Green and Sustainable Technologies
2 Credits
Applications of Biochar for Sustainability

Dr. Renuka Ariyawansha

Department of Environmental Technology, Faculty of Technology

renukaa@sltc.ac.lk

SLTC Research University

Outline

1. **Introduction – Biochar**
2. **Biochar production technologies**
3. **Characteristics of biochar**
4. **Benefits of biochar**

Definition: Biochar

Biochar is **a charcoal carbon product derived from biomass that can enhance soils, sequester or store carbon, and provide useable energy** (Leheman et al., 2006).

Biochar is produced by thermal decomposition of organic material under limited supply of oxygen (O), and at relatively low temperatures (<700°C) (Leheman, 2009)

Biochar is a carbon-rich product obtained from the thermo-chemical conversion of biomass

Biochar is charcoal made for application in soil

The origin of biochar management and research: Some facts

Trimble (1851) shared observations of ‘evidence upon almost every farm in the county in which I live, of the effect of charcoal dust in increasing and quickening vegetation’ (Lehmann, 2009)

In 1927, Morley (1927) writes in the first issue of The National Greenkeeper that ‘charcoal acts as a sponge in the soil, absorbing and retaining water, gases and solutions’.

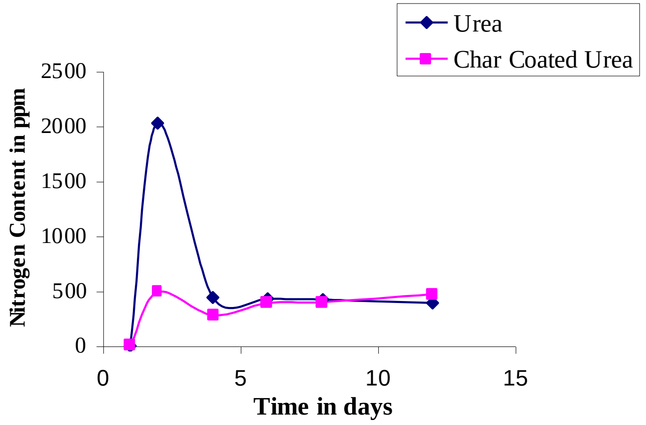
Early research on the effects of biochar on seedling growth (Retan, 1915) and soil chemistry (Tryon, 1948) yielded detailed scientific information.

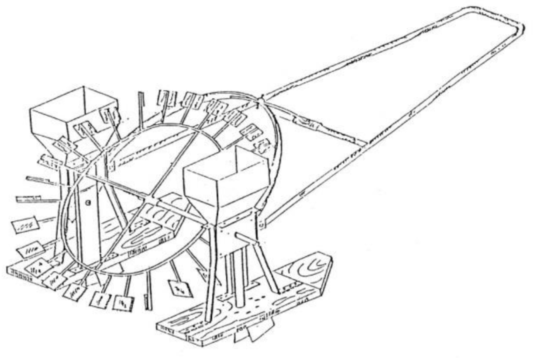
In Japan, biochar research significantly intensified during the early 1980s (Kishimoto and Sugiura, 1980, 1985).

The Center for Agricultural Machinery, Land, Water, and Forestry Management (CEMAGREF) in France welcomed the idea of making char from agricultural wastes proposed by Prof. Basnayake in 1982. They were interested in using it for fueling gasifiers to run tractors, while Prof. Basnayake’s intention was for replacing fertilizer for increasing agriculture productions.

Basnayake BFA (1986) Conception and functioning of a multi-product pyrolyzer (Conception et fonctionnement D’un carbonisateurmultiproduits). DEng Thesis. Université de Pierre et Marie Curie, Paris, France

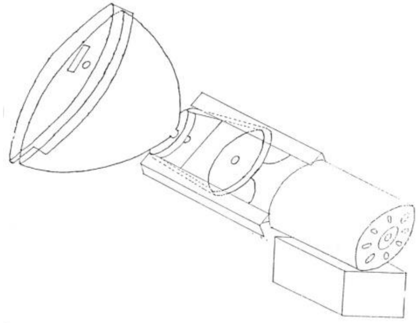
Nitrogen transfer to soil from Prilled and Char Coated Urea after deep placement





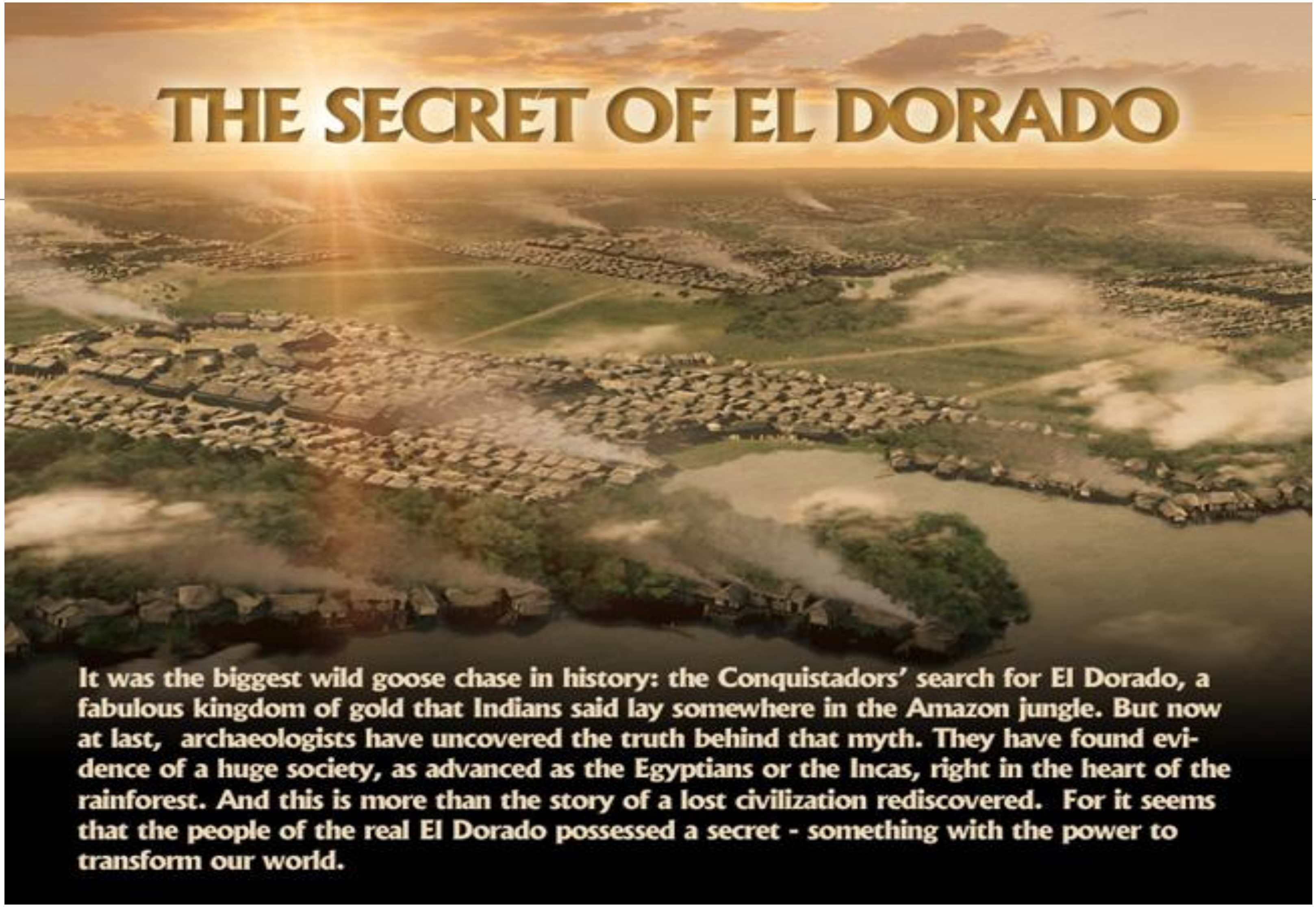
Deep Placement Fertilizer Applicator

Comparative study – Prilled Urea and Char Coated Urea (Basnayake, 1994)



The Plateau Granulator

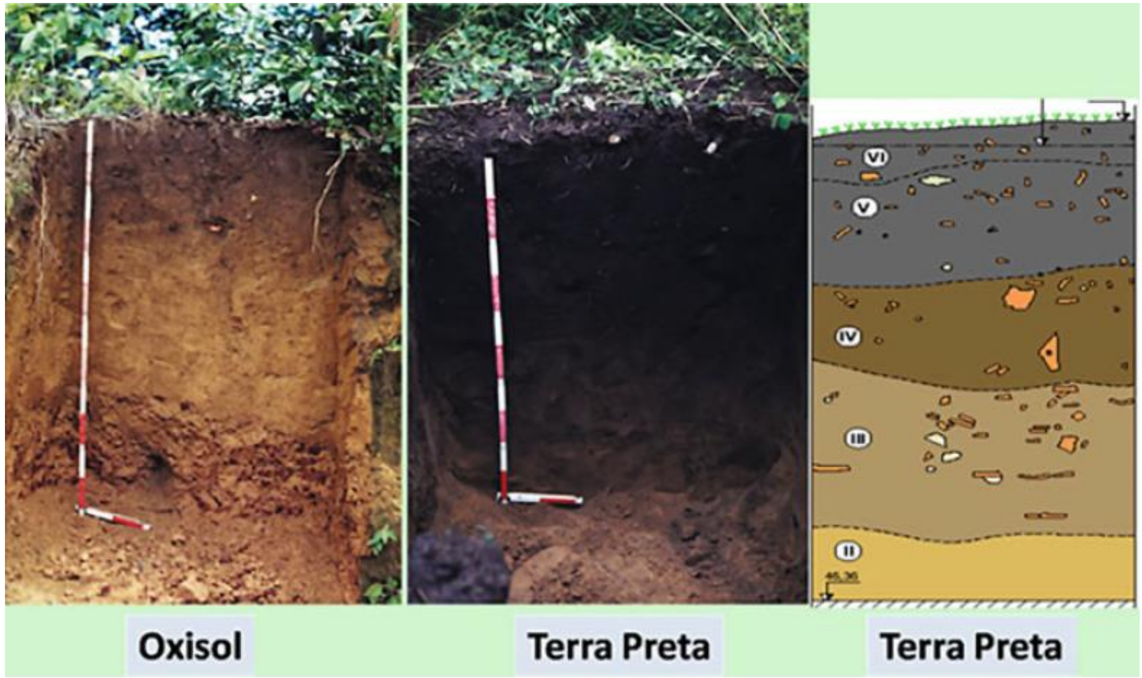
Patent No: 10665	Discovery of a process to retard the release of nitrogen fertilizer by using charcoal and manioc



(https://www.bbc.co.uk/science/horizon/2002/eldoradoqa.shtml)

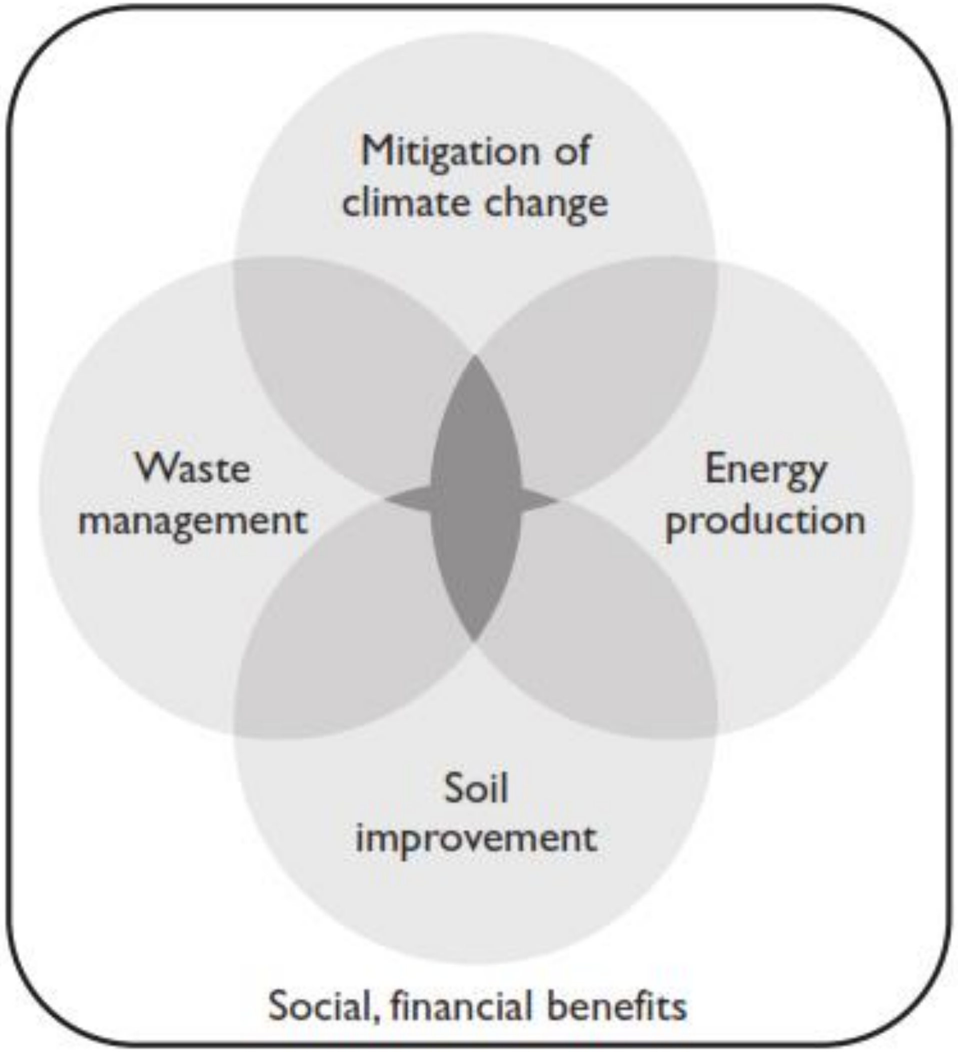
How did ancient people survive in poor tropical soils?

- Peculiar soils in the Amazon basin
  - Terra Preta de Indio (Black Soils of the Indians)
- Made by indigenous people before arrival of the Europeans
- They are formed under the trash piles of the indigenous people
- 2 m deep, 7000 years old, much more fertile than surrounding soil
- These soils have biochar, pot pieces, animal skeleton
- The terra preta display high levels of soil organic matter (SOM) and nutrients such as nitrogen, phosphorus, potassium and calcium.



Oxisol and Terra Preta

(Source: B. Glaser cited by https://www.geozentrum-hannover.de/DE/Gemeinsames/Nachrichten/Veranstaltungen/2009/Hauskolloquium_2009_2010/2009_10_06_abstracts.html)



Net benefit of using biochar in terms of mitigating global warming and as an active strategy to manage soil health and productivity

Motivation for applying biochar Technology (Lehmann, 2009)

Biochar Feedstocks

- Wood chip and wood pellets, tree bark
- Crop residues (including straw, nut shells and rice hulls)
- Grass
- Organic wastes including bagasse from the sugarcane industry, paper sludge
- Chicken litter (Das et al., 2008), dairy manure
- Municipal green waste from gardens and parks, composted or compostable urban waste
- Digested sewage sludge(Shinogi et al., 2002)
- By-products of other bioenergy or bio-fuel systems

How biochar is made?

