Respuestas, 23 (1) January - June 2018, pp. 60-67, ISSN 0122-820X

Respuestas
Journal of Engineering Sciences

Original Article https://doi.org/10.22463/0122820X.1336

Evaluation of sludge hydrogels resulting from the washing of sand and gravel as an alternative for the treatment of arid soils

Evaluación de hidrogeles de lodos resultantes del lavado de arena y piedra como alternativa para el tratamiento de suelos áridos

Michel Juliett Arango-Toloza[a*], Pedronel Araque-Marín[b], Carlos Alberto Peláez-Jaramillo[c].

[a]*Ingeniera Biotecnológica, Universidad Francisco de Paula Santander, Cúcuta, Colombia. orcid.org/0000-0003-2736-4202*

[b]*Magister en Ciencias Químicas, Universidad EIA, Envigado, Colombia. orcid.org/0000-0002-8225-472X*

[c]*Doctor en Ciencias Químicas, Universidad de Antioquia, Medellín, Colombia. orcid.org/0000-0003-1040-6031*

How to cite: M.J. Arango-Toloza, P. Araque-Marín and C.A. Peláez-Jaramillo, "Evaluation of sludge hydrogels resulting from the washing of sand and gravel as an alternative for the treatment of arid soils", *Respuestas,* vol. 23, no. 1, pp. 60-67, 2018.

Received on July 23, 2017; Approved on November 29, 2017

Keywords:

Arid soils
Hydrogels
Phytotoxicity
Sludge

ABSTRACT

In building materials manufacturing a large amount of wastes which cannot be used in the other production processes are generated. Among the residues there is the sludge, it is generated during the process of washing the materials aggregates originating from rocks, sand and gravel; depending on the finished product. Besides it is necessary to create alternatives for the management and disposal of these wastes. For this reason, this work aims to evaluate the effect of hydrogels formulated from sludge as an alternative for the treatment of arid soils. The sludge was studied by physicochemical, microbiological and microscopical characterization and the phytotoxicity was evaluated in the biological models *Raphanus sativus* and *Brachiaria dictyoneura*. The hydrogel type sludge was formulated to evaluate the capacity of retention and recovery of water. Besides, kinetics of evaporation and phytotoxicity was evaluated. The analyzes carried out determined that the sand sludge is a suitable candidate for the treatment of arid soils since it is optimal for the germination, the growth and the development of some plants like *R. sativus* and *B. dictyoneura*.

Palabras Clave:

Fitotoxicidad
Hidrogeles
Lodos
Suelos áridos

RESUMEN

En la fase de elaboración de materiales para la construcción, se genera una gran cantidad de residuos como el lodo generado en los procesos de lavado de los materiales agregados, originados de rocas, arena y gravas que no pueden ser reutilizados o aprovechados en los demás procesos de producción. En tal sentido, se busca crear alternativas de manejo y disposición de estos residuos. Para ello se requiere evaluar la fitotoxicidad de hidrogeles formulados a partir de lodos procedentes de las aguas resultantes del lavado de arena y piedra como alternativa para el tratamiento de suelos áridos y se evaluó la fitotoxicidad en los modelos biológicos *Raphanus sativus y Brachiaria dictyoneura.* De tal manera, para el estudio, se caracterizaron fisicoquímica, microbiológica y microscópicamente los lodos de lavado de arena y piedra. Los lodos fueron formulados tipo hidrogel para valorar la capacidad de retención y recuperación de agua, cinética de evaporación y fitotoxicidad. Los análisis realizados determinaron que el lodo de arena es un buen candidato para el tratamiento de suelos áridos, ya que este es óptimo para la germinación, promueve el crecimiento y desarrollo de las plantas como *R. sativus y B. dictyoneura.*

Introduction

Desertification is defined as the "reduction or destruction of land biological potential which may create analogue conditions from a common desert," as well as a change in flora and fauna composition followed by low biological productivity levels, a worsening of the waters regime [1] and the enhancement of eolian erosion destructive processes. The latest processes can remove the most fertile section of soils, pollute the air, plug curbs, lower survival, increase seedling, lessen the commercialization of horticultural crops, and in extreme cases, create new desert shapes and landscapes by means of some processes commonly known as desertification [2].

Aeolian erosion and desertification have been increasing as arid and half-arid soils become vulnerable to erosion due to climate change, population growth, housing development, subsistence agriculture and overgrazing [3].

For this reason, aridity is caused by a lack of water availability for all types of living beings and is related to meteorological or climate factors. Likewise, it can characterize a specific area and has a relatively permanent behavior. Additionally, arid areas may be identified according to precipitation values. Those areas whose precipitation rate is under 250 mm/year are regarded as arid, and those whose rate swings from 250 to 500 mm/year are regarded as half-arid [1].

Aggregate is obtained by extracting sand and gravel which are ground, washed and classified [4]. The washing and the classification of natural aggregate produce residual sludge grout. The stagnant water resulting from this process is dissolved by using a flocculant substance that causes sludge to be settled down on the bottom.

This lifeless waste is usually purified in settling ponds. Because of the enormous amounts of waste manufactured along with its

*Corresponding author.
E-mail address: pedronel.araque@eia.edu.co (Pedronel Araque-Marín),

transportation and the drop of settling ponds, the elimination of residual sludge has come to be a concern for society [5]. The environmental pollution caused by the production of such residues has urged the quest for solutions to the above mentioned current difficulties and has contributed to create new sustainable methods. One of those is to recover arid soils by applying sludge waste as soil conditioners, allowing the settlement of a productive rhizosphere and a healthy and vast vegetal layer [6]. In connection with this remedial action, hydrogels may absorb and keep massive amounts of water during certain periods [7].

