Determining the Filtration Quality of Different Soil Types Using Turbidity, Bacterial Content, and Drainage Ability for Filtering Greywater

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Abstract

Greywater is wastewater produced by showers and sinks and thus contains soaps, food particles, and bacteria. In the vast majority of Monteverde, greywater is disposed of onto the ground or streets, and is directed to the nearest stream. This wastewater may seep into the regional groundwater and can potentially transmit water-borne diseases. I investigated the filtration qualities of clay, organic soil, and gravel. Measuring the changes in bacterial count, turbidity, and the percentage of initial volume recovered, I determined the best soil for greywater filtration. In addition, I used my results to suggest an alternative media to be used in wastewater trench construction. I found that clay filtration produced the greatest reduction in bacteria and organic soil recovered the least amount of water. I did not find differences in the change of light absorbance of the water samples between soil types. I concluded that clay's natural characteristics should be used as a small scale water filter where drainage is not an issue. I also concluded that gravel should remain the medium used in wastewater trench construction because of its drainage abilities, lack of ecological importance, and commercial availability.

Resumen

Agua gris es aguas residuales producidas por las duchas y los fregaderos y contiene así los jabones, las partículas del alimento, y las bacterias. En la mayoría extensa de Monteverde, el greywater se dispone sobre la tierra o las calles, y se dirige a la corriente más cercana. Estas aguas residuales pueden filtrar en la agua subterránea regional y pueden potencialmente transmitir enfermedades flotantes. Investigué las calidades de la filtración de la arcilla, del suelo orgánico, y de la grava. Midiendo los cambios en cuenta bacteriana, la turbiedad, y el porcentaje del volumen inicial me recuperaron determinaron el mejor suelo para la filtración del greywater. Además, utilicé mis resultados para sugerir los medios alternativos que se utilizarán en la construcción del foso de las aguas residuales. Encontré que la filtración de la arcilla produjo la reducción más grande de bacterias y el suelo orgánico recuperó la menos cantidad de agua. No encontré diferencias en el cambio de la absorbencia ligera del agua entre los tipos del suelo. Concluí que las características naturales de la arcilla se deben utilizar como filtro del agua de la escala pequeña donde no está una edición el drenaje. También concluí que la grava permanece como el medio usado en la construcción del foso de las aguas residuales debido a sus capacidades del drenaje, la carencia de la importancia ecológica, y la disponibilidad comercial.

Greywater is wastewater produced by showers, baths and basins (55%), laundry (34%), and the kitchen (11%) (Dallas 2005). Greywater may contain soaps, detergents, food particles, grease, lint, hair, bacteria and traces of other household cleaning products.

The presence of soaps, suspended matter such as organic matter, inorganic matter, plankton and other microscopic organisms causes a change in the water's clarity, namely its turbidity. Turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted with no change in direction of flux level through the sample (Eaton 1995). The clarity of a natural body of water is an important determinant of its condition because it could be an indicator of water quality. Untreated greywater thus got its name based on its turbid nature.

Currently, domestic greywater is discharged from the house, untreated, into the streets and streams of Monteverde (Dallas 2005). Untreated greywater can thus pose as a breeding ground for various pathogenic bacteria, parasites, and viruses which may lead to many health risks. Some waterborne pathogenic diseases include ear infections, dysentery, typhoid fever, viral and bacterial gastroenteritis, and hepatitis A. Among others, *E. coli* is a bacteria usually found in household greywater. The presence of fecal coliforms, particularly *E. coli*, indicate that there are mammal or bird feces in the water (Ludwig 2006). In most instances, coliforms themselves are not the cause of sickness, but they are easy to culture and their presence is used to indicate that other pathogenic organisms of fecal origin may be present. Though often harmless, *E. coli* can cause illness by infection of a bodily cavity or by synthesis of a toxin which attacks the body (CDC 2006). Fecal coliform bacteria may occur in ambient water as a result of the overflow of domestic sewage or nonpoint sources of human and animal waste.

In Monteverde, little research has been done about the effects of soil as a filter for the treatment of wastewater with respect to turbidity and bacterial content. As for soils, clay is known to be very cohesive, have a large surface area-to-volume ratio, and to slow down the movement of water. Organic soil is very arid and permeable to air and water while gravel is loose and lacks cohesiveness. It is not yet known whether these soil characteristics play a role in affecting the turbidity or bacterial content for filtering wastewater.

