Charcoal for terra preta

Michael J. Antal, Jr, Goro Uehara, Jonathan Deenik, and Tai McClellan

Hawaii Natural Energy Institute and
The College of Tropical Agriculture & Human Resources
University of Hawaii at Manoa

Modern Biomass Refineries

- Ethanol from corn grain and biocarbons from corn stover (USA)
- Biodiesel from sunflower oil and biocar-bons from sunflower shells and stalks (EU)
- Biodiesel from coconut oil and biocarbons from coconut shells, fronds, etc. (Malaysia)
- Biodiesel from marine algae and biocarbons from residual (dry) algal material (Hawaii)

Fuel Costs

FOSSIL		RENEWABLE	
Coal		Charcoal	$8/GJ
Oil	$15/GJ	Ethanol	$14/GJ
Gas	$6-17/GJ	Hydrogen	$18-24/GJ

How can we use charcoal?

- Potting soil (orchids and ornamentals)
- Cooking (barbeque) fuel
- Ultra clean coal (power production)
- Activated carbon (water treatment)
- Metal reductant
- Terra preta (carbon sequestration!)
- Biocarbon fuel cell

Some questions concerning the production of biocarbons:

1. In theory, what limits the yield of bioC (charcoal) from biomass?
2. In theory, what is the energy conversion efficiency of biomass into bioC?
3. In practice, what yield and energy conversion efficiency can be achieved?
4. In practice, how quickly can we convert biomass to bioC?

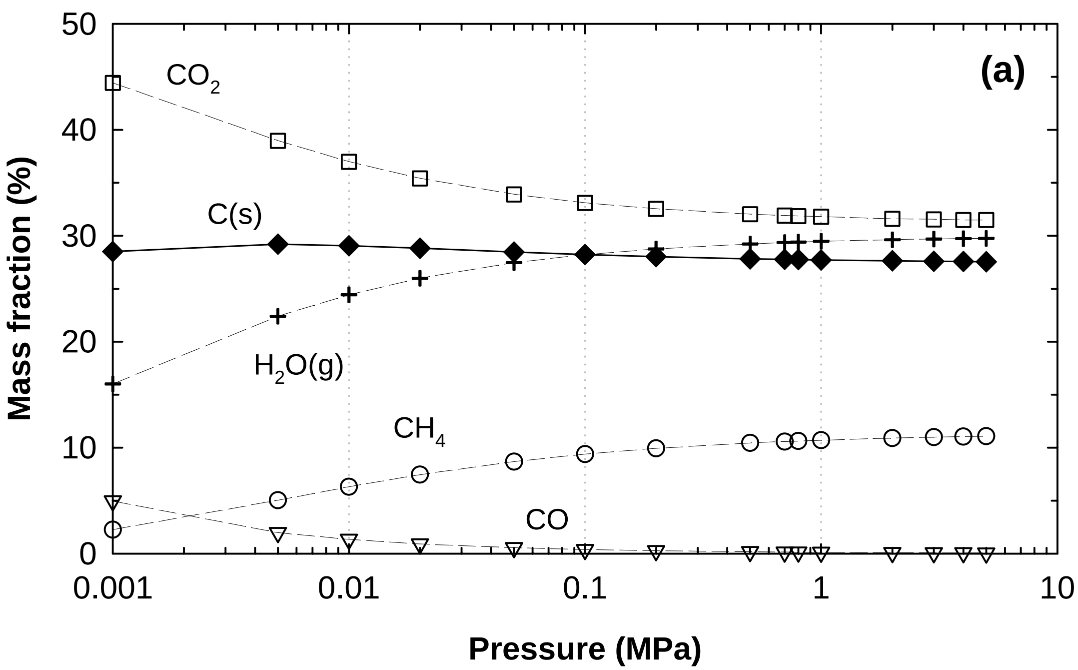
Useful definitions:

1. $y_{char} = m_{char} / m_{bio}$
2. $100 = \% \text{ VM} + \% \text{ fC} + \% \text{ ash}$; where

   VM = volatile matter; fC = fixed carbon
3. $y_{fC} = y_{char} \times \{\% \text{ fC} / (100 - \% \text{ feed ash})\}$
4. $\eta_{char} = y_{char} \times (HHV_{char} / HHV_{bio})$

Thermochemical equilibrium predictions for the products of cellulose pyrolysis at 400 C (*Ind. Eng. Chem. Res.* 2003, *42*, 3690-3699).

- C, H_2O, CO_2, and CH_4 are the only significant products.
- The theoretical charcoal (i.e. C) yield is 28 wt%.
- The gas contains significant energy (i.e. CH_4).

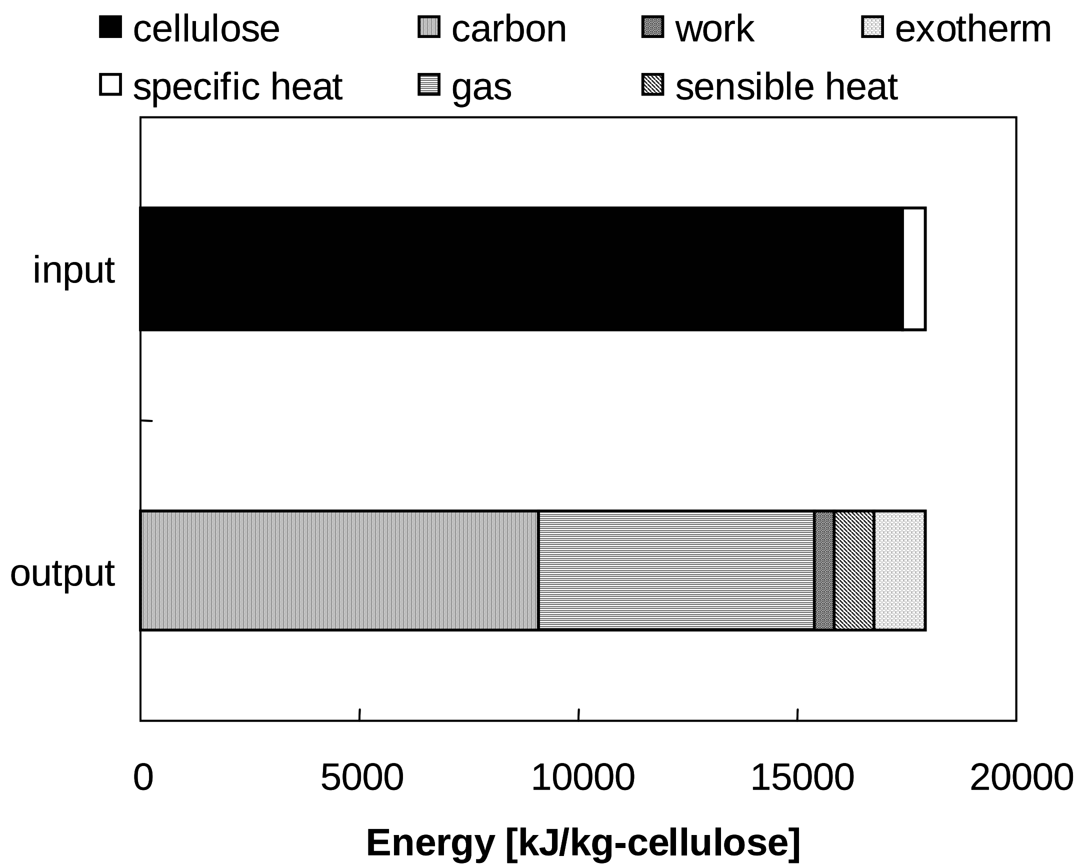


Reaction stoichiometry for the products of cellulose pyrolysis at 400 C & 1 MPa (*Ind. Eng. Chem. Res.* 2003, *42*, 3690-3699)