Biochar making is arguably the most ancient technology man has developed

- Earthen mounds

Pyrolysing biomass

- Pyrolysis is similar to baking with low oxygen
- Pyrolysis also produce heat, liquid and gasses

Quality of biochar depends on

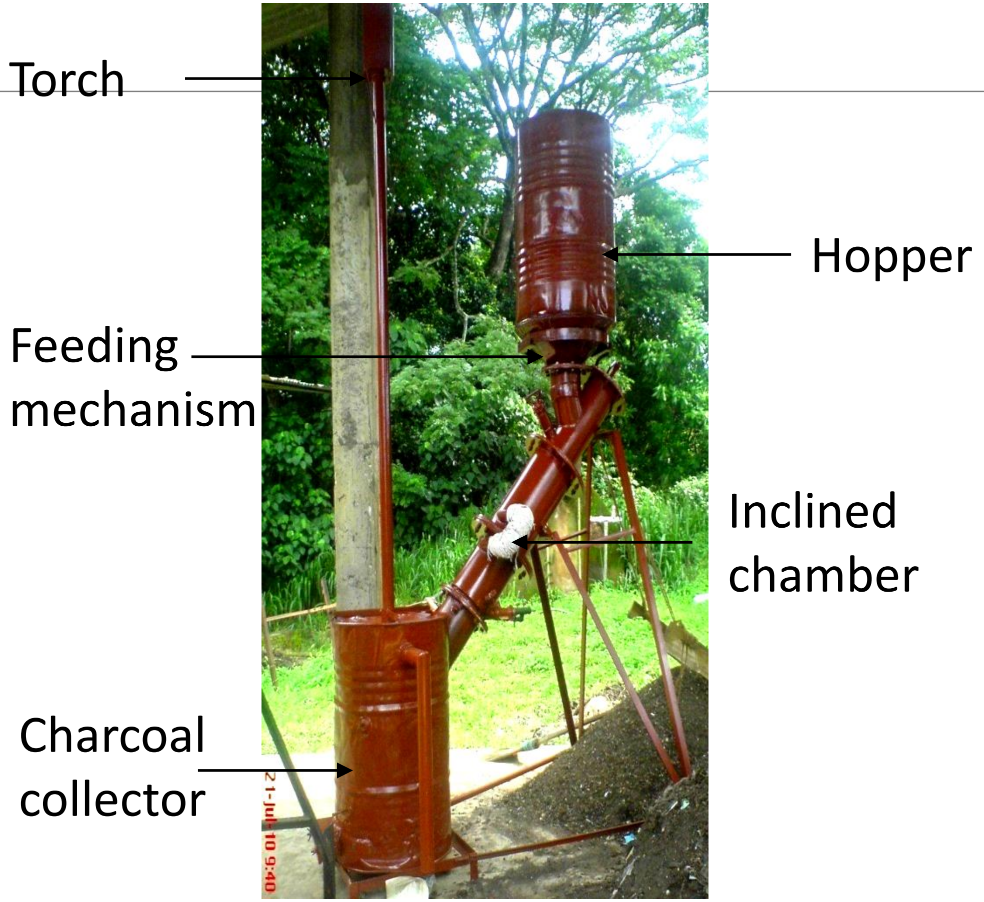
- Feed stock (source, composition, size, water content)
- Types of pyrolysis
- Pyrolysis conditions (temperature, residence time, heating rate, pressure)

Traditional process of charcoal production

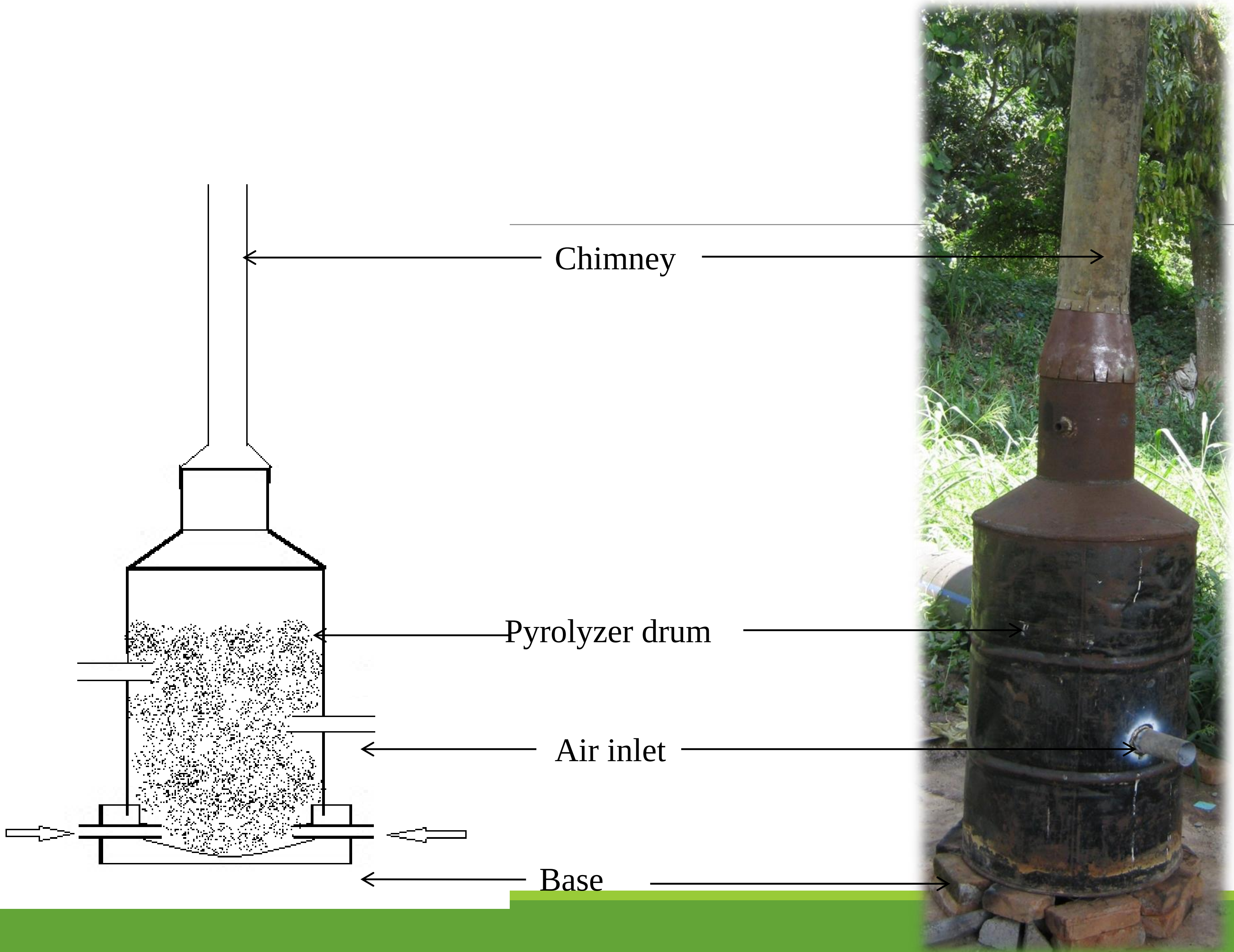
- Using pits, mounds or kilns
- Generally involve some direct combustion of biomass generally wood as heat source in the kiln which reduce the carbon yield
- Liquid and gas produce often not collected but escape as smoke as well as particulates and carbon monoxide as well as other hydrocarbon and amide
- Leading to net radioactive forcing effect even if the biochar product is used for carban storage
- Hence traditional charcoal making techniques are not generally compatible with the objectives of pyrolysis biochar system (Lenton and Vaughan, 2012).

How biochar is Made?

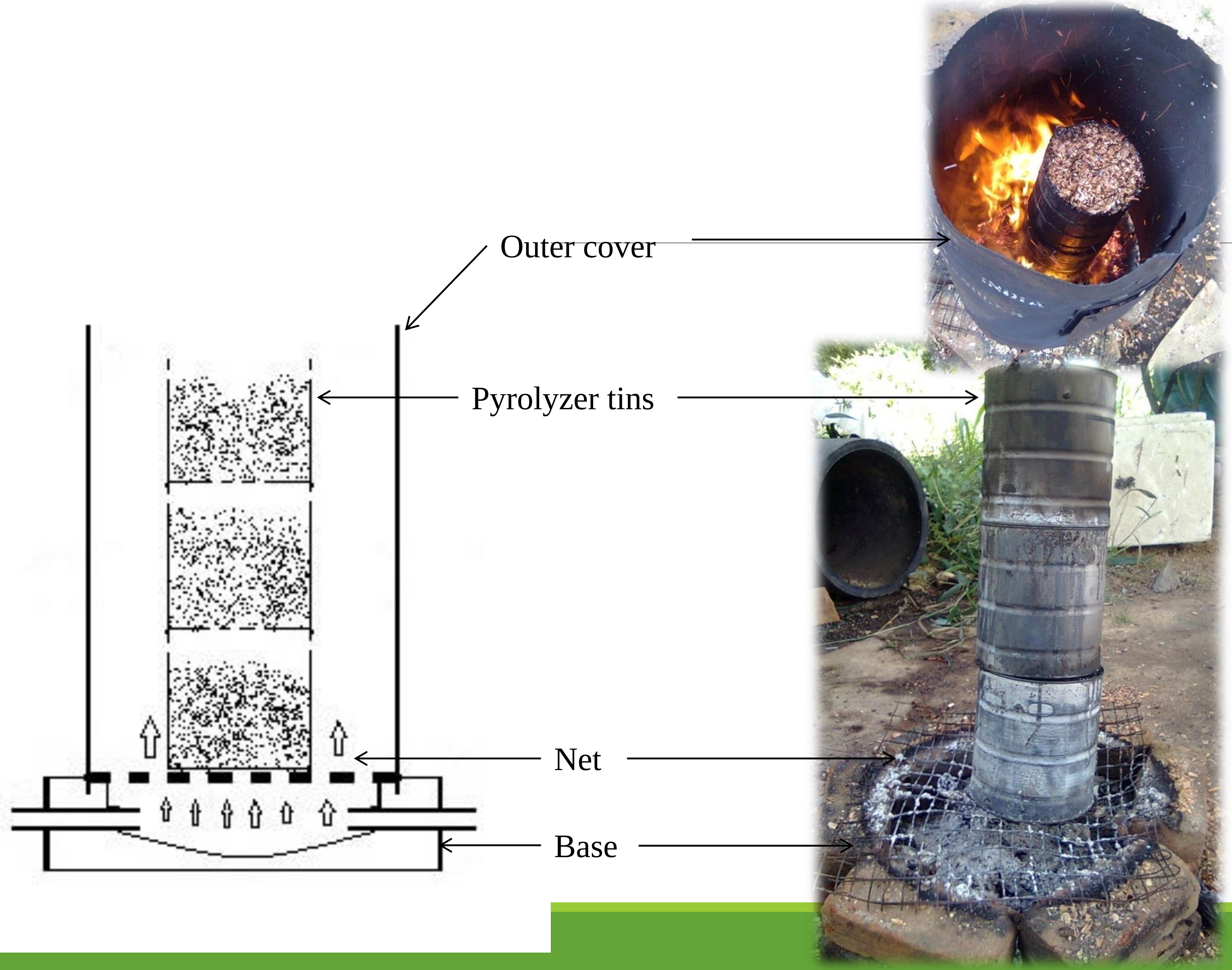
Development of a Municipal Solid Waste Pyrolyzer for Producing High Quality Charcoal



Constructed Pyrolyzer Manel, 2010



Kargen, 2011


Outer cover
Pyrolyzer tins
Net
Base

Feed stock

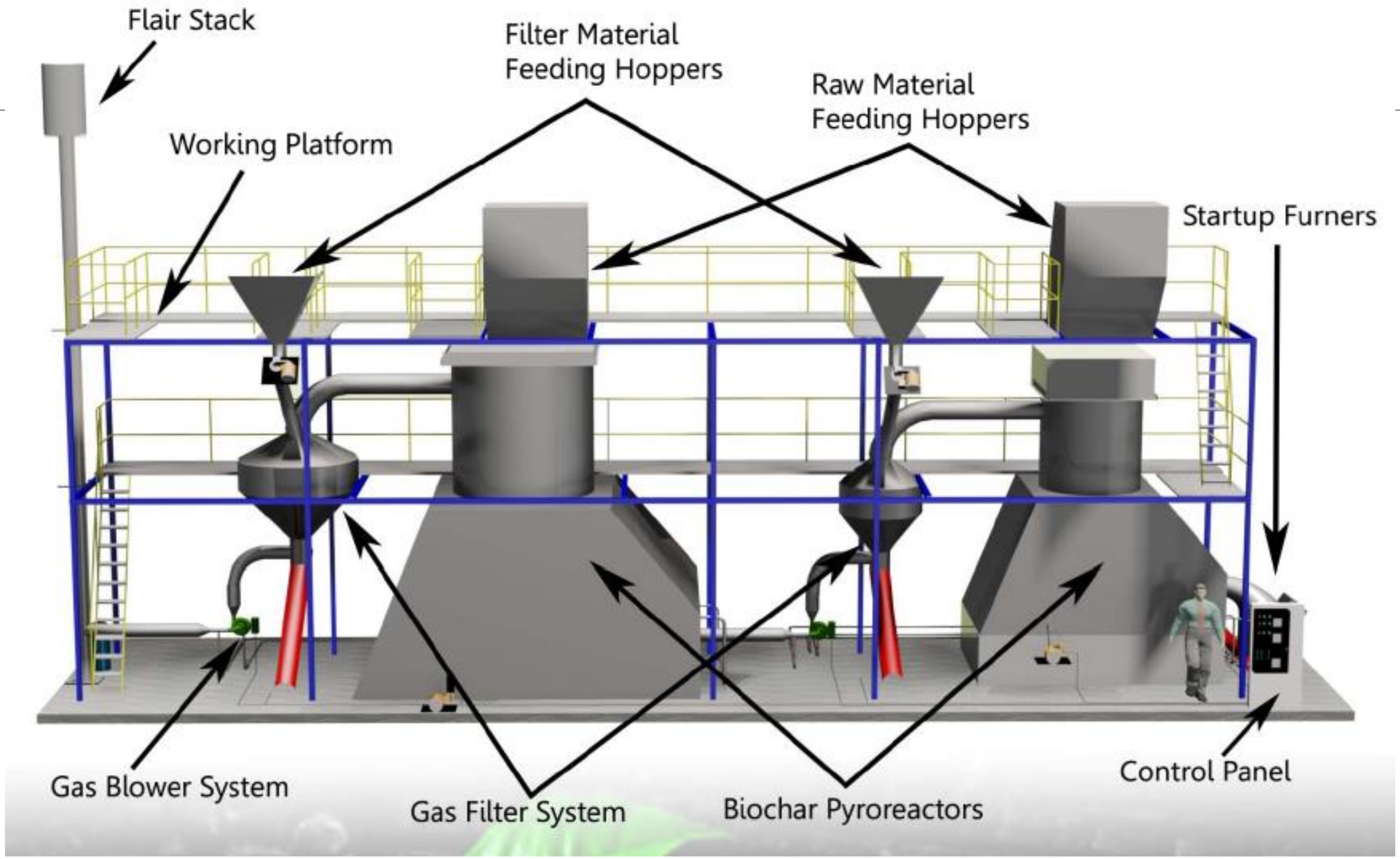
Bio char

Kiln used for production of biochar (Weerasekara, 2013)

Biochar Plant at Gohagoda Project site

Biochar Plant at Operation

The Fabricated Pyrolyser and Gasifier (Eoctech Lanka Ltd)

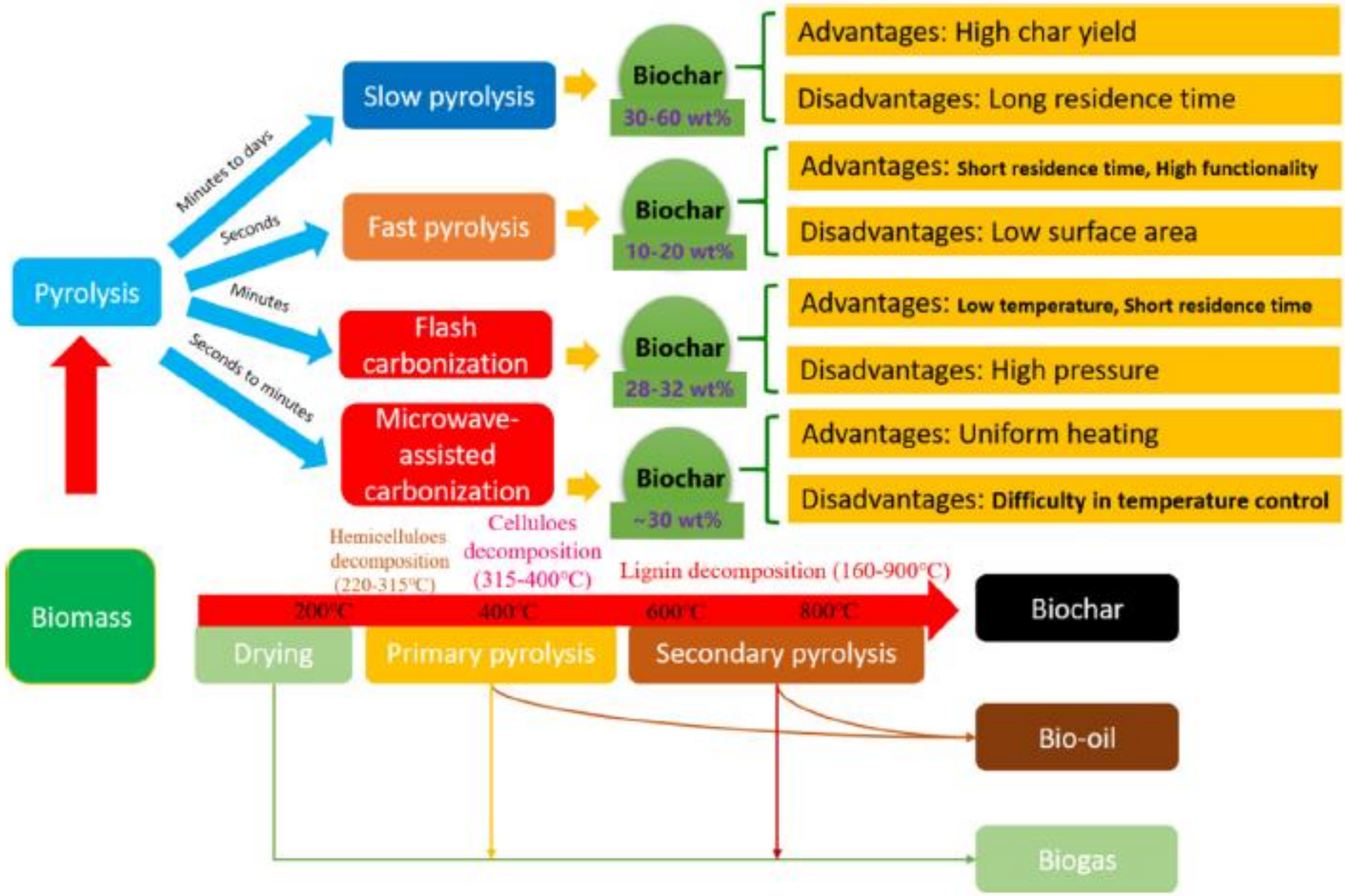


Biochar production system (Ecotech Lanka Ltd)

The pyrolysis mechanism based on biochar structure evolution

- Biomass decomposition generally occurs during the primary decomposition process at 200 – 500 °C.
- Biomass is converted to biochar by intramolecular and intermolecular reactions.
- The pyrolysis of cellulose involves the initial conversion of cellulose into amorphous cellulose intermediates
- Then converted into irregular carbohydrates before converting into aromatic carbon as the end product.
- With a further increase in temperature, the hemicellulose components are transformed into porous smooth substances, thus leading to a decline in the functional groups (e.g. hydroxyl and methoxy groups).
- Secondary reactions of biochar, such as cracking and polymerization, occur after the primary reaction.
- The secondary formation is mainly caused by polymerization (Li et al., 2020)

