International Journal of Scientific Research in Biological Sciences **Research Paper**
Vol.9, Issue.2, pp.01-07, April (2022) **E-ISSN:** 2347-7520

Evaluating Species Diversity and Aboveground Biomass Carbon at Bindura Nickel Tailings Dumps Rehabilitated with *Acacia saligna* (Labill) Trees

Lawrence Mango

Department of Agriculture Management, Zimbabwe Open University, Bindura, Zimbabwe

Author's Mail Id: lawrencemango@gmail.com, Tel.: +263773416375

Available online at: www.isroset.org

Received: 09/Jan/2022, Accepted: 10/Feb/2022, Online: 30/Apr/2022

***Abstract*—** Disposal of mine tailings on the ecosystem can cause alterations in plant productivity. A study was carried out to assess the effects of grass, herbaceous and woody diversity, and aboveground biomass C on nickel mine tailings dumps with 19, 22, 24 and 26-years old *Acacia saligna* trees at Trojan Nickel mine, Zimbabwe. The total counting method was used to determine the number of individual herbaceous and woody species. The Braun Blanquet abundance and cover scale was used for the diversity of grass species while the Shannon-Wiener Diversity Index (H') was used to determine diversity of herbaceous and woody species among the mine tailings dumps. Aboveground biomass C data was estimated from allometry equations using tree height, diameter at breast height and wood density measurements. Analysis of variance was used to determine mean aboveground biomass C with difference in tree age. The aboveground biomass C including surface litter increased significantly ($p<0.05$) with the age of *A. saligna* trees on tailings' dumps. The diversity of herbaceous, woody and grass species increased with the age of *A. saligna* trees. Herbaceous species diversity was highest (H'=2.21) in the tailings' dump with 26-years old *A. saligna* trees while the tailings' dump with 22-years old *A. saligna* trees recorded the least species diversity (H'=1.87). Re-vegetation of mine tailings should be considered in ecological restoration. However, aboveground biomass C content of different plant species thriving on mine tailings' dumps has to be studied in order to determine the mine tailings' dump ecosystem C stocks. The study also recommends an in-depth research on seasonal diversity of specific species on mine tailings' dumps.

Keywords— Aboveground biomass carbon, allometry equations, carbon sequestration, species diversity, wood density

I. INTRODUCTION

Globally, forests of the tropics are crucial components of the carbon cycle [24]. Live tree biomass estimates are essential for carbon accounting, bio-energy feasibility studies, and other analyses. About 40 per cent of the land carbon is embodied in trees and are efficient carbon sinks which provides greater than 50 per cent of the world's gross primary productivity (GPP) [34]. According to [14], about 50 per cent of the total carbon in tropical forests is stored in the aboveground biomass and 50 per cent in the top one meter of the soil. The aboveground biomass carbon of the African tropical forest is three times more than of a soil to a one meter depth [15]. Four carbon pools of the land ecology include; the aboveground biomass, the belowground biomass, woody debris and the dead litter [17]. The aboveground biomass of trees comprises of the greater percentage of the carbon source, and is the most abundant in terrestrial forest ecosystem [37]. Soil organic matter contributes secondly to carbon stocks of forests.

Examining the productivity of forest communities is important for the estimation of the accumulated biomass. Biomass estimation of the re-vegetated mine tailings enables the calculation of the amount of carbon dioxide that can be sequestered by trees. Estimation of tree biomass can be done using geographical information systems (GIS) and remote sensing techniques [37]. Re-vegetation has been the most successful way of restoring tailings' dumps. Re-vegetation of mine tailings involves the addition of neutralizing materials (carbonates, hydroxides, and silicates), inorganic fertilizers and/or organic materials, such as natural organic wastes (municipal sewage sludge, paper mill sludge or sawdust), and seeds of native plants [20]. Vegetation protects the soil from surface erosion, reduces the loss of nutrients and promotes aggregate stability of the slimes dam [10; 26].

Species diversity contributes to the regulation of carbon flux, climate control and water cycle. Most mine tailings disposal sites are devoid of vegetation [27], and are considered environmentally harmful due to their high heavy metal concentrations [10]. *Acacia saligna* or the Port Jackson willow, is very adaptable, fast growing tree native to Western Australia and has been extensively used for stabilizing soils in tailings dumps [28]. Revegetation of mine tailings is the most fundamental aspect in the improvement of soil quality, assemblage of plant species and the physiological state of the disturbed ecosystem [19; 25].

The significance of trees in carbon sequestration and species composition has long been recognized, but few researches have been conducted to establish biomass content and species diversity on nickel mine tailings dumps. Thus, herbaceous, grasses and woody vegetation are important tools in the net removal of CO_2 and climate change mitigation.

