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# Estimation and Assessment of Carbon Sequestration Stocks in Topsoils of Reclaimed and Revegetated Mined-Land in Mineral Extraction Site in Bunawan, Davao City

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**Abstract.** Carbon (C) emissions from mining and industrial activities can potentially contribute to global warming. To compensate for CO2 released into the atmosphere increased by mines, an independent secondary forest assessment was carried out on reclaimed post-mining land based on its natural mode of atmospheric sequestration. This study aimed to explore the potential C sequestration activity of reclaimed post-mining land with 3–20 years secondary reforestation. This site-specific study was conducted in 47 ha of reclaimed mining land at Bunawan, Davao City of Holcim Mining and Development Corporation. Based on the vegetation types, the study areas were divided into five (5) different locations. The prevalent vegetation was bamboo (Fargesia rufa), Falcata (Paraserianthes falcataria), Lawaan (Shorea contorta Vidal) and Narra (Pterocarpus indicus). Topsoil grab sampling methods were performed in three trials in three replications. Soil pH, bulk density and percentage of organic carbon (percent organic carbon) was analysed from the test samples applying routine laboratory methods. The study found the pH of topsoils from the five sites to be 5.9-6.0 in the range. This is an advantageous condition as most of the plants are good in pH at 6.0 – 7.0, which is moderately acidic to neutral. Bulk density values of 0.862-1.069 g/cm3 might reflect soil high nutrient supply. Site organic carbon concentration was in the range of 2.04–3.00% which reflects the cumulative carbon sequestered potential 429.94Mg/ha and on average 86.0Mg/ha per area. Land with the most sequestration of carbon was recorded during the 20 years of reforestation when Lawaan (Shorea contorta Vidal) and Narra (Pterocarpus indicus) prevailed vegetation. According to the obtained

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studies it can be inferred that CO2 flux increases with the aging time of the planting process. The recommendations for protecting previously reclaimed mined areas to be further improved with regrading, topsoiling, and plantation are as follows: to enhance initial soil formation as well as to increase the terrestrial C pool on reclaimed fields.

# 1 Introduction

Carbon sequestration is the long-term storage of carbon in plants, soils, geologic formations, and the ocean. Considering the increasing concern that climate change will increase due to increased carbon dioxide in the atmosphere, this topic received much attention while land use and forestry activities are proposed to increase the capacity of carbon sequestration [1]. The Kyoto protocol pledged to cut global emissions of greenhouse gases (GHGs) by at least 18% below the 1990 level between 2013–2020. Deforestation and land degradation due to anthropogenic activities like surface mining can contribute to greater carbon dioxide (CO2) emission to the Earth. Even if surface mining can degrade environmental quality, it will enable the study of regenerating ecosystems in post-mining sites. A crucial role to be played by atmospheric carbon (C) sequestering in the soil, and biomass plays an integral vital role in combating global warming [2], is revealed by the excavation of post mining land. Surface mining completely removes vegetation, topsoil and subsoil cover, which reduces the C stock significantly, decreases soil fertility and destroys the C sink [3].

In the recent past, it is not simply redeveloping the forest anymore; there is an increasing focus on analyzing the health of reforested land and for assessing the revegetated sites' C sequestration capability by field examination. Since C sequestration in mine soil predominantly relies on SOC accumulation, this has been explored through numerous approaches to quantify soil C stock [4]. Differences in the C pool can be attributed to varied geographical conditions. In this project, under HOLCIM's operations quarry sites are actively being rehabilitated, with the aim of restoring quarry sites to a condition nearly, if not exactly, identical to that of pre-quarry operations. The plants and the other trees were planted and manipulated not just to manage the earth but to restore the native microfauna and flora of the land. Once the suitable vegetation is established, cohorts of animals and other plants also will start to establish, increasing CO2 flux. That is at least the assumption. Sure, the best way in general to test this assumption so you can determine whether goals for rehabilitation are being met or not is to go to these sites and do surveys.

The formation of forest cover on post-mining land is always a difficult endeavour. This includes mine soil fertility recovery, improvement of soil characteristics, vegetation cover re-establishment, nutrient enrichment, and improved biomass productivity.