According to the heating rate, residence time, heating method



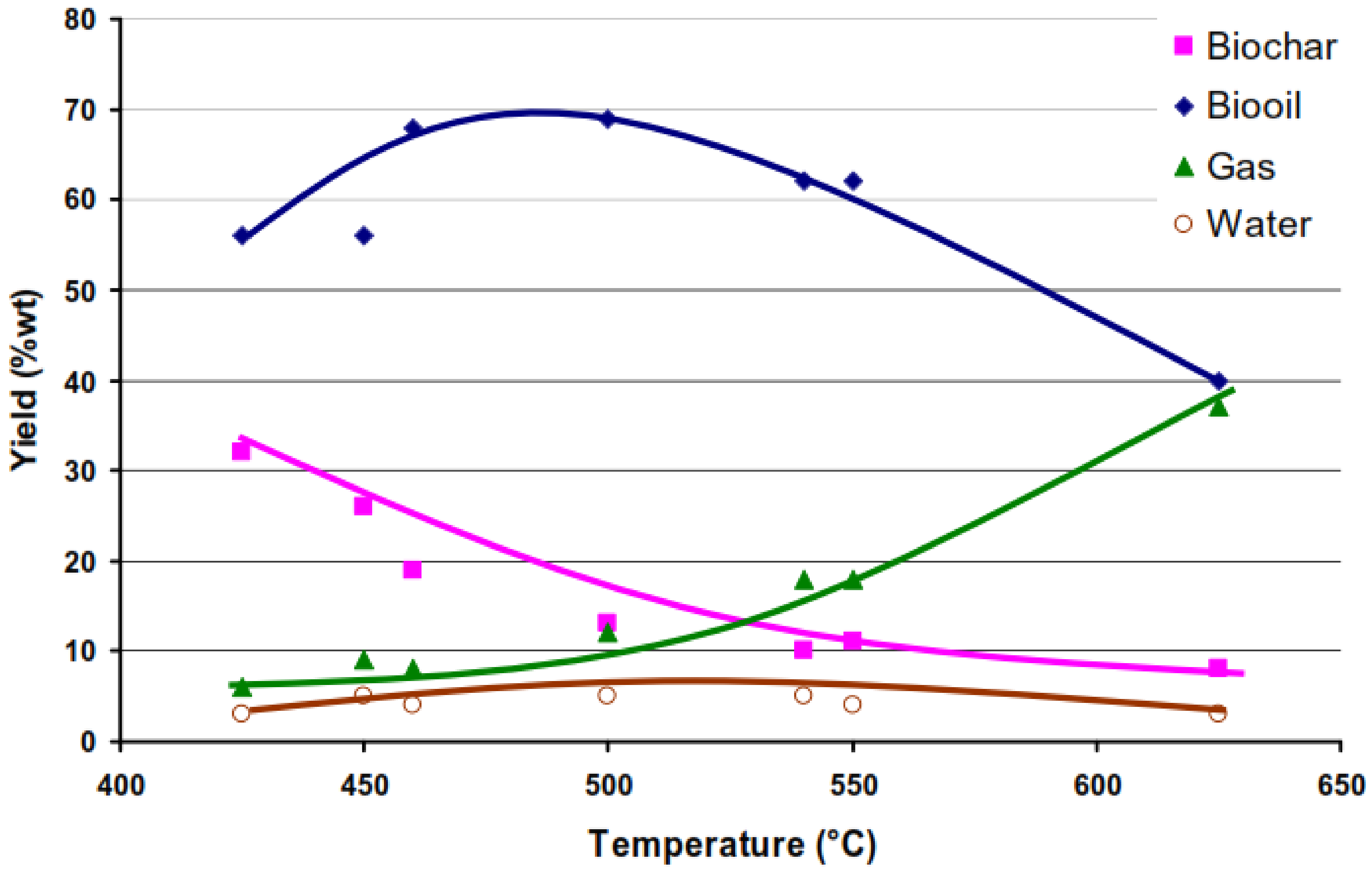
Biomass pyrolysis types and its advantages and disadvantages (Li et al., 2020)

Fate of initial feedstock mass between products of pyrolysis processes

	Slow pyrolysis	Intermediate pyrolysis	Fast pyrolysis
Process			
Temperature (° C)			
Range	250-750	320-500	400-750
Typical	350-400	350-450	450-550
Heating and residence time			
Range	mins-days	1-15 mins	ms-s
Typical	2-30 mins	4 mins	1-5 s
Yields (as % o.d. feedstock mass)			
Char			
Range	2-60	19-73	0-50
Typical	25-35	30-40	10-25
Liquid			
Range	0-60	18-60	10-80
Typical	20-50	35-45	50-70
Gas			
Range	0-60	9-32	5-60
Typical	20-50	20-30	10-30

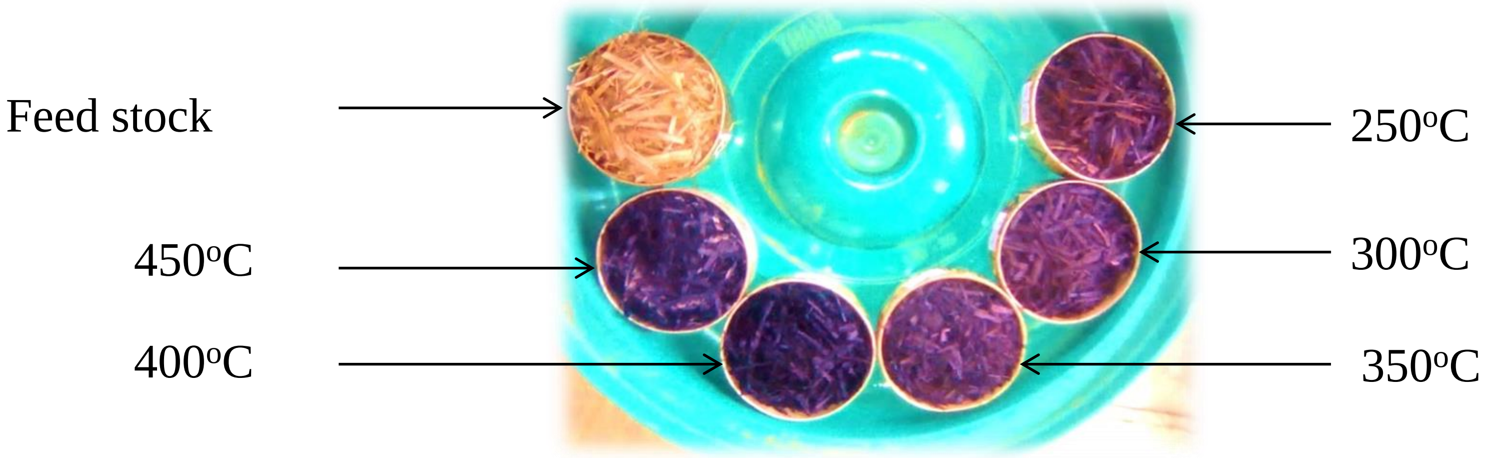
The mean post-pyrolysis feedstcok residues resulting from different temperatures and residence times (IEA, 2007)

Mode	Conditions	Liquid	Biochar	Syngas
Fast pyrolysis	Moderate temperature, ~500°C, short hot vapour residence time of ~ 1 s	75%	12%	13%
Intermediate Pyrolysis	Moderate temperature ~500°C, moderate hot vapour residence time of 10 – 20 s	50%	20%	30%
Slow Pyrolysis (Carbonisation)	Low temperature ~400°C, very long solids residence time	30%	35%	35%
Gasification	High temperature ~800°C, long vapour residence time	5%	10%	85%



A graph showing the relative proportions of end products after fast pyrolysis (adapted from IEA, 2007)

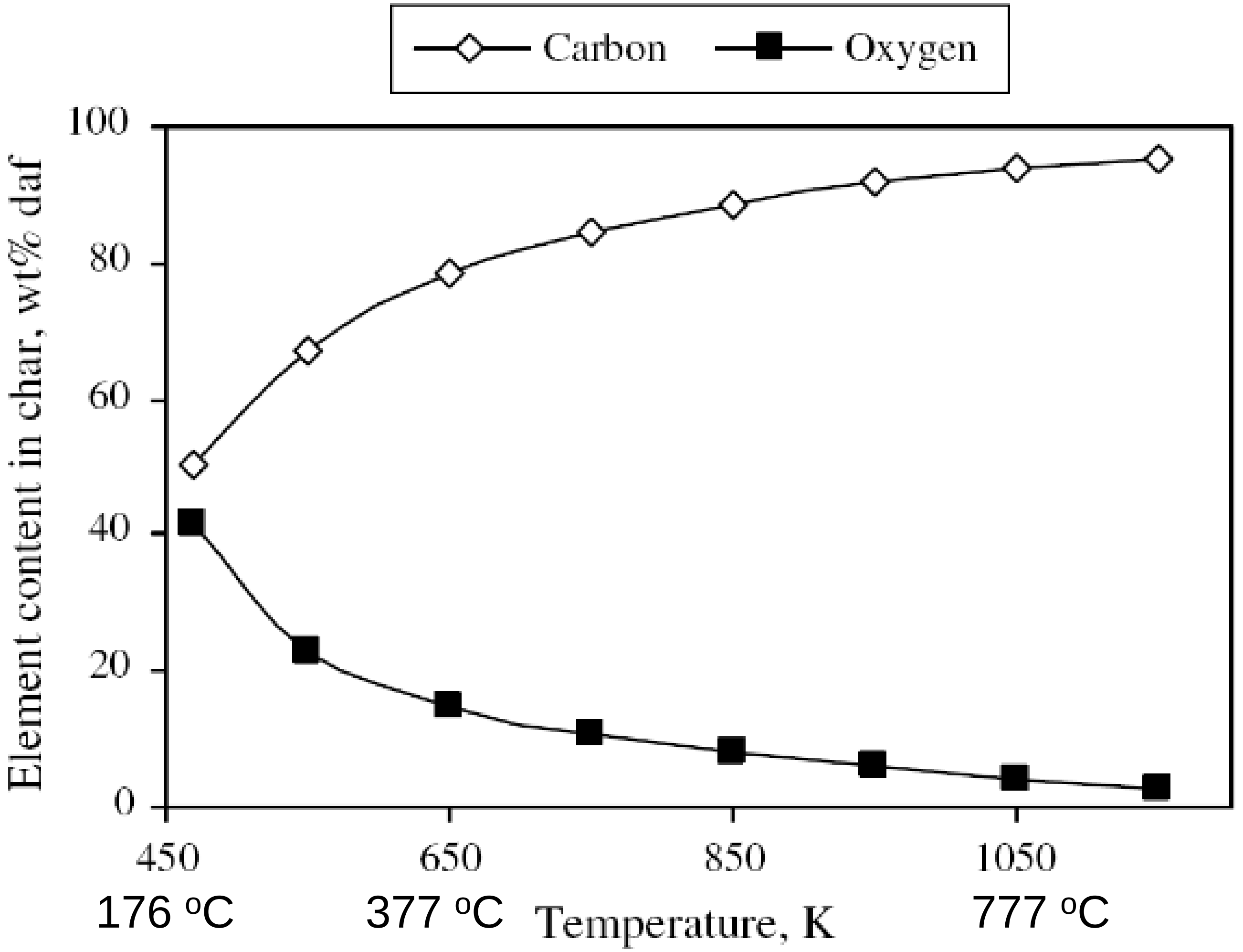
Determination of Pyrolitic Parameters of Paddy Straw for Enhancing Biochar Quality



Biochar Samples at 250, 300, 350, 400 and 450 ^{o}C for 6 hours

Pyrolysis at 400^{o}C temperature for 6 hours was the best pyrolytic condition

Udayanga, 2012



Effect of temperature on carbon and oxygen contents in biochar from biomass. Sourced from Demirbas (2008).

In general, the pyrolysis temperature affects the **surface area, pH, carbon content, surface charge, stability, volatile fraction, and other physicochemical properties**.

Biochar produced at a relatively low temperature has a high acidity, polarity, low aromatic content, and hydrophobicity.

With an increase in the process temperature, acid functional groups (e.g. –OH and –COOH) and the biochar yield decrease, that is, the alkaline functional groups, pH, and ash content in biochar increase.

The surface area of biochar also increases with the release of volatiles from the biomass.

In consideration of the economic feasibility, and according to the nature and type of the raw material, a temperature of between 450 °C and 700 °C is most suitable for biochar production.

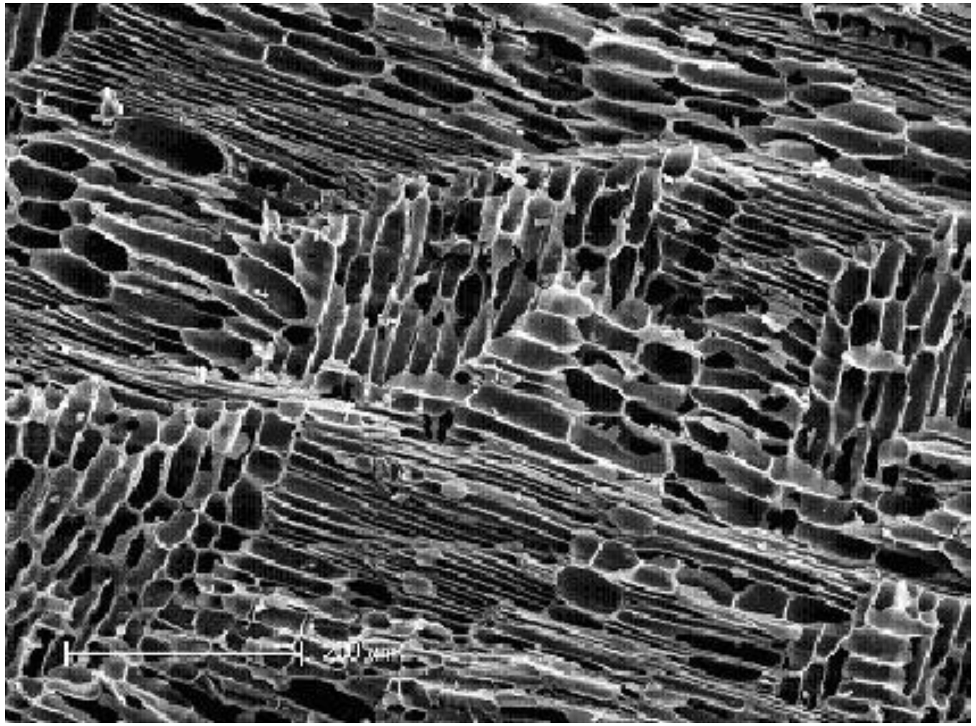
General Characteristics of biochar

Highly porous / large surface area

Reacts and interacts with other soil constituents

Has a low bulk density

Contains stable C



Factors effect on physicochemical properties of biochar

- The production process parameters (temperature, residence time, heating rate, and pressure)
- The composition,
- Structure, and
- Intrinsic binding of the original biomass also influence

Physical and chemical characterization

- Feedstock is a primary factor governing the chemical and physical properties of biochar.
- Increasing pyrolysis temperature from 300 to 800°C decreased the yield of biochar from 67 to 26% and increased the fixed carbon content from 56 to 93% (Tanaka, 1963).

Major constituents in biochar

1. **Stable C**
   - **Related to how long biochar remains in soil**
2. **Unstable C**
   - **Relatively rapidly decomposed, can influence plant nutrition**
3. **Ash**
   - **Can provide nutrients and increase soil pH**
   - **High ash content can be harmful**
4. **Moisture**
   - **Holds large amounts of water**

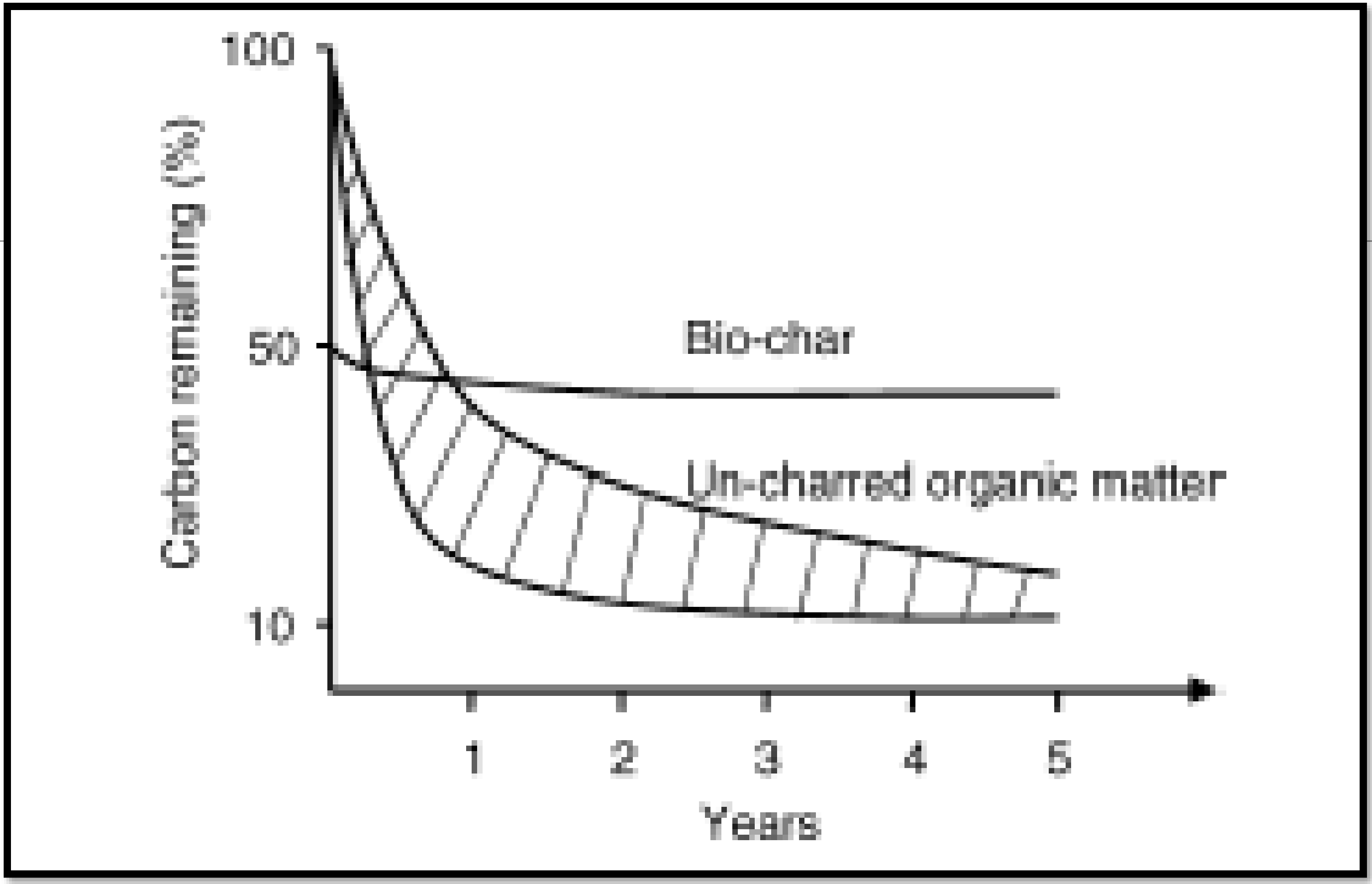
Biochar components as a percentage of total weight

Component	Proportion (%)
Fixed carbon	50-90
Volatile matter	0-40
Moisture	1-15
Ash (mineral matter)	0.5-5

(Verheijen et al., 2010)

Adopted from Brown, 2009, Antal and Gronil, 2003

- Biochar has a porous structure with abundant functional groups (i.e. it is rich in surface free radicals and surface charges) and a high surface area, and also contains minerals and trace metals (Wang & Wang, 2019).
- Biochar is a reservoir of electron acceptors and donors with a pH buffering capacity and cation exchange capacity (Leng et al., 2020).
- These properties lend a high reactivity to biochar, and are mainly affected by the composition of the raw materials and production methods



Simplified stability of biochar C and biomass C in soil (Lehmann et al., 2006)

Organic and inorganic composition of biochar

- At even higher temperatures of up to 1000 ^{o}C (typically to produce so-called “activated carbon”, but also gasification biochars), carbons are mainly hydrophobic and do not sorb appreciable amounts of nutrients or polar organic substances, such as sugars (Yam et al., 1990).

