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Performance of tree stand growth and nutrient status of a reclaimed land

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Abstract The evaluation of tree growth performance and their corresponding effect on soil nutrient status is very crucial in selection of suitable species for reclamation and revegetation of degraded lands for their prompt recovery. This study was therefore evaluated the growth performance and nutrient status of a 30.4 hectares' land reforested by Newmont Ghana Gold Limited in 2002. Five 50 x 50 m plots were conducted in pure stands of *Senna siamea, Tectona grandis, Cedrela odorata* and mixed stand with an adjacent control plot. The 50 x 50 m plots were then divided into twenty-five (25) 10 x 10 m subplots from which five were randomly selected under each stand for growth performance and soil nutrient status assessment. The results showed significant differences in all growth and soil parameters measured among the stands. Among all the growth parameters measured *Cedrela odorata* stand generally recorded the highest growth followed by the mixed, *Senna siamea* and *Tectona grandis* stands respectively. The *Cedrela odorata* stand recorded a mean height of 17.29 m followed by 13.16 m, 12.89 m and 12.32 m for the *Senna siamea*, mixed and *Tectona grandis* stands respectively. Mean diameter values of 24.35 cm, 19.43 cm, 17.57 cm and 16.03 cm were recorded in *Cedrela odorata,* mixed, *Senna siamea* and *Tectona grandis* stands respectively. The highest levels of soil macro nutrient, pH (6.21), organic matter (6.05 %) and organic carbon (3.51 %) content were generally recorded under the *Cedrela odorata* stand. Generally, *Cedrela odorata* proved to be very useful tree species for reclamation of degraded lands.

Keywords: depleted soils, nutrient level, mixed stand, pure stand, tree species

Introduction

Ghana like many other developing countries in the world is experiencing an alarming rate of deforestation and forest degradation in recent times. Within 15 years (1990-2005), the country lost about 26 % of its total forest cover with an annual deforestation rate of 2.0 % (Domson and Vlosky, 2007). Forests in Ghana apart from their contribution to the national GDP also provides

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environmental and socio-cultural benefits to the country. About 70 % of Ghana's population live in the rural areas and depend on natural resources for their livelihood (Ghana, 2006). The forest forms an integral part of the rural economy, providing subsistence goods and services such as non-timber forest products (NTFP's) which contribute in many ways to improving diets, combating hunger and increasing incomes for rural households in Ghana (Acheampong, 2003). Major activities in which the fringe forest communities are involved include wild-meat production, fuel wood and charcoal production, wood-carving and canoe-carving, rattan production, chew stick-gathering, chainsaw lumber production, and hunting (Domson and Vlosky, 2007). The continuous loss of the forest cover in the country is an issue of concern since it poses threats to the lives of a large number of rural populations which depend on it for survival. A number of factors have been attributed to this fast depletion of the forest cover of Ghana which includes excessive logging, unsustainable agricultural practices, bush burning, mining and quarrying, settlement and related infrastructure construction.

These have disrupted the balance in the environment hence putting the lives of humans in danger. The habitat of most plants and animals have been severely degraded through these activities and have hence lost their capacity to provide the ecosystem goods and services enjoyed in the past. This has resulted in negative effects such as global warming, increased frequency and intensity of wildfires, floods, fuel wood and timber shortage, soil degradation, and food shortage which has put the lives of living organisms in danger. The situation is expected to worsen if the degraded lands are not restored to their initial condition or a condition similar to their initial state usually forest and farmlands.

Reclamation has been adopted by many developed and developing countries as a means of restoring degraded lands to their pre disturbed state. There have however been recent concerns by some environmentalists on the ability of reclamation to restore the forest ecosystem to its pre disturbed condition. The extent to which reclaimed lands restore the forest ecosystem to its pre disturbed condition is largely unknown. The evaluation of the stand growth performance and their corresponding effect on the nutrient status of soils under them is crucial in selection of suitable species for reclamation and revegetation of degraded lands for their prompt recovery. This study therefore seeks to evaluate the stand growth performance and nutrient status of Newmont Ghana Gold Limited Reclamation Test Plot.

The specific objectives were to determine the growth of tree species in the pure stands and mixed stand established om reclaimed land and to examine the nutrient status of soils under the pure stands, mixed stands and an adjacent fallow land.

