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Pruning as a successful treatment to improve growth of *Acacia mangium* Willd. plantation in the reclamation of gold mine spoils of Guyana

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Abstract

Deforestation and land degradation due to mining activities are much studied environmental concerns globally. As such, policy-makers are setting ambitious goals to restore hundreds of millions of hectares of deforested and degraded lands. Therefore, it is important to understand the growth response of species used in the reclamation of deforested and degraded areas or areas proposed for restoration. In this study on the pruning of *Acacia mangium* Willd. planted on gold mine spoils in Guyana was assessed to determine stem growth responses to various pruning treatments. Trees were pruned at 0.5 m, 1 m, 1.5 m and 2 m for three-year old Acacia plantation.

Pruning treatment was done to increase growth rates and to improve bole quality of trees so they will have valuable timber when they mature. A Linear Mixed Effects model was used to quantify the treatment effects for the one year after pruning. The results indicated that after one year the growth rates average 5.92 cm yr-1. Application of pruning lead to 0.36cm gain in diameter increments compared to unpruned trees. Pruning at 1.5 m height has the greatest effect on diameter increments.

The effect of pruning significantly improved the aesthetics of the plantation and tree bole diameter of the Acacia trees and underscores the importance of pruning as an effective post-planting treatment in reforestation activities of three-year old Acacia plantation in Guyana.

Keywords: Reclamation, Pruning, *Acacia mangium*, Pruning heights, mining\

Introduction

In Guyana mining activities, specifically gold and bauxite possess a major threat to the environment. Impact of mining activities has been shown to adversely affect total environment and human well-being (Marschalko et al. 2013; Candeias et al. 2015; Schaider et al. 2014, Lewis et al., 2020). Mining in recent years has served as a major boon to the Guyana economy and it is also being recognized as one of the country’s main contributors to its deforestation and degradation rate (GFC, 2014). FAO (2010) reported that the majority of deforestation between 2009 and 2011 has been attributed to increased mining activity accounting for 91% of the deforestation in 2009-2010 and 93% in 2010-2011 (FAO, 2010).

Mining operations degrade significant areas of land and replace existing ecosystem with undesirable waste materials in the form of mine spoil dump. Land degradation by mining negatively affects the soil functionality in the ecosystem (Kneller et al. 2018, Lewis et al., 2020). Mining involves the removal of forest cover to allow stripping to be carried out. This represents a direct destruction of portions of the ecosystem, the major casualties being elements of fauna and flora (Singh et al., 2007). Reduction in intact forest landscapes and environmental degradation are inevitable consequence of mining and extractive industry associated activities (Potapov et al. 2017, Lewis et al., 2020).

Mining in Guyana can be considered as one of the most economically viable industry which contributes approximately 30-35% to the GDP of the country (GFC, 2014). In 2014 the exploitation of gold earned US 986 million dollars in foreign exchange and at that time making it the most valued export commodity in the country. The exploitation of the mineral resources continues unabated for foreign exchange earnings, infrastructure gains, and employment generation (World Bank, 2018). In recent times, the mining sector activities have greatly increased due to the increases in world market price for gold. This has created new challenges for the sustainable management and utilization of forest resources, particularly vegetation of Guyana thereby promoting continuous soil degradation and deforestation. In order to mitigate the effects of soil degradation and deforestation due to mining, Guyana has embraced the concept of land reclamation which is a mechanism aimed to "revegetate" these sites to strengthen the resilience of landscapes and thereby keeping future management options open (ITTO, 2005).

