

COVER CROPS AS A WEED CONTROL METHOD AND THEIR EFFECT ON THE INITIAL GROWTH OF A *Tectona grandis* PLANTATION

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Resumo

*Culturas de cobertura como método de controle de ervas daninhas e seu efeito no crescimento inicial de uma plantação de Tectona grandis L.f. Tectona grandis L.f. (Teca), é uma das espécies tropicais mais utilizadas no reflorestamento comercial. O controle de plantas daninhas é uma das atividades de manejo mais comuns nessas plantações. O objetivo do presente estudo consistiu em avaliar o efeito de plantas de cobertura no controle de ervas daninhas e no crescimento inicial de uma plantação de teca recém-estabelecida na zona sul da Costa Rica. Os tratamentos foram: a) controle (sem controle de ervas daninhas), b) controle químico de plantas daninhas, c) controle manual de plantas daninhas, d) cultura de cobertura *Canavalia ensiformis*, e) cultura de cobertura *Vigna radiata*, f) mistura entre *Vigna radiata* e *Pueraria phaseloides* e cultura de cobertura *Crotalaria juncea*. Além disso, calcularmos os custos totais para todos os tratamentos. Todas as espécies ultrapassaram 60% de cobertura terrestre, sendo *C. juncea* e *V. radiata* as de melhor desempenho. Embora todas as plantas de cobertura tenham apresentado valores de altura mais elevados que os outros tratamentos, apenas a *C. ensiformis* teve um efeito significativo no crescimento em altura aos 6 meses de idade. O controle manual de plantas daninhas foi o tratamento mais econômico. Com base nos resultados obtidos, concluímos que as plantas de cobertura podem ser utilizadas como um método alternativo de controle de plantas daninhas, sem que haja risco de afetar o crescimento das árvores.*

Palavras-chave: métodos culturais, gestão de plantações, teca, leguminosas, Costa Rica

Abstract

Tectona grandis L.f. (teak) is one of the most used tropical species in commercial reforestation projects. Weed control is a common activity within these plantations. The study aimed to evaluate the effect of cover crops in weed control and the initial growth of a young teak stand in the southern part of Costa Rica. We used a randomized complete block design with three replications and seven treatments: a) control (without weed control), b) chemical weed control, c) manual weed control, d) cover crop *Canavalia ensiformis*, e) cover crop *Vigna radiata*, f) mix between *Vigna radiata* and *Pueraria phaseloides*, g) cover crop *Crotalaria juncea*. In addition, we calculated the total costs for all treatments. All species exceeded 60% ground coverage, with *C. juncea* and *V. radiata* being the best performers. Although all cover crops had higher height values than the other treatments, only *C. ensiformis* had a significant effect on height growth at six months of age. Manual weed control was the most economical treatment. Based on the results obtained, we concluded that the cover crops can be used as an alternative method of weed control without affecting the growth of the trees.

Keywords: cultural methods, plantation management, teak, legumes, Costa Rica.

INTRODUCTION

Tectona grandis (teak) is one of the most valuable tropical woods worldwide (KOLLERT AND KLEINE, 2017). Its propagation, establishment, and management are easy; its wood of excellent quality is highly appreciated for furniture construction, structural elements, boats, carpentry, plates, floors, among others (KEOGH, 2013, MOYA *et al.*, 2014). In Costa Rica, it has been used in reforestation projects for commercial purposes (MONTAGNINI, 2004, BOLEY *et al.*, 2009) and until 2014, the National Institute of Statistics and Census (INEC) reports 47,167 hectares planted and more than 150,000 scattered trees on farms (INEC 2015).

There are many activities within plantation forest management that must be contemplated to guarantee their success. Among them are weed control operations. Weeds are one of the major impediments to the successful establishment (survival), initial growth, and productivity of forest plantations. (ADAMS *et al.*, 2003; GARAU *et al.*, 2009; LADRACH, 2010).

A wide variety of weed control alternatives have been researched and tested in the forestry field ranging from manual and mechanical control (sowing machines or agricultural tractors with cutting implements) to chemical control (GEORGE and BRENNAN, 2002). In Costa Rica, weed control operations have been carried out in several ways, including manual weeding and, more recently, herbicide application, used more frequently due to their speed, effectiveness, and prolonged effect (GUEVARA, 2011).

Despite the contributions of these methods, there are many disadvantages and challenges. Manual and mechanical control are high cost and can disturb soil properties through compaction processes (JABRAN *et al.*, 2015). On the other hand, the potential effects that herbicides have on human health, soil, surface, and groundwater have led organizations, such as the Forest Stewardship Council (FSC) and the World Health Organization (WHO), to increasingly restrict the use of herbicides in commercial forest plantations (JABRAN *et al.*, 2015, FSC 2015).

