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Effect of Plant Density and Height on in University of Agriculture, Abeokuta, Nigeria

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Abstract: The increase in residential and commercial development has led to a substantial reduction in the natural canopy cover and this has led to increase in the rate of soil erosion and reservoir sedimentation. This study determined the extent to which plant density and plant height will affect throughfall. Throughfall which is the rain water that gets to the ground under a canopy cover is an important parameter in estimating interception. Gross precipitation and throughfall in mm were measured using a manual form of rain guage between August ending and September 2009 for individual storm events under a *Tectona grandis* and *Gmelina arborea* tree plantation considering their density and height at the University of Agriculture Abeokuta. The total mean average of all the Gross precipitation and throughfall of both trees was calculated and a linear relation was examined between the Gross precipitation and throughfall of both tree plantation. In both tree plantations, the densely packed tree covers and the tall trees intercepted more rain water at the experimental sites therefore reducing the amount of rain water that gets to the ground as throughfall. The dense and tall trees can hence be said to be the suitable tree type that can reduce soil erosion and also encourage alley cropping.

Key words: Throughfall · Stem flow · Rainfall intensity

INTRODUCTION

Interception can be technically defined as the capture of precipitation by plant canopy and its subsequent return to the atmosphere through evaporation. The process was first described by Horton [1] as the process by which the first precipitation drops falling on the leaf surface is mostly retained. The incoming rainfall adheres to the surface of the vegetation by surface tension. When the vegetative cover cannot retain anymore water, the incoming rain falls off the vegetation as throughfall. The term interception capacity is often used for the amount of water held by the vegetation canopy at the end of the storm. The amount of abstraction attributable to interception loss depends on the vegetative cover, rainfall intensity and storm duration. Interception losses are usually larger when the storm event has low-moderate rainfall intensity and long duration of rainfall compared to storm events that have high intensity of rainfall and are short in duration [2]. The vegetative cover plays an important role in the prevention of the topsoil soil and soil nutrient from being easily eroded by the direct impact of raindrops when rain falls. Plant vegetative cover modifies the intensity and distribution of precipitation falling on and through its leaves and the most obvious effect plant canopy cover has on falling precipitation. It has been known that vegetation cover intercepts precipitation and controls rainfall intensity that will get to the ground and the dearth of the vegetation cover will lead to surface runoff which then results in erosion and increase in reservoir sedimentation [3-5] and this study intends to determine the extent to which plant density and height can combine to influence throughfall and runoff.

The experimental work was carried out at a site located around the forest nursery (07° 23^{I} N, 03° 44^{I} E, ALT 138m) in the Federal University of Agriculture, Abeokuta, Ogun State which is in the South-western part of Nigeria. The site is characterised by flat topography and about 2-2.5m lower to the main road level. The vegetation at this study site consists of mainly two tree plantations with some other few but *Gmelina arborea* and *Tectona grandis* are more dominant and evenly established having the trees 2.5- 3m apart. The plantation were mainly of 3 ages, the 6 years old section which were

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established very close to the main road, the 8 years old section which were established at the far back of the former plantation and the 2-4 years old section which are established in between the two plantations growing continuously over the years. The three plantations were used since the experiment required four different categories of the trees (Densely packed, sparsely packed, tall and short trees). The site has a total of about 1000 m^2 and the total area of land used as the experimental plot was about 200 m^2, given 80 trees in the experimental plot and about 20 trees were considered for each category in both plantation. The *Tectona grandis* tree (Teak) plantation had more dense canopy cover and little sparse canopy cover and its branched to about 1.5-2 m in average from the ground, while in the case of short Teak trees, it branches about 0.2 m in average from the ground. There is no vegetation found at the floor of the Teak tree plantation since the canopy cover is dense permitting little penetration of sunlight. The tall *Tectona grandis* trees have an average height of 16 m with occasional emergent trees reaching 18m while the short once have an average height of 2 m with some few once reaching between 4-6 m. *Tectona grandis* trees have average leaf of 0.093 m^2. *Gmelina* arborea tree plantation has more sparsely dense canopy cover and less densely packed canopy cover, it is branched to the average height of 12 m from the ground surface. The canopy allows the penetration of sunlight thereby giving the little vegetations to survive under it; *Gmelina arborea* tree has an average height of 15 m and average leaf area of 0.038 m^2. There was no visible short tree for *Gmelina arborea* making it impossible to get throughfall data for the short *Gmelina* tree.

