

## INTRODUCTION AND OBJECTIVES

Digestate has been widely studied in agriculture as an organic amendment, but its role in the restoration of degraded soils (e.g., burned forest areas, road embankments, and quarries) has received less attention. Within the Spanish pilot of the European ECOLOOP project, one focus is to investigate the influence of digestate in degraded environments, specifically quarry soils in this case. The objective was to evaluate how the application method (superficial vs. mixed) and particle size (>6 mm vs. <6 mm) affect soil erosion parameters, with particular emphasis on their potential to improve physical characteristics related to erosion resistance and their capacity to store water.

## MATERIAL AND METHODS

### Soil

Quarry soil with a loam clay texture.

Organic matter	Coarse elements
1,46%	54%

### Digestate

1,6 kg of digestate by tray (30 T/ha).

Derived from cow, manure and slurry, and the organic fraction of Municipal Solid Waste (OFMSW).

Organic matter is 85%.

### Rainfall simulator



Rain simulator dripper

Tray with mineral soil (3 replicates)



Example of control tray

Tray dimension 75 × 68 × 10 cm

Splash hose

Runoff hose

Experiment conditions

Soil conditions at the start of rainfall

- Wet
- Dry

Size

- Fine < 6mm
- Coarse > 6mm

Position

- Superficial
- Mixed in 0-10 cm

Rainfall intensity 80 mm/h

Slope 20%

*i.e.* Rainfall simulator with digestate tray

## CONCLUSIONS

The study demonstrates that digestate application can significantly reduce surface runoff and soil loss under simulated rainfall. Among the treatments tested, surface application of coarse digestate particles proved to be the most effective, delaying runoff onset, minimizing accumulated runoff and sediment yield, and maintaining stable infiltration rates. Overall, surface application had a protective effect by mitigating the direct impact of rainfall, thereby allowing the soil to preserve its structure over time. Future research on soil aggregation would be required to confirm this hypothesis. In contrast, digestate incorporated into the soil, particularly under wet conditions, led to faster runoff initiation and higher runoff and sediment values. The results highlight the importance of both the mode of application and particle size in determining the effectiveness of digestate in controlling runoff and erosion. Overall, the findings suggest that applying coarse digestate on the soil surface under dry conditions offers the greatest potential for improving infiltration and reducing erosion risks.

## RESULTS

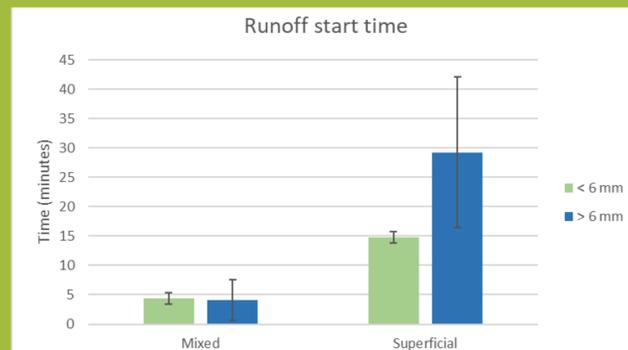


Figure 1. Runoff start time depending on size and position.

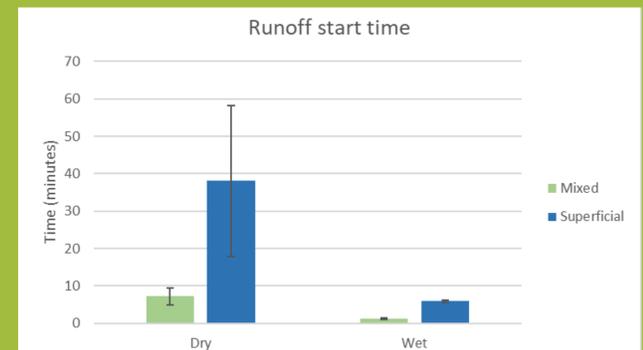


Figure 2. Runoff start time depending on position and condition.