A major interest in the usage of hydrogels for agricultural purposes has recently come to life due to the significant advantages they represent, such as: affordability, biodegradability, acceptable specific resistance, low density, good thermic properties, recyclability, no health risk, optimized generosity and energy [8]. During the last 70 years, several studies on the usage of hydrogels have been conducted, which prove the capacity of this substance to boost water absorption in soils (especially rain water), lessen nutrients lixiviation and improve soil aeration and drainage. In addition, hydrogels may favour vegetal growth systems along with the improvement of their biological activity and production [9]-[12].

Their most important effects are identified in high drainage level soils [13], sandy-textured soils [10], as well as in arid climates [11], [14], [15]. Sodium polyacrylate, a polymer compound of monomers (−CH2−CH(CO2Na), as it appears in (figure 1a and 1b), is known as a super absorbent polymer because of its ability to retain massive amounts of water. In a solid state, it takes the form of white powder and its polymer chains are added to an unspecified structure (figure 1c). However, when it encounters water, those polymer chains are aligned to interact with water molecules by generating a reticular structure called hydrogel (figure 1c).

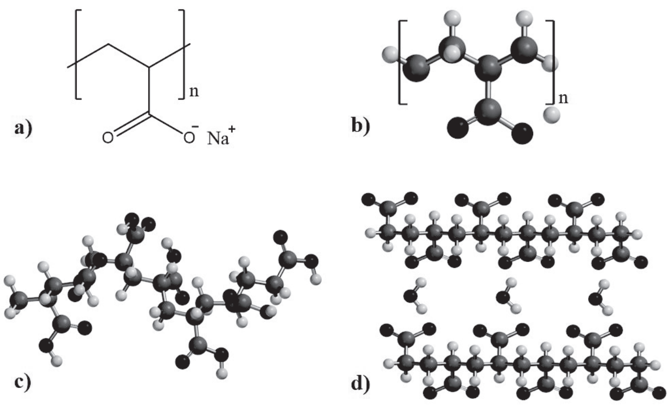

Figure 1. Structural formula of the sodium polyacrylate polymer: a) two-dimensional structure of the monomer; b) three-dimensional structure of the monomer; c) three-dimensional structure of the polyacrylate in a solid state; d) three-dimensional structure of the polyacrylate gel

Hydrogel formulas report an improvement in physical, chemical and biological properties of soils [16], enlarge the content of organic matter, add essential nutrients capable of stimulating plants rooting and growth; lessening metals bioavailability [17], [18]; optimizing moisture retention [19] and fertilizing soils [20]. Therefore, those hydrogels boost water retention capacity and balance the right temperatures to grow plants such as *Beta vulgaris* (Swiss chard) [21], *Glycine max* (soya) [22], *Zea mays* (corn) [23], *Apium graveolens* (celery) [24], *Licopersi- cum esculentum* (tomato) [25] and forest plants [26].

Materials and methods

The evaluation methodology applied to hydrogels resulting from sludge, sand and gravel washing is depicted in figure 2.

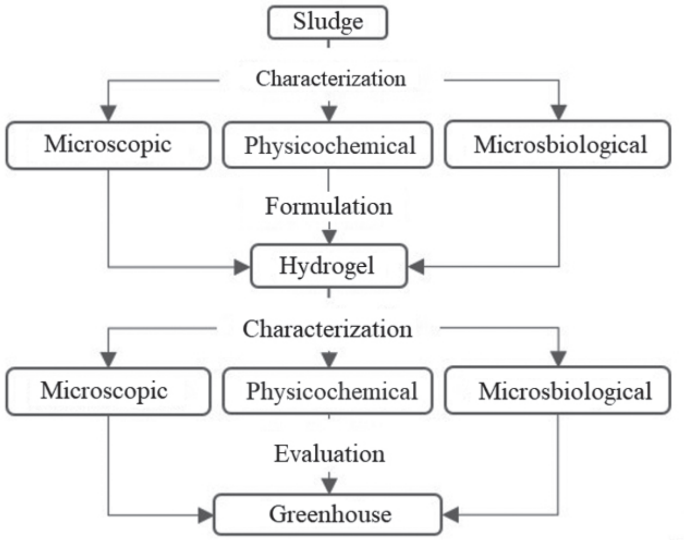

Figure 2. Schematic representation of the applied methodology

Reagents Silver nitrate AgNO3(s) (≥ 99%) and sodium hydroxide, NaOH(s) (≥ 99%) came from Aldrich Chemical Co. Ltd., Proanalysis. Sodium polyacrylate MW ~5,100 (92%), Potato dextrose agar (PDA, Oxoid), Nutrient agar (Agar Scharlau Microbiology 01-140-500), Bismuth bisulphite agar and Violet Red Bile Glucose Agar (VRBG) were provided by Sigma Chemical Co. (St. Louis, MO).

Sowing material The sludge coming from the water, resulting from sand and gravel washing, were supplied by the CECOLTEC S.A.S company and Grupo Interdisciplinario de Estudios Moleculares-GIEM of Universidad de Antioquia. As well, the Andisol soil (Fulyuland) was supplied by Grupo de Investigación e Innovación en Formulaciones Químicas of Universidad EIA.

Raphanus sativus and *Brachiara dictyoneura* were acquired at the AGROSEMILLAS S.A. trading house, to 96% of purity and 85% of germination. These seeds were stocked in the dark, to 30% of moisture and at 4 °C on the purpose of inhibiting germination and maintaining their viability.

Control sludge preparation 100g of soil Andisol was suspended in a liter of distilled water with continuous agitation for 10 minutes, then left in percolation for 6 hours and finally separated by decanting, the purified liquid was used as control sludge.