II. Related Work

The biomasses of standing trees are calculated using allometric equations and their reliability cannot be easily validated [29]. As in [31] found an aboveground biomass of 4.72Mg ha^{-1} in an offsite native soil, 6.71 Mg ha^{-1} on an 11 year old gold and copper treated mine tailings and 0.63Mg ha^{-1} on an 11 year old gold and copper untreated mine tailings. The carbon contained in the litter pool of the 12-year old *Eucalyptus grandis* plantation on post-mining reforestation activities on the KwaZulu-Natal coast in South Africa was found to be 13.34 Mg ha^{-1} and an equal aged *Casuarina equisetifolia* plantation had 10.78 Mg ha^{-1} [41].

Dead root, litter and leaf drop, and the bodies of soil animals such as insects and worms are the primary sources of organic matter in the soil [11]. A 20-year old nickel mine dump had species richness of 28 mite (Acari) whilst a copper tailings had a higher diversity (H'=1.79), a 40-year old tailings had species richness of 20 and diversity index (H) of 1.31, whereas an eight year old tailings had a species richness of 15 and a diversity index of 1.21 [22]

III. Methodology

Description of the study site

The study was carried out at Bindura Trojan Nickel Mine tailings' dumps (31°17'E; 17°19'S, altitude), west of Bindura town. The area is located in Zimbabwe's agro-ecological region IIa which is characterized by a savannah climate, where rainfall pattern is moderately distributed throughout the season. Average rainfall ranges from 700-900 mm per annum with most of it falling between November and January, giving a fair distribution across the season, and a dry season between April and October. Mean temperatures are above 24.6°C in November and as low as 6.5°C in July [40].

The area is generally hilly with some valleys from where a small stream flows in an easterly direction. The area with 26-years old *A. saligna* trees is at the base of the dump and is parallel to the flowing stream. Tailings dump seven (7) has a south facing slope whilst tailings' dump three (3) has a northerly facing slope. The area actually rests on a greenstone belt mainly consisting of basaltic rocks (komatiitic basalt, tholeitic basalt and banded iron structures) and volcanic tuffs [32]. The ore is rich in Pyrrhotite. The intrusive rocks consist of dolerite, gabbroic rocks and quartz feldspar porphyry [40]. Soils are generally red clays (fersiallitic) in the hills having moderate amounts of active clay [34], and vertisols occupy the lower catenary positions.

The vegetation is typically miombo woodland dominated by *Brachystegia spiciformis*, *Brachystegia boehmii*, *Brachystegia glaucescens* and *Julbernadia globiflora* species. Other associated trees include *Terminalia sericea*, *Senegalia polyacantha*, *Vachellia gerrardii*, among others. Dominant grasses that are found together with *A. saligna* trees on the mine tailings dump include: *Pogonathria squarrosa*, *Hyperrhenia filipendula*, *Craspedorachis rhodesiana*, *H. dissoluta*, *Brachiaria brizantha* and *Eragrostis* species [35].

The grass species that were planted at Trojan Nickel mine tailings dump comprised of *Chloris gayana*, *Panicum repens*, *Agrostis alba*, *Cynodon dactylon* and *Cynodon nlemfuensis*. *Acacia saligna* (Labill) trees are the only woody species that were planted on dumps 3 and 7. Approximately 2900-3000 *A. saligna* (Labill) trees were planted per hectare. Top soil with organic matter was taken from natural sites and was used as the growth medium for newly planted species at mine tailings' dumps.

Selection of study sites

Bindura Trojan Nickel mine has 10 tailings' dumps numbered one to ten for tailings deposition. The areas planted with *A. saligna* (Labill) trees of different ages were purposively selected (Table 1). Two tailings' dumps (3 and 7) were selected as study sites basing on the variation in the age of *A. saligna* (Labill) trees. Tailings' dump 3 was established in 1968 and was the first to be de-commissioned in 1998 whereas; dump 7 was established in 1971 and de-commissioned in 2003. Dump 3 has five heaped and stepped layers whilst dump 7 has six layers. The absolute height of the deposition layers ranges from 1170 m to 1216 m above sea level (dump 3) and 1168 to 1176 m above sea level (dump 7).

Table 1. Year of establishment of *A. saligna* trees and elevation of layers at Bindura Trojan Nickel mine dumps 3 and 7, Zimbabwe

Dump/ Layer	Year when *Acacia saligna* was planted (age)	Layer elevation (m)
Dump 3/ Layer 1	1994 (26 years)	1170 -1173
3	1996 (24 years)	1194 -1198
5	1998 (22 years)	1216 - 1217
Dump 7/ Layer		
3	2001 (19 years)	1168 -1176

Aboveground Woody Biomass Estimation

All the *A. saligna* trees in each area (1200 m^2) were measured for stem diameter (DBH) at breast height and tree height (H). Diameter tape was used to measure stem diameter and tree height was measured using Suunto hypsometer in metres. In case where trees with several trunks, the diameter for each trunk was recorded separately and those with multiple trunks above the height of 1.3 metre were measured as an individual tree [5].

