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Research Article

Productivity evaluation of *Eucalyptus urophylla* plantation established in dryland ecosystems, East Nusa Tenggara

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Abstract: The establishment of the *Eucalyptus urophylla* plantation has a potential contribution to the improvement of dryland ecosystem productivity in East Nusa Tenggara. However, the productivity of *E. urophylla* stand in this area is rarely documented even though it has been managed for more than 20 years. This study was directed to evaluate the growth performance, biomass accumulation, and carbon storage in *E. urophylla* plantation managed by Timor Tengah Selatan Forest Management Unit (FMU). Data were collected by a field survey using N-trees sampling method. Results demonstrated the mean tree density of *E. urophylla* in this area was 182 trees/ha with an average stand volume of 150.12 m^3/ha. The mean annual increment in volume varied from 1.83 to 19.45 m^3/year. The mean biomass accumulation and carbon storage in *E. urophylla* plantation approached 171.76 and 52.25 Mg/ha. Around 65% of total biomass and carbon storage were accumulated in the stem. Interestingly, the relative contribution of the stem to total biomass increased slowly with diameter class increasing while the dissimilar trend was observed in root, branch, and foliage. Based on the results, this study confirmed that the existence of *E. urophylla* plantation could increase the productivity of dryland ecosystem in East Nusa Tenggara.

Keywords: *biomass accumulation, carbon, Eucalyptus urophylla, growth performance, N-trees sampling*

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Introduction

Eucalyptus urophylla S.T. Blake is an indigenous species from Indonesia which naturally distributes in East Nusa Tenggara and Maluku (Sumardi et al., 2016). It has rapid growth, straight stem, and dense canopy like other eucalyptus families such as *E. pellita*, *E. alba, E. grandis,* etc. (Wirabuana et al., 2020). Furthermore, this species also has high adaptability to the various environmental gradient (Saadaoui et al., 2017). Several studies confirm *E. urophylla* can grow well in dry and wet condition with altitude ranged from 100 to 2,000 m above sea level (Morris et al., 2004; Zhang et al., 2015; Sumardi et al., 2016; Zhang et al. 2016). Another study also reports that *E. urophylla* can survive in the variety of soil condition such as acid soil and alkaline soil (Yang et al., 2015).

Interestingly, *E. urophylla* has been managed intensively as the main species of plantation forest in several countries, such as Vietnam, China, and Brazil (Du et al., 2015; Van Bich et al., 2019; Viera and Rodríguez-Soalleiro, 2019). This plant is selected because it has high economic value and can be harvested in short rotation (Ferreira et al., 2017). Some literature notes the optimum rotation of *E. urophylla* used in a plantation forest ranges from 5 to 8 years depending on the management objective and site quality (Imana-Encinas et al., 2011; Carneiro et al., 2014; Zhou et al., 2017).

For example, in the Brazilian plantation forest, the ideal rotation for *E. urophylla* used in pulp and paper industry is 5 years (Zanuncio et al., 2016). But the rotation will be longer until 8 years if the main purpose of management in *E. urophylla* plantation is directed to supply raw materials for other fields, such as furniture industry (Filho et al., 2018). In another side, a study in Vietnam determines the prospective rotation of *E. urophylla* plantation is 6 years for pulp and paper industry (Cuong et al., 2020). Those examples indicate that the growth performance of *E. urophylla* in a plantation forest relatively varies in each location. Many factors can influence on this trend, including plant materials, site quality, and silvicultural treatments (Binkley et al., 2017). Therefore, it is substantially essential to assess the growth performance of *E. urophylla* in the context of sustainable forest management (SFM), including in Indonesia.

The development of *E. urophylla* plantation in Indonesia has been widely conducted in several regions, one of them are situated in Timor Island, East Nusa Tenggara. Besides becoming a natural habitat (Sumardi et al., 2016), this region becomes the most priority site for establishing *E. urophylla* since this plant has a high potential to encourage the rural development, industry improvement, and climate change mitigation (Nambiar, 2015; Bayle, 2019; Cuong et al., 2020). Surprisingly, the area of *E. urophylla* plantation in this region is managed by Timor Tengah Selatan FMU as a representative of the local government in East Nusa Tenggara. This condition is considerably different from other *E. urophylla* plantation in Indonesia, which is ruled by a private company.