In 2009 the exotic Legume tree Australian species *Acacia mangium* Willd. was used for the reclamation of a mined out site situated at St. Elizabeth, Mahdia in Guyana under the Guyana Environmental Management and Capacity Development Programme (GENCAPD). *A. mangium* was chosen given that it is well adapted to a wide range of environmental conditions, grows rapidly in sites with low levels of soil nutrients, even on acidic soils and degraded sites with high potential to the very harsh conditions present at the Mahdia mine site (National Research Council 1983; Midgley, 2007; Domboro, 2009; Krisnawati et al., 2011). *A. mangium* is one of the most widely used fast-growing tree species in plantation forestry programmes throughout Asia and the Pacific (Manubag et al., 1995; Krisnawati et al., 2011). Over 1000 seedlings were planted on the site and the species showed great tolerance for the poor quality of soils created after mining. However, the species has a poor self-pruning ability, therefore singling and pruning are silvicultural treatments necessary at an early stage of stand development if the aim is to maintain full growth potential for increasing growth and produce good-quality timber (Krisnawati et al., 2011). Pruning is a silvicultural treatment that removes live and/or dead branches from a certain portion of tree stem, starting from ground level. The most common purpose of pruning is to produce knot-free wood and straight bole (Erkan et al., 2016). In addition, pruning encourages free bole development, tree growth, good quality woods (Krisnawati et al., 2011), plantation health and enhances the aesthetic value of the plantation (Sein and Mitlöhner, 2011). In general reclamation projects give little or no priority to long-term silvicultural management (Kamo et al., 2009). However, if the reclamation aims to optimize growth and future commercial use of the wood, large diameter pruning is required.

Pruning was conducted in 2011 and this study was aimed to determine the effect of pruning on the growth increase of the Acacia plantations.

This study addressed a fundamental research question facing the potential optimization of reclamation in mined areas of Guyana through pruning as a post plantation silvicultural management namely: will pruning in *Acacia* plantations be a good silvicultural technique to increase growth in rehabilitated mines?. Our hypothesis is that pruning will increase growth accumulation in *Acacia* plantations

At St. Elizabeth, Mahdia pruning was carried out to improve the stem form by removing multiple leaders which tend to produce forked trees, the removal of weak, dead or cracked limbs to enhance the aesthetics of the plantation for the purpose of rehabilitation of mined out sites. Acacia was considered a primer species which created the appropriate environmental/ecological conditions for the late colonization of native species.

Materials and Methods

Study Area

The study was conducted in an *Acacia mangium* plantation trial in a mined out concession located at St. Elizabeth, Mahdia in the Potaro-Siparuni, Administrative Region # 8, Guyana (Figure 1) in a Tropical Rain Forest Ecoregion (415 m asl, average annual rainfall of 1800 mm to 2500 mm, average temperature of 37^0C). The soil texture in the remaining areas of the mining is sandy with occurrence of clay in some areas. Figure 2 shows a closeup photograph of the mined area.

a) b)

Fig2. a)Photograph of the area under rehabilitation process with Acacia, b) Acacia trees selected for pruning in the plantation

Methods

The experimental layout was a Completely Randomized Design (CRD). The experiment consisted of two treatments - pruned and unpruned. The pruned and unpruned treatments were replicated three times per each treatment. A total of 211 trees were pruned and 198 unpruned being a total of 409 trees.

Trees were pruned every two months; pruning was conducted four times on the six replicates, pruning was done at four standard heights (0.5 m, 1 m, 1.5 m and 2 m) on the 3-year-old Acacia trees.

Pruning cuts were made as close as possible to the branch bark ridge and the branch collar to avoid damage to the callus area and avoid leaving stubs (Tarigan, et al., 2011). Furthermore, large branches were removed in a series of cuts to reduce damage to the main stem of the tree. The initial pruning measurement for each tree was taken on the first 0.5 m using a Caliper and thereafter every two months after. DBH measurement was taken as dependent variable to investigate the effects of pruning on DBH growth (Tarigan, et al., 2011).

Statistical analysis and models tested

The data on height and diameter was coded and formatted using Microsoft EXCEL, processing and statistical analysis was conducted with RStudio (R Core Team, 2012).

There were four observations per replicates, with a total of 6 replicates for the experimental area. A determination was then made on how much variation was there between the observations of the study since nested data was being used. Boxplots were constructed to summarize the distribution of the explanatory variables such as, Treatment, Replicates and Pruning height.

The response variable was the log-transformed diameter of *A. mangium* trees for normality and the explanatory variables were treatments (nominal with two levels) and replicates (nominal with six levels). First a simple linear model was applied on the data to investigate whether pruning has an effect on diameter. To account for the repeated measure it was specified replicates as the random effect.