Aboveground biomass was estimated without cutting down the trees and this is relevant for plantations, forests and agroforestry ecosystems with scarce tree resources and where harvesting is highly unacceptable [8]. Estimating aboveground forest biomass by non-destructive method involves measuring the DBH, tree height, volume of the tree and wood density. This gives a better calculation of tree biomass using allometry equations [37]. According to [8] the total aboveground biomass (AGB) of a tree with diameter, D, is directly related to the product of trunk basal area ($BA = \pi D^2/4$), total tree height (H), wood density (ρ) and a standard stem form factor (F) of 0.4 by [6]. The following model was assumed in this study:

$$AGB_{est} = F \times \rho \times (\pi D^2/4) \times H \quad [1]$$

To determine wood density, the water displacement method was used [36], and this allows for the asymmetrically shaped wood samples to be easily measured. The sample of wood was oven heated at an unchanged temperature of 85°C for 7 days, up to until the wood sample achieved an invariable weight [7], and its weight was recorded. Six wood disks were taken from the field and their average wood densities were considered for the estimation of the aboveground tree biomass. The sample was sunk completely underwater. The displaced water was recorded to calculate the sample's green volume. The recorded weight of the displaced water is equivalent to the sample's green volume. Wood density was then calculated as the relationship of weight of the oven heated wood sample to its green volume.

Surface litter Carbon determination

A 28 cm diameter ring was used to collect surface litter by inserting the ring on top of the litter, and the litter was collected from inside the ring up to the soil surface (g cm^{-2}) [2; 30].

The surface litter was oven dried for 48 hours at 70°C and the weight was recorded. The residue sample was then combusted at 400°C for six hours [2]. The surface area from which litter was collected was then calculated. The amount of C was calculated as the proportion of the weight of the sample after combustion to that of the initial sample weight divided by the area of the diameter ring. The C obtained in g cm^{-2} was then converted into tonnes (Mg) per hectare (equation 2).

Surface litter C = [(weight of litter after combustion/ mass of litter after oven drying) ÷ Area of the collection ring] [2]

Determination of floral species diversity

Vegetation data were obtained by measuring plant life-forms: grasses, herbs and trees in each tailings' dump. Braun Blanquet abundance and cover scale was used for the diversity and composition of grass species [4]. The total counting method was used to determine the number of individual herbaceous and tree species. Species diversity and composition of flora was analysed using Shannon Wiener diversity index (H') (equation 3). The abundance and cover scale of Braun-Blanquet has five classes (1 to 5) with intermediate scores in determining floristic composition. The score of 1 indicates less than 5 per cent plant cover, score of 2 has a range of 5-25 per cent plant cover, score of 3 has a range of 25-50 per cent plant cover, score 4 has a range of 50-75 per cent plant cover and a score of 5 representing greater than 75 per cent plant cover (Table 2). Identification of grass species in the area was guided by a grass manual. Unidentified species were pressed and later identified at the National Herbarium in Harare.

The Shannon-Wiener Diversity Index (H') was used to compare species composition and diversity of flora among the dumps planted with *A. saligna* trees (Equation 3):

The Shannon-Wiener Diversity Index, H', = $-\sum p_i \ln p_i$ [3]

p_i = proportion of the *i*th species to the total count or the importance value of a species as a proportion of all species.

Table 2. The Braun-Blanquet abundance and cover scale

Grass cover score	Percent plant cover (%)
1	<5
2	5-25
3	25-50
4	50-75
5	>75

IV. RESULTS AND DISCUSSION

Aboveground biomass and surface litter Carbon at Bindura Trojan mine tailings dumps planted with *A. saligna*, Zimbabwe

The amount of aboveground biomass C differed with the age of trees (F = 8.524; P = 0.000) (Figure 1). The mean ± SD aboveground biomass C (Mg ha^{-1}) was similar for the dump with 26-years old *A. saligna* trees (5.32 ± 4.33), dump with 24-years old *A. saligna* trees (5.49 ± 5.80) and dump with 19-years old *A. saligna* trees (4.27 ± 2.55). However, dumps with 26 and 24-years old *A. saligna* trees had higher aboveground biomass C than the one with 22-years old *A. saligna* trees. Aboveground biomass C differed significantly with the age of *A. saligna* trees (Figure 1). The aboveground biomass C of *A. saligna* for dumps from the same tailings dump 3 was similar for dumps with 24-years old and 26-years old trees (Figure 1). The dump from the same tailings' site with trees seven years younger had low aboveground biomass C. This is in accordance to [42] who found aboveground biomass of 2.04 Mg ha^{-1} on iron ore mine tailings after seven years in Beijing, China. Even though the range for aboveground biomass C in this study was lower than the findings by [21], in the five and seven years old *Acacia mangium* Willd in coal mine tailings, a positive trend was observed.