Hydrogels preparation Hydrogels preparation was made based on their swelling power (understood as sludge retention capacity) along with other types of sludge. One gram of polyacrylate of sodium required 97 ml of control sludge, 48 ml of sand sludge and 33 ml of gravel sludge.

Growth media preparation Growth media were independently prepared with the following quantities of agar: PDA (36g/l), Nutrient agar (28g/l), Bismuth bisulphite agar (52g/l) and Violet Red Bile Glucose Agar (VRBG) (41,5 g/l). The various kinds of Agar were suspended in one litter of distilled water. Then, the latest were heated by means of a constant stirring for one minute up till they were totally dissolved. Growth media were sterilized by using an autoclave at 121 ° C and with 15 pounds of pressure for 20 minutes.

Microbiological analysis of sludge The sludge was qualitatively and quantitatively analysed to identify the presence of mesophile microorganisms, thermophiles, anaerobes, salmonella, mildew, yeast and Enterobacteria. Several dissolutions were made based on a pattern solution, that was prepared by mixing 10 ml of sludge with 90 ml of distilled water, from which 1 ml was taken with 9 ml of peptone sterile water up to 10 7. 100 µl of the concentrations 1x10 1, 1x10 3, 1x10 5 and 1x10 7 were planted in the growth media concerned. The dishes meant for anaerobes, salmonella, mildew, yeast and Enterobacteria were incubated at 37 ° C for 24 hours. Nonetheless, thermophile bacteria were incubated at 57 ° C for 24 hours. Nutrient agar was used for mesophile organisms, thermophiles and anaerobes; Bismuth bisulphite agar for salmonella; PDA agar for mildew and yeast and finally Violet Red Bile Glucose Agar (VRBG) for Enterobacteria.

Physicochemical analysis The physicochemical analyses were carried out within the rules of Norma Técnica Colombiana ((NTC 370; NTC 234; NTC 5167), Soil Survey Laboratory Methods Manual Report Nº42, Version 2.0, 1992 (SSLMM-42-2-92, Standard Methods (SM3111B; SM3112A; SM3114C), American Public Health Association (APHA), American Water Works Association (AWWA), International Standard ISO 13320 and Water Pollution Control Federation (WPCF) as it is illustra- ted in table I.

Table I. Physicochemical analysis parameters

Parameters	Indicated as	Technique	Regulation
Nitrogen	Total Nitrogen	Kjeldahl	NTC 370
Carbon	Total Organic Carbon	Titration	NTC 5167
Carbon/Nitrogen ratio	Does not apply	Does not apply	Does not apply
Phosphorus	P2O5	Spectrophotometry	NTC 234
Potassium	K2O	Atomic absorption	SM 3111B
Sodium	N_a	Atomic absorption	SM 3111B
Calcium	C_aO	Atomic absorption	SM 3111B
Magnesium	M_gO	Atomic absorption	SM 3111B
Zinc	Z_n	Atomic *absorption*	SM 3111B
Chromium	C_r	Atomic absorption	SM 3111B
Cadmium	C_d	Atomic absorption	SM 3111B
Lead	P_b	Atomic absorption	SM 3111B
Nickel	N_i	Atomic absorption	SM 3111B
Arsenic	A_s	A:A: Hydride generator	SM 3114C
Mercury	H_g	A: A: Cooling system	SM *3112*[a]
Density (20°C)	Does not apply	Gravimetry	NTC 5167
pH	Does not apply	Potentiometry	SSLMM*42-2-92*
Electrical conductivity	Does not apply	Potentiometry	NTC 5167
Suspended particulate matter	Does not apply	Gravimetry	APHA-AWWA WPCF 2540D
Particle *size*	Does not apply	Laser light diffraction	ISO 13320

Microscopical analysis The microscopical characterization was conducted by using a Phenom SEM. electronic microscope. The optical magnification equal to 20-135X. SEM, the magnification equal to 80-130000X and the particle size were stated through laser light dispersion technique, by using a Mastersizer Maylern 3000.

Sludge phototoxic analysis The seeds were placed on 595 Rundfilter 110 mm paper filters, permeated by 5 ml of sludge in (90x15mm) sterile petri dishes, to which 20 *R. Savitus* and *B. dictyoneura* seeds were added. Regarding *R. sativus*, germination was measured within 24 hours; radicular lengthening within 48 hours and hypocotyl lengthening within 72 hours, while concerning *B. dictyoneura*, germination was measured within 48 hours, root lengthening and main leaf within 72 hours. All the tests were made in triplicate.

Hydrogels phototoxic analysis The seeds were placed on 60 grams of each hydrogel in (90x15mm) sterile Petri dishes, to which 20 *R. sativus* and *B. dictyoneura* seeds were added. The respective test was made in triplicate.

Test assembly in greenhouses As soon as the Andisol soil was already ranging from 50% and 60% of the highest capacity of moisture retention, 2,3168 g of *B. dictyoneura* seeds were planted; (182 seeds /200g of treatment) in 11,9 cm x 11,9 cm x 12 cm pots. The seeds were planted under natural light at Universidad de Antioquia, in the Medellín City (Department of Antioquia, 6°15´06" N; 75°33´48" O, 1500 m of latitude). It is precise to clarify that no water was added to the treatments for 15 days. The seeds were randomly distributed when the sowing time came, as well as the experimental design implementation. Every treatment was repeated three times.

Statistical analysis The results were statistically compared by implementing analysis of variance (ANOVA), after the multiple comparison test applied to the differences among all the measures by means of STATGRAPHICS Centurion XVI. II.