$$C_6H_{10}O_5 \rightarrow 3.74\ C +$$

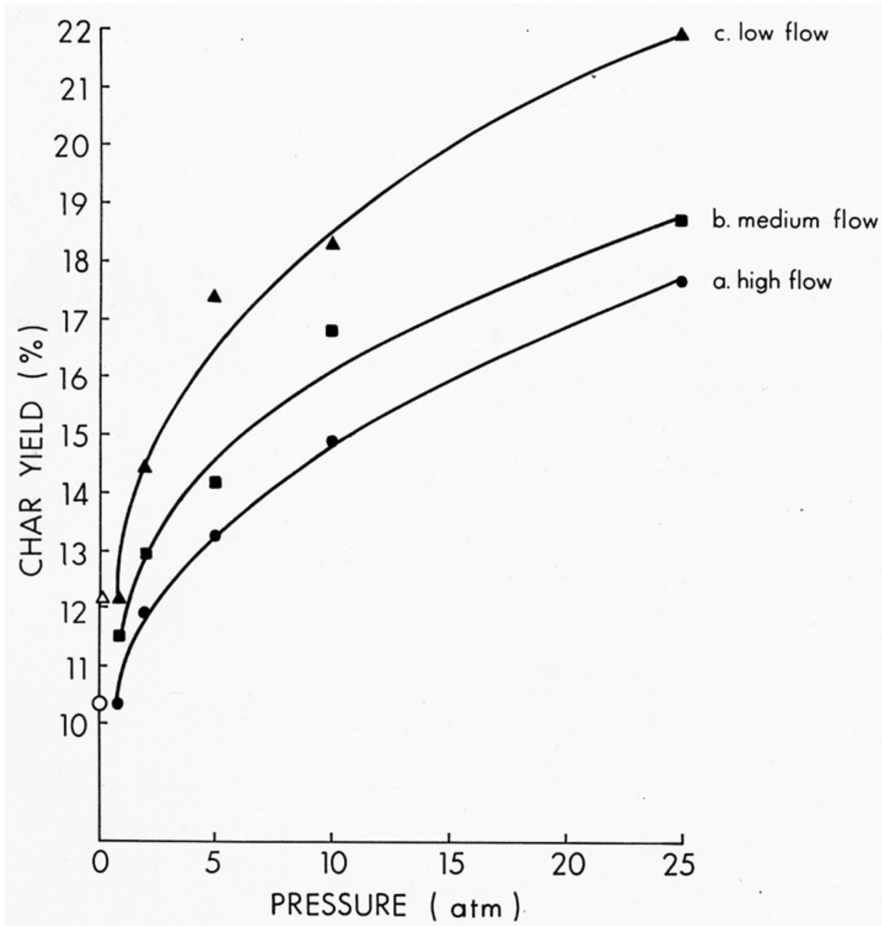
$$2.65\ H_2O + 1.17\ CO_2 + 1.08\ CH_4$$

Energy balance for cellulose pyrolysis following thermochemical equilibrium (*Ind. Eng. Chem. Res.* 2003, *42*, 3690-3699)

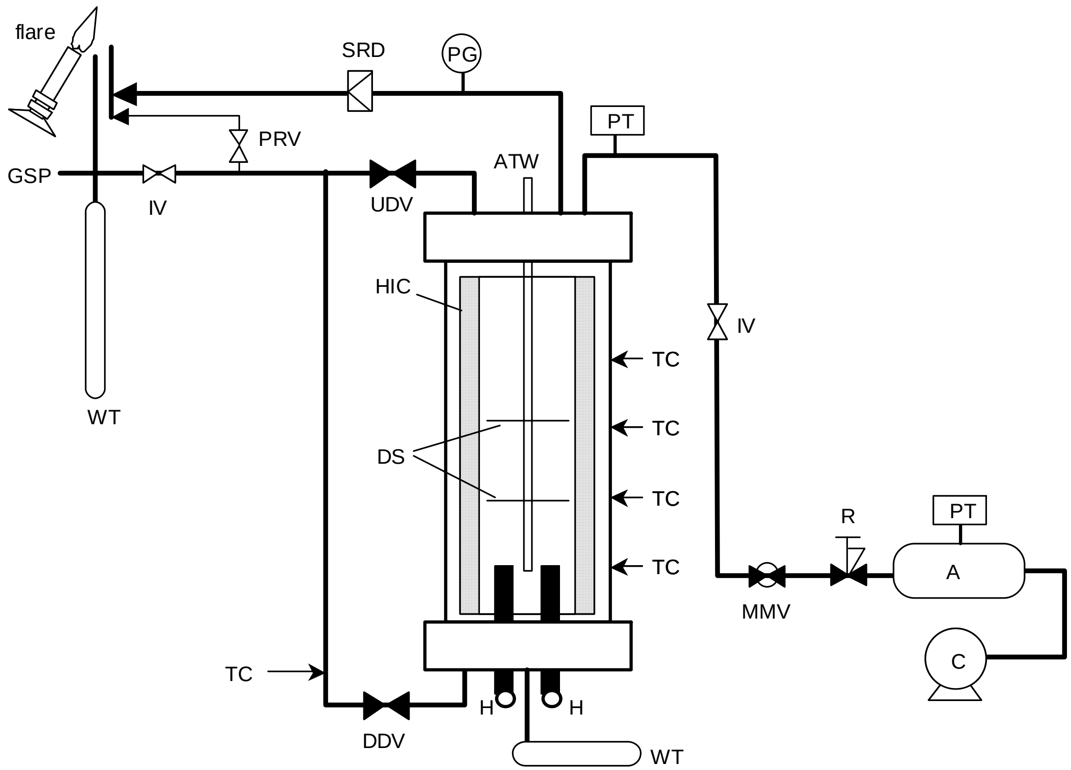


Plot of charcoal yield from cellulose pyrolysis vs. pressure (*Thermochim. Acta*, 1983, *68*, 165-186).

- Pressure strongly favors formation of charcoal.
- Low gas flow rates also favor the formation of charcoal.
- Elevated pressure and low flow rates together double the yield of charcoal.