Data Collection and Analysis: The gross precipitation and throughfall readings were measured on the storm basis between August ending and November ending, 2009. The readings were taken at 9.00 GMT after every storm and measured with a depth measuring cylinder.

Gross Precipitation: This was measured at the control plots which were the open spaces close to each experimental plot which are the places the throughfall data were taken. 5 bottle gauges with PVC funnel each mounted on them were place like 1m from each other in an open space to collect the incident rainfall. The funnels were steep slope in order to prevent raindrop splashing out, with a diameter of 10 cm. The gauges were buried into the ground to prevent wind from blowing them off; they were about 6 m from obstacles like trees etc, which may influence aerodynamic error causing alteration in the catch of the gauges. Typically, storms recorded in this study were averagely of low intensity and accompanied by light wind. The values of the gross precipitation were taken as the arithmetic mean of all the gauges for each storm. The measurements were taken at every 9.00 GMT with a measuring cylinder during the period of the experiment.

Throughfall: The throughfall depths per storm at each tree category were measured manually with 20 bottle gauges for each tree plantation. The gauges were mounted with PVC funnels on each of them with the diameter of 10 cm, the gauges were placed under and around each tree canopy and the steep slope funnels were used to minimize any splash out from the gauges during rain storms. The gauges were buried in the ground to avoid wind blowing them away or any contact by animals so as to have a precise data. The measurements were taken at every 900 GMT using a measuring cylinder during the period of the experiment.

The mean throughfall and gross precipitation were calculated for both *Gmelina arborea* and *Tectona grandis* with their respective density and height parameters. Correlation and Regression were used to establish a linear relationship between the Throughfall and Gross precipitation for each tree. A paired sample T-test was used to determine if the average throughfall for the density and height parameters for each tree were different or not.

RESULTS

The results for average throughfall and gross precipitation of each category for the 10 storms collected under a *Tectona grandis* tree plantation is given in Table 1 while Table 2 showed the result for average throughfall and gross precipitation of each category for the 10 storms collected under a *Gmelina arborea* tree plantation.

The mean average of the Throughfall and Gross precipitation data collected for each category under the two trees was calculated in order to find their mean average as shown in Tables 1 and 2. The average throughfall for the dense *Tectona grandis* was 23.33mm and the gross precipitation was 29.12mm while that of *Gmelina arborea* was 26.52mm and 28.89 mm, respectively. The average throughfall for the sparse *Tectona grandis* 25.71mm and the gross precipitation was 28.80mm while that of *Gmelina arborea* was 28.21mm and 28.71mm, respectively.

Table 1: Average Throughfall data for *Tectona grandis* tree plantation(mm)

Storm	$Tf1_{dt}$	Gp	$Tf1_{St}$	Gp	$Tf1_{Tt}$	Gp	$Tf1_{st}$	Gp
1	5.4	5.8	5.0	5.4	5.1	5.7	5.3	5.4
2	25.6	32.5	26.4	30.0	25.1	32.0	28.6	29.7
3	8.4	13.0	12.1	13.4	12.4	13.1	12.3	13.0
4	17.7	26.0	20.8	24.0	19.0	26.0	21.3	25.8
5	49.8	70.7	59.0	71.4	54.4	70.5	59.5	69.9
6	24.7	27.5	25.0	27.4	25.5	27.8	25.0	27.5
7	15.3	19.6	17.5	20.3	16.1	20.2	17.6	20.1
8	29.4	32.0	29.6	32.1	30.1	32.0	30.7	32.1
9	19.1	22.8	21.4	22.8	20.0	22.8	21.7	22.8
10	37.9	41.3	40.3	41.2	38.8	41.2	40.2	41.1
Average	23.33	29.12	25.71	28.80	24.65	29.13	26.22	28.74

