



# AGRO4AGRI

## Engineering Forest-derived Biochar as a Nanoplatform for Sustainable Nutrient Delivery in Plants

Pathways to Impact in Sustainable Agrochemistry  
A 360° Innovation Approach form Lab to Market



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# CTC in Biochar production as nanoplatform for sustainable nutrient delivery in plants



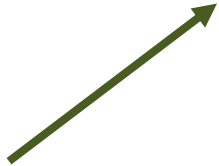
AGRO4AGRI

<https://agro4agri.eu/>



- ❑ CTC is located in the Cantabria Science and Technology Park (PCTCAN)



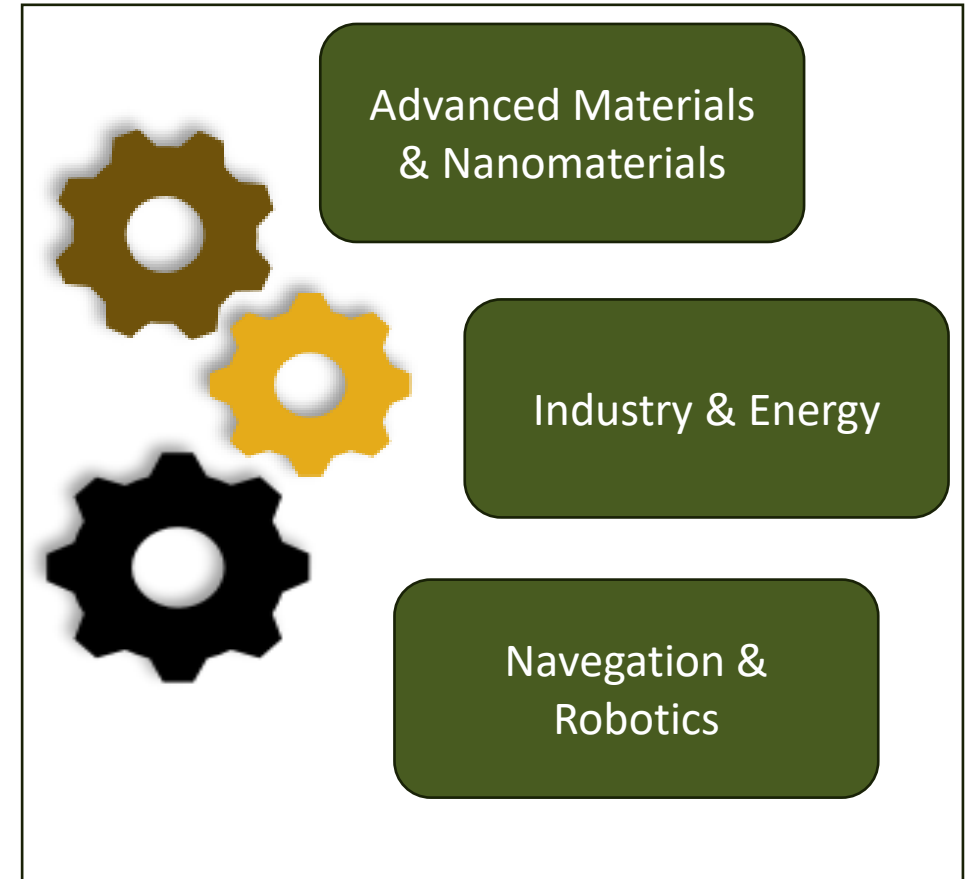


## Companies (80 %)



- A private, non-profit foundation. Funded by
- Founded in 2000
- Our objectives: To design innovative solutions
  - ✓ To contribute to economic and social development
  - ✓ To foster convergence between science, technology and business
- Operating model
  - ✓ Business units
  - ✓ Customer focus

## Pillars



## Introduction – What is Biochar?



Forestry residues



Gorse (*Ulex europaeus*)

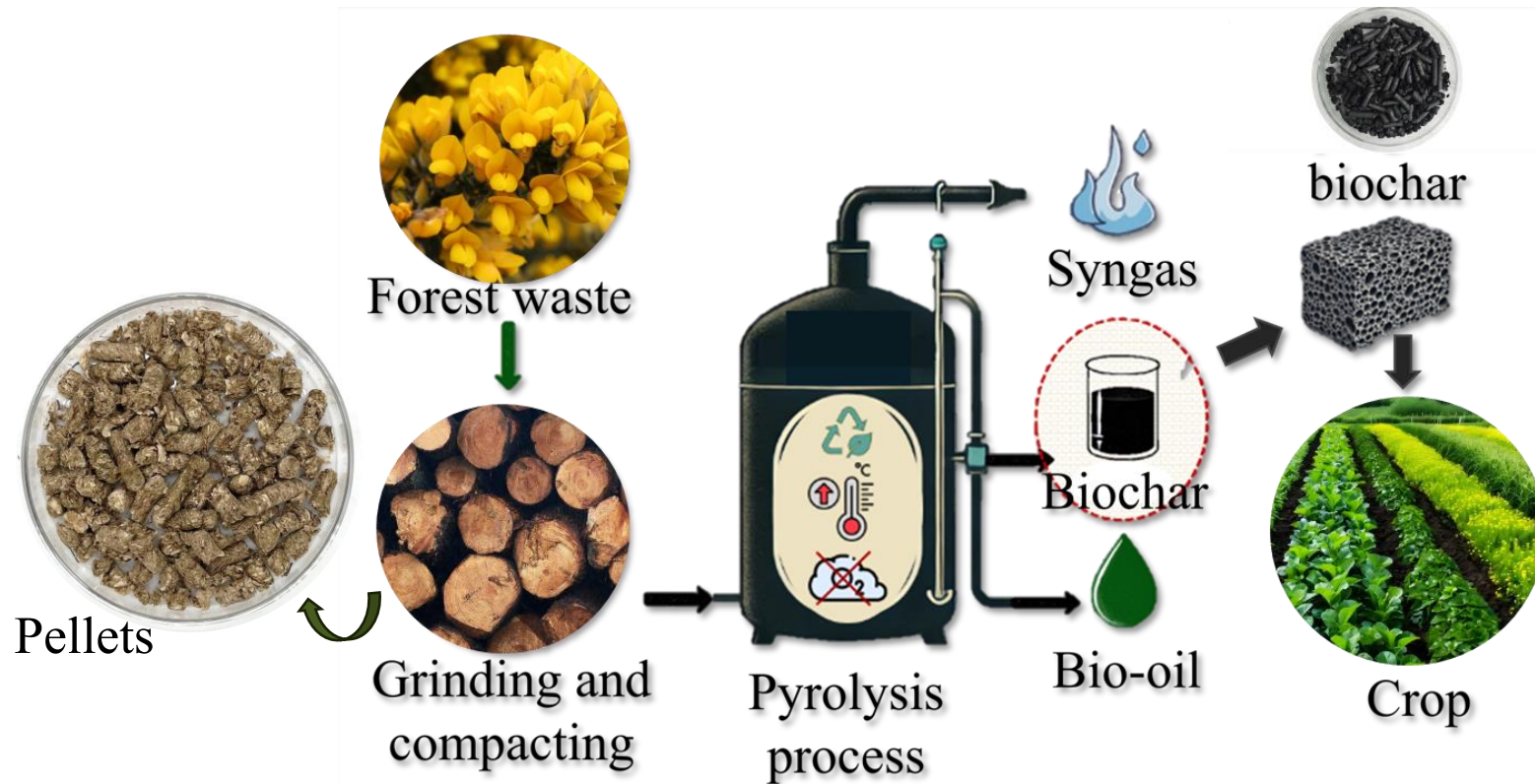
**Biochar** is a charcoal-like material produced by heating **biomass** in the absence of oxygen through pyrolysis. As a by-product of this process, it exhibits versatile properties and a high adsorption capacity, which has led to its proposal as a bio-based nanocarrier for fertilizers, in addition to its common use in soil improvement and carbon storage.