# 2 Materials and Methods

## 2.1. Site Description

The existing vegetation within the concession area of HOLCIM Philippines in Bunawan District, Davao City is predominantly an agricultural area planted mostly with coconut trees. Reforestation efforts were also observed, especially with the quarry area, using the fast-growing introduced species of *Acacia auriculiformis* (auri), *Gmelina arborea* (melina or yemane), *Fargesia* rufa (Bamboo), *Paraserianthes falcataria* (Falcata), *Shorea contorta* Vidal (Lawaan) and *Pterocarpus indicus* (Narra). In the early $19^{th}$ century, the area may have been part of the vast dipterocarp forest which was characterized under 'tropical lowland evergreen rain forest' type of formation. Dipterocap forest is present in Davao Gulf and in the Island City of Samal, which is located on the opposite side of Metropolitan Davao, of which the Bunawan Concession is a part. Although the Island City of Samal was characterized as forest over limestone, the physiognomy of the Bunawan area was very different.

## 2.2. Sample Collection

The present project was conducted from reclaimed post mining land of Holcim Mining and Development Corporation in Bunawan, Davao City. The study areas were segmented to five (5) different sites based on years of rehabilitation and the types of vegetation, with Bamboo (*Fargesia* rufa), Falcata (*Paraserianthes falcataria),* Lawaan (*Shorea contorta* Vidal) and Narra (*Pterocarpus indicus*) as the dominant vegetations. Grab sampling technique for topsoils (0-10cm) in pre determined areas was done in three trials and in three replications.

## 2.3. Laboratory Procedures

To obtain soil samples from reclaimed sites, the samples were dried by air for 2-3 weeks. After drying the soil was ground by a mechanical mortar-pestle model and passed through a 12-mesh (roughly 2 mm) screen [5]. The soil pH and bulk density were determined in the first analyses. The composition of soil organic carbon (SOC) is examined by means of the rapid oxidation method of $K_2Cr_2O_7$–$H_2SO_4$ [6]. More precisely, soil pH was determined by means of potentiometric methods from the soil-to-water ratio of 1:2 (deionized water suspension) after 24 h. Total organic carbon (TOC) was determined by the same $K_2Cr_2O_7$–$H_2SO_4$ rapid oxidation method. The soil bulk density (BD) was measured by placing dry, undisturbed soil samples into a glass measuring beaker of known volume, then the weight of the soil (g) divided by its volume ($cm^3$), with values converted to $Mg/m^3$.

## 2.4. Computation of Carbon Sequestration

Carbon sequestration was computed using mathematical equations based on the percentage of soil organic carbon (SOC) in the test samples. The SOC percentage was calculated using the following equation:

$SOC$ % = = (10.5 - (Vpx × N × F × AS)) × 0.3 Equation 1

The SOC stock of the revegetated sites was then determined by incorporating SOC concentration, corrected bulk density, and the thickness of the soil layer, as shown below:

$$\text{SOC stock (Mg/ha)} = (\text{SOC\%} \times \text{BD (Mg/m}^3) \times \text{T (m)} \times 10^4) / 100 \quad \text{Equation 2}$$

where SOC is soil organic carbon concentration, BD is the corrected bulk density, and T is the thickness of the soil layer. The total carbon sequestration potential of the study area was calculated by summing the estimated carbon sequestered in soils within the 0–10 cm depth. The corresponding amount of CO2 sequestered (Mg ha−1) by the revegetated sites was determined based on the ratio of carbon in CO2 using the equation:

$$CO_2 \text{ sequestered (Mg ha}^{-1}) = \text{Carbon stock (Mg ha}^{-1}) \times 3.666 \quad \text{Equation 3}$$

Statistical analysis was performed by expressing the results as mean ± standard deviation (SD). Differences between means were evaluated using one-way and two-way analysis of variance (ANOVA), followed by Tukey's HSD test, with the level of significance set at $P < 0.05$.

## 3 Results and discussion

### 3.1. Dominant Vegetation

Tree species characteristics and spread of the tree species may have a great impact on soil and C stock [7]. Thus, tree species choice for mine reclamation, and the role of trees in C sequestration is necessary. List of tree species on revegetated reclaimed mining area are shown in Table 1.

**Table 1.** Dominant Vegetation of Reclaimed Areas

| Site/Location | Years Reclamation | Land area, Ha | Dominant Vegetation | Scientific name |
|---|---|---|---|---|
| Adlawan | 2-3 | 4.0 | Bamboo | *Fargesia* rufa |
| Cabonila | 9 | 3.5 | Falcata | *Paraserianthes falcataria* |
| Gotera | 10-11 | 21.3 | Lawaan | *Shorea contorta Vidal* |
| Marquez | 10-11 | 13.5 | Lawaan | *Shorea contorta Vidal* |
| Roxas | 20 | 4.22 | Narra, Lawaan | *Pterocarpus indicus, Shorea contorta Vidal* |

The dominant vegetation of five newly reclaimed mining sites, according to table 1, was Bamboo (*Fargesia rufa*), Falcata (*Paraserianthes falcataria*), Lawaan (*Shorea contorta Vidal*), Narra (*Pterocarpus indicus*), which exhibited more than 80% of the total biomass C stock. The vegetation was supposed to have contributed significantly to total biomass C stock. A soil's sequestration potential will depend on the vegetation it maintains, its mineralogical mix, soil depth, soil drainage, water and air content and temperature [8]. The International Network for Bamboo and Rattan (INBAR) indicated the carbon storage potential of bamboo. In particular the report reveals how bamboo products are able to 'save' carbon by replacing cement, plastics and a number of other more emissions-intensive materials. Thus, bamboo is more efficient as a carbon storage material than the other trees.