Results and discussions

Physicochemical characterization Based on the Norma Técnica Colombiana NTC 5167, which states that compost or organic-mineral fertilizers and liquids must abide by the requirements brought to light in (table II), although sand and gravel sludge does not meet some of the parameters approving the usage of fertilizers underneath the state-mandated limit, it is essential to highlight that sludge pH finds itself within an optimal range for biological structures growth 5,5-7,0 [27] and satisfies the requirements reported for heavy metals, which play a significant role in germination processes; especially in *Brachiara dictyoneura* [28]. The latest was used as a nutritional base on eastern savannahs and in the continuous bovine overgrazing processes in the Colombian plains. Furthermore, it is a widely studied plant in agriculture as pasture [14].

Table II. Physicchemical characterization of sand and gravel sludge

Parameters	Indicated as	Control sludge	Sand sludge	Gravel sludge	Units	NTC 5167
Nitrogen	Total Nitrogen	0,20 ± 0,01	0,031 ± 0,002	1,60 ± 0,01	g/L	≥ 15 g/L
Carbon	Total Organic Carbon	0,60 ± 0,01	0,082 ± 0,003	0,046 ± 0,002	g/L	> 50 g/L
Carbon/Nitrogen ratio	Does not apply	3,00	2,6	0,29	Does not apply	Does not apply
Phosphorus	P2O5	0,12 ± 0,02	Undetected	Undetected	g/L	≥ 15 g/L
Potassium	K2O	2.16 ± 0,03	0,109 ± 0,004	0,062 ± 0,004	g/L	≥ 15 g/L
Sodium	Na	0,10 ± 0,03	0,341 ± 0,001	0,706 ± 0,001	g/L	≤ 10g/L
Calcium	CaO	1,59 ± 0,8	1,068 ± 0,004	261,8 ± 0,004	g/L	≤ 10g/L
Magnesium	MgO	0,98 ± 0,2	1,930 ± 0,008	1,1814 ± 0,001	g/L	≤ 10g/L
Zinc	Zn	0,0010 ± 0,0001	0,0066 ± 0,0003	0,0076 ± 0,0003	g/L	To be reported
Chromium	Cr	Undetected	18,70 ± 0,03	35,50 ± 0,04	ppm	≤ 1200 ppm
Cadmium	Cd	Undetected	Undetected	1,93 ± *0,02*	ppm	≤ 39 ppm
Lead	Pb	Undetected	Undetected	16,78 ± 0,09	ppm	≤ 300 ppm
Nickel	Ni	Undetected	7,53 ± 0,06	6,50 ± 0,01	ppm	≤ 420 ppm
Arsenic	As	Undetected	Undetected	Undetected	ppm	≤ 41 ppm
Mercury	Hg	Undetected	Undetected	Undetected	ppm	≤ 17 ppm
Density (20°C)	Does not apply	6,85 ± 0,02	7,36 ± 0,01	7,32 ± 0,01	Does not apply	≤ 8,5 ppm
pH	Does not apply	1,01 ± 0,01	1,05 ± 0,05	0,97 ± 0,04	g/ml	To be reported
Electrical conductivity	Does not apply	6,31 ± 0,2	0,21± 0,01	0,14± 0,01	ds/m	To be *reported*
Suspended particulate matter	Does not apply	0,8	123,7	168,8	g/l	≤ 40 g/L
Particle size	Does not apply	*0,4-150*	*1,5*-200	0,3–100	µm	To be reported

In (figure 3) the particle size distribution results for sand and gravel sludge are shown. Sand sludge presented a polydisperse particle size distribution that ranges from 1,5µm to 200µm, possibly due to aggregates among particles at this level.

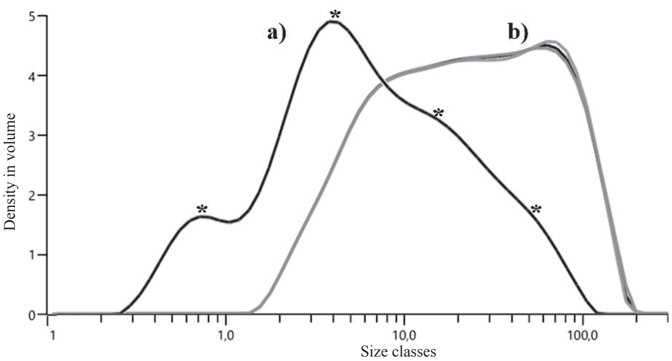

Figure 3. Particle size distribution: a) Gravel sludge; b) Sand sludge

While gravel sludge experienced a bimodal polydisperse behavior with an average diameter per particle equal to d32 (1)

= 0,6 µm; d32(2) = 4 µm; d32(3) = 20 µm y d32(4) = 50 µm, reaching a better resolution for d32(1) and d32(2) in the range between 0,3 µm and 100 µm. This indicates a major stability for sedimentation processes. Through Scanning electronic microscopy (SEM), sludge aggregates polydispersity and morphological differences are validated, as it is illustrated in figure 4.

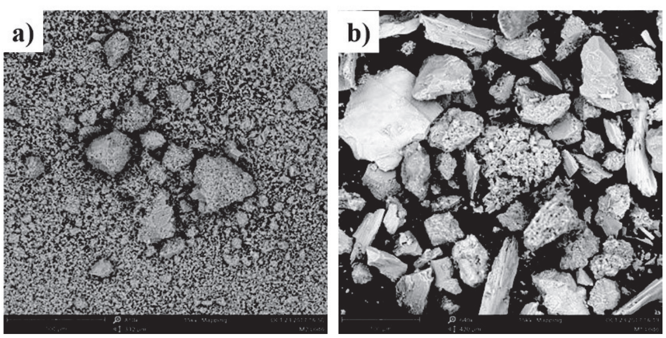

Figure 4. Sludge scanning electronic microscopy (SEM): a) Solid particles in gravel sludge at 810x; b) solid particles in sand sludge at 640x