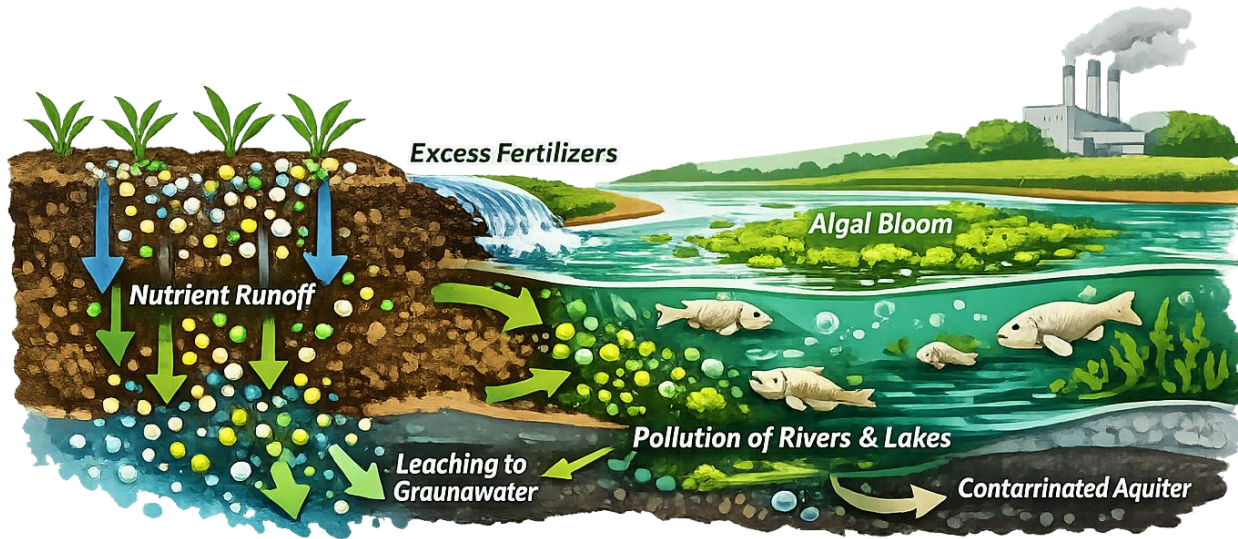
Biochar

## Introduction – Pyrolysis

**Pyrolysis** is a thermochemical process in which organic materials are heated to high temperatures in the absence (or near absence) of oxygen, causing them to decompose into **solid** (char), **liquid** (bio-oil), and **gaseous** products.

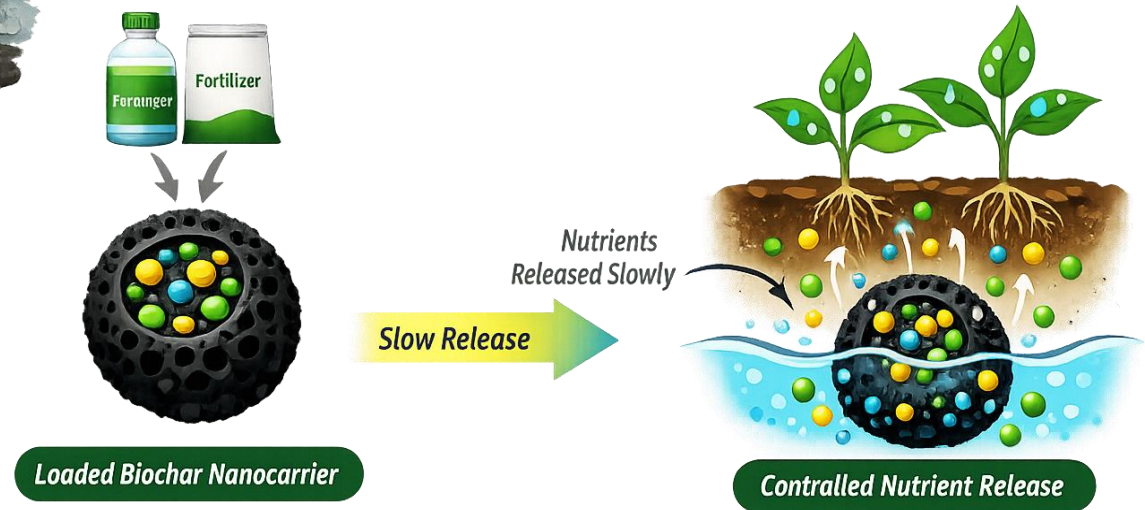


# Introduction – Biochar application as nanoplatform for sustainable nutrient delivery



Biochar is an ideal candidate for designing of **controlled nutrient delivery systems**, which are essential for improving plant nutrition and enhancing fertilizer efficiency.