The management of *E. urophylla* plantation in Timor Island has been conducted for more than 20 years. However, the growth of *E. urophylla* stands in this site is still not evaluated even though it has a potential contribution to enhancing the productivity of dryland ecosystem like in East Nusa Tenggara. It is caused by the history management wherein at the previous time, the objective management of *E. urophylla* plantation is only directed to accelerate forest rehabilitation program in the bare land area without having a business orientation. In contrast, starting in 2016, the orientation management of *E. urophylla* have been gradually transformed into a commercial plantation forest for encouraging economic development (Figure 2). Therefore, it is essential to assess the productivity of *E. urophylla* stand as the fundamental requirement of planning strategy, particularly in silvicultural prescriptions and yield regulation. In order to realize those objectives, this study was directed to evaluate the growth performance, biomass accumulation, and carbon storage of *E. urophylla,* which established in Timor Tengah Selatan FMU. The results are expected to support the plantation forest managers in determining the best strategy for SFM.

Materials and Methods

Study area

Forest inventory was implemented in *E. urophylla* plantation which managed by Timor Tengah Selatan FMU. It covers two different villages, namely Buat and Fatukoto. The study area is principally located in Timor Tengah Selatan District, around 180 km of Kupang (Figure 1). It has a geographic position in 9º50′ to 9º50′ S and 124º15′ to 124º15′ E. Total area of *E. urophylla* plantation in this site is 250 ha which is divided into 3 estates according to the planting periods, i.e. Fatukoto 1997 (25 ha), Fatukoto 1983 (100 ha), and Buat 1982 (75 ha).

Altitude ranges from 800 to 1,000 m above sea level. Topography is relatively gradient with slope level varying from 15 to 45%. Soil type is predominantly by cambisol which has sandy loam texture and high cation exchange capacity (Tabel 1). The study location is categorized as having a humid condition with the average air humidity of 85.5%. The mean daily temperature reaches 29ºC with a minimum of 23ºC and a maximum of 30ºC. The annual rainfall ranged 1,500-3,000 mm/year during the past ten years from 2010 to 2019. Most rainfall occurs from November to January with the highest rainfall is recorded in January. This area has dry periods for 7 months from March to September (Kalima et al., 2019).

Table 1. Soil chemical properties in the study area based on the results of laboratory analysis for soil pH, soil organic carbon (SOC), total nitrogen (N), available phosphorus (P), total potassium (K), and cation exchange capacity (KTK).

Parameters	**Estates**		
	Buat 1982	**Fatukoto 1983**	**Fatukoto 1997**
pH	5.10	4.32	6.50
SOC (%)	1.96	1.02	0.62
N (%)	0.36	0.22	0.39
P (ppm)	40.83	29.12	41.60
K (cmolc/kg)	1.10	0.51	0.59
CEC (cmolc/kg)	34.90	33.12	34.56

Source: Kurniadi and Pujiono (2009)

At the early beginning, before converted into *E. urophylla* plantation, the study area was a bare land without trees vegetation. The land cover was only dominated by *Imperata cylindrica*. Starting from the 1980s, the local government initiated forest and land rehabilitation program by determining *E. urophylla* as a main species for reforestation. This effort was continuously undertaken until late 2016 without having an economic orientation. But, since 2017, after constructing Timor Tengah Selatan FMU and considering the economic value of *E. urophylla*, the aims of management was changed into a commercial plantation forest for supporting economic development in the rural area.