Microbiological characterization In (table III) sludge microbiological characterization is presented. The presence of these microorganisms mainly stems from the unsterile process carried out into the open. However, it is relevant to highlight the presence of aerobe and mesophile organisms, which enhance organic matter decomposition; nitrogen fixation; mineralization and cation-exchange capacity [15]

Table III. Sludge microbiological characterization

Microorganisms	Control sludge	Sand sludge	Gravel sludge	NTC 5167 Regulation
Mesophile aerobes	2x102 UFC	5,4x107 UFC	8,5x107 *UFC*	To be reported
Thermophiles	0	2x106 UFC	3x106 UFC	To be reported
Enterobacteria	0	<102 UFC	2x102 UFC	To be reported
Anaerobes	0	1x106 UFC	1,2x108 UFC	To be reported
Mildew and yeast	0	1x105 Mildew	6x103 yeast	To be reported
Salmonella spp	Absent	Absent	Absent	Absent in 25 g
Total coliform bacteria	Absent	Absent	Absent	< 1000 UFC/g
Helminths eggs	Absent	Absent	Absent	< 1 in 4g
Pathogenic plants	Absent	Absent	Absent	Absent

Fungi and yeast presence has a stimulant effect that becomes active on vegetal growth and development, which results in: productivity improvement, phosphate solubility, siderophore production and a stimulation of mycorrhiza root colonization. Furthermore, there are several reports on yeast effect upon pathogenic fungus reduction [16], [17].

The absence of Salmonella, total Coliform bacteria, Helminth eggs and pathogenic plants for sludge indicates the respect of Norma Técnica Colombiana 5167/04 [18] for soil conditioners.

Sludge phytotoxic activity evaluation In (table IV) sludge phytotoxic effect on biological structures is observed. Sand sludge did not experience a phytotoxic effect on *R. sativus* and *B. dictyoneura* given the fact that germination percentage was higher than 85%. Radicle and main root lengthening did not show a significant difference (P-value < 0,005), compared to the control, and the hypocotyl stimulated its growth.

Table IV. Sludge phytotoxic activity on R. sativus on B. dictyoneura

	Raphanus sativus			Brachiaria dictyoneura		
	Germination (%)	Radicle (cm)	Hypocotyl (cm)	Germination (%)	Root (cm)	Leaf (cm)
Control sludge	97 ± 3	4,2 ± 0,3	2,0 ± 0,3	98 ± 3	1,5 ± 0,1	1,8 ± 0,3
Sand sludge	85 ± 5	3,7 ± 0,2	2,7 ± 0,2	87 ± 2	1,9 ± 0,2	2,8 ± 0,1
Gravel sludge	77 ± 3	3,2 ± 0,1	2,2 ± 0,1	10 ± 1	0	0

Gravel sludge developed phytotoxicity in both biological structures. On *R. sativus* and *B. dictyoneura*, germination percentages were lower than 80% and 10% respectively. Thus, this lessening is attributed to insoluble solids percentage (168,8 g/l), to the particle size (d32(1) = 0,6 μm) and to the coating yielded by these particles to the seeds.

Evaluation of the phytotoxic activity of hydrogels Table V shows the phytotoxic effect of sludge hydrogels, on biological models. The sand sludge showed no phytotoxic effect on R. sativus and B. dictyoneura, given that the percentage of germination was higher than 85%. The hypocotyl and the main leaf did not show significant difference (p-value <0.005) compared to the control and in the main root of B. dictyoneura growth stimulus was observed. The stone muds generated phytotoxicity in the two biological models. On R. sativus and B. dictyoneura germination percentages were lower than 60% and 0% respectively, this decrease is attributed to the stone mud.

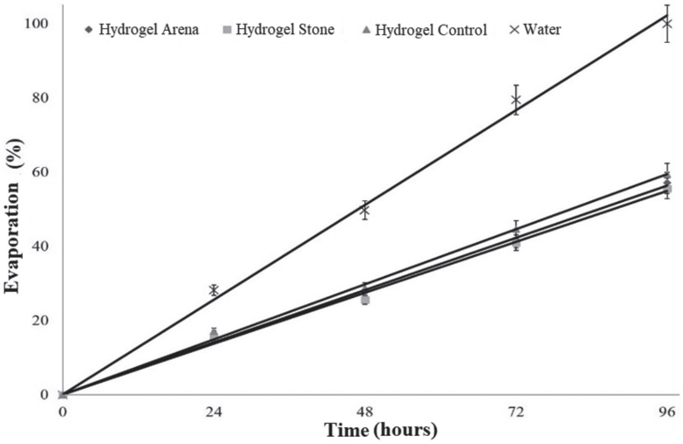

Figura 6. Hydrogels evaporation percentage evaluation over the course of time

Hydrogels kinetics order marked 0, and the lineal equations are exposed in table VI.

Table V. Phytotoxic activity of hydrogels on R. sativus and B. dictyoneura

	Raphanus sativus			*Brachiaria dictyoneura*		
	Germination (%)	Radicular (cm)	Hypocotyl (cm)	Germination (%)	Root (cm)	Leaf (cm)
Hydrogel Control	97 ± 3	0,4 ± 0,1	1,2 ± 0,3	98 ± 3	1,2 ± 0,5	2,9 ± 0,2
Hydrogel Arena	90 ± 2	0,5 ± 0,1	1,1 ± 0,5	99 ± 2	2 ± 0,4	2,4 ± 0,1
Hydrogel Stone	55 ± 5	0,9 ± 0,2	1,1 ± 0,4	0	0	0

Hydrogels evaporation kinetics In (figure 5), hydrogels evaporation percentage is observed over the course of time. Within 4 days (96 hours) of exposition, water had evaporated to 100 % while hydrogels only to 55%. Hydrogels evaporation was completed within 8 days (192 hours).