**Conventional fertilization methods** often lead to **nutrient losses** through leaching or volatilization, reducing plant uptake and impacting both crop productivity and environmental sustainability.



## Introduction - Control nutrient delivery systems



Biomaterial-based carriers, such as engineered biochar, can retain nutrients and release them gradually according to plant demands, minimizing losses and supporting sustainable agricultural practices.



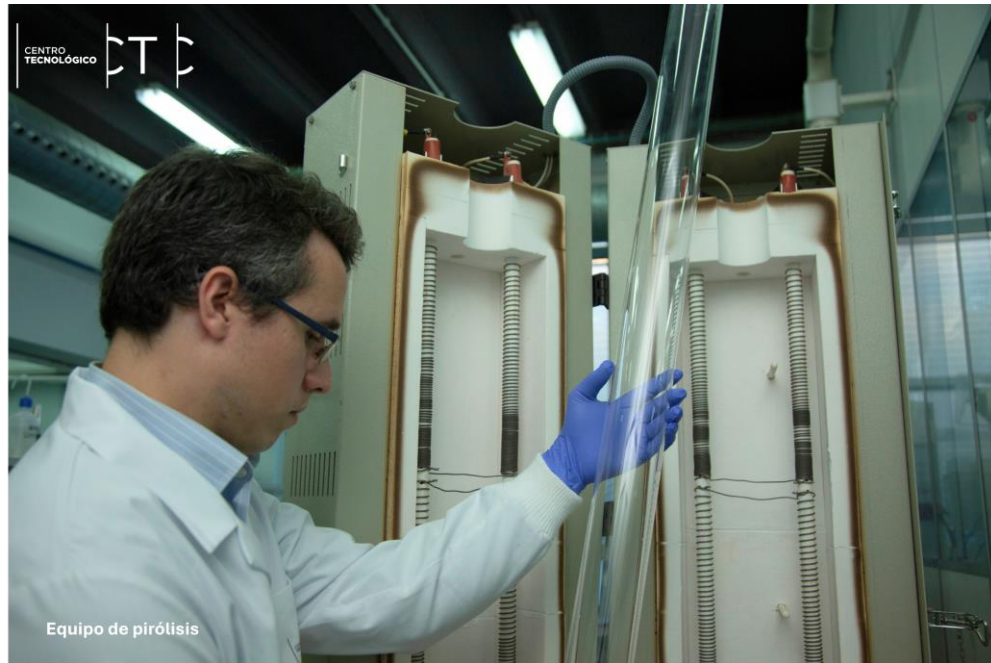
## Obtention of biochar by pyrolysis process from biomass



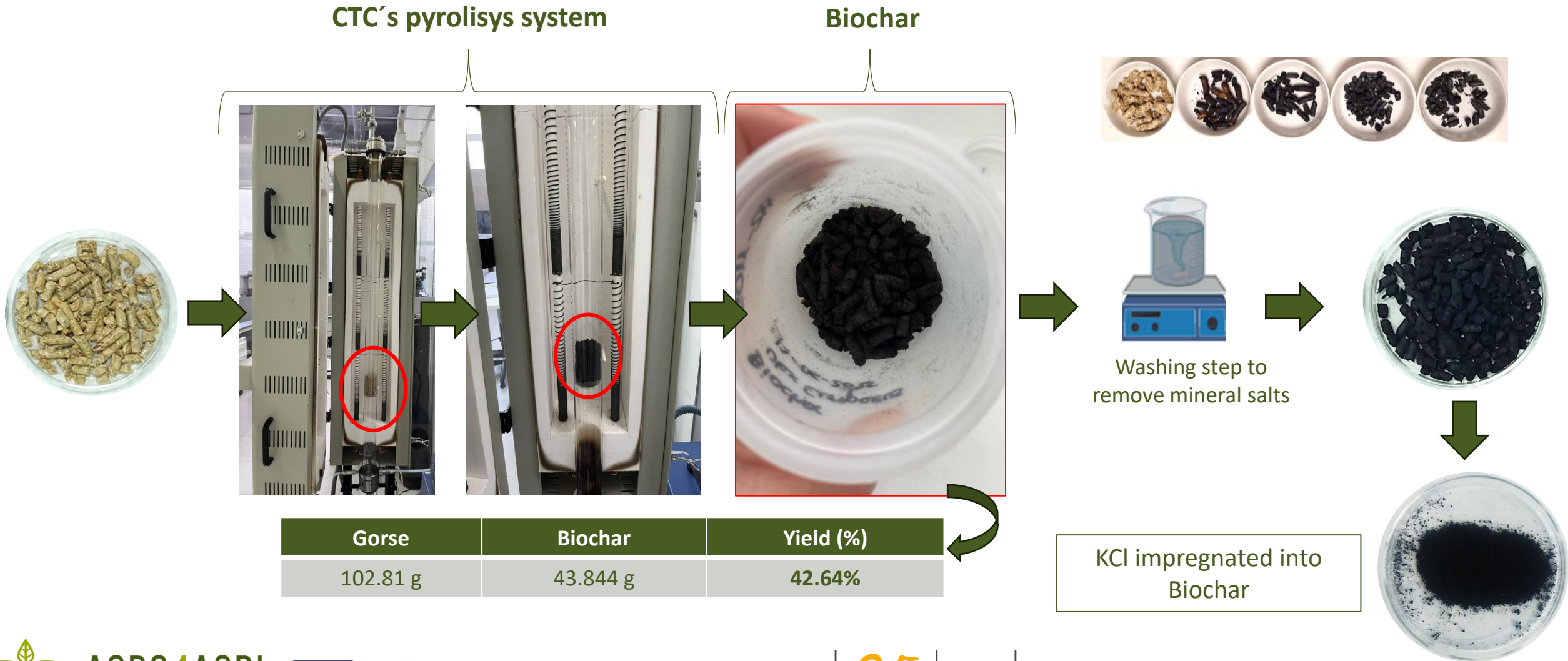
Gorse is a thorny shrub that is very common in northern Spain, particularly in regions such as Cantabria. While it can be found in natural ecosystems, it often behaves as an invasive species or aggressive coloniser.