With this project I wanted to find out which soil best filters the discharged greywater as it trickles towards the nearest stream in addition to discovering a better alternative for the current medium, gravel, used in wastewater trench construction. I investigated three different types of soil; clay, organic soil, and gravel. Clay has relatively small particles, organic has slightly bigger particles, and gravel has the biggest particles (Brady 1996). I also wanted to find out if particle size played a role in a soil's filtration qualities.

In this paper, I assessed the filtering qualities of three different soil types by analyzing the change in bacterial count, and turbidity of the water after passing through each soil. I postulated that the soil with a finer texture and less pore space will serve as a better filter since the water would have to move through a finer matrix which may remove more unsanitary debris (Brady 1996).

Materials and Methods

Experiment Location

I conducted this study at the Instituto Monteverde in Monteverde, Puntarenas, Costa Rica, from November 24 to December 3 of 2006. I collected the soils used for the project from the Gindon Maxon Farm. I collected the greywater from the Estación Biológica Monteverde and from a residence in the Manakin neighborhood.

Soil Characteristics and Preparation

I collected three different types of soils: clay, organic soil, and gravel. Clay is a type of soil that has particles smaller than 0.002 mm in diameter and a very large surface area-to-volume ratio, giving it a tremendous capacity to adsorb water and other substances on its surfaces (Brady 1996). Its large adsorptive surface area also causes clay particles to cohere together in a sticky, plastic mass that can be easily molded when wet (Brady 1996). Organic soils, also known as histosols, are far more permeable to air and water with particles about 0.05mm in diameter (Brady 1996). Gravel has particles that are greater than 2 mm in diameter and display very little cohesion or aggregation into the soil matrix (Brady 1996).

In order to ensure homogenous trials, I separately mixed each type of soil in a large container for 5 minutes. Then, to rid the soils of their natural bacterial content, I sterilized each type by heating them at 300 ℃ for one hour (USDA 2000).

Apparatus Sterilization and Setup

To hold the soil, I sterilized 50cm long PVC pipes, that were 5.08cm in diameter, by pouring 100 ℃ water through them in a bucket (USDA 2000). For maximum sterilization of the insides of the pipes, I filled them three-quarters of the height with water then turned over after 30 minutes and left to cool and dry. I sterilized funnels made from aluminum foil and 10cm x 10cm metal squares of window screen (1mm x 1mm grid) molded to the ends of the pipes were sterilized at 300 ℃ for 30 minutes (USDA 2000).

After sterilization, I secured the molded screens to the ends of the pipe. Then I filled each pipe with a different soil type and compacted them by hitting the pipe on the floor against sterile aluminum foil. I secured sterile aluminum foil funnels to the end with the screen to direct the resulting sample into sterile collection cups. I then secured the pipes vertically to wooden stands.

I re-hydrated the soils because they would have absorbed all of the greywater and nothing would have come out. Thus, I hydrated each soil-filled apparatus with 250mL of sterilized water and allowed the water to soak through for 12 hours. I then placed a column, weighing the respective masses of each 50cm soil-filled pipe, on top of their respective soil samples after re-hydration in order to standardize the degree of compactness amongst each soil type. I did this to recreate the natural soil compaction of a typical home drainage system and came from the fact that 50cm is the standard depth of drainage pipes used in construction.

For each trial there was one pipe for clay soil, one pipe for organic soil, one pipe for gravel, and one pipe for a control which contained no soil. I setup the pipes to perform three trials at a time. Therefore all materials were prepared for 12 pipes. In total, I ran six trials in two groups of three trials. For each group, I used greywater from different sources.

Greywater Collection

At Estación Biológica Monteverde, I determined the location of the greywater outlet. I then collected a bucket full of greywater immediately after 30 students ate breakfast and washed their dishes. For the second set of trials, I obtained greywater from a residence in the Manakin neighborhood in Monteverde. I collected the water after the family had taken showers, washed their dishes from breakfast, and washed a load of laundry.

I sampled the greywater before being poured through the soil pipes as a pre-filtration sample. I then measured 500mL of greywater for each pipe and poured greywater into the top end of the pipes, allowing the greywater to seep downwards. For each trial, I noted the initial and final volume of greywater that came out. After each trial, I took notice to which soil type was first to produce filtrated water in order to note which type drained water fastest.