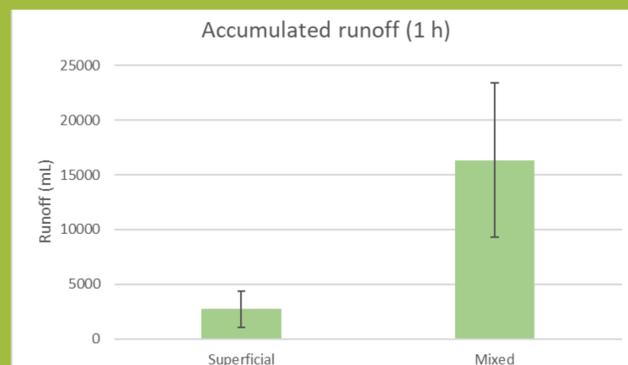


Figure 3. One-hour accumulated runoff depending on digestate position.

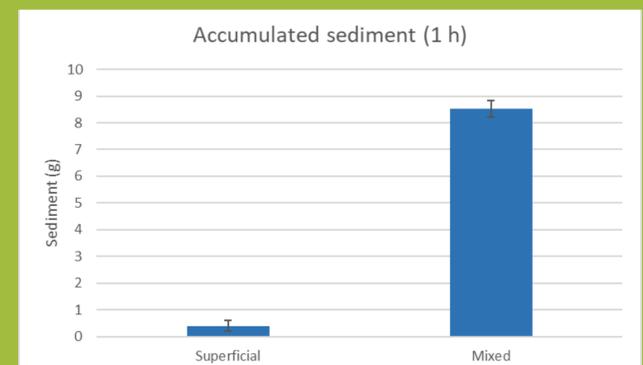


Figure 4. One-hour accumulated sediment depending on digestate position.

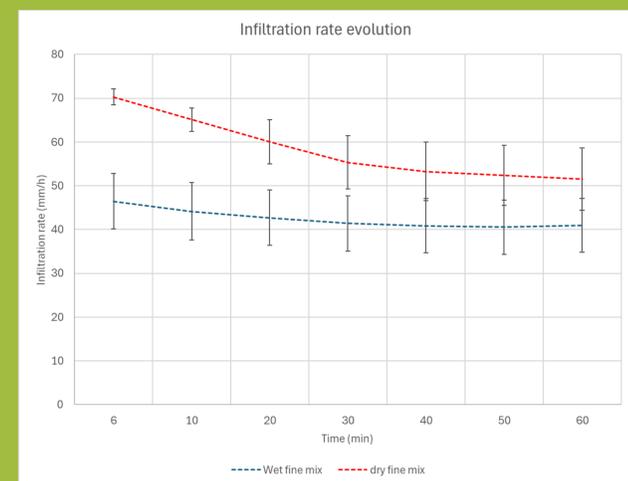


Figure 5. Infiltration rate evolution depending on humidity condition in fine mixed digestate.

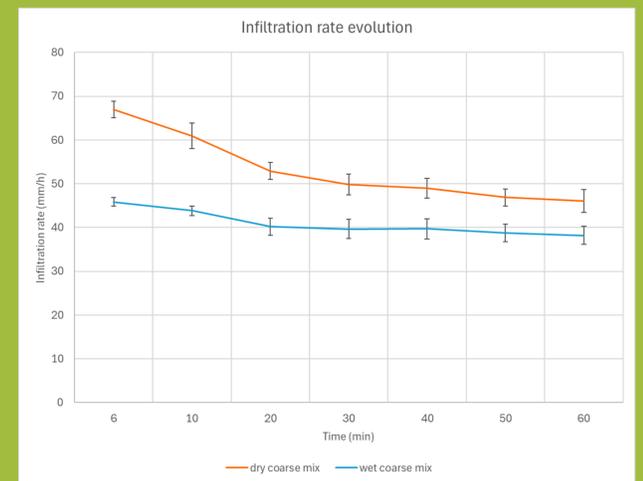


Figure 6. Infiltration rate evolution depending on humidity condition in coarse mixed digestate.

