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Interaction of Fertilization and Weed Control Influences on Growth, Biomass, and Carbon in Eucalyptus Hybrid (*E. pellita* × *E. brassiana*)

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Abstract

*Fertilization and weed control are regularly conducted as the main silvicultural prescriptions in the eucalyptus plantation. However, the both treatment's interaction effects on eucalyptus performance are still not deeply understood, even though these treatments require high investment. This circumstance may potentially inhibit the managers in formulating a more efficient maintenance strategy for increasing stand productivity. This study examined the interaction effects of fertilization and weed control on growth, biomass, and carbon storage in eucalyptus hybrid (*E. pellita E. brassiana*). Results demonstrated that without both treatments, the average stand volume only reached 37.9 m^3 ha^{-1} with the mean biomass and carbon storage approached 25.4 and 12.7 Mg ha^{-1}, respectively. In contrast, the use of both treatments simultaneously improved the mean volume around 60.4 m^3 ha^{-1} with the average biomass and carbon storage closed to 37.6 and 18.8 Mg ha^{-1}. The development of eucalyptus hybrid using fertilization without weed control only gained the mean wood production approximately 58.7 m^3 ha^{-1}. In contrast, weed control application without fertilization only resulted in an average volume of nearly 43.7 m^3 ha^{-1}. These facts indicated fertilization exhibited more substantial influence than weed control on the performance of eucalyptus hybrid.*

Keywords: Silvicultural prescription, plantation forest, stand productivity, efficient maintenance strategy, high investment

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Introduction

Nowadays, eucalyptus plantation's existence plays an important contribution to stabilizing wood supply for forestry industries, especially in pulp and paper (Pirralho et al., 2014). Every year, more than one-third of wood availability in the market was supplied by eucalyptus plantation, mainly from tropical countries like Indonesia, Malaysia, Brazil, Colombia, and Vietnam (McEwan et al., 2019). However, it is still not able to fulfill the need of wood for industry development. In order to answer this challenge, most of the forest managers in eucalyptus plantation provide the best strategies to increase stand productivity by implementing the practice of intensive silviculture in their concession forest area, including fertilization, weed control, soil tillage, and tree improvement (Gonçalves et al., 2013). Among those efforts, the practice of fertilization and weed control are common silvicultural prescriptions regularly conducted in every eucalyptus plantation since they have a strong relationship with plant physiology, mainly related to nutrient and water absorption (Carrero et al., 2018).

The primary objective of fertilization is to provide sufficient nutrients for the plant. Thus it can grow optimally without resulting abnormal growth (Brancalion et al., 2019). Fertilization is one of the nutrient management efforts that highly required in the site with having low soil fertility (Viera et al., 2016). In this context, fertilization potentially enhances soil chemical properties regarding nutrient availability (Mendham et al., 2009). For example, potassium fertilization for *Eucalyptus grandis* plantation in Brazil increases stem wood biomass around 173% higher in trees fertilized than in trees without fertilization application at mid-rotation (3 years) (Battie-laclau et al., 2016). Another example from Colombia reported that the implementation of fertilization using phosphorus in *E. pellita* plantation improves timber volume ranging from 20% to 35% compared to the trees with no fertilization at 34 months (Amezquita et al., 2018). Similar trends are also recorded in Indonesia, where the effect of fertilization demonstrates a positive result to provide productivity gain in a commercial eucalyptus plantation. In Riau, the additional NPK fertilizer

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on *E. hybrid* (*E. grandis* × *E. pellita*) can improve total aboveground biomass around 105% greater than in trees without fertilization treatment at two years (Halomoan et al., 2015). Meanwhile, a study from South Sumatra reports that phosphorus fertilization on the growth performance of *E. pellita* plantation substantially increases total aboveground biomass approximately 100–300% higher than unfertilized trees six months after establishment (Wirabuana et al., 2019). Those examples indicate the importance meaning of fertilization as a silvicultural regime in a eucalyptus plantation.

Apart from fertilization, the implementation of weed control aims to minimize the competition between young eucalyptus and weed vegetation (Little & Rolando, 2008). This prescription is essential since weed vegetation's growth is relatively faster than eucalyptus seedling; thus, they dominate in competition for obtaining water and light at early periods after planting (Vargas et al., 2018). Much literature has reported that the risk of growth loss in eucalyptus plantation if weed control is not applied precisely. A study from Kerala State in South India documents that the mean annual increment (MAI) of *E. grandis* and *E. tereticornis* declined almost 13% and 55% at 6.5 years without the weed application control as maintenance activity (Pillai et al., 2013). Another study from New South Wales, Australia, reports that the unpractice of weed control impacts the growth loss of diameter and height in young *E. dunni* plantation nearly 10–22% at one year (Stone & Birk, 2001). Furthermore, the study about the influence of weed control on the growth of *E. pellita* in South Sumatra realizes that the use of weed control for stand maintenance can prevent the risk of growth loss ranging from 16% to 30% at six months after field establishment (Inail & Thaher, 2016). Those studies clearly emphasize the prominent contribution of weed control to eucalyptus plantation management.