Analyzing the Samples

To determine whether the soils filtered bacteria, I analyzed the greywater samples before and after they had filtered through the soil. I collected each sample in a 100mL-sterile plastic cup and refrigerated it at 3 ℃ in order to inhibit bacterial growth (Ambient 2004). From each sample, I pipetted 1mL of filtered greywater onto a 3M® *E.coli*/Coliform Count petrifilm then incubated for 24 hours at 37 ℃ (3M Instruction Manual). The *E.coli*/Coliform Count petrifilm contains media for the growth of both *E.coli*, and coliform. For that, I differentiated the bacterial growth using microbiological indicators of the bacteria. Fecal coliform produces gas bubbles around its colonies, *E.coli* forms blue-colored colonies, and non-fecal coliform is the same as fecal coliform but does not produce gas around its colonies. After incubation, I counted the number of colony forming units per milliliter of filtered greywater (CFU/mL). If the petrifilm had no evidence of colonies I did not consider that as zero colonies. Instead, I noted that there were less than two CFUs per milliliter (3M Instruction Manual). If there were more than ten colonies in any square centimeter, then that sample's petrifilm would be appointed as too numerous to be counted (TNC) (3M Instruction Manual). This indicated that there would be more than 220 colonies because the petrifilm has a total area of $20cm^2$ (3M Instruction Manual).

I also measured the light absorbance of each sample and directly correlated it with turbidity by using the Spectronic 601 light spectrophotometer. I assumed that the light absorbance reading would indicate the amount of substances suspended in the sample and thus would give me an indication of turbidity. Before obtaining the readings of the water samples, I found out the wavelength at which the samples would absorb the most light. Generally, I found that clay had the lowest absorbance, organic soil had a moderate absorbance, and gravel had the highest absorbance at all wavelengths. I did this by manually determining their individual peak wavelengths. I found that all soil samples had a peak absorbance at 519nm and used this wavelength to measure the absorbance for all samples. I used one milliliter of the resulting sample and placed it in a clean, dry cuvette to be placed in the spectrophotometer. Before each new sample, I zeroed the spectrophotometer with a blank cuvette of de-ionized water then inserted the sample. From this procedure, I obtained values in units of absorbance representing the amount of light being absorbed by the water sample.

Analyzing the Data

Being that the colony counts for the petrifilms did not produce actual numbers for those which had less than two CFUs per milliliter or for those which were counted as TNC, I marked the counts with less than 2 CFUs per milliliter as zero and those with TNC as 220 CFUs per milliliter for statistical purposes.

After counting the number of CFUs, I analyzed the difference between the types of soils using various indicators of water quality. I calculated the percentage of initial volume of water recovered by dividing the final volume by the initial volume, and multiplied that value by 100. I applied this calculation to all trials. To calculate the change in light absorbance, I subtracted the light absorbance reading of the pre-filtered sample from the final light absorbance reading for each sample. To calculate the change of CFUs per millimeter for *E.coli*, fecal coliform, and total coliform, I subtracted the initial greywater bacterial count from the final bacterial count per soil type. For my non-parametric data I used Kruskal-Wallis tests in the statistical program JMP to find whether there was a statistical difference of the change they induced in light absorbance, bacterial count, and percentage of initial volume recovered, between the greywater filtered by the different soil types.

Results

I found that organic soil had recovered an average of 74.67% of the initial greywater, gravel recovered an average of 62.59% of the initial greywater, clay recovered an average of 38.4% of the initial greywater, and the control recovered 100% of the initial greywater (Fig. 1, Kruskal-Wallis=15.39, df=3, p = 0.0015).

For the change in the number of fecal coliform, I found clay produced the greatest change (Fig. 2, Kruskal-Wallis=13.67, df=3, p = 0.0034). Clay also produced the greatest change in the number of total coliform (Fig. 2, Kruskal-Wallis=16.07, df=3, p=0.0011). For *E.coli,* however, organic soil produced the greatest change (Fig. 2, Kruskal-Wallis=9.51, df=3, p=0.02).

I found no difference between the soils' ability to significantly alter the water's turbidity (Fig. 3, f=1.42, df=3, df-error=19, p = .27).

