Cultivos Tropicales, 2020, vol. 41, no. 4, e09
ISSN impreso: 0258-5936
ISSN digital: 1819-4087

octubre-diciembre
Ministerio de Educación Superior. Cuba
Instituto Nacional de Ciencias Agrícolas

http://ediciones.inca.edu.cu

Bibliographic review

Impacto de filtros verdes sobre la emisión de los gases de efecto invernadero

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ABSTRACT

The present investigation began its study wondering in what way the implementation of green filters influences the quality of wastewater, where the main objective is to study the impact of green filters as an unconventional strategy for wastewater treatment. All this in relation to the release of greenhouse gases, analyzing their emission or retention during the purification process; in addition to demonstrating that it is an appropriate technology for small communities. However, during the purification process, greenhouse gases (GHGs) can be generated as anaerobic degradation of organic matter takes place, which can be emitted into the atmosphere and thus contribute to global warming. The species commonly used in the purification process are willow (*Salix* spp.) Poplar (*Populus* spp.) and eucalyptus (*Eucalyptus* spp.), since they have a high purification capacity, assimilation of nutrients and rapid growth. This is how agroforestry systems have great

potential for carbon sequestration due to their greater capacity to capture and use growth resources, considering them as a mitigation measure to reduce GHG emissions.
Key words: wastewater, agroforestry systems, mitigation, carbon, plantation

INTRODUCTION

The growth of the population worldwide is increasing at an accelerated rate and for its development it requires surface and underground waters, which are increasingly scarce and of poor quality, demanding the search for appropriate management to optimize the supply of drinking water and wastewater purification. Concerns arise about how to find new resources capable of helping to achieve a balance within demand and supply [(1)]. By 2025, it is estimated that 80 % of the Earth's population lives under conditions of high hydric resource scarcity. Wastewater production is responsible for generating 5 % of global carbon dioxide (CO_2) emissions in 2005, and these emissions are projected to increase by 27 % by 2030 [(2)].

Wastewater treatment has evolved at different rates throughout history; for millennia, they were poured into water sources and, alternatively, they were poured over fields to increase soil fertility. The application, with or without crops, remained active until well into the 20th century and is currently practiced in developing countries or where water is scarce and the management of sanitation systems is poorly developed, with Mexico being one of the main Latin American countries to use wastewater for forest irrigation [(3)].

The European Union (EU) Regulation 525/2013 of the United Nations Framework Convention on Climate Change and its Kyoto Protocol establish obligations to reduce GHG emissions, as well as information on anthropogenic emissions and sinks of these gases. This global framework aims to mitigate the effects of global warming [(2)].

Within this context, and as a result of the purification process, the emission of greenhouse gases (GHGs), especially methane (CH_4), (CO_2) and nitrous oxide (N_2O), could occur. Therefore, the main objective is to study the impact of green filters in relation to the release of greenhouse gases, analyzing their emission or retention during the wastewater treatment process.

Green filters in the treatment of wastewater to the ground

In green filters, purification occurs naturally, based on ecological and biological principles that complement or replace current civil works. It consists of a forest plantation area (mainly poplars, willows or eucalyptus) on which a controlled flow is applied of residual water, where the physical filtration, the absorption in the soil, the biodegradation and the absorption of the plant are the main physical, chemical and biological processes. With the joint action between the soil the microorganisms and the plants are responsible for the attenuation of pollutants [(4)], optimal and recommended for populations of less than 25,000 inhabitants [(5)].

In this type of treatment, the soil acts as a receiving medium for wastewater and as an active agent in the purification process, mainly eliminating nutrients, organic matter (OM), microorganisms and other components, such as heavy metals or organic micro-contaminants. In the green filters, (FVs) arboreal vegetation is installed (poplars, willows or eucalyptus) and a controlled flow of pre-treated residual water is applied as irrigation water. The water evaporates partially and the rest is captured by the roots of the trees and filtered (to a greater or lesser extent depending on the design criteria), through the soil [(6)]. Plants, microorganisms and soil interrelate to carry out purification processes, where physical processes, such as filtration, occur; chemical, such as precipitation or ion exchange and biological, such as the degradation of OM found in water [(7)].

Pollutant removal mechanism

Next, the mechanisms of elimination of the pollutants present in the wastewater are described, detailing which are the physical, chemical and biological processes that will lead to the formation of the different GHGs.

Suspended solids. In water treatment systems, by applying residual water to the ground, the removal of suspended solids (SS), organic and inorganic, occurs mainly by filtration, through the whole that forms the soil with the rhizomes and roots depending on the grain size and texture of the soil [(8)]. Since most of the SS is removed on the ground surface, treatment systems need to be designed in a way that minimizes loss in filtration capacity.