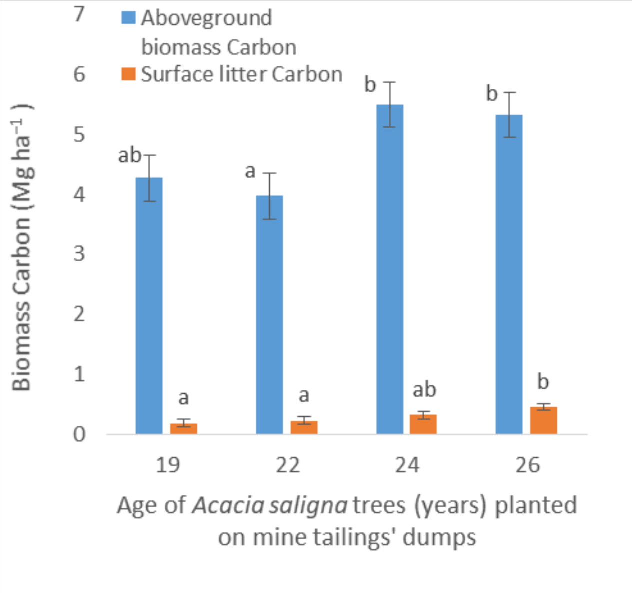

Figure 1. Aboveground biomass Carbon over an age sequence of *A. saligna* trees at the mine tailings' dumps. *Letters in superscript show significant difference ($p < 0.05$) for aboveground biomass C of A. saligna and surface litter. Error bars ± 1 SD of the mean.*

The amount of surface litter C accumulation significantly ($p < 0.05$) increased with an increase in years of *A. saligna* trees (Figure 1). Surface litter C increased by 3.4 per cent over a three-year period from 19 to 22 years, 7.5 per cent over a two-year period from 22 to 24 years, 11.6 per cent over a two-year period from 24 to 26 years and 22.5 per cent over a seven-year period from 19 to 26 years. The mean surface litter C ± SD (Mg ha^{-1}) under *A. saligna* trees was: 0.46 ± 0.17 for 26-years old, 0.32 ± 0.09 for the dump with 24-years old *A. saligna* trees, 0.23 ± 0.13 for the 22-years old trees and 0.19 ± 0.07 for the dump with 19-years old *A. saligna* trees. This concurs with [31] who observed that the surface litter C increases with the increasing age of trees while working in a *Pinus patula* chronosequence in Zimbabwe. Similarly, [42] reported an increase in the accumulation of surface litter C with the age of the re-vegetated trees in a post-mining area of KwaZulu-Natal coast in South Africa. The dump with 26-years old *A. saligna* trees had the highest surface litter C probably due to the fact that is located at the foot of the tailings site, parallel and closer to the running stream, which creates a moist environment that supports vegetative growth resulting in high production and leaf fall. On the other hand, differences could be attributed to natural successional cycle where re-seeders are replaced by the environmentally adaptive re-sprouting shoots that grow to dominate the over-storey in older aged forests.

Herbaceous species diversity and composition on Nickel Tailings' dumps over time

A total of 1651 individuals representing 25 herbaceous species were recorded from all the four dumps planted with *A. saligna* trees (Table 3). Species diversity was highest (H'=2.21) in the dump with 26-years old *A. saligna*. The dominant herbaceous species showed noticeable differences with years after the revegetation with *A. saligna*. Species that were most dominant or diverse on a tailings' dump with 26-years old *A. saligna* trees included: *Sesbania sericea* (H'=0.36), *Celosia trigyana* (0.26), *Ageratum conyzoides* (0.24), *Trichodesma zeylanicum* (0.26), *Tagetes minuta* (0.22) and *Amaranthus* species (0.16). Other species that were less abundant included the *Richardias scabra* (0.06), *Solanum retroflexum* (0.01) and *Gloriosa superba* (0.01). The most dominant species in the dump with 24-years old *A. saligna* trees were: *Celosia trigyana* (0.33), *Ageratum conyzoides* (0.31), *Sesbania sericea* (0.21), *Tagetes minuta* (0.21) and *Bidens pilosa* (0.19) whereas in the dump with 22-years old *A. saligna* trees abundant species included: *Sesbania sericea* (0.33), *Tagetes minuta* (0.31), *Commelina benghlensis* (0.23), *Celosia trigyana* (0.17), *Bidens pilosa* (0.16) and *Ageratum conyzoides* (0.15). In the dump with 19-years old *A. saligna* trees species that contributed more to diversity included: *Ageratum conyzoides* (0.34), *Aloe* spp (0.27), *Celosia trigyana* (0.22), *Sesbania sericea* (0.19) and *Bidens pilosa* (0.19).