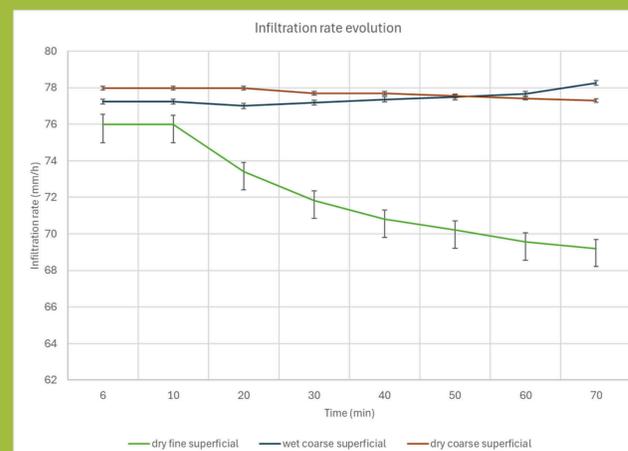


Figure 7. Infiltration rate evolution depending on humidity condition and size in superficial digestate.

The surface application of digestate in dry and wet soil conditions resulted in very high infiltration rates, which translated into virtually negligible runoff values. In the case of fine superficial digestate in wet conditions, there was no runoff in any of the simulations.

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## INTRODUCTION AND OBJECTIVES

Ecoloop is a European project aimed at revalorizing by-products from renewable energy production in agri-food systems within the framework of a circular economy. In the Spanish pilot, digestate generated through the anaerobic digestion of biogas plant residues is considered for use as a fertilizer or organic amendment in agricultural soils. Nonetheless, its potential to stimulate microbial activity may be modulated by factors such as temperature and particle size. As a preliminary approach, a controlled laboratory experiment was conducted to investigate the effects of these parameters (temperature and digestate particle size) on soil respiration, organic carbon mineralization, and enzymatic activity.

## MATERIAL AND METHODS

Laboratory incubations were carried out in hermetically sealed 250 mL Erlenmeyer flasks containing 29,9 g of soil and 0,1 g of digestate. The incubation period lasted 56 days in an experimental design that combines four digestate particle sizes (>4 mm, 4–2 mm, 2–1 mm, and <1 mm) and three temperatures (15, 25, and 35 °C).

### Soil properties

Loam texture  
Organic matter 2,8%

### Digestate

Derived from cow manure and slurry  
Organic matter 85%

### Digestate particle size



### Organic Carbon Determination

- Oxidizable Organic Carbon (XOC): Measured using the **Walkley-Black** method (1934).
- Water-Soluble Organic Carbon (WSOC): Analyzed following the **Yakovchenko and Sikora** method (1998).

### Enzyme Activity

- Phosphatase: The activity of this enzyme was determined using the **Tabatabai and Bremner** method (1969).

### Soil Respiration

- Respiration Measurements: The respiration rate was quantified using a **Dansensor CheckPoint 3 ® gas analyzer** in 250 ml Erlenmeyer flasks

## CONCLUSIONS

When evaluating the effects of temperature and digestate particle size on soil, temperature was identified as the most influential factor.

Analyzing particle sizes without considering the temperature effect, no significant differences were determined. In the case of phosphatase enzyme activity, a statistically significant effect was observed in the lower sizes.

However, when data were broken down by temperature, it was observed that at 35 °C both water-soluble organic carbon (WSOC) and phosphatase enzyme activity increased as particle size decreased, indicating that particle size becomes relevant at higher temperatures.