Organic Matter. The transformation of OM occurs by bacterial degradation, developing mainly on the ground surface in aerobic conditions. Plants assimilate the nutrients from OM (phytoextraction), carrying out two main transformation processes: photosynthesis and aerobic respiration carried out by aerobic bacteria in the so-called aerobic horizons (soil), where degradation occurs up to 5 cm deep in the areas near the roots [(9)]. As water percolates in the soil, the amounts of O_2 are reduced, producing anaerobic conditions, where anaerobic heterotrophic bacteria can degrade OM by anoxic route, using nitrate (NO_3^-) as electron acceptor (denitrification process) [(8)]. Anaerobic degradation of OM follows the processes of hydrolysis, acidogenesis, acetogenesis and methanogenesis [(10)], to obtain mainly CO_2 and CH_4 as final products (Scheme 1) [(11)].

$$Organic\ matter + H_2O \xrightarrow{anaerobiosis} CH_4 + CO_2 \qquad \text{(Sch.1)}$$

The process begins with the hydrolysis of complex organic biopolymers (proteins, carbohydrates and lipids) into monomers (amino acids, sugars, long-chain fatty acids), by the action of hydrolytic bacteria. It is important to note that, in acidogenesis and acetogenesis, the products of hydrolysis are transformed into short-chain organic acids, H_2 and CO_2 [(8)]. Finally, CH_4 is produced in the methanogenesis by action of the methanogenic bacteria.

Nitrogen. Urban wastewater is characterized by containing N mainly in the form of NH_4^+, NO_3^- and organic N [(12)]. The mechanisms involved in the elimination of N vary depending on the way in which this nutrient is present:

- **Organic nitrogen:** the fraction that is associated with the SS and OM present in the wastewater, it is removed by filtration, and can be incorporated directly into the soil. In the case of OM that is not easily degraded, the soluble part in amino acids is hydrolyzed to then have NH_4^+ as a product [(8)].
- **Ammoniacal nitrogen:** NH_4^+ in soluble form can be removed by direct volatilization into the atmosphere as gaseous NH_3 (10 %), but most of NH_4^+ (and the converted) is reversibly adsorbed, through exchange reactions ionic to soil particles (clays and electrically charged organic molecules) [(8)]. The adsorbed NH_4^+ can be captured by the vegetation and by the microorganisms present in the soil and can be transformed into NO_3^- by means of biological nitrification reactions. Vegetation can assimilate NO_3^-, but this only occurs near its roots and during growth periods [(8)].
- **Nitrate:** NO_3^- can be removed by biological denitrification and release of N_2 gas and N_2O into the atmosphere. This mechanism constitutes the main route of elimination of N in the systems of application to the terrain. Denitrification is carried out by facultative bacteria under anoxic conditions, it is not necessary that the entire system be anoxic, taking into account that the C/N ratio is sufficiently high, at least 2:1, since NO_3 is taken during the process as electron acceptors for the degradation of MO [(9)]. In this case, denitrification in the root zone (rhizosphere) can also contribute to a decrease in the concentration of N in the system. N_2O and NO are produced in the soil mainly during two microbial processes: nitrification (from NH_4^+ to NO_2- and from this to NO_3^-) and denitrification (from NO_3^- to N_2O and finally to N_2) [(13)].

Impact of green filters on the emission of GHGs

In the treatment of residual waters with FVs, the nutrients (N, P) are captured and retained by the plant to be later expelled through the leaves and roots into the atmosphere. Organic pumping through the root nodules, which has a high water absorption capacity, will carry out decontamination. This action of water absorption decreases the leaching of pollutants into deep layers of the soil (7). It has been reported that there is an exact coupling of gas transport at the biochemical level that is necessary, because CH_4 and N_2O can be produced and consumed in the soil, and the eventual flow to the atmosphere depends on the reaction sites and the escape routes of these gases (14).

Influential factors in the emission of GHGs

Microbial activity, chemical decomposition processes, as well as the heterotrophic respiration of microorganisms, produce GHG in soils. During the purification process with VFs, anaerobic, aerobic respiration and reactions such as methanogenesis and denitrification are affected by external factors; as the organic load contained in the waste water, which implies greater production of gases, especially CH_4 (15).

Temperature. Soil temperature can explain 74 and 86 % of the variations in NO and N_2O emissions, respectively. An increase in soil temperature leads to higher emissions and higher soil respiration rates as a positive feedback response to increased microbial metabolism. CH_4 and N_2O emissions are also by increasing soil respiration rates forced with increasing soil temperatures (16).

