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Design and Validation of a Wastewater Treatment Scheme to Enhance Macronutrients from Biosolids. A Case Study in the Dominican Republic

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Abstract:
Background: *The Rafey Wastewater Treatment Plant (WWTP) produces approximately 80% of the sewage sludge generated in the wastewater treatment plants of the city of Santiago de los Caballeros, Santiago province, Dominican Republic. The disposal of such sludge is not specifically regulated in the country and there is a great opportunity to use the sludge as biosolids for agricultural purposes. The objective of this research is to design and validate a wastewater treatment model that enhances the nutritional characteristics of sewage sludge in order to use it as biosolids for agricultural crops.*

Materials and Methods*: During the experimental period of the scheme, five sludge analyses were carried out on each sample. The first analysis was performed at (day 1) after extraction and the following four analyses were performed as described below: at one month (30 days), at two months (60 days), at three months (90 days) and at four months (120 days), the time elapsed since sample extraction. This experiment was evaluated by analysing three sludge samples, one taken in the first month of the nitrification and denitrification cycle, one in the second month and one in the third month.*

Results*: The results show that the treatment scheme model designed and validated has proven to be valuable in enhancing the macronutrients in the biosolids. The model ensures that the biosolids produced contain the main macronutrients needed by the crops, such as Total Nitrogen, Calcium, Total Phosphorus, Magnesium, Potassium and Sulphur.*

Conclusion*: The model scheme designed and validated has proven to be valuable for enhancing the macronutrients in biosolids. The model ensures that the biosolids produced show the presence, in appropriate amounts, of the main macronutrients necessary for crop development. Future research suggests further analysis of the presence and behavior of micronutrients in biosolids, using the above treatment scheme model.*

Key Words: *Wastewater; micronutrients; biosolids; Treatment.*

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I. Introduction

The information contained in the National Sanitation Strategy Proposal of the Dominican Republic[1] indicates that 90% of the wastewater collected by the networks of 37 sanitary sewerage systems in the country does not receive any type of treatment, a situation that represents a serious environmental problem, constituting a threat to the health of the population. In Santiago de los Caballeros, the second largest city in the Dominican Republic in socio-economic terms, 76% of the wastewater generated is discharged into waterways without any treatment process.

In the province of Santiago, the wastewater treatment systems of domestic origin reach a total of eight treatment plants currently in service, with an installed treatment capacity of 137,116.80 cubic metres per day, operated by the Santiago Aqueduct and Sewerage Corporation (CORAASAN), which has as one of its fundamental objectives to manage the wastewater treatment systems generated in the province, complying with the quality standards in force in the country and thus consolidating the continuous improvement of the processes and the conservation of the environment.

The treatment of approximately 24% of the wastewater generated in the city of Santiago de los Caballeros produces about 7,500 cubic metres of dewatered sludge each year. The management, transport and final disposal of this sludge involves the expenditure of considerable economic resources, which is currently one of the main problems for the managing institutions[1].

The Rafey Wastewater Treatment Plant (WWTP) produces 80% of the sewage sludge generated in the wastewater treatment plants of the city of Santiago de los Caballeros. The way in which sewage sludge is currently disposed of has a negative impact on the environment where it is deposited. It is therefore necessary to propose strategies to optimise its production and use, as well as to establish appropriate application methodologies for its use in agriculture. In this sense, it is to convert sludge into biosolids, with a biosafety level such that they can be safely handled, marketed and used in agriculture.

Scientific research carried out at national and international level proposes the use of biosolids as a soil recovery system and as a friendly fertiliser for mass use[2-5]. In the Dominican Republic, soils are divided into 8 classes[6], but only class I (1.09%), class II (5.91%) and class III (7.47%) have good productivity. Class IV (8.68%) and Class V (15.59%) have limited soils for cultivation. The remaining soils are not suitable for cultivation and are intended for protected areas or natural areas. Therefore, a high percentage of the country's soils do not have high agricultural productivity, facilitating the application of biosolids to encourage their improvement.