Due to their fast growth rates, giant woody bamboos "are already thought to be effective CO2 absorbers". A thriving bamboo, as the report highlights, stores approximately the same amount of carbon as tree plantations - 100-400 tonnes per hectare [9]. Falcata based agroforestry system with total carbon stocks was 43.85, 51.93, and 67.36 tC/ha for the poor, average and good standing plots, as described by Malayao and Mendoza (2013) (Plots 1, 2, 3). This demonstrates that Falcata is a leguminous tree that grows quickly and bioaccumulates high biomass because of the uniform distribution of rain and a rich water supply in the site. It also demonstrated the ability to deliver ecological services, such as carbon sequestration, whilst giving considerable benefits.

Alternatively, diversified tree species on the plantation could increase CO2 sequestration: additional tree species added to the plantation could increase total carbon stocks by 6 percent. Afforestation programs that encourage trees to sequestered CO2 away from the atmosphere should evolve from a single plant species to a wider variety of plants, it was found. Planting a variety of trees as well could also bring many other advantages, offering habitats for a larger number of animals [10].

## 3.2. Soil Properties

The physico-chemical properties of collected soil samples (0-10cm depth) were analyzed based on pH, bulk density and % organic carbon. Results are shown in Table 2.

**Table 2.** Soil pH, bulk Density, and soil Carbon of Reclaimed Areas in Holcim Mining

| Site/Location | Replicate | Source | pH (1:2 in water) | Bulk Density ($g/cm^3$) | % Soil Carbon[b] |
|---|---|---|---|---|---|
| Adlawan | 1 | 0-10 cm | 5.9 ±0.10 | 0.864 ±0.0 | 2.12 ±0.07 |
| | 2 | 0-10 cm | 6.0 ±0.0 | 0.863 ±0.0 | 2.04 ±0.04 |
| | 3 | 0-10 cm | 6.0 ±0.10 | 0.862 ±0.0 | 2.25 ±0.19 |
| Cabonilla | 1 | 0-10 cm | 6.0 ±0.10 | 0.997 ±0.0 | 2.49 ±0.02 |
| | 2 | 0-10 cm | 6.1 ±0.10 | 0.995 ±0.0 | 2.45 ±0.06 |
| | 3 | 0-10 cm | 6.0 ±0.0 | 0.996 ±0.0 | 2.48 ±0.08 |
| Gutera | 1 | 0-10 cm | 6.4 ±0.10 | 0.849 ±0.0 | 2.56 ±0.04 |
| | 2 | 0-10 cm | 6.3 ±0.10 | 0.854 ±0.0 | 2.51 ±0.06 |
| | 3 | 0-10 cm | 6.4 ±0.10 | 0.857 ±0.0 | 2.55 ±0.02 |
| Marquez | 1 | 0-10 cm | 5.9 ±0.10 | 0.909 ±0.0 | 2.55 ±0.02 |
| | 2 | 0-10 cm | 6.0 ±0.10 | 0.916 ±0.0 | 2.56 ±0.04 |
| | 3 | 0-10 cm | 6.0 ±0.10 | 0.924 ±0.01 | 2.55 ±0.05 |
| Roxas | 1 | 0-10 cm | 5.9 ±0.10 | 1.069 ±0.0 | 3.00 ±0.04 |
| | 2 | 0-10 cm | 5.9 ±0.10 | 1.060 ±0.01 | 2.96 ±0.07 |
| | 3 | 0-10 cm | 5.9 ±0.10 | 1.047 ±0.0 | 2.95 ±0.02 |

[a]Avg value ± SD
[b]By rapid dichromate digestion

Results showed that the topsoils obtained were mildly acidic with pH values varying between 5.9-6.4. This decrease in soil pH with age of revegetation can be explained by organic C accumulation and release of organic acid into the soils [11]. A trend of increasing bulk density with respect to age of revegetated sites showed the range of 0.862-1.069. Hence, in early successional phase, soil moisture and bulk density support vegetation establishment. The topsoil application may facilitate this [12].