On the other hand, Linear Mixed Model (*lme4)* was used to perform a Linear Mixed Effects analysis for testing the hypothesis. A linear model was done in the first instance to test the hypothesis on the effect of pruning on the growth of the Acacia trees on mined out site. Then, a linear mixed effect (LME) analysis was done to test the random and fixed effects between pruned and unpruned treatments. A summary function of the linear mixed effect model was done to interpret the results that is to reject or fail to reject the null hypothesis based on the Akaike's Information Criterion (AIC). All test carried out had a confidence interval of 95% (α=0.05). The results were represented using boxplots, graphs and tables.

The data was considered nested because multiple observations were taken from the same replicates. A total of 409 trees were observed and six (6) replicates were sampled. The assessment was conducted by taking the variables total height and diameter at breast height (DBH =1.35 meters).

Linear models was used to estimate "fixed effects", which consist of specific and repeatable categories that are representative of an entire population (e.g., species, age and diameter) (Franzi Korner-Nievergelt, 2015). It was important to recognize that the experimental unit in this study were the replicates not the trees because the treatment was applied at the replicate level. Therefore, it must be taken into account the fact that trees are nested in the replicates to avoid pseudo replication (Duursma, Powell, & Stone, 2016).

Diameter at breast height was a numeric variable and its measurement were grouped using six replicates (A, B, C, D, E, F), three replicates were pruned and three replicates were unpruned (control). As fixed effect, the factors treatment and replicates were entered into the model. The observations were grouped since there were repeated diameter measurements on the same replicates and also because of the measurement from the same trees are nonindependent. It was used mixed model to analyze the data therefore “lmer” function from the “lme4” package (Bates, Mächler and Bolker, 2012).

In this study, diameter at breast height was selected as fixed effect because it represents measurements from a sampling population of a three year *A. mangium* trees. The pruning effect on diameter growth model was then classified according to whether the effect of pruning treatment on diameter changes after four (4) years. The following linear mixed-effect models were used to develop diameter (cm) at 1.3 m above ground as a function of pruning treatment. Then the “best” model for analyzing the relationship diameter-pruned treatment was selected.

(Model 1): Diameter (cm) ~ Treatment + (1|Replicates)

$$D_i = ß_0 + b_0 + e_i$$

(Model 2): Diameter (cm) ~ Treatment + Date + (1|Replicates)

$$D_i = ß_0 + (b_0 \times b_1) + e_i$$

(Model 3): Diameter (cm) ~ Treatment + Date + Treatment + Date + (1|Replicates)

$$D_i = ß_0 + (b_0 + b_1 + b_0 \times b_1) + e_i$$

Where D_i = Diameter at breast height (1.3m) of the i^{th} tree of *A. mangium* species; $ß_0$ = fixed-effect coefficients; b_0, b_1 = random-effect coefficients and e_i = random error of the model.

Replicates were treated as random-effect in all these models. The goodness-of-fit criteria of Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) having the smallest value were used to select the best fit diameter growth model, AIC and BIC have been reported to be useful for evaluating goodness-of-fit of different mixed effect models (Bates, 2010). The model with the smallest AIC and BIC values were used as the final criteria was considered best fit model. The fixed-effect and the random-effect coefficients were estimated using restricted maximum likelihood (REML) method.

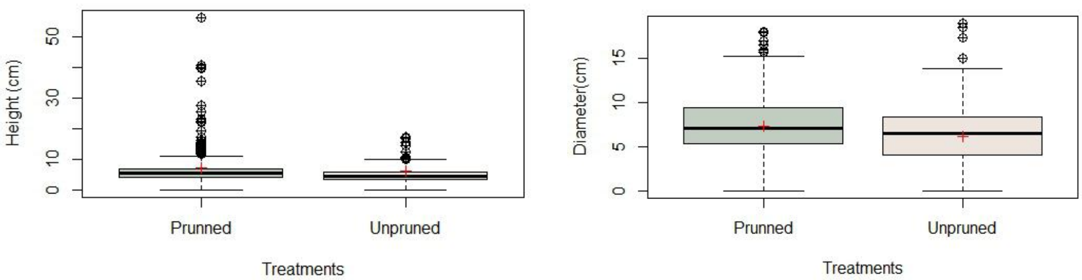
Results and Discussion

The results of the descriptive statistics for DBH and Height are presented in Table 1.