Exposure and air pressure. Exposure of the site (elevation, morphological position, vegetation cover) influences soil temperature and humidity. N_2O emissions are higher on troughs than on slopes and ridges due to higher soil moisture. Lower air pressure supports higher soil emissions due to reduced backpressure in the ground (16).

Organic matter. The OM of the soil is a diverse mixture composed of microbial biomass, dead roots, plant residues in various stages of decomposition and soil humus (17), being the humus the result of microbial activity that comprises 60-80 % of the total OM of the soil.

The decomposition of OM constitutes a basic biological process in which C is recirculated into the atmosphere, as CO_2; N is available, as NH_4^+ and NO_3^- appear as required by higher plants. In this process, part of the C is assimilated into the microbial tissue (soil biomass) and another part is converted into humus (18). In the process of mineralization and decomposition of OM, CO_2 is emitted into the atmosphere; while, during the time that C is forming part of the plant structures, considering C as retained (C sink). The same occurs with C, which is part of non-bioavailable biodegradable materials (humus) [18].

The higher the content of C retained in plants or soil and for a longer time, then the less is the amount that will exist in the atmosphere. The application of wastewater to the soil significantly increases the content of organic C in all forms of C, both labile forms and recalcitrant fraction [19]. The amendment of the soil with charcoal obtained from plant remains and biomass residues (biochar) is evaluated worldwide, as a means to improve soil fertility, mitigate climate change [20,21] and decrease GHG emissions from the ground, such as N_2O or CH_4.

Sustainable biochar production (used as a soil amendment) has been shown to have the mitigation potential due to its highly recalcitrant nature, slowing down the rate at which photosynthetically bound C returns to the atmosphere [22]. It is possible that CO_2 precipitates as CO_3^{2-} on biochar surfaces, which have high pH and abundant alkali metals, which would explain the reduced detection of CO_2, despite the increases measured in microbial biomass [23].

Microbial activity. The microorganisms in the soil represent the living fraction of the OM, and the obtaining of recalcitrant materials will largely depend on them but microorganisms to become recalcitrant OM [24] transform another large part of OM.

The MO content and the amount of N in the soil control microbial activity. The soil is a favorable habitat for the proliferation of microorganisms and microcolonies develop in the particles that form it. Microorganisms isolated from the soil include viruses, bacteria, fungi, algae and protozoa. OM concentrations are relatively high in such environments, which favor the development of heterotrophic microorganisms. Large contributions of OM and nutrients can improve the growth of microbial organisms and, therefore, the nitrification and denitrification processes provide a greater amount of dissolved organic C (COD) [25].

Vegetation. The selection of the vegetation to be implanted in the FVs will depend on the function of the cultivation type and the age. Being optimal those that present a high capacity of assimilation of nutrients, rapid growth, great consumption of water by transpiration, tolerance to humid soils, low sensitivity to the components of the wastewater and minimal operating requirements [26].

Among the crops that meet all, or most, of these conditions are different herbaceous species (couch grass) (*Cynodon dactylon*), ryegrass (*Lolium*), Italian ryegrass (*Lolium multiflorum*), and certain tree species such as willow (*Salix poplar*) or *poplar* (*Populus* spp.) and eucalyptus (Eucalyptus spp). The use of tree species with a high rate of evapotranspiration, and the fact that their root systems show excellent tolerance to anaerobic conditions, allows the application of considerable amounts of wastewater. Generally tree species such as willows (Salix spp.) Poplars (*Populus* spp.) and eucalyptus (*Eucalyptus* spp.) [(25)].

C retention in agroforestry systems as a mitigation measure

Agroforestry systems (AFS) have received increased attention due to their ability to sequester CO_2 from the atmosphere in aerial biomass, stems, branches and foliage, and in underground biomass, i.e. roots and on the ground. AFS are to have great potential for C sequestration believed due to their ability to capture and use growth resources (light, nutrients and water) than monoculture or pasture systems [(27)].

The volume of aboveground biomass and deep tree root systems in the AFS have received increased attention for adaptation and mitigation of climate change. In agroforestry systems up to 1m deep in the ground, global estimates of C sequestration potential over a 50-year period range from 1.1 to 2.2 mg C year^{-1} but in particular, land area estimates are very uncertain [(28)].

Willow (*Salix* spp.), Poplar (*Populus* spp.) and eucalyptus (*Eucalyptus* spp.) are the main types of tree vegetation used in PV. In particular, the presence of willows and poplars positively influences the GHG treatment process [(29)]. In the same way, they studied the performance of the poplar, since the photosynthesis process is among the highest due to its great capacity for growth, and for fixing CO_2 from the atmosphere [(25)].