$Tf1_{dt}$ - throughfall for Dense Tectona grandis tree plantation; $Tf1_{St}$ - throughfall for Sparse *Tectona grandis* tree plantation; $Tf1_{Tt}$ - throughfall for Tall *Tectona grandis* tree plantation; $Tf1_{st}$ - throughfall for Short *Tectona grandis* tree plantation

Table 2: Average Throughfall data for *Gmelina arborea* tree plantation

Storm	$Tf2_{dg}$	Gp	$Tf2_{Sg}$	Gp	$Tf2_{Tg}$	Gp
1	5.3	6.0	5.4	5.6	5.6	6.1
2	28.6	30.2	29.3	29.6	28.6	29.7
3	12.2	13.1	12.7	13.1	12.5	13.0
4	22.4	25.9	25.4	25.9	23.9	26.0
5	68.0	71.1	69.0	70.5	68.4	70.8
6	22.8	26.9	26.1	26.5	24.8	26.0
7	14.6	19.5	19.2	20.2	17.5	20.2
8	29.5	32.0	31.5	32.2	31.1	32.2
9	20.7	22.9	22.4	22.9	22.7	22.9
10	41.1	41.3	41.1	41.2	41.0	41.1
Average	26.52	28.89	28.21	28.77	27.61	28.80

$Tf2_{dg}$ = throughfall for Dense *Gmelina arborea* tree plantation; Tf2Sg = throughfall for Sparse *Gmelina arborea* tree plantation; $Tf2_{Tg}$= throughfall for Tall *Gmelina arborea* tree plantation

Table 3: Correlation analysis of GP on TF for *Tectona grandis* and *Gmelina arborea*

Tree	TF	GP	P-value	Remarks	R-squared
Tectona grandis	Dense	0.971	<0.05	Significant	0.943
	Sparse	0.992	<0.05	Significant	0.985
	Tall	0.984	<0.05	Significant	0.968
	Short	0.993	<0.05	Significant	0.968
Gmelina arborea	Dense	0.996	<0.05	Significant	0.992
	Sparse	1.000	<0.05	Significant	1.000
	Tall	0.999	<0.05	Significant	0.998
	Short	-	-	-	-

The average throughfall for the tall *Tectona grandis* was 24.65mm and the gross precipitation was 29.13mm while that of *Gmelina arborea* was 27.61mm and 28.80mm respectively. It was only the *Tectona grandis* that had a short tree with throughfall of 26.22mm and a gross precipitation of 28.74mm due to the fact that the short *Gmelina arborea* were not established at the experimental site and as such both the throughfall and gross precipitation data could not be measured.

Data presented in Table 3 showed the correlation coefficient analysis between the Throughfall and Gross precipitation for all the parameters of the two trees was analysed and it showed that there were strong positive linear relationships (correlation coefficients) between their throughfall and gross precipitation. From Table 3, the Sparse *Gmelina arborea* even recorded a perfect positive correlation coefficient, which implies that all of the throughfall on the sparse *Gmelina arborea* was determined by the Gross precipitation (R-square = 1.00).