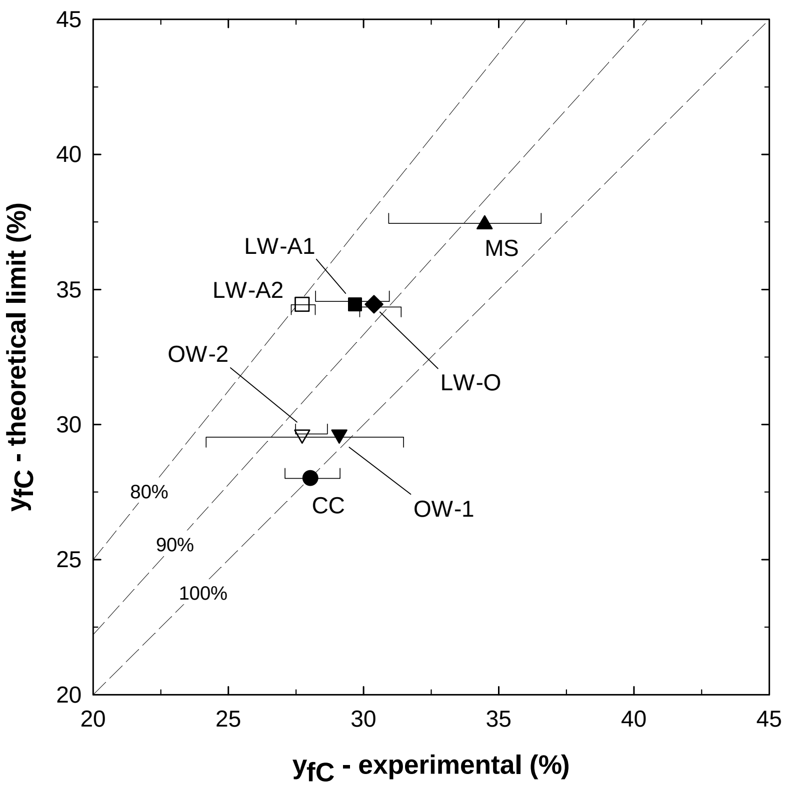


Flash Carbonization™ reactor schematic (U.S. patent # 6,790,317; September 14, 2004).



Parity plot of Flash Carbonization™ fixed-carbon yields from various biomass feedstocks (*Ind. Eng. Chem. Res.* 2003, *42*, 3690-3699)

- Fixed-carbon yields from corn cob, oak, and macshell approach the theoretical limit.
- Leucaena offers almost 90% of the theoretical limit.



Flash Carbonization™ demo reactor on the UH campus

Terra Preta (Amazonian Dark Earths): Highly Fertile Anthropogenic Soils

Picture source: http://www.gerhardbechtold.com/TP/gbtp.php

Photo source: University of Bayreuth

Terra Preta Soil

Photo source: University of Bayreuth

Typical Upland Amazonian Soil

Effect of Terra Preta on Plant Growth

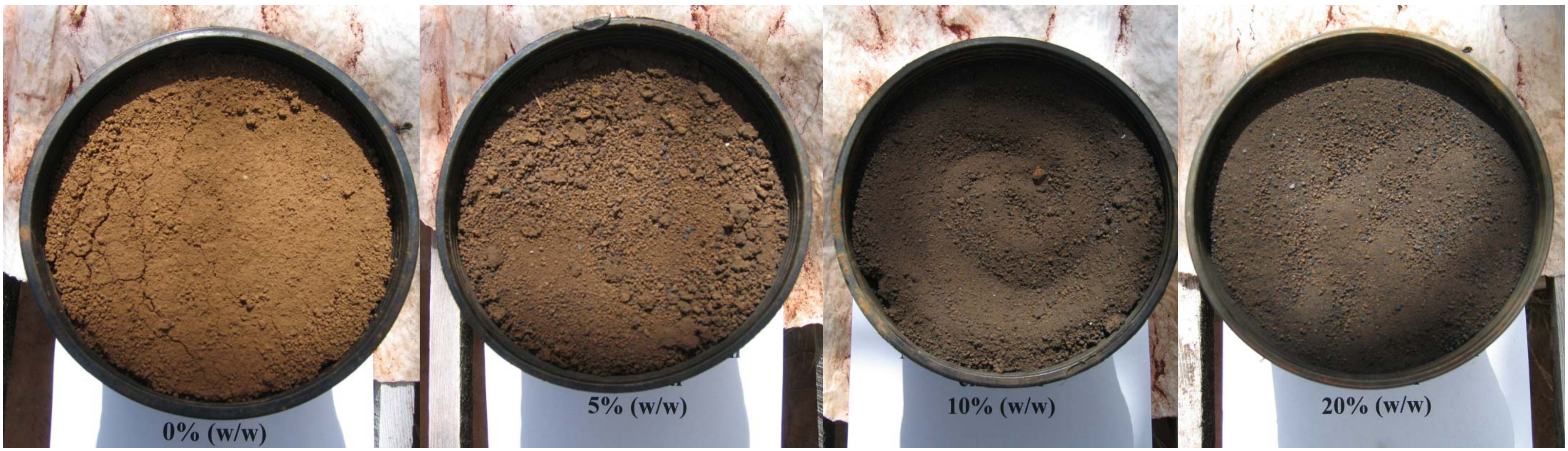
Photo source: http://tinselwing.wordpress.com/tag/terra-preta/

Terra Preta

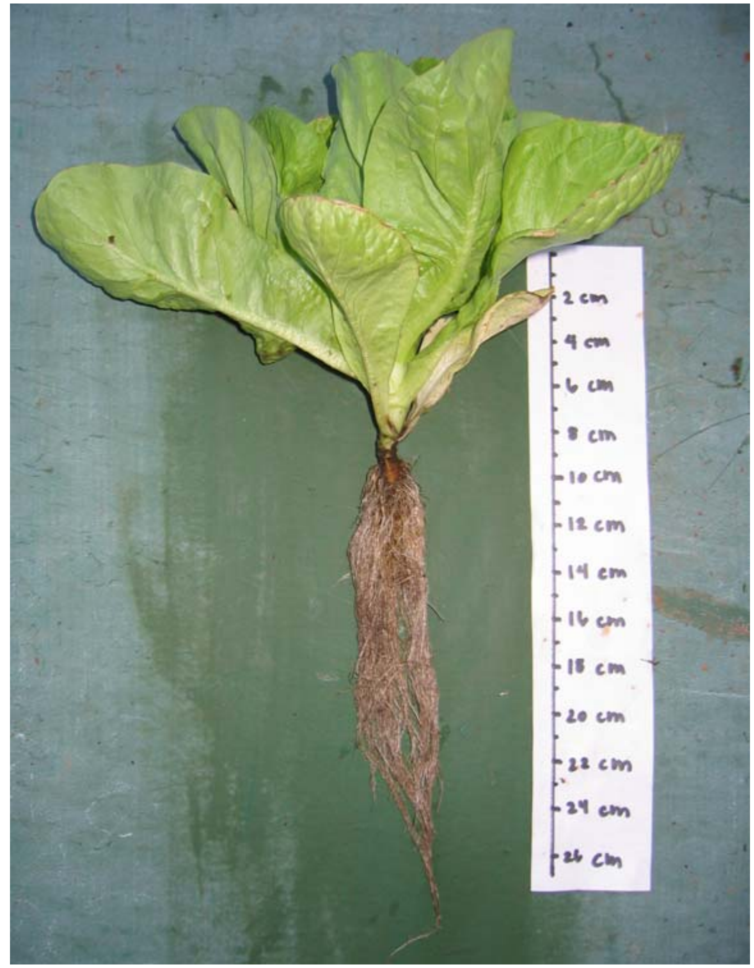
Unamended Soil

Volcanic ash soil treated with flash carbonized macadamia nut shell charcoal

0% (w/w) 5% (w/w) 10% (w/w) 20% (w/w)