In countries such as Sweden, Poland, Denmark and Estonia, the efficiency of willow as a green filter in wastewater purification has been proven where the roots have the capacity to absorb 75-95 % of nitrogen (N) and phosphorus (P) in wastewater (30). When willow is used for energy purposes, that is, for the conversion of electricity from heat, this energy source can be considered as CO_2 neutral, because it does not affect the amount of so-called greenhouse gases in the atmosphere.

During growth, willow recovers the same amount of CO_2 as it is released during combustion, and the delay time is a matter of months rather than years [(30)].

CONCLUSIONS

- Green filters are highly efficient, as technologies applied to the soil for the treatment and reuse of pretreated wastewater. Thanks to the joint action of soil, microorganisms and vegetation, they turn out to be an efficient method of reducing the emission of pollutants the higher the C content retained in the plants and soil; the amount of GHGs in the atmosphere will be less.

- The efficiency of the FVs in relation to the GHGs will depend on various factors including temperature, the amount of organic matter contained in the wastewater, and mainly type of vegetation. The poplar (*Populus* spp) and the willow (*Salix* spp) are the tree species commonly used, not only for their rapid growth, resistance to pests and climate changes, but also for the great capacity for absorption and accumulation of CO_2 and C fixation. That is why, the practice of AFS is a mitigation measure that helps C sequestration to help reduce GHG emissions, and demonstrate that it is an appropriate technology for small communities both economically and environmentally.

BIBLIOGRAPHY

1. Hernández-Baranda Y, Rodríguez-Hernández P, Peña-Icart M, González-Hernández P, San Nicolás-López FT. Caracterización química y agronómica de las aguas residuales del yacimiento Castellano, Pinar del Río. Cultivos Tropicales. 2018;39(3):11–7.
2. Sweetapple C, Fu G, Butler D. Identifying sensitive sources and key control handles for the reduction of greenhouse gas emissions from wastewater treatment. Water Res. 2014 Oct 1;62:249–59.
3. Organización de las Naciones Unidas para la Alimentación y la Agricultura. Reutilización de aguas para agricultura en América Latina y el Caribe. 2017;133. Available from: http://www.fao.org/3/a-i7748s.pdf
4. Martínez-Hernández V, Leal M, Meffe R, de Miguel A, Alonso-Alonso C, de Bustamante I, et al. Removal of emerging organic contaminants in a poplar vegetation filter. J Hazard Mater. 2018 Jan 15;342:482–91.
5. Moreno L, Fernández MA, Rubio JC, Calaforra JM, López JA, Beas J, Alcaín G, Murillo JM. La depuración de aguas residuales urbanas de pequeñas poblaciones mediante infiltración directa en el terreno fundamentos y casos prácticos. In: Moreno L, editor. 1st ed. Madrid: 2003; [cited 14/03/2020]. Available from: http://aguas.igme.es/igme/publica/depuracion_aresidual/indice.htm
6. De Bustamante I, Lillo J, Segura M, Iglesias JA, Gómez D, Ortiz I, Gil J. Adaptación de los filtros verdes: de estaciones depuradoras de agua (EDAR) a estaciones de regeneración y reutilización de aguas depuradas (ERRAD).

Conferencia Nacional sobre la reutilizacion del agua. Madrid. 2009.

7. Vicente Nuevo C. Aplicación de Tecnologías Blandas a la Depuración de Aguas Residuales. Dimensionamiento para la Población de Huerta. Salamanca: Universidad de Valladolid; 2017.
8. Centa, Secretariado de Alianza por el agua E y D. Manual de depuración de aguas residuales urbanas. Centa, Secretariado de Alianza por el agua, Ecología y Desarrollo [Internet]. Ideasamare. España; 2008. p. 264. Available from: http://alianzaporelagua.org/documentos/MONOGRAFICO3.pdf
9. Prieto R. Emisión de gases de efecto invernadero en el tratamiento de aguas residuales. Universidad de Cataluña; 2011.
10. Appels L, Baeyens J, Degrève J, Dewil R. Principles and potential of the anaerobic digestion of waste-activated sludge. Prog Energy Combust Sci. 2008;34(6):755–81.
11. FAO, MINENERGIA, PNUD, GEF. Manual del Biogás. Proy CHI/00/G32 [Internet]. 2011;120. Available from: http://www.fao.org/docrep/019/as400s/as400s.pdf
12. Mara D, Horan N. Handbook of Water and Wastewater Microbiology. 2003. 427-439.
13. Smith KA, Ball T, Conen F, Dobbie KE, Massheder J, Rey A. Exchange of greenhouse gases between soil and atmosphere: interactions of soil physical factors and biological processes. Eur J Soil Sci. 2018;69(1):10–20.
14. Blagodatsky S, Smith P. Soil physics meets soil biology: Towards better mechanistic prediction of greenhouse gas emissions from soil. Soil Biology and Biochemistry. Pergamon. 2012;47:78-92.
15. Doorn MRJ, Towprayoon S, Manso Vieira SM, Irving W, Palmer C, Pipatti R, et al. Tratamiento Y Eliminación De. Directrices del IPCC 2006 para los Inventar Nac gases Ef invernadero. 2006;1–31.
16. Oertel C, Matschullat J, Zurba K, Zimmermann F, Erasmi S. Greenhouse gas emissions from soils—A review. Vol. 76, Chemie der Erde. Elsevier GmbH. 2016. p. 327–52.
17. Cambardella C-C. Carbon cycle in soils formation and decomposition. Encycl Soils Environ [Internet]. 2005 [cited 17/03/2020];1(9780123485304):170–5. Available from: https://www.ars.usda.gov/research/publications/publication/?seqNo115=167297.
18. Julca-Otiniano A, Meneses-Florián L, Blas-Sevillano R, Bello-Amez S. La materia