Materials and Methods

Study Area Description

The study was conducted at the Newmont Ghana Gold Limited reclamation test plot located at Terchire, a town in the Tano-North District of the Brong-Ahafo Region of Ghana. The Tano-north district is located at latitude 70 00'N and 70 25' N and longitude 20 03' W and 20 15'W. The area was a borrow pit created as a result of the construction of the Kumasi – Sunyani highway in the early 1980s. The topsoil was stripped and the subsoil was taken for road construction leaving the area bare. The area was grassed in 1999 and was later reforested by Newmont Ghana Gold Limited in 2002. Greater portions of the site were planted as a mixed stand which composed of *Senna siamea*, *Tectona grandis*, *Cedrela odorata* and other portions as pure stands of *Senna siamea, Tectona grandis, Cedrela odorata* (Koomson, 2011)**.** The study area is currently a forest land with different tree species assemblages. The Tano North District experiences bimodal rainfall (Major and Minor). The mean annual rainfall of the district is between 1250 mm and 1800 mm and the mean monthly temperature ranges between 26 ^{0}C in August and 30 ^{o}C in March (MoFA, 2013). The study area lies in the moist semi-deciduous forest zones of Ghana and has a gross forest area of 157.45 square kilometres.

Tree Growth Measurements

The study area was stratified into four plots to capture the four different planting mixtures, with an adjacent fallow land as a control plot. Five 50 x 50 m plots were laid out, one in each stratum of pure stands of *Senna siamea*, *Tectona grandis, Cedrela odorata* and mixed stand *(Senna siamea, Tectona grandis, Cedrela odorata*) and the control plot. The 50 x 50 m plots were then divided into twenty-five 10 x 10 m subplots. A Simple Random Sampling Technique was then used to select five 10 x 10 m subplots from which data on growth parameters were collected. The identification of the tree species was aided by a local botanist and a field photo guide. The growth parameters were measured as follows:

Tree Height Measurement

In each selected 10 m x 10 m subplot of trees (≥ 10 cm in diameter) were measured using a clinometer. The apex of all trees within the plots were observed through a clinometer and the angle between the observer and the top of the tree recorded. The distance between the observer and the tree from the point of observation was also measured and added to the height of the observer at eye level. Trigonometric equations were then used to estimate the height of the tree from the measurements taken. Tree height was estimated using the formulae:

$$A = B \tan \theta \quad (1)$$

$$H = A + O \quad (2)$$

Where: A = Height of the tree from the observer eye level, B = Distance between the observer and the base of the tree, θ = Angle between observer's eye level and apex of the tree, O = Height of observer to eye level, H = Total height of the tree.

Tree Diameter Measurement

The diameter of all trees (≥ 10 cm in diameter) within each selected 10 m x 10 m subplot were measured using a diameter tape. The diameter was measured at a distance of 1.3 m from the base of the tree.

Estimation of the Basal Area of the Stands

The basal area (A) of trees on each stand was calculated from the diameter of trees using the formula by Reid (1999).

$$A = (DBH/200)^2 \times \pi \quad (3)$$

Where: A = Basal area of tree (m^2), DBH = Diameter at breast height (cm), π = constant (3.142).

The A values for all measured tree on each plot were added and multiplied by the area of the plot (0.01) to obtained the basal area of each plot in m^2/ha.

Estimation of the Total Volume of the Stands

The total volume (V) of the trees on each plot was calculated from the diameter and total height values using the formula by Reid (1999).

$$V = (DBH/200)^2 \times \pi H) \quad (4)$$

Where: V= Total volume of tree (m^3), DBH = Diameter at breast height (cm), H = Total height of tree (m), π = constant (3.142).

The V values for the measured tree on each plot were added and multiplied by the area of the plot (0.01) to obtained the total volume of each plot in m^3/ha.

Soil Sampling and Laboratory Analysis

In each 50 x 50 m plot, five of the 10 x 10 m subplots were randomly selected and soil samples collected at the vertices and centre of each plot, at a depth of 0 – 15 cm. The samples collected were then bulked into a composite sample and three subsamples were taken and air dried for laboratory analysis. After air drying, the soil samples were passed through a 2.0 mm (20 mesh) sieve to remove roots. The soil samples were then analysed to determine their macro nutrient concentration as well as soil organic carbon, soil organic matter, pH, and CEC.

Statistical Analyses

All collected data were subjected to one-way analysis of variance (ANOVA) using SPSS (Version 20). A Tukey HSD All-Pairwise Comparisons Test of individual mean values by plots was done to determine which the plot means were significantly different from one another. All statistical analysis and differences were evaluated at 5 % probability level.