The diversity and composition of herbaceous species recorded an improvement with the increase in the years of *A. saligna* trees (Table 3). The increase in diversity with the age of the tailings' dump conforms to the observation by [3] who found an increase in species diversity with time while working on Tikak mine tailings. In addition to age, the high number of species richness (18) on a dump with 26-years old *A. saligna* trees may also be attributed to the presence of the running stream at the foot of the dump. Also in [12] soil nutrient availability, landscape position and water availability are also related to species composition and abundance in the forest understory. Contrary to the results of this study; [38] analyzed herbaceous species diversity and richness between May to August in 1992 and 1993 in Allegheny hardwood forests, Western Pennsylvania and found no significant difference with the increase in age of trees. In this study, the dump with 19-years old *A. saligna* had similar species richness as to the dump with 22-years old *A. saligna* species. The dump with 19-years old *A. saligna* trees is geographically located away from the rest of the tailings' dumps. Furthermore the dump with 22-years old *A. saligna* species had the lowest herbaceous species diversity maybe due to its closeness to human settlement, where the diversity of species might be affected by anthropogenic activities [9].

Woody species diversity and composition at Bindura Trojan mine tailings' dumps

A. saligna and *Lantana camara* were the two most abundant woody species in all the dumps. Woody species diversity was higher in the dump with 26-years old *A. saligna* trees than other dumps, but the dump with the 24-years old *A. saligna* trees had the lowest tree diversity (Table 3). Other sparsely distributed woody species in the revegetated areas included: *Cussonia arborea*, *Jacaranda mimosifolia*, *Ficus spps*, *Senegalia polyacantha*, *Vachellia nilotica*, *Ziziphus mauritiana*, *Bauhunia thonningii*, *Eucalyptus camuldulensis* and *Terminalia sericea*. The dump with 26-years old *A. saligna* trees recorded the highest tree species diversity (Table 3). The species composition of woody vegetation in dumps with 26 and 22-years old *A. saligna* trees was identical, and the dumps with 24 and 19-years old *A. saligna* also had similar tree structure. Vegetation at Bindura Trojan mine tailings' dumps consisted mainly of the introduced species which were planted for the stabilization of the dumps. The species richness describes diversity, the larger the H' value the greater the species diversity and vice versa. As in [9] indicated that an ecosystem with H' value of less than two is a less diverse community. Trojan nickel mine tailings' dumps have rationally low woody species diversity, which agrees to [16] who found out that only planted tree species survived on Mhangura copper mine tailings' dumps.

The lower the H' values in this study may be attributed to habitat incomplexity [23] and allelopathic effects from *Lantana camara* which exudes toxins and retards growth of other plants. As in [16] only a few species that are adapted to the geochemical environment of a particular mine tailings dump could become established. The most prevalent tree species was the *Acacia saligna* and the indigenous tree species are struggling to survive and establish on the nickel mine tailings dumps. The few indigenous tree species might have been dispersed on the dumps by wind and animal seed dispersers from the nearby natural forest. *Lantana camara* invaded the nickel tailings dumps and was most dominant in all the tailings' dumps because of its high invasiveness and propagative nature [39].

Table 3. Species diversity over time at Bindura Nickel mine tailings dumps revegetated with *A. saligna* trees

Measure	**Age of *A. saligna* trees (Years)**			
	19	**22**	**24**	**26**
Herbaceous				
Species richness	14	14	16	18
Species diversity (H')	1.93	1.87	2.05	2.21
Total number of Herbaceous species	214	486	264	687
Woody				
Species richness	13	11	19	21
Species diversity (H')	2.06	1.79	1.84	2.18
Total number of Woody species	124	91	113	111

Grass species diversity and composition over time at Bindura Nickel mine tailings' dumps, Zimbabwe

The dumps with 26 and 22-years old *A. saligna* trees recorded the highest grass species (14), while the dump with 24-years old *A. saligna* trees recorded 12 grass species and the dump with 19-years old *A. saligna* trees recorded the lowest species richness (11). The dump with 26-years old *A. saligna* trees recorded six dominant grass species which included: *Dactylotenum giganteum* (0.33), *Agrostis alba* (0.32), *Chloris gayana* (0.20), *Melenis repens* (0.18), *Panicum repens* (0.15) and *Penisetum setaceum* (0.13). The abundance of grass species tended to decrease with the age of the planted *A. saligna* trees. Other grass species that were less diverse (< 5 per cent cover) were; Hyparrhenia filipendula, *Hyperthelia dissoluta*, *Heteropogon contortus*, *Eleusine coracana*, *Setaria megaphylla*, *Heteranthera zosterifolia* and *Rottboellia cocchinchinensis*. The dump with 24-years old *A. saligna* trees had four dominant grass species: *Imperata cylindrica* (0.23), *Agrostis alba* (0.20), *Chloris gayana* (0.18) and *Penisetum setaceum* (0.12). Five main grass species which dominated the dump with 22-years old *A. saligna* trees were: *Chloris gayana* (0.20), *Imperata cylindrica* (0.20), *Melenis repens* (0.15), *Penisetum setaceum* (0.22) and *Agrostis alba* (0.16). Six grass species that dominated the dump with 19-years old *A. saligna* were; *Agrostis alba* (0.35), *Panicum repens* (0.20), *Chloris gayana* (0.20), *Dactylotenum giganteum* (0.18), *Imperata cylindrica* (0.15) and *Melenis repens* (0.13).