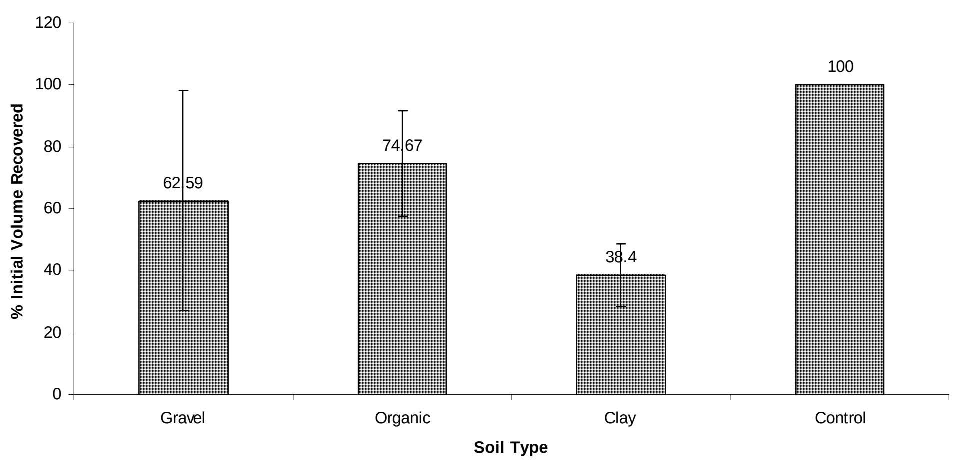

Fig 1. Percent of initial volume recovered per soil type.

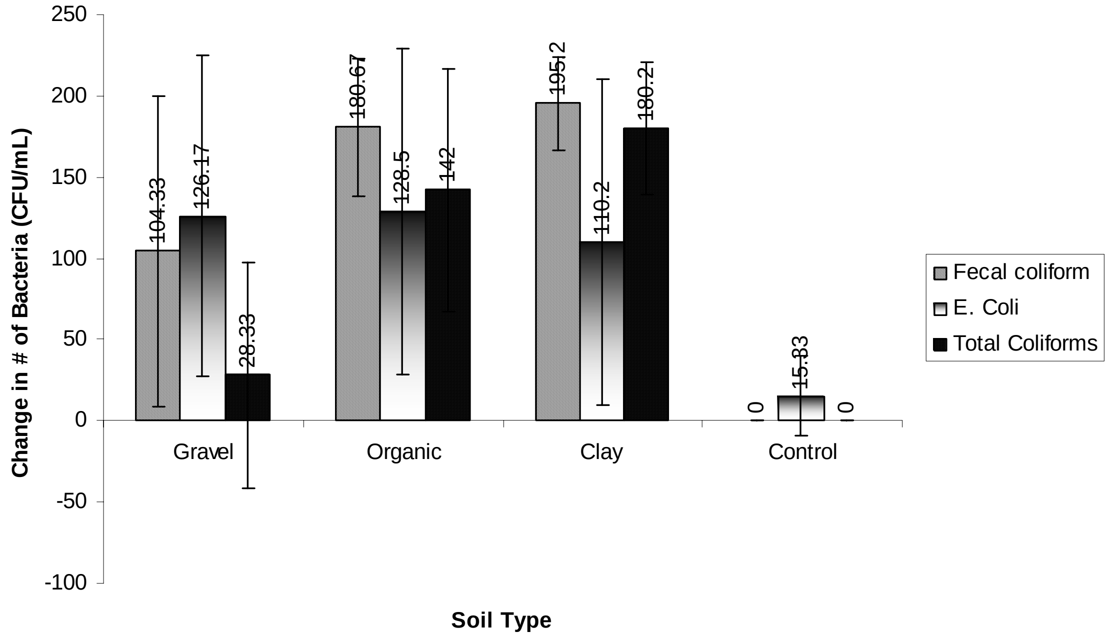

Fig 2. The change in number of greywater bacteria after soil filtration per soil type for the fecal coliform, E.coli, and total coliform.

