Effects of High Intensity Tillage Applications to Improve Productivity on Established Teak (*Tectona Grandis*) Plantations in Specific Site Conditions in Northern Costa Rica

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Abstract

Available land for Teak (Tectona grandis L. f.*), cultivation has specific chemical and physical limitations to productivity of tea plantations, which requires further study and possible solutions. This research has addressed improvements of soil conditions to enhance growth, by applying physical not used in reforestation. A three-block experimental design was established using eight treatments, combining the effect of two deep tillage levels and three "intensities" of tillage implements, using 1, 3 and 5 Chisel ploughs; additionally two treatments more including a fertilized non-tilt treatment and a control plot. The experiment was conducted at a 4 years of age-established plantation, with a 2.8 x 3 m spacing with no previous soil preparation. Physical conditions such as bulk density and shear resistance were improved, however growth responses area inconclusive relative to control treatments, indicating that root pruning might have been severe and that the plantation has not yet reacted to improved conditions.*

1. Introduction

By 2012, the area of teak (*Tectona grandis* L. f.) planted around the world was distributed as follows: 469 800 ha in Africa (10.8%), 3 598 040 ha in Asia (82.8 %), 15 320 ha in the Caribbean (0.4%), 132 780 ha in Central America (3%), 8 130 ha in Oceania (0.2% and 122 300 in South America (2.8%) (Kollert 2012). In the past few years, Latin America´s forest sector has increased its production and trade of plantation based products. Teak plantations have been widely established in Central America, initially in Costa Rica and Panama and more recently in Guatemala, El Salvador and Nicaragua. Teak has become an important species in the quality tropical hardwood sector (Fernández-Moya and Alvarado et al. 2014). Teak is the most commercially important timber species planted in Asia, totaling around 1 million hectares (Enters and Nair 2000). High teak demand worldwide has intensified the concept of technological management of forest plantations. Tree breeding programs have has allowed an increase in productivity, as mentioned by Goh and Monteuuis (2005) where they describe the benefits of clonal forestry in the Teak ICSB reforestation project, where the selection of plus trees facilitates the implementation of forest plantations in less favorable environmental conditions. Nevertheless, site preparation and the propagative material of plants go a long way to determine the growth performance and biomass production. A good stock will always depend on adequate site conditions, and genetic material alone is not a guarantee of a successful plantation in terms of timber production, therefore proper tillage activities could offer the possibility to enhance yield on soils with low productivity.

One example is the study by Boyle et al (2009) who showed the effect of forest plantations as amendments of soil physicochemical conditions in Costa Rica; while Zimmermann et al (2006) report the negative effect on soil caused by intensive grazing and visible after 10 years of cultivation of teak. This effect involves the rapid saturation of the surface layers causing water overflow. Reforestation experiences in Costa Rica, including successes and failures point to two key decisions: the selection of the species (and its genotype) and soil management. Subsequent aspects, except for weed management, have been well developed and technically improved in recent years (pruning, thinning). At present, companies are recognizing that improving the physical and chemical soil conditions are crucial in site preparation in order to improve the use of water in the soil and drainage, to minimize compaction and improve aeration effect, which greatly favors growth and health of the stand (Alvarado et al 2004) Nevertheless, tillage practices in forestry in Costa Rica, offer no good practice guidelines, and companies do not follow validated methods of tillage aimed at improving productivity and sustainability of production.

This study aims to increase the productivity of establish teak plantations, with delay in growth and which were established without initial soil preparation, through deep tillage levels, not used in the forestry species before, with the fundamental hypothesis that mechanization after establishment would have a positive effect on growth of plantations.

2. Materials and methods

2.1. Experimental trials

The study was established at plantation sites of the Reforestation Group International (RGI), a company dedicated to teak plantation establishment for commercial purposes (RGI). The sites selected sites were selected by obvious delays in growth, believed to be an influence on soil conditions and fertility (Table 1). This site is located at Los Chiles County, Alajuela Province, Costa Rica, approximately 10 km west of Pavón town (Figure 1).