## RESULTS

### Effect of temperature on soil biochemical properties after incubation (average of all particle sizes)

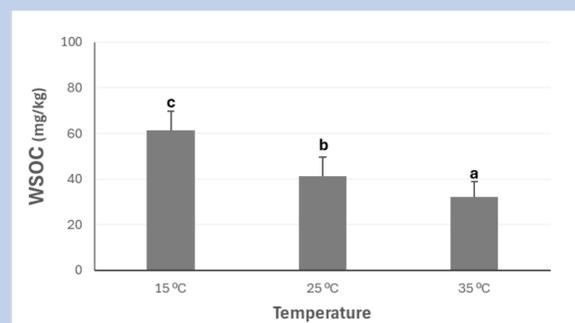


Figure 1. Amount of WSOC obtained at each temperature

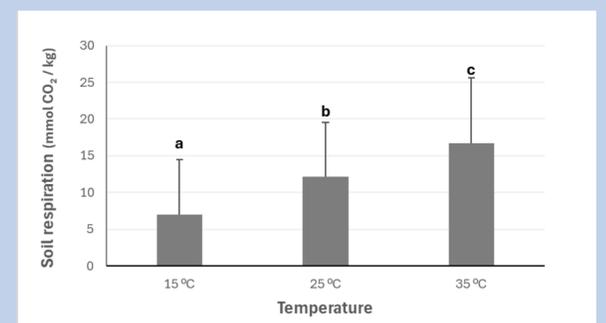


Figure 2. Average of Soil Respiration after incubation

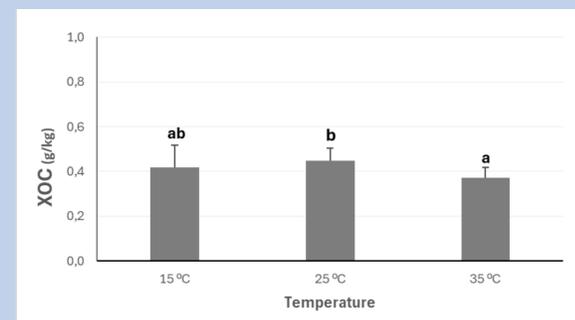


Figure 3. Amount of XOC obtained at each temperature

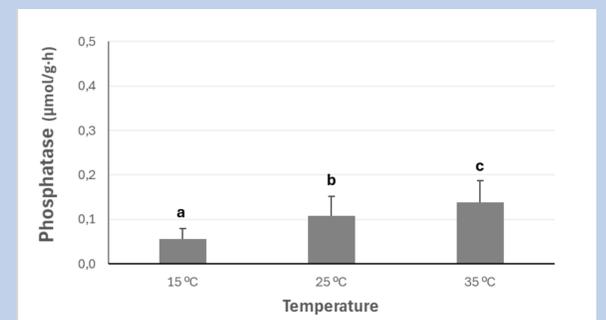


Figure 4. Amount of phosphatase activity obtained at each temperature

### Effect of digestate size on soil biochemical properties after incubation (average of all temperatures)

Properties	Size			
	>4 mm	4 - 2 mm	2 - 1mm	<1 mm
WSOC (mg /kg)	49,40 ± 6,45 a	43,34 ± 6,16 a	41,43 ± 3,81 a	47,01 ± 8,09 a
XOC (g/kg)	0,422 ± 0,054 a	0,396 ± 0,058 a	0,440 ± 0,168 a	0,437 ± 0,108 a
Phosphatase activity (µmol/g·h)	0,094 ± 0,034 a	0,084 ± 0,034 a	0,102 ± 0,075 ab	0,138 ± 0,071 b
Soil respiration <sup>1</sup> (mmol CO <sub>2</sub> / kg)	10,58 ± 8,47 a	10,18 ± 7,60 a	12,05 ± 8,72 a	14,95 ± 9,33 a

<sup>1</sup>The soil respiration values are the average of the 56 days.

Values correspond to average ± standard deviation of three replicates. Different letters in the same row indicate significant differences between digestate particle size ( $p < 0.05$ ).