Results

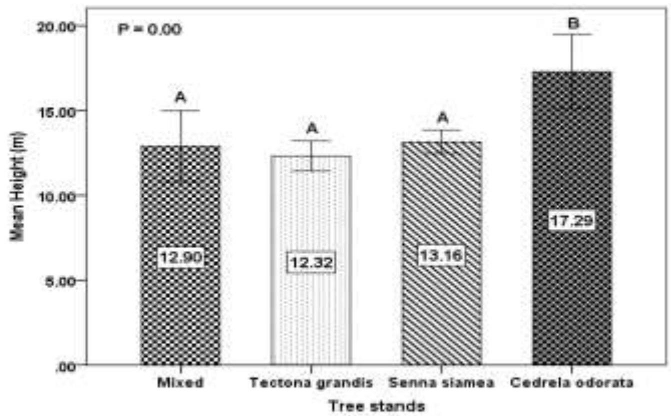
Mean Height of Trees under Different Stands

The results of the mean heights of the different tree stands revealed a significant difference ($P < 0.05$) between the stands (figure 1). *Cedrela odorata* stand recorded the highest mean height (17.29 m) compared to the other stands. The mixed, *Tectona grandis* and *Senna siamea* stands recorded mean height values of 12.89, 12.32 and 13.16 m respectively. A Tukey HSD Multiple Comparisons test on the mean height values revealed a significant difference ($P < 0.05$) in mean height between the *Cedrela odorata* stand and the other stands. However, there was no significant difference ($P > 0.05$) between the other stands (figure 1).

Mean Diameter of Trees under Different Stands

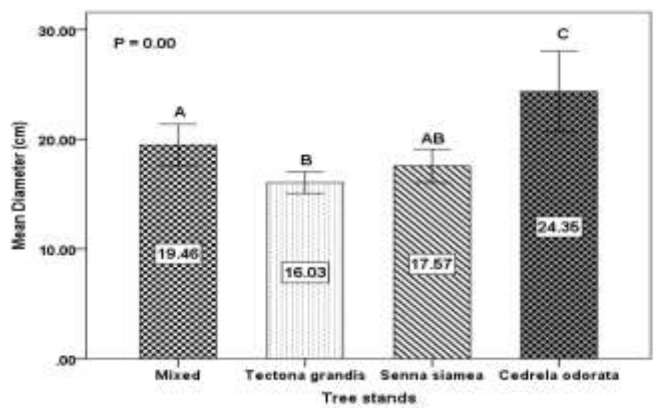
The *Cedrela odorata* stand recorded the highest mean diameter of 24.35 cm (figure 2). The mean diameter of mixed, *Tectona grandis* and *Senna siamea* stands were 19.46 cm, 16.03 cm and 17.57 cm respectively. Analysis of the mean diameter revealed significant difference ($P < 0.05$) between the *Cedrela odorata*, mixed and *Tectona grandis* stands. However, no significant difference

(P > 0.05) was realized between the *Tectona grandis* and *Senna Siamea* stands and the *Senna siamea* and mixed stands (figure 2).



*Means of same letters are not significantly different at 5 % probabilty level

Figure 1. Variations in mean height of tree species under different stands

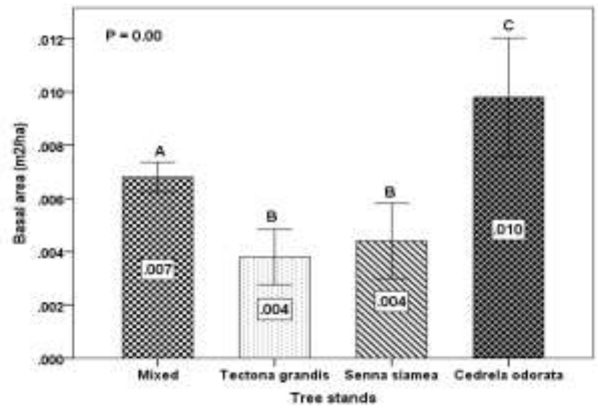


*Means of same letters are not significantly different at 5 % probability level

Figure 2. Variations in mean diameter of tree species under different stands

Basal Area of Trees under Different Stands

A one-way analysis of variance of the basal area of the different stands at 5 % probability level revealed significant difference (P < 0.05) between the stands (figure 3). The *Cedrela odorata* stand recorded the highest basal area (0.010 m^2/ha), followed by 0.007, 0.004 and 0.004 m^2/ha for the mixed, *Senna* *siamea* and *Tectona grandis* stands respectively. Basal area of *Cedrela odorata* was significantly differed from the others (Figure 3).