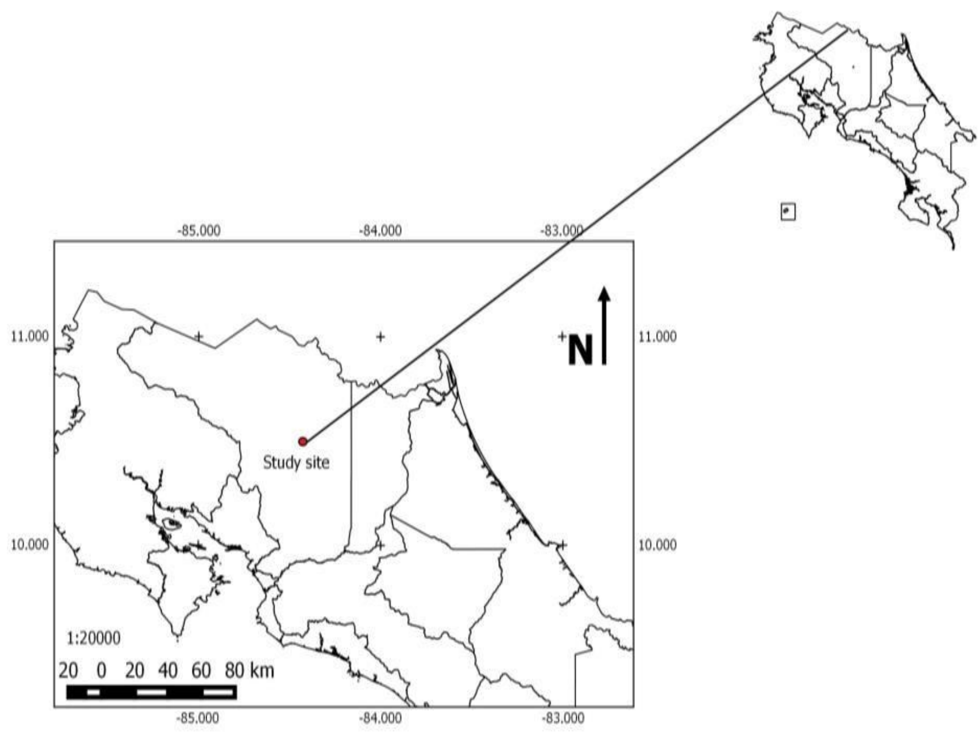


Figure 1. Site location of Tillage experiment at RGI teak farms, Los Chiles, Costa Rica.

Table 1. Chemical analysis of plantation site at different horizons before tillage operations

Horizon		**A**	**B**	**C**
Depth	cm	0-29	29-40	40->100
pH	H_2O	5,2	5,6	5,5
Acidity		0,64	0,21	0,31
Ca		3,27	2,47	2,67
Mg		1,17	0,95	1,22
K		0,04	0,02	0,02
CICE	cmol(+)/L	5,12	3,65	4,22
AS	%	13	6	7
P		3	3	1
Zn		1,0	0,4	0,4
Cu		12	9	11
Fe		143	57	33
Mn	mg/L	27	1	1
C	%	1,98	0,84	0,50
N		0,23	0,11	0,09
OM		2,83	1,20	0,72
Rate	C/N	8,6	7,6	5,6
S	mg/L	6	49	68

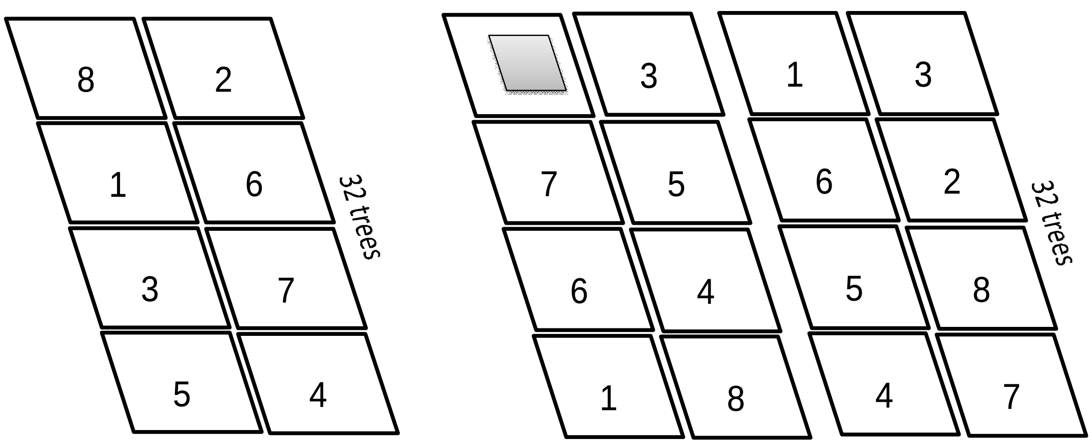


Figure 2. Tillage experimental design and treatment distribution within blocks, where: (1) control, , no tillage and no dolomite application [C]; (2) no tillage with dolomite application [0PD]; (3) 1 chisel plow at 25 cm of 105 depth [1P25]; (4) 3 chisel plows at 25 cm of depth [3P25]; (5) 5 chisel plows at 25 cm of depth [5P25]; (6) 1 chisel plow at 40 cm of depth [1P40]; (7) 3 chisel plows at 40 cm of depth [3P40]; (8) 5 chisel plows at 40 cm of depth [5P40]. Emphasized grey area in block 2 treatment 2 represents the effective number of trees for 108 variable analysis.

The field experiment was carried out at a 4 years of age-established plantation (2013), with a 2,8 x 3 m spacing with no previous soil preparation. The plantation was established using seedlings from a certified seed orchard; pruning and weed control were applied according to the silvicultural program for the plantation. Growth and yield at the time were notoriously deficient, and the farm's previous land uses were cattle husbandry and marginal agricultural use. The experimental design consisted of 3 complete random blocks with a factorial arrangement of 8 treatments with 3 repetitions each. A trapezoid rectangle area consisting of 8 x 8 trees comprised the treatment area; an effective number of 20 trees per experimental unit were used for analysis of information, in order to avoid edge effect from the treatment and the block edge (Figure 2).