### Effect of digestate size on soil biochemical properties only at 35 °C.

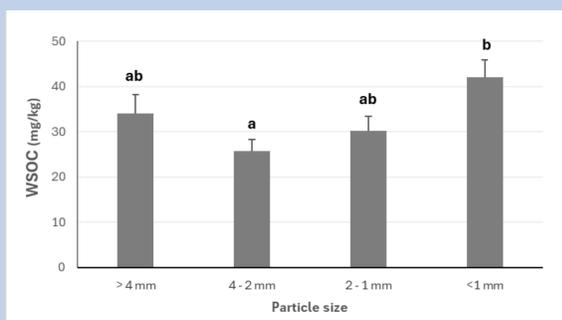


Figure 4. Amount of WSOC obtained at 35 °C in the four sizes.

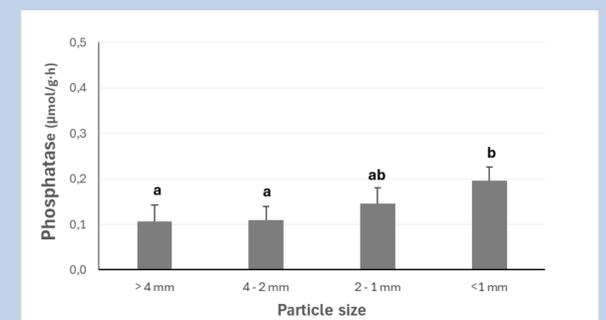


Figure 5. Amount of phosphatase activity obtained at 35 °C in the four sizes.

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## AIM OF THE STUDY

Examine whether digestate and OFMSW pellet (composted Organic Fraction of Municipal Solid Waste) amendments show different effects on carbon and nitrogen dynamics, microbial activity, and organic matter transformation in a loam and sandy loam soils over time.

## METHODOLOGY

### Laboratory test conditions

30 g of soil with digestate and OFMSW pellet incubated for 56 days at 25 °C.

### Organic Carbon Determination

- Oxidizable Organic Carbon (OOC): Measured using the **Walkley-Black** method (1934).
- Water-Soluble Organic Carbon (WSOC): Analyzed following the **Yakovchenko and Sikora** method (1998).

### Nitrogen Determination

- Nitrates: Measured using the **Sempere, Oliver y Ramos (1993)** second derivative.
- Kjeldahl nitrogen: Analyzed following the **Bremner** method (1996).

### Soil Respiration

- Respiration Measurements: The respiration rate was quantified using a **Dansensor CheckPoint 3 ® gas analyzer** in 250 ml Erlenmeyer flasks.

Table 1. Initial analytical tables of soil types.

Texture	Organic matter (%)	Nitrogen (%)
Loam	2,8	0,04
Sandy Loam	0,91	0,02

Table 2. Initial analytical tables for bioproducts.

Bioproduct	Organic matter (%)	Nitrogen (%)
OFMSW pellet	59,38	2,87
Digestate	85,68	1,99



## CONCLUSIONS

Once time evaluated the effect of different soils and applied bioproducts, higher microbial activity was observed in the loam soil compared to the sandy loam. Regarding the form of organic matter, the digestate application showed slightly higher decomposition than the OFMSW pellet. Microbial activity was greater in loam soil, with a slight advantage for digestate over OFMSW pellet. SWOC showed an initial consumption followed by a marked increase from day 7 onwards in both soils. OOC decreased until day 14 and then increased, likely due to the decomposition of more complex carbon compounds. Kjeldahl nitrogen declined over time, although digestate application promoted greater organic N availability, especially in loam soil. Nitrate levels increased up to day 14 and then decreased in both treatments and soils. These results are consistent with the higher respiration observed under digestate compared to OFMSW pellet.