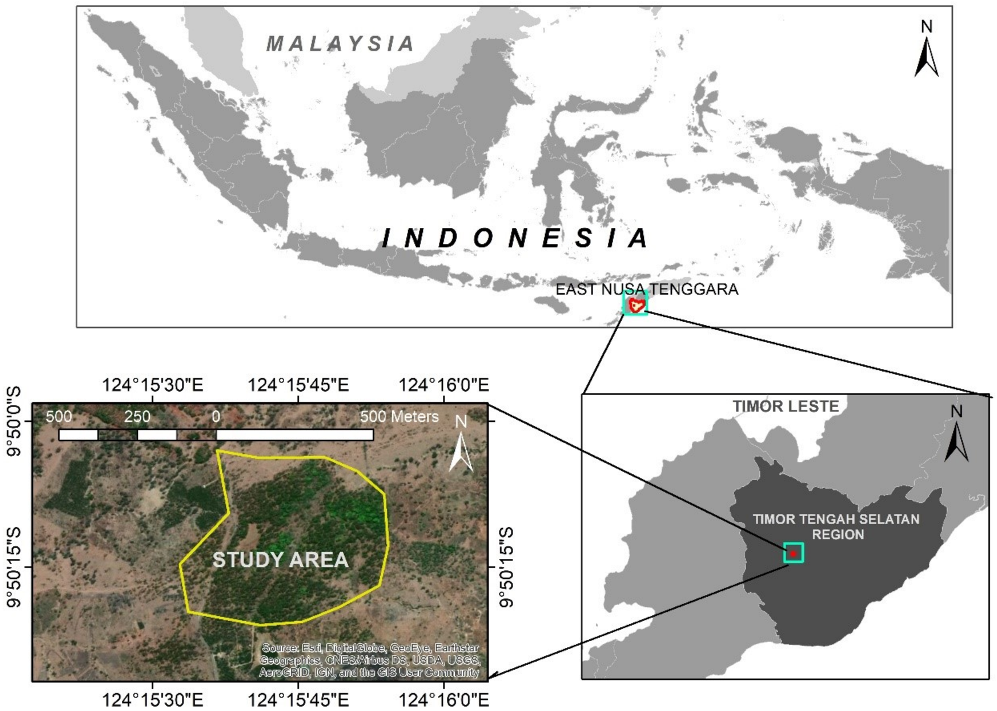

Figure 1. The study area of *E. urophylla* plantation managed by Timor Tengah Selatan FMU. The yellow polygon signified the primary compartments of *E. urophylla* plantation which allocated as a commercial plantation forest.

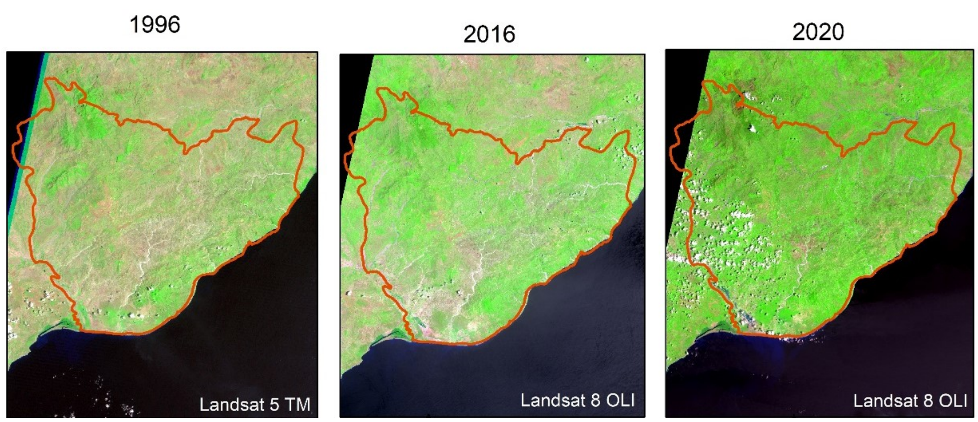

Figure 2. Land cover transition of *E. urophylla* plantation in the study site from 1996 to 2020 evaluated from LANDSAT images. Data demonstrated the activity of forest rehabilitation from 1996 to 2016 was occurring slower than from 2016 to 2020. It indicated the transformation of objective management into a commercial plantation forest has a considerable contribution to increasing the land cover of *E. urophylla* more rapidly compared to the previous time.

Data collection

Data were collected by a field survey from March to May 2020. The measurement activity was done using N-trees sampling method. This method was a forest inventory technique in which the process of stand measurement was only undertaken at the nearest trees from the centre point (Sadono et al., 2019). In this case, the centre point was assumed as a centre of the sampling plot. The principle of this method was basically similar to the point centred quarter method which generally used in an ecological survey, particularly for trees vegetation (Haxtema et al., 2012). But, both methods differed in the number of sample trees. The use of point centred quarter method measured around four sample trees while the practice of N-trees sampling method observed approximately six sample trees (Silva et al. 2017).

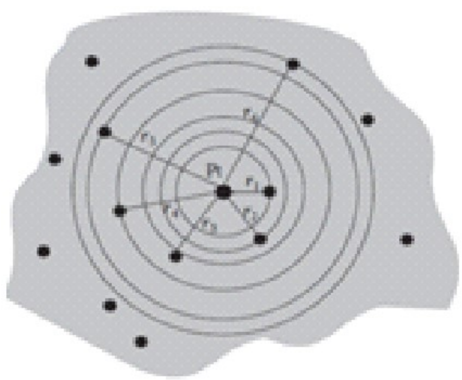

Figure 3. The illustration of sampling plot resulted by N-trees sampling method. P_t was a centre point of sampling plot while r_n indicated the distance between trees and centre point (Silva et al. 2017).