Globally and mainly in agriculture, cover crops have become one of the alternative methods for weed control and replacement of major herbicides. In tropical crops, nitrogen-fixing plants (legumes) are the most commonly used as cover plants because they produce a large quantity of leaves (biomass), effectively suppress weeds, have the ability to maintain soil moisture and increase the content of organic matter, and improve soil structure and herbivores control (BRUST *et al.*, 2014, JABRAN *et al.*, 2015). Among the main species are *Arachis pintoi*, *Phaselos vulgaris*, *Mucuna priurens*, *Pueraria phaseloides*, *Crotalaria sagittalis*, and *Desmodium* sp.

The use of cover crops in Costa Rica has occurred mainly in oil palm, banana, and coffee crops. Authors such as Ortiz *et al.* (1995) have presented positive results in terms of weed control using *Pueraria phaseloides*. However, they indicate that its maintenance must be intensive since it has climbing habits. Other authors have found positive results in terms of soil erosion control. In the forestry field, there are few experiences developed in Central America, and they have focused only on evaluating the percentage of soil coverage and the effect of mixing some legume species with traditional weed control methods.

In Costa Rica, there are no scientific studies on the use of cover crops in forest plantations; for this reason, this study aimed to evaluate the effect of cover crops in the control of weeds and the initial growth of a newly established teak plantation in Costa Rica's southern zone.

MATERIALS AND METHODS

Study area

The study was conducted in Salamá, Puntarenas province, Costa Rica (8°48'41" N, 83°17'37" W) at an altitude of 20 meters above sea level (Figure 1). According to Holdridge, the life zone is a "very humid tropical forest," with an average temperature of 26 °C and an average annual precipitation of 4450 mm. The soil is classified as an Inceptisol according to the USDA classification (2003).

Land preparation and sowing of cover crops

Before establishing the cover crops, the experimental site was mechanized using a Same® tractor of 95 horsepower, a chisel plow, and a 16-disc harrow. After initial mechanization, 30 cm high raised beds were established, and the trees were planted with a distance of 3.1 x 3.1 m. The site was free of weeds at the time of cover crop sowing. Cover crops were planted 15 days after the plantation was established. Sowing was done manually at a distance of 50 cm between holes and rows for the cover crops.



Figure 1. Experimental unit overview within the study site.

Figura 1. Visão geral da unidade experimental no local do estudo.

Evaluated variables

Percentage of soil coverage of cover crops

Weed assessment was undertaken at 2, 4, 8, and 16 weeks after planting. To determine the percent cover, we used a wooden frame of 1 x 1 m divided every 10 centimeters to obtain small squares of 100 cm² each. At every treatment, eight samples were taken. The average height was recorded in each sample square for each cover crop.

Tree growth

The measured variables were diameter at 0.10 m above ground (D_{base}), total height (h), and diameter at breast height (1.30 m) (DBH) for the trees in each treatment. The measurements over time were systematically distributed and followed the same sequence every time. Measurements were made at six and 12 months.

Costs

We kept a record on the number of times weed control was performed in each treatment. We calculated total costs for each treatment based on the productivity per hectare of each labor, the number of times per year, inputs, and the cover crop seed cost. Chemical control costs included herbicide, application, and safety equipment. Company estimates were used to determine productivity. In the case of cover crops, a study of times and movements was carried out, and data were subsequently extrapolated to hectare values.

We built two scenarios based on the information collected through the study of times:

- a. Productivity and costs of the different treatments used as it was performed in the trial.
- b. Productivity and costs of the use of covers only in the planting row of trees.

Experimental design

A randomized complete block design with seven treatments and three repetitions was used. The treatments applied were the following: T0: Control (without weed control); T1: Chemical weed control; T2: Manual weed control; T3: *Canavalia ensiformis* cover crop; T4: *Vigna radiata* cover crop; T5: Mix between *Vigna radiata* and *Pueraria phaseloides*; T6: *Crotalaria juncea* cover crop.

Each experimental unit consisted of 60 trees, including edges. The effective plot of measurement was 40 trees distributed in four rows with ten trees, each with an effective plot area of 260m².

Statistical analysis

All statistical analyses were performed using SAS (SAS 9.3, SAS Institute, Cary, NC) with $\alpha = 0.05$. The data were subjected to a homoscedasticity analysis, and the Shapiro-Wilks test was applied to verify its normality, using SAS statistical software. An analysis of variance was performed with longitudinal analysis. The comparison of means was carried out using the Tukey test with a 95% confidence level significance.