## Obtention of biochar by pyrolysis process from biomass

### CTC's pyrolysis system



# Obtention of biochar by pyrolysis process from biomass



# Characterization of biochar

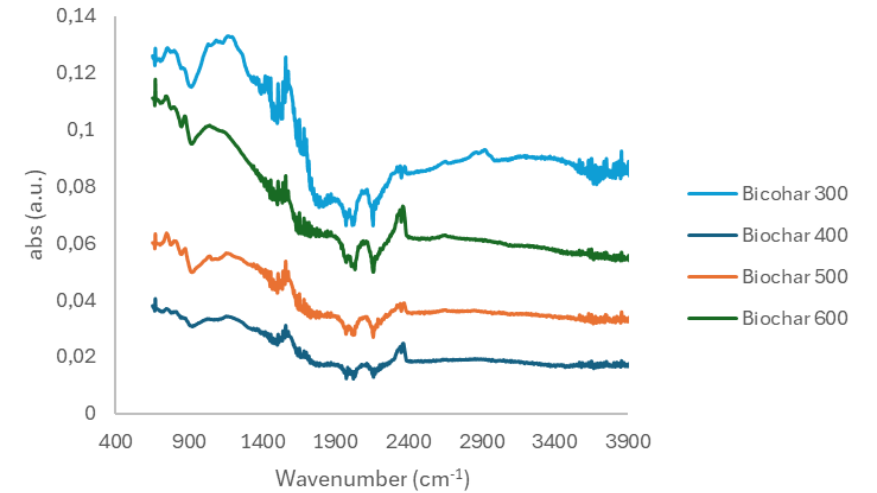
FTIR analysis of biomass.



Pellets of biomass

Wavenumber (cm <sup>-1</sup> )	Functional groups
3600-3000	O-H stretching
3000-2770	C-H <sub>n</sub> stretching
1785-1670	C=O stretching
1670-1530	C=C stretching
1278-1185	C-O-C stretching
1136-1088	C-O-C stretching
800	C-H stretching

FTIR spectrums of biochar



Results obtained of CO<sub>2</sub> isothermal absorption on obtained biochar.

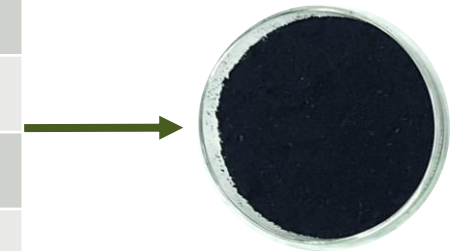
Product	Pyrolysis temperature (°C)	Gas used	Specific surface area (m <sup>2</sup> /g)	Type of porosity
Biochar	300	CO <sub>2</sub>	96.13	Microporous
	400	CO <sub>2</sub>	287.48	Microporous
	500	CO <sub>2</sub>	194.43	Microporous



## Development of biochar impregnation process for fertilizers adsorption



NPK Fertilizers	Fertilizers	Formula
<b>Nitrogen based fertilizers</b>	Urea	$\text{CO}(\text{NH}_2)_2$
	Ammonium sulfate	$(\text{NH}_4)_2\text{SO}_4$
	Potassium nitrate	$\text{KNO}_3$
	Calcium nitrate	$\text{Ca}(\text{NO}_3)_2$
	<b>Ammonium nitrate</b>	<b><math>\text{NH}_4\text{NO}_3</math></b>
<b>Phosphorus based fertilizers</b>	Superphosphate	$\text{CaH}_6\text{O}_8\text{P}_2+2$
	Diamonic phosphate (DAP)	$(\text{NH}_4)_2\text{HPO}_4$
	<b>Monoamonic phosphate (MAP)</b>	<b><math>\text{H}_6\text{NO}_4\text{P}</math></b>
	Monopotasic phosphate	$\text{KH}_2\text{PO}_4$
	<b>Phosphoric acid</b>	<b><math>\text{H}_3\text{PO}_4</math></b>
<b>Potassium based fertilizers</b>	<b>Potassium chloride</b>	<b><math>\text{KCl}</math></b>
	<b>Potassium sulfate</b>	<b><math>\text{K}_2\text{SO}_4</math></b>
	Potassium nitrate	$\text{KNO}_3$

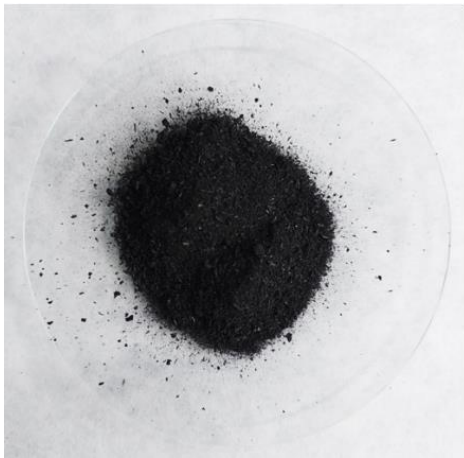


# Characterization of controlled and slow delivery system based on biochar

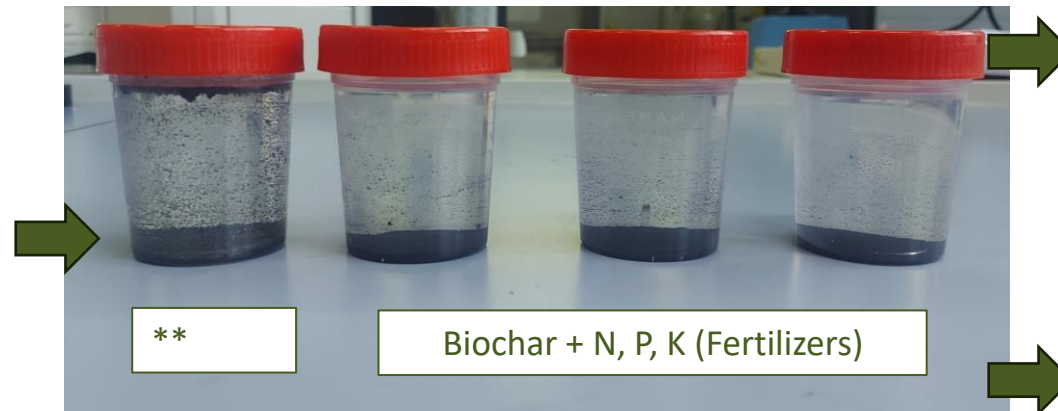


## Schematic experimental workflow for evaluated delivery systems in **water assay**

**STEP 1:** Weigh 1 g of impregnated biochar with fertilizers



**STEP 2:** Incubate the impregnated biochar with fertilizers in 50 ml of distilled water



\*\*As a control, uncoated fertilizer impregnated Biochar was incubated under the same conditions.