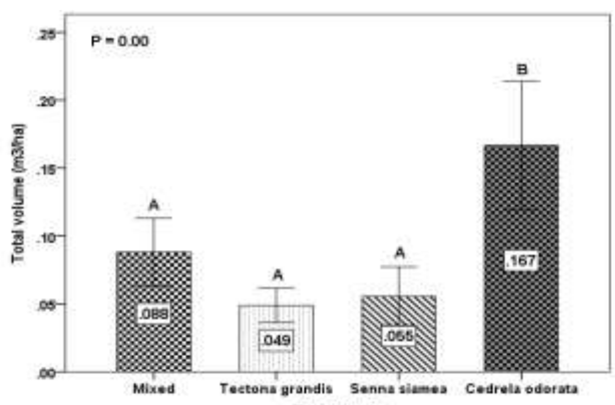


*Means of same letters are not significantly different at 5 % probability level

Figure 3. Variations in basal area of tree species under different stands

Total Volume of Trees under Different Stands

The results showed that *Cedrela odorata* stand recorded the highest total volume of 0.167 m^3/ha, followed by 0.088 m^3/ha, 0.055 m^3/ha and 0.049 m^3/ha for the mixed, *Senna siamea* and *Tectona grandis* stands respectively (figure 4). A Tukey HSD Multiple Comparisons test on the total volume revealed a significant difference ($P < 0.05$) between the *Cedrela odorata* and the other stands (figure 4).



*Means of same letters are not significantly different at 5 % probability level

Figure 4. Variations in total volume of tree species under different stands

Soil Nutrient Status under Different Stands

The results of the ANOVA test on soil pH values of the various stands revealed a significant difference ($P < 0.05$) in soil pH between the stands. The *Cedrela odorata* stand recorded the highest compared to the other forest stands. This was followed by 6.25, 5.97, 5.50 and 5.42 for the mixed, *Tectona grandis*, control and *Senna siamea* stands respectively (Table 1).

Soil organic carbon content of the different stands were also significant ($P < 0.05$). The *Cedrela odorata* stand recorded the highest soil organic carbon content (3.51 %) followed by 3.21, 2.60, 2.48 and 1.45 % for the *Senna siamea*, *Tectona grandis*, control and mixed stands respectively (Table1). Furthermore, Cedrela *odorata* stand recorded the highest total nitrogen content (0.25 %) followed by 0.21, 0.19, 0.11 and 0.10 % for the *Senna siamea*, control, *Tectona grandis* and mixed stands respectively (Table 1). There was however no significant difference ($P > 0.05$) between the mixed and *Tectona grandis* stands, control and *Senna siamea* stands and the *Senna siamea* and *Cedrela od*orata stands. The results also revealed a significant difference ($P <0.05$) in potassium content (Table 1). The highest potassium content was recorded under the *Senna siamea* stand (0.26 cmol/kg) followed by 0.24 cmol/kg, 0.23 cmol/kg, 0.23 cmol/kg and 0.15 cmol/kg for the mixed, control, *Cedrela odorata* and *Tectona grandis* stands respectively. There was however no significant difference ($P > 0.05$) in potassium content between the *Senna siamea*, mixed, control and *Cedrela odorata* stands. Also, the highest available phosphorus content was recorded under the *Senna siamea* stand (8.61 ppm) (Table 1).

Table 1. Variations in nutrient status of soils under different stands

Soil Chemical Properties	Stand Type					
	Mixed	***Tectona grandis***	***Senna siamea***	***Cedrela odorata***	**Control Stand**	**P value**
pH 1:1(H_2O)	6.15^{bc}	5.97^{b}	5.42^{a}	6.21^{c}	5.50^{a}	0.00
% Organic Matter	2.50^{a}	4.48^{b}	5.53^{c}	6.05^{d}	4.28^{b}	0.00
E.CEC. cmol/kg	7.17^{a}	6.99^{b}	6.24^{c}	7.13^{a}	5.45^{d}	0.00
% Total Nitrogen	0.10^{a}	0.11^{a}	0.21^{bc}	0.25^{c}	0.19^{b}	0.00
Exchangeable Cations						
Potassium (K^+) cmol/kg	0.24^{a}	0.15^{b}	0.26^{a}	0.23^{a}	0.23^{a}	0.00
Phosphorus(P^{3-}) (ppm)	0.40^{a}	3.35^{a}	8.61^{b}	5.10^{c}	8.31^{d}	0.00
Potassium(K^+) (ppm)	99.59^{a}	74.33^{b}	88.76^{c}	73.71^{d}	79.74^{e}	0.00

*Means with the same superscripts horizontally are not statistically significant at 5 % probability level.