The treatments are a combination of two tillage depths and three different tillage intensities, defined by the number of chisel plows used, and a general application of dolomite ($CaMg(CO_3)_2$) at 3 tons/ha to reduce soil acidity for all treatments except a full control; the experimental units had a random distribution within each block (Figure 3).

The resulting combination gave the following treatments: (1) control, no tillage and no dolomite application[C]; (2) no tillage with dolomite application [0PD]; (3) 1 chisel plow at 25 cm of depth [1P25]; (4) 3 chisel plows at 25 cm of depth [3P25]; (5) 5 chisel plows at 25 cm of depth [5P25]; (6) 1 chisel plow at 40 cm of depth [1P40]; (7) 3 chisel plows at 40 cm of depth [3P40]; (8) 5 chisel plows at 40 cm of depth [5P40]. The implement used was a SAME tractor of 65 hp (figure 3), where the three average speeds of tillage were 1.33 ms-1 for 1 chisel, 0.75 ms-1 for 3 chisels and 0.56 ms^{-1} for 5 chisels. Each experimental unit consisted of 64 trees on a 576 m^2 plot which gave 0.46 ha per block and a total of 1.4 ha for the whole experiment.

Figure 3: Tractor and implement used on treatment implementation and dolomite application.

2.3 Physical soil properties

An initial soil profile characterization was made with a 1x1m soil pit of 1 meter depth to evaluate conditions prior to the beginning of the experiment (Table 1). The physical characteristics evaluated included, texture, bulk density, and shear strength and penetration resistance. Texture for each horizon was determined using a 2 mm sieve in the laboratory. Smaller pits were dug-out following the strips of treatment application to compare physical properties and to make observations on root development at each experimental unit. Both shear resistance (using a vane penetrometer) and penetration resistance. Physical properties after treatment application were averaged for all treatments, since the pass of the chisel would have the same effect be this 1, 3 or 5 chisels; the values are presented by horizon. Average values for non-tillage areas were obtained from the control treatment and non-tillage with dolomite treatment. Bulk density (Bd) was determined by taking 6 samples at each experimental unit at depths of 0-20 cm and 20-40 cm, taking them with a borehole for Bd sampling with cylinders of 5 cm in diameter. The volume of each cylinder was determined (± 0.01 mm) as well as soil dry weight (± 0.1 g) in order to use the formula:

$$B_d = \frac{Sdw_{105°C}}{V_c}$$

Where: Bd: Bulk density
Sdw 105º C: Soil dry weight at105ºC (g)
Vc: Cylinder volume (cm^3)

2.4. Measured variables

Growth variables (diameter at breast height and total height) were measured every nine months coinciding with the rainy season. DBH was measure with a simple diameter tape and total height with a laser hypsometer (Trimble Laser Ace 1000 rangefinder). Commercial volume was calculated using growth models from Perez 2008. Visual confirmation of the tillage effect on root development was recorded after a year, by digging low depth soil pits where treatment was applied; the length of the pit varied according to the width of application.

2.5 Statistical analysis

Data were analyzed by a general ANOVA. The Info Stat® software was used to run tests of significant differences among treatments and Turkey's HSD (honestly significant difference) test was performed for post-hoc comparisons between treatments mean at the 95% probability level ($p < 0.05$). Shapiro Wilks normality test was applied ahead of analysis to check the normality, to ensure that assumptions of the model were met. Homoscedasticity was verified with Levene test.

3. Results and Discussion

3.1 Horizon characterization

In general, soil characteristics are uniform at the site. Soil characteristics indicate an acid Alfisol with a reported depth of more than 100 cm with three defined horizons. The A horizon is clayish with a depth of 29 cm, root presence is high secondary and tertiary development, with poor structure, large lumps, with identified compaction and loss of structure. Horizon B is also clayish with a depth from 29 to 40 cm, secondary and tertiary root growth is still present, with mostly dead roots with horizontal growth. The C horizon has a depth from 40 to more than 100 cm, with pseudo-clay structure and the existence of roots is not perceived (Table 2). Both horizons A-B have a blocked structure with pronounced porosity. The site, as other close by areas, can be considered as a bad quality site for teak growth (Alvarado 2004).

Table 2: RGI Horizon characteristics in terms of porosity and particle size distribution percentage

Horizon			Particle size distribution(%)		
	Texture and root presence	Depth(cm)	Sand	Clay	Silt
A	Clayish with apparent presence of roots	0-29	5,8	79,8	14,4
B	Clayish with small presence of roots	29-40	2,05	89,8	8,15
C	Clayish with no presence of roots	40->100	3,3	88,55	8,15

3.2 Physical properties.

The physical properties changed after treatment application (Figure 4). Average values for shear resistance and penetration resistance were calculated according to tillage or non-tillage application. The change of shear resistance is evident passing from 0.5 kgcm-2 to 0.16 kgcm-2 in the A horizon, and even more successful at the B horizon, passing from 1.08 kgcm-2 in the non-tillage area to 0.08 kgcm-2 in the tillage area.