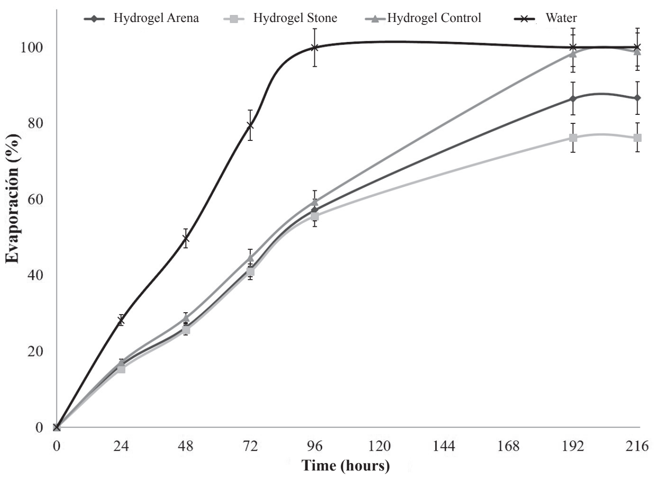

Figure 5. Hydrogels evaporation percentage evaluation over the course of time

Taking into account that the largest linear region was observed until 4 days (96 hours), we proceeded to determine the evaporation kinetics of the hydrogels as shown in Figure 6.

Table VI. Hydrogels evaporation kinetics assessment

System	Equation	r^2
Water	% Evaporation = (1,06 ± 0,05)*t	0,9965
Hydrogel Control	% Evaporation = (0,62 ± 0,03)*t	0,9972
Hydrogel Arena	% Evaporation = (0,59 ± 0,03)*t	0,9950
Hydrogel Stone	% Evaporation = (0,57 ± 0,03)*t	0,9965

The statistic results of the evaporation percentage analysis, within 4 days of hydrogels exposition, are shown in (table 3). The hydrogels evaporation percentage did not present a significant difference and they were 60% slower than water control.

The values obtained experienced a statistical significative correlation (p-value < 0,05), with a level of trust to 95%. As well, the correlations for control hydrogel, sand hydrogel and gravel hydrogel were 0,9972; 0,9950 and 0,9965 respectively; which indicates an adequate proportionality between the evaporation and time percentage.

Hydrogels recovery capacity After 10 dehydration days, hydrogels were submerged into each one of the treatments (sludge control, sand sludge and gravel sludge). Control sludge and sand sludge preserved their sludge retention capacity: (97 ml and 48 ml) per gram of dehydrated hydrogel, while gravel sludge showed a hardening process, with a rigid structure and no dehydration. This phenomenon might be associated with the interaction established between the carboxylate groups of polyacrylate polymer chains and calcium divalent ions present in gravel sludge, as it is shown in figure 7, resulting in an insoluble complex.

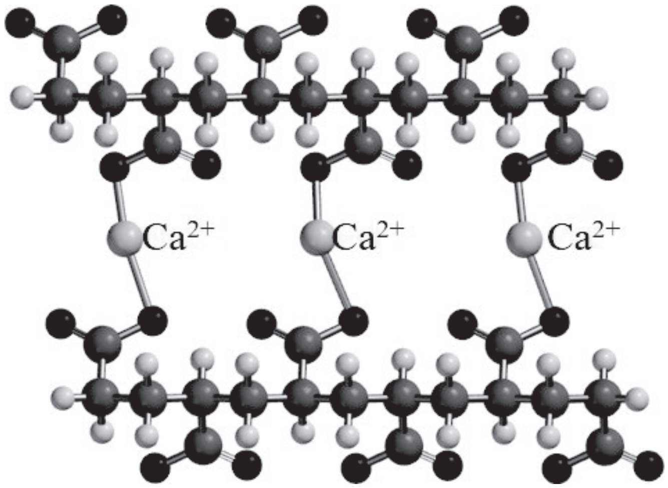

Figure 7. Molecular structure of the complex formed by carboxylate groups of polyacrylate polymer chains and calcium divalent ions present in gravel sludge

Hydrogels microscopic characterization After dehydration, hydrogels were characterized through Scanning electronic microscopy as it is shown in figure 8. Control and sand hydrogels show a heterogenic and granular surface, while sludge and gravel hydrogel evince a far more homogenic surface, which indicates a higher solid particles incorporation inside of the hydrogel and this is due to its reduced particle size and, possibly to induration processes during water loss.

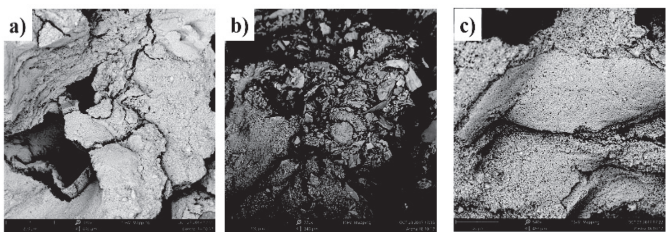

Figure 8. Hydrogels scanning electronic microscopy (SEM): a) Control sludge at 470x; b) Sand sludge at 540x

Greenhouse type evaluation Temperature and moisture measures were developed by means of greenhouse type evaluation, noting that during the test no treatment was added. On day 1 germination percentage was evaluated and on day 15 developed plants percentage was evaluated as well. In (Table VII) it is observed that 85% of seeds sown got to develop in hydrogels, while plants development failed to be materialized, claiming every plant was directly influenced by water content and a restricted metabolism when water supplies were limited [18].

