Improving Innovation Capacities of Private and Public Actors for Sustainable and Profitable Recycling of Livestock Waste.

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Abstract

The Mediterranean region is known for its intensive livestock farming, especially for the breeding of pigs and cattle. These activities result in vast amounts of waste that necessitate proper treatment. Inadequate manure treatment can cause eutrophication of surface waters, enrichment of nitrates and pathogens into groundwater, detection of excess nutrients and heavy metals in soil, and increase GHGs emissions. RE-LIVE WASTE is an Interreg MED project (2/2018-4/2021) that focused on testing innovative solutions for livestock waste management in Cyprus, Italy, Spain, and the Federation of Bosnia and Herzegovina. The proposed route to address the environmental and financial problems associated with livestock waste was through nutrient recovery and the precipitation of an organo-metallic fertilizer known as struvite. Each participating region constructed and operated a struvite precipitation plant that transformed anaerobically treated and untreated livestock waste from cattle, pig, and mixed waste into struvite. Different treatment trains were followed in each demonstrative pilot to record the effects of treatment and source of waste on the final product. In Cyprus struvite was produced by a mixed effluent that was anaerobically digested and filtered with filter bags and UF ceramic membranes. The struvite produced had a purity between 90-99% based on the applied conditions.

Keywords: struvite, livestock waste, anaerobic digestion, nutrients.

1. Introduction

The Mediterranean region is characterized by intensive cattle and pig livestock farming, that in return results into high volumes of waste. Release of greenhouse gases (GHGs) into the atmosphere, nitrates and pathogens leaching into surface and groundwater, buildups of excess nutrients and heavy metals in soil, and destruction of fragile ecosystems through eutrophication are the major problems associated with poor waste management (Casasús et. al., 2012).

It has been reported that agricultural production is expected to increase by 60% by 2050 to address word-hunger, which means if we still use conventional agriculture practices phosphorus-mining demand will also increase, since it is an important nutrient for plant growth and a vital component of fertilizers. However, P-resources are constantly declining, and predictive models indicated that they may be extinct within the next 100 years, it becomes a necessity to find alternatives to industrially produced P-fertilizers so that food availability and security are sustained.

Nutrient recovery (N and P) from livestock wastewater through struvite crystallization/precipitation could be a sustainable solution to alleviate this problem. Struvite is a crystalline organo-mineral, known for its insect repellent properties and slow nutrient releasing properties that make it a high-value organic fertilizer. It contains equal molar concentrations (1:1:1) of magnesium, ammonium, and phosphate (struvite $MgNH_4PO_4 \cdot 6H_2O$), that can be recovered from nutrient-rich wastewater streams including livestock, dairy, agro-industrial, and industrial (Le Corre et al., 2009).

The Interreg MED project RE-LIVE WASTE that was completed in April 2021 (total duration 39 months) applied this innovative nutrient recovery solution for livestock waste in demonstrative struvite precipitation pilot plants located in nitrogen vulnerable regions of Cyprus, Italy, Spain, and the Federation of Bosnia and Herzegovina. The project aimed to alleviate all the previously mention environmental and financial problems associated with livestock waste management, that are of particular concern to small scale farmers, through strong cooperation among the 4-helix actors (academia, government, industry, and public). Herein, the treatment processes applied along with the outcomes of the Cypriot pilot are presented and discussed.

2. Materials and Methods

In order to fully address the goal of the project to provide solutions that can be applied in small- and large-scale applications, different treatment processes on different types of livestock waste for the production of struvite were applied. The end products from each pilot were evaluated for their chemical composition and quality, environmental footprint (Life-cycle assessment analysis), and production cost (Cost benefit analysis). In addition, they were evaluated as fertilizers for crop development to assess their agronomic potential. Specifically, each pilot investigated different effluents (treated and untreated, slurries from cow, pig, or mixed wastes), pre-treatments prior to struvite crystallization (SC), and operating conditions during struvite crystallization.

The Cypriot demonstrative pilot plant was already constructed to address the goals of the LIFE Livestock Waste Project (LIFE12 ENV/CY/000544) to produce a zero waste/zero energy livestock waste treating pilot unit. The pilot was relocated to Monagroulli at Nicos Armenis and Sons Ltd farm and was re-operated. In addition, the struvite crystallization reactor was upgraded from 50 L to 250 L to increase the quantity of struvite produced, while a phosphoric pump was added as well to achieve the optimal solution molar ratio of Mg^{2+}: $P\text{-}PO_4^{3-}$: $N\text{-}NH_4^+$.