- The same has also been observed for naturally occurring black C (Cornelissen et al., 2005).

- In soil, biochars (those produced at or below 600e700^{o}C) seem to oxidize rapidly and attain greater amounts of CEC (Cheng et al., 2008; Nguyen et al., 2010), but initially still retain a significant proportion of non-polar surfaces (Smernik, 2009).

Summery of total elemental composition and pH range of biochar from a variety of feedstocks and pyrolysis conditions

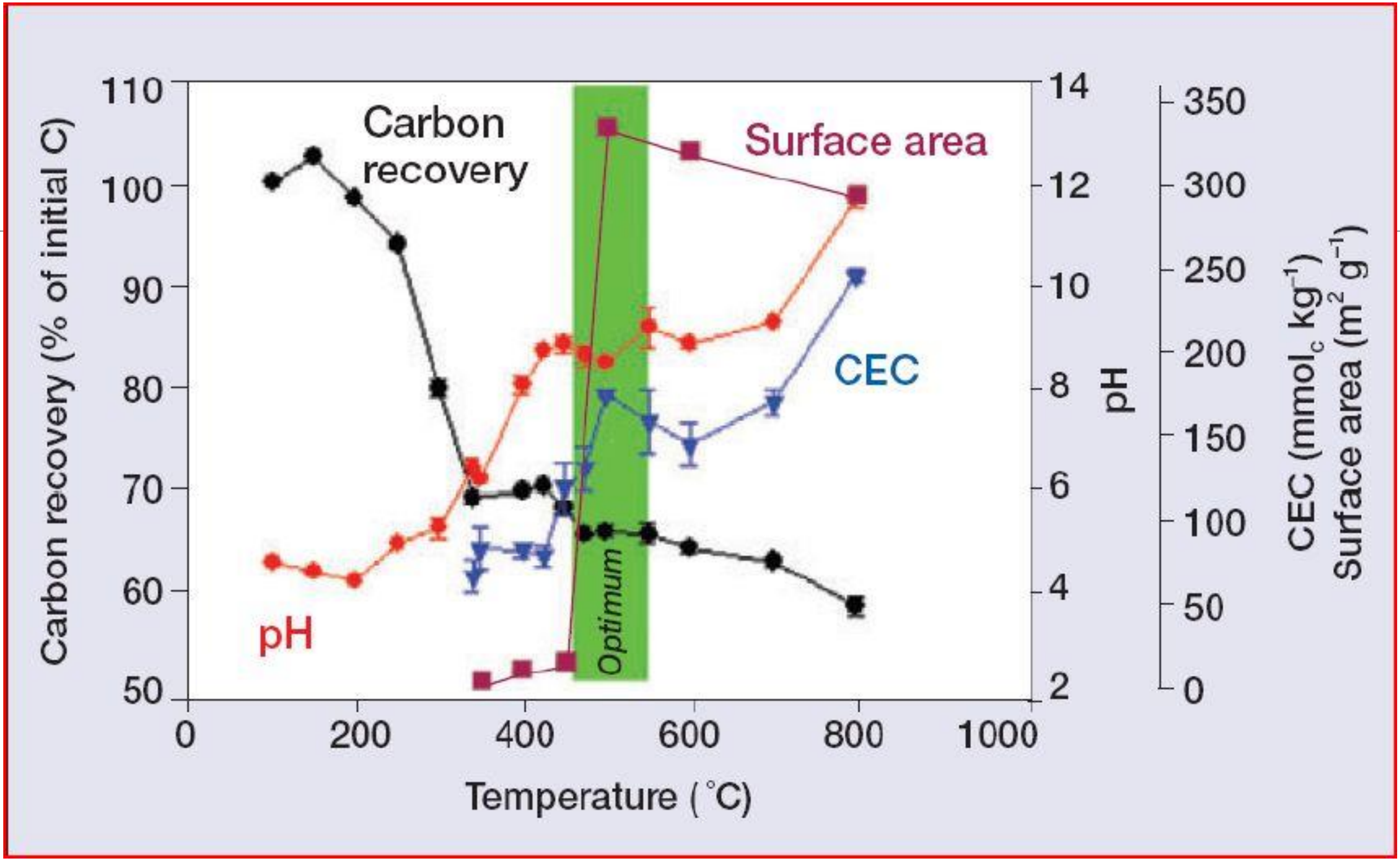
		pH	C	N	N (NO^{-3}, NH_4^+)	P	Pa	K
			(g/kg)	(g/kg)	(mg/kg)	(g/kg)	(g/kg)	(g/kg)
Range	From	6.2	172	1.7	0.0	0.2	0.015	1.0
	To	9.6	905	78.2	2.0	73.0	11.6	58
Mean		8.1	543	22.3	-	23.7	-	24.3

Source: Verheijen, 2009

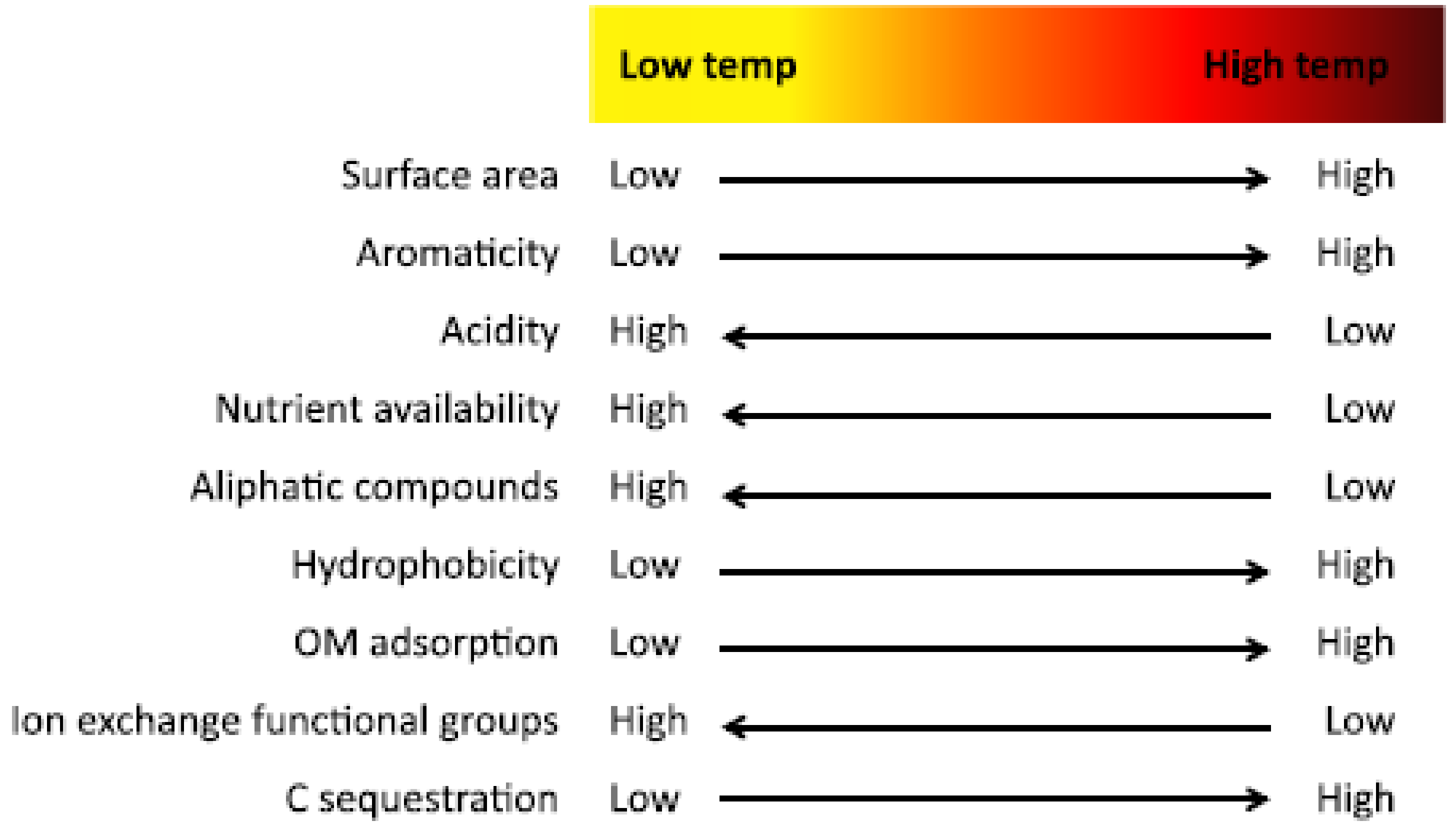
Reported elemental composition for a range of bio-oil and biochar products (% dry ash-free mass)

Product	Elemental composition (%)				HHV* (MJ/kg)
	C	H	N	O	
Beech-trunk bark biochar	87.9	2.9	0.6	10.6	33.2
Beech-trunk bark bio-oil	68.8	8.9	0.8	21.5	34.6
Rapeseed cake biochar	66.6	2.5	6.1	24.3	30.7
Rapeseed cake bio-oil	73.9	10.8	4.7	10.6	36.5
Wood bark biochar	85.0	2.8	–	12.2	30.8
Wood bark bio-oil	64.0	7.6	–	28.4	31.0
Cotton stalk biochar	72.2	1.2	–	26.6	21.4
Cotton stalk bio-oil	59.7	7.8	1.8	30.6	26.0
Bio-char from hazelnut shell	95.6	1.3	–	3.1	32.0
Sunflower bio-oil	72.1	9.8	5.2	12.9	36.2

*HHV= higher heating value (enthalpy of complete combustion of a fuel including the condensation enthalpy of former water); Demirbas et al.,(2004)



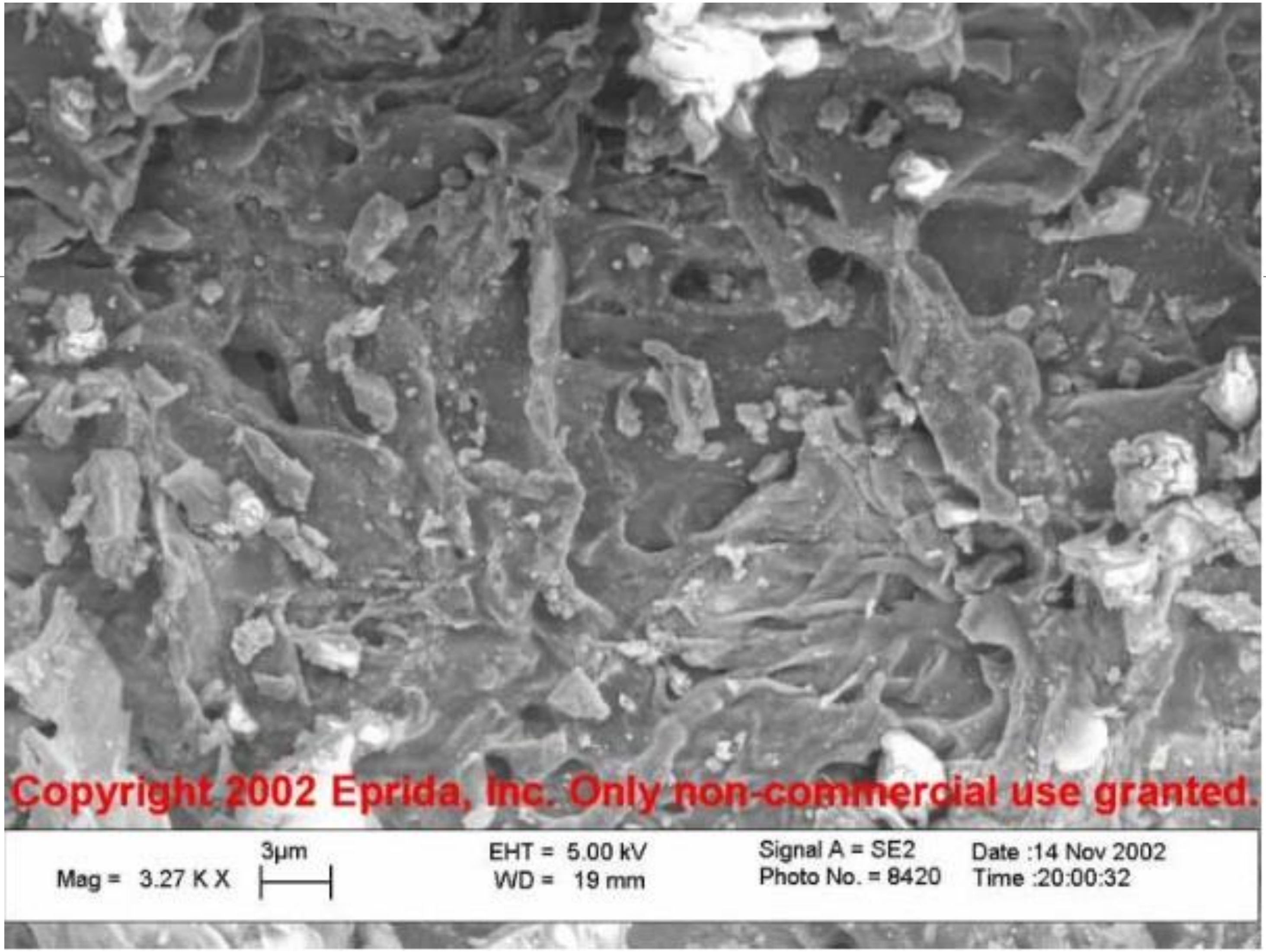
Evolution of biochar characteristics during pyrolysis (Lehmann, 2007)



Effects of pyrolysis temperature on biochar properties and functions (El-Naggar et al., 2019)

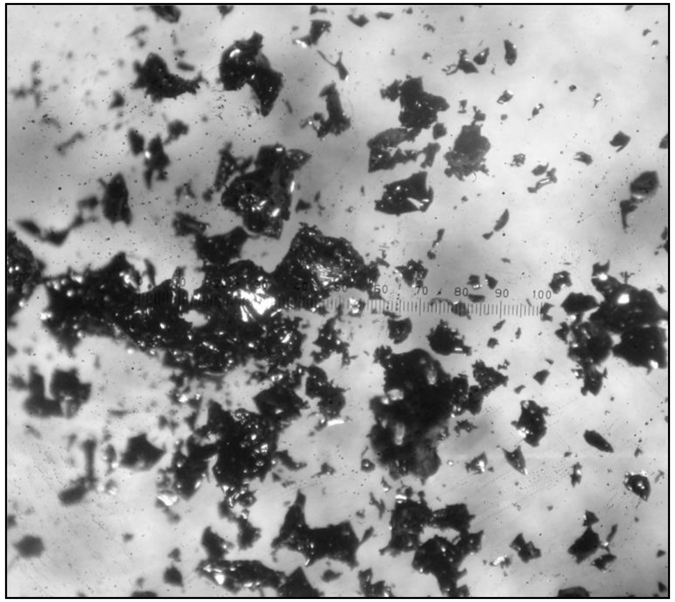
- Scanning electron microscopy (SEM) is often used to describe the physical structure of biochar, and the architecture of cellulosic plant material is clearly retained.

- It has been suggested that the porous structure of biochar can explain its impact on soil water holding and adsorption capacity (Day et al., 2005; Ogawa et al., 2006; Yu et al., 2006).