The improvement of soils for agricultural purposes is due to the presence of different nutrients. Nitrogen, phosphorus and potassium are the main nutrients analysed in the scientific literature[7]. However, sulphur[8], magnesium[9], calcium[10], copper[11], iron[12] and zinc[11] have also been addressed for their importance for crop growth. All these nutrients have been evidenced in the biosolids generated at the Rafey WWTP[2].

The rationale for this research is based on the significant and potential environmental, socio-economic, agricultural and innovation contributions, as well as others related to health, which are manifested in the development and use of an environmentally friendly product, which can be used to restore and improve the soils of the Dominican Republic, especially those with agricultural vocation. Thus, producing and using quality biosolids provides greater sustainability than traditional fertilisers, as biosolids can be used as fertilisers that do not require components extracted from natural resources and therefore do not degrade the environment.

The objective of this research is to design and validate a wastewater treatment model to enhance the nutritional characteristics of biosolids. The wastewater treatment scheme proposed in this research aims to improve the nutritional characteristics of the sewage sludge and thus produce a quality biosolid as a final product that can be used for various applications, including soil remediation and bio-organic fertilisation for agricultural development and gardening.

II. Material and Methods

Experimental area

The experimental area of this research is the Rafey Wastewater Treatment Plant (WWTP), located in Santiago de los Caballeros. This plant was built in 1976, with a capacity of 890 litres per second (lps). In 2006 it was rehabilitated, with improved equipment and physical infrastructure, increasing its treatment capacity to 1217 lps. Improvements at the plant also included the modification of process types, such as the replacement of the conventional activated sludge system with an activated sludge system with extended aeration.

Currently, the entire treatment system is automated and has a SCADA (Supervisory Control And Data Acquisition) system for the control and management of recorded information. The plant was put into operation with this new system on 12 May 2006, with a pollutant removal efficiency of 90%, meeting the national standards for treated wastewater quality established by the Ministry of Environment and Natural Resources of the Dominican Republic.

Experimental design

The plant was put into operation with this new system on 12 May 2006, with a pollutant removal efficiency of 90%, meeting the national standards for treated wastewater quality established by the Ministry of Environment and Natural Resources of the Dominican Republic. During this cycle, the concentration of oxygen, ammonium, nitrate was allowed to fluctuate and the concentration of suspended solids was limited in the range of 8,500 to 18,000 mg/l (Table no 1). The described scheme was monitored and controlled in a continuous, automated manner through the SCADA system installed in the treatment plant, which facilitated immediate and constant decisions regarding the control of the limits established for the defined parameters. The activated sludge system operated with a minimum sludge age of 15 days, which allowed for the completion of nitrification and adequate effluent quality. The scheme was tested for three months.

Table no 1: Parameters to check.

Parameter	Ranking	Units
Oxygen	0-5.0	Mg/l
Ammonium	0.4-3.0	Mg/l
Nitrate	0.4-3.0	Mg/l
Suspended solids	8,500 – 15,000	Mg/l

Source: own elaboration.

During the experimental period of the scheme, five sludge analyses were carried out on each sample. The first analysis was performed at (day 1) after extraction and the following four analyses were performed as described below: at one month (30 days), at two months (60 days), at three months (90 days) and at four months (120 days), the time elapsed since sample extraction. This experiment was evaluated by analysing three sludge samples, one taken in the first month of the nitrification and denitrification cycle, one in the second month and one in the third month. Table no 2 shows the parameters measured and the analytical method used for each sample. The samples were obtained at the Rafey WWTP by the company Laboratorio Ambiental y Energético (LAMENER), which is certified by the Ministry of Environment and Natural Resources of the Dominican Republic. Subsequently, each sample was stored and analysed in the company's laboratory.

Table no 2: Parameters and analytical methods.

Parameter	Symbol	Unit	Analytical method
Total nitrogen	N	Mg/kg	SM-4500-N-C
Total phosphorus	P	Mg/kg	SM-4500-P-C
Potassium	K	Mg/kg	SM-4500-K
Sulphur	S	Mg/kg	RC-363.08
Magnesium	Mg	Mg/kg	SM-3500-Mg-E

Source: own elaboration.

Data analysis

The data report was prepared by LAMENER. Subsequently, the data were tabulated in Microsoft Excel format and analysed with the IBM SPSS 24 statistical software.

