Comparison of hydrothermal carbonization and low-temperature pyrolysis for nutrients recovery from the milk/dairy processing sludge

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Introduction

- Dairy Processing Sludge (DPS) is rich in nutrients and low in heavy metals.
- Constraints of application of DPS:
    - Transportation cost limits its use to farmlands near the wastewater treatment plants, which leads to local oversupply and accumulation of certain substances in soil and uncontrolled nutrients losses;
    - Need to store DPS before land application.
- There is a need to find a way of concentrating nutrients in an easy to store and transportable form.

Aim of the study

- To investigate hydrothermal carbonization (HTC) and low-temperature pyrolysis (LTP) of dairy processing sludge (DPS) as ways of concentrating nutrients

- To compare plant nutrients in hydro-char and bio-char

Properties of Dairy Processing Sludge (DPS)

- Moisture content: 90.03 %
- Ash content: 2.86%
- pH: 7.56

DPS

Composition

Element	Concentration, mg/kg ± SD (dry matter)
P	25503 ± 590
Ca	62185 ± 1493
K	4363 ± 6
Mg	1813 ± 60
Na	6618 ± 95
S (inorganic)	5856 ± 60
Al	33990 ± 1399
Ba	34.17 ± 1.25
Fe	495.87 ± 33.65
Mn	47.19 ± 0.10
Mo	0.83 ± 0.00
Si	5224 ± 1251
Ti	73.95 ± 4.26
Cu	8.33 ± 0.02
Cr (total)	8.33 ± 1.20
Zn	73.33 ± 3.77
Ni	8.89 ± 1.56
Cd	nd
Pb	nd
As	nd
Hg	nd

Macronutrients

Other major elements

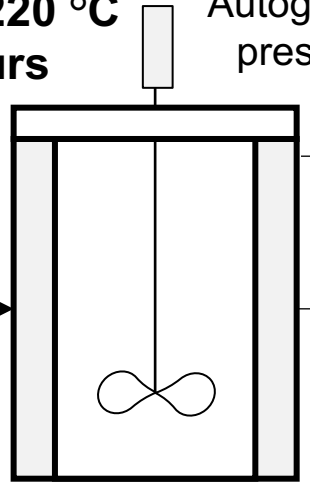
Regulated metals

Hydrothermal Pyrolysis (HTC)