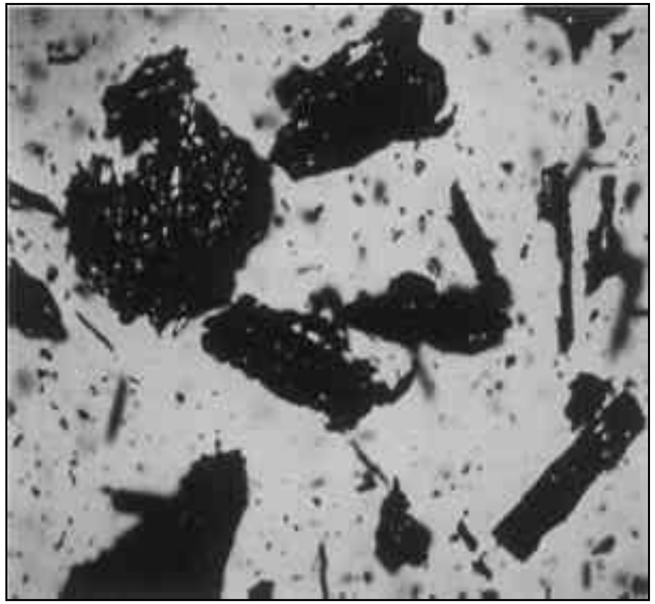


Scanning electron microscope (SEM) image of biochar produced at 400°C from pelletised peanut shell (Jason Nadler, Eprida, Day et al., 2005) (sochi et al., 2009)

Light Microscopic Structure of Charcoal

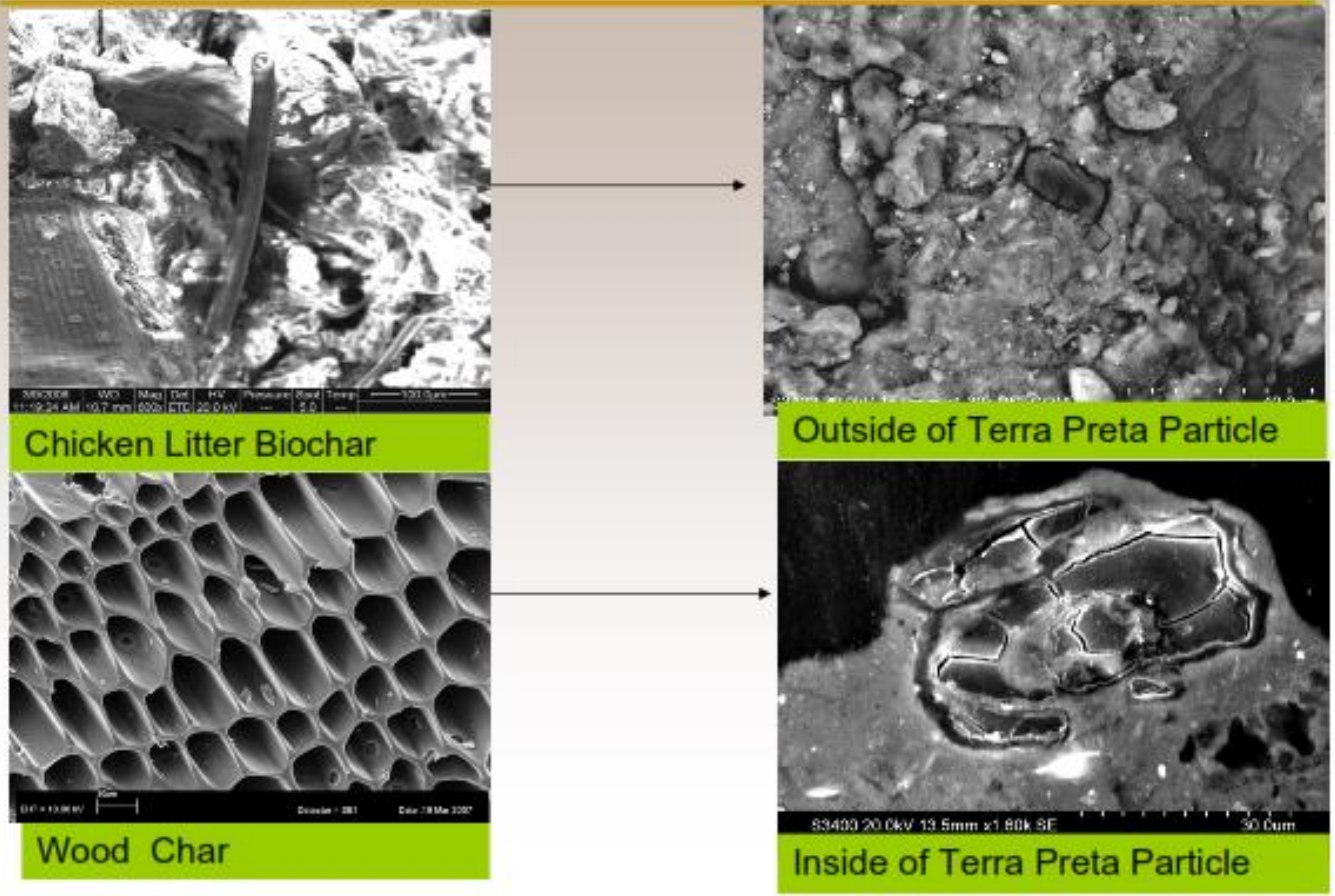


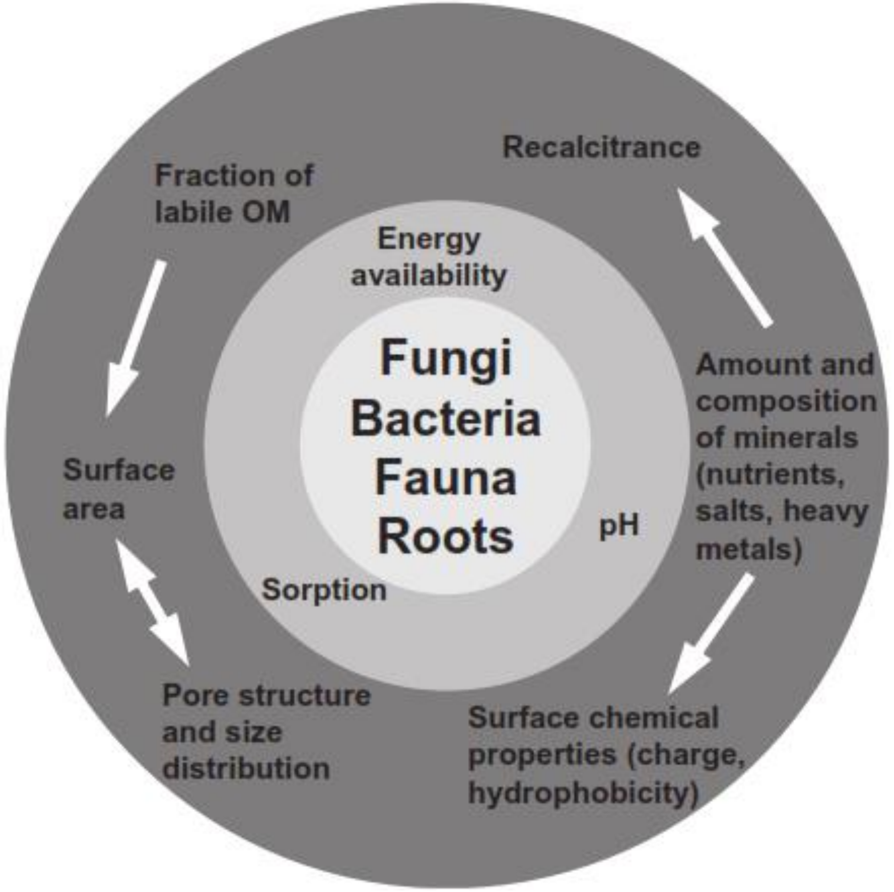
MSW Charcoal



Wood Charcoal
(Source - Ryu *et al*., 2005)

BIOCHAR WILL REACT WITH SOILS TO FORM ORGANO-MINERAL COMPLEXES





Schematic overview of the connection between primary biochar properties (outer circle),
the soil processes they may influence (intermediate circle) and
the soil biota (inner circle) (shorter distance give a qualitative estimate of the strength of the connection).
White arrows indicate influence between biochar properties.

Surface area of biochar

- Process temperature greatly affects the surface area of pyrolysis products.
- In one study, surface area was shown to increase from 120 m^2g^{-1} at 400°C to 460 m^2g^{-1} at 900°C (Day et al., 2005).
- This effect of temperature has led to suggestions that biochar created at low temperature may be suitable for controlling the release of fertiliser nutrients (Day et al.,2005)
- whilst high temperature biochars would be more suitable for use as activated carbon (Ogawa et al., 2006).
- The surfaces of low temperature biochar are, however, hydrophobic and this may limit the capacity to store water in soil.

Total pore volume of biochar is divided in to

- Micro-pore – pores internal diameter less than 2nm
- Meso-pores – internal diameter 2nm-50nm

Macro-pores < 200nm

Macro-pore – 50nm< = relevant to aeration, hydrology , movement of roots, as a habitant to variety of microbes

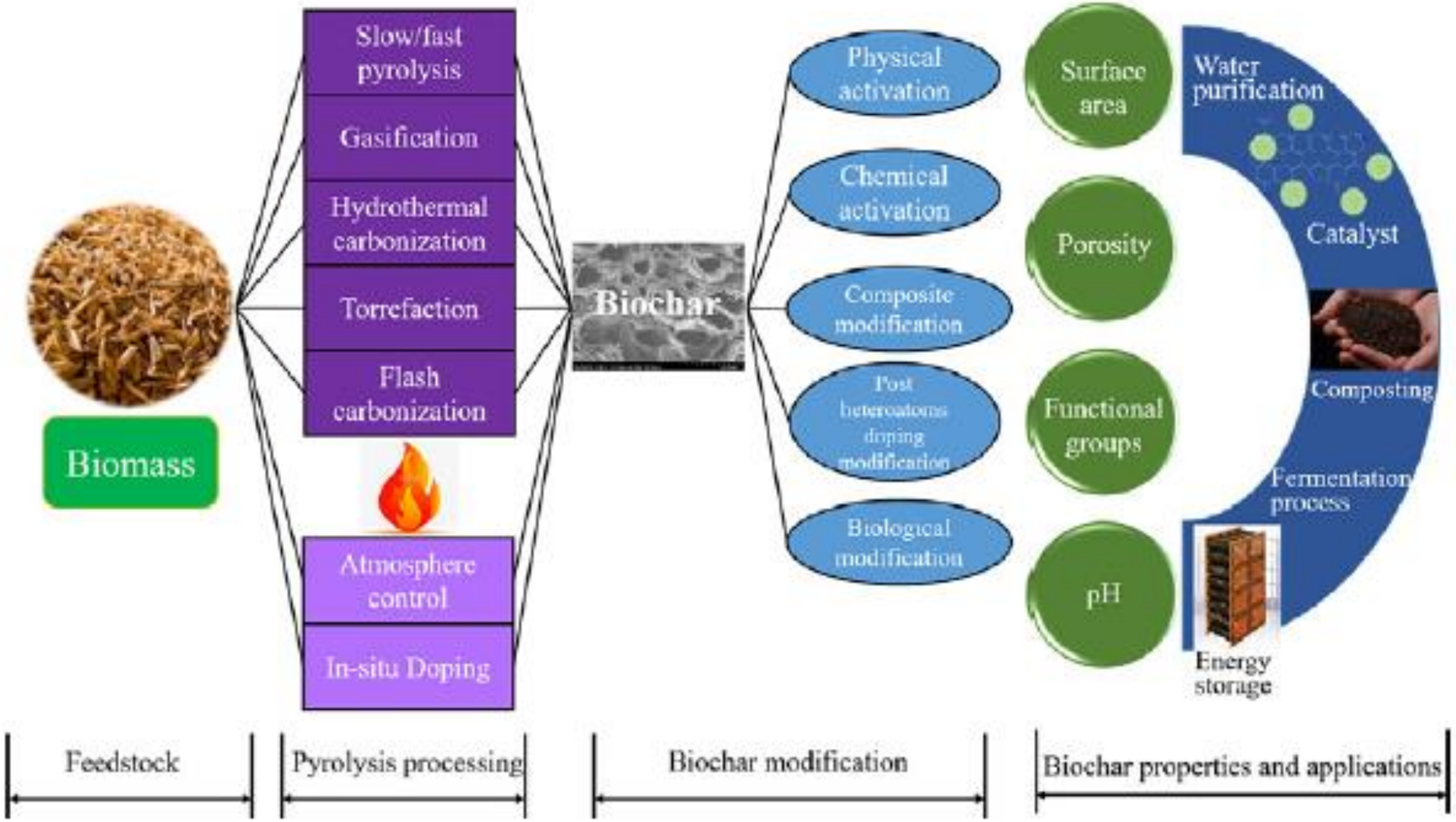
Pyrolysis regulation for biochar production

In addition to altering the pyrolysis parameters, the pyrolysis process of biomass can also be regulated by changing the pyrolysis atmosphere and in-situ activation/doping as a means of obtaining excellent biochar

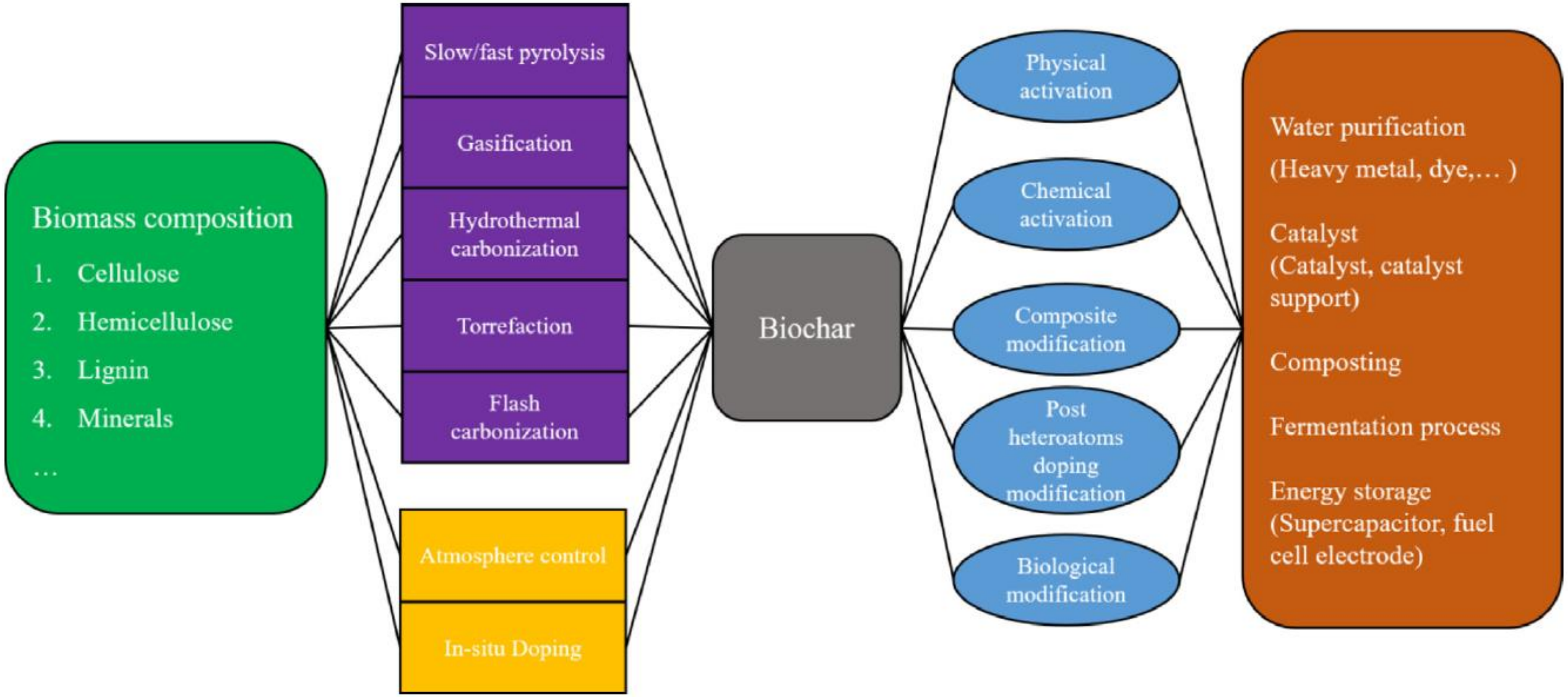
Atmosphere control

In-situ activation and doping

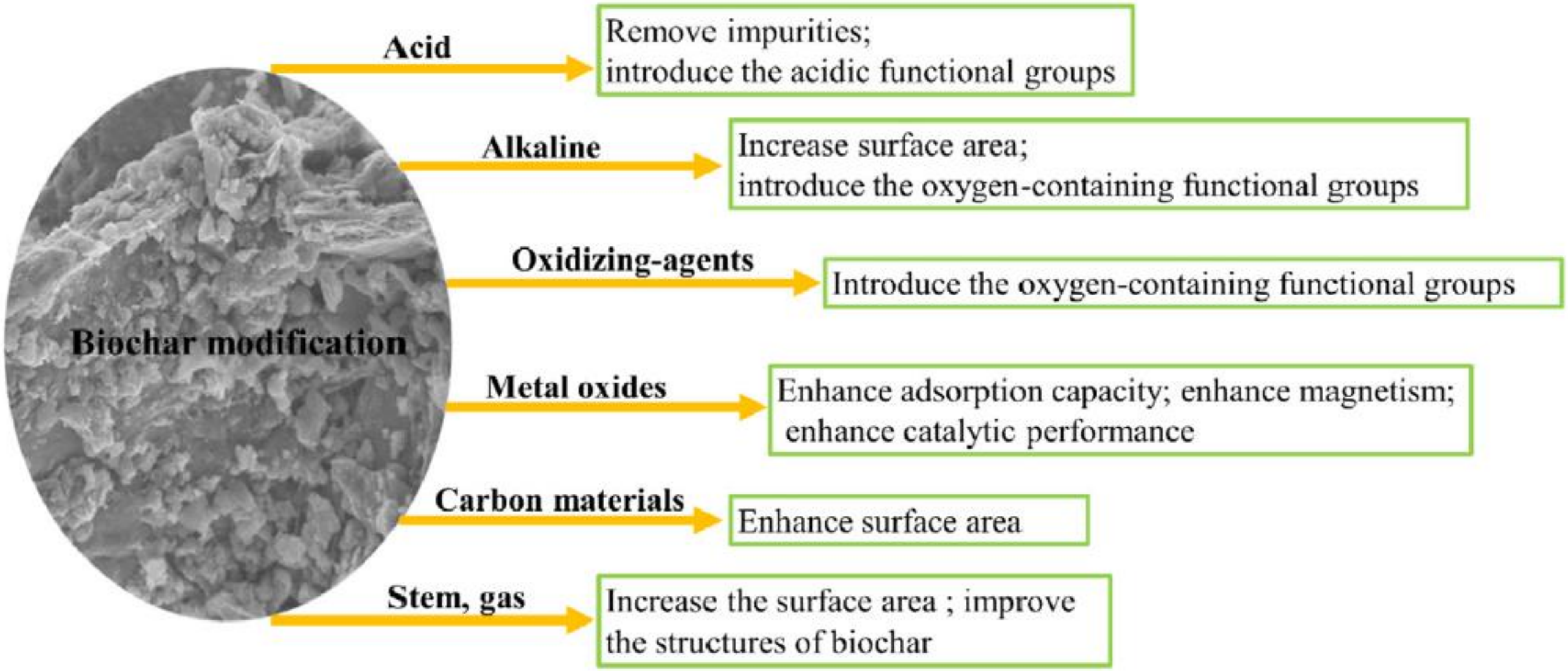
- Co-pyrolysis of biomass with activator/dopant
- Co-pyrolysis with different types of biomass