**STEP 3:** Carry out conductivity measurements to evaluate the slow and controlled release fertilizers

### *Slow and Controlled release fertilizers conditions*

- ✓ Room temperature (22°C)
- ✓ With stirring
- ✓ 10 mL aliquots for conductivity measurements

EC-method



### *Slow and Controlled release fertilizers conditions*

- ✓ Room temperature (22°C)
- ✓ Without stirring
- ✓ 1 mL aliquots for UV-Vis spectrophotometry

UV-Vis



# Characterization of controlled and slow delivery system

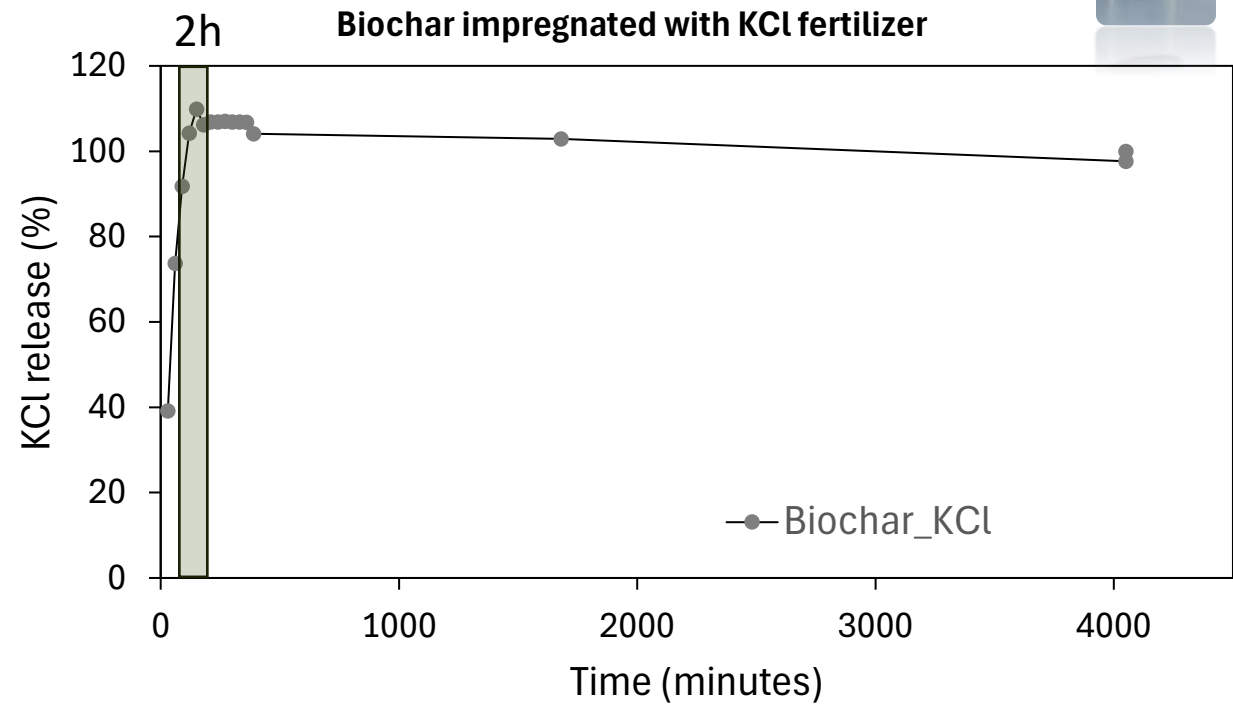
## Schematic experimental workflow for evaluated delivery systems in water assay

**STEP 3:** Carry out conductivity measurements to evaluate the slow and controlled release fertilizers

### Slow and Controlled release fertilizers conditions

- ✓ Room temperature (22°C)
- ✓ With stirring
- ✓ 10 mL aliquouts for conductivity measurements

EC-method



# Characterization of controlled and slow delivery system

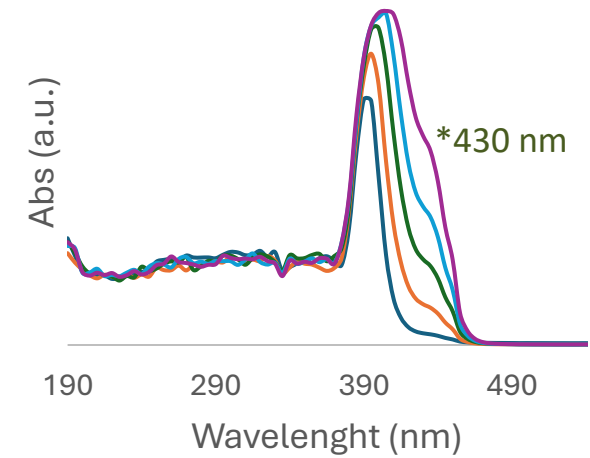
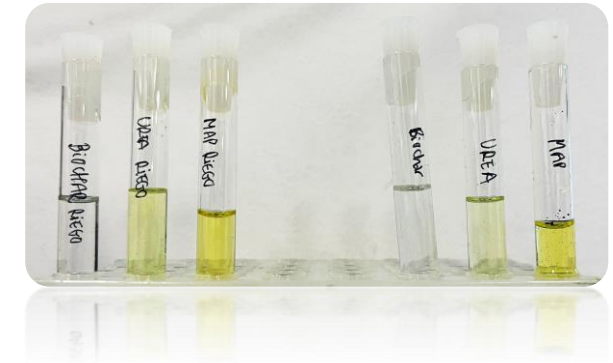
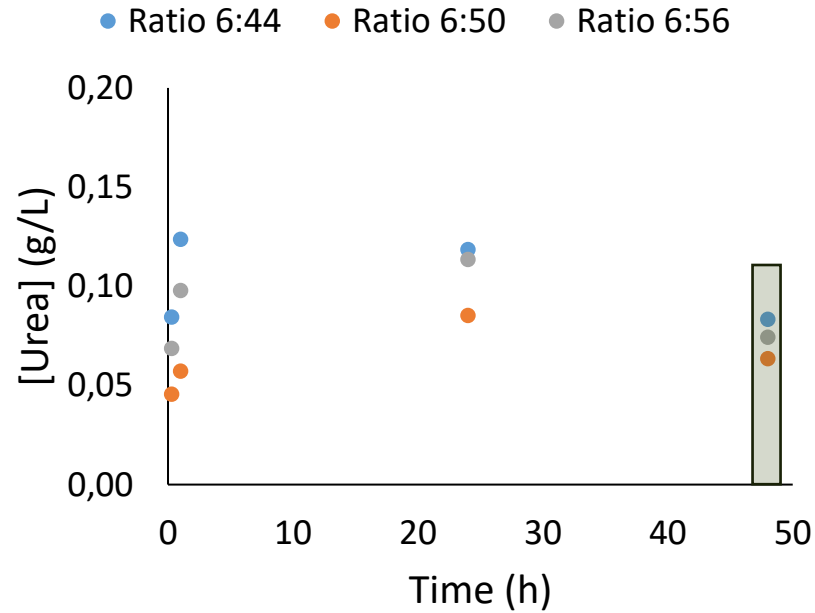
## Schematic experimental workflow for evaluated delivery systems in water assay