180, 200, 220 °C
1, 2 hours

Autogenous pressure

DPS



Hydrolysis, dehydration

Gases

Mostly CO_2 with presence of CO

Slurry

Separation

Drying, grounding

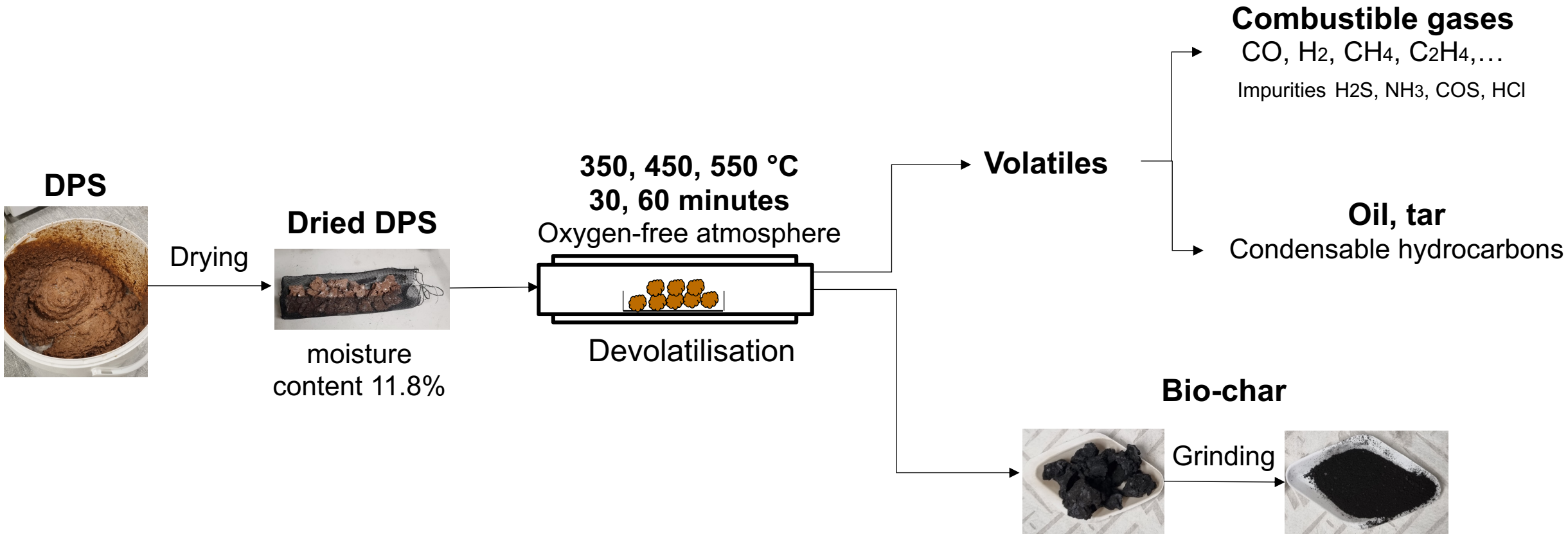
Hydro-char

Nutrient and C-rich solid product

Process water

Contains water-soluble inorganic salts and organic components

Low-Temperature Pyrolysis (LTP)



Design of Experiments

Experimental runs were conducted in randomized order.

- Mass balance of each run
- Yield of solid product
- Concentration of nutrients
- Recovery of nutrients (P, K, Ca, Na, Mg, S) in solid product

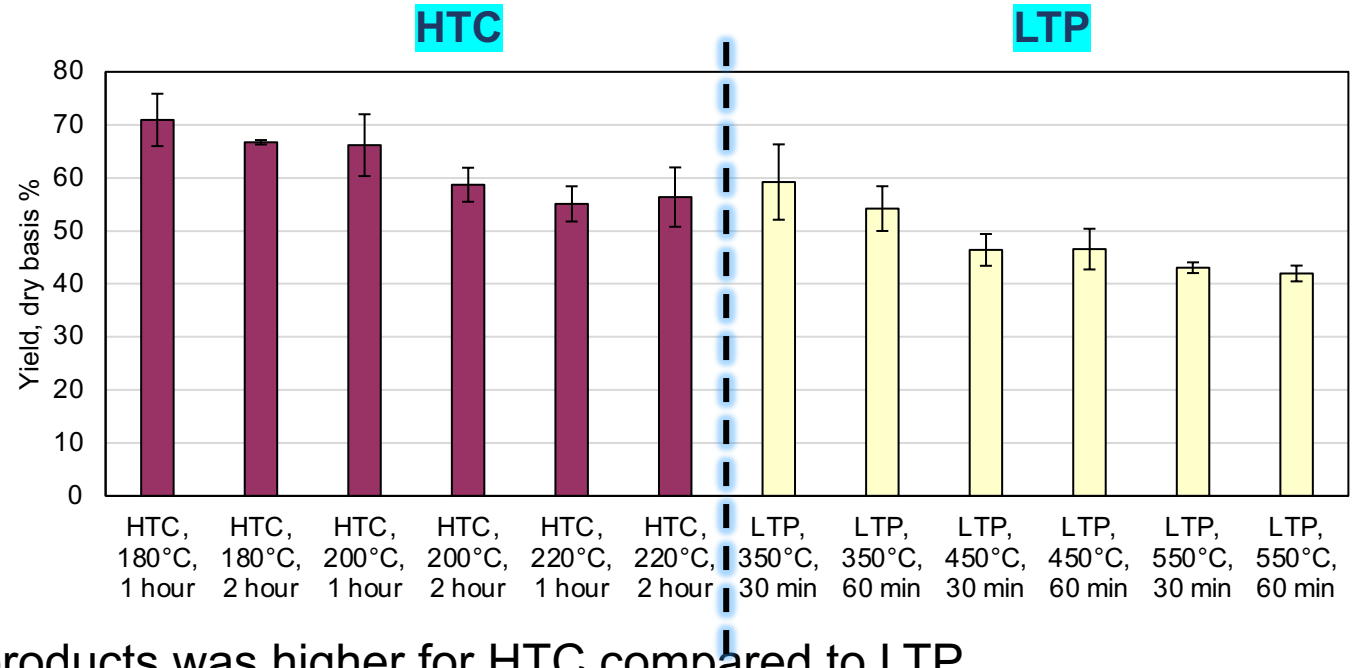
HTC

Temperature, °C	Time, hours
200	2
220	2
220	1
180	2
200	1
180	1
180	1
200	1
200	2
220	2
220	1
180	2