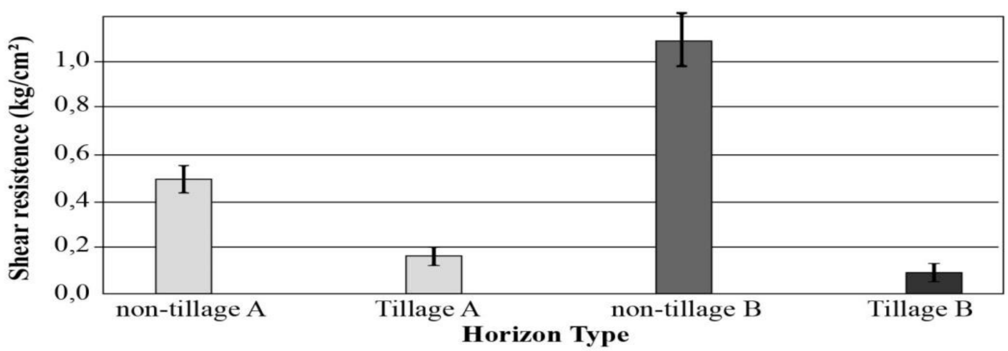


Figure 4. Average shear Resistance at non-tillage and tillage areas from treatment application.

Average bulk density was equally improved by the treatments, which is reflected on the decrease of its value, passing from 1.08 g $cm^{-3}$and 1.16 g cm^{-3} in the A and B horizon respectively before treatment application to 0.86 g cm^{-3} after treatment application in both horizons (Figure 5). The results indicate an obvious improvement especially for the B horizon, allowing the radical system to access with greater ease to this layer, which can improve the absorption area of fine roots, allowing the uptake of available nutrients from this previously un-accessed area, as long as acid saturation percent allows it (Edmeades et al 1995).

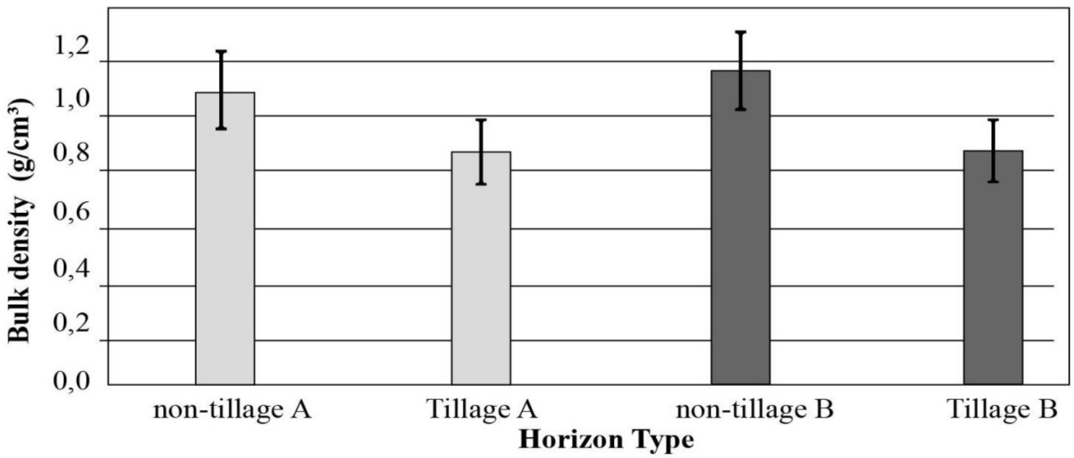
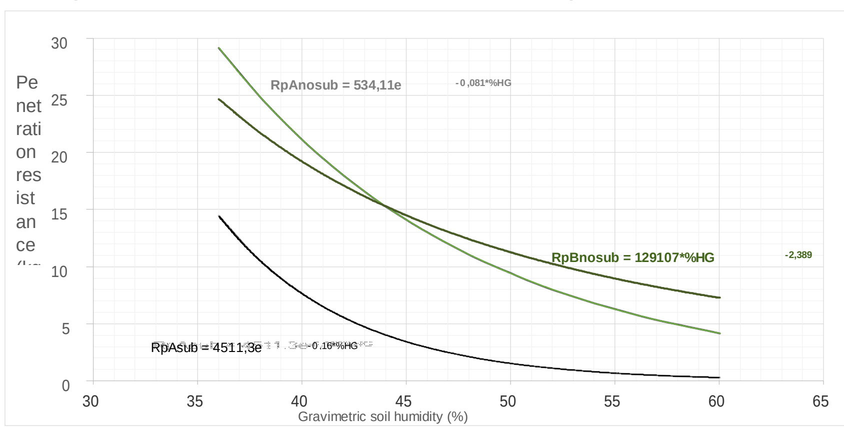


Figure 5. Average bulk density (Bd: g/cm3) at non-tillage and tillage areas from treatment application.

Field data for penetration resistance test was adjusted to exponential models to explain the behavior of this physical property for non-tillage and tillage sections of the soil as a function of gravimetric humidity change. The A horizon penetration resistance improves considerably as shown in figure 6. Penetration resistance is equally decreased for B horizon with increasing gravimetric humidity. The scope of change in humidity for tillage B horizon samples did not offer enough data points to adjust the exponential curve. Mechanization obviously improves the access by the root system in the soil as demonstrated by the changes of this variable in the A horizon.

Figure 6. Average penetration resistance (Rp) at non tillage and tillage areas at both A and B horizons, following an exponential model as a function of gravimetric humidity (%).