Data (3 years old, n = 818 trees)		
Attributes	DBH (cm)	HEIGHT(m)
Min	0.00	0.00
Max	19.0	5.64
Mean	6.76	5.48
Median	6.80	5.00
SD	2.39	

Table 1. Summary statistics of tree diameter

Figure 1 shows that there are significant differences (p> 0.95) between pruned and unpruned treatments and also between-replicates.



a) b)

Figure 1. Boxplots shows the explanatory variables (Treatments and Replicates) for a) diameter and b) height.

Based on Akaike's Information Criterion (AIC) and Bayesian Information Criterion (BIC) results, the LINEAR MIXED-EFFECT MODEL (Model 2) obtained the best fit for predicting DBH on *A. mangium* trees subjected to pruning in St. Elizabeth, Mahdia (Table 2). Model 2 had the smallest AIC (-670.23) and BIC (-643.23).

LINEAR MIXED-EFFECT MODEL (Model 2) was further evaluated based on the analysis of residuals. Residuals were plotted against predicted values and against individual explanatory variables so as to determine any poorly fitted data to the model or the presence of outliers (Razali, et al., 2015). Analysis of variance (ANOVA) and least significant difference (LSD) tests were utilized in order to detect any significant difference in models between the six replicates.

Tables 3 and 4 shows the value of fixed-effect coefficients ($ß_0$, $ß_1$) for treatments and pruning height and random effect coefficients (b_0, b_1) for each model and Table 5 indicates best fit equations for the predicting diameter using Model 2.

Model	AIC	BIC	logLik	deviance	Chisq	Chi df	Pr(>Chisq)	Signif.codes
Model2	-670.23	-643.23	340.12	-680.23	33.845	1	5.97E-09	***
Model3	-668.65	-636.25	340.32	-680.65	34.261	2	3.63E-08	***
Model4	-668.65	-668.65	340.32	-680.65	34.261	2	3.63E-08	***

Table 3. Comparison of criteria between models. *Coefficient estimate of best fit model*

Fixed-effect coefficient	Estimate	Std.error	t-value
$ß_0$	0.0371	0.0355	17.76
$ß_1$	-0.0188	0.0502	-0.37
$ß_2$	0.0501	0.0086	5.85

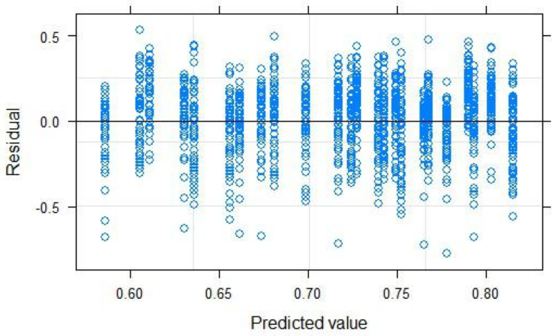
Table 4. Fixed-effect coefficients of Model 2

$ß_0$ = Intercept (TRTSpruned), $ß_1$ = TRTSunpruned, $ß_2$ = PHEIGHT

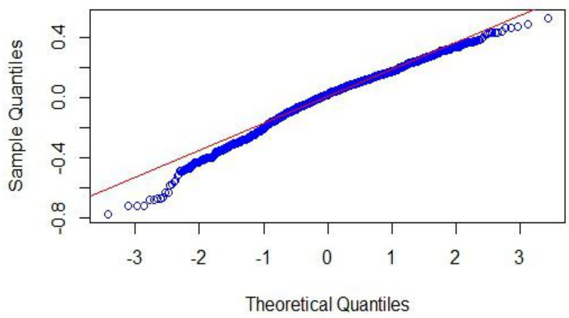
Models	Groups	Name	Variance	Std.dev
3	Replicates	Intercept	0.0036	0.0604
	Residual		0.0382	0.1954

Table 5.Random-effect coefficients of Model 2

Residual plot analysis (Figure 2) showed no clear evidence of variance in heterogeneity. The variance of residuals was distributed almost homogeneously over the full range of predicted values. Furthermore Table 6 shows the Confidence Intervals for Model 2



a)



b)

Figure 4. Residual analysis for Model 2. *a)* residual versus predictor variable for Linear Mixed effects model (Model 2), *b)* Normal qqplot of the residuals.