LTP

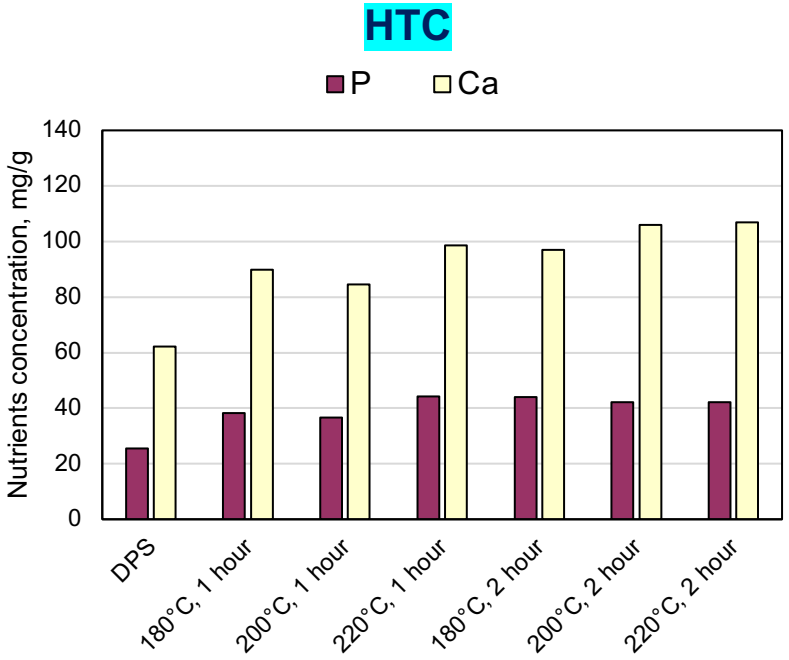
Temperature, °C	Time, minutes
550	60
450	60
350	30
550	30
350	60
450	30
350	30
450	60
450	30
350	60
550	60
550	30

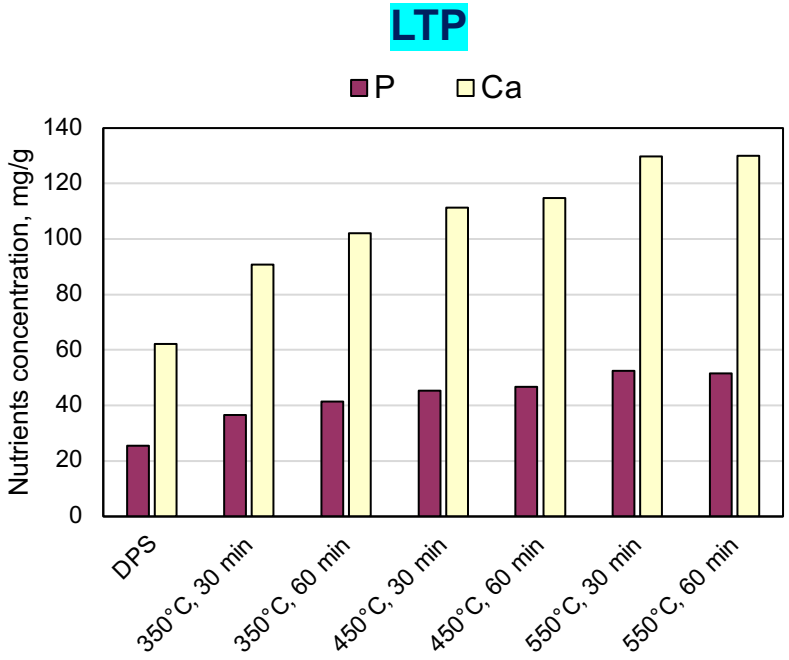
Results
Yields of solid product



- The yield of solid products was higher for HTC compared to LTP.
- The yields of hydro-chars varied from 70.93 to 56.09 % of dry feedstock.
- The yields of pyrolysis bio-chars varied from 59.21 to 41.96% of dry feedstock.
- The effect of temperature on product yield was more significant than the residence time, for both processes.
- Bio-char yield was more affected by temperature than hydro-char yield.

