar without	*P value*
Flux of CO_2 (mg CO_2 m^{-2} s^{-1})	↓ 17%	**9.0**	**10.9**	***0.01***

- ✓ **Increased carbon-use efficiency from co-location of soil microbes, soil organic matter and nutrients**
- ✓ **Precipitation of CO_2 onto the biochar surface (e.g. carbonate)**

(Case et al 2014)

Biochar soil amendment (after 2 years) – Soil mineral content

	Control	10 % biochar	P value	
NO_3 (mg L^{-1})	**843**	**1008**	**0.0019**	↑ **20%**
NH_4 (mg L^{-1})	64	65	0.8565	
Mn (mg L^{-1})	**31**	**42**	**<0.0001**	↑ **35%**
Zn (mg L^{-1})	**493**	**298**	**<0.0001**	↓ **40%**
CEC (mEq/100g)	85	85	0.7527	→ Relatively low specific surface area

No significant difference for the mineral content of the soil solution

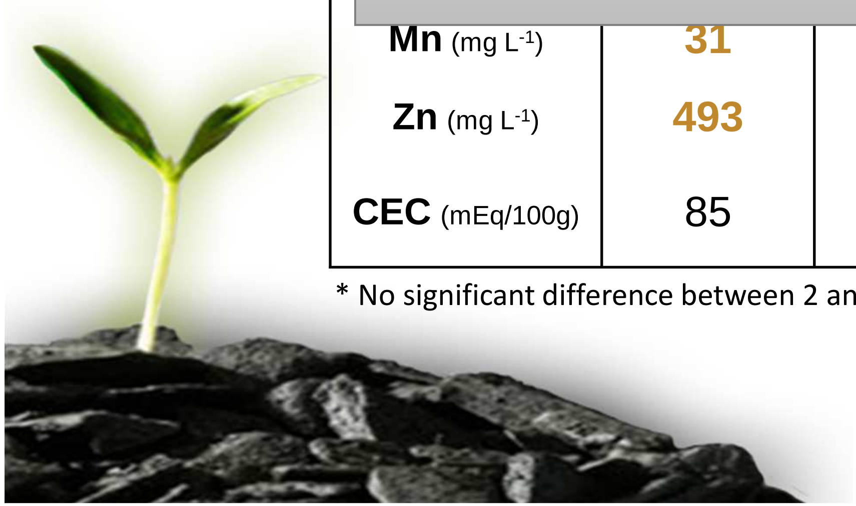
weekly analysis

↑ **17%**

↑ **24%**

↑ **60%**

* No significant difference between 2 and 4 week interval fertilization periods

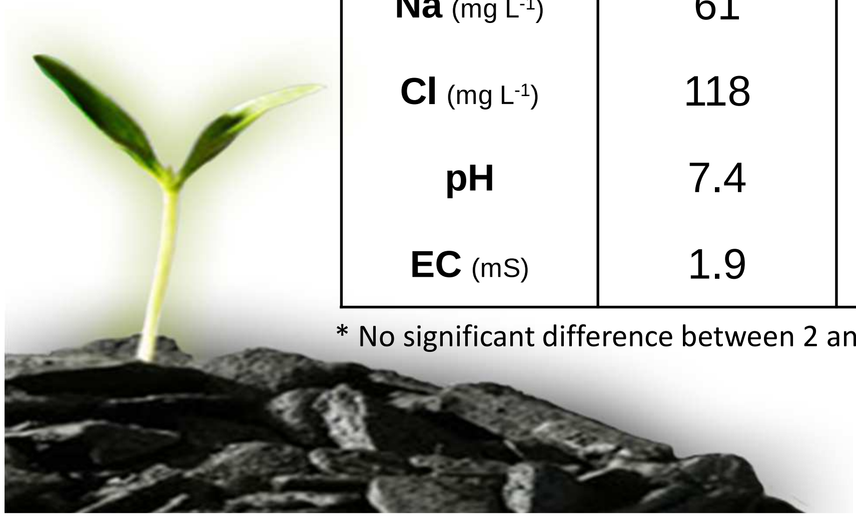


Soil mineral content in the leachate

	Control	10 % biochar	P value
NO_3 (mg L^{-1})	359	252	0.0216
PO_4 (mg L^{-1})	26	23	0.1855
K (mg L^{-1})	43	37	0.4223
Ca (mg L^{-1})	253	221	0.1885
Mg (mg L^{-1})	51	44	0.2534
SO_4 (mg L^{-1})	212	223	0.5695
Na (mg L^{-1})	61	59	0.7748
Cl (mg L^{-1})	118	127	0.6470
pH	7.4	7.4	0.2258
EC (mS)	1.9	1.7	0.1509