**STEP 3:** Carry out conductivity measurements to evaluate the slow and controlled release fertilizers

**Slow and Controlled release fertilizers conditions**

- ✓ Room temperature (22°C)
- ✓ Without stirring
- ✓ 1 mL aliquots for UV-Vis spectrophotometry

UV-Vis

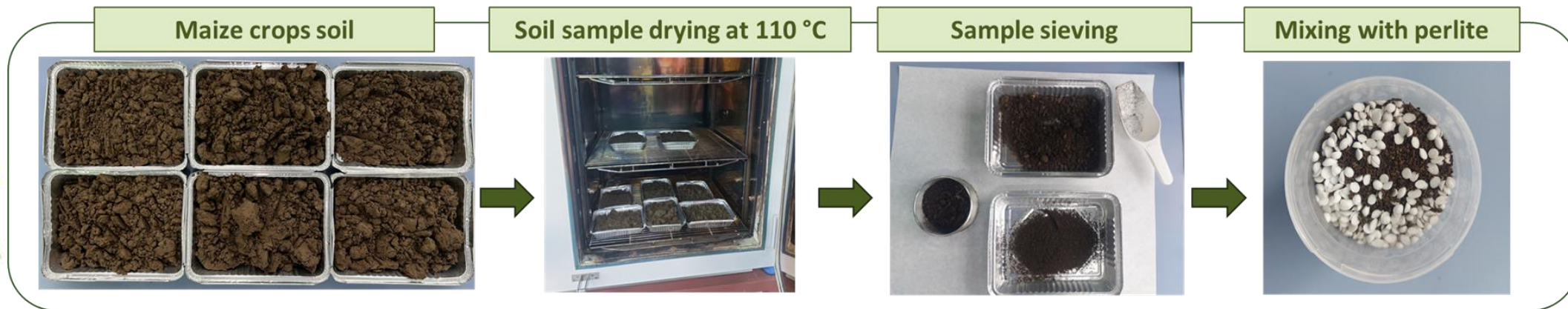




# Characterization of controlled and slow delivery system



## Schematic experimental workflow for evaluated delivery systems in soil columns



✓ Divided soil samples in different batches

✓ Reduction of water content (moisture) and autoclave soil

✓ Improved soil homogeneity

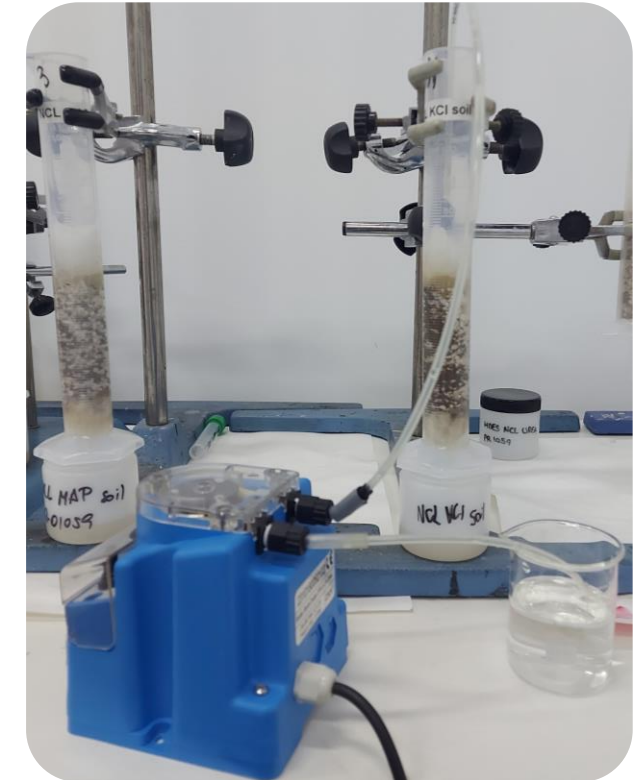
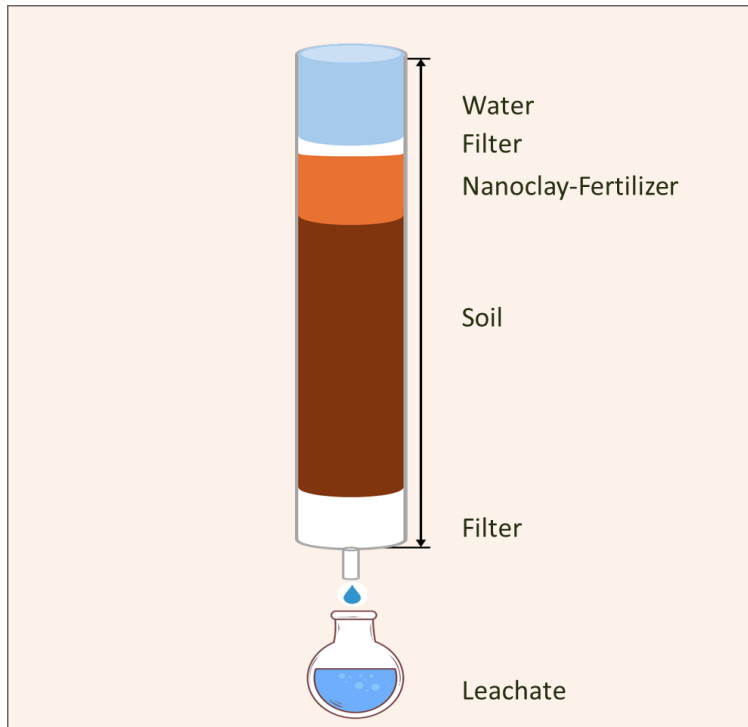
✓ Enhances drainage during irrigation