Effect of Process Conditions on P and Ca





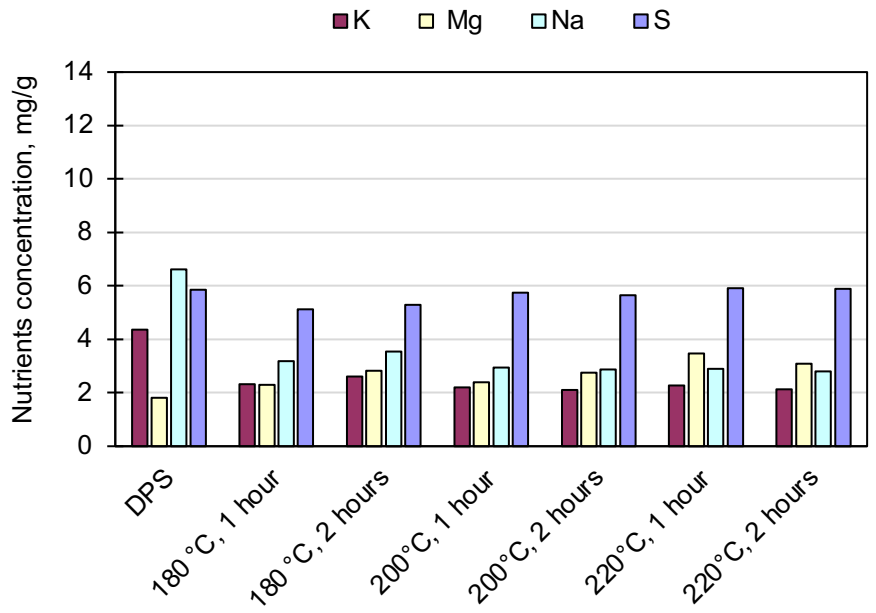
- P, Ca are concentrated in hydro-chars and pyrolysis chars.
- Concentration of P is slightly higher in pyrolysis chars than in hydro-chars:

  36.7 – 52.4 mg/g and *36.7 – 42.1 mg*/g respectively
- Concentration of Ca is significantly higher in pyrolysis chars compared to hydro-chars:

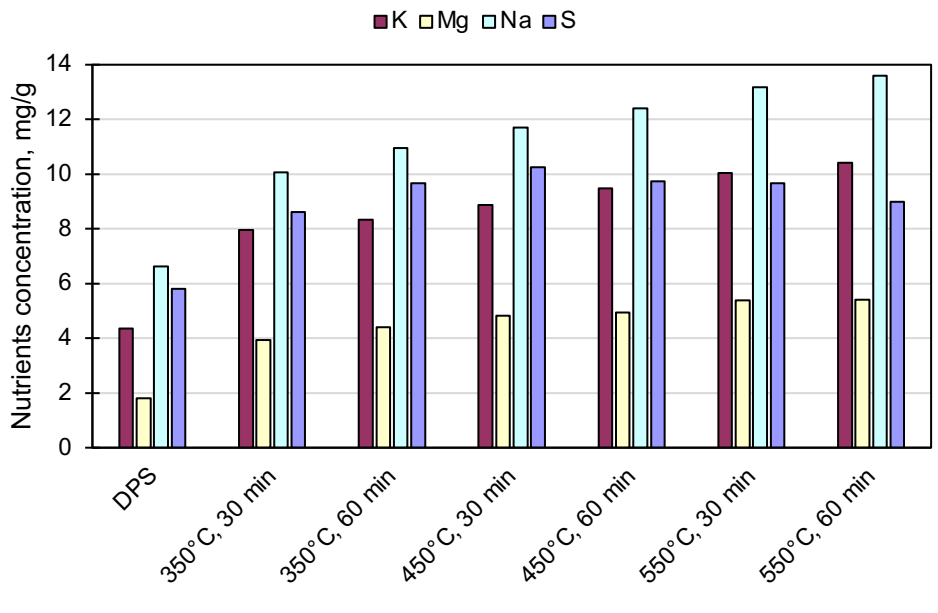
  90.8 – 129.2 mg/g and *62.2 – 106.9* mg/g respectively