↓ 30%

* No significant difference between 2 and 4 week interval fertilization periods



Biochar soil amendment (10% v/v) – after 2 years

Biochar had little or **no significant effect** on :

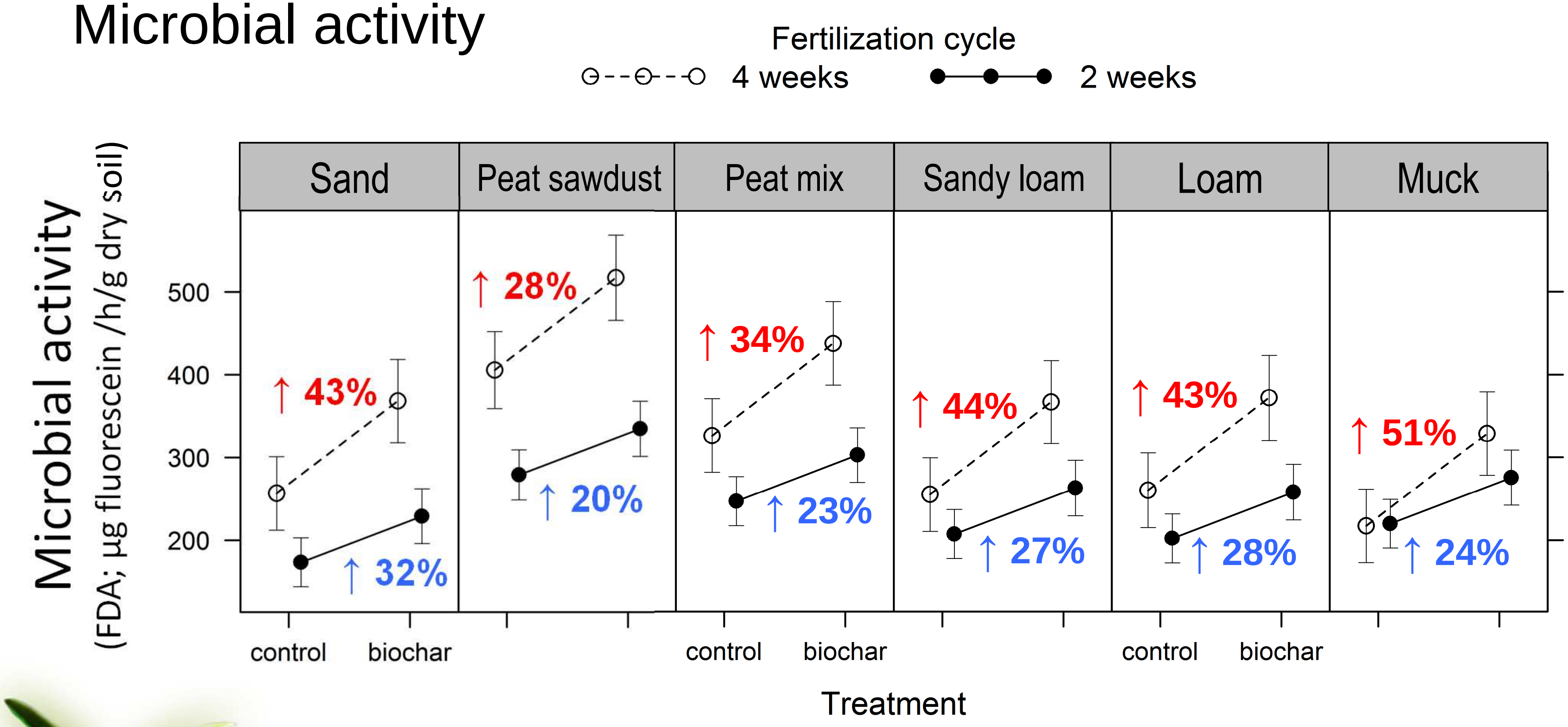
- Plant growth & total yield
- Root mycorrhization
- Leaf nutrient content
- Soil N_2O emission