## RESULTS

Loam-Control  
Loam-OFMSW Pellet  
Loam-Digestate

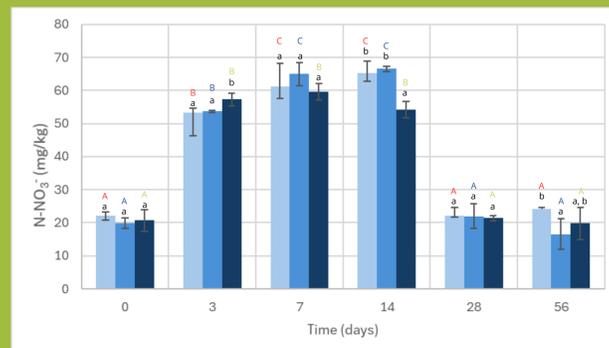


Figure 1. Amount of N-NO<sub>3</sub><sup>-</sup> (mg/kg) obtained for loam soil with OFMSW pellet, digestate, and soil without mixture.

Sandy Loam-Control  
Sandy Loam-OFMSW pellet  
Sandy Loam-Digestate

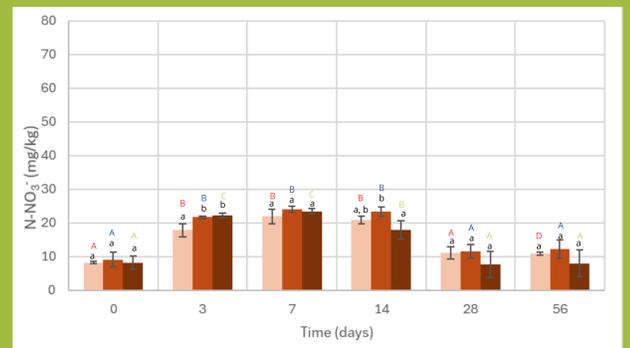


Figure 2. Amount of N-NO<sub>3</sub><sup>-</sup> (mg/kg) obtained for sandy loam soil with OFMSW pellet, digestate, and soil without mixture.

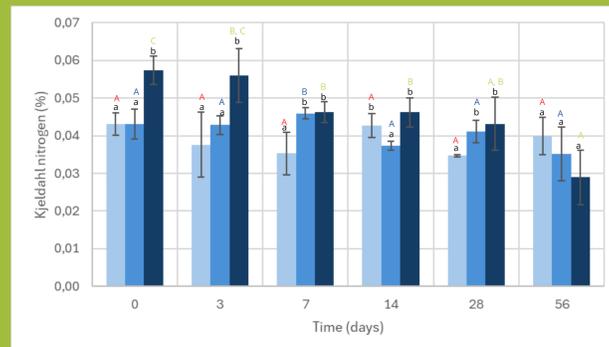


Figure 3. Amount of Kjeldahl nitrogen (%) obtained for loam soil with OFMSW pellet, digestate, and soil without mixture.

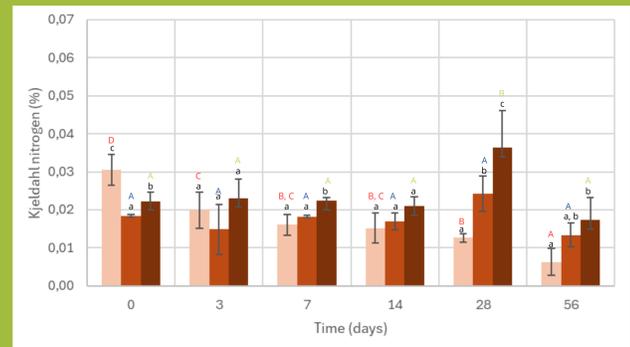


Figure 4. Amount of Kjeldahl nitrogen (%) obtained for sandy loam soil with OFMSW pellet, digestate, and soil without mixture.