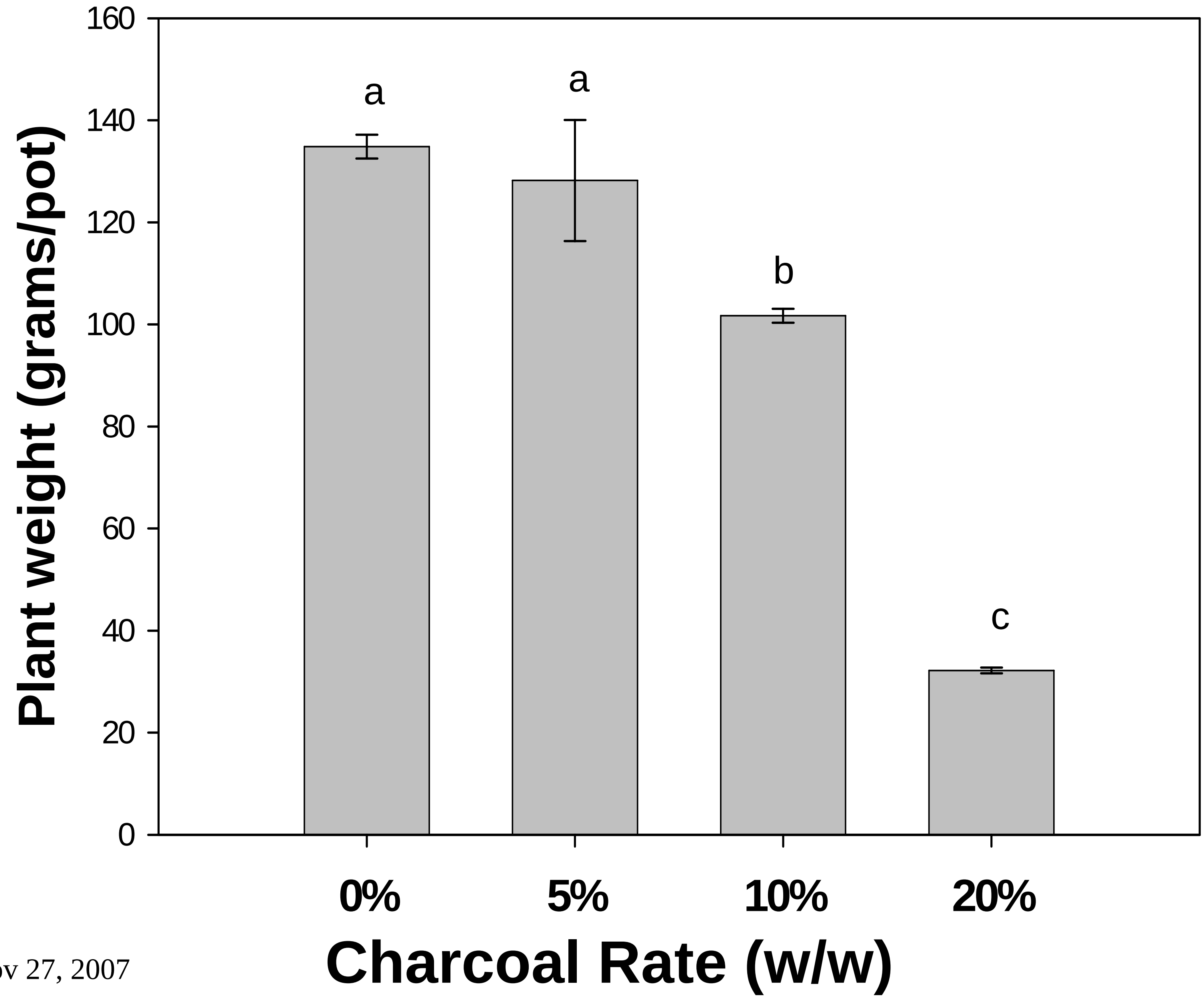


Control



20% (w/w) charcoal

Lettuce Shoot Biomass



Charcoal Effect in an Acid, Infertile Soil

0% **5%** **NPK + Lime**

NPK + Lime

5% + NPK + Lime

Preliminary Conclusion:

Charcoal used in the experiment caused a negative effect on plant growth

<u>But why</u>?

- Crop?
- Soil??
- Charcoal???

• **Volatile Matter (VM) content**: a measure of the susceptibility of charcoal to further decompose and form carbon when heated