The higher grass abundance and cover in the dump with 26 years old *A. saligna* trees might be attributed to the flowing stream closer to this area. Most of the grass species found in the tailings' dumps were planted by the safety health and environment (SHE) department of Trojan mine, whilst the other species grew naturally with the improvement in growth conditions. Some plants found in this study such as *Cynodon dactylon*, *Imperata cylindrica*, *Heteropogon contortus* and *Pennisetum setaceum* have also been reported in a study in Mexico by [13]. The planted grass species contributed more to diversity in areas re-vegetated with *A. saligna* trees reflecting their potential in reclaiming nickel mine tailings dumps. Most grasses can survive under environmental and edaphic stress which may contribute to their existence on tailings sites. Although a few gaps existed, most of the surface was covered by well-established grasses and shrubs.

V. CONCLUSION AND FUTURE SCOPE

The aboveground biomass C and surface litter C on the tailings' dump increased significantly with the age of *A. saligna* trees. Results from this study suggest that the dumps with 26 older aged *A. saligna* trees accumulated more aboveground biomass C than with 24, 22 and 19 year old *A. saligna* trees. The diversity of herbaceous, woody and grass species showed an increasing trend with the age of *A. saligna* trees (19, 22, 24 and 26 years) on mine tailings' dumps. The differences in surface litter C, species diversity and composition on mine tailing dumps have shown that species diversity on a mine tailings' dump improves with the passage of time (19, 22, 24 and 26 years). The tailings soil quality produced relatively diverse vegetation with a composite of species. However, re-vegetation on mine tailings' dumps should be promoted as this has the capacity to restore degraded mining ecosystems and mitigate the effects of climate change. There is also need to understand the effects of surface litter and associated chemical interactions with the soil.

ACKNOWLEDGMENT

The author is thankful to Bindura Trojan Nickel Mine management and staff for allowing him to conduct this study on their mine tailings' dumps. The author is also grateful to Mr G. Chikorowondo of Bindura University for the assistance on species identification.

REFERENCES

[1] Beer, C. Reichstein, M. Tomelleri, E. Ciais, P. Jung, M. Carvalhais, N. Rodenbeck, C. Altaf Arain, M. Balocchi, D. Bonan, G.B. Bondeau, a. Cescatti, A. Lasslop, G. Lindroth, A. Lomas, M. Luyssaert, S. Margolis, H. Oleson, K.W. Roupsard, O. Veenendaal, E. Viovy, N. Williams, C. Woodward, F.I. & Papale, D., "Terrestrial gross carbon dioxide uptake: global distribution and covariation with climate," Journal of Science, Issue.**329**, pp. **834-838, 2010.**

[2] Bell, G. Kerr, A. McNickle, D. & Woollons, R., "Accuracy of the line intersect method of post thinning sampling under orientation bias," Forest Ecology and Management, Issue.**84**, pp. **23-28, 1996**.

[3] Borpujari, D., "Studies on the occurrence and distribution of some tolerant plant species in different spoil dumps of Tikak opencast mine," The Ecoscan Issue.**2**, pp. **255-260, 2008.**

[4] Braun-Blanquet, J., "Plant sociology: the study of plant communities: McGraw-Hill, New York, USA, **1932.**

[5] Brown S. & Lugo A.E., "Aboveground biomass estimates for tropical moist forest of the Brazilian Amazon," Interciencia, Issue.**17**, pp. **8-18, 1992.**

[6] Cannell, M.G.R., "Wood biomass of forest stands. Forest Ecology and Management," Issue.**8**, pp. **299-312, 1984.**

[7] Chave, J., "Measuring Wood Density for Tropical Forest trees: A field manual, Sixth Framework Programme: Project for the Advancement of Networked Science in Amazonia, Pan-Amazonia," **2002-2006**.

[8] Chave. J. Andalo. C. Brown. S. Cairns. M. Chambers. J. & Eamus, D. et al., "Tree allometry and improved estimation of carbon stocks and balance in tropical forests," Oecologia, Issue.**145**, pp. **87-99, 2005.**

[9] Chidumayo, E.N., "Land use, deforestation and reforestation in the Zambian Copperbelt. Land Degradation and Rehabilitation," Issue.**1**, pp. **209-216, 1989**.

[10] Conesa, H.M. Schulin, R. & Nowack, B., "A laboratory study on revegetation and metal uptake in native plantspecies from neutral mine tailings," Journal of Water, Air, and Soil Pollution, Vol.**183**, Issue.**(1-4)**, pp. **201-212, 2007**.