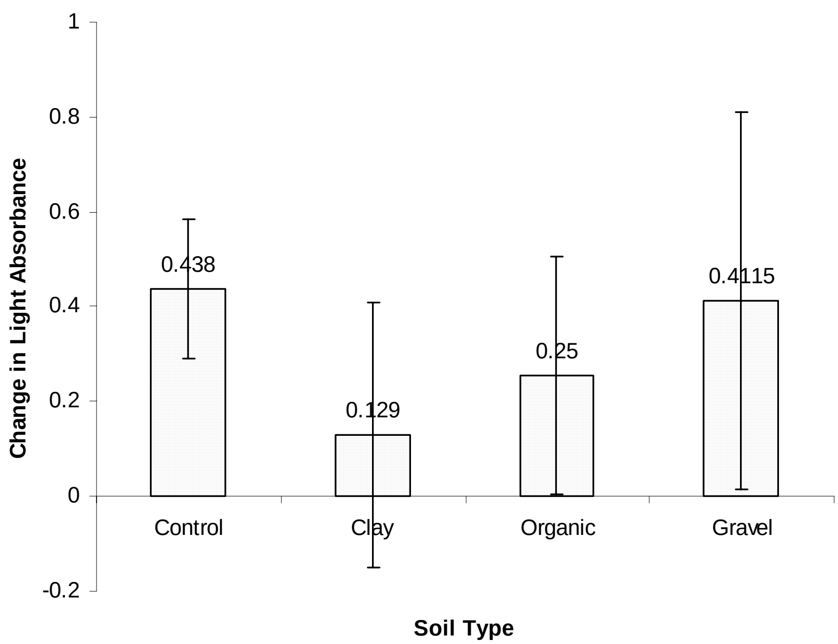

Fig 3. Change in light absorbance produced by each soil.

Discussion

The results indicate that organic soil drains water the fastest, gravel drains moderately well, and clay has the worst drainage ability (Fig. 1). This is due to the extensive pore space in organic soil (Brady 1996). Studies have shown that the addition of organic matter makes any soil easier to work with and improves its drainage properties (Whiting 2005). Also, organic soil is not as dense as clay and therefore does not possess the ability to become very compact which may contribute to the ability of organic matter to drain water easily. It is suggested to add organic matter to minimize soil compaction in gardening (Whiting 2005). Gravel has a greater surface area because of the larger sizes particles making it more likely to catch water on it than organic soil, and thus drains more slowly (Ludwig 2006). The presence of clay in a soil gives it a fine texture and slows water and air movement (Brady 1996). As mentioned before, clay has a very large surface area-to-volume ratio, giving it a tremendous capacity to adsorb water and other substances on its surfaces (Brady 1996).

The results showed that clay produced the greatest reduction in fecal coliform and total coliform (Fig. 2). The reason for this is that clay minerals all have a great affinity for water and have the ability to soak up ions from a solution (USGS 2006). In addition, the property of clay minerals that causes ions in solution to be fixed on clay surfaces or within internal sites applies to all types of ions, including organic molecules like pesticides (USGS 2006). This allows clay to effectively remove and trap harmful molecules from the water. Similar to clay, organic soil matter has humus which is its colloidal fraction. The surface charges of humus, like those in clay, attract and hold both nutrient ions and water molecules (Brady 1996). This helps explain why organic soil only had a slightly greater change in *E. coli* than clay. Gravel does not possess the ability to trap ions due to their loose nature and lack of cohesiveness and was unable to reduce bacteria as well as clay or organic soil.

The results showed that none of the soils produced a significant difference in the greywater's light absorbance. A possible reason for this could be that miniscule soil sediment in the samples may have interfered with the spectrophotometric readings. This can be especially true in the case of clay because its particles are extremely small.

Taking drainage and bacterial removal into account, I consider gravel to be the most suitable medium to use in wastewater trench construction. Although organic soil had the best drainage capabilities, it plays an important role in the carbon cycle, thus rapid extraction of it from nature for commercial purposes would greatly affect all living organisms (Brady 1996). In effect, the important drainage characteristic of gravel is its large grain size and not its chemical makeup. Thus gravel can easily be bought from construction supply companies or made by crushing large rocks into much smaller sizes.

As for clay, its drainage qualities are lacking but it does excel in bacterial removal. Thus, I am suggesting that clay be used in a context where time and drainage would not be an important factor but bacterial removal is and clay's attributes can be taken advantage of on a smaller scale than commercial drainage construction. The use of clay with this idea has already been implemented by such bodies as the Ceramic Water Filter Project who has developed a low-tech, low-cost, colloidal silver-enhanced ceramic water filter that effectively eliminates approximately 99.88% of most water-born disease agents (Darby 2006). The utilization of clay's natural characteristics has already begun to benefit those in undeveloped countries where potable water is inaccessible, thus leading to many water-borne diseases and has the potential to aid in the purification of water throughout the world. I hope that this study can be a stepping stone to further investigation of economical alternatives for filtering wastewater and thus reduce the spread of pathogenic disease.

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