orgánica, importancia y experiencia de su uso en la agricultura. Idesia (Arica). 2006 Apr;24(1):49–61.

19. Zamora FR, Guevara NJR, Rodríguez DGT, Héctor José Yendis Colin. Uso de agua residual y contenido de materia orgánica y biomasa microbiana en suelos de la llanura de Coro, Venezuela. Agric Técnica en México. 2009;35(2):211–8.
20. Cayuela ML, Oenema O, Kuikman PJ, Bakker RR, van groenigen JW. Bioenergy by-products as soil amendments? Implications for carbon sequestration and greenhouse gas emissions. GCB Bioenergy. 2010;2:201–13.
21. Lehmann J, Rillig MC, Thies J, Masiello CA, Hockaday WC, Crowley D. Biochar effects on soil biota - A review. Soil Biology and Biochemistry. Pergamon. 2011;43:1812-36.
22. Woolf D, Amonette JE, Street-Perrott FA, Lehmann J, Joseph S. Sustainable biochar to mitigate global climate change. Nat Commun. 2010;1(5):1–56.
23. Escalante A, Pérez G, Hidalgo C, López J, Campo J, Valtierra E, et al. Biocarbón (biochar) I: Naturaleza, historia, fabricación y uso en el suelo Biocarbon (biochar) I: Nature, history, manufacture and use in soil. Terra Latinoam [Internet]. 2016;34:367–82. Available from: http://www.scielo.org.mx/pdf/tl/v34n3/2395-8030-tl-34-03-00367.pdf
24. Milian L. Influencia de la materia orgánica del suelo en el secuestro de carbono. Biochar, una estrategia potencial [Internet]. Universidad Complutense de Madrid. 2015. Available from: http://147.96.70.122/Web/TFG/TFG/Memoria/LAURA MILIAN GAY.pdf
25. Miguel A de, Meffe R, Leal M, González-Naranjo V, Martínez-Hernández V, Lillo J, et al. Treating municipal wastewater through a vegetation filter with a short-rotation poplar species. Ecol Eng. 2014 Dec 1;73:560–8.
26. Alvarez Vega F. (PDF) Filtros verdes. Un sistema de depuración ecológico. Ing hidráulica y Ambient [Internet]. 2002 [cited 17/03/2020];1(1680–0338). Available from: https://www.academia.edu/39200917/Filtros_verdes._Un_sistema_de_depuración_ecológico.
27. Concha JY, Alegre JC, Pocomucha V. Determinación de las reservas de carbono en la biomasa aérea de sistemas agroforestales de theobroma cacao l. En el departamento de san martìn, peru. Ecol Apl. 2007;6(1–2):75.
28. Pardos JA. Los ecosistemas forestales y el secuestro de carbono ante el calentamiento global. Instituto Nacional de Investigacion y Tecnologia Agraria

yAlimentaria . 2010. 11–29 p.

29. Khurelbaatar G, Sullivan CM, van Afferden M, Rahman KZ, Fühner C, Gerel O, et al. Application of primary treated wastewater to short rotation coppice of willow and poplar in Mongolia: Influence of plants on treatment performance. Ecol Eng. 2017, Jan 1;98:82–90.

30. Börjesson P, Berndes G. The prospects for willow plantations for wastewater treatment in Sweden. Biomass and Bioenergy. 2006 May 1;30(5):428–38.