Despite having different purposes, fertilization and weed control are commonly conducted simultaneously in every plantation forests. Not only in eucalyptus plantation, but both treatments are also carried out in other plantation forests such as teak, populus, and pine. Unfortunately, most forest managers should allocate high investment to implement those maintenances even though they offer a good opportunity to improve stand productivity. Therefore, it will be better for forest managers, particularly in the eucalyptus plantation, to evaluate the advantage and disadvantages of fertilization and weed control by considering other management aspects like financial ability, market opportunities, and long-term of environmental impacts. In order to support the goals, forest managers principally should have a deep understanding related to the interaction effects of fertilization and weed control on eucalyptus stand performance before they consider other points of view to determine the more efficient maintenance strategy for increasing eucalyptus productivity. Based on those explanations, this study aims to investigate the influence of fertilization and weed control on growth, biomass, and carbon storage in a commercial eucalyptus plantation.

Compared to other similar studies, our study has several aspects, covering the type of stand, specific site characteristics, and detail of treatments. The type of stand as an observation unit consisted of a homogenous stand of eucalyptus hybrid. Meanwhile, the previous studies focus on other kinds of eucalyptus stands such as Carrero et al. (2018) in *E. grandis, E. urophylla, E. hybrid (E. grandis × E. urophylla)*; Pillai et al. (2013) in *E. grandis* and *E. tereticornis*; as well as Stone & Birk (2001) in *E. dunni*. The study site has soil conditions with dominant ultisols. This soil type has a high clay content of more than 50% (Inail et al., 2019). It is relatively different from other studies about fertilization and weed control in eucalyptus plantation, commonly conducted in sandy soil like Brazil, India, and Australia (Stone & Birk, 2001; Pillai et al., 2013; Carrero et al., 2018). Moreover, we use simple factors to facilitate the forest managers for better understanding the importance of both silvicultural prescriptions with contrast comparison for each treatment. Some research questions were formulated to help the process of data interpretation:

1. Does the interaction of fertilization and weed control significantly influence the performance of a eucalyptus hybrid?
2. What is more critical between fertilization and weed control as a silvicultural regime to increase the eucalyptus hybrid productivity?
3. How many percentages of productivity gain from the eucalyptus hybrid will be obtained by conducting both treatments (fertilization + weed control) compared to single treatments (only fertilization or only weed control)?

Methods

Study area This study was conducted in a commercial eucalyptus plantation located in a concession forest area of PT Musi Hutan Persada (MHP). It is situated in Muara Enim District, approximately 150 km at southern of Palembang as the capital city of South Sumatra Province. This site had a geographic condition in S3°00' to S4°00' and E103°00' to E104°30' (Figure 1). The effective eucalyptus plantation area in MHP ranged 190,000 ha (Fujita et al., 2014). It was classified into lowland plantation forests with its altitude ranging from 60 to 200 m above sea level. The land configuration is dominated by a hilly area with a slope level varying 0–25%. Most of the area was categorized as having humid conditions with air humidity varied from 76.5% to 84.2%. The mean daily temperature was 29 °C, with an average minimum of 23 °C and a maximum of 35 °C. Annual rainfall reached 1,880 to 3,894 mm^{-1} during the past ten years from 2009 to 2018. The majority of the rainfall occurred between October and May, with the highest rainfall was recorded every December. Dry periods were relatively longer for four months between June to September (Wirabuana et al., 2019). Before establishing the eucalyptus plantation, the majority of areas in MHP were covered by acacia plantation (Hardiyanto & Nambiar, 2014). Unfortunately, acacia plantation productivity declined rapidly, along with increased rotation due to the impact of pest and disease (Hardie et al., 2018). To maintain the forestry industry's future viability, acacia plantation has been replaced with eucalyptus plantation from 2012 to 2017 (Nambiar et al., 2018). The length rotation of eucalyptus plantation in this area was around 4–5 years.

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Experimental design A factorial experiment comprising two levels of fertilization and weed control was arranged in a randomized complete block design with four replicate blocks. Fertilization treatment consisted of unfertilized plots that did not receive additional fertilizer (F0) and fertilized plots that obtained approximately 133 kg ha^{-1} of triple superphosphate (TSP 46%, P2O5) (F1). The fertilization application was only conducted at planting time, and there was no supplementary fertilizer until the end of the rotation. Meanwhile, weed control treatment comprised poor plots that did not obtain weed control activities (W0) and good plots that received intensively weed control (W1). The practice of weed control was carried out by slashing and chemical spraying with different intensity depending on the age of the stand. Under one year, weed control was applied three times in 3, 6, and 12 months after planting. It was then only conducted two times in 18 and 24 months when the age of stand reached 1–2 years. The time duration of fertilization and weed control was implemented, referring to the operations of this company.

There were four combination treatments in this study (Table 1). Each treatment was represented in a square plot (0.03 ha) consisting of 25 measured trees and 24 border trees. The given border trees aimed to ensure the boundaries between treatments in every replication. To facilitate the monitoring process, a nameplate was placed in every treatment plot using a specific code that showed the sort of blocks and the detail of combination treatments. Furthermore, each measured tree was also marked by a number of identities (Figure 2).