It has been thoroughly demonstrated that tillage would have effects on physical parameters and that it allowsfor easier penetration of the soil by the root system; this should be reflected on changes in growth, as the radical system would have an ease to colonize previously denied regions of the soil matrix at a deeper level and on an easier manner. Parallely this would increase anchorage and root network and given than teak has association with arbuscular mycorrhiza (AM), it would increase the absorption area and even possible nutrient transfer among trees (Rajan et al. 2000). Ideal commercial plantation's soil preparation should include soil reaping at a depth of 50 cm (normally done with one chisel pass) (Ugalde 207 2014). With an improvement on soil physical conditions, an increase in growth should be expected, which in turn should be reflected on improvement of growth variables like height, diameter and the consequent total volume (González-Barrios et al 2015). When evaluating the effect reported in absolute growth from the 210 treatments applied through time, the analysis of these variables indicates adverse results; as the intensity of 211 treatments could have been more severe, affecting root biomass, and consequent capacity for nutrient and 212 water uptakes as compared to controls.

3.3 Growth variables

The behavior of growth variables through time can be seen in table 3. For average height, there were no immediate significant differences the first year after treatment application; in 2014 the response in height, showed a statistical tendency towards grouping, however an inference on a preferred treatment vs another cannot be made. This confirms that mechanization applied here, represented a root pruning, which effects are not clearly shown on a short term basis. In 2015 statistical analysis ratifies that the most intensive treatment [5P40], was the most severe against growth and recovery of root biomass in the plantation, producing a negative effect on height growth. A plantation as low quality evaluated is considered to have a 14 m site index (SI) at rotation age and 26 m to 22 m when is considered from high to excellent, for Costa Rica (Vallejos and Ugalde 1998). Based on Ugalde 2014, an expected height of 9 m for a low quality site and of 21 m for an excellent site at age five, places theplantation at a bad quality site (de Camino and Morales 2013), which justifies corrective measures, be physical of chemical to improve yield. Throughout the experiment, no changes in leaf area index were recorded. Diameter growth, as a densitydepended variable, was not affected since thinning did not take place within the experimental units (Arias and Camacho 2004).

Table 3: Growth variables for the tillage treatments used in the study.

Treatment	Height (m)			Diameter (cm)		
Code	2013	2014	2015	2013	2014	2015
1) [C]	9.16 a	10.18 c	12.15 c	9.31 b	10.15 b	11.55 b
2) [0PD]	8.19 a	9.51 ab	11.77 b	9.17 ab	10.05 ab	11.47 b
3) [1P25]	8.79 a	9.63 ab	11.79 b	9.25 ab	9.95 ab	11.25 ab
4) [3P25]	8.92 a	9.77 abc	11.74 b	9.20 ab	9.94 ab	11.26 ab
5) [5P25]	8.71 a	9.91 bc	11.76 b	9.39 b	10.13 b	11.41 ab
6) [1P40]	9.09 a	9.95 bc	11.83 bc	9.31 b	10.04 ab	11.07 ab
7) [3P40]	8.81 a	9.62 ab	11.69 b	8.81 ab	9.42 a	10.77 ab
8) [5P40]	8.67 a	9.33 a	11.14 a	8.64 a	9.40 a	10.54 a

Definition: (1) control [C]; (2) no tillage with dolomite [0PD]; (3) 1 chisel plow at 25 cm of depth [1P25]; (4) 3 chisel plows at 25 cm of depth [3P25]; (5) 5 chisel plows at 25 cm of depth [5P25]; (6) 1 chisel plow at 40 cm of depth [1P40]; (7) 3 chisel plows at 40 cm of depth [3P40]; (8) 5 chisel plows at 40 cm of depth [5P40].