Effect of Process Conditions on K, Mg, Na, S

HTC



LTP

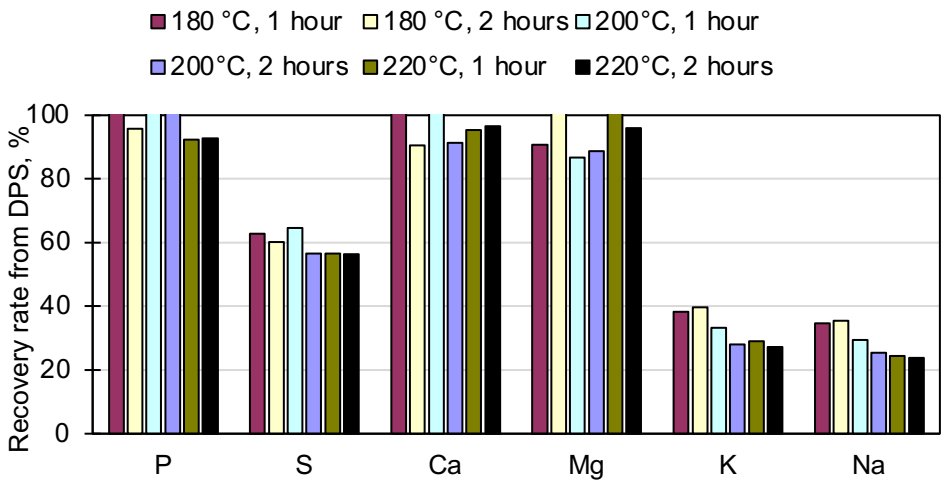


- Mg is concentrated in hydro-chars and pyrolysis chars
- K and Na are reduced in hydro-chars and concentrated in pyrolysis chars
- Inorganic S remains at the same level for hydro-chars and pyrolysis chars but is slightly higher in bio-chars
- Pyrolysis chars have higher content of K, Mg, Na, S compared to hydro-chars

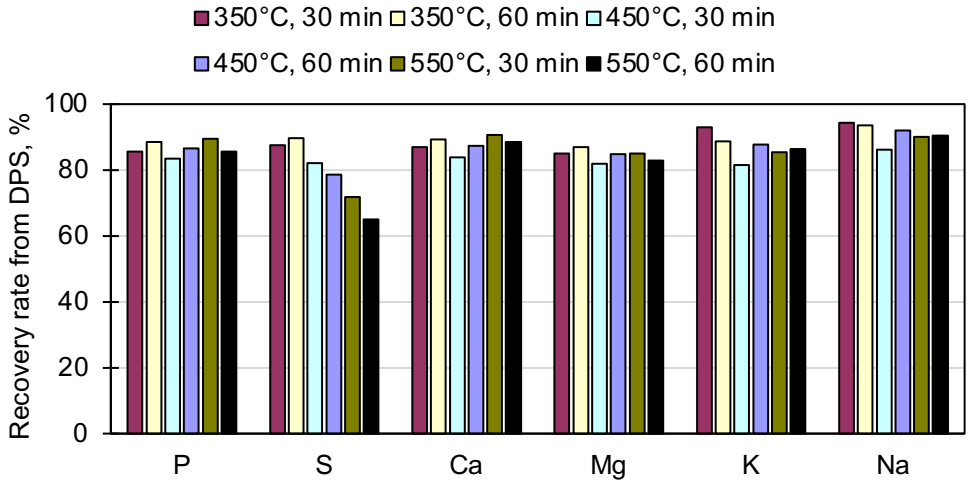
Recovery of Nutrients in Chars

- High recovery of P, Mg and Ca in hydro-chars (80 - 100 %) for all HTC process conditions.
- About 60% of inorganic S remained in hydro-chars.
- Only 25-40% of K and Na were recovered in hydro-chars due to the high solubility of their salts in process water. The recovery of K and Na decreased with temperature and residence time increase.
- LTP bio-chars have higher recovery of K and Na (82 – 94 %) due to absence of water media.
- Recovery of all nutrients excluding S in bio-chars was in the range from 83 – to 94%.