This trial was established in March 2017 on-site that had previously grown one rotation of *E. pellita* stand. Before planting, we conducted site preparation to ensure the distribution of biomass residue from harvesting spreading evenly. It was also directed to understand the environmental gradient such as soil properties, slope level and direction, waterlog, and wind disturbance. It aimed to design a homogenous condition in every block for minimizing the disturbance to the experimental plot (Gonçalves et al., 2010). Soil sampling was undertaken at five different points in three depth layers, namely 0–10 cm, 11–20 cm, and 21–30 cm (G. Li et al., 2018). They were then composited and brought to the laboratory for quality test, covering soil texture, soil acidity, soil organic carbon, total nitrogen, available phosphorus, and cation exchange capacity (Table 2). Soil texture was measured using a hydrometer, while soil acidity was assessed by pH meter. The Walkey and Black method was used to quantify soil organic carbon, while total nitrogen was estimated by the Kjeldahl method. The examining protocol of available phosphorus and cation exchange capacity for each were Bray I and ammonium acetate methods. Those processes were done by referring to the guide for soil, plant, and water analysis methods (Estefan et al., 2013).

The plant material used in this trial was a eucalyptus hybrid (*E. pellita E. brassiana*). The seedlings were grown

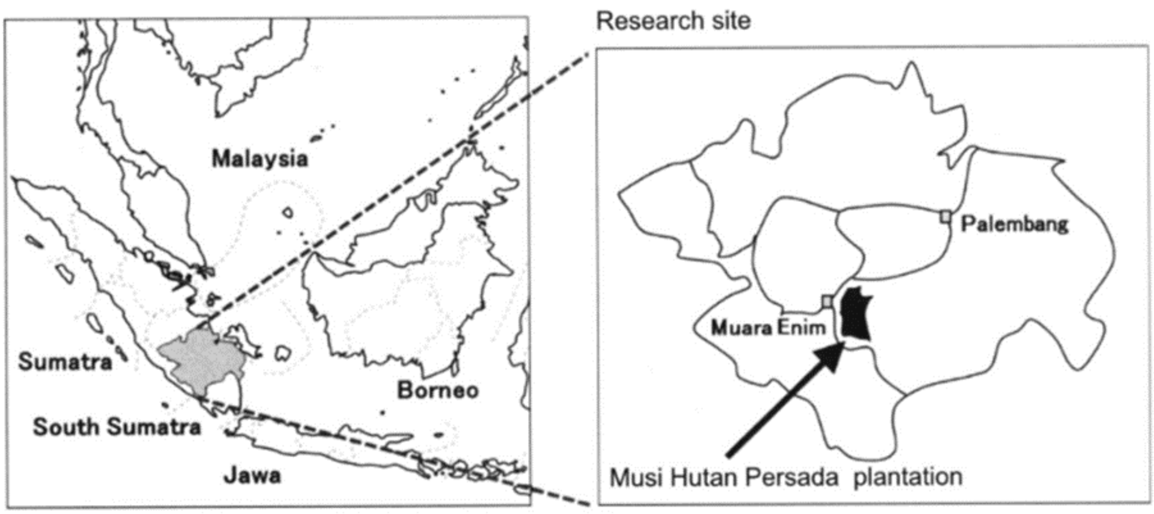

Figure 1 Study area of eucalyptus plantation located in South Sumatera (Mori et al., 2018).

Table 1 Details of treatment applied in the experiment

Treatment	Component of treatment		Number of replications
	Fertilization (kg ha^{-1}, TSP46% P_2O_5)	Weed control	
F0W0	0	no weed control	4
F0W1	0	slashing + spraying	4
F1W0	100	no weed control	4
F1W1	100	slashing + spraying	4

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in the nursery for around three months. A week before planting, the seedlings were graded for quality. In this trial, only seedlings with a height of 30 cm and having healthy condition were selected for field establishment. The seedlings were planted by initial spacing 3 m 2 m referring to this company's operations.

Data collection and analysis In this article, the observation was focused on the growth, biomass, and carbon storage in eucalyptus hybrid at two years. Data collection was undertaken in March 2019. The measurement process was conducted at the stand level. Several indicators were considered to evaluate the performance of eucalyptus hybrid, i.e., average height (m), mean diameter (cm), wood volume (m^3 ha^{-1}), biomass (Mg ha^{-1}), and carbon stock (Mg ha^{-1}). Every tree's total height was estimated from aboveground to top crown, while the tree diameter was measured at 1.3 m aboveground. Individual tree volume (v) was calculated as shown in Equation *[1]*.

$$v = 0.25\pi d^2 hf \qquad [1]$$

note: d was the individual tree diameter, h represented the individual tree height, and f described form factor (0.48) (Supriyadi, 2011). In this context, we adopted the form factor of *E. pellita* on this site since the specific form factor of eucalyptus hybrid was still not available. A similar assumption was also used to estimate the biomass using allometric equations from *E. pellita* on this site (Table 3) (Inail et al., 2019). The biomass was predicted on the aboveground condition, in every eucalyptus hybrid component, including stem, bark, branches, and leaves. Then, biomass estimation outcomes would be used to determine carbon storage within every element of eucalyptus hybrid because approximately 50% of the biomass production was composed of carbon (Viera & Rodríguez-Soalleiro, 2019).