Significant effect of biochar on :

- Higher soil biological activity (FDA)
- Higher soil nutrient content (N, P, Fe, Cu, Mn)
- Reduction of soil CO_2 flux
- Reduction of 30% N leaching
- Reduction of fruit cuticle cracking

Biochar soil amendment (20% v/v) – after 3 years

Microbial activity



May-August 2014 (4-wk interval)	August-October 2014 (2-wk interval)
Mean increase = 41% ***P = 0.0009***	**Mean increase = 26%** ***P = 0.0004***

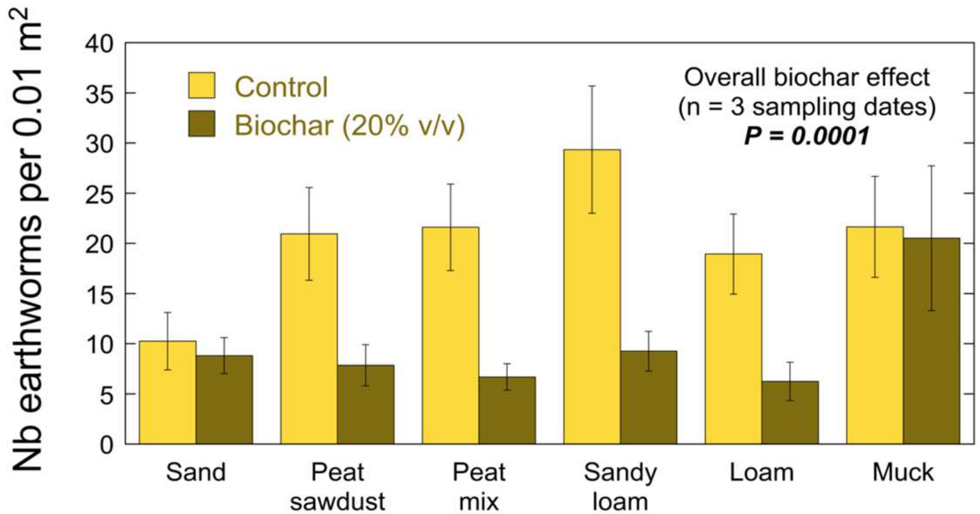
Biochar soil amendment (20% v/v) – Root mycorrhization (AMF)

	July 2014 Biochar		November 2014 Biochar	
	with	without	with	without
% of E.U. with mycorrhized roots	67%	83%	33%	55%
P-value	0.2637		0.1925	

⇨ No significant effect of biochar on root colonisation by mycorrhizae CH1

Biochar soil amendment (20% v/v) – Earthworms

Lower density of earthworms (↓ 50%) in soils with biochar



⇨ polycyclic aromatic hydrocarbons, dioxines or particule size

Dia 14

CH1 Chris Hadfield, 11-4-2016

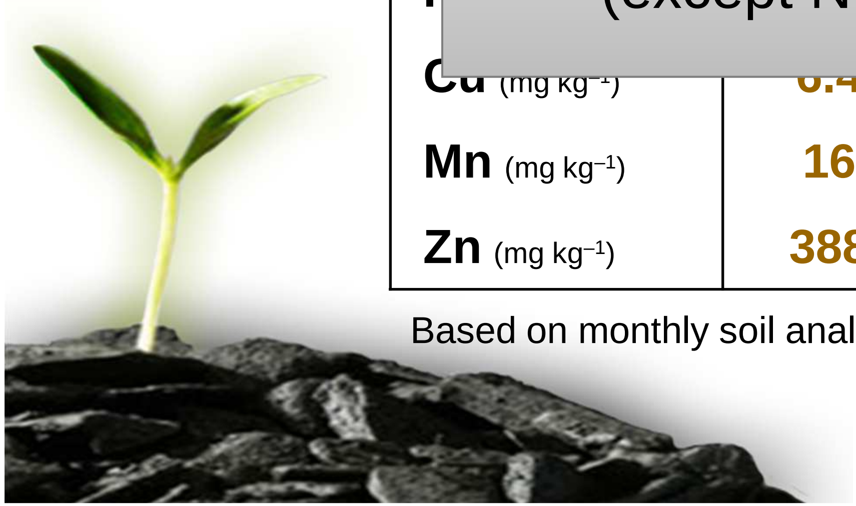
Biochar soil amendment (20% v/v) – Soil mineral content