On the other hand, soil organic carbon (%) varied from 2.04 to 3.0%. The growth of trees and its organic matter input into the soils can explain the increase in SOC concentrations relative to years of revegetation. Similarly, the differential distribution of soil particles in mine spoils might have played a role in the soil organic carbon (SOC) content variation. Furthermore, with the increasing age level of the site, high SOC increases in the present study can be seen, which implies that the process of soil carbon deposition increases in reclaimed sites. These results indicate that both soil composition and period of site recovery are influential in SOC.

### 3.3. Statistical analysis

To determine if there is an existing significant difference on the topsoil physical-chemical properties from revegetated mine sites, One-Way Analysis of Variance was utilized and results are shown in Table 3.

**Table 3** Testing Significant Difference of Soil pH, Bulk Density, and Soil Carbon for the Reclaimed Areas in Holcim Mining

| Test Parameters | F value | P value | Remarks |
|---|---|---|---|
| pH | 38.50 | 0.0001 | Significant |
| Bulk Density | 593.64 | 0.0001 | Significant |
| SOC | 100.78 | 0.0001 | Significant |

The results of statistical analysis indicated that there is already a significant ($p<0.05$) difference between the topsoil pH, bulk density, and % soil organic carbon in the five areas investigated. These differences were attributed to differences in years of reclaimed revegetation and types of plantation. This clearly indicates that establishment and growth of various trees and age of revegetation has a significant impact on ecosystem C.

The age of revegetation is the major sink of C in the reforested/revegetated mined land for this study since it sequesters significant amounts of total C over a period of time.

### 3.4. Carbon Dioxide ($CO_2$) Sequestered

To assess the potential of C sequestration of topsoils from reforested mine lands, computation of total CO2 sequestered was done and shown in Table 4.

**Table 4** Carbon Dioxide ($CO_2$) Sequestered from Reclaimed Areas

| Area | Years of Reclamation | | Carbon Dioxide Sequestered (Mg/ha) | | | |
|---|---|---|---|---|---|---|
| | | N | Mean | Std. Deviation | Minimum | Maximum |
| Adlawan | 2-3 | 3 | 67.55 | 3.3757 | 64.44 | 71.14 |
| Cabonilla | 9 | 3 | 90.27 | 0.8347 | 89.36 | 91.00 |
| Gutera | 10-11 | 3 | 79.31 | 0.8168 | 78.39 | 79.95 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Marquez | 10-11 | 3 | 85.59 | 0.7503 | 84.74 | 86.16 |
| Roxas | 20 | 3 | 115.10 | 2.2030 | 113.01 | 117.40 |

Results of the study showed that C sequestered in 5 sites ranged from 67.55 to 115.10 Mg/ha according to the study results. The highest level of CO2 sequestered found on the oldest revegetated site (Roxas, mixed trees species) was two times higher than on the youngest sites. It indicates that the C content increased greatly with the age of the site, which is believed to be predominantly attributable to tree growth.

The high differences of the C in sequestration values can also be attributed to substrate type, tree species as well as age of the revegetation. The also higher SOC with respect to vegetation age suggests the trees are more able to build up high concentration of C, being retained in their soils. The average in situ CO2 sequestration in the reclaimed mine site for the present investigation was determined to be 87.56 Mg C ha−1. The C sequestration rate for the current study was slightly higher than that of the other studies possibly due to the age of revegetation, geo-climatic conditions and tree species used for revegetation [13]. The overall trend of the soil C with respect to the stand age of revegetation is in line with the other studies of tropical ecosystems.

### 3.5. Statistical Analysis

To determine if there is an existing significant difference on the carbon dioxide (CO2) sequestered from reclaimed areas, One-Way Analysis of Variance was utilized and results are shown in Tables 5 and 6. Correlational analysis was done and shown in Table 7.

**Table 5** Testing Significant Difference of Carbon Dioxide ($CO_2$) Sequestered from Reclaimed Areas

| Area | Years of Reclamation | N | $CO_2$ Sequestered (Mg/ha) | SD | F value | P value | Remarks* |
|---|---|---|---|---|---|---|---|
| Adlawan | 2-3 | 3 | 67.55 | 3.3757 | | | |
| Cabonilla | 9 | 3 | 90.27 | 0.8347 | | | |
| Gutera | 10-11 | 3 | 79.31 | 0.8168 | 255.419 | 0.0001 | Significant |
| Marquez | 10-11 | 3 | 85.59 | 0.7503 | | | |
| Roxas | 20 | 3 | 115.10 | 2.2030 | | | |