Statistical analysis was processed using software R version 3.6.1 with a significant level of 5% (Waghorn et al., 2015). A descriptive test was directed to identify the data distribution in each observation parameters. Data normality was examined using the Kolmogorov-Smirnov test. Levene's test evaluated the homogeneity of variance among the treatments. The influence of fertilization and weed control on growth, biomass, and carbon storage in eucalyptus hybrid was analyzed separately of each indicator using ANOVA and

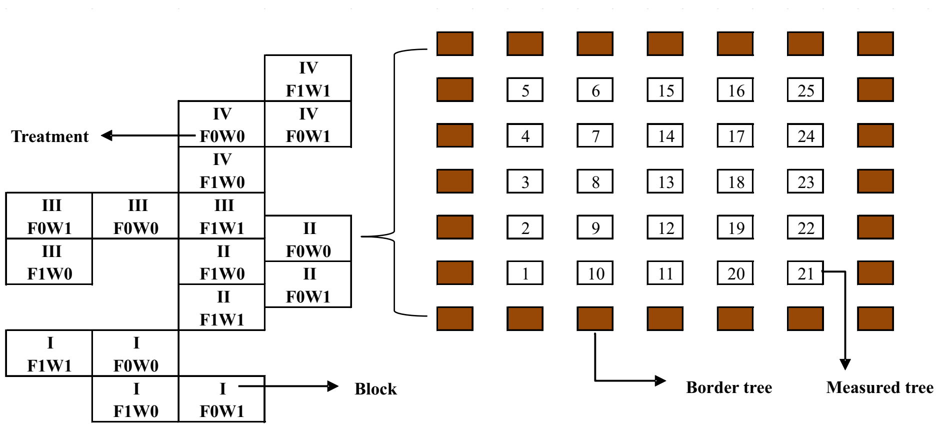

Figure 2 Layout of experiment design in the study site consisting of the plot placement and trees position.

Table 2 Soil texture, soil acidity (pH H_2O), soil organic carbon (C-organic), total nitrogen (N-total), available phosphorus (P-avl), and cation exchange capacity at the depth 0–30 cm in the site experiment

Sampling point	Soil texture (%)			pH H_2O	C-organic (%)	N-total (%)	P-avl (ppm)	CEC (cmolc kg^{-1})
	Sand	Silt	Clay					
1	35	27	38	4.72	1.93	0.08	5.21	15.21
2	36	26	38	4.51	1.48	0.06	6.32	13.62
3	32	28	40	4.47	1.76	0.07	7.36	10.54
4	30	27	43	4.38	1.24	0.07	7.43	9.35
5	30	25	45	4.51	1.83	0.17	9.36	8.57

Table 3 Allometric models for predicting aboveground biomass in every component of trees (Y) with diameter at breast height 1.3 m (D) as predictor variable. The unit of data estimation was in kg $tree^{-1}$

Tree component	Equations	n	R^2	SSE
Stemwood	$Y = 0.005D^{3.576}$	54	0.97	16.11
Bark	$Y = 0.005D^{2.799}$	54	0.96	2.00
Leaves	$Y = 0.631D^{0.918}$	33	0.72	1.28
Branches	$Y = 0.135D^{1.560}$	49	0.81	2.32

Source: Inail et al. (2019)

followed with HSD Tukey. The analysis protocol stage referred to a similar study conducted by (Pillai et al., 2013).

Results and Discussion

The response of eucalyptus hybrid to fertilization treatment The fertilization application still demonstrated a significant influence on growth, biomass, and carbon storage in a eucalyptus hybrid at two years after planting (Table 4). Without the practice of fertilization, the growth of height and diameter declined approximately 8.5% and 20%. In contrast, this study documented that volume, biomass accumulation, and total carbon stock of eucalyptus hybrid considerably increased along with the treatment of fertilization, ranging for every indicator around 45.8%, 30.9%, and 31.7%. Interestingly, by conducting fertilization, eucalyptus hybrid had the percentage of biomass distribution in the stem was 9% higher than trees with no fertilized (Figure 3a). However, the biomass allocation in branches and leaves within trees that received fertilization was relatively lower than trees without fertilizer, ranging from 35%.

Even though the eucalyptus hybrid's performance showed better results in the fertilization plots, our study revealed that fertilization activity did not provide a meaningful effect on the growth rate of height from 1 to 2 years (Table 5). A similar trend was observed in the increment of biomass and carbon in branches and leaves during the same periods. On another side, fertilization still exhibited an expressive effect on the increment rate of diameter by nearly 15.8% greater than without fertilization. The related outcome was also noticeable in the enhancement of volume (35.3%), total biomass (30.9%), and the sum of carbon stock (31.7%).

Compared to another eucalyptus species developed in a similar site, the eucalyptus hybrid response to fertilization was relatively lower. A study initiated by Inail et al. (2019) in *E. pellita* documented that at two years, the application of fertilization using 133 kg ha^{-1} of triple superphosphate (TSP46%, P2O5) significantly enhance stand volume around 70% higher than trees with no fertilization. In contrast, our study only recorded productivity gain in the eucalyptus hybrid volume by around 45.8%. Nevertheless, the total volume of eucalyptus hybrid was higher than *E. pellita* at two years. Several factors could be affected by this condition, such as different genetic materials and site quality.

Referring to these findings, it was described that the implementation of fertilization was essential to increase the growth, biomass, and carbon in eucalyptus hybrid. As one of the nutrient management, fertilization activity could enhance soil quality, especially related to the availability of nutrients for plants. The majority of plants, including eucalyptus hybrid, would grow well and avoid detrimental growth when they absorbed sufficient soil nutrients. Many studies have reported that most eucalyptus trees were highly required the adequate phosphorus nutrient (Albaugh et al., 2015; Novais et al., 2016; Bassaco et al., 2018). Unfortunately, soil type in the study site was classified as ultisols with low phosphorus availability (Nurudin et al., 2013). Ultisols principally had a high total phosphorus content, but when nutrient mineralization occurred, the availability of phosphorus was fixed by aluminum and iron (Singh et al., 2015). Therefore, fertilization treatment, particularly with phosphate fertilizer, is very important to support eucalyptus plantation growth. The eucalyptus hybrid would uptake the nutrients more effectively when the fertilizer dissolved since it was placed near the root systems.