	Control	20 % biochar	P value	
NO_3 (mg kg⁻¹)	358	519	0.0003	↑ 45%
NH_4 (mg kg⁻¹)	32	20	<0.0001	↓ 38%
P[illegible]	[illegible]	[illegible]	[illegible]	↑ 13%
K[illegible]	[illegible]	[illegible]	[illegible]	↑ 39%
C[illegible]	[illegible]	[illegible]	[illegible]	
M[illegible]	[illegible]	[illegible]	[illegible]1	↑ 5%
F[illegible]	[illegible]	[illegible]	[illegible]1	↑ 75%
Cu (mg kg⁻¹)	6.4	14.6	<0.0001	↑ 129%
Mn (mg kg⁻¹)	16	32	<0.0001	↑ 97%
Zn (mg kg⁻¹)	388	178	<0.0001	↓ 54%

Greater concentrations of soil nutrients in biochar-amended soils

(except NH_4, Ca and Zn)

Based on monthly soil analysis using the Mehlich-3 method

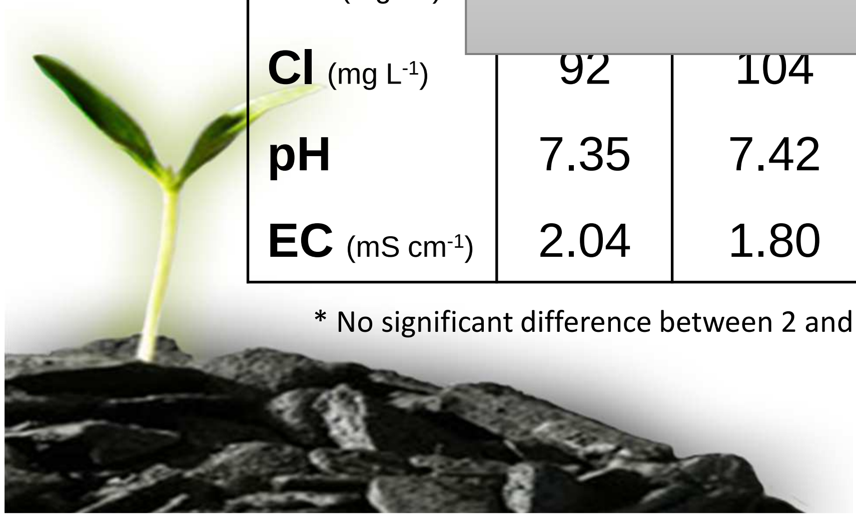


Soil mineral content in the leachate

	Control	20% biochar	*P* value Trt	Soil	Trt*soil
↓ 50% **NO_3** (mg L^{-1})	**210**	**105**	**<0.0001**	**<0.0001**	**<0.0001**
PO_4 (mg L^{-1})	25	26	0.8425	**<0.0001**	0.4987
K (mg L^{-1})					
Ca (mg L^{-1})					
Mg (mg L^{-1})					
SO_4 (mg L^{-1})					
Na (mg L^{-1})					
Cl (mg L^{-1})	92	104	0.4169	*0.0585*	0.5803
pH	7.35	7.42	**0.0483**	**<0.0001**	0.2208
EC (mS cm^{-1})	2.04	1.80	0.0788	**<0.0001**	0.1380