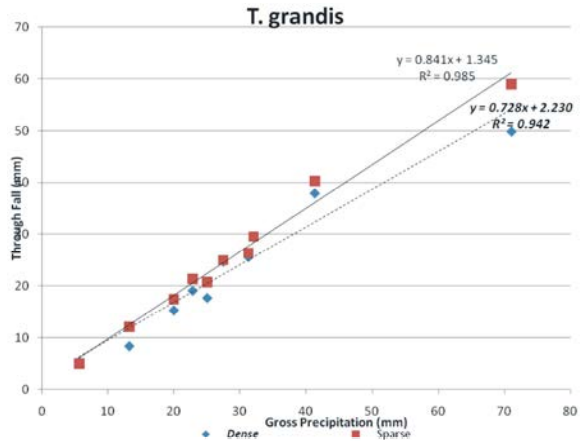

Fig. 1: Graph showing TF and GP relationship between Dense and Sparse Tectona grandis

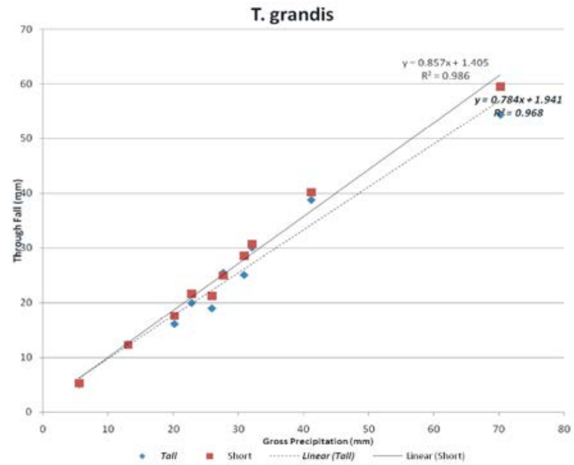

Fig. 3: TF and GP relationship between Tall and *Short Tectona grandis*.

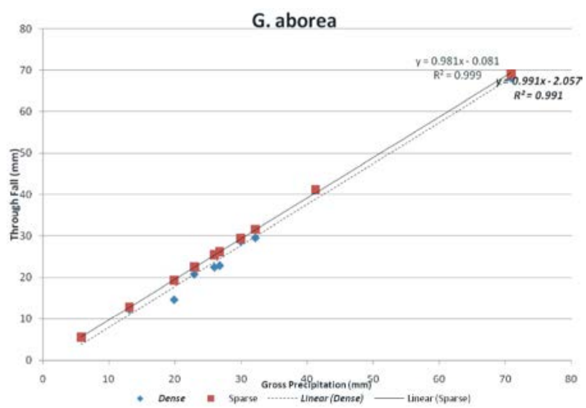

Fig. 2: Graph showing TF and GP relationship between Dense and Sparse Gmelina arborea

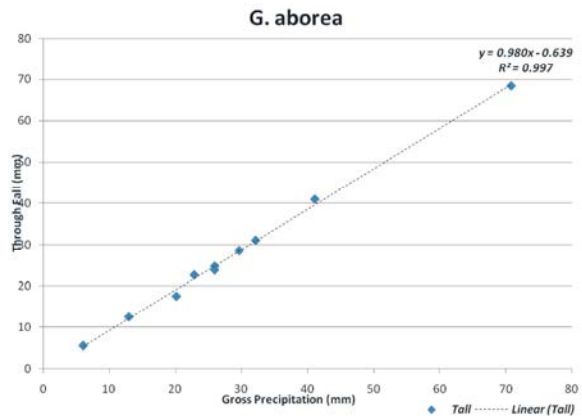

Fig. 4: Graph showing TF and GP relationship between Tall and Short *Gmelina arborea*

The results of regression analysis indicating the relationship between the two plant species and the parameters of throughfall and gross precipitation is given in Fig. 1-4.

Figure 1 shows the relationship between Gross precipitation and throughfall under a dense and sparse *Tectona grandis* tree and it shows that as gross precipitation increases, there is also a unit increase in throughfall. Therefore, as rainfall intensity increases, the rate of throughfall also increases.

Figure 2 The relationship between gross precipitation and throughfall under a dense and sparse Gmelina arborea tree. The result is similar to the result from *Tectona grandis*, that is, as gross precipitation increases, there is also a unit increase in throughfall. Therefore, as rainfall intensity increases, the rate of throughfall also increases.