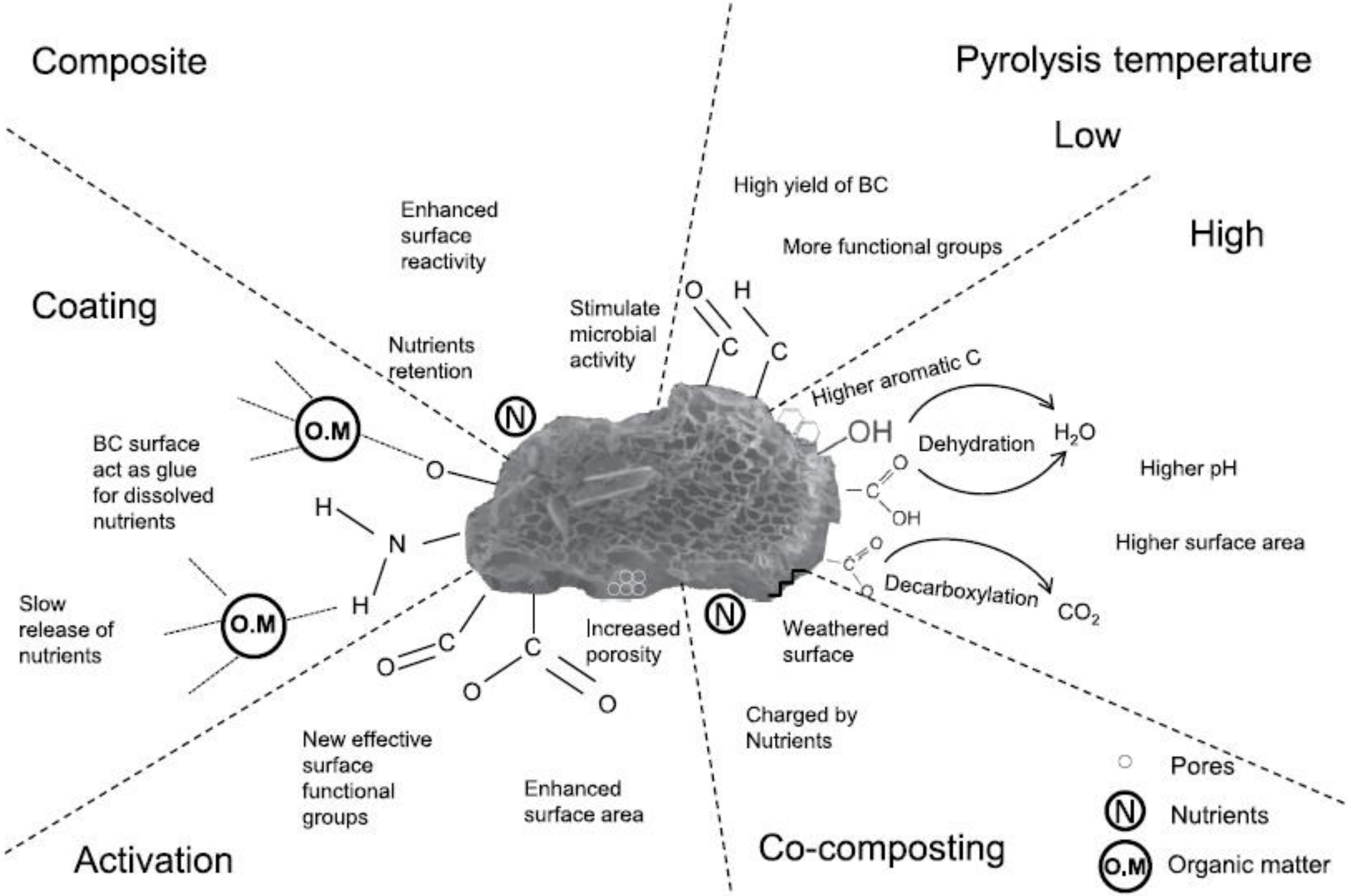
Production and advanced utilization of biochar (Li et al., 2020)



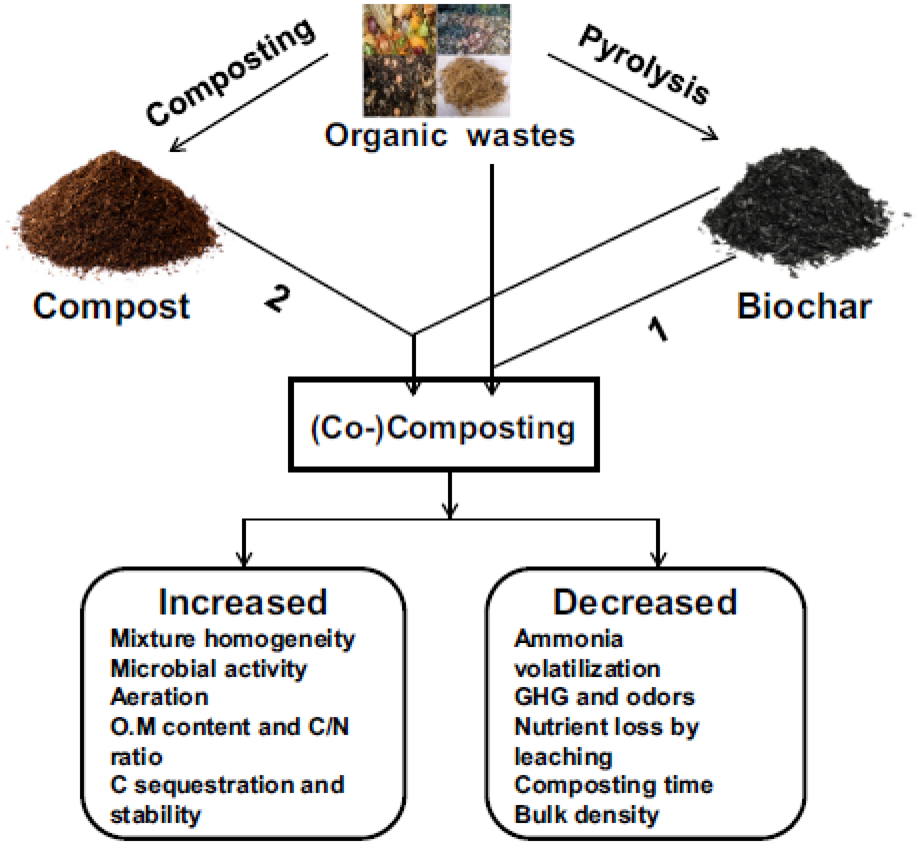
Production and application of biochar (Li et al., 2020)



Modification methods of biochar (Wang and Wang, 2019)



Improvement in biochar surface properties by different modification methods (Rajapaksha et al., 2016; Godlewska et al., 2017; Wang et al., 2017). El-Naggar et al., 2019.



Schematic illustration of the co-composting process for biochar and the positive effects of biochar on the composting process

Arrow 1 illustrates the process of producing composted biochar, and

Arrow 2 illustrates the process of producing co-composted biochar (modified from Agegnehu et al. (2017))

El-Naggar et al., 2019.

Nitrogen enriched compost inoculum prepared with biomass and biochar at low temperatures (Samudrika et al., 2020)

No	Treatment	Bedding materials (biochar) (kg)	Amount of materials (kg)			Blanketing materials (biochar) (kg)
			Young *Guinea* grass	*Gliricidia* leaves	Biochar	
1	Control	Not added	18	2	Not added	Not added
2	3 % biochar (dry basis)	1.5	18	2	0.17	1
3	6 % biochar (dry basis)	1.5	18	2	0.33	1
4	9 % biochar (dry basis)	1.5	18	2	0.5	1

Chopping the leaves

Mixing of leaves

Mixing with bio-char

Bedding of bio-char

Prepared pile

Piles of four treatments (Samudrika et al., 2020)

6% bio-char mixed treatment has lesser nitrogen loss than other three treatments.

It can be used as a nitrogen source for fertilizers.

Bio-char can absorb and adsorb nitrogen and because of that it can be used as a solution for the nitrogen loss during composting.

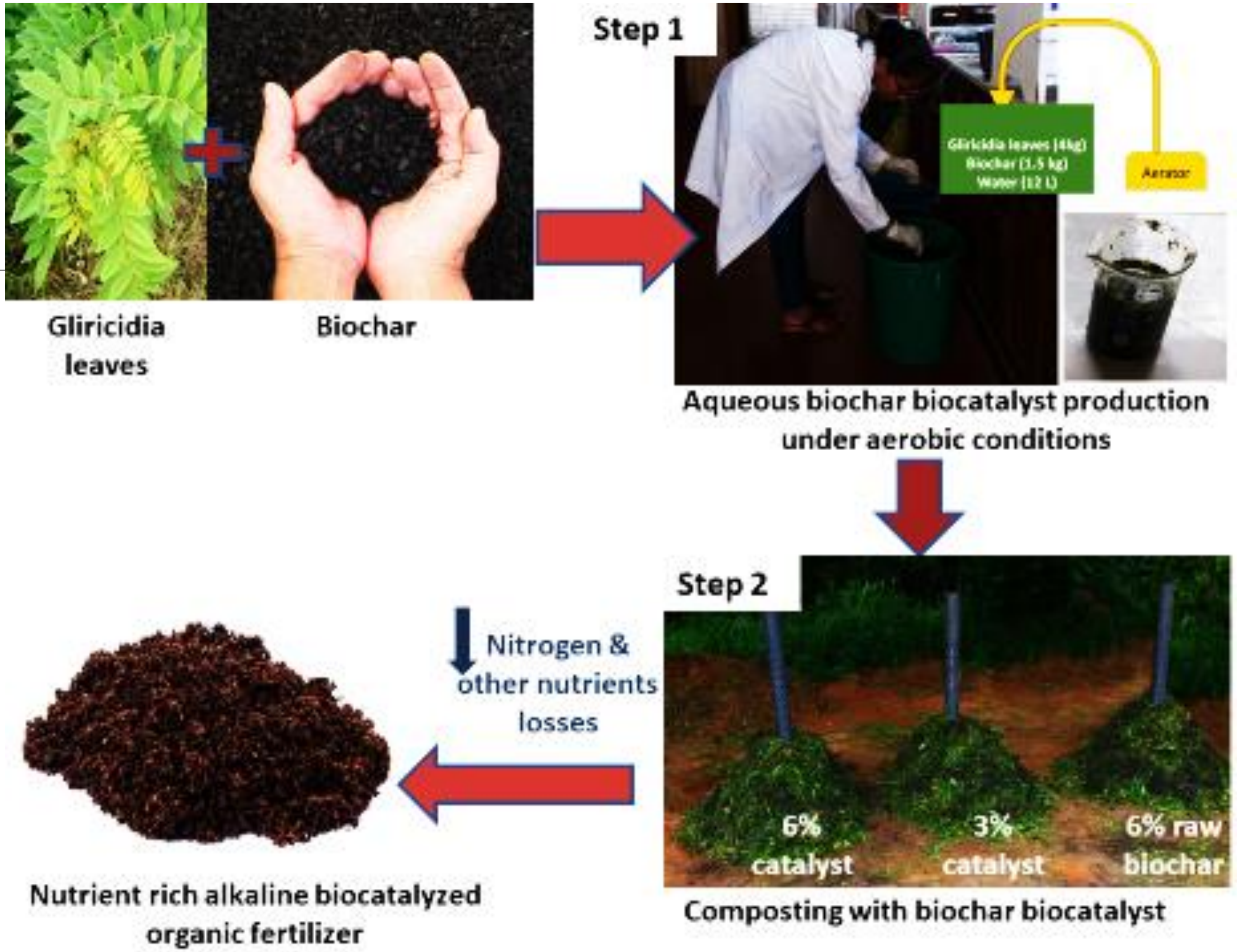
The kinetics of VS loss can predict the level of decomposition required to maintain a C:N of 9.

Higher the N retaining in source material, greater the N fixation from atmosphere.

The pH has to be adjusted when using as a fertilizer.

Kinetics of decomposition enables up scaling the small piles to large ones.

This N enriched compost use as an inoculum for large scale applications (Samudrika et al., 2020).



Production of aqueous biochar biocatalyst for agricultural sustainability (Wasana et al., 2019)

Production of aqueous biochar biocatalyst for agricultural sustainability

This study was done to produce a super quality organic fertilizer with addition of activated biochar during the active phase of composting.

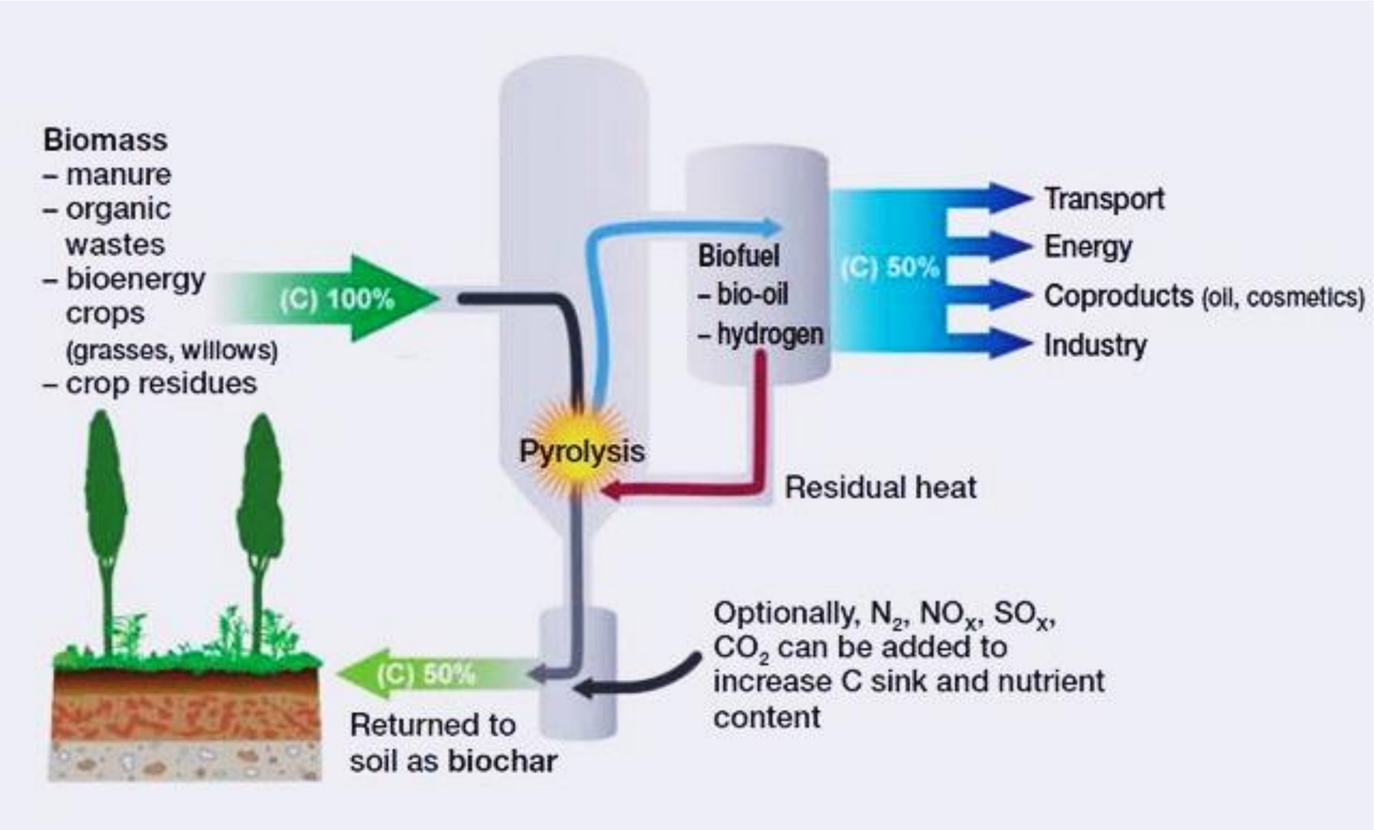
1.5 kg of *Gliricidia sepium* wood biochar was activated using a aqueous aerobic biocatalyst with 1 kg of *Gliricidia sepium* leaves: 3 L of water: 8 g of Eppalawa rock phosphate ratio.

Two compost piles were prepared using 18 kg fresh immature *Panicum maximum* grass and 2 kg *Gliricidia sepium* leaves/ pile.