The response of eucalyptus hybrid to weed control treatment Weed control implementation did not perform a meaningful influence on the growth, biomass, and carbon in eucalyptus hybrid at the end of 2 years (Table 4). It also did not significantly affect the growth rate of height, diameter, and volume (Table 5). The percentage of biomass distribution in every tree component was also looked like equal (Figure 3b). However, the practice of weed control in a eucalyptus hybrid stand resulted in the volume that was slightly higher than the stand without weed control, around 2.1 m^3 ha^{-1} or equivalent to 4.27% (Table 4). Attractively, our study discovered that the treatment of weed control still has a high effect on the increment of biomass accumulation and total carbon in eucalyptus hybrid from 1 to 2 years (Table 5). It was caused by the higher growth rate of branches biomass in the plots with weed control applications. Without a high density of weed vegetation, the crown development in the eucalyptus hybrid was better. Thus the number of branches increased proportionally.

At two years after planting, weed control practice did not have a significant effect on the performance of eucalyptus hybrid since the dimension of trees was bigger than weed vegetation. In this period, eucalyptus trees were more capable of competing against weed vegetation for obtaining resources, such as water and light. This condition was different in early periods when the eucalyptus hybrid's seedlings have been planted in the field. Several studies explained that at the initial growth period, the root systems of a eucalyptus still stayed in the surface soil layer where its growth overlapped with the root systems of weed vegetation (Laclau et al., 2001; Barton & Montagu, 2006; Silva et al., 2009; Grant et al., 2012). Consequently, it was relatively difficult for young plants to absorb water optimally for supporting their physiological process. Moreover, weed vegetation's growth rate was also extremely fast and potentially decreased the light availability for young eucalyptus seedlings (Little et al., 2018). The activity of weed control is substantially required to facilitate the growth of young eucalyptus. After trees grew prominently, their root penetration has developed until the subsoil layer, and trees also had total height taller than weed vegetation (Vargas et al., 2018). Thus, the competition level for water and light between eucalyptus and weed became lower along with the stand's increased age.

Some references also documented that the long-term influence of weed control on the growth of eucalyptus was additive since it was commonly directed to manage the natural competition between eucalyptus and weed at early growth periods, under one year (George & Brennan, 2002; Little et al., 2018; Vargas et al., 2018). However, in several commercial eucalyptus plantations, weed control was still conducted for more than one year until the end of rotation (Vance et al., 2014). This effort aimed to minimize forest fire risk in the eucalyptus stand (Wagner et al., 2006).

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Table 4 Comparison growth, biomass, and carbon storage in eucalyptus hybrid (*E. pellita E. brassiana*) affected by fertilization and weed control at 2 years

Treatment	H (m)	D (m)	V (m^3 ha^{-1})	AGB (Mg ha^{-1})					CS (Mg ha^{-1})				
				Stem	Bark	Branches	Leaves	Total	Stem	Bark	Branches	Leaves	Total
F response													
F0	11.7 ± 0.2a	7.8 ± 0.1a	40.8 ± 2.8a	12.8 ± 0.9a	2.5 ± 0.1a	5.1 ± 0.2a	6.3 ± 0.2a	26.8 ± 1.5a	6.4 ± 0.4a	1.2 ± 0.0a	2.5 ± 0.1a	3.1 ± 0.1a	13.4 ± 0.7a
F1	12.8 ± 0.1b	9.0 ± 0.0b	59.5 ± 1.9b	19.9 ± 0.7b	3.5 ± 0.1b	6.2 ± 0.1b	7.0 ± 0.1b	36.8 ± 1.1b	9.9 ± 0.3b	1.7 ± 0.0b	3.1 ± 0.0b	3.5 ± 0.0b	18.4 ± 0.5b
p-value	< 0.001*	< 0.001*	< 0.001*	0.002*	0.006*	0.006*	0.048*	0.008*	0.002*	0.006*	0.006*	0.048*	0.008*
W response													
W0	11.8 ± 0.4a	8.3 ± 0.2a	49.1 ± 4.9a	16.3 ± 1.8a	3.0 ± 0.2a	5.5 ± 0.3a	6.6 ± 0.2a	31.5 ± 2.6a	8.1 ± 0.9a	1.5 ± 0.1a	2.8 ± 0.1a	3.3 ± 0.1a	15.7 ± 1.3a
W1	12.2 ± 0.3a	8.4 ± 0.2a	51.2 ± 3.6b	16.5 ± 1.2a	3.1 ± 0.1a	5.7 ± 0.2a	6.7 ± 0.2a	32.1 ± 1.8a	8.2 ± 0.6a	1.5 ± 0.0a	2.8 ± 0.1a	3.3 ± 0.1a	16.0 ± 0.9a
p-value	0.182	0.494	0.5931	0.866	0.774	0.637	0.617	0.774	0.866	0.774	0.637	0.617	0.774
FxW response													
F0 × W0	10.8 ± 0.3a	7.6 ± 0.2a	37.9 ± 3.7a	12.1 ± 1.2a	2.3 ± 0.2a	4.8 ± 0.2a	6.0 ± 0.2a	25.4 ± 2.0a	6.0 ± 0.6a	1.1 ± 0.1a	2.4 ± 0.1a	3.0 ± 0.1a	12.7 ± 1.0a
F0 × W1	11.4 ± 0.3a	7.9 ± 0.1a	43.7 ± 4.3b	13.6 ± 1.3a	2.6 ± 0.2a	5.3 ± 0.3a	6.5 ± 0.3a	28.2 ± 2.2b	6.8 ± 0.6a	1.3 ± 0.1a	2.6 ± 0.1a	3.2 ± 0.1a	14.1 ± 1.1a
F1 × W0	12.7 ± 0.2b	8.9 ± 0.1b	58.7 ± 2.0a	19.4 ± 0.5b	3.4 ± 0.1b	6.1 ± 0.2b	7.0 ± 0.2b	36.0 ± 1.1c	9.7 ± 0.2b	1.7 ± 0.0b	3.0 ± 0.1b	3.5 ± 0.1b	18.0 ± 0.5b
F1 × W1	12.9 ± 0.0b	9.0 ± 0.1b	60.4 ± 3.7b	20.5 ± 1.3b	3.6 ± 0.2b	6.3 ± 0.2b	7.1 ± 0.2b	37.6 ± 1.9c	10.2 ± 0.6b	1.8 ± 0.1b	3.1 ± 0.1b	3.5 ± 0.1b	18.8 ± 0.9b
p-value	0.048*	0.042*	0.043*	0.039*	0.037*	0.032*	0.036*	0.031*	0.039*	0.036*	0.032*	0.036*	0.030*