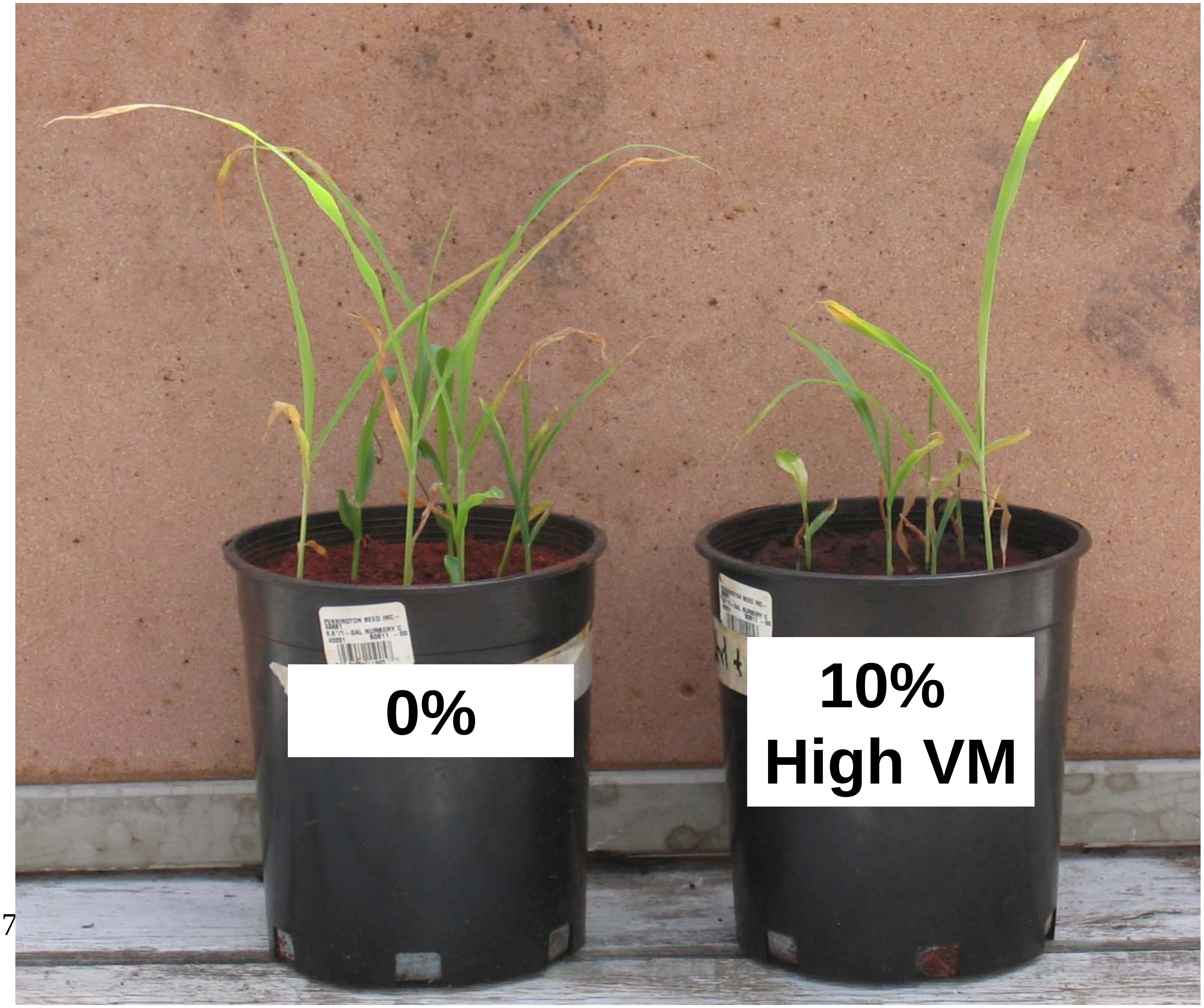
Hydrophobic

22.5% VM Content

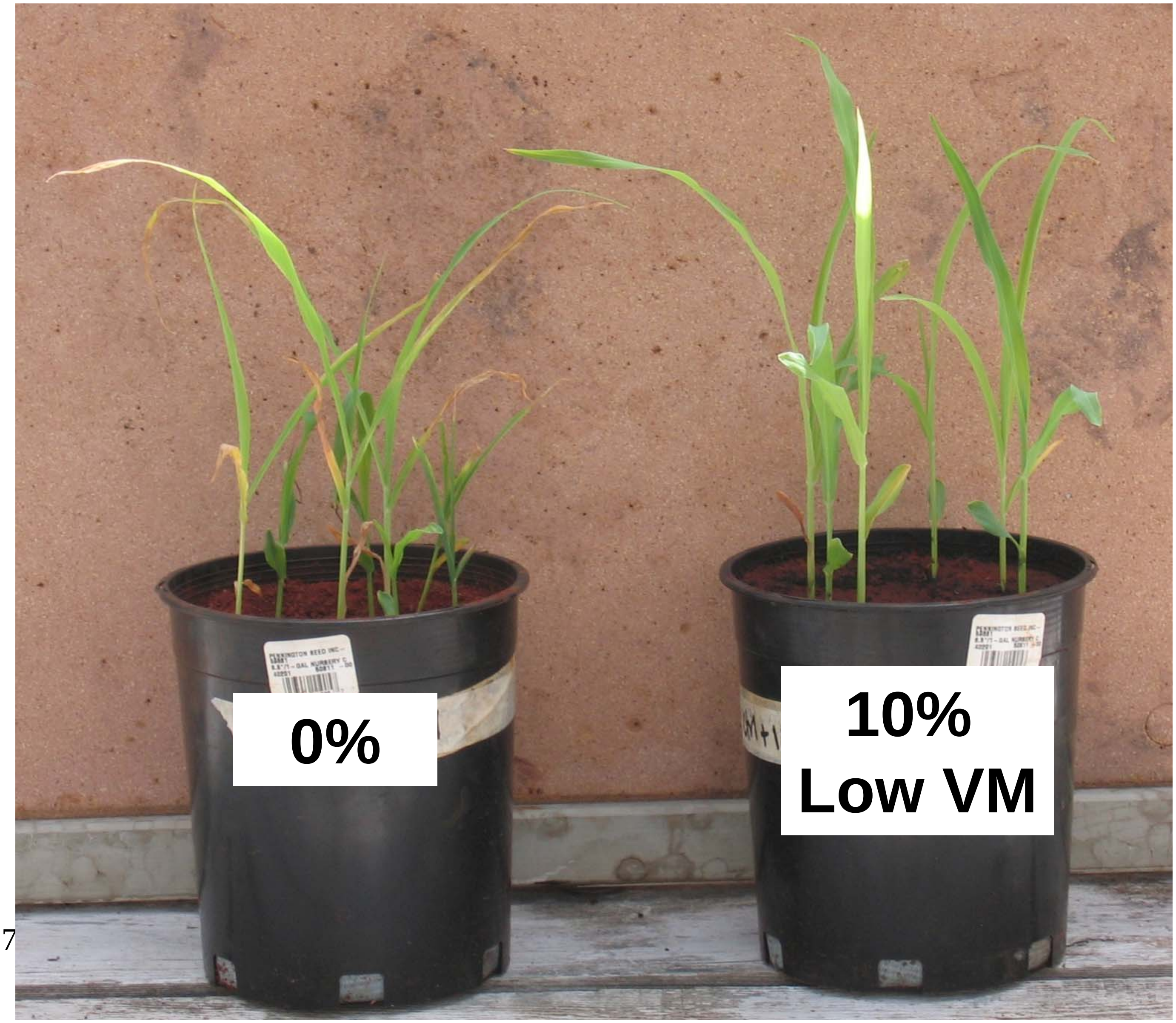
Hydrophilic

6.3% VM Content

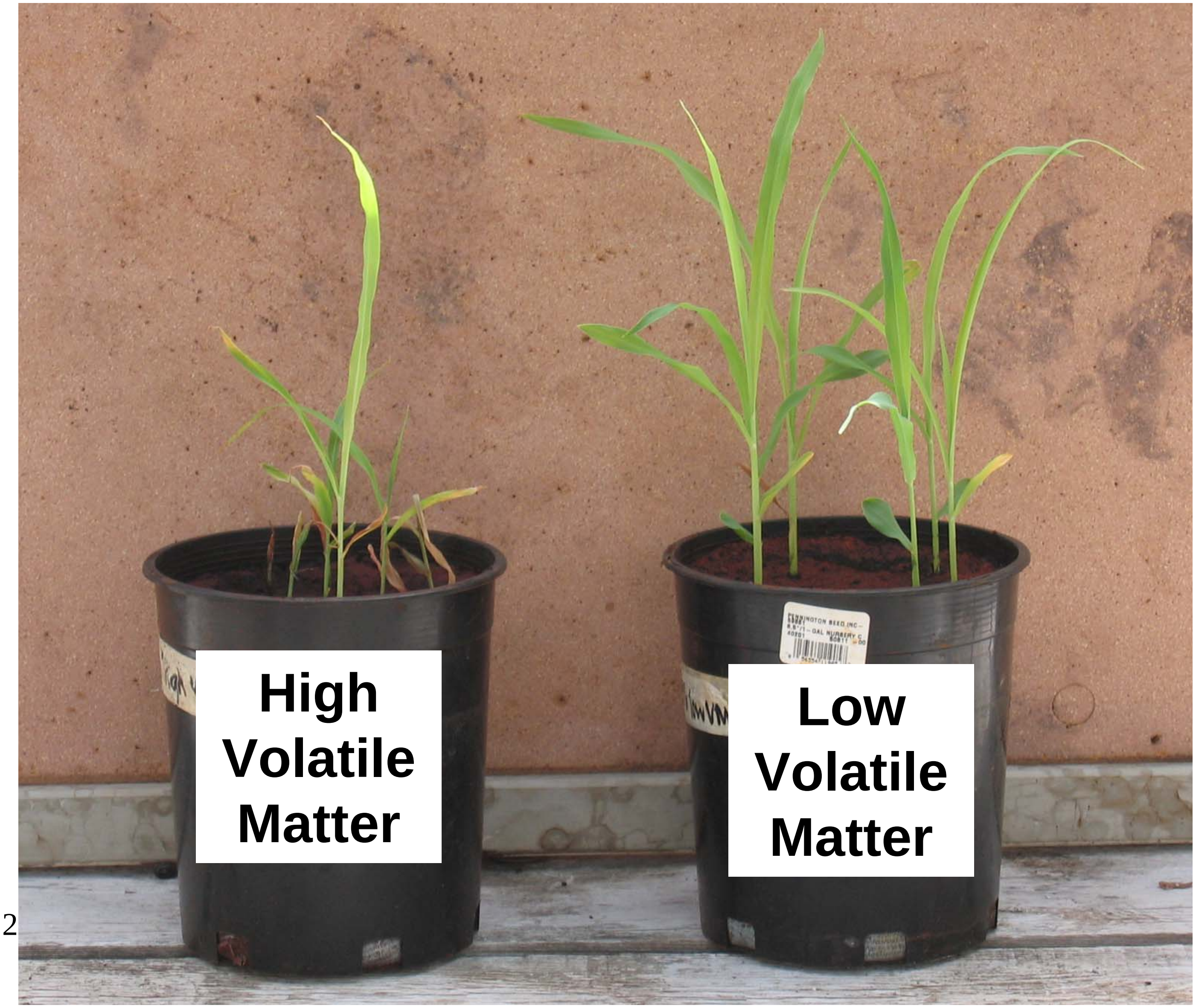
Effect of High Volatile Matter (22.5%) Charcoal on Plant Growth



