Evaluating Rest Period and Sludge Composition in Sludge Treatment Wetland

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Sludge Treatment Wetland (STW) systems have been used in Denmark since 1988 to treat sewage sludge (SS) generated in wastewater treatment plants (WWTPs). Each year, approximately 1.6 to 2 billion tonnes of sludge are produced. Therefore, the proper management of this waste is crucial. STW systems are particularly beneficial in Mediterranean communities with up to 10,000 PE due to their cost-effectiveness and low energy consumption. A STW system consists of multiple individual beds, where the sewage sludge is distributed through feeding cycles via pipes over the top of the bed, ensuring even distribution throughout the system. During these cycles, the sludge undergoes drainage, evapotranspiration, and mineralization, resulting in a significant reduction in sludge volume, up to 98%. Furthermore, after the sludge has been dehydrated, mineralization and stabilization occur due to the movement of the reed stems, which crush the surface layer of the sludge. Also, microbial activity and oxygen transfer through the roots promote the aeration of the inner layers of the sludge, leading to a dehydrated, stable, and mineralized by-product known as biosolids. Biosolids are rich in essential nutrients for plant growth and can be utilized for agricultural purposes (Kolecka & Obarska-Pempkowiak, 2013). However, before biosolids can be applied to the soil, they must meet specific standards established by regulations. Therefore, after completing all the feeding cycles, a rest period of 4 to 24 months is required to complete the treatment and ensure that the biosolids can be safely used as biofertilizers in agriculture. The objective of this study was to determine the necessary rest time for the stabilization of the SS after the last feeding cycle to effectively reuse the biosolids in the Mediterranean region. The study also analyzed the impact of climate on these systems by comparing rest periods beginning in summer versus those beginning in winter. Additionally, the viability of *Phragmites australis* rhizomes was studied to rule out any potential regrowth after the application of biosolids in fields.

The research focuses on two Wastewater Treatment Plants: La Guixa-Sentfores (1000 PE) and Santa Eulàlia de Riuprimer (2000 PE), both located in Osona Region, Barcelona, Spain. Over 9 months, 8 sampling campaigns were conducted during the rest period in June 2022, September 2022, December 2022, March 2023, June 2023, and September 2023, respectively. To obtain a composite sample of the sludge, one representative bed was selected in each facility, divided into 4 sections, and one sample was collected from each section, which was then carefully mixed. The samples were analyzed in triplicate using standard techniques following the Standard Methods (APHA et al., 2017). Various parameters were analyzed, including pH, Total and Volatile solids (TS and VS), stability degree (SD), nutrients, phytotoxicity, heavy metals, fecal bacteria indicators, and rhizome viability.

Table 1 presents the physicochemical characterization, stabilization, and agronomic properties of biosolids. The pH values remained constant between 4.8 and 5.7 in both resting periods started in summer and winter, possibly due to acidifying bacteria and organic matter decomposition (Larsen et al., 2017). The nutrient content was also analysed. Total kjeldhal nitrogen (TKN) varied between 2.4% and 2.8% in summer, while in winter, it ranged from 2.4 to 2.7% in La Guixa and Santa Eulàlia, with similar values. Phosphorus, in the form of P_2O_5, exhibited elevated levels (6.20%-9.35% TS in summer and 7.72%-8.97% TS in winter) compared to other studies, showing a slight decrease due to phosphate immobilization in microbial cells. Regarding potassium, in the form of K_2O, it varied between 0.66%-1.09% TS in summer and 0.57%-0.79% TS in winter. These values provide valuable information about the composition and stabilization of biosolids, offering an alternative biofertilizer to reduce the use of chemical fertilizers.

On the other hand, the mineralization and stabilization of the biosolids can be observed in Table 1. The stability degree (SD) reached approximately 39.4%, indicating favorable conditions for use as biofertilizers. It notes an increase in dry matter content during summer (50%TS), showcasing successful drying (Table 1). The influence of temperature and seasonal conditions on stabilization is observed, with low humidity levels after 3 months of rest in both WWTPs. The high solid content in summer makes biosolids suitable for potential reuse, and there is a significant reduction in organic matter, especially in summer after 3 months of rest period in both beds analyzed (between 38-41%SV/TS).