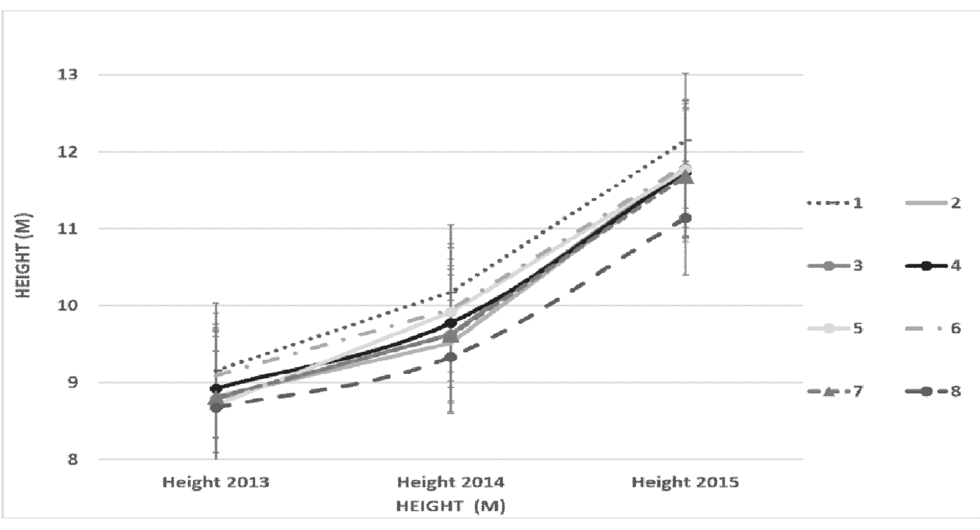


Figure 6: Treatment height growth during the three year period at RGI Teak (*Tectona grandis*) plantations in Los Chiles, Costa Rica. (1) control [C]; (2) no tillage with dolomite application [0PD]; (3) 1 chisel plow at 25 cm of depth [1P25]; (4) 3 chisel plows at 25 cm of depth [3P25]; (5) 5 chisel plows at 25 cm of depth [5P25]; (6) 1 chisel plow at 40 cm of depth [1P40]; (7) 3 chisel plows at 40 cm of depth [3P40]; (8) 5 chisel plows at 40 cm of depth [5P40].

In spite of the restrain in growth experienced by each treatment, a clear tendency of height and diameter increase still occurs through time. The tendency of growth is maintained through time, shadowing the control treatment. For height, the 5P40 shows the lowest value, clearly separated from the rest of the treatments. Diameter (Figure 7) shows the same tendency, however the gap between the control treatment and the immediate best treatments (5P25 and 1P40) is shorter; treatment 7 (3P40) and 8 (5P40) clearly show the lowest diameter with a considerable gap from all other treatments.

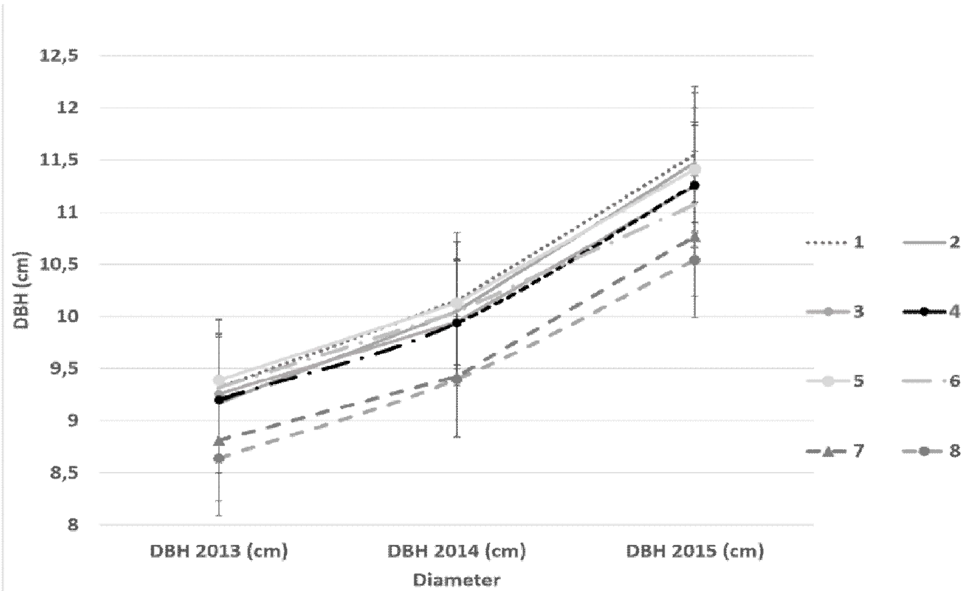


Figure 7. DBH growth during the three year period at RGI Teak (Tectona grandis) plantations in Los Chiles, Costa Rica. (1) control [C]; (2) no tillage with dolomite application [0PD]; (3) 1 chisel plow at 25 cm of depth [1P25]; (4) 3 chisel plows at 25 cm of depth [3P25]; (5) 5 chisel plows at 25 cm of depth [5P25]; (6) 1 chisel plow at 40 cm of depth [1P40]; (7) 3 chisel plows at 40 cm of depth [3P40]; (8) 5 chisel plows at 40 cm of depth [5P40].

Although the control comes with the highest values for diameter and height, increments show a reflection for improvement on certain treatments, which in turns suggests that the time frame to assess improvement from application should be longer than two growth periods, thus further measurements from these studies might be needed. It can be seen from figure 8 than treatment 4 (3 chisels at 25 cm depth) and 8 (5 chisels at 40 cm depth) for diameter show a relative higher increment than other treatments; and treatments 3 (1 chisel plow at 25 cm of depth), 5 (5 chisel plows at 25 cm) and 7 (3 chisel plows at 40 cm) show the highest relative increment for height in 2015. This can be considered a burst of growth that will later be seen; however it is not well established whether low or high intensity tillage systems are more beneficial, and reports regarding the effect of tillage intensities on tree growth are not consistent and may be site-specific (González-Barrios et al 2015). Even further, there are no significant differences among treatments for such increments as compared to control (Table 4).