Table VII. Hydrogels greenhouse-like assessment

	Day 1		Day 15	
	Andisol Soil	Sand Sludge hydrogel	Andisol Soil	Sand Sludge hydrogel
Moisture (%)	60	85,84	6	56,62
Temperature (°C)	22,6	22,5	23,2	22,5
Germination (%)	97	95	---	---
Vegetal development (%)	---	---	0	85

The usage of hydrogels based on sludge on farmland, especially in arid and desert regions, might be able to improve physical, chemical and biological properties of the soil, increase productivity in the farming sector and thereby lessen vegetal mortality rate, as well as, to optimize soil fertility [17], [33].

From the results obtained, it was shown that the main hydrogels advantage is to control stocked water elimination as soil dries off, maintaining soil moisture in optimal sowing conditions (50-80%) during a 15 days period. Besides, hydrogel presence does not only raise soil porosity levels that provide a better root oxygenation [34], but also provides the proper conditions for a vegetal development to 85%.

Conclusions

Sludge, coming from water, resulting from sand and gravel washing as industrial waste, might represent an alternative for compost or liquid organic-mineral fertilizer formulation, by meeting the requirements of Norma Técnica Colombiana NTC 5167.

Also, hydrogel type formulations might be used to foster vegetal growth and development, such as B. dictyoneura, which is included as an animal nutritional base and has been found on eastern savannahs and in continuous bovine overgrazing processes in the Colombian plains.

In addition, it is a widely studied plant on agriculture as pasture. Regarding gravel sludge, although it is not an alternative to elaborate hydrogel types systems to recover arid soils, it is possible to explore its usage as building material and as an additive to reinforce cement hardening processes.

Acknowledgements

The authors express great gratitude to the CECOLTEC S.A.S company and to the Program of Professional Practicum on Biotechnical Engineering of Universidad Francisco de Paula Santander Ocaña, for their contributions during the conduction of this project.

References

[1] G. Vargas y C. Gómez, “La desertificación en Colombia y los cambios climáticos”, *Cuadernos de Geografía: Revista Colombiana de Geografía*, no. 12, pp. 121 - 134, 2003.

[2] Z. Masri, S. Van Donk, A. Bruggeman and F. Turkelboom, “Post-harvest summer tillage to control wind erosion in the Khanasser”, *Aeolian Research*, vol. 17, pp. 219–229, 2015.

[3] G. Guoli, L. Jiyuan, S. Quanqin and Z. Jun, "Sand-Fixing Function under the Change of Vegetation Coverage in a Wind Erosion Area in Northern China Sand- fi xing Function under the Change of Vegetation Coverage in a Wind Erosion Area in Northern China", *Journal of Resources and Ecology*, vol. 5, no. 2, pp. 105–114, 2014.

[4] P. Taylor, S. Hu, S. Hu and Y. Fu, "Co-melting technology in resource recycling of sludge derived from stone processing", *Journal of the Air & Waste Management Association,* vol. 62, no. 12, pp. 1449-1458, 2012.

[5] F. Chang, M. Lee, S. Lo and J. Lin, "Artificial aggregate made from waste stone sludge and waste silt", *Journal of Environmental Management*, vol. 91, no. 11, pp. 2289–2294, 2010.

[6] A. A. Juwarkar and H. P. Jambhulkar, "Phytoremediation of coal mine spoil dump through integrated biotechnological approach", *Bioresource Technology*, vol. 99, pp. 4732–4741, 2008.

[7] Z. Liu, Y. Miao, Z. Wang and G. Yin, "Synthesis and characterization of a novel super-absorbent based on chemically modified pulverized wheat straw and acrylic acid", *Carbohydrate Polymer*, vol. 77, no. 1, pp. 131–135, 2009.

[8] V. Kumar, M. Kumari and R. Kumar, "Graft copolymers from cellulose: Synthesis, characterization and evaluation", *Carbohydrate Polymer*, vol. 97, no. 1, pp. 18–25, 2013.

[9] W. Bres and L. A. Weston, "Influence of gel additives on nitrate, ammonium, and water retention and tomato growth in a soilless medium", *Journal of the American Society for Horticultural Science*, vol. 28, no. 10, pp. 1005–1007, 1993.

[10] C. Ross, R. Sojka and J. Foerster, "Scanning electron micrographs of polyacrylamide-treated soil in irrigation furrows", *Journal of Soil and Water Conservation*, vol. 58, no. 5, pp. 327–331, 2003.

[11] B. Rojas et al., "Estudio de la germinación de semillas de tomate en suelos áridos extraídos de la península de Araya (Venezuela) al utilizar polímeros de tipo hidrogeles", *Revista Iberoamericana de Polímeros*, vol 5, no. 1, pp. 17-27, 2004.

[12] C. A. Rivera, C. A. Baeza y W. Chavarriaga, "Efecto de un retenedor de agua y dosis crecientes de fertilizantes foliares sobre la producción de tomate chonto y larga vida bajo cubierta plástica agroclear", *Agronomía (Manizales)*, vol. 15, no. 1, pp. 103-119, 2007.

[13] H. Idrobo, A. M. Rodríguez y J. Díaz, "Comportamiento del hidrogel en suelos arenosos", *Ingeniería de Recursos Naturales y del Ambiente*, no. 9, pp. 33-37, 2010.

[14] I. A. Katime, "Hidrogeles inteligentes", *Revista Iberoamericana de Polímeros*, vol. 4, no. 1, pp. 1-42, 2003.

[15] J. A. C. Alburquerque, V. L. A. Lima, D. Menezes, C. A. Azevedo, N. Dantas e J. Silva, "Características vegetativas do coentro submetido a doses do polímero hidroabsorvente e lâminas de irrigação 1 Vegetative characteristics of coriander submited to doses of the hydrogel polymer and water depths ", *Revista Brasileira de Engenharia Agrícola e Ambiental*, no. 81, pp. 671–679, 2009.