Table 5 Mean increment of growth, biomass, and carbon storage in eucalyptus hybrid (*E. pellita E. brassiana*) affected by fertilization and weed from 1 to 2 years

Treatment	H (m)	D (m)	V (m^3 ha^{-1})	AGB (Mg ha^{-1})					CS (Mg ha^{-1})				
				Stem	Bark	Branches	Leaves	Total	Stem	Bark	Branches	Leaves	Total
F response													
F0	6.7 ± 0.1a	3.8 ± 0.1a	36.3 ± 2.3a	10.9 ± 0.9a	1.9 ± 0.1a	2.4 ± 0.4a	1.8 ± 0.4a	16.5 ± 1.8a	5.4 ± 0.4a	0.9 ± 0.1a	1.2 ± 0.2a	0.9 ± 0.2a	8.2 ± 0.9a
F1	6.8 ± 0.1a	4.1 ± 0.1b	49.2 ± 1.4b	15.9 ± 0.8b	2.4 ± 0.1b	2.4 ± 0.5a	2.3 ± 0.2a	21.6 ± 2.3b	7.9 ± 0.4b	1.2 ± 0.1b	1.2 ± 0.2a	1.1 ± 0.1a	10.8 ± 1.1b
p-value	0.382	0.03*	0.002*	0.029*	0.030*	0.99	0.58	0.038*	0.002*	0.029*	0.99	0.355	0.049*
W response													
W0	6.6 ± 0.1a	3.8 ± 0.1a	42.1 ± 3.4a	12.6 ± 0.8a	1.9 ± 1.4a	1.5 ± 0.4a	1.6 ± 0.3a	15.7 ± 1.6a	6.3 ± 0.4a	0.9 ± 0.1a	0.7 ± 0.2a	0.8 ± 0.1a	7.8 ± 0.8a
W1	6.8 ± 0.1a	4.0 ± 0.1a	43.3 ± 2.6a	14.2 ± 1.5a	2.4 ± 0.2a	3.2 ± 0.2b	2.5 ± 0.2b	22.4 ± 2.1b	7.1 ± 0.7a	1.2 ± 0.1a	1.6 ± 0.1b	1.2 ± 0.1a	11.2 ± 1.1b
p-value	0.165	0.146	0.146	0.228	0.36	0.002*	0.34	0.034*	0.22	0.072	0.002*	0.67	0.012*
FxW response													
F0 × W0	6.6 ± 0.1a	3.9 ± 0.1a	34.3 ± 3.1a	11.7 ± 1.3a	1.8 ± 0.2a	1.9 ± 0.6a	1.3 ± 0.6a	15.0 ± 3.0a	5.6 ± 0.7a	0.9 ± 0.1a	0.9 ± 0.3a	0.9 ± 0.3a	7.5 ± 1.5a
F0 × W1	6.7 ± 0.1a	4.2 ± 0.1a	38.3 ± 3.6a	10.7 ± 1.3a	1.9 ± 0.2a	2.9 ± 0.4b	2.4 ± 0.4b	17.9 ± 2.3a	5.3 ± 0.6a	0.9 ± 0.1a	1.4 ± 0.2b	1.2 ± 0.2a	8.9 ± 1.1a
F1 × W0	6.7 ± 0.1a	3.7 ± 0.1a	48.3 ± 1.8b	14.1 ± 0.2b	2.0 ± 0.1a	1.2 ± 0.5a	1.9 ± 0.2a	16.3 ± 1.9a	7.0 ± 0.1b	1.0 ± 0.1a	0.6 ± 0.2a	0.9 ± 0.1a	8.1 ± 0.9a
F1 × W1	6.8 ± 0.1a	3.8 ± 0.1a	50.0 ± 2.5b	17.7 ± 1.1c	2.8 ± 0.1b	3.6 ± 0.2b	2.7 ± 0.2b	26.9 ± 1.7b	8.8 ± 0.5c	1.4 ± 0.1a	1.8 ± 0.1b	1.3 ± 0.1a	13.4 ± 0.8b
p-value	0.982	0.261	0.046*	0.021*	0.031*	0.231*	0.047*	0.036*	0.012*	0.101	0.032*	0.772	0.049*