III. Result

To focus on the results of the macronutrients, it was previously verified that the low content of heavy metals obtained at the Rafey WWTP made it possible to have a biosolid of excellent quality, due to the fact that the values obtained do not exceed those established in the standards in force in the countries of the region (the Dominican Republic does not have regulations in this respect). This has also been proven in previous studies[2]. Having verified the above, the study focused on macronutrients, which are essential for the development of any plant, and whose balanced presence determines the conditions in which it will live its life and productive cycle[13].

Table no 3 shows the values for the nutrient Total Nitrogen. It is observed that, for the sample obtained in the first month of the experimentation, the total nitrogen has a maximum value of 399,322.00 mg/kg (90 days) and a minimum value of 48,638.00 mg/kg (day 1); for the sample obtained in the second month, the maximum value also corresponds to 90 days (192,762. 00 mg/kg) and the minimum value at 30 days (47,847.00 mg/kg); finally, the third month sample has its maximum value at 90 days (286,885.00 mg/kg) and the minimum value at day 1 (71,429.00 mg/kg).

Table no 3: Total Nitrogen Concentration in Biosolids.

Total Nitrogen Concentration (N)			
Number of days after extraction:	Sample produced and extracted in the first month of experimentation	Sample produced and extracted in the second month of experimentation	Sample produced and extracted in the third month of experimentation
	Concentration (mg/kg)	Concentration (mg/kg)	Concentration (mg/kg)
1	48,638.00	85,034.00	71,429.00
30	123,396.00	47,847.00	249,500.00
60	84,296.00	192,762.00	209,732.00
90	399,322.00	231,303.00	286,885.00
120	176,211.00	92,250.00	134,420.00

Source: own elaboration.

Table no 4 shows the concentration of Total Phosphorus. It is observed that, for the sample obtained in the first month of the experimentation, the Total Phosphorus has a maximum value of 9,196.00 mg/kg (90 days) and a minimum value of 3,332.00 mg/kg (day 1); for the sample obtained in the second month, the maximum value corresponds to 60 days (6,486. 00 mg/kg) and the minimum value at 120 days (2,329.00 mg/kg); finally, the third month sample has its maximum value at 30 days (6,163.00 mg/kg) and the minimum value at 60 days (1,867.00 mg/kg).

Table no 4: Total Phosphorus Concentration in Biosolids.

Total Phosphorus Concentration (P)			
Number of days after extraction:	Sample produced and extracted in the first month of experimentation	Sample produced and extracted in the second month of experimentation	Sample produced and extracted in the third month of experimentation
	Concentration (mg/kg)	Concentration (mg/kg)	Concentration (mg/kg)
1	3,332.00	3,984.00	3,357.00
30	4,837.00	5,550.00	6,163.00
60	5,154.00	6,486.00	1,867.00
90	9,196.00	3,701.00	3,626.00
120	5,771.00	2,329.00	2,625.00

Source: own

The potassium concentration is shown in Table no 5. It is observed that, for the sample obtained in the first month of the experimentation, the Total Phosphorus has a maximum value of 1,057.00 mg/kg (120 days) and a minimum value of 243.00 mg/kg (day 1); for the sample obtained in the second month, the maximum value corresponds, also, to 120 days (1,614. 00 mg/kg) and the minimum value at 30 days (191.00 mg/kg); finally, the third month sample has its maximum value at 120 days (931.00 mg/kg) and the minimum value at 30 days (299.00 mg/kg).

Table no 5: Potassium concentration in biosolids.

Potassium concentration (K)			
Number of days after extraction:	Sample produced and extracted in the first month of experimentation	Sample produced and extracted in the second month of experimentation	Sample produced and extracted in the third month of experimentation
	Concentration (mg/kg)	Concentration (mg/kg)	Concentration (mg/kg)
1	243.00	729.00	381.00
30	256.00	191.40	299.00
60	482.00	473.00	755.00
90	678.00	616.00	660.00
120	1,057.00	1,614.00	931.00

Source: own

The sulphur concentration is shown in Table no 6. It is observed that, for the sample obtained in the first month of the experimentation, Sulphur has a maximum value of 528.00 mg/kg (120 days) and a minimum value of 211.00 mg/kg (day 1); for the sample obtained in the second month, the maximum value corresponds to 90 days (366. 00 mg/kg) and the minimum value at 30 days (170.00 mg/kg); finally, the third month sample has its maximum value at 90 days (425.00 mg/kg) and the minimum value at 60 days (231.00 mg/kg).

