THE FEASIBILITY OF UTILIZING VETIVER(*Chrysopogon zizanioides*) ROOT SYSTEMS AS SILT BARRIERS FOR SEDIMENT CONTROL OF RUN-OFF FROM OPEN PIT MINES

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ABSTRACT

The study aims to determine the feasibility of vetiver as silt barriers for surface runoff from open pit mines using the vetiver root systems as the primary means of filtering the silt. Its objectives are to utilize vetiver as silt barriers for open pit mines, to decrease the silted water velocity as it passes through the vetiver root systems, and to determine the relationship of vetiver density and efficiency in trapping silt. The experiment uses three systems: (1) the no vetiver system with varying silt concentrations (50g, 100g, 150g), (2) varying number of vetiver (1 row, 2 rows, 3 rows) with constant amount of silt, and (3) varying amount of silt (50g, 100g, 150g) with constant number of vetiver.

A plexiglass box with a movable ramp at the front and end of the system was created with a removable reservoir placed above the ramp. A discharge reservoir was installed below the end ramp. For every system, silt is introduced into the discharge reservoir where a pump circulates silted water into the inflow reservoir and is made to flow into the ramp passing into the vetiver root system. The filtered water exits the whole system via a horizontal ramp and falls into the discharge reservoir. The water is circulated for 3 hours and is sampled for every hour at the discharge container while the accumulated silt at the main reservoir is collected at the end of each system experiment. Then the silt is allowed to settle and be filtered for weighing.

Upon conducting the methodology, the researchers were able to find out from System 1 that despite the absence of vetiver, silt has its natural tendency to settle. However, upon inclusion of vetiver in System 3, the amount of total silt collected in the discharge container decreased significantly as compared to no vetiver at all. From System 2, it is apparent how the presence of vetiver aided in the settling and accumulation of silt with an almost linear relationship between the number of vetiver rows and the amount of accumulated silt, having a coefficient of determination (R^2) equal to 0.972.From the Anova Single Factor calculations, it is evident that there is a significant difference between the no vetiver and the four vetiver rows system. Since the three rows of vetiver did not vary significantly to the four rows of vetiver, the researchers were able to conclude that the most efficient number of vetiver rows to be used is three.Observing the behaviors from all the set-ups, it was analyzed that the vetiver roots helped in lessening the velocity of inflow, thereby encouraging settling; thus, it can be concluded that vetiver roots can be used as silt barriers.

Key words: Nickel laterite soil, open pit mine, silt, silt barrier, siltation

1. Introduction

Located within the Pacific Ring of Fire, Philippines has an undoubtedly rich geologic history. The Archipelago together with its 7,109 islands were formed 43 million years ago due to the outpourings of molten rocks from the earth's interior, thereby creating an ideal setting for mineral deposition(Wolfe, 1983)

Two of the rich mineral resources in the Philippines include nickel and iron. These deposits occur in the form of nickeliferous laterite which is mostly found along the eastern and western margins of the country and in the northeastern part of Mindanao. In the 1970s, the Philippines was believed to have the biggest nickel reserves in the world and until now it continuous to be one of the biggest suppliers of nickel and iron ores.

The nickel and iron resources make the Philippines very attractive to mining companies. In order to extract these ores, the top soil must be stripped downwards creating a large pit from the surface to the ore. Along with the increasing number of mining companies, environmental issues and problems arose as well.

1.1 Significance of the Study

The most pressing environmental issue regarding surface mining is siltation. Siltation has a high risk of contaminating larger bodies of water, aquatic life sensitive to suspended material and the surrounding communities if not taken care of responsibly. Clearing the vegetation of mine areas leads to soil erosion, specifically regarding fine soil particles such as silt. These fine particles are easily carried by water during rains and transported to nearby bodies of water, increasing the concentration of suspended sediments.

Surface mines have used siltation ponds as a mitigating measure, and silt barriers to lessen the effects of siltation. Siltation pond traps the silt carried by water before reaching bodies of water nearby but there are still large amounts of silt that pass through. Some mining companies use silt screens to prevent the silt from skirting the pond but the high price of these screens make it uneconomical. Thus, bio-filtration for controlling siltation was thought of by the researchers.