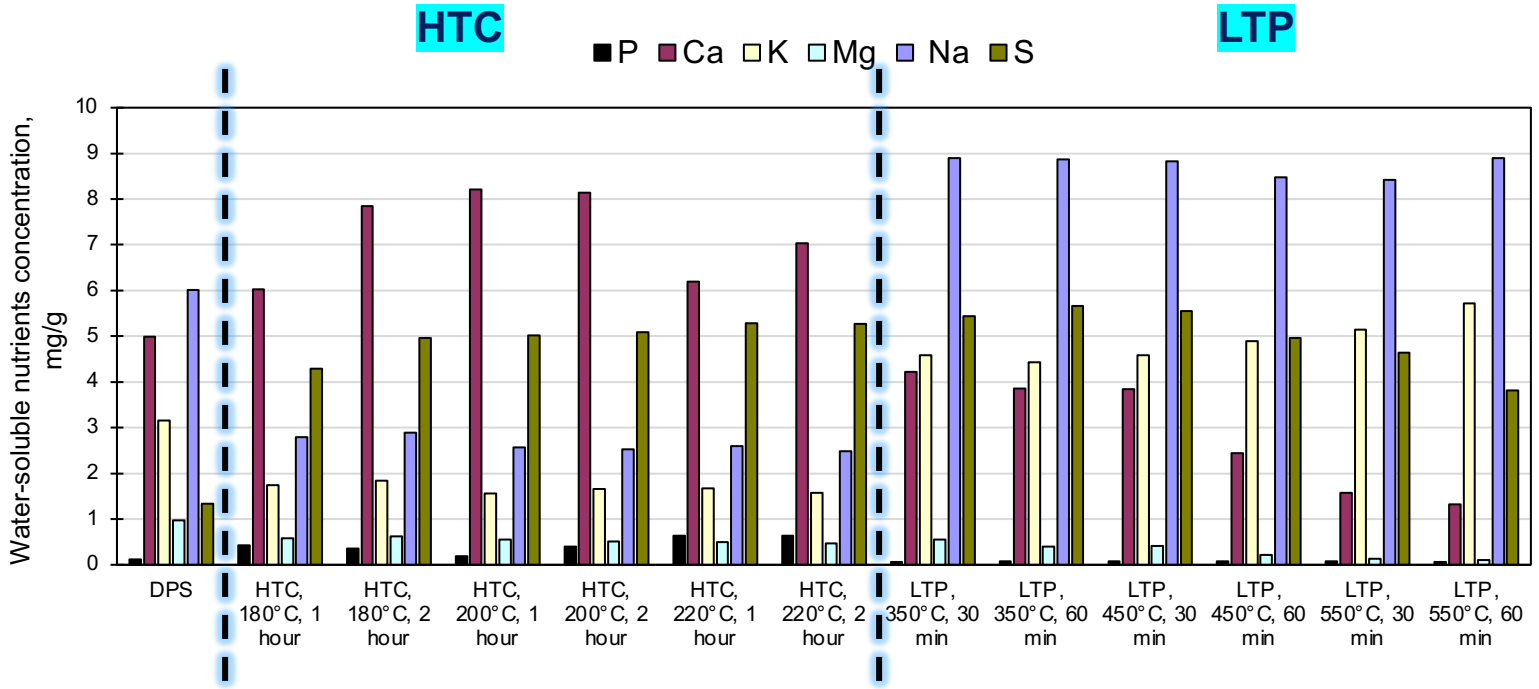
Recovery of nutrients in **hydro-chars**