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Interaction effect of fertilization and weed control on eucalyptus hybrid performance Our study observed the interaction of fertilization and weed control provided a prominent effect on the growth, biomass, and carbon in eucalyptus hybrid at two years after field planting (Table 4). Nevertheless, a significant influence of the interaction between fertilization and weed control was not recorded in the increment of height, diameter, and carbon storage in bark and leaves from 1 to 2 years (Table 5). The combination treatment of fertilization and weed control directly correlates with the percentage of biomass distribution in every tree component (Figure 3c). The highest performance of eucalyptus hybrid has resulted in the stand which received fertilization and weed control. At the same time, the lowest productivity was occupied by trees without fertilization and weed control (Table 4).

Interestingly, even though the combination treatment of fertilization and weed control demonstrated the greatest outcome, but the distance of stand volume in this treatment was only 2.9% higher than the eucalyptus stand, which received fertilization without weed control application. In contrast, this prescription substantially improved timber volume, approximately 59.3% greater than trees that did not obtain additional fertilization and weed control intensively. Meanwhile, if the stand were only maintained by weed control without fertilization, the wood volume would decrease around 38.21% or equal to 16.7 m^3 ha^{-1}. This result was extremely lower than the best performance of a eucalyptus hybrid, which was generated by fertilization and weed control as a silvicultural prescription for stand maintenance.

Summarized results of observation delivered that fertilization was more important than weed control in affecting the performance of eucalyptus hybrid at two years after establishment. It was evaluated from the eucalyptus hybrid response to the interaction of fertilization and weed control as common silviculture techniques in eucalyptus plantation, specifically in the study site. It was visibly noticeable that eucalyptus's productivity resulted from fertilization without weed control, which was higher than stand with no fertilization but received a high intensity of weed control by approximately 34.3% or equivalent to 15 m^3 ha^{-1} (Table 4).

Several aspects should be considered why fertilization was more dominant than weed control in affecting the growth, biomass, and carbon of eucalyptus hybrid in the study site. Based on our results, we suspected two main reasons why the influence rate of fertilization was higher