Significant reduction in NO_3 concentration in biochar-amended soils

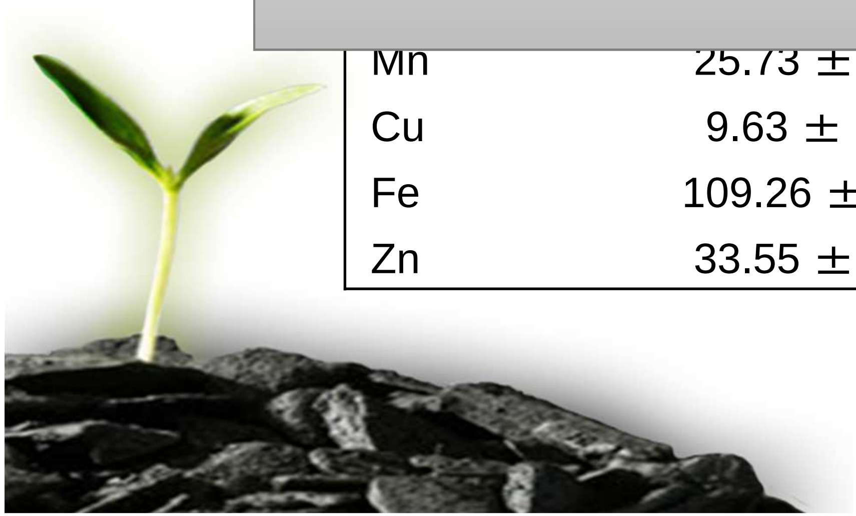
* No significant difference between 2 and 4 week interval fertilization periods



Dry matter and mineral content of the 5th leaf

(%)	Biochar	
	With	Without
Dry matter	12.44 ± 0.33	12.17 ± 0.31
N	4.18 ± 0.16	4.23 ± 0.16
Mn	25.73 ± 1.39	22.22 ± 1.17
Cu	9.63 ± 0.74	8.50 ± 0.37
Fe	109.26 ± 8.70	112.53 ± 8.68
Zn	33.55 ± 7.03	35.18 ± 6.00

No difference in concentrations of foliar nutrients between soils with 20% biochar and controls



Biochar soil amendment (20% v/v) – Plant growth

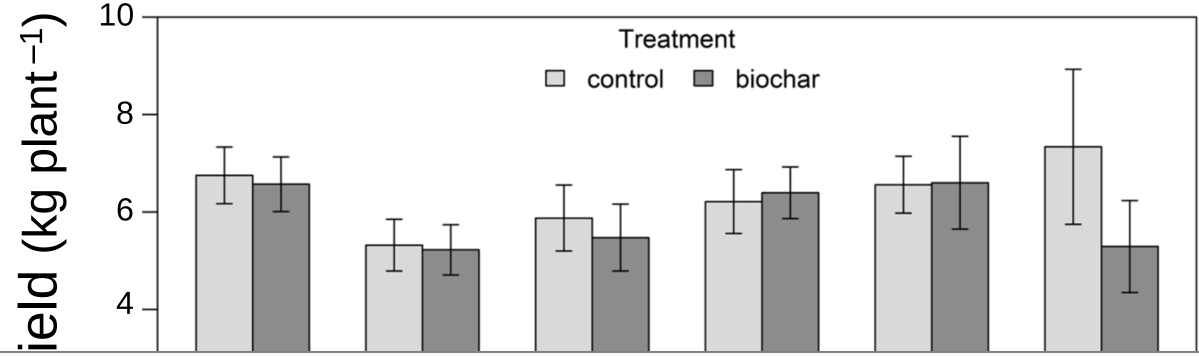
Stem height growth (cm)

Fertilization	Biochar with	Biochar without	*P value*
4-week interval	269	265	0.6450
2-week interval	205	207	0.6078

No difference in plant growth parameters between soils with 20% biochar and controls

Leaf dry weight (g)	[illegible]	[illegible]	[illegible]
Fruiy dry weight (g)	83	81	0.8991
Stem dry weight (g)	41	42	0.6886
October 2014			
Leaf dry weight (g)	55	52	0.0955
Fruit dry weight (g)	98	98	0.9151
Stem dry weight (g)	75	71	0.1590

Biochar soil amendment (20% v/v) – Productivity



No difference in productivity and fruit quality with 20% biochar and controls

May to October 2014	Control	20 % biochar
Fruit nb with physiological disorders	7.93	7.33
Fruit weight with physiological disorders	1.057	0.998

Summary – after 3 years of biochar amendment (10%, 10% and 20%)

Biochar had little or **no significant effect** on :