Recovery of nutrients in pyrolysis **bio-chars**

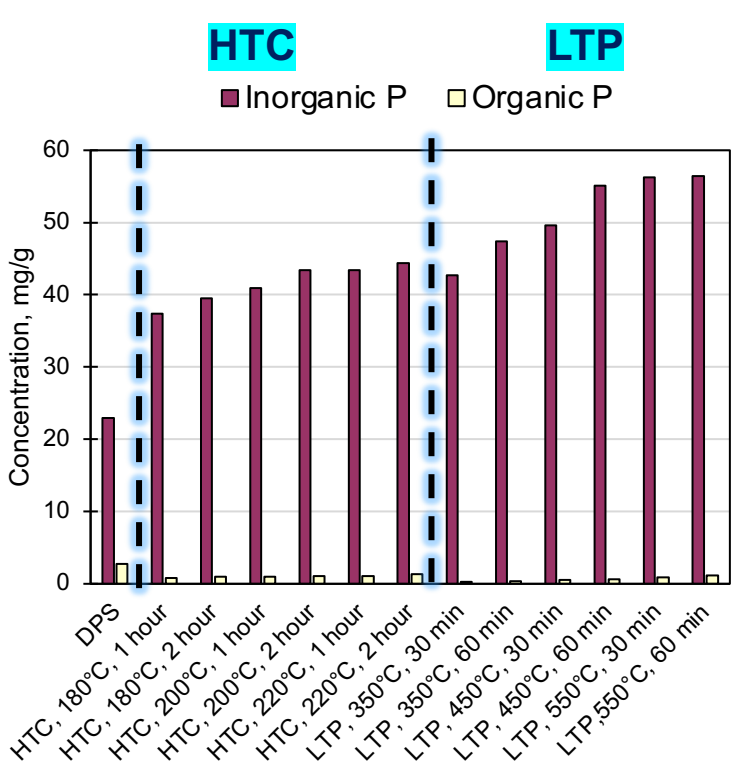


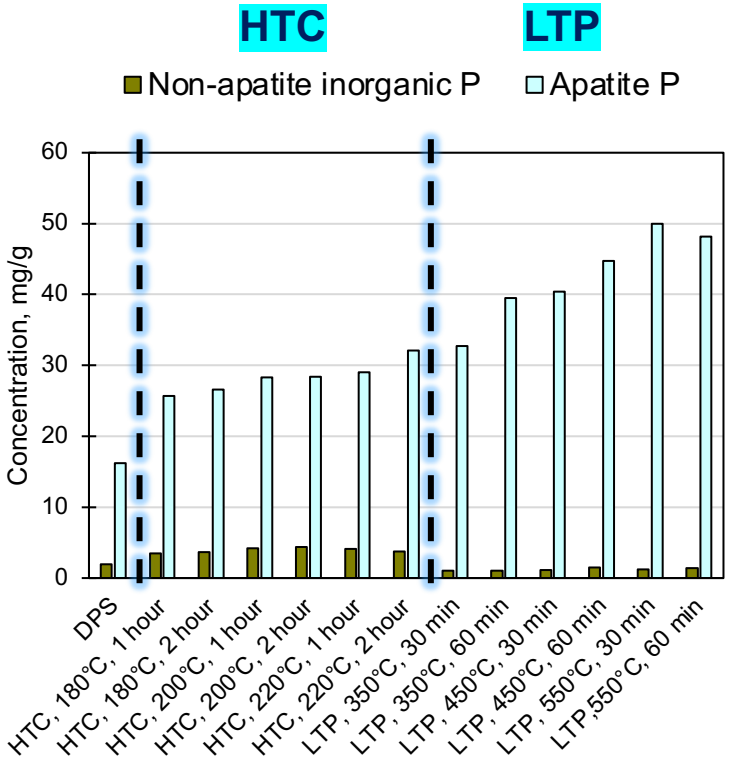
Water soluble-nutrients in hydro-chars/bio-chars



- The water-soluble P in DPS and all bio-chars and hydro-chars was below 1 mg/g. Hydro-chars contain more water-soluble P than bio-chars after LTP.
- The water-soluble Ca increased after HTC compared to DPS and decreased after LTP in bio-chars.
- The contents of water-soluble K and Na were higher for pyrolysis bio-chars compared to hydro-chars.
- The water-soluble S content increased after HTC and LTP compared to DPS.

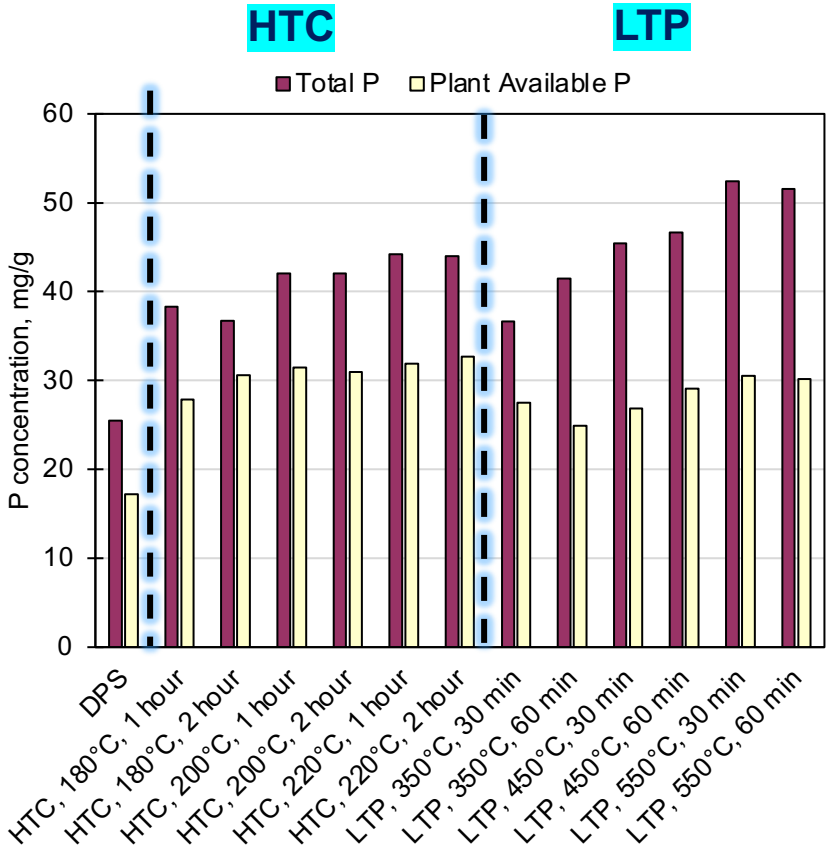
P speciation (SMT extraction protocol)