The Vetiver Root System, already used in soil erosion and sewage disposal, may be used as an effective solution for siltation. It has been widely used for other purposes such as soil and water conservation, pollution control, and rehabilitation. The extensively dense and deep roots of the vetiver grass, its high tolerance to most heavy metals, and its ability to survive extreme climate make it an interesting consideration for possible application to the mining industry.

Suspended silt circulating in the runoff mine water is a threat to the environment and poses health risks as well. Although mining companies employ the use of siltation ponds and other measures, it is still not enough to fully remove silt in the run-off water. An application of dense vetiver root systems (VRS) as a silt barrier can become a cheap mitigating measure to remove silt from the run-off water of established mines. Instead of creating a new siltation pond or redesigning the silt control process of the mine, an addition of VRS as silt barrier after a series of siltation ponds may be a more practical and economical solution, thereby reducing health hazards and mining costs while keeping the area environmentally friendly.

1.1.1 Statement of the Problem

The main problem of this study is to determine the feasibility of utilizing the VRS as silt barriers for surface runoff from open pit mines. More specifically, this study has the following objectives:

- To utilize vetiver as silt barriers for open pit mines
- To decrease the silted water velocity as it passes through the VRS
- To determine the relationship of vetiver density and efficiency in trapping silt

1.1.2 Hypothesis

The researchers have formulated the following hypotheses:

Ha: There is a significant difference between the no vetiver set-up and the ones with vetiver

Ho: There is no significant difference between the no vetiver set-up and the ones with vetiver

1.1.3 Scope and Limitations of the Study

- The set-up used is a representative of a larger body of water that has passed through a series of siltation ponds in a surface mine.
- The dimensions of the main reservoir are 0.25m deep, 0.25m wide, and 0.032m long and the vetiver roots used are fitted just right for the dimensions given.
- The study is intended to show only the capacity of the VRS to trap and accumulate silt in laminar, recirculated water.
- Results and conclusions are only applicable for silted water with an amount of 50g, 100g and 150g of silt with particles less than 63 microns (μm).
- The experiment was conducted in the Department of Mining, Metallurgical, and Materials Engineering Pilot Plant, University of the Philippines, Diliman, Quezon City

2. Material and Methods

2.1 Plant Propagation

Fifteen vetiver bundles from Vetiver Farms Philippines were propagated in a hydrophonic set-up in soapy standing water for 28 days. The roots were allowed to grow to a length of 0.25m, washed and dried to clean out excess soil particles, and prepared for experimental use. Preparation for experimental use included selection of root bundles, trimming of leaves, and removal of charred pieces from the plant bundles.

2.2 Particle Size Reduction

Silt introduced into the system is of nickel lateritic origin that has been reduced in particle size. The nickel laterite soil was damp and needed to be dried. Hence, it was air dried for 1 day, oven dried for 10 hours at 110^{o}C, and then placed into the ball mill for 20 min. It was then placed in a series of sieves and rotap for 20 min. Particles of size less than 63μm were used in this study.

2.3 Experimental Design

A 0.5m by 0.25m by 0.25m plexiglass box with a 0.25m movable ramp at the front and end of the system was created with a removable reservoir placed above the ramp. A

discharge reservoir was installed below the end ramp. A metal grill was placed above the box system that served as a placeholder for the vetiver system which were placed in rows.
Three systems were used to determine the control set-up, effect of varying root density with constant silt concentration, and effect of varying silt concentration in constant root density.

Table 1. Systems with the corresponding vetiver density and silt concentration

System No.	Vetiverdensity	Amount of silt introduced (g)
1	0	50
	0	100
	0	150
2	1 row	100
	2 rows	100
	3 rows	100
3	4 rows	50
	4 rows	100
	4 rows	150

For every system, silt is introduced into the discharge reservoir where a pump circulates silted water into the inflow reservoir; it is made to flow into the ramp and then passes into the VRS. The filtered water exits the whole system via a horizontal ramp and falls into the discharge reservoir. The water is circulated for three hours.

Figure 1. Set-up System 1: No Vetiver System, 100 g silt circulated

Figure 2. Set-up System 2:3 rows of vetiver, silted water not yet circulated

Figure 3. Set-up System 3: 4 rows vetiver, 100 g silt circulated

2.4 Sampling

The flow rates are also monitored closely. Grab sampling is employed at random by collecting data at 30 min after the start of running the set-up, then 1 hr, 2 hr, and 3 hr marks after the start of the run. A timed collection of 500 ml of silted water from the inflow reservoir is made for the inflow rate. Another timed collection of 500 ml of silted water from the discharge reservoir is made for the outflow rate. The water collected is then returned slowly into their respective reservoirs.