- Plant growth & total yield
- Root mycorrhization
- Leaf nutrient content

Significant effect of biochar on :

- Higher soil biological activity (FDA)
- Higher soil nutrient content (except Ca and Zn)
- Reduction of CO_2 flux (1st and 2nd years)
- Reduction of 30 to 50% N leaching
- Reduction of fruit cuticle cracking (2nd year)

Conclusion – 3 year experiment

Adding 10-20% (v/v) biochar to soils of organic greenhouse tomato **increased soil biological activity** and **nitrogen retention** resulting in lower nitrogen leaching and improved crop system sustainability

Different types of soil

No significant effect on productivity

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Thank you very much

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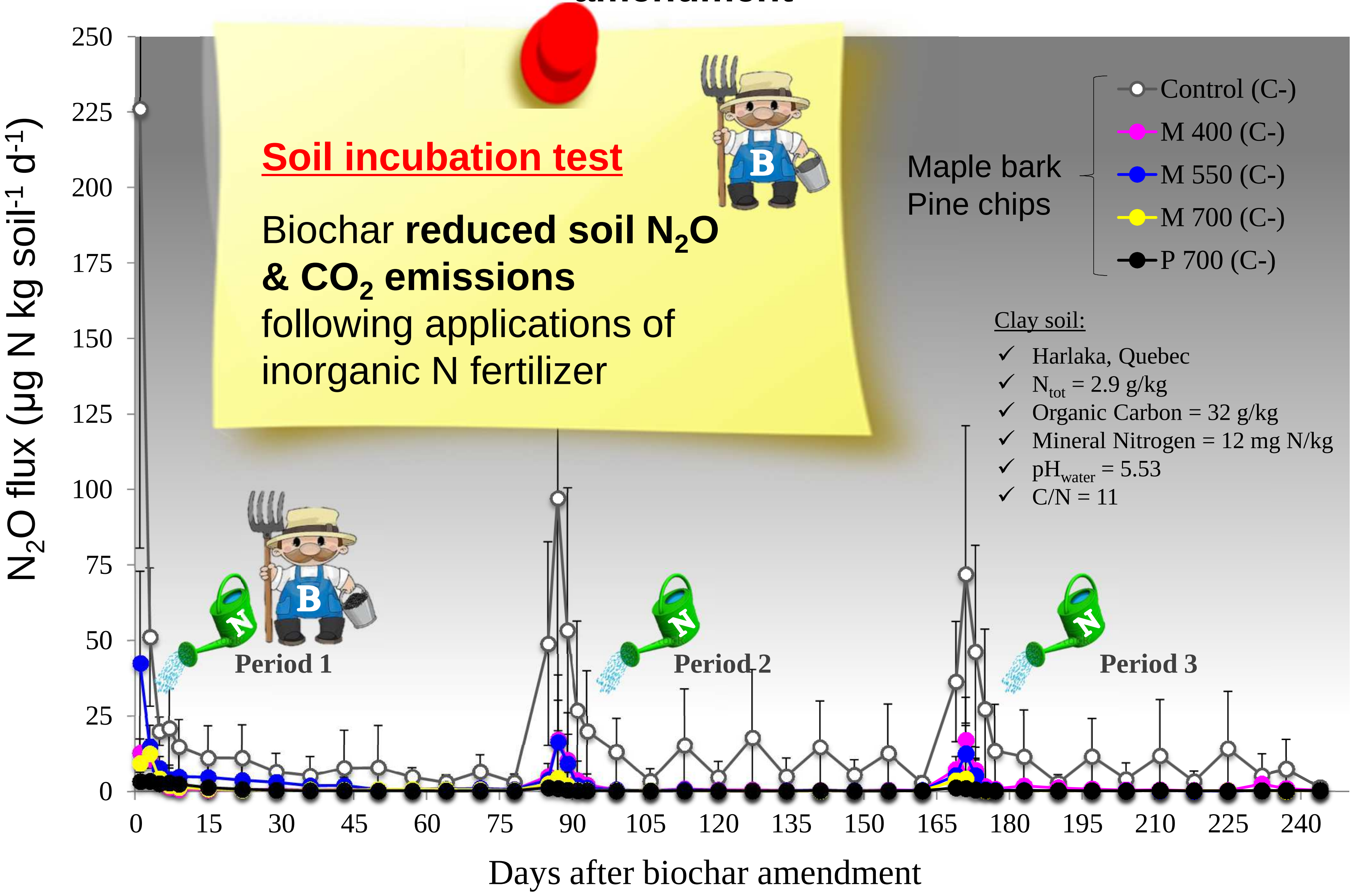
N_2O and CO_2 emissions following N applications after biochar amendment