Table no 6: Sulphur concentration in biosolids.

Sulphur concentration (S)			
Number of days after extraction:	Sample produced and extracted in the first month of experimentation	Sample produced and extracted in the second month of experimentation	Sample produced and extracted in the third month of experimentation
	Concentration (mg/kg)	Concentration (mg/kg)	Concentration (mg/kg)
1	211.00	186.00	378.00
30	220.00	170.00	349.00
60	337.00	284.00	231.00
90	460.00	366.00	425.00
120	528.00	251.00	271.00

Source: own

The Magnesium concentration is shown in Table no 7. It is observed that, for the sample obtained in the first month of the experimentation, Magnesium has a maximum value of 7,600.00 mg/kg (90 days) and a minimum value of 2,221.00 mg/kg (day 30); for the sample obtained in the second month, the maximum value corresponds to 30 days (4,928. 00 mg/kg) and the minimum value at day 1 (1,895.00 mg/kg); finally, the third month sample has its maximum value at 60 days (7,235.00 mg/kg) and the minimum value at 120 days (2,065.00 mg/kg).

Table no 7: Magnesium concentration in biosolids.

Magnesium Concentration (Mg)			
Number of days after extraction:	Sample produced and extracted in the first month of experimentation	Sample produced and extracted in the second month of experimentation	Sample produced and extracted in the third month of experimentation
	Concentration (mg/kg)	Concentration (mg/kg)	Concentration (mg/kg)
1	3,964.00	1,895.00	3,762.00
30	2,221.00	4,928.00	5,015.00
60	2,769.00	4,210.00	7,235.00
90	7,600.00	4,067.00	6,270.00
120	7,026.00	4,681.00	2,065.00

Source: own

Table no 8 shows the concentration of calcium. It is observed that, for the sample obtained in the first month of the experimentation, the Calcium has a maximum value of 21,128.00 mg/kg (90 days) and a minimum value of 11,352.00 mg/kg (day 30); for the sample obtained in the second month, the maximum value corresponds to 120 days (17,158. 00 mg/kg) and the minimum value at day 1 (9,475 mg/kg); finally, the third month sample has its maximum value at 30 days (17,390.00 mg/kg) and the minimum value at 120 days (9,630.00 mg/kg).

Table no 8: Calcium concentration in biosolids.

Calcium Concentration (Ca)			
Number of days after extraction:	Sample produced and extracted in the first month of experimentation	Sample produced and extracted in the second month of experimentation	Sample produced and extracted in the third month of experimentation
	Concentration (mg/kg)	Concentration (mg/kg)	Concentration (mg/kg)
1	14,961.00	9,475.00	16,952.00
30	11,352.00	9,497.00	17,390.00
60	13,993.00	15,255.00	12,793.00

90	21,128.00	10,986.00	11,905.00
120	20,705.00	17,158.00	9,630.00

Source: own

IV. Discussion

Environmental restrictions associated with the use of chemical fertilisers remain a global problem and an obstacle to achieving reasonable sustainability in agriculture. In addition, cost increases resulting from over-application of chemical fertilisers reduce profit margins for producers[13]. Therefore, there are other, more sustainable, options for fertilising agricultural crops and soils. Among the different options are biosolids generated in wastewater treatment plants. The present study was carried out at the Rafey WWTP, located in the city of Santiago de los Caballeros, Dominican Republic.

The values obtained in the sample of the first, second and third month of experimentation indicate a sequence of abundance of Total Nitrogen > Calcium > Total Phosphorus > Magnesium > Potassium > Sulphur. In relation to the values and behaviour of the samples for each month, it is not observed that they follow the same pattern, and it is therefore suggested that this behaviour be analysed in depth in a new line of research. In the case of total nitrogen, the highest concentration was obtained in the analysis carried out at 90 days. Total nitrogen is a nutrient that is frequently supplied to the crop soil, as it is involved in plant growth, favouring the development of stems and leaves, and helps to emphasise their greenness, although excessive amounts weaken the plant, making it less resistant to diseases and reducing the quality of production[14-16].