RESULTS

Cover crop establishment and ground cover percentage

The initial development of all species used was similar, starting its germination two weeks after planting (WAP). At four WAP, *C. juncea* and *V. radiata* had a more vertiginous growth and an increase of coverage of more than 50%, reaching full coverage between eight and ten WAP. The mixture between *V. radiata* and *P. phaseloides* was dominated by the latter, and its development was similar to *C. ensiformis*. At the end of the 16 weeks of evaluation, only *C. juncea* managed to have a 100% coverage percentage; however, all the species used managed to surpass 60% coverage (figure 2).

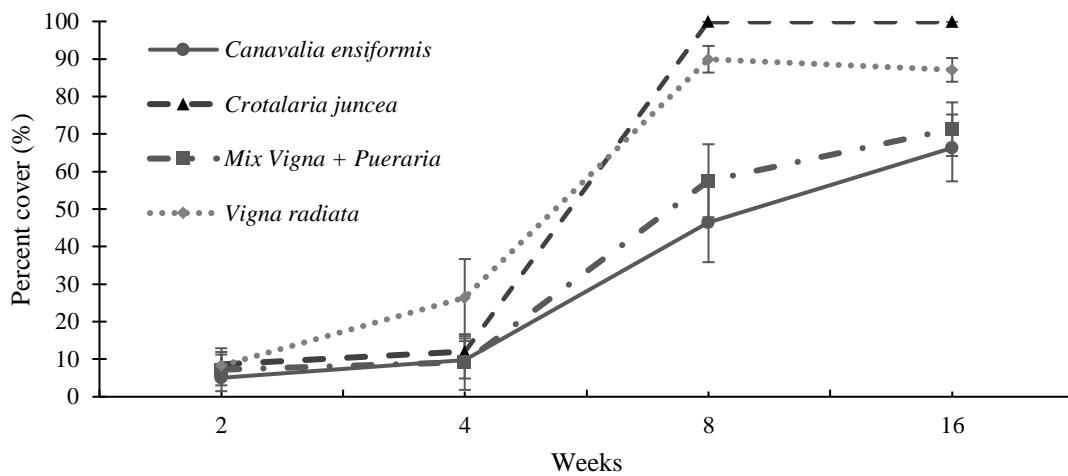


Figure 2. Percent cover of four cover crops intercropped with teak plants over 16 weeks after planting (WAP). Error bars represent standard deviation.

Figura 2. Cobertura percentual de quatro plantas de cobertura consorciadas com plantas de teca durante um período de 16 semanas após o plantio. Barras de erro representam desvio padrão.

The maximum height reached by the cover crops used varied depending on the species. Species such as *V. radiata* and *P. phaseloides* showed a creeping behavior with maximum heights of 20 and 40 cm, respectively. *C. ensiformis* showed a shrubby behavior with a maximum height of 1 meter, while *C. juncea* grew up to 2.5 meters in height. This coverage had to be eliminated because of the shadow effect generated on the plantation.

Plantation growth

Table 1 shows the results obtained for the growth in height, diameter at 0.10 m above ground, and DBH.

Table 1. Average values and standard deviation (between brackets) of height, diameter at base, and diameter at breast height for a *T. grandis* plantation at six and 12 months of age in the south region of Costa Rica.

Tabela 1. Valores médios e desvio padrão (entre parênteses) de altura e diâmetro na base de um plantio de *T. grandis* aos 6 e 12 meses de idade na região sul da Costa Rica.

Treatment	Height (cm)		D _{base} (cm)		DBH(cm)
	6 months	12 months	6 months	12 months	12 months
Control	169.0 ^a (73.1)	464.3 ^a (98.4)	3.3 ^a (1.4)	6.1 ^a (1.4)	3.9 ^a (0.9)
Chemical control	137.2 ^a (69.2)	452.6 ^a (86.8)	2.9 ^a (1.2)	6.1 ^a (1.3)	3.8 ^a (1.0)
Manual control	125.4 ^a (65.8)	475.2 ^a (89.2)	2.4 ^a (1.0)	6.7 ^a (1.3)	4.4 ^a (0.9)
<i>C. ensiformis</i>	187.3 ^b (75.5)	515.3 ^a (101.6)	3.2 ^a (1.1)	6.7 ^a (1.5)	4.4 ^a (1.1)
<i>V. radiata</i>	159.0 ^a (77.9)	483.9 ^a (111.7)	2.8 ^a (1.0)	6.6 ^a (1.5)	4.2 ^a (1.2)
<i>V. radiata</i> + <i>P. phaseloides</i>	174.9 ^a (72.0)	502.5 ^a (112.8)	3.3 ^a (1.3)	6.8 ^a (1.7)	4.5 ^a (1.2)
<i>C. juncea</i>	158.2 ^a (74.0)	487.3 ^a (113.2)	3.1 ^a (1.1)	6.6 ^a (1.5)	4.2 ^a (1.2)

For height values, significant differences were found at six months of age, being *C. ensiformis* the one that showed the highest value ($p < 0.05$). Despite the fact that, at 12 months, all the treatments with cover crops had higher heights, we did not find significant differences. All cover crops fulfilled their life cycle during the dry season (nine months of age).