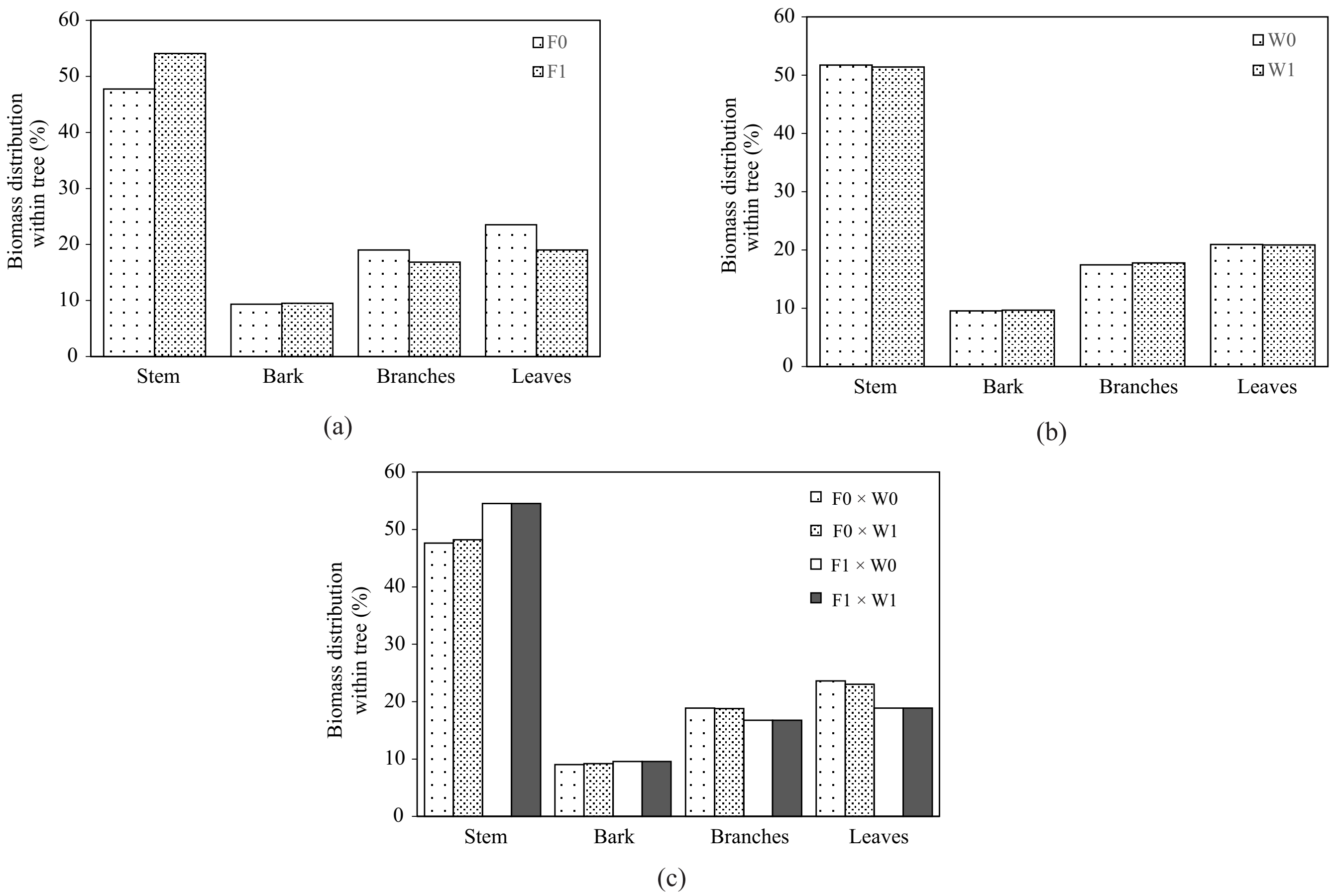

Figure 3 Biomass distribution in every tree component affected by fertilization and weed control treatment. (a) response biomass distribution to fertilization; (b) response biomass distribution to weed control; and (c) response biomass distribution to interaction on fertilization weed control.

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than weed control at two years – the first reason highly related to the site attributes and specific characteristics of eucalyptus hybrid. According to the outcomes of soil quality examination (Table 1), the experimental site had low phosphorus availability in the soil. At the same time, this type of nutrient was essential to support the growth of eucalyptus. Many studies have evidenced that eucalyptus species is efficient in phosphorus absorption (Amezquita et al., 2018; Bassaco et al., 2018; Crous et al., Van Bich et al., 2019). By conducting fertilization, particularly using phosphate fertilizer, the concentration of phosphorus in soil could be improved. Thus this nutrient was more available for eucalyptus hybrid. Several references also evidenced a positive effect of fertilization on phosphorus availability (Barbieri et al., 2014; Tng et al., 2014; González-García et al., 2016; Mori et al., 2018).

The second reason was strongly correlated to the age of the stand. In general, weed control in the eucalyptus plantation was implemented to minimize the competition between weed vegetation and young eucalyptus seedlings (George & Brennan, 2002; Little & Rolando, 2008; Carrero et al., 2018; Little et al., 2018). Therefore, the young plants could absorb water and light optimally for supporting their growth and development. Along with the increasing age of stand, the tree's growth dimension became bigger, where it was relatively taller and superior to weed vegetation. In this phase, the competition rate between trees and weeds became lower, as they were not very responsive to weed control (Vargas et al., 2018).

Implication results for eucalyptus plantation management Our study indicated a significant effect of fertilization and weed control on a eucalyptus hybrid's performance, where the influence of fertilization was relatively more dominant than weed control at two years after field planting. However, this finding did not declare that weed control was not important to support the eucalyptus hybrid's growth and development in the study area. It would be better for forest managers to arrange a detailed schedule of weed control activities. Besides requiring high investment, both treatments (fertilization + weed control) also had different benefits for maximizing the productivity of eucalyptus hybrid. By regulating the duration of weed control, forest managers reduced the cost of plant maintenance. However, they also minimized the risk of loss growth in young eucalyptus hybrid due to the occurrence of high competition against weed vegetation an early period after planting. On another side, understory vegetation was also essential to maintain the nutrients and energy cycle in plantation forests since they could potentially inhibit runoff and keep soil moisture (Li et al., 2015). Most importantly, the root systems of understory was a habitat for decomposers that played an important role in the decomposition process (Jacoby et al., 2017). Understory vegetation was classified into weed when they disturbed the growth of young eucalyptus. After trees had a bigger dimension, the circumstance was different since there was no high competition between trees and understory. Even though the eucalyptus plantation was adopted monoculture, considering the ecological aspect of plantation forest was also essential to stabilize the life cycle of ecosystems.

Conclusion

At the end of 2 years, the interaction of fertilization and weed control still demonstrated a significant influence on stand volume, biomass accumulation, and carbon storage in eucalyptus hybrid. However, the meaningful effect of both treatment did not record on the increment rate of height, diameter, and leaves carbon storage from 1 to 2 years. Compared to weed control, the practice of fertilization indicated a higher contribution to the performance of a eucalyptus hybrid. Our study observed that the application of fertilization + weed control could increase the eucalyptus hybrid's productivity by approximately 59.3% higher than control treatment (without fertilization + weed control). Meanwhile, this treatment resulted in productivity by around 38.2% and 2.89% greater than a single treatment, including only weed control or just fertilization.

Recommendation

Referring to our results, we suggest forest managers, especially in the study site, consider the intensity of weed control, conducted to maintain eucalyptus stand, particularly related to the eucalyptus hybrid. At the end of 2 years, weed control practice did not significantly influence the growth, biomass, and carbon storage in a eucalyptus hybrid. However, the interaction of fertilization and weed control provides the highest eucalyptus hybrid performance than other treatments, relatively. To minimize the cost of stand maintenance, weed control should be conducted at the early growth periods when the young plant still had a high competition with weed vegetation.

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