2.5 Data Analysis

One hundred ml samples of discharge water is taken every hour. This determines if the concentration of silt has been lessened by the vetiver system. After each run, fluid from the discharge reservoir is removed. The water, along with the trapped silt in the vetiver system is collected. The root system is washed carefully, removing excess silt and collected into a collecting tub.

The water from the system is then allowed to settle for atleast 6hr and is then decanted, filtered, oven dried and weighed. Samples are collected and are made to settle and decanted and then filtered to collect the silt. The filters are oven dried and weighed.

Data collected includesthe flow rates of each set-up for all systems at hourly intervals, silt content in samples collected every hour, and the amount of silt trapped and accumulated in the main system. These data are tabulated and compared to each system. The ANOVA Single Factor of Variance with 5% degree of probability is used to determine if the presence of the VRS has created significant change in silt accumulation.

3. Results and Discussion

For the no vetiver system, three (3) set-ups were used: 50 g, 100 g and 150 g of silt. As seen on Figure 4, the least amount of silt, which is set-up A, obtained the least amount of suspended solids throughout the experiment. The same with set-up C, which also had the highest content of silt after the 3-hr running time. Furthermore, for set-up A, it can be seen that the amount of suspended solids did not relatively change with respect to time as compared to the other two set-ups. It can be concluded that most of the 50 grams of silt did not settle in the main reservoir, rather it just kept circulating around the system. For set-ups B and C, there is a downward slope which means that there is still settling despite the absence of any barriers. Based on this set-up it can be seen that the amount of silt introduced in the system is proportional to the amount of remaining suspended solids per unit time, and the more silt introduced in the system, the higher the tendency was for the silt to settle.

For the second system,consisting of varying vetiver with constant silt concentration, the mean silt concentration of 100g was chosen as a constant for System 2. During the first hour, set-up A had the highest amount of total suspended solids collected in the discharge container; however, after the succeeding 47 min until the remaining hours, set-up B, with two rows of vetiver, emerged to have the highest amount of total suspended solids, having a short lead of 0.108g during the second hour and 0.073gin the third hour sampling. The quantitative difference between set-ups A and B was not that huge, which implies that two rows of vetiver do not really vary with one row of vetiver. In order to produce appreciable results, set-up 3 with three rows of vetiver must be used.

For the third system, the graph produced depicts similar trends to the graph of System 1; but with a major difference on the amount of silt collected during sampling. Using Table 2, the difference of the two set-ups and the amount of suspended solids in the discharge container are tabulated. It can be seen how vetiver has aided in the accumulation and settling of silt.

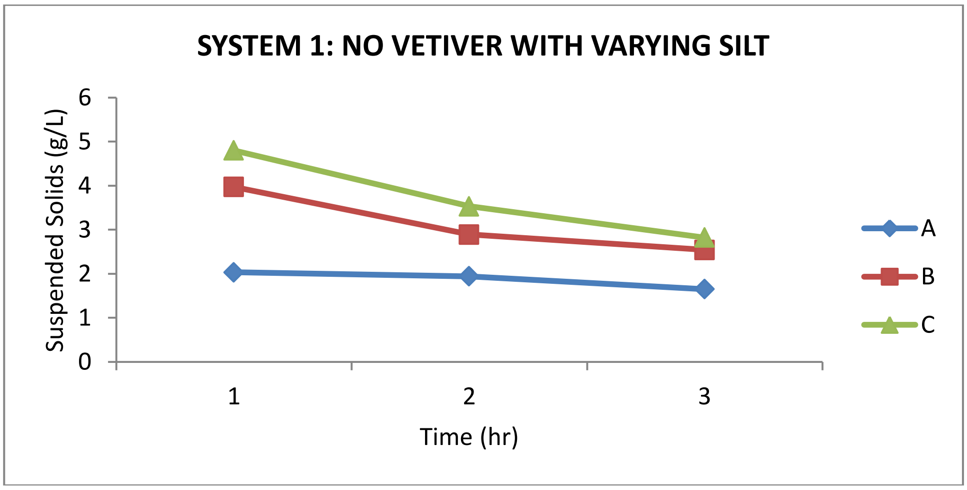

Figure 4. System 1: No vetiver with varying silt concentration. Set-up A with 50 g of silt; Set-up B with 100 g of silt; and Set-up C with 150 g of silt