# Characterization of controlled and slow delivery system



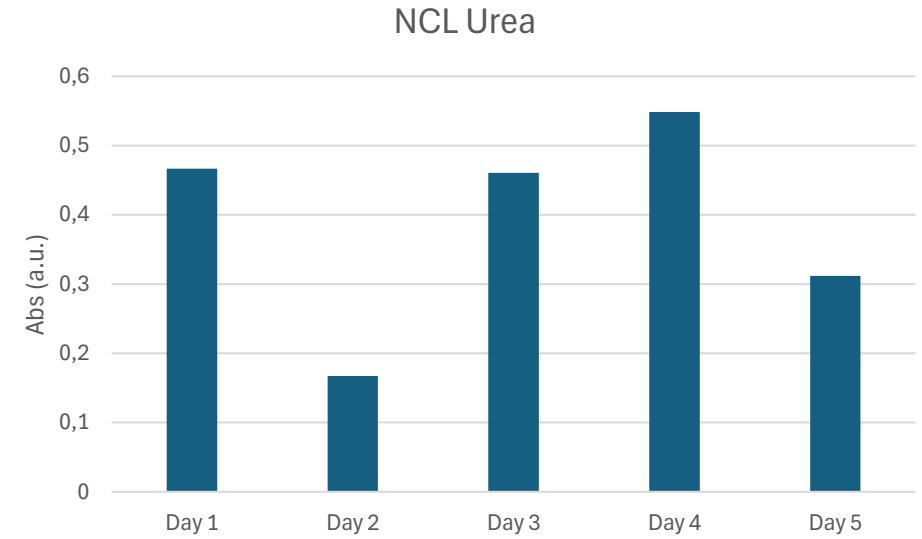
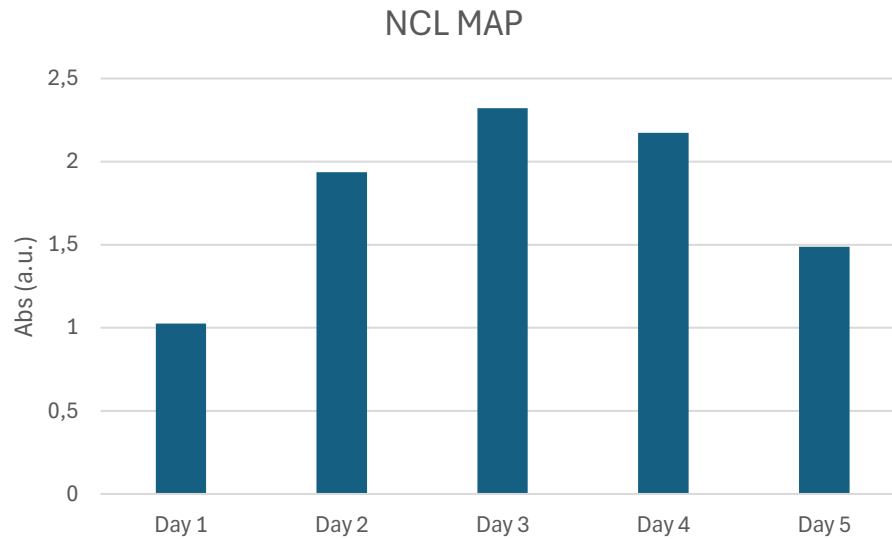
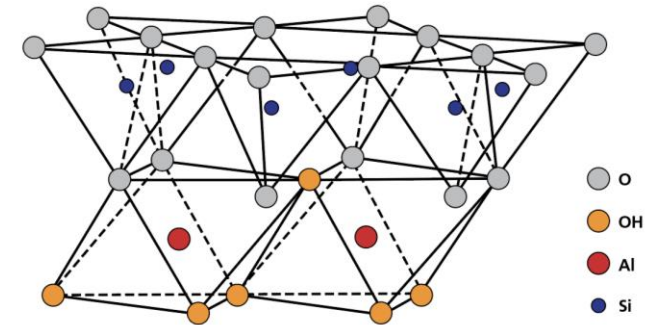
## Evaluation of delivery systems based on biochar in soil columns



# Characterization of controlled and slow delivery system

## Evaluation of delivery systems based on biochar in soil columns

Nanoparticle-based systems evaluated as an example of fertilizer release systems at laboratory scale.



## POSTER SESSION



### Porous inorganic nanoparticles for Improved Nutrient Delivery and Environmental Sustainability

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#### Introduction & Objective

Precision agriculture requires sustainable nutrient delivery systems, as conventional fertilization leads to significant nutrient losses and environmental contamination. Traditional agrochemicals present several limitations, including low bioavailability, poor target precision, high environmental impact, and considerable economic losses due to their inefficiency.

In this context, porous inorganic nanomaterials, as nanoclay (NC) and porous silica nanoparticles (PSi), emerge as promising alternatives to enhance nutrient use efficiency and promote more sustainable agricultural practices. Therefore, it is essential to evaluate these inorganic nanoparticles as sustainable nanopatforms for slow and controlled nutrient delivery.

Our main objective is to evaluate and characterize nanoclay and porous silica nanoparticles as sustainable bio-based nanopatforms for slow and controlled fertilizer delivery, aiming to improve nutrient efficiency while minimizing fertilizer leachate and their environmental impact. To achieve this objective, laboratory-scale assays have been used to evaluate the performance of release systems based on inorganic nanoparticles in both water and soil.



#### Materials & Methods

- The selected inorganic nanoparticles were impregnated with fertilizers such as urea and ammonium nitrate via mechanical mixing to ensure uniform nutrient loading.
- A fixation step was carried out to remove non-impregnated fertilizer from the structure of nanoclay and porous silica nanoparticles.
- The fertilizers impregnated into nanoparticles were dried and ground to reduce and homogenize the particle size for further application.