No differences were found for base diameter values both six and 12 months after the trial was established. The diameter at breast height values at 12 months was higher in the treatments that used cover crops as a weed control method; however, like D_{base} values, they did not show differences either.

Costs

Manual control of weeds was the cheapest treatment followed by control with the cover crop *C. juncea*, *V. radiata*, and the mixture (Table 2). Although labor costs in chemical control were much lower, the price of materials (application equipment, herbicide, and safety equipment) increased the total cost.

Table 2 shows that cover crops sowing is the activity that demands the most time (working hours) per hectare. Sowing density and covering the whole terrain makes this activity to have a high labor cost. An important result that is not reported in the literature nor had originally been contemplated is the maintenance that should be provided to cover crops. Although cover crops were used, maintenance activities such as clearances around the trees were always carried out.

The total costs of cover crop treatments can decrease if they are only sowed on the tree planting line (Table 3). Based on the study of times, it was determined that establishing cover crops only in the planting line of the trees reduced the cost of seed acquisition and labor costs. With this reduction, three of the established cover crops presented less total cost than manual control.

Table 2. Productivity and total cost (US\$/ha/year) for all evaluated treatments.

Tabela 2. Produtividade e custo total (US\$/ha/ano) para todos os tratamentos avaliados.

Treatment	Labor			Materials			Total cost (US\$/ha/year)
	Productivity	Daily wage	Wages (US\$)	Times per year	Unitary Price	Quantity	
Manual control							
Manual weeding 1	2.1	16.8	139.5	4.0			8.3
Manual weeding 2	1		33.5	2.0			
Subtotal treatment			173.0				8.3 181.3
Chemical control							
Chemical weeding	1	16.8	52.3	3.0	150.0		150.0
Hand weeding 1	1		33.5	2.0	8.3		8.3
Subtotal treatment			85.9				158.3 244.2
<i>Canavalia ensiformis</i>							
Seed sowing	8	16.8	134.4	1.0	kg	12.5	20.0
Hand weeding 1	2.1		69.9	2.0			
Subtotal treatment			204.3				250.0 454.3
<i>Vigna radiata</i>							
Seed sowing	8	16.8	134.4	1.0	kg	3.3	10.0
Hand weeding 1	2.1		34.9				
Subtotal treatment			169.3				33.3 202.7
<i>V. radiata + P. phaseloides</i>							
Seed sowing	8		134.4	1.0	kg	3.3	10.0
Hand weeding 1	2.1	16.8	34.9				
Subtotal treatment			169.3				33.0 202.3
<i>Crotalaria juncea</i>							
Seed sowing	8	16.8	134.4	1.0	kg	6.7	5.0
Hand weeding 1	2.1		34.9	2.0			
Subtotal treatment			169.3				33.3 202.6

Note: Materials from chemical control consists of hand equipment, security equipment, and herbicide.

Table 3. Productivity and total cost (US\$/ha/year) for all evaluated treatments using cover crops only in the tree planting line.

Tabela 3. Produtividade e custo total (US\$/ha/ano) para todos os tratamentos avaliados, utilizando culturas de cobertura apenas na linha de plantio de árvores.