Discussion

Growth performance of pure and mixed stands on reclaimed land

Cedrela odorata pure stand showed great potential for reclamation of degraded lands due to the rapid growth recorded. It has been reported that *Cedrela odorata* fast growth makes it ideal for plantation species (Pasieczink, 2008). As a light demanding species (Orwa *et al*., 2009), its use in mixed plantations could suppress its growth and limit its potential. That is why the growth in the mixed plantation stands was lower. *Cedrela odorata* also is not demanding of soil nutrient (Orwa *et al*., 2009), an attribute which makes it ideal for reclamation of degraded areas. Its additional benefit as a timber species could help supplement income of farmers who could harvest it on a rotational basis. Despite the highest growth of *Cedrela odorata*, others have seen it as an invasive species (Pasieczink, 2008). Its invasive nature can be exploited to improve the fertility of degraded areas as its biomass can decompose and improve the structure of the soil. The species could be used in agroforestry to replenish nutrients and a result of the high biomass obtained in the study.

In forest reclamation to restore the land cover by vegetation process requires an evaluation of biomass content (Wahyuni *et al.*, 2016). Leaf litter is the main and fastest organic matter and nutrient to the soil (Park and Kang-Hyun, 2003). The nutrients in litter were added to the soil through decomposition (Hossain *et al.,* 2011). The highest tree height, diameter, basal area and voulunme recorded in pure stand of *Cedrela odorata* would be very helpful in reclamation process. On the contrary, others have reported higher diameter and basal area in mixed stands compared to pure stands (Montagnini, 2000; Piotto *et al*., 2004).

Cedrela odorata stand recorded the highest mean height and diameter values which contributed to the highest total volume of the *Cedrela odorata* stand compared to the other stands. This result is consistent with the findings of other authors who reported a higher total volume in some pure stands compared to mixed stands (Petit and Montagnini, 1999; Opoku, 2012).

Soil nutrient status under different stands

The soil pH under *Cedrela odorata* (6.21) stand was the highest due to the release of base cations into the soil which reduces the acidity of the soil (Dutta and Agrawal, 2002). This finding is supported by the high biomass recorded on *Cedrela odorata* stands. It could be used in ameliorating soil acidity.

The results revealed variable but significant total nitrogen concentration between the stands The *Cedrela odorata* recorded the highest total nitrogen concentration (0.25 %). The difference in nitrogen levels could be associated with the differences in foliar nitrogen, nutrient cycling, leaf decomposition rate and organic carbon content of the soils under the different stands (Garcia, 2007; Richards *et al.,* 2010). This result disproves the findings of Garcia (2007), who reported higher nitrogen levels in mixed stands compared to other pure stands.

The high organic matter content of the under Cedrela *odorata* stands can be attributed to the difference in microbial activity and carbon content of the different stands. This can also be attributed to the differences in vegetation cover, and amount of litter and plant debris produced (Chiti *et al.,* 2006). These results disprove that of other authors who reported no significant difference between the pure and mixed stands.

The study also revealed a significant concentration of available P concentration among the stands. The *Senna siamea* stand recorded the highest phosphorus concentration which might be due to different phosphorus uptake by tree species under the different stands. This disproves the reports of no differences in P levels between mixed and pure stands (Sayyad *et al.,* 2007; Jahed *et al.,* 2014).

Furthermore, potassium concentration was also high in soil under the *Senna siamea* stands due to variation in litter decomposition which influences nutrient return to soil hence improving potassium levels in one stand compared to the other (Wang *et al.,* 2008). This result is consistent with the findings of authors who reported that pure stands have higher K levels compared to other mixed stands (Jahed *et al.*, 2014). However, a comparison of the mixed stand with the other pure stand revealed a higher K level in the mixed stand (0.24 cmol/kg) compared to the *Tectona grandis* stand (0.15 cmol/kg). The results are consistent with other research which revealed higher K levels in mixed stands compared to other pure stands (Wang *et al.*, 2008). Therefore, conclusions of higher or lower K concentration in pure and mixed species plantations should be species specific.

Effective CEC was high in mixed stand by the higher nutrient levels in the mixed stand compared to the other pure stands. This result supports the findings of authors who reported higher effective CEC values under mixed stands compared to other pure stands (Garcia, 2007).

Conclusion

Cedrela odorata performed better than mixed and other pure stands and therefore a potential species for reclaiming degraded areas. Its potential to improve soil nutrient status and structure was proven beyond doubt. It can there be recommended as a good agroforestry species for amelioration of degraded lands. Apart from its reclamation potential, it fast growth makes it desirable for plantation development in rural areas to supplement income of farmers.

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