*Calculation was performed at the 0.05 level of significance

**Table 6** Multiple Mean Comparison Test of Carbon Dioxide ($CO_2$) Sequestered from Reclaimed Areas

| (I) Types of Area | (J) Types of Area | Mean Difference (I-J) | P value | Remarks* |
|---|---|---|---|---|
| Adlawan | Cabonilla | -22.72000* | .000 | Significant |
| | Gutera | -11.76000* | .000 | Significant |
| | Marquez | -18.04000* | .000 | Significant |
| | Roxas | -47.54667* | .000 | Significant |
| Cabonilla | Adlawan | 22.72000* | .000 | Significant |
| | Gutera | 10.96000* | .000 | Significant |
| | Marquez | 4.68000* | .013 | Significant |

| | | | | |
|---|---|---|---|---|
| | Roxas | -24.82667* | .000 | Significant |
| Gutera | Adlawan | 11.76000* | .000 | Significant |
| | Cabonilla | -10.96000* | .000 | Significant |
| | Marquez | -6.28000* | .002 | Significant |
| | Roxas | -35.78667* | .000 | Significant |
| Marquez | Adlawan | 18.04000* | .000 | Significant |
| | Cabonilla | -4.68000* | .013 | Significant |
| | Gutera | 6.28000* | .002 | Significant |
| | Roxas | -29.50667* | .000 | Significant |
| Roxas | Adlawan | 47.54667* | .000 | Significant |
| | Cabonilla | 24.82667* | .000 | Significant |
| | Gutera | 35.78667* | .000 | Significant |
| | Marquez | 29.50667* | .000 | Significant |

*Calculation was performed at the 0.05 level of significance

**Table 7** Correlation of Carbon Sequestration with Age of Revegetation

| Years of Reclamation | Carbon Dioxide Sequestered/Stocks | Pearson R | Remarks |
|---|---|---|---|
| 3 | 67.55 | | |
| 9 | 90.27 | | |
| 10 | 79.31 | 0.922 | Positive, Very High Correlation |
| 10 | 85.59 | | |
| 20 | 115.10 | | |

Statistical analysis results made it evident that there is an existing significant difference on the CO2 sequestration potential of various revegetated mine sites. Of these, the highest CO2 sequestration was recorded in Roxas area by 41.3%, 21.6%, 31.1% and 25.6% as compared to Adlawan, Cabonila, Gutera and Marquez, respectively. Roxas has at least 20 years of revegetation having a mixed tree species. These findings validate previous measurements [14], which found that on average mixed, sustainably managed plantations have 67.5% more ecosystem carbon than traditional pure conifer plantations. It was further reported that if all pure plantations were gradually converted into mixed plantations over the next 10 years, carbon stocks could increase by 260.22 TgC by 2050.

Further analysis revealed a strong positive and significant relationship (R = 0.922) between the age of vegetation and carbon sequestration. This indicates that as vegetation matures, its capacity to sequester carbon increases, likely due to greater biomass accumulation and enhanced ecosystem development over time. These findings suggest that both stand age and vegetation growth play important roles in influencing carbon sequestration.

Based on the types of planted species, the results of this study indicate that there is no direct evidence suggesting that plant species composition alone significantly enhances carbon sequestration in the area. This implies that carbon storage may not necessarily depend on species diversity, but rather on other factors such as biomass accumulation and stand development. However, the findings also suggest that a small number of dominant species may contribute disproportionately to overall carbon stocks, highlighting the importance of species performance and growth characteristics rather than diversity alone in influencing carbon sequestration.

The current C increase could be maintained in the long run by increasing soil organic carbon, planting plants with long life spans. The level of SOC

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sequestration, and the magnitude and quality of soil C stocks, are influenced by the intricate interaction of climate, soils, tree species and management as well as chemical composition of the litter as determined by the dominant tree species [15].

## 4. Conclusions

The present research determined the C sequestration of five (5) areas in Holcim Mining Development Corporation in Bunawan, Davao City, from revegetation of post mining sites according to the chronosequence of plantation. Results indicated that mine soil quality had increased with time and recovered significant concentration of organic carbon. Soil organic carbon in the region was between 2.04 and 3.00% showing cumulative carbon sequestration of 429.94Mg/ha with a mean of 86.0Mg/ha per area. The highest carbon sequestered land was found at 20 years of reforestation with mixed tree plantations of Lawaan (*Shorea contorta Vidal*) and Narra (*Pterocarpus indicus*). As indicated in the results, the CO2 flux had an increased rate with age of revegetation irrespective of tree species planted. These findings suggest that rehabilitation methods should encompass proper regrading, topsoiling of backfilled dumps and subsequent planting of selected tree species to promote early development of the soil and to increase terrestrial C pool.

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