Figure 3 shows the relationship between Gross precipitation and throughfall under a tall and short *Tectona grandis* tree. The gross precipitation determines the throughfall that is as gross precipitation increases, there is also a unit increase in throughfall. The rate of interception in a tall tree is also high compared to the short trees at the experimental plots.

Figure 4 would have shown the relationship between Gross precipitation and throughfall under a tall and short *Gmelina arborea* tree but there are no short *Gmelina arborea* trees at the experimental plot. The gross precipitation determines the throughfall that is as gross precipitation increases, there is also a unit increase in throughfall. At the experimental plot, the rate of interception of the tall *Gmelina arborea* is also high.

The results of the test to show how much of the throughfall impacts on the ground are given in Fig. 5 -7.

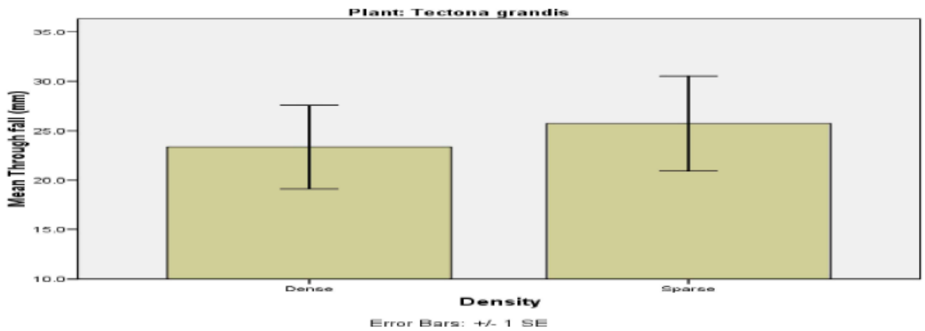

Fig. 5: Bar chart representation of the T-test of Dense and Sparse *Tectona grandis*

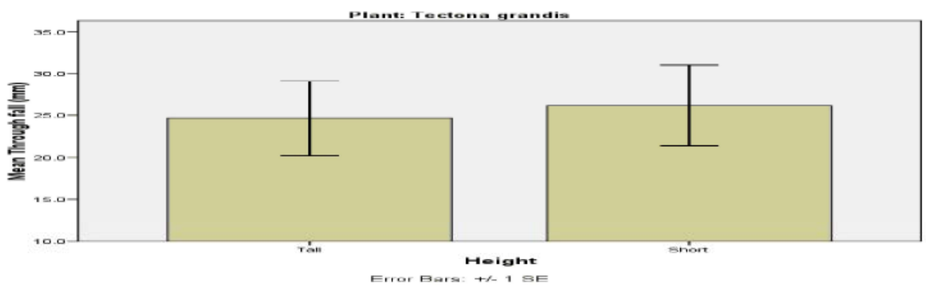

Fig. 6: Bar chart representation of the T-test of Tall and Short *Tectona grandis*

Fig. 7: Bar chart representation of the T-test of Dense and Sparse Gmelina arborea

Figure 5 shows the extent at which the throughfall that gets to the ground under a *Tectona grandis* tree plantation varies with respect to density. The densely packed trees has less throughfall average than in the sparsely packed trees and this implies that at the experimental plot, the densely packed *Tectona gandis* trees intercepts more water and allows less water to get to the ground as throughfall and in the case of the sparsely packed trees, the rainfall interception rate is low and as a result more rain water gets to the ground. Therefore, a tree with a very high density in an area will be more suitable for high rate of interception and a low rate of throughfall.