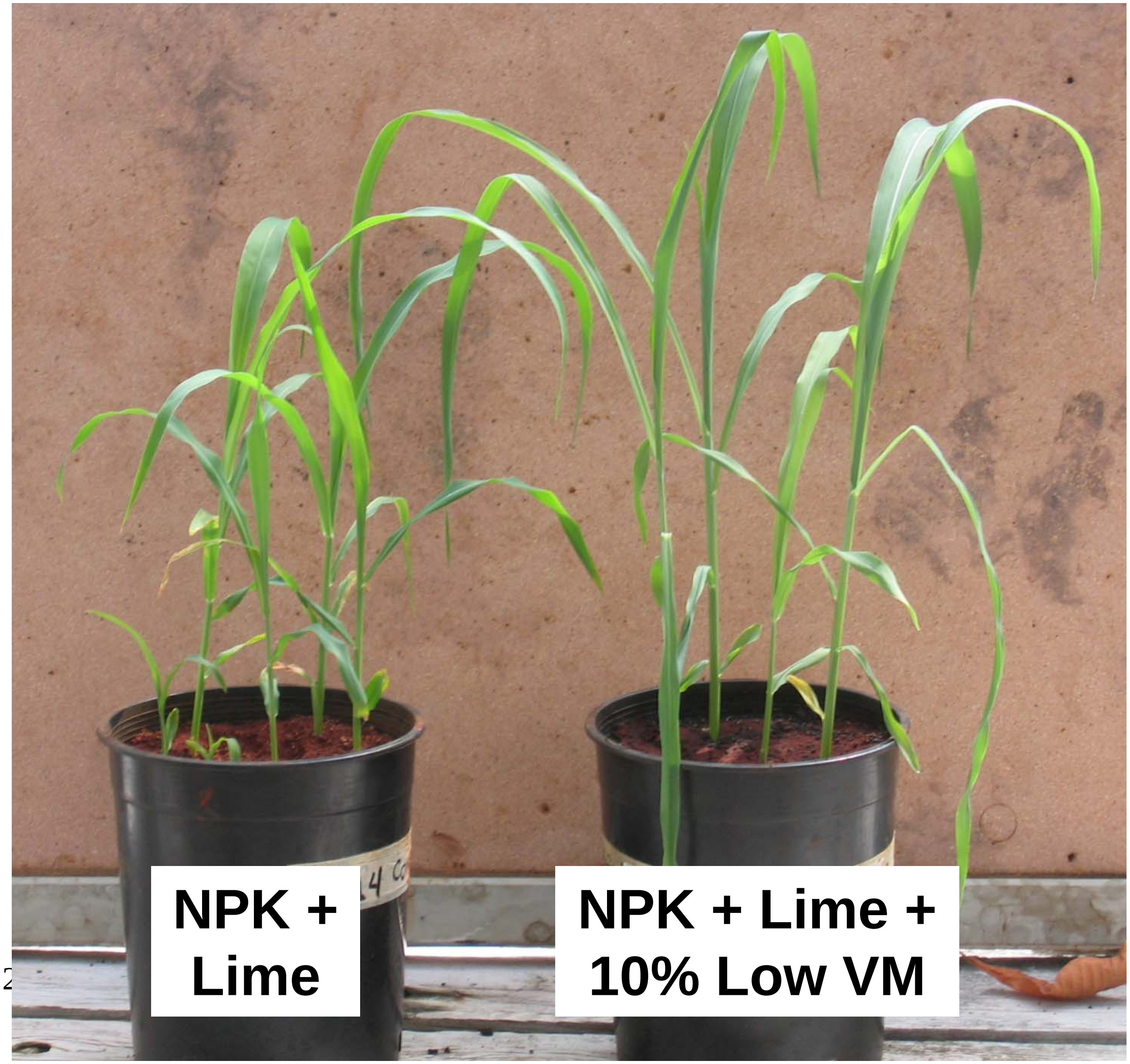
Effect of Low Volatile Matter (6.3%) Charcoal on Plant Growth



Low Volatile Matter Charcoal (6.3%) versus High Volatile Matter Charcoal (22.5%)