	2.5 %	97.5 %
.sig01	0.03636119	0.12279343
.sigma	0.18884813	0.20227060
(Intercept)	0.57461475	0.74338832
TRTSunpruned	-0.13530160	0.09779281
PHEIGHT	0.03358415	0.06747399

Table 6. Confidence Intervals for Model2

The results of the best fit model (Model2) indicated that pruning had a significant effect on the diameter (P=5.97E-09) of the pruned *A. mangium* trees when compared to those that were unpruned (Fig. 1). Pruning had a significant positive effect on the growth of the *A. mangium* in the mined out site at St Elizabeth, Mahdia. This result highlights the importance of pruning as an effective post management objective of *Acacia* plantations in Guyana. These results were not similar to those that were obtained in studies that were conducted in Indonesia, Malaysia and Hawaii, however they too found pruning to be essential in the management of plantations. Previous studies as reported by Beadle et al. (2006) in South Sumatra, Indonesia suggested increments of diameter at breast height over bark (DBHob) during the 18-month period following pruning was just over 8 cm and a total DBHob was over 12 cm at age of three years. In *A. mangium* plantations in Vietnam, it was noted that pruning was an important treatment in the management of the plantation and when done carefully can cause an increase in the growth of the species, increase timber value and the health of the plantation (Sein and Mitlöhner, 2011) vice versa when it is carelessly done, it may cause a reduction in growth, introduce diseases and diminish timber value (Ramos et al., 1998). In pruning, care must be taken to avoid damage to the branch, bark, ridge and the branch collar to avoid pests and diseases. Large branches are avoided as much as possible, since pruning large branches can lead to diseases such as heart rot (Beadle et al., 2007). Studies in South Sumatra indicated that there was no significant difference in growth between lift and crown pruning techniques applied to the plantation. Sein and Mitlöhner (2011), Ramos et al., (1998) stated that pruning some branches increases the growth rate of the remaining branches. Majid and Paudyal (1992) reported that *Acacia* mangium Willd, growth was only affected if pruning removed more than 40% of lower green crown length. A pruning trial study was conducted in the Peninsular Malaysia at three different sites which included a 3-year-old *Acacia* mangium plantation where pruning treatments ranging from 0 up to 3 m for the purpose of produce saw logs. The result of the study indicated that pruning treatments have a significant effect on tapering of the stem, the diameter decrease of 1 cm on every 1 m in height (Nick and Paudyal, 1992).

Pruning encourages free bole development, improves the general appearance of the trees by reducing the amount of branches in the lower stem and facilitates easy access to the plantation (Nick and Paudyal, 1992). Pruned and unpruned trees showed similar growth pattern for diameter. However, pruned trees would have responded more positively to the increases in light and space after pruning.

While there were many studies in various countries about the use of pruning in *Acacia* plantations (Majid and Paudyal, 1992; Beadle et al., 2006; Ramos et al., 1998) none of them was conducted on mined out sites to determine the effect of pruning on *Acacia* of mined out sites and as such the findings are important for future reclamation/reforestation programme in Guyana.

Conclusion

It can be concluded from this study that light pruning of *A. mangium* showed small but significant increase of 0.36 cm in diameter increment and corroborates the statement by Sein and Mitloner (2011) that pruning was an important treatment in the management of the plantation and when done carefully can cause an increase in the growth of the species, increase timber value and the health of the plantation. Pruning treatment is acceptable for future post-plantation management objectives for *Acacia* planted on mined out sites in Guyana.

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