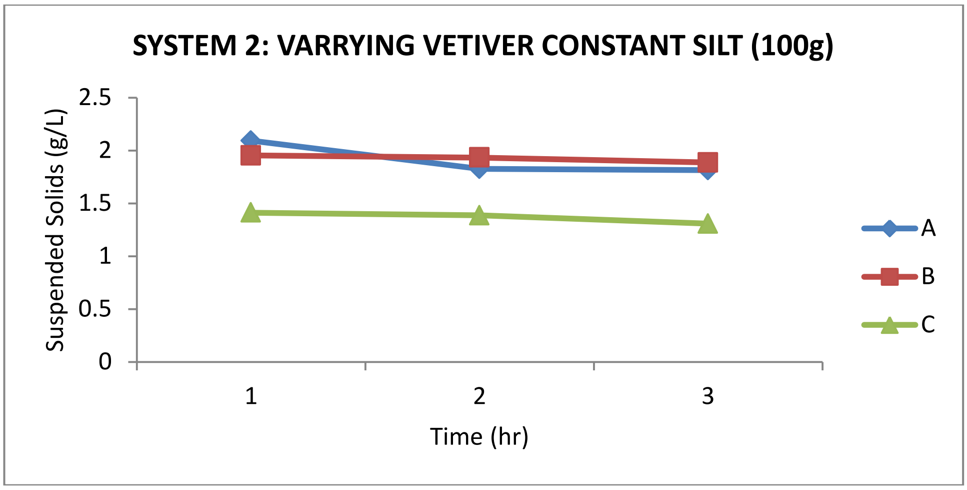

Figure 5. System 2: Varying number of vetiver with constant silt (100g). Set-up A with 1 row of vetiver, Set-up B with 2 rows of vetiver, and Set-up 3 with 3 rows of vetiver

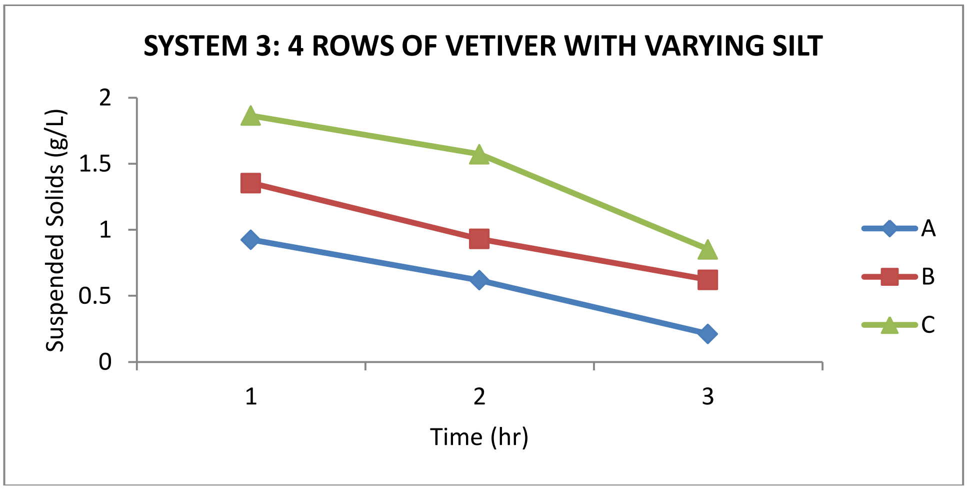

Figure 6. Set-up 3: 4 rows of vetiver with varying silt. Set-up A with 50g of silt; Set-up B with 100g of silt; and Set-up C with 150g of silt

Table 2. Difference between the suspended solids of the four (4) vetiver rows and without vetiver

Silt concentration	Time (hr)	No vetiver (g)	4 Rows of vetiver (g)	Difference (g)
50 g	1	2.03	0.92	1.11
	2	1.94	0.92	1.02
	3	1.65	0.21	1.44
100 g	1	3.97	1.86	2.11
	2	2.89	1.57	1.32
	3	2.54	0.85	1.69
150 g	1	4.80	1.35	3.45
	2	3.53	0.93	2.60
	3	2.82	0.62	2.20

Tabulation of the silt accumulated at the main reservoir for 3-hours:

Tables3-5. Weight of the accumulated silt during the 3-hr run for the three systems analyzed.