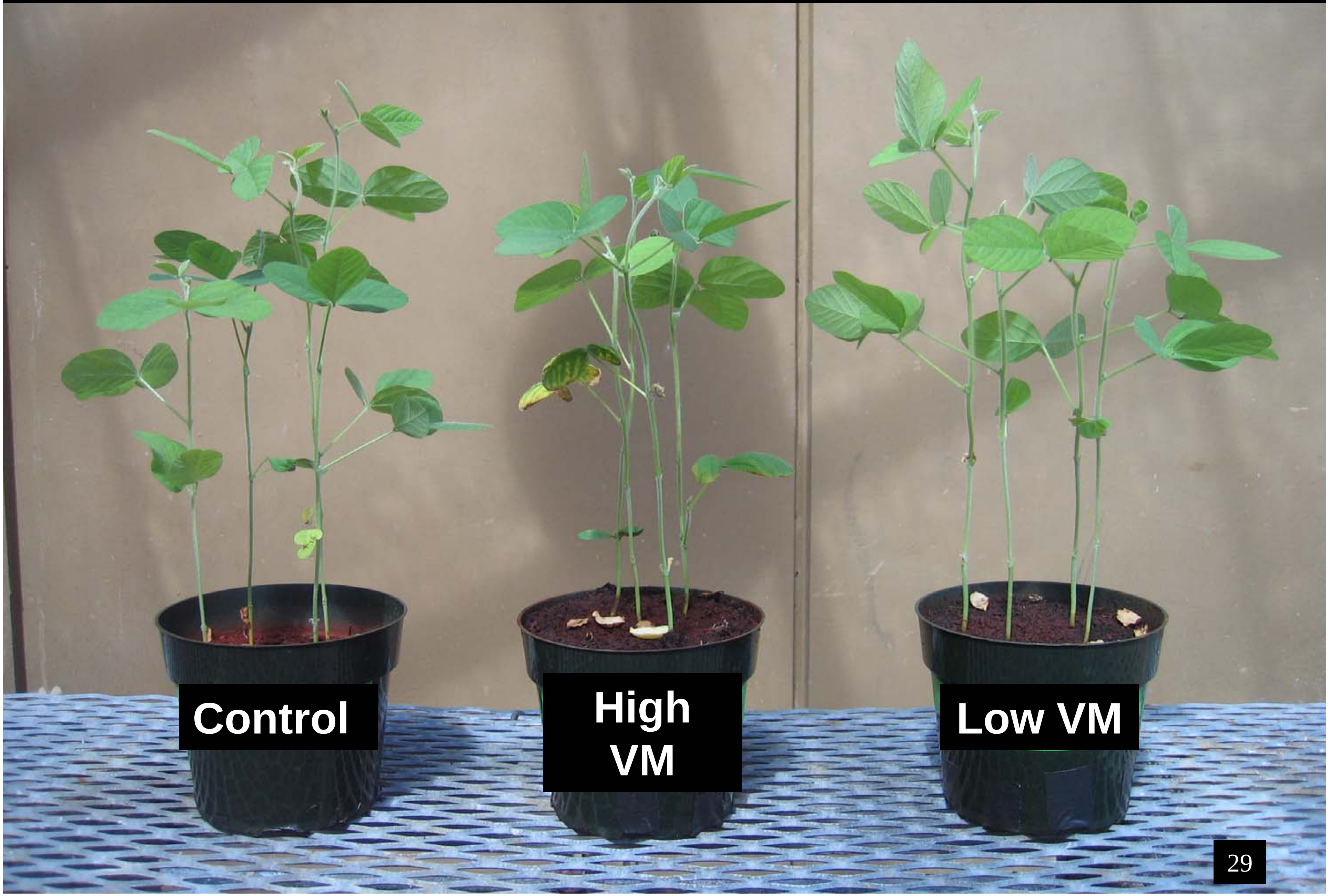
Combined Effect of Low Volatile Matter Charcoal Plus Fertilizer