(Lévesque et al., 2015)

Without compost = C-

Amending potting soils with biochar

Study by Gravel *et al*. (2013) on potted plants grown in a substrate amended with 50% (v/v) biochar:

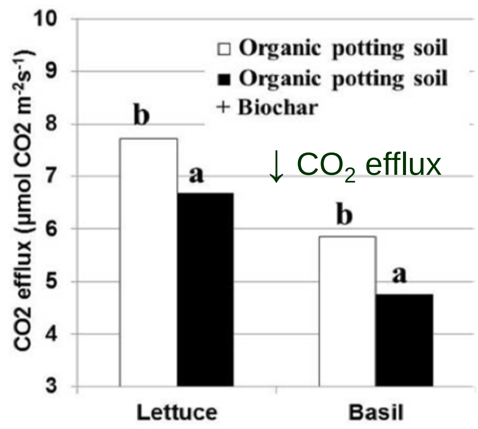
① Increased pH, no effect on EC, lower CO_2 efflux

② + 46% aboveground dry weight of coriander

③ – 44% on DW of lettuce

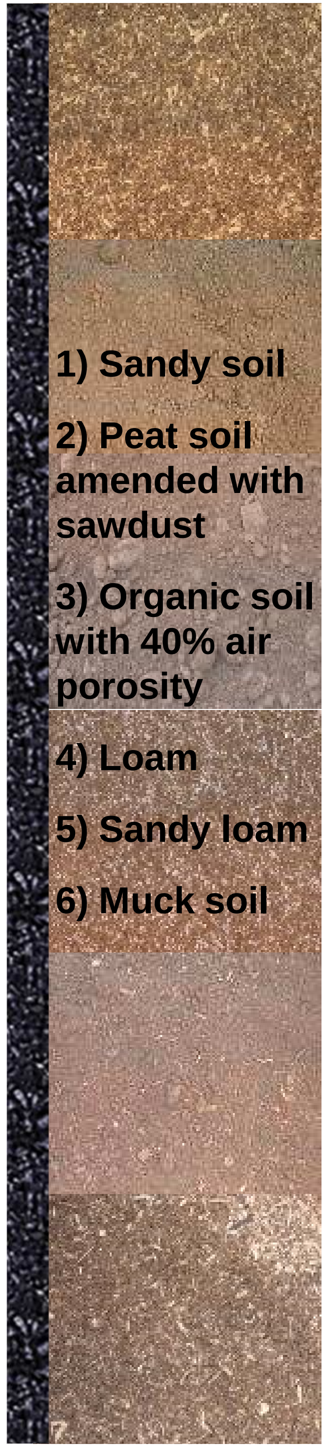
④ No effect on DW of basil, pepper and geranium

Shoot	Pepper		Geranium		Coriander		Basil		Lettuce	
Vol 1:1	F.W.. (g/plant)	D.W.. (g/plant)	F.W.. (g/plant)	D.W. (g/plant)	F.W. (g/plant)	D.W.. (g/plant)	F.W. (g/plant)	D.W. (g/plant)	F.W. (g/plant)	D.W. (g/plant)
Organic soil	77	8.6	55.3	8.1	74.2b	4.3b	60	5.5	165a	4.7a
Org soil + Biochar	73	8.4	56.8	8.6	91.2a	6.3a	54	5.1	132b	2.6b
P values	*0.0891*	*0.7775*	*0.7616*	*0.4376*	*0.0025*	*0.0059*	*0.0749*	*0.2263*	*0.0011*	*0.0009*