The visualization of the sampling plot generated by N-trees sampling method was circular (Figure 3). But, the plot size (A_i) was different from each others depending on the distance between the sixth tree and centre point (r_6). In this method, the sixth tree was the furthest tree located from center point. Then, the radius of every sampling plot (R_i) and plot size (A_i) was calculated by these equations (Haxtema et al., 2012; Silva et al., 2017; Sadono et al., 2019)

$$R_i = r_6 + ½ d_6 \quad (1)$$

$$A_i = \pi R_i^2 \quad (2)$$

where d_6 indicated tree diameter of the sixth tree in meter unit while π was a constant of 3.14 that frequently used for computing the area of the circular plot. Some references also confirm that the use of N-trees sampling method for supporting forest inventory presents an equal accuracy with other methods as long as it is applied in a plantation forest with monoculture plant species (Lynch and Rusydi, 1999; Mirzaei and Eslam, 2016; Basiri et al., 2018). To obtain a representative outcome, the sampling plots were placed systematically (Figure 4). The distance among plots was approximately 100 m based on the suggestion from the previous studies (Silva et al., 2017; Basiri et al., 2018).

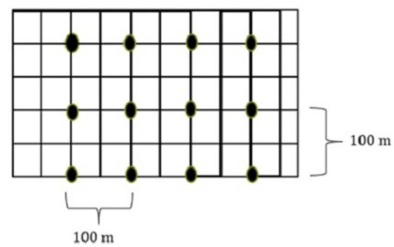

Figure 4. The design of sampling plot placement for field survey in *E. urophylla* plantation which managed by Timor Tengah Selatan FMU.

Several parameters were selected to evaluate the individual tree dimension in each plot, such as diameter at breast height (*d*), tree height (*h*), basal area (*g*), tree volume *(v*), biomass allocation, and carbon storage. The measurement of *D* was done by diameter tape at 1.3 m from aboveground. *H* was measured by hypsometer from aboveground to top crown. The basal area and tree volume were calculated by the formula:

$$g = 0.25\pi d^2 \quad (3)$$

$$v = 0.25\pi d^2 h f \quad (4)$$

where *f* is a form factor of *E. urophylla* around 0.4 (Susila and Darwo, 2015). Afterwards, biomass accumulation and carbon storage was estimated in every tree component, i.e. root, stem, branch, and foliage by using allometric models (Table 2).

Table 2. Several allometric models for estimating biomass accumulation and carbon storage in every component of *E. urophylla.*

Component	Allometric models	R^2
	Biomass distribution	
Root	$Y = 0.017D^{2.589}$	0.984
Stem	$Y = 0.066D^{2.622}$	0.995
Branch	$Y = 0.046D^{2.300}$	0.982
Foliage	$Y = 0.016D^{2.106}$	0.966
	Carbon storage	
Root	$Y = 0.008D^{2.478}$	0.990
Stem	$Y = 0.021D^{2.604}$	0.992
Branch	$Y = 0.011D^{2.380}$	0.984
Foliage	$Y = 0.008D^{2.012}$	0.972

Source: Marimpan and Purwanto (2010).

Results of individual tree measurement were used to estimate several stand attributes, covering the number of tree density, average tree diameter, mean tree height, stand basal area, stand volume, mean annual increment, total biomass, and total carbon. It was conducted by converting the value in every plot into hectare unit.

Data analysis

Statistical analysis was processed using software R version 4.0.2 with a significant level of 5%. The Agricolae packages were used for facilitating the process of data analysis (Wirabuana et al., 2019). The descriptive test was conducted to identify the data characteristics, including minimum, maximum, mean, standard deviation, and standard error (Mishra et al., 2019). This stage was directed to describe the results of a field survey in the study area for every parameter. Then, a histogram was also created to recognize stand structure in this plantation according to the distribution of diameter class. This was a general approach which regularly used to show the forest structure (Mateus and Tomé, 2011). The relative contribution of tree components to total biomass and carbon storage in *E. urophylla* were examined by ANOVA and followed by HSD Tukey (Arora et al., 2014). Then, the normality of data residuals was evaluated using the Shapiro-Wilk test (Ghasemi and Zahediasl. 2012). Moreover, to understand the relationship between biomass and carbon allocation with the growth performance of *E