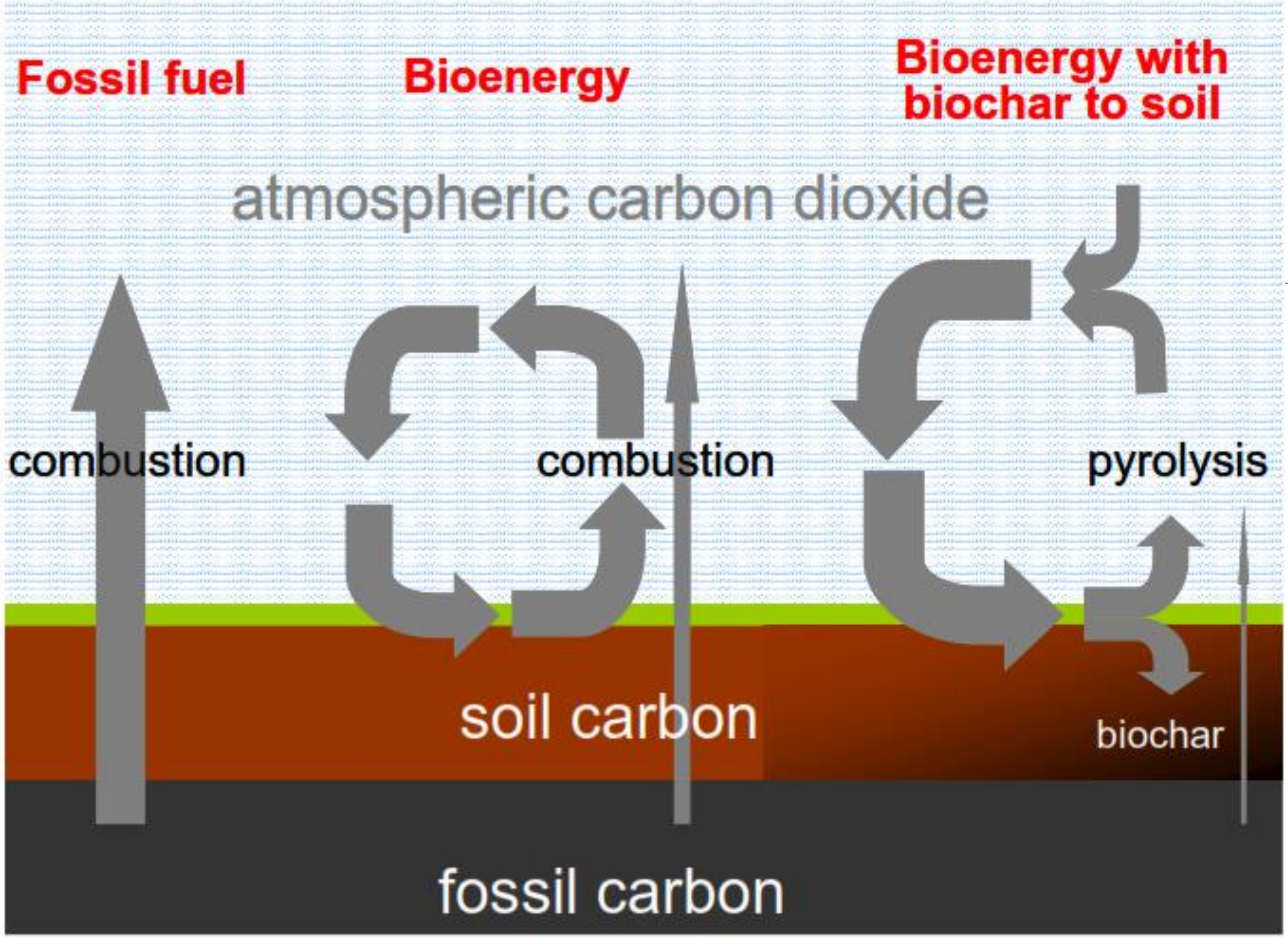
After 25 days of activation, biochar biocatalyst was mixed with 6% dry weight basis to one pile and raw biochar (6%) was incorporated to the other pile.

Produced compost had Nitrogen of 20.3 g/kg, potassium of 83.71 g/kg and phosphorous of 0.67 g/kg with 8.8 pH.

The made compost is very suitable and perhaps cost-effective for acidic soils to improve soil nutrient status unlike the addition of lime (Wasana et al., 2019).

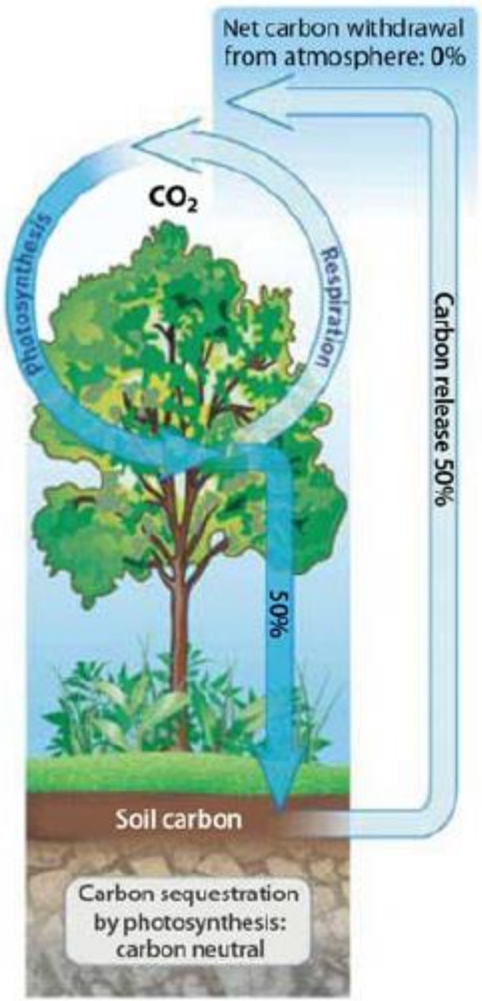


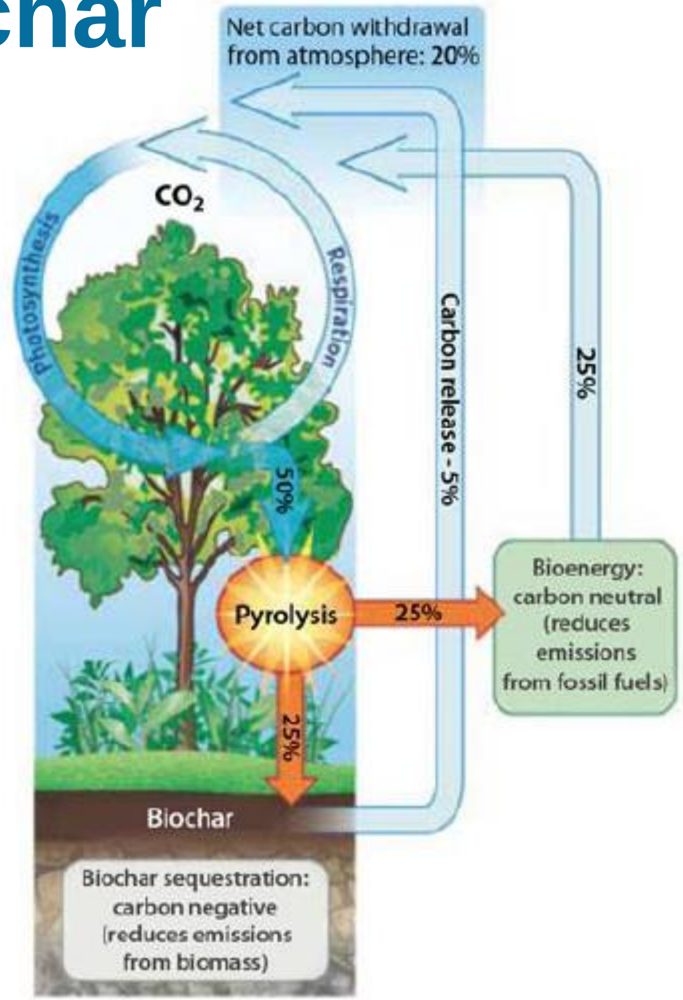
A schematic of a slow pyrolysis facility for the production of biochar (Lehmann, 2007)



Biochar can result in a net removal of carbon from the atmosphere, especially with enhanced net primary productivity (IEA, 2007)

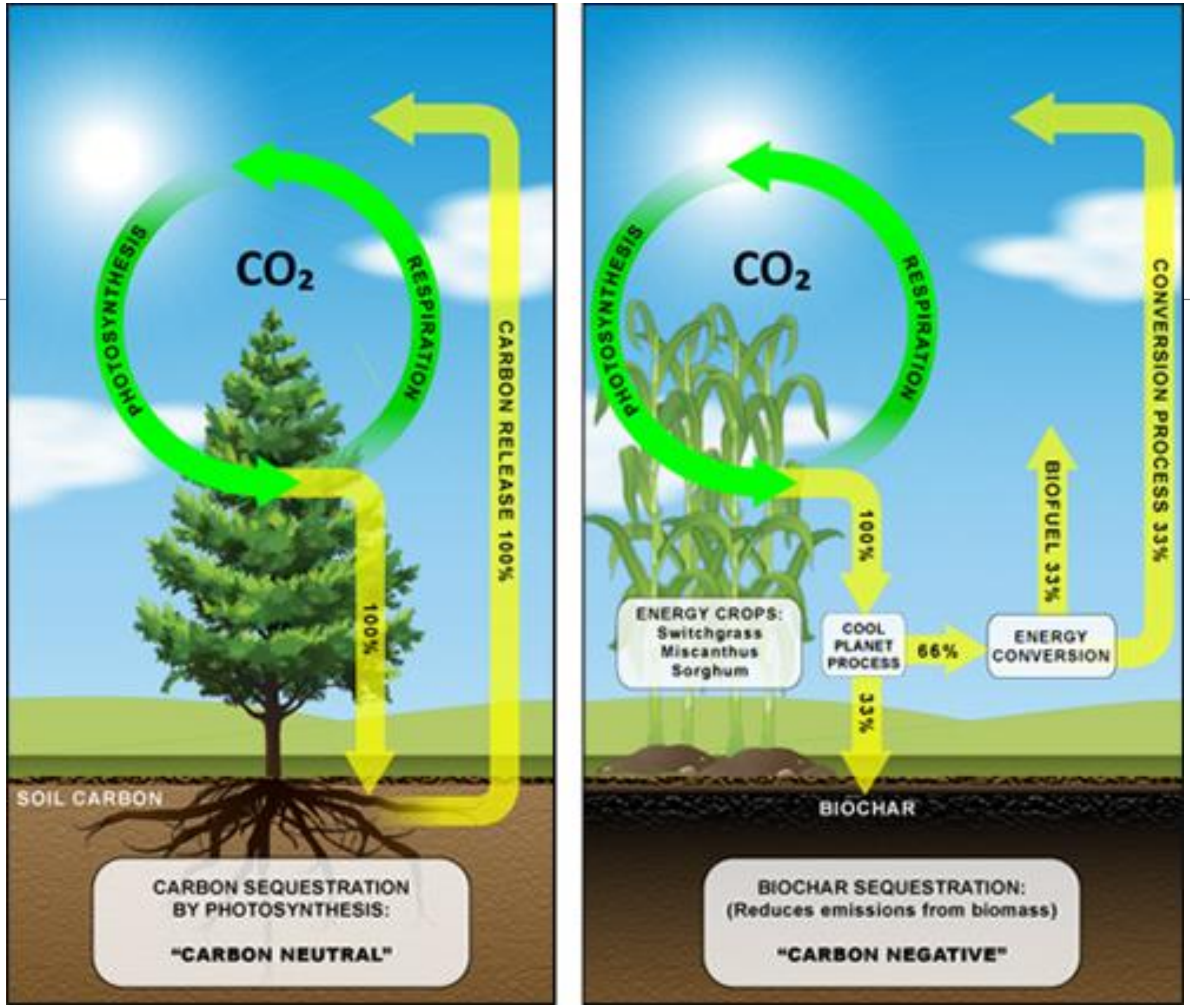
Benefits of Biochar





Biochar can be a carbon-negative renewable fuel source

(www.biochar-international.org/biochar/carbon)



Carbon Negative Bio Char
(http://neurodope.com/carbon-negative-bio-char/)

Biochar, crop productivity, and resource management

Conceptually three main mechanisms have been proposed (described in detail below) to explain how biochar might benefit crop production:

i. Direct modification of soil chemistry through its intrinsic elemental and compositional make up.

ii. Providing chemically active surfaces that modify the dynamics of soil nutrients or otherwise catalyse useful soil reactions.

iii. Modifying physical character of the soil in a way that benefits root growth and/or nutrient and water retention and acquisition.

A particularly striking characteristic is a stronger relationship between soil carbon content and soil CEC in soils, indicating that biochar comprises a greater proportion of soil carbon (Liang et al., 2006).

A key factor where differences in crop Productivity

Since CEC is indicative of the capacity to retain key nutrient cations in the soil in plant-available form and minimise leaching losses.

High rates of biochar addition in the tropical environment have been associated with increased plant uptake of P, K, Ca, Zn and Cu (Lehmann and Rondon., 2006).

In contrast to mainstream chemical fertilizer, biochar also contains bioavailable elements such as selenium that have potential to assist in enhancing crop growth.

Applications

Traditional agriculture in Asian countries have applied charcoal

- **Japan – establish trees in trenches**
- **India – paddy fields**

DOA of Sri Lanka has introduced paddy husk charcoal

Now used extensively on a large scale in the US, China, Africa, Haiti, Australia and Latin America

The Australian government provide massive incentives for biochar application to ensure sustainable ecosystems

Biochar properties in agriculture

Factor	Impact	Source
Cation Exchange Capacity	50% Increase	(Glaser, 2002)
Fertilizer Efficiency	10-30% Increase	(Gaunt and Cowie, 2009)
Liming Agent	1 Point pH Increase	(Lehmann, 2006)
Soil Moisture Retention	Up to 18% Increase	(Tryon, 1948)
Crop Productivity	20-120% Increase	(Lehman and Rondon, 2006)
Methane Emissions	100% Decrease	(Rondon et al., 2005)
Nitrous Oxide Emissions	50% Decrease	(Yanai, 2007; Renner, 2007)
Reduced Bulk Density	Soil Dependent	(Laird, 2008)
Mycorrhizal Fungi	40% Increase	(Warnock, 2007)
Biological Nitrogen Fixation	50-72% Increase	(Lehmann and Rondon, 2006)

Source: http://www.biocharapplication.com/biochar-and-agriculture.html

Crop	Country	Citation/Publication	Application rate
Tomato	Australia	Hossain, 2010	10 T/ha
Miscanthus		Hartley, 2009	Unknown
Rice	Laos	Asai, 2009	0-16 T/ha
Common Beans		Rondon, 2007	0, 30, 60, and 90 g kg^{-1} soil
Maize		Oguntunde, 2004	Unknown
Maize, cowpea, peanut		Yamato, 2006	Unknown
Soybeans and a tropical grass (B. humidicola)		Rondon, 2006	5.7 ton/ha to 6.6 and 7.3 ton
Tea Trees	Japan	Hoshi, 2001	100 g per meter 2
Maize	Columbia	Major, 2010	0, 8 and 20 t ha
rice (Oryza sativa L.) and sorghum (Sorghum bicolor L.)	Brazil	Steiner, 2007	11 T/ha
Maize	Brazil	Steiner, 2008	11 T/ha with 67 T/ha compost
Spring onion (Allium cepa)	China	Yu, 2009	0%, 0.1%, 0.5% and 1% by soil weight
Soybean and maize	Indonesia	(Igarashi, 1996)	Unknown
Soybean	Thailand	(Oka et al, 1993)	10 T/ha
Soybean	Indonesia	(Ogawa and Yamabe, 1986)	5 – 10 T/ha
Carrots and beans	Columbia	(Rondon et al, 2004)	30 T/ha
Maize	Indonesia	(Yamato et al, 2006)	15 T/ha
Maize and *Brachiaria* pasture	Columbia	(Rondon et al, 2006)	0.8-20 T/ha
Beans	Columbia	(Rondon et al, 2007)	
Bananas	Brazil	(Steiner, 2006)	11 T/ha
Maize	Kenya	(Kimetu et al, 2008)	6 T/.ha
Rice	Brazil	(Nehls, 2002)	7.9 T/ha
Maize (sweetcorn) Faba beans	Australia	(Van Zwieten et al, 2008)	Maize: 0.5–50t ha Beans: 10t ha
Pasture legume and rye grass	Australia	(Sinclair et al, 2008)	10 T/ha
Wheat	Australia	(Blackwell et al, 2007)	6 T/ha
Sorghum and rice	Brazil	(Steiner et al. 2007)	11 T/ha

http://www.biocharapplication.com/biochar-and-agriculture.html

Paddy field trials

Biochar application with 30% of urea gave comparative yields with recommended inorganic fertilizer (IF)   (Gamage, 2010)