Figures 2a and 2b show the results of rhizome viability test. Control samples had very low microbial activity throughout the entire 9-month period. In contrast, rhizomes treated with FDA showed a gradual decrease in microbial activity, dropping from 0.99 µm/h·g TS at the beginning to 0.32 µm/h·g TS after 6 months, and maintaining this level thereafter. This decrease is likely due to the lack of nutrients caused by the stoppage of sludge feeding into the beds, which in turn affects plant growth and rhizome viability.

Table 1. Physicochemical and agronomic characterization of biosolids during the summer and winter rest period at the La Guixa-Sentfores (A) and Santa Eulàlia de Riuprimer (B) WWTPs.

			Parameters						
Campaigns	**Resting period (months)**	**WWTP**	**pH**	**%TS**	**%SV /ST**	**%DS**	**NKT (%TS)**	**P_2O_5 (%TS)**	**K_2O (%TS)**
[(a)]Campaign I - summer	0	A	5.6	33	43	-	-	8.95	0.97
		B	6.4	35	41	-	2.5	7.49	0.66
[(b)]Campaign I - winter		A	4.8	34	48	39	2.7	8.97	0.57
[(c)]Campaign II - summer	3	A	5.2	53	39	36	2.4	8.25	0.84
		B	5.7	47	41	18	2.8	6.20	1.09
[(d)]Campaign II - winter		A	4.7	38	45	42	2.54	8.49	0.59
[(e)]Campaign III - summer	6	A	4.8	50	38	-	2.4	8.74	0.81
		B	5.4	49	41	-	2.6	6.91	0.85
[(f)]Campaign III - winter		A	4.9	40	45	40	2.6	7.81	0.75
[(g)]Campaign VI - summer	9	A	4.6	49	35	32	2.4	9.35	0.66
		B	5.4	51	37	-	2.5	7.42	0.86
[(h)]Campaign VI - winter		A	4.2	47	44	41	2.4	7.72	0.79

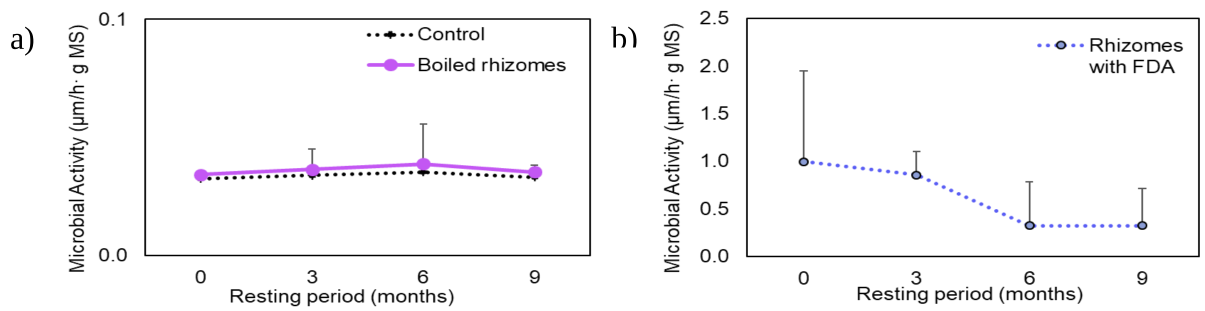

Figure 1. Test of reeds' rhizomes from STW systems. a) FDA-free and FDA-boiled rhizomes (controls). b) rhizomes with FDA.

The rest period for STW systems in the Mediterranean region should begin in the summer (June), when weather conditions are optimal for sludge drying (50%TS) and stabilization and mineralization processes (40%VS/TS). Given the findings and the nutrient composition required for plant growth, biosolids can be considered potential biofertilizers.

Viability test on rhizomes revealed a decrease in microbial activity as the sludge was treated, effectively inhibiting reed growth in agricultural fields.

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