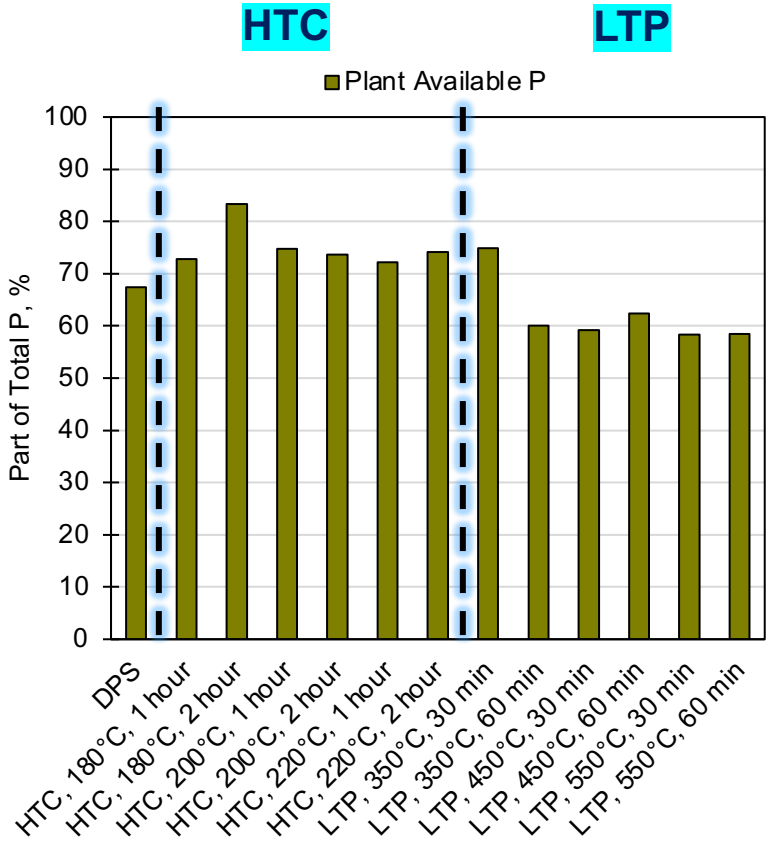




- DPS, hydro-chars and pyrolysis bio-chars contain mainly Inorganic P and small amount of Organic P
- Apatite P (AP) and Non-apatite inorganic P (NAIP) together form inorganic P fraction
- Apatite P is the main P fraction in DPS, hydro-chars and pyrolysis bio-chars. The content of AP increased after the HTC and LTP compared to DPS, but it was higher in bio-chars.

Plant available P (Neutral Ammonium Citrate)





- The content of plant-available P increases with increase in temperature and residence time for both processes which can be attributed to concentration effect.
- Higher percent of total P in hydro-chars is plant-available compared to bio-chars (72 – 83% of total P in hydro-chars and 58 – 75% of total P in bio-chars)

Conclusions

- LTP overall provides better recovery of nutrients (P, K, Ca, Mg, Na) due to fact that water-soluble nutrients remain in pyrolysis bio-chars. However, both treatment processes HTC and LTP concentrate P either in hydro-char or bio-char, respectively.
- Higher temperature and longer residence time had negative impact on S recovery in solid product for both processes.
- Plant-available P content was slightly higher in hydro-chars than in bio-chars. Higher percent of total P that was plant-available was obtained for processes with milder process conditions – lower temperature and residence times

Acknowledgment

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Thank You!

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