[11] Daniels, W.L. & Haering, K.C., "Concepts of Basic soil science. In: The Mid-Atlantic nutrient management handbook (eds. K.C Haering and G.K. Evanylo), Mid-Atlantic Regional water program," Virginia Tech**, 2006.**

[12] Davis, M.A. Wrage, K.J. & Reich. F.B., "Competition between tree seedlings and herbaceous vegetation: support for a theory of resource supply and demand," Journal of Ecologyl, Issue.**86**, pp. **652-661, 1998.**

[13] Dı´az-Gardun˜ o, L.M. Dı´az-Osornio, A. Carrillo-Gonza´ lez, R. & Gonza´ lez-Cha´vez, M.C., "Plantas que se desarrollan en a´ reas contaminadas con residuos mineros. In: Gonza´ lez-Cha´vez, M.C., Pe´rez-Moreno, J., Carrillo-Gonza´ lez, R. (Eds.), El Sistema Planta-Microorganismo-Suelo en A´ reas Contaminadas con Residuos de Minas. Colegio de Postgraduados, Mexico, pp. **9-33, 2005.**

[14] Dixon, R.K. Solomon, A.M. Brown, S. Houghton, R.A. Trexler, M.C. & Wisniewski, J., "Carbon pools and flux of global forest ecosystems," Journal of Science, Issue.**263**, pp. **185-190, 1994**.

[15] Djomo, A.N. Knohl, A. & Gravenhorst, G., "Estimations of total ecosystem carbon pools distribution and carbon biomass current annual increment of a moist tropical forest," Forest Ecology and Management, Issue.**261**, pp. **1448-1459, 2011.**

[16] Dowo, G.M. Kativu, S. & Tongway, D.J., "Application of ecosystem function analysis (EFA) in assessing mine tailings rehabilitation: an example from the Mhangura Copper Mine tailings, Zimbabwe Tropical Resource Ecology Programme, Department of Biological Science, University of Zimbabwe, Harare, Zimbabwe," The Southern African Institute of Mining and Metallurgy, **2013.**

[17] Eggleston, H.S. Buendia, L. Miwa, K. Ngara, T. & Tanabe, K., "IPCC Guidelines for National Greenhouse Gas Inventories," Institute of Global Environmental Strategies (IGES), Agriculture, Forestry and other land-use, Hayama, Japan, Vol.**5**, **2006.**

[18] Grace, J., "Understanding and managing the global carbon cycle," Journal of Ecology, Issue.**92**, pp. **189-202, 2004.**

[19] Hao, X.Z. Zhou, D.M & Si, Y.B., "Revegetation of copper mine tailings with ryegrass and willow, Pedosphere," Vol.**14**, Issue.**3**, pp. **283-288, 2004.**

[20] Ilyas, S., "The impact of revegetation on microclimate in coal mining areas in East Kalimantan," Journal of Environment and Earth Science, Vol.**2**, Issue.**11, 2012**.

[21] Ilyas, S., "Allometric Equation and Carbon Sequestration of *Acacia mangium* (Willd) in Coal Mining Reclamation, in East Kalimantan, Indonesia," Journal of Civil and Environmental Research, Vol.**3**. Issue.**1**, **2013**.

[22] John, M.G. St. Bagatto, G. Behan-Pelletier, V. Lindquist, E.E. Shorthouse, J.D. & Smith, I.M., "Mite colonization of revegetated mine tailings: Mite (Acari) colonization of revegetated mine tailings near Sudbury, Ontario, Canada," Journal of Plant and Soil Science, Issue.**245**, pp.**295-305, 2002.**

[23] Kotler, B.P. & Brown, J.S., "Environmental heterogeneity andthe coexistence of desert rodents," Annu Rev Ecology System, Issue.**19**, pp. **281-307, 1988**.

[24] Malhi, Y. & Grace, J., "Tropical forests and atmospheric carbon dioxide. Trends," Vol.**15**, Issue.**8**, pp. **332-337, 2000.**

[25] Mango, L. & Kugedera, A.T., "Vertical distribution of soil bulk density, SOC and soil pH to a depth of ninety centimetres on mine tailings' dumps revegetated with *Acacia saligna* (Labill) trees," Journal of Agriculture and agribusiness, Vol.**4,** Issue.**1**, pp. **102-107, 2019.**

[26] Mango, L. & Kugedera, A.T., "Effects of re-vegetating mine tailings on genetic diversity and role of micro-fauna on improving mine tailings: A Review," Journal of Agriculture and agribusiness, Vol.**4,** Issue.**1**, pp. **108-123, 2019.**

[27] Mendez, M.O. & Maier, R.M. "Phytoremediation of mine tailings in temperate and arid environments: Reviews," Environmental Science and Biotechnology, Issue.**7,** pp. **47-59, 2008.**