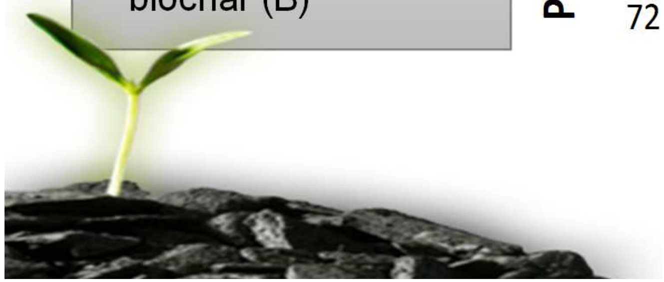
Effects of biochar on seedling tomato growth and root colonization by *Pythium ultimum*

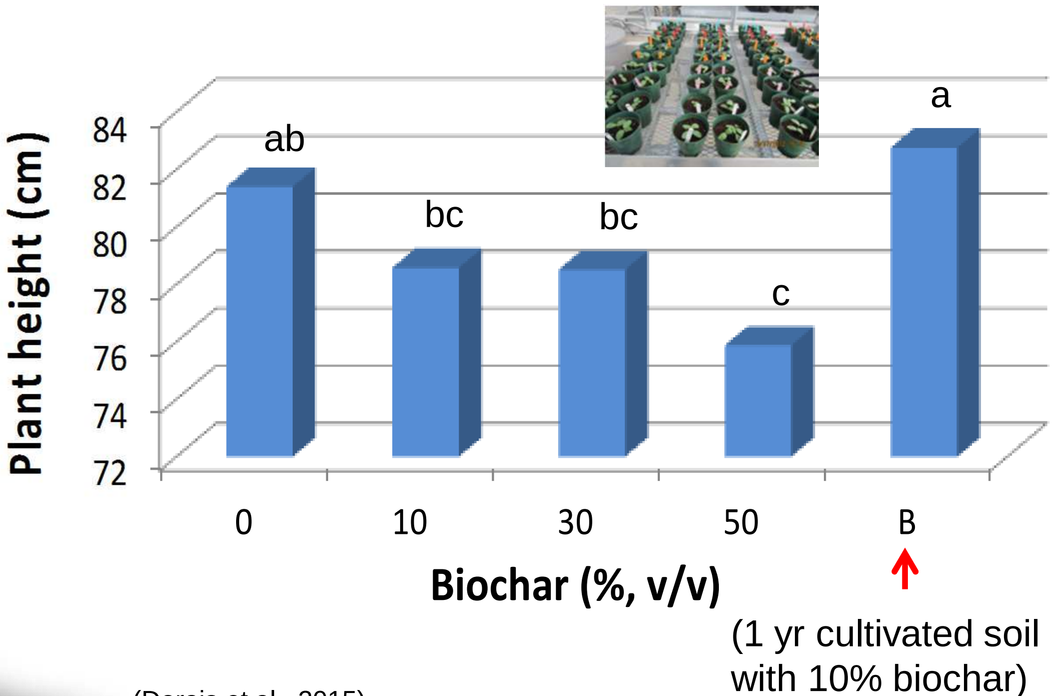
P-value	Soil	Biochar	S*B	Pythium	S*P	B*P	S*B*P
Height (cm)	0.0480	0.0004	NS	NS	0.0305	NS	NS
Dry Wt (g)	0.0001	0.0001	0.0001	0.0001	0.0215	NS	NS
Fresh Wt (g)	0.0001	0.0001	0.0001	0.0002	NS	NS	NS



Soil * Biochar

- 30% and 50% biochar (v/v) had negative effect on plant DW
- Positive effects on FW & DW of plants in soils cultivated for one year with 10% biochar (B)





(Dorais et al., 2015)

Biochar soil amendment (20% v/v) – Flux of CO_2

May–August 2014 (4-wk interval)		Biochar with	Biochar without	*P value*
CO_2 efflux ($\mu mol\ CO_2\ m^{-2}\ s^{-1}$)	↑ 11%	9.9	9.0	***P = 0.0141***

August–October 2014 (2-wk interval)		Biochar with	Biochar without	*P value*
CO_2 efflux ($\mu mol\ CO_2\ m^{-2}\ s^{-1}$)	↑ 21%	9.3	7.7	***P = 0.0001***

Enhanced soil respiration (↑16%) in biochar-amended organic soils