SYSTEM 1. NO VETIVER, VARYING SILT		
Silt (g)	Rows of vetiver	Total accumulated silt (g)
50	0	16.78
100	0	40.56
150	0	59.06

SYSTEM2. VARYING VETIVER, CONSTANT SILT (100g)		
Silt (g)	Rows of betiver	Total accumulated silt (g)
100	1	55.39
100	2	60.95
100	3	75.54

SYSTEM 3. VARYING SILT, 4 ROWS OF VETIVER		
Silt (g)	Rows of vetiver	Total accumulated silt (g)
50	4	25.86
100	4	80.32
150	4	104.28

The silt accumulated at the main reservoir for the three (3) systems was recorded in Tables 3-5. Taking a look at Table 3, despite the absence of silt barriers such as vetiver, a mass of silt accumulated in the main reservoir which explains the silt's natural tendency to settle at low energy environments. To find how much the four (4) rows of vetiver changed the system, we used this equation:

$$Percent\ Change = \frac{Mass\ Accumulated_4 - Mass\ Accumulated_0}{Mass\ Accumulated_0}\ x\ 100$$

Table 6. Percent of change from zero to four rows of vetiver

Silt (g)	No. of rows	Mass $(g)_0$	Mass $(g)_4$	Percent ofchange (%)
50	0-4	16.78	25.86	54.11
150	0-4	59.06	104.28	76.57

Given the data presented in Tables 6 and 2, it can be concluded that the more vetiver placed in the system, the more it is capable to trap and filter silt, as depicted in Figure 7, from zero vetiver to four rows of vetiver, using the 100g of silt concentration.

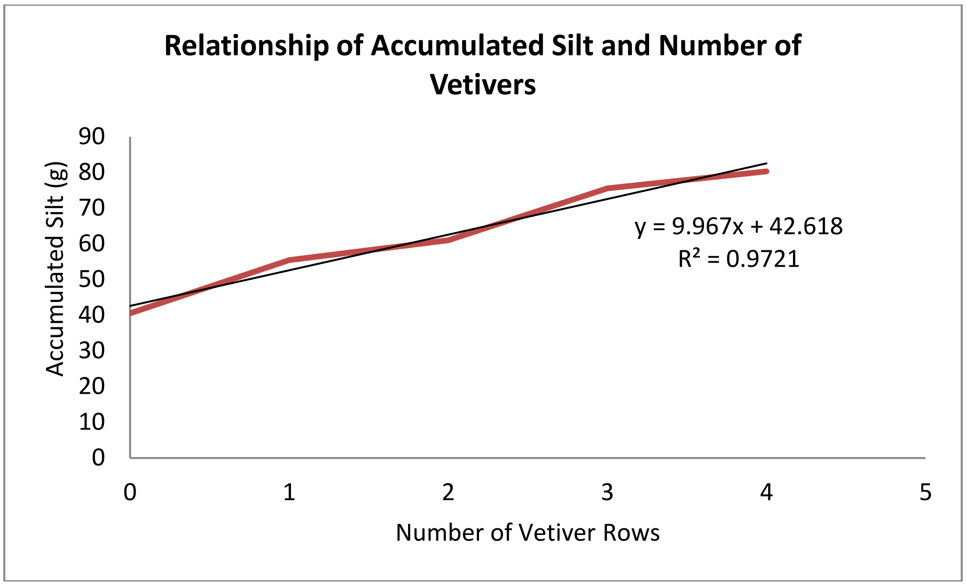

Figure 7. Relationship of accumulated silt and number of vetiver

In order to find out how much the vetiver roots changed the velocity, the inflow and outflow of System 3 have been keenly monitored using the equation:

$$Flow\ Rate = \frac{Volume}{Time}$$

During the experiment the inflow rates were kept constant as much as possible. All set-ups were consistent in having an outflow rate lower than the inflow rate, having the average change of flow calculated as follows: 1.52E-05 m^3/s.