#### Results

##### Physicochemical characterization of nanoparticles delivery systems

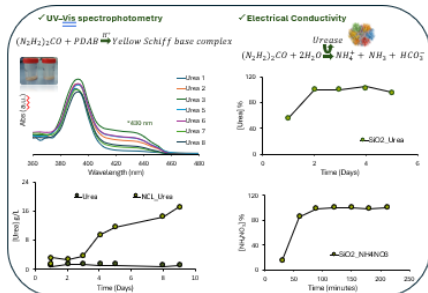
Table 1. TGA analysis of urea-impregnated into nanoparticles.

Nanocarrier : Fertilizer Ratio	Temperature range (°C)	Weight Loss (%)
Nanoclay : Urea	240 - 220 - 100	76.47
Nanoclay : Urea	640 - 220 - 100	76.84
Porous silica : Urea	240 - 220 - 100	83.63
Porous silica : Urea	640 - 220 - 100	85.87

✓ Bionite nanoclay (Urea 0:80)  
 ✓ Silica NPs

##### Water release test and characterization at laboratory scale

Water release test involved the incubation of fertilizers impregnated into inorganic nanostructures in water, followed by monitoring their release through the analysis of aliquots. The fertilizer release was evaluated using two different experimental methods:



#### Main Conclusions

- Bionite nanoclay serves as an efficient nanocarrier for controlled nutrient release, as demonstrated by the results obtained from laboratory-scale water and soil release tests. Its high surface area, layered structure, and cation-exchange capacity enables effective nutrient retention and controlled desorption.
- Although porous silica nanoparticles are excellent nanocarriers for fertilizer adsorption, the laboratory release tests showed that fertilizers are released within a few seconds, limiting their effectiveness for controlled delivery compared with bionite nanoclay.
- Laboratory-scale release tests in water and soil allowed that both spectrophotometric and electrical conductivity measurements are suitable for monitoring the release of fertilizers impregnated into nanostructures.
- Soil release tests for the evaluated systems indicate that Bionite nanoclay is a promising nanopatform for the development of controlled-release fertilizer systems.

#### Acknowledgments

This project has received funding from the European Union's Horizon Europe Research and Innovation programme under AGRO4AGRI (Grant Agreement No. 101130890). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Health and Digital Executive Agency (HADEA). Neither the European Union nor the granting authority can be held responsible for any errors.

##### Optimization of fertilizers loading into inorganic nanoparticles

Two different strategies to enhance the absorption capacity by fertilizers, such as urea and ammonium nitrate, into nanoclay and porous silica nanoparticles have been tested:



The most effective method of loading fertilizers into the inorganic nanoparticles (nanoclay and porous silica) was found to be the impregnation method, mechanical mixing during mixing at room temperature. The physicochemical performance of the resulting product was evaluated using various techniques, including thermogravimetric analysis (TGA-DSC), as shown in Table 1.

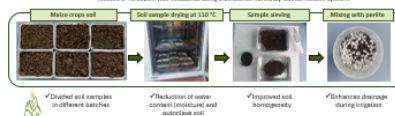
##### Table 2. Active substance adsorption ratio for evaluated nanoparticles.

Nanocarrier	Fertilizer	Ratio	ASAL wt.%
Nanoclay	Urea	0:80	96%
	Urea	0:80	95%
Silica NPs	Urea	0:80	58%
	Urea	0:80	58%

✓ Nanoclay  
 ✓ Silica NPs

##### Soil release test and characterization at laboratory scale

Soil release tests were taken from maize crops and used to program soil columns, in which the controlled release of fertilizers was evaluated using a bionite nanoclay-based release system.



##### Table 3. Desorption time of fertilizers based on evaluated delivery systems.

System	Fertilizer	Ratio	Desorption in water	Desorption in soil
Without NPs	Urea	-	Few seconds	1 day
Bionite - NC	Urea	0:80	3 days	6 days**
Silica NP	Urea	0:80	Few seconds	-
Without NPs	NH <sub>4</sub> NO <sub>3</sub>	-	Few seconds	1 day
Bionite - NC	NH <sub>4</sub> NO <sub>3</sub>	0:80	2 days	4 days**
Silica NP	NH <sub>4</sub> NO <sub>3</sub>	0:80	<2 hours	-

\*\*The uptake is ongoing, results obtained after four days indicate a progressive and controlled release of fertilizer in soil. Bionite-NC used as soil structure. The release time is not expected to be longer than 4 days because the fertilizer is very mobile.

Fertilizers incorporated into nanoclay demonstrated a slower release profile than other non-impregnated fertilizers or those loaded into porous silica nanoparticles. This could be due to the ion exchange that occurs within the nanoclay structure and the flexibility of its framework, which enables it to hold fertilizers such as urea inside it.

In soil release studies, desorption proceeded even more slowly, likely owing to reduced water interaction during irrigation. However, soil release test better reflects the real conditions under which the developed systems are applied.



## Main Conclusions

- ✓ Biochar serves as an **efficient nanocarrier** for nutrient release, as demonstrated by the results obtained from laboratory-scale water release tests.
- ✓ Laboratory-scale release tests in water showed that both **electrical conductivity** and **spectrophotometric measurements** are **suitable for monitoring the release of fertilizers** impregnated into biochar.
- ✓ Its **high surface area**, and **cation charge capacity** enable effective nutrient retention.
- ✓ The **impregnation of fertilizers** into the structure of **biochar increases the release time** of nutrients into water, ensuring their persistence and assimilation by plants.

**KPI.** Active substance adsorption ratio (ASAR).

Nanocarrier	N fertilizer	Molar ratio	Adsorption rate wt%
Biochar (300°C)	Urea	6:40	-
Biochar (400°C)	Urea	6:40	41.10
Biochar (500°C)	Urea	6:40	50.11
Biochar (600°C)	Urea	6:40	64.09

**KPI.** Desorption ratio of active substance in laboratory scale using a rapid water release test.

Nanocarrier	Fertilizer	Molar ratio	Desorption ratio %
Biochar (300°C)	KCl	6:40	100 %
	NH <sub>4</sub> NO <sub>3</sub>	6:40	100 %
Biochar (500°C)	KCl	6:40	100 %
	Urea	6:40	100%

Friday 10<sup>th</sup> April 2026

09.00 -12:30 CEST



# AGRO4AGRI

**Thank you for your attention!**

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