[28] Midgley, S.J. & Turnbull, J.W., "Domestication and use of Australian Acacias: Case studies of five important species," Australian Systematic Botany, Vol.**16**, Issue.**1**, pp. **89-102, 2003.**

[29] Montes, N. Gauquelin, T. Badri, W. Bertaudiere, V. & Zaoui, E.H., "A non-destructive method for estimating above-ground forest biomass in threatened woodlands," Journal of Forest Ecology and Management, Isuue. **130,** pp. **37-46, 2000.**

[30] Mujuru, L. Leemans, R. & Hoosbeek, M.R., "The potential of Carbon Sequestration to Mitigate against Climate Change in Forests and Agro-Ecosystems of Zimbabwe, PHD Thesis," The Netherlands Research School for the Socio-Economic and Natural Sciences of the Environment, Wageningen University, **2014**.

[31] Neuman, D. & Ford, K.L., "Phytostabilisation as a remediation alternative at mining sites, Bureau of Land Management," Denver, CO. pp. **48**, **2006**.

[32] Nyakudya, I.W. Jimu, L. Katsvanga, C.A.T., & Dafana, M., "Comparative analysis of the early growth performance of indigenous Acacia species in revegetating Trojan Nickel Mine tailings in Zimbabwe," Journal of Environmental Science and Technology, Vol.**5**, Issue.**3**, pp. **218-227, 2011**.

[33] Nyamapfene, K., "The Soils of Zimbabwe," Nehanda Publishers: Harare, **1991.**

[34] Pan, Y. Birdsey, R.A. Fang, J. Houghton, R. Kauppi, P.E. Kurz, W.A. Phillips, O.L. Shvidenko, A. Lewis, S.L. Canadell, J.G.

Ciais, P. Jackson, R.B. Pacala, S.W. McGuire, A.D. Piao, S. Rautiainen, A. Sitch, S. & Hayes, D.A., “Large persistent carbon sink in the world’s forests,” Journal of science, Issue.**333**, pp. **988-993, 2011.**

[35] Piha, M.I. Vallack, H.W. Michael, N. & Reeler, B. M., “A low-input approach to vegetation establishment on mine and coal ash wastes in semiarid regions.. Lagooned pulverized fuel ash in Zimbabwe,” Journal of Applied Ecology, Issue.**32**, pp. **382-390, 1995.**

[36] Pyo, J.K. Son, Y.M. Lee, K.H. & Lee, Y.J., “Estimating basic wood density and its uncertainty for Pinus densiflora in the Republic of Korea,” Ann. For. Res, Vol., Issue.**1**, pp**. 105-111, 2012.**

[37] Ravindranath, N.H.,& Ostwald, M., “Methods for estimating above-ground biomass. In N. H. Ravindranath, and M. Ostwald, Carbon Inventory Methods: Handbook for greenhouse gas inventory, carbon mitigation and roundwood production projects,” Springer Science + Business Media, pp. **113-14, 2008.**

[38] Ristau, T.E. Horsley, S.B. & Cormick, L.H.Mc., “Sampling to assess species diversity of herbaceous layer vegetation in Allegheny hardwood forests,” Journal of the Torrey Botanical Society, Vol.**128**, Issue.**2**, pp. **150-164, 2001.**

[39] Sharma, S. Mukherjee, S. Kumar, A. & Dillon, W.R., “A simulation study to investigate the use of cutoff values for assessing model fit in covariance structure models,” Journal of Business Res, Issue.58, pp. **935-943, 2005.**

[40] Trojan Mine Report, “Unpublished document,” **2007.**

[41] van Rooyen, M.W. van Rooyen, N. & Stoffberg, G.H., ‘Carbon sequestration potential of post-mining reforestation activities on the KwaZulu-Natal coast, South Africa,” Journal of Forest Research, Issue.**86**, pp. **211-223, 2012.**

[42] Yan, D. Zhao, F. & Sun, O.J., “Assessment of Vegetation Establishment on Tailings Dam at an Iron Ore Mining Site of Suburban Beijing, China, 7 Years After Reclamation with Contrasting Site Treatment Methods,” Institute of Forestry and Climate Change Research, Beijing, China, **2013**.

AUTHORS PROFILE

L. Mango pursed BSc Environmental Science., Msc Agroforestry., both from Bindura University of Science Education in 2012 and 2015 respectively, and the Executive Certificate in Programme and Project Monitoring and Evaluation from University of Zimbabwe in 2021. He is currently a PhD (Environmental Management) student with Prince of Songkla University, Thailand. He is currently working as lecturer in Department of Agriculture Management at Zimbabwe Open University. He has published many research papers in reputed international journals. His main research work focuses on Agroforestry management, Ecology, Forest Management, and Climate change and sustainable development. He has 6 years of research experience.