The concentration of Total Phosphorus has not followed a similar behaviour and values for each sampling, although it is observed that this macronutrient continues to be present in the biosolid over time, which is important because Total Phosphorus benefits the development of roots and seedlings and their resistance to low temperatures. It also improves water use efficiency and neutralises excess nitrogen, and supports fruit ripening and fruit set[17]. Their scarcity causes slow and limited growth[18].

In the same way as for Total Nitrogen and Total Phosphorus, the concentration of Potassium has not followed a similar behaviour and values for each sampling, although it is observed that it reaches its maximum values in the samplings carried out at 120 days, and its minimum values during the first 30 days. Ensuring adequate potassium values is of paramount importance for crops, as this macronutrient is one of the key minerals for the formation of plant matter, promoting vegetative growth and keeping the amount of water retained by tissues stable[19]. Deficiency can cause necrotic spots on older leaves, and yellowing edges and dry tips on other leaves[20,21].

The analysis of the biosolids produced shows that sulphur is in the recommended quantities, although it does not follow a homogeneous pattern of behaviour in the analyses carried out for each sampling. Its presence in the biosolid helps to promote plant photosynthesis and activate growth by contributing to the development of the root system, which is responsible for taking up nitrogen from the atmosphere[22,23]. When absent, it causes chlorosis or dark spots on certain vegetables[24].

The values and behaviour of the magnesium samples analysed each month do not follow the same pattern, although the samples taken between 30-90 days have shown better values. The presence of magnesium in biosolids is essential for crops, because this macronutrient is essential for chlorophyll, and influences water regulation within the plant organism[25,26]. Their lack of presence in the soil leads to lower tissue resistance, causing, for example, branches to become brittle or fruit to fall off more quickly[27].

The calcium values obtained do not show a general pattern either, although they follow a similar behaviour to magnesium. Through calcium, the crops strengthen the cell wall and protect the membranes against damage and delay leaf ageing[28]. The lack of this nutrient increases the acidity of the soil, which causes the plants to grow with very thick stems but very weak roots[29].

V. Conclusion

The commercialisation and use of biosolids significantly reduces the negative impacts on the environment by reducing the use of chemical fertilisers, as well as reducing operating costs for CORAASAN and producing a lower impact on health as a result of inadequate handling and disposal of biosolids. Thus, an advantage of using biosolids is that they are integrated into the cycle of returning nutrients to soils to maintain continuity of use. To this end, it is necessary to further develop treatment schemes that enhance the nutritional characteristics of biosolids. In this sense, the aim of this research has been to design and validate a wastewater treatment model to enhance the nutritional characteristics of biosolids.

The model scheme designed and validated has proven to be valuable for enhancing the macronutrients in biosolids. The model ensures that the biosolids produced show the presence, in appropriate amounts, of the main macronutrients necessary for crop development (total nitrogen, calcium, total phosphorus, magnesium, potassium, and sulphur). Therefore, the results of this study show that it is advisable to implement, at the Rafey WWTP, the treatment scheme developed in this research and to promote the use of the biosolids produced as fertiliser. This research has also found that macronutrient values are different over time, showing variations in macronutrient values. The latter situation should be analysed in depth in future research, in order to find out when each macronutrient reaches its optimum value for use as a fertiliser in crops. Therefore, it is recommended that whenever biosolids are to be used as fertiliser, a macronutrient analysis should be carried out as close as possible to the day of application to the crop, in order to determine whether the macronutrient values are optimal or whether it is necessary to wait longer to apply them to the crop.

It should be noted that the Dominican Republic does not have regulations or standards for the treatment, management, use and final disposal of sewage sludge generated by wastewater treatment. Thus, there are significant gaps in legislation and regulatory instruments to prevent or reduce negative environmental impacts and, most importantly, there are weaknesses in the monitoring of implementation. It is necessary to consider the absence of regulatory instruments for the reuse of treated wastewater and for the disposal of sludge; the few guidelines in place for waste treatment and disposal, and the sludge resulting from the operation of WWTP plants[1].

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