As previously mentioned, the produced struvite in the pilot was analyzed for its quality characteristics which included TN, NH_4^+, $P\text{-}PO_4^{3-}$, Ca^{2+}, Mg^{2+}, organic C, and water content. Detection of heavy metals in the precipitated was performed through X-Ray Fluorescence (XRF), while its purity was assessed through X-Day Diffraction (XRD). Scanning electron microscopy with energy dispersive spectroscopy (SEM-EDS) was used to determine the morphology of the precipitate (size, shape), and its elemental composition. Finally, the precipitate was evaluated for its compliance with the EU legislative requirements for fertilizers (Regulation (EU) 2019/1009).

3. Results and Discussion

The demonstrative pilot of Cyprus was treating anaerobically digested effluent from mixed waste comprising of 50% pig slurry, 25% cheese whey, and 25% chicken manure, with small additions of fruit waste and barley. The treated effluent was first filtered through filter bags and ultra-filtration ceramic membranes and then was directed into the struvite crystallization reactor, where struvite was precipitated. As stated before, prior to the operation of the pilot, bench scale experiments with the same matrix we conducted so that the process is optimized in terms of added molar ratios of Mg^{2+}, $P\text{-}PO_4^{3-}$, and $N\text{-}NH_4^+$, pH, and contact time. It was decided that the 1.2 to 1.5 molar ratio of Mg^{2+} to $P\text{-}PO_4^{3-}$and $N\text{-}NH_4^+$ was the optimum for struvite precipitation. The obtained material was dried at 40°C (to avoid phase change) and was analyzed for its chemical characteristics, purity, and morphological properties.

XRD analysis on the struvite produced in the Cypriot plant had a purity over 90 wt % as indicated in Figure 1. Moreover, SEM imaging (inserted pictures in Figure 1) revealed that the shape of the struvite chrystals formed was irregular and their size ranged between 80 to 200 μm. The internal side of these agglomerates is characterized by rectangular-shaped blocks of around 20 μm x 5 μm. Though the prefered shape of struvite crystals is orthorhombic, this irregular shape did not seem to have an effect on struvite's properties as a fertilizer. Based on the cited literature, our results appear to be compatible with those of other studies where struvite was produced from different matrices (Huang et al., 2011; Zhang et al., 2014; Xiao et al., 2018). However, in our case the struvite purity from our precipitates was higher. This serves as a concrete proof that the chosen treatment conditions (as first optimized in the lab) were indeed the optimum for the pilot reactor as well. Lastly, additional analysis on the struvite obtained from the Cypriot pilot, proved that it did not contain pathogens, heavy metals, and carcinogens, hence making it safe for use in gardening and crops.

4. Conclusions

This study demonstrated the importance of bench-scale experiments for processes optimization prior to pilot operation. The technical protocols produced in the lab were successfully applied at the pilot and we were able to consistently produce high-quality and quantity of struvite. It is important to note that the struvite produced in the Cypriot pilot was safe for use in crops since it did not contain pathogens, heavy metals, and carcinogens. It is our belief that the pre-treatment applied (filtering of the treated effluent through the UF ceramic membranes) prior to struvite crystallization, was to. Based on the above, it is safe to state that nutrient recovery from livestock wastewater through struvite crystallization, can play a key role in sustainable growth and food security maintenance.

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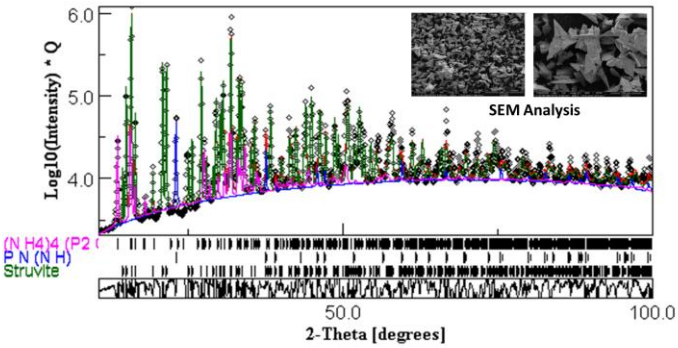

Figure 1. X-ray diffractogram of precipitates (struvite purity 92.5 %). Inserted pictures SEM analysis.

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