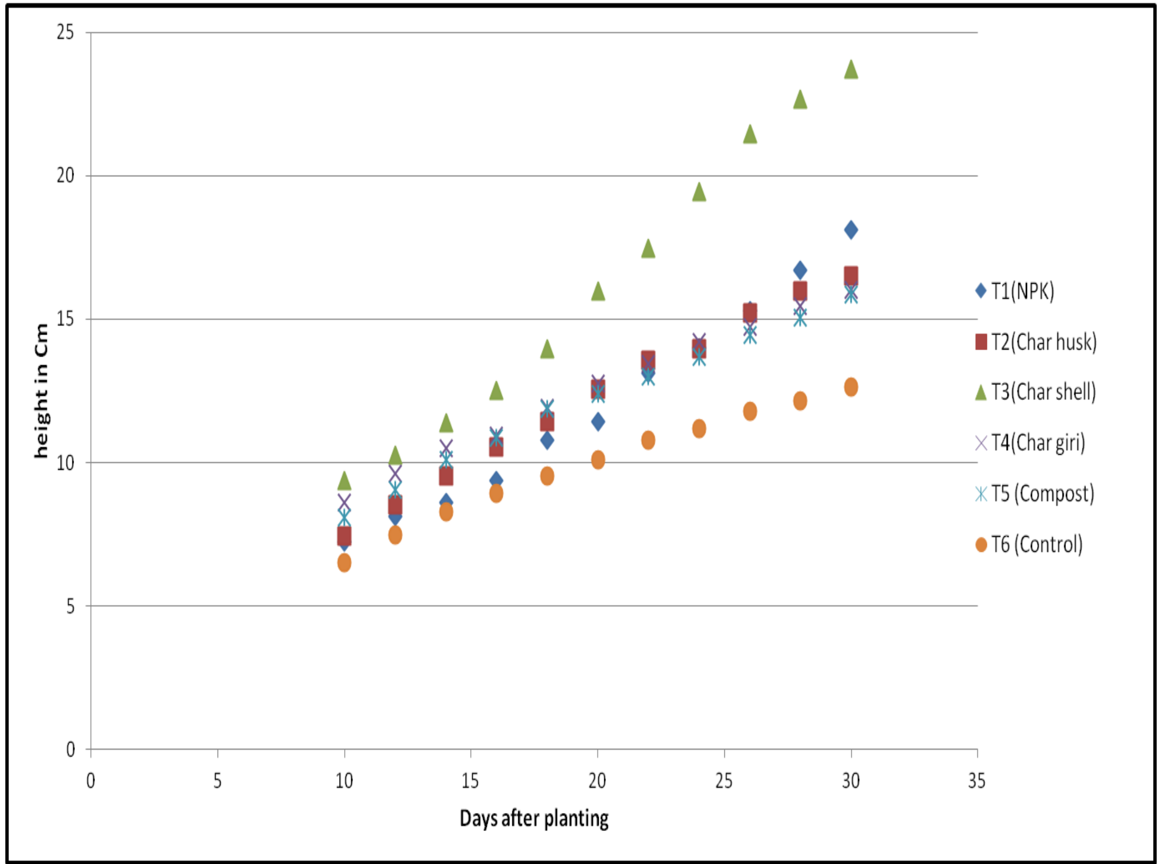
Use of Coconut Based Biochar as Soil Amendment for Integrated Maize Cultivation in Coconut Lands

Treatment	α	β	t_{max}	α/β(Peak value)
T1	0.102960	0.000520	38	198
T2	0.065711	0.000154	70	427
T3	0.112162	0.000544	37	206
T4	0.091059	0.000492	48	185
T5	0.093863	0.000431	44	218

α – Growth Coefficient β – Retardation Coefficient

The overall best performances of plant growth were observed in treatment 3, with 50g of biochar made from coconut shell and recommended chemical fertilizers were applied.

Waduge, 2011



Amaranthus cruentus

Amaranth, Tampala

(Vijenayake, 2011)

Treatment	T1 NPK	T2 Char Husk	T3 Char Shell	T4 Char Gliricidia	T5 Compost	T6 Control
Total Fresh Weight (g)	2070	2780	4355	2395	1815	1268
	4	2	1	3	5	6

Evaluation of Biochar Influence on Nutrient Regulation for Growth and Yield Improvements of Gherkin

Export Quality Grade 01 (ø 11-15mm) obtained from T9 = Soil +70% Biochar + 30% Inorganic fertilizers and Compost

(Weerasekara, 2012)


Site Selection


Site Clearing


Land Preparation


Bed Preparation


Basal Dressing
Application


Seeding


Irrigation


Trellising


P & D Management

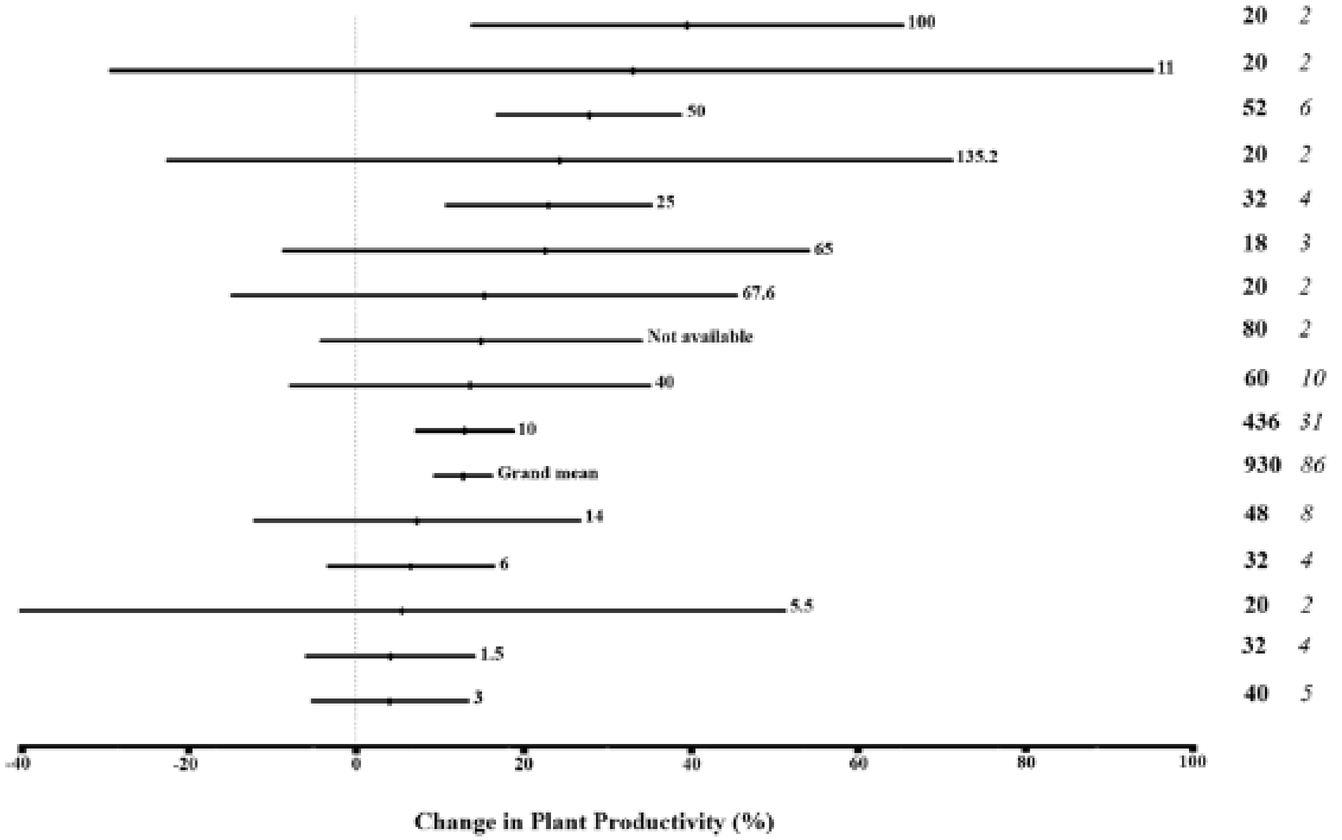


Figure 3.2 The percentage change in crop productivity upon application of biochar at different rates, from a range of feedstocks along with varying fertiliserco-amendments. Points represent mean and bars represent 95% confidence intervals. Numbers next to bars denote biochar application rates (t ha^{-1}). Numbers in the two columns on the right show number of total 'replicates' upon which the statistical analysis is based (bold) and the number of 'experimental treatments' which have been grouped for each analysis (italics)

Verheijen et al., 2010

Authors	Study outline	Results summary
Iswaran et al (1980)*	Pea, India	0.5 Mgha-1 char increased biomass 160%
Iswaran et al (1980) *	Mung bean, India	0.5 Mgha-1 char increased biomass 122%
Kishimoto & Sugiura (1985) *	Soybean on volcanic ash loam, Japan	0.5 Mgha-1 char increased yield 151% 5 Mgha-1 char decreased yield to 63% 15 Mgha-1 char decreased yield to 29%
Kishimoto & Sugiura (1985) *	Sugi trees on clay loam, Japan	0.5 Mgha-1 wood charcoal increased biomass 249% 0.5 Mgha-1 bark charcoal increased biomass 324% 0.5 Mgha-1 activated charcoal increased biomass 244%
Chidumayo, (1994)*	Bauhinia trees on alfisol/ultisol	Charcoal increased biomass by 13% and height by 24%
Glaser (2002)	Cowpea on xanthic ferralsol	67 Mgha-1 char increased biomass 150% 135 Mgha-1 char increased biomass 200%
Lehmann (2003)	Soil fertility and nutrient retention. Cowpea was planted in pots and rice crops in lysimeters at the Embrapa Amazonia Ocidental, Manaus, Brazil	Bio-char additions significantly increased biomass production by 38 to 45% (no yield reported)

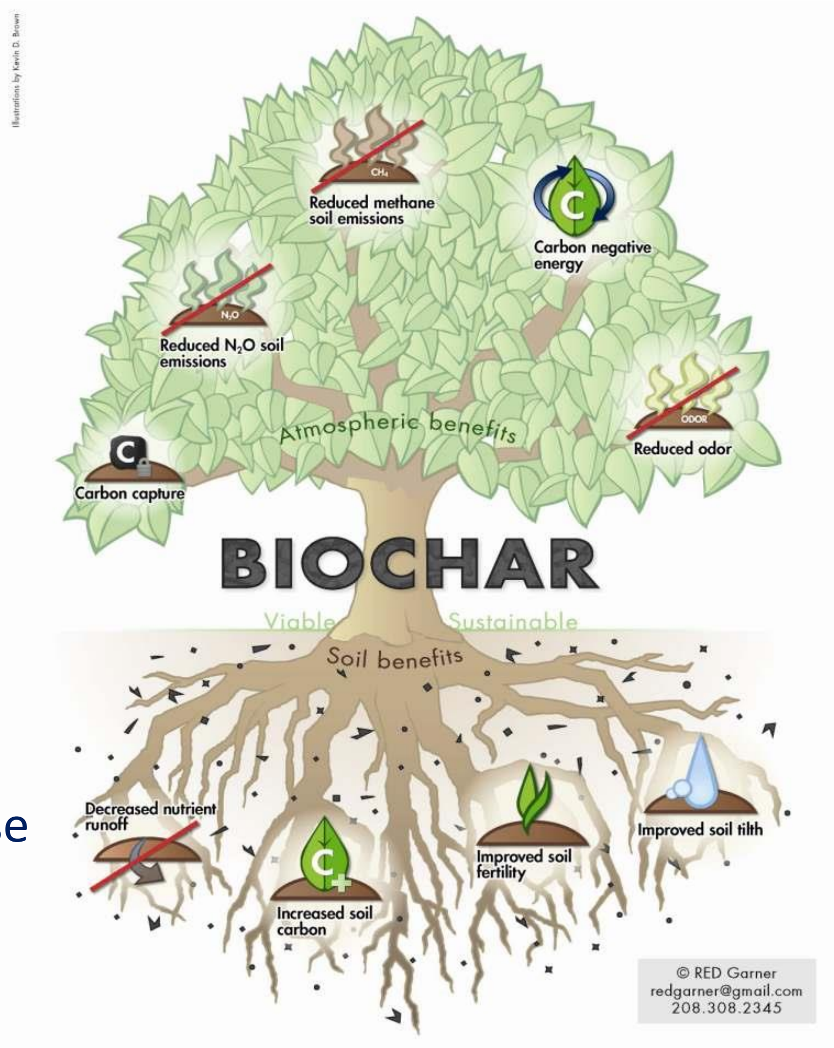
Sohi et al., 2009

Lehmann (2003)	Soil fertility and nutrient retention. Cowpea was planted in pots and rice crops in lysimeters at the Embrapa Amazonia Ocidental, Manaus, Brazil	Bio-char additions significantly increased biomass production by 38 to 45% (no yield reported)
Oguntunde (2004)	Comparison of maize yields between disused charcoal production sites and adjacent fields. Kotokosu watershed, Ghana	Grain yield 91% higher and biomass yield 44% higher on charcoal site than control.
Yamato (2006)	Maize, cowpea and peanut trial in area of low soil fertility	Acacia bark charcoal plus fertiliser increased maize and peanut yields (but not cowpea)
Chan (2007)	Pot trial on radish yield in heavy soil using commercial greenwaste biochar (three rates) with and without N	100 t ha^{-1} increased yield x3; linear increase 10 to 50 t ha^{-1} - but no effect without added N
Rondon (2007)	Enhanced biological N-2 fixation (BNF) by common beans through bio- char additions. Colombia	Bean yield increased by 46% and biomass production by 39% over the control at 90 and 60 g kg(-1) bio-char, respectively.
Steiner (2007)	Four cropping cycles with rice (Oryza sativa L.) and sorghum (Sorghum bicolor L.)	Charcoal amended with chicken manure amendments resulted in the highest cumulative crop yield (12.4 $Mgha^{-1}$)
Kimetu et al. (2008)	Mitigation of soil degradation with biochar. Comparison of maize yields in degradation gradient cultivated soils in Kenya.	doubling of crop yield in the highly degraded soils from about 3 to about 6 tons/ha maize grain yield
*source of selected references (Woolf 2008)		

Sohi et al., 2009

Agronomic benefits of biochar

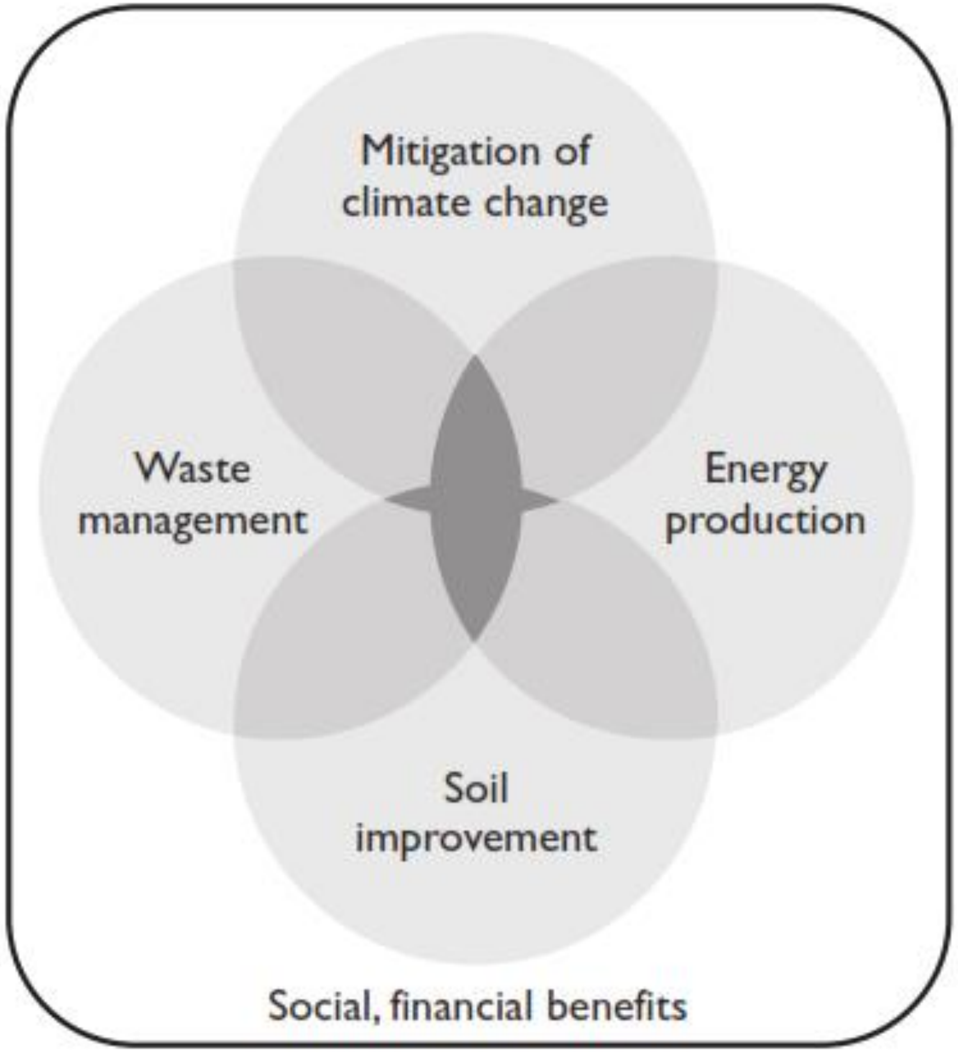
- Greater nutrient availability
- Potential to improve soil physical properties
- Increase microbial activity
- Improves crop growth
- Potential for better fertilizer use efficiency
- These benefits persists in the long run



Environmental benefits of biochar

- Leads to long-term C sequestration in soil, accumulation of **Carbon** each year
- Reduce leaching of fertilizers and other chemicals from agricultural land
- Potentially reduce green house gas (N_2O, CH_4) emissions from soil

Benefits of Biochar (https://biochar-international.org/)



Net benefit of using biochar in terms of mitigating global warming and as an active strategy to manage soil health and productivity

Motivation for applying biochar Technology (Lehmann, 2009)

Visionaries point of view

"One of the most exciting new strategies for restoring carbon to depleted soils, and sequestering significant amounts of CO_2 for 1,000 years and more, is the use of biochar."

- Al Gore,45th Vice President of the United States and 2007 Nobel Peace Prize Co-recipient

"If you could continually turn a lot of organic material into biochar, you could, over time, reverse the history of the last two hundred years..."

- Bill McKibben, author, climate activist and founder of 350.org

"Replacing slash-and-burn agriculture with slash-and-char and use of agricultural and forestry wastes for biochar production could provide a CO_2 drawdown of ~8 ppm or more in half a century"

- Dr. James Hansen, Director, NASA Goddard Institute for Space Studies

Thank you