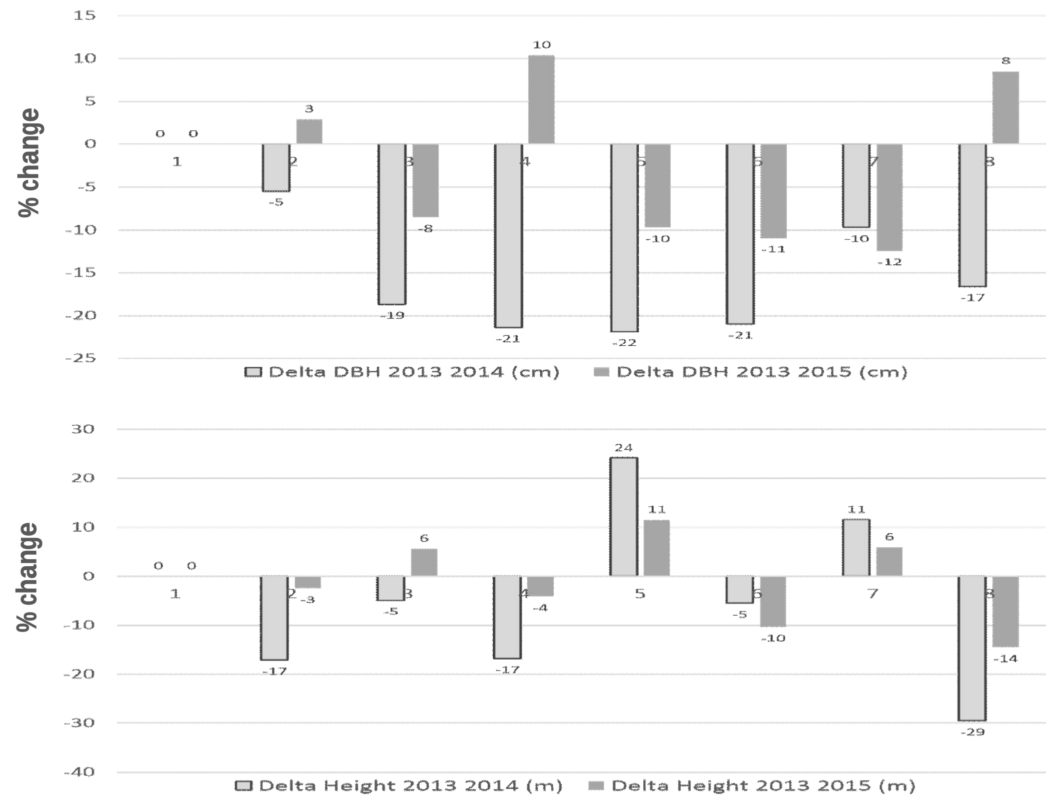


Figure 8. Treatment DBH and Height deltas for 2013 to 2014 and 2013 to 2015 during the three year period at RGI Teak (Tectona grandis) plantations in Los Chiles, Costa Rica. (1) control [C]; (2) no tillage with dolomite application [0PD]; (3) 1 chisel plow at 25 cm of depth [1P25]; (4) 3 chisel plows at 25 cm of depth [3P25]; (5) 5 chisel plows at 25 cm of depth [5P25]; (6) 1 chisel plow at 40 cm of depth [1P40]; (7) 3 chisel plows at 40 cm 277 of depth [3P40]; (8) 5 chisel plows at 40 cm of depth [5P40].

Table 4. Absolute increments for height and diameter growth tillage treatments used in the study.

Treatment	*Height (m)*		*Diameter (cm)*	
	Period 2013-2014	*Period 2013-2015*	*Period 2013-2014*	*Period 2013-2015*
1) [C]	1.28 a	3.46 a	1.05 a	2.65 a
2) [0PD]	1.06 a	3.38 a	0.99 a	6.89 a
3) [1P25]	1.22 a	3.66 a	0.85 a	6.97 a
4) [3P25]	1.07 a	3.32 a	0.82 a	7.38 a
5) [5P25]	1.59 a	3.86 a	0.82 a	5.10 a
6) [1P40]	1.21 a	3.11 a	0.83 a	6.10 a
7) [3P40]	1.43 a	3.67 a	0.95 a	6.48 a
8) [5P40]	0.90 a	2.96 a	0.87 a	5.86 a

Definition: (1) control [C]; (2) no tillage with fertilization [0PD]; (3) 1 chisel plow at 25 cm of depth [1P25]; (4) 3 chisel plows at 25 cm of depth [3P25]; (5) 5 chisel plows at 25 cm of depth [5P25]; (6) 1 chisel plow at 40 cm 282 of depth [1P40]; (7) 3 chisel plows at 40 cm of depth [3P40]; (8) 5 chisel plows at 40 cm of depth [5P40].

3.4 Improvement of physical conditions vs growth variables change

The information presented in figures 4 through 6 clearly demonstrates that an improvement in physical soil properties took place with the application of chisel plows, regardless of its intensity for the sector where it was applied. However, this improvement does reflect positively on neither height nor diameter on any of the experimental units; on the contrary treatments seem to have a negative effect on growth when compared to control. As an analogy, crown pruning has obvious advantages on increasing yield, however, excess pruning can have detrimental effects on growth variables, which can make trees susceptible to decreased diameter (Ugalde 2013), and therefore lower volume growth.

It is evidently difficult to evaluate the percentage of fine root and medium size root biomass removed by each treatment; and no direct evidence is given in literature on the effect on fine root reduction with these systems for teak yet (Ugalde 2013).