Tratamiento	Labor			Times per year	Materials			Total cost (US\$/ha/year)
	Productivity	Daily wage	Wages (US\$)		Units	Unitary price	Quantity	
Manual control								
Manual weeding 1	2.08	16.8	139.5	4.0				8.3
Manual weeding 2	1		33.5	2.0				
Subtotal treatment			173.0					8.3 181.3
Chemical control								
Chemical weeding	1.04	16.8	52.3	3.0		150.0		150.0
Hand weeding 1	1		33.5	2.0		8.3		8.3
Subtotal treatment			85.9					158.3 244.2
<i>Canavalia ensiformis</i>								
Seed sowing	2.6		43.7	1.0	kg	12.5	7.00	87.5
Manual weeding 1	2.1	16.8	69.9	2.0				
Manual weeding 2	1		33.6	2.0				
Subtotal treatment			113.6					87.5 201.1
<i>Vigna radiata</i>								
Seed sowing	2.6	16.8	43.7	1.0	kg	3.3	4.00	13.3
Manual weeding 1	2.1		34.9	2.0				
Manual weeding 2	1			2.0				
Subtotal treatment			78.6					13.3 91.9
<i>V. radiata + P. phaseloides</i>								
Seed sowing	2.6		43.7	1.0	kg	3.3	4.00	13.2
Manual weeding 1	2.1	16.8	34.9	2.0				
Manual weeding 2	1		33.6	2.0				
Subtotal treatment			78.6					33.0 111.6
<i>Crotalaria juncea</i>								
Seed sowing	2.6	16.8	43.7	1.0	kg	6.7	2.0	13.3
Manual weeding 1	2.1		34.9	2.0				
Manual weeding 2	1		33.6	2.0				
Subtotal treatment			78.6					33.3 111.9

Note: Materials from chemical control consists in hand equipment, security equipment and herbicide.

DISCUSSION

The field development of the cover crops was heterogeneous; however, it was possible to verify its potential to suppress weeds in the first months of establishing the plantation. The results obtained were similar to those found by Rebollo et al. (2011) in species such as *Mucuna priurens* and *Clitoria ternate* in combination with mango trees. Although we do not recommend species *C. juncea* for its use in newly established plantations, it should not be discarded as an option, but rather it could be evaluated in dense canopy plantations (i.e., plantations between one to three years old).

LITTLE et al. (2002) mention that combining cover crops as a control method can generate larger quantities of allelochemicals and produce more biomass, suppressing weeds more effectively. Nevertheless, the combination of species used in this experiment did not present the best results. The germination percentage of *P.*

phaseloides was low, and its development was very slow, which affected the mixture's performance. The combination with other species used in this study, as *C. ensiformis* and *V. radiata*, could have better results.

Herbaceous plants can seriously affect the survival and growth of forest species through interspecific competition and have strong influences on height, diameter, and leaf area (GARAU *et al.*, 2009). There are differences of criteria in the literature regarding the effect of cover crops on the growth of forest species. While Mendham *et al.* (2004) found negative effects on the growth of eucalyptus plantations using the genera *Mucuna*, *Stylosanthes*, and *Pueraria*, authors such as Moreira and Moletto (2008) found a positive response using *Avena strigosa* and *Lupinus albescens* covers.

At six months, three of the four species evaluated had no effect on the initial growth of the trees; only *Canavalia ensiformis* treatment showed an increase in height values. At 12 months of age, height differences were not significant, indicating there was an equal efficacy of the different weed control methods, and there is no threat that the species evaluated reduce tree growth. Furthermore, the results obtained (table 1) did not show the effects of the cover crops in the diameter growth because the growth of *T. grandis* in the juvenile stage focuses on the apical development, as a survival strategy of the species to maintain itself in one place (KHANDURI *et al.*, 2008). For future studies, the effects of cover crops on N fixation, the contribution of organic matter and erosion control, and its relation to the maintenance and increase of plantation productivity should be considered.

The effectiveness of any control method and its cost are decisive for choosing the control strategy to establish commercial plantations on a large scale. For any method of weed control to be economically viable, it must generally be cheaper to implement than an opposite method or, if more expensive, additional costs should be rewarded with greater growth gains (LITTLE *et al.*, 2002). Economic considerations related to the decision to adopt or use cover crops are multi-faceted. As with many innovative practices, cover crops come with costs of adoption, both direct and indirect (BERGTOLD *et al.*, 2017).

Seed size, price, and sowing are significant costs of establishing cover crops. Seed costs (Table 1) may vary depending on species, seed quality, and availability. This can be causing difficulty for producers to adopt the use of these alternative methods of weed control.

The use of herbicides remains a financially viable option, and its effect on weed suppression is proven. However, it is important to remember the pressure from certification companies to limit the use of chemical methods. Combining alternatives (i.e., integrated weed management) may be the best option for small and medium producers as it could lower maintenance costs during the first year of planting without affecting tree productivity.

CONCLUSIONS

Our study concluded that

- cover crops effectively suppressed the weeds in the field, being *C. juncea* the one with the most ground cover percentage;
- only *Canavalia ensiformis* showed greater growth in height six months after the trial was established. No significant differences were found for the other variables (diameter at base and at breast height) and time of evaluation (until 12 months);
- manual weed control was the most economical treatment during the study of times;
- sowing cover crops only in the tree line and combining weed control methods reduces costs compared to using one single control method.

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