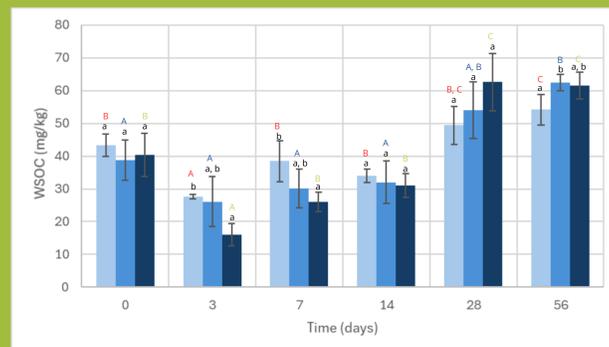


Figure 5. Amount of WSOC (mg/kg) obtained for loam soil with OFMSW pellet, digestate, and soil without mixture.

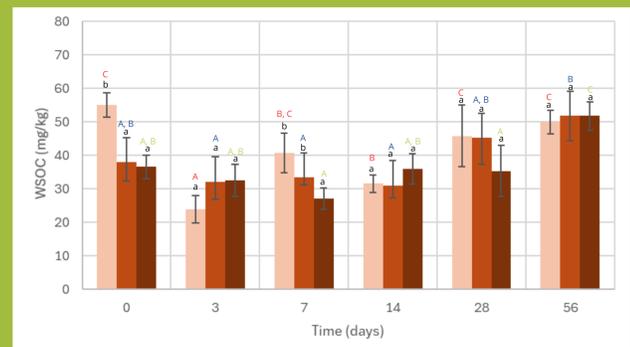


Figure 6. Amount of WSOC (mg/kg) obtained for sandy loam soil with OFMSW pellet, digestate, and soil without mixture.

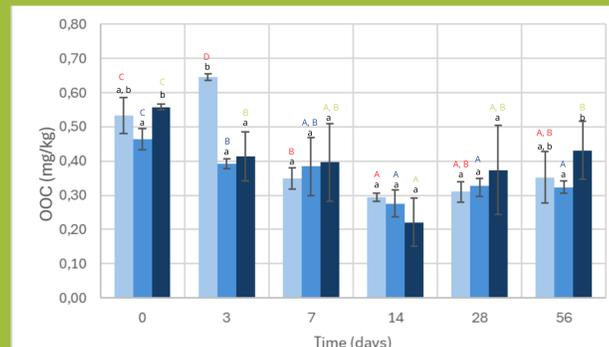


Figure 7. Amount of OOC (mg/kg) obtained for loam soil with OFMSW pellet, digestate, and soil without mixture.

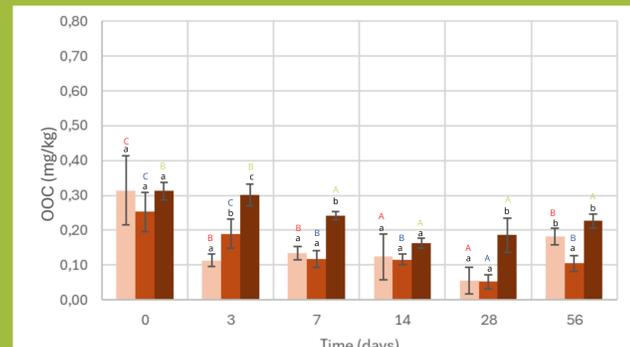


Figure 8. Amount of OOC (mg/kg) obtained for sandy loam soil with OFMSW pellet, digestate, and soil without mixture.

\*Lowercase letters indicate significant differences between treatments at the same time, while uppercase letters indicate differences over time within the same treatment.

Table 3. Effect of applying pellets and digestate to different soil types on microbial respiration.

Soil	Treatment	mmol CO <sub>2</sub> /kg
Loam	Control	3,12
Loam	OFMSW pellet	4,11
Loam	Digestate	55,30
Sandy Loam	Control	2,69
Sandy Loam	OFMSW pellet	4,96
Sandy Loam	Digestate	23,40