[16] G. Navarro, *Agricultura Orgánica y Alternativa*. Texcoco, México: Universidad Autónoma Chapingo, 2009.

[17] C. G. Chiochetta, S. Cotelle, J. Masfaraud and H. Toumi, "Use of agro-industrial organic sludge amendment to remediate degraded soil: chemical and eco (geno) toxicological differences between fresh and stabilized sludge and establishment of application rates", *Environmental Science and Pollution Research*, vol 23, no. 4, pp. 3018–3025, 2015.

[18] S. Hwa, S. Yeon, J. Seul, I. Kim and E. Young, "Application of sodium polyacrylate and plant growth-promoting bacterium, Micrococcaceae HW-2, on the growth of plants cultivated in the rooftop," *international biodeterioration & biodegradation*, vol. 113, pp. 297–303, 2016.

[19] R. J. L. Mendoza y C. J. Macías, "Materia Orgánica, su Importancia en el Mantenimiento y Mejoramiento de la Fertilidad de los Suelos," *Centro Investigación Regional del Noroeste. INIFAP*, los Mochis, Sinaloa, México,32, 1998.

[20] S. A. Pedroza y B. S. Duran, "Efecto del acolchado plástico, fertilización nitrogenada y composta orgánica en el crecimiento y desarrollo de sábila Aloe barbadensis Miller con riego por goteo automatizado", *Revista Chapingo-serie Zonas áridas*, vol. 4, pp. 1–7, 2005.

[21] C. I. Gutiérrez, C. Sánchez, W. Cueto, C. Trucios, C. Trejo y H. Flores, "efecto del polímero AQUASTOCK® en la capacidad de retención de humedad del suelo y su efecto en el rendimiento de la acelga (*Beta vulgaris var cycla*)", *Revista Chapingo-serie Zonas Áridas*, vol. 7, pp. 65–72, 2008.

[22] D. C. Galeş, L. Răus, C. Ailincăi and G. Jităreanu, "The influence of Aquasorb on morpho-physiological properties on corn and soybeans yield, in the conditions of Iasi County", *Revista Lucrări ştiinţifice Seria Agronomie*, vol 55, no. 2, pp. 173-178, 2012.

[23] S. A. Pedroza, C. L. G. Yanez, C. I. Sanchez and G. J. Samaniego, "Effect of Hydro Gel and Vermicompost on Corn Production", *Revista Fitotecnia Mexicana*, vol. 38, no. 4, pp. 375–381, 2015.

[24] E. Kosterna, A. Zaniewicz-Bajkowska, R. Rosa and J. Franczuk, "The effect of AgroHydroGel and irrigation on celeriac yield and quality", *Folia Horticulturae*, vol. 24, no. 2, pp. 123–129, 2012.

[25] B. Rojas, M. Ramírez, R. Aguilaera, J. L. Prin y C. Torres, "Los hidrogeles poliméricos como potenciales reservorios de

agua y su aplicación en la germinación de semillas de tomate en diferentes tipos de suelos”, *Revista Iberoamericana de Polímeros*, volumen 7, no. 3, pp. 199–210., 2006.

[26] J. C. Ríos-Saucedo, M. Rivera-Gonzalez, L. Valenzuela-Núnez, R. Trucios-Casiano, E. Roman-Paoli y D. Sotomayor-Ramírez, “Diagnóstico de las reforestaciones de mezquite y métodos para incrementar su sobrevivencia en Durango, México”, *Revista Chapingo-Series Zonas Áridas*, vol 11, no. 2, pp. 63-67, 2012.

[27] J. Chen et al., “Science of the Total Environment Environmentally friendly fertilizers: A review of materials used and their effects on the environment*”, Science of the total environment*, vol. 613–614, pp. 829–839, 2017.

[28] C. Arroyave, P. Araque y C. A. Peláez, “Evaluación de la bioacumulación y toxicidad de cadmio y mercurio en pasto llanero (*Brachiaria dictyoneura*)”, *Vitae*, vol. 17, no. 1, pp. 45–49, 2010.

[29] F. Laich, “El papel de los microorganismos en el proceso de compostaje”, Unidad de Microbiología Aplicada. Instituto Canario de Investigaciones Agrarias, pp. 1–7, 2011 [En línea]. Disponible en: https://www.icia.es/biomusa/en/jornadas-y-actividades/jornada-tecnica-sobre-calidad-y-fertilidad-del-suelo/65-el-papel-de-los-microorganismos-en-el-proceso-de-compostaje/file. [Accedido: 18-ago-2016]

[30] K. Amprayn, M. T. Rose, M. Kecskés, L. Pereg, H. Thanh and I. R. Kennedy, “Plant growth promoting characteristics of soil yeast (Candida tropicalis HY) and its effectiveness for promoting rice growth”, *Applied Soil Ecology*, vol. 61, pp. 295–299, 2012.

[31] A. Botha, “The importance and ecology of yeasts in soil*”, Soil Biology and Biochemistry*, vol. 43, no. 1, pp. 1-8, 2011.

[32] *Norma Técnica Colombiana NTC 5167*, Instituto Colombiano de Normas Técnicas y Certificación, (Segunda actualización)” pp. 1–51, 2011.

[33] A. M. Elbarbary, H. A. A. El-rehim, N. M. El-sawy, E. A. Hegazy and E. A. Soliman, “Radiation induced crosslinking of polyacrylamide incorporated low molecular weights natural polymers for possible use in the agricultural applications*”, Carbohydrate Polymers*, vol. 176, pp. 19–28, 2017.

[34] M. R. Guilherme et al., “Superabsorbent hydrogels based on polysaccharides for application in agriculture as soil conditioner and nutrient carrier: A review”, *European Polymer Journal*, vol. 72, pp. 365–385, 2015.