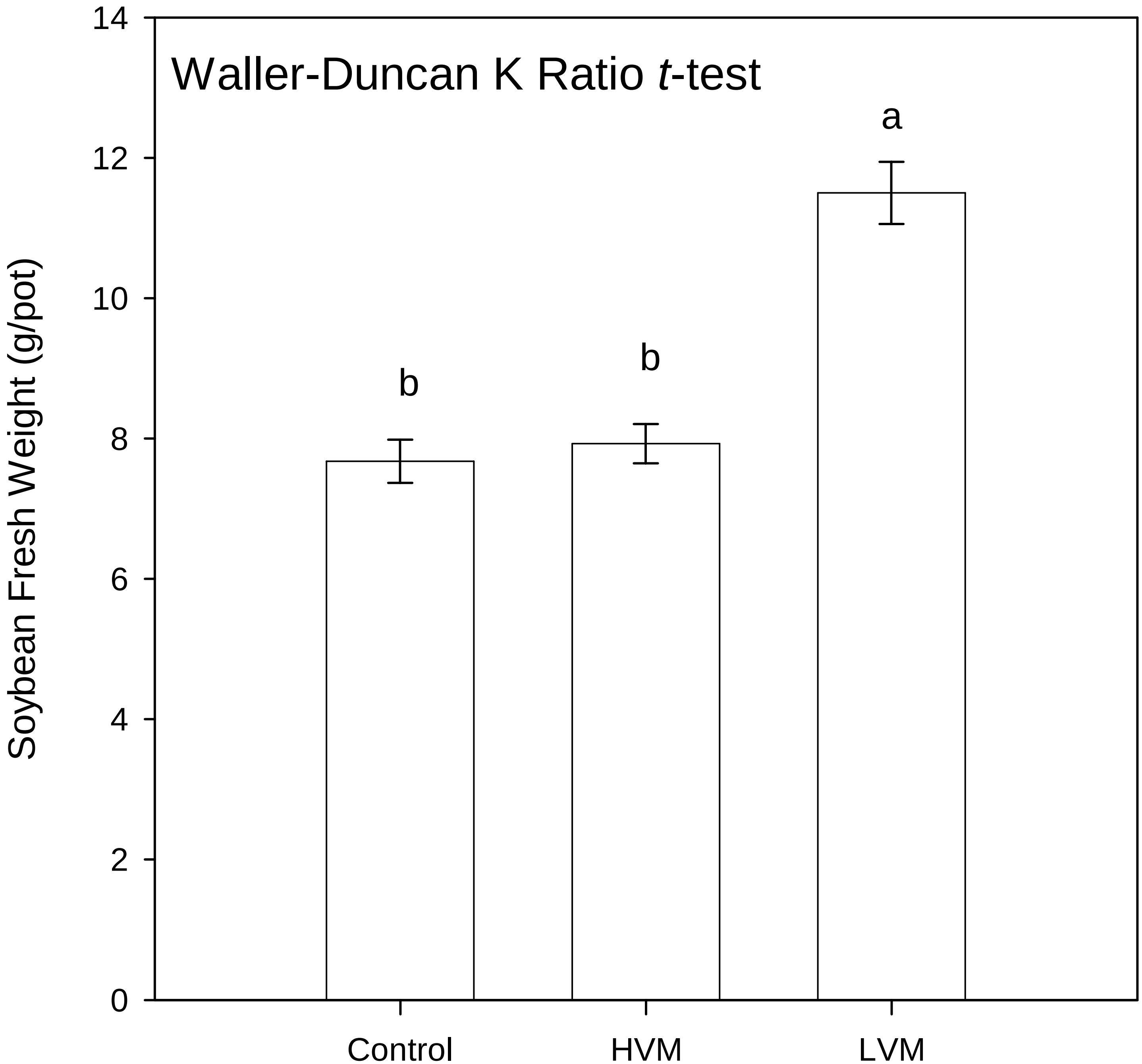


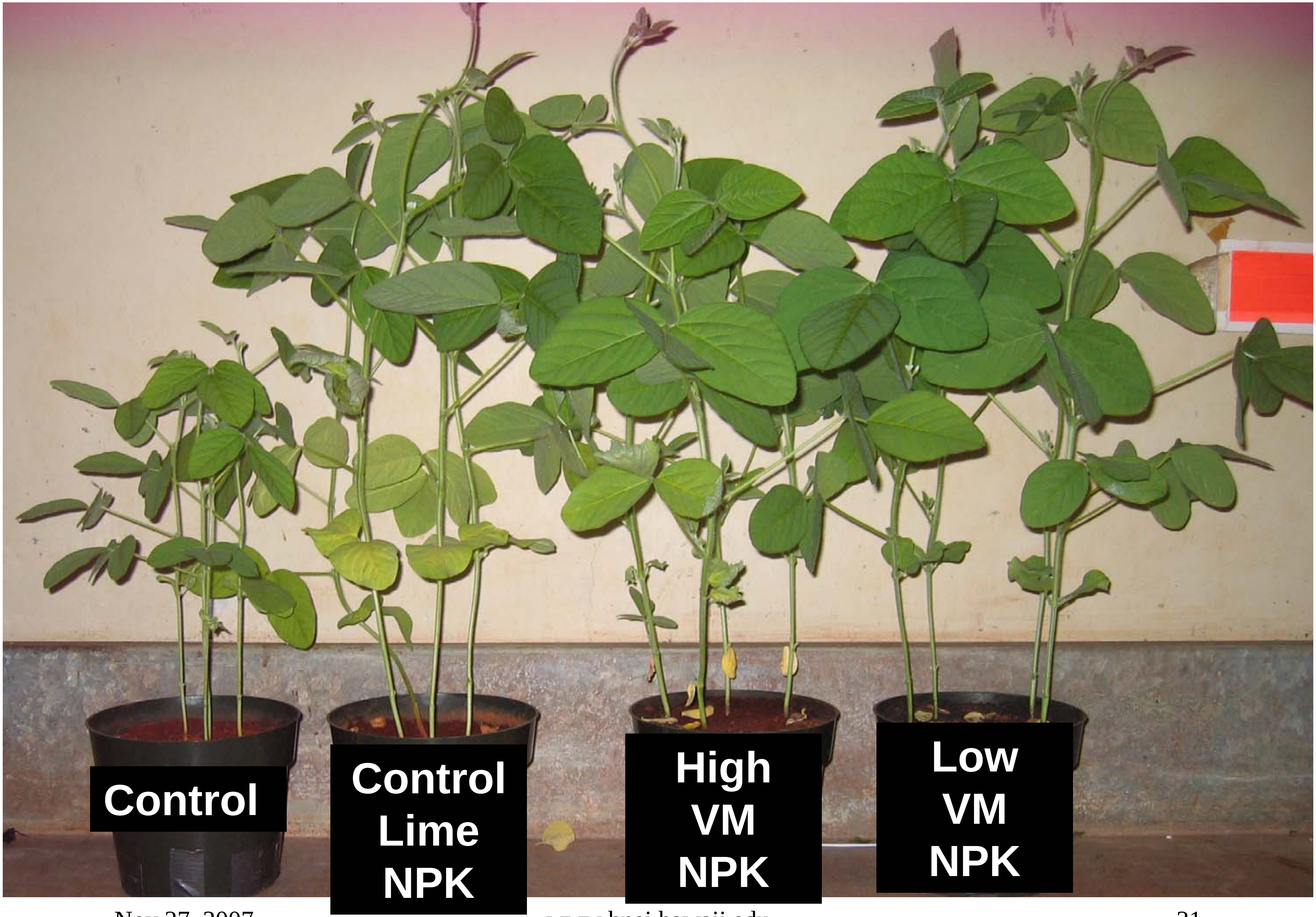
Volatile Matter or Feedstock?

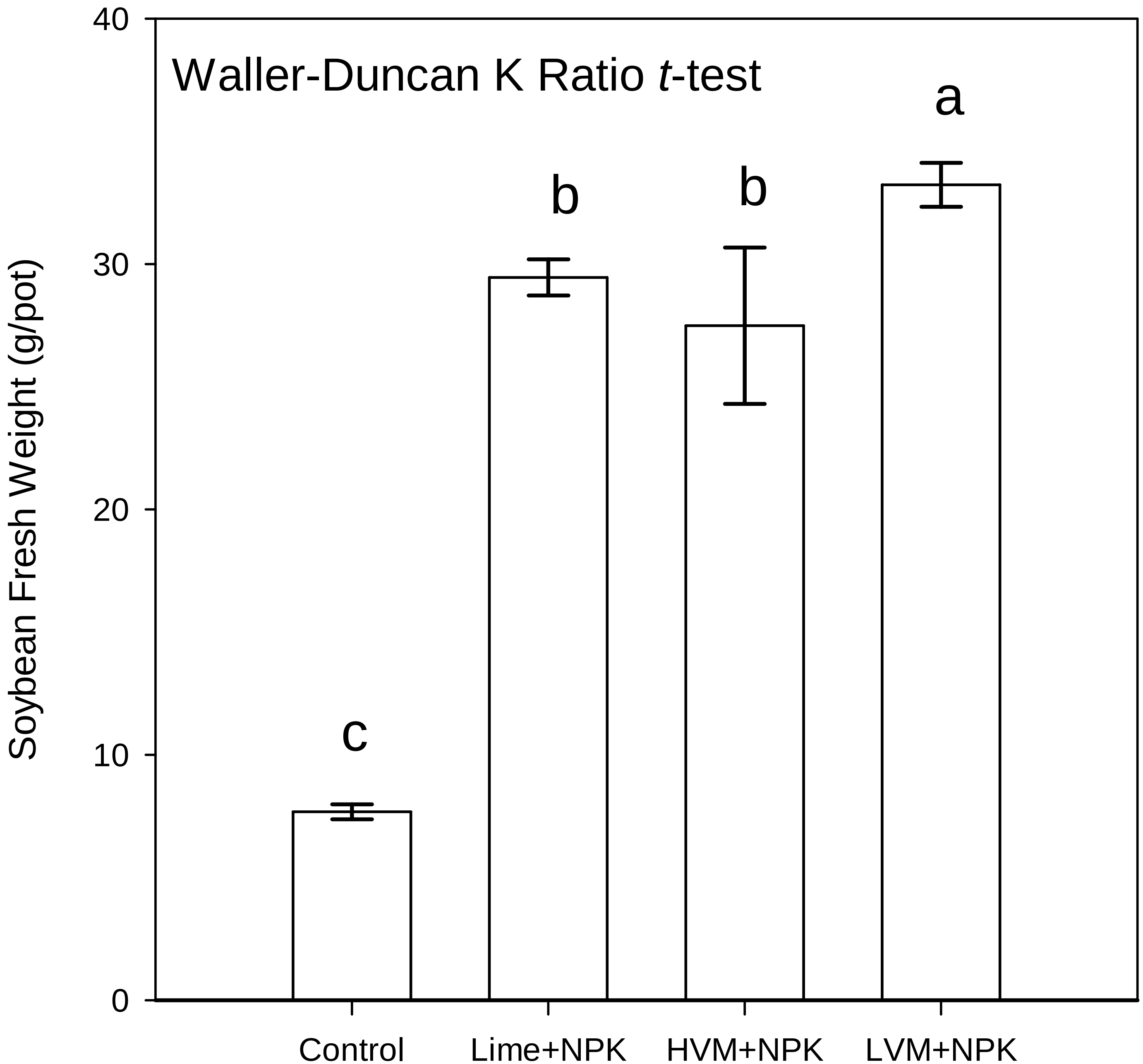
- VM content affected plant growth in macnut shell charcoal
- Does feedstock make a difference?
- Repeat trial with corn cob charcoal

Effect of corn cob charcoal on soybean




Waller-Duncan K Ratio *t*-test
Soybean Fresh Weight (g/pot)
14
12
10
8
6
4
2
0
a
b
b
Control
HVM
LVM


Control
Control Lime NPK
High VM NPK
Low VM NPK


Waller-Duncan K Ratio *t*-test
Soybean Fresh Weight (g/pot)
0
10
20
30
40
c
b
b
a
Control
Lime+NPK
HVM+NPK
LVM+NPK

Conclusions

- Volatile matter content influences a charcoal’s effectiveness as a soil amendment
- Low volatile matter charcoals are more effective soil amendments than high volatile matter charcoals

Future Studies

- Will the positive effects observed in greenhouse tests carry over into field trials?
- Will the positive effects persist or diminish with time?
- Will the negative effects of high volatile matter charcoal persist or diminish with time?