Figure 6 shows the extent at which the throughfall that gets to the ground under a *Tectona grandis* tree plantation varies with respect to height. The tall trees has less throughfall average than in the short trees and this implies that at the experimental plot, the tall *Tectona gandis trees* intercepts more rainfall and allows less rain water to get to the ground as throughfall and in the case of the short trees, the rainfall interception rate is low and as a result more rain water gets to the ground. Therefore, tall trees in an area will be more suitable for high rate of interception and a low rate of throughfall.

Figure 7 shows the extent at which the throughfall that gets to the ground under a *Gmelina arborea* tree plantation varies with respect to density. The densely packed trees has less throughfall average than in the sparsely packed trees and this implies that at the experimental plot, the densely packed *Tectona gandis* trees intercepts more water and allows less water to get to the ground as throughfall and in the case of the sparsely packed trees, the rainfall interception rate is low and as a result more rain water gets to the ground. Therefore, a tree with a very high density in an area will be more suitable for high rate of interception and a low rate of throughfall.

DISCUSSION

The study of the effect of plant density and height on throughfall was carried out in the University of Agriculture under two tree plantations, *Tectona grandis* and *Gmelina arborea*, in which their gross precipitation and throughfall data collected, was used to determine the extent to which plant density and height will affect throughfall. The results presented here indicates that throughfall is the most important in the calculation of interception loss and this results agrees with those obtained by Horton [1] and Hoppe [6]. From the calculation of the mean averages, the measured throughfall for the dense and tall *Tectona grandis* Tree plantation showed less throughfall data through the plantation of the incident rainfall and high throughfall data in the sparse and short tree plantation likewise the dense *Gmelina arborea* also showed less throughfall data through the plantation and high throughfall data in the sparse tree plantation. The tall and short *Gmelina arborea* cannot be compared since there were no short established *Gmelina arborea* trees at the experimental plot. The results showed that the dense and tall trees in both cases intercepted more rain water with respect to the gross precipitation compared to the sparse and short tree plantations. Where there is a tall and dense vegetation cover, rainfall intensity and distribution will be affected as a result of its interception rate and the ability to prevent the rain drop from getting in direct contact with the ground surface which may lead to splash erosion and in turn grow to soil erosion. Analysis of the results showed a linear relationship exist between the gross precipitation and throughfall of both the *Tectona grandis tree* plantation and the *Gmelina arborea* tree plantation implying that as the gross precipitation increases so also will the throughfall increase.

It was observed that the vegetative characteristics played a great role in the distribution of throughfall in the tree plantations that is the plantation which had more leaf and stem density had low throughfall amount (*Tectona grandis*). This explains the slight differences in the mean averages of the throughfall data collected under *Tectona grandis* tree plantation and *Gmelina arborea* tree plantation, *Tectona grandis* have average leaf size of $0.093m^2$, while *Gmelina arborea* tree have an average leaf size of $0.038m^2$. This implies that leaf size plays more role in the in the interception rate regardless of the density, this findings ar in agreement with Herwitz and Slye [7] and Whalan and Anderson [8] that canopy characteristics is most important control throughfall redistribution.

The differences in the density and height of *Tectona grandis* tree plantation and *Gmelina arborea* tree plantation was compared and analysed to be able to really differentiate them using the T-test. The results showed that for the *Tectona grandis* tree plantation, the dense tree plantation had less rainwater getting to the ground than the sparse tree plantation which had more rainwater getting to the ground. Also in the case of the Tall *Tectona grandis* tree plantation which showed that less rainwater reaches the ground as throughfall and the short tree plantation had more rainwater reaching the ground surface. Finally in the *Gmelina arborea* tree plantation, the dense tree plantation had less throughfall than in the sparse tree plantation. The tall and short *Gmelina* tree plantation cannot be compared because there was no short *Gmelina arborea* tree plantation at the experimental plot.

This study showed to a large extent, that dense and tall tree plantation regardless of the leaf size will have less rainwater getting to the ground and in other words they intercept rainwater more than the sparse and short tree plantation, as earlier reported by Ufoegbune *et al*. [10].

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