Evidence in literature, suggest that a consequence of root biomass pruning would have a reduction on growth (Poni et al 1992, 298 Geisler and Ferree 1984, Richards and Rowe 1977). A consequent reduction in root biomass could have also affected leaf biomass and therefore photosynthetic area. It was not possible for this study, to conduct photosynthetic measurements due to logistics such as tree height. Parallely, it is possible that the tillage experiment has been performed at an age in which the plantation experiences more damage than benefits, severing root networks already established. Only a change in physical properties does not seem sufficient to improve the conditions that limit the growth of teak on that particular site. As chemical requirements for teak goes, the quantity of nutrients absorbed by a plantation can be calculated by the concentration of the specific nutrient and the amount of dry biomass, multiplying these values would indicate the quantity absorbed (de Camino & Morales 2013); however, this is linked to the actual concentration of nutrients at the site. A change in physical properties does not increase productivity. When a tree has a limitation on growth, improve chemical conditions are subject to Liebig minimum law, so that the lowest element is the limiting factor. This test demonstrates that if physical conditions are improved but chemical characteristics are not heavily considered, the trees will not respond to treatment. Although the root system distribution cannot be directly assessed, it seems that the methods used were more drastic than the tree can bear on those conditions at that age. Analysis conducted and published in closed by sites (Alvarado 2004) suggest chemical deficiencies in the area; therefore if the limiting factor is not improved, growth would remain halted. In light of the above if the trees have physical and chemical limitations, working on only one strategy would be insufficient to improve growth.

This study presents the effect on fine root demography (Table 5 and 6) after treatment application. Treatment 4 showed an increase significantly different from other treatments for both depths; and again the more intensive treatment seems to be the most severe as fine root not only did not recover but also keeps being lower than the controltreatment. A preference for treatment 4 intensity can be justified, by the amount of dead vs live root, where no significant difference can be found overall for the treatments. A consequent reduction in root biomass could have also affected leaf biomass and therefore photosynthetic area. Parallely, it is possible that the tillage experiment has been performed at an age in which the plantation experiences more damage than benefits, severing root networks already established.

Table 5. Amount of live and dead fine roots treatment application at the last measuring period in Ton/ ha and Ton/m3 for 2 depths (0-20 cm and 20-40 cm).

Condition	Depth variable	0-20 cm		20-40 cm	
		Ton/ha	Ton/m^3	Ton/ha	Ton/m^3
Live roots		6.36a	0.0032a	5.00a	0.0025a
Dead roots		4.87a	0.0024a	4.24a	0.0021a

Table 6. Fine root proliferation after treatment application at the last measuring period in Ton/ ha and Ton/m3 for 2 depths (0-20 cm and 20-40 cm).

Treatment	Depth *variable*	0-20 cm		20-40 cm	
		Ton/ha	*Ton/m^3*	*Ton/ha*	*Ton/m^3*
1) [C]		*6.1ab*	*0.0031ab*	*4.10ab*	*0.0020ab*
2) [0PD]		*8.43b*	*0.0042b*	*5.03ab*	*0.0025ab*
3) [1P25]		*8.2b*	*0.0041b*	*7.33ab*	*0.0037ab*
4) [3P25]		*8.58b*	*0.0043b*	*7.98b*	*0.0040b*
5) [5P25]		*6.26ab*	*0.0031ab*	*3.63ab*	*0.0018ab*
6) [1P40]		*3.35ab*	*0.0017ab*	*4.45ab*	*0.002.2ab*
7) [3P40]		*1.66a*	*0.00083a*	*2.07a*	*0.0010a*
8) [5P40]		*2.33a*	*0.0012a*	*2.35a*	*0.0012a*

Definition: (1) control [C]; (2) no tillage with fertilization [0PD]; (3) 1 chisel plow at 25 cm of depth [1P25]; (4) 3 chisel plows at 25 cm of depth [3P25]; (5) 5 chisel plows at 25 cm of depth [5P25]; (6) 1 chisel plow at 40 cm of depth [1P40]; (7) 3 chisel plows at 40 cm of depth [3P40]; (8) 5 chisel plows at 40 cm of depth [5P40].

A crucial part of the experiment, dolomite fertilization, seemed to have had no effect on growth variables; even though a chemical deficiency by Ca was present (Table 1); the percentage of acidity saturation was found also to be high for the site. According to review (Ugalde 2014) the relationship between soil fertility and teak growth is not clear. Although the species can remove great quantities of nutrients from good sites, it can also thrive in relatively infertile soils when good physical conditions are present. Appropriate root development would present a well-developed tap root, which gives anchorage and the possibility to establish a wide fine root system. Observations from this study show the impediment of root development and actions to correct it (Figure 9).

Figure 9. Soil physical profile characteristics and treatment application in established plantations at RGI´s site “Gallito”, Los Chiles Costa Rica; a) Initial soil profile conditions, b) root development 2 years after treatment application, c) machinery implement set for treatment application, d) application of treatments.

4. Conclusion

The fundamental hypothesis, that tillage on established plantations, would have a positive effect on growth, cannot be confirmed by the findings of this experiment. Results show the necessity to apply soil physical improvement methods at the moment of plantation establishment, given that no effects on growth improvement were found.

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