Manning's Equation for open channel flow was also used to compute for the velocity at the removable ramp, main reservoir and at the discharge ramp. Using the following equations:

$$V = \frac{1}{n}R^{\frac{2}{3}}S^{\frac{1}{2}} \quad R = A/P$$

Where:

V = Velocity

n = Manning's roughness coefficient

*0.01 for smooth surfaces

*0.1 for natural channel with heavy brush

R = Hydraulic radius

S = Slope

A = Area

P = Wetted perimeter

The three areas were determined to have 0.702 m/s, 0.155 m/s, 0.271 m/s velocity at the removable ramp, main reservoir and at the discharge ramp, respectively. The very small velocity at the main reservoir was due to the presence of vetiver roots which aided in the faster settling of silt.

* Manning's roughness coefficient values taken from http://udel.edu/~inamdar/EGTE215/Open_channel.pdf

Finally, inorder to find out if there was a significant difference between the set-ups conducted, the researchers used a Single-Way Anova as statistical treatment. The data is tabulated below.

Table 7. Tabulation of the Anovacalculation of all the 100g set-ups

Rows of vetiver	F value	F critical value	Conclusion	
0-1	7.739	7.709	Reject Null Hypothesis	There is no significant difference
0-2	7.881	7.709	Reject Null Hypothesis	There is no significant difference
0-3	16.728	7.709	Reject Null Hypothesis	There is no significant difference
0-4	20.366	7.709	Reject Null Hypothesis	There is no significant difference
1-2	0.023	7.709	Accept Null Hypothesis	There is a significant difference
1-3	31.706	7.709	Reject Null Hypothesis	There is no significant difference
1-4	16.655	7.709	Reject Null Hypothesis	There is no significant difference
2-3	223.321	7.709	Reject Null Hypothesis	There is no significant difference
2-4	20.129	7.709	Reject Null Hypothesis	There is no significant difference
3-4	3.485	7.709	Accept Null Hypothesis	There is a significant difference

From the data presented, most of the set-ups have a significant difference except for set-ups 1-2 and 3-4 which means that from one row to two rows of vetiver and three rows to four rows, the amount of suspended silt on the discharge container didnot differ much from each other. From Figure 5, System 2, it was shown that set-ups A and B had a very small difference; thus, from these Anova values, it can be articulated that they don’t significantly vary. As for Figure 5, System 2, set-ups B and C, which have two rows and three rows of vetiver, results vary significantly from each other as depicted with an F value of 223.32.

4. Conclusion

The researchers propose the use of vetiver as silt barriers in controlling runoff from open pit mines. The Vetiver Root System (VRS) was employed by containing the vetiver roots averaging 24 inches in length in a main reservoir that serves as a small partition of a settling pond. A second reservoir was constructed to function as both inflow and outflow containers. The research’s objectives were to utilize vetiver as a silt barrier for open pit mines, decreasing the silted water velocity when passing through the VRS, and to determine the relationship of vetiver density and efficiency as a barrier.

Upon conducting according to the methodology, the researchers were able to find out from Systems 1 and 3 that the amount of silt introduced into the system was proportional to the amount of suspended solids and total amount of silt accumulated for three hours. Furthermore, it was also observed that despite the absence of vetiver, silt has its natural tendency to settle. However, upon inclusion of vetiver, the amount of total silt collected in the discharge reservoir significantly decreased as compared to no vetiver at all, consistent with the sampled suspended solids of System 3 which emerged to have lower amounts compared to

System 1.

From System 2, densities of vetiver were varied by changing the number of vetiverrows present in the set-up. By checking Figure 7, an almost linear relationship can be observed between the number of vetiver rows and the amount of accumulated silt, with a coefficient of determination (R^2) equal to 0.972. From there, it is apparent how the presence of vetiver aided in the settling and accumulation of silt.

Inflow and outflow rates have been strictly monitored, and from all the set-ups outflows were always slower than inflows. These measurements were due to the vetiver roots which lowered the velocity of the inflow, thereby encouraging settling.

From the Anova Single Factor calculations, it is evident that there is a significant difference between the no vetiver and the four vetiver rows system. Due to the fact that the three rows of vetiver did not vary significantly to four rows of vetiver, the researchers were able to conclude that the most efficient number of vetiver rows to be used is three.

Observing the behaviors from all the set-ups, it was analyzedthat the vetiver roots helped in lessening the velocity of inflow, thereby encouraging settling; thus, it can be concluded that vetiver roots can be used as silt barriers and this new system, if used in a mine setting,would introduce a viable solution to the Mining industry's number one problem which is siltation. Through this method, environmental impacts and health risks caused by siltation would be minimized, thereby promoting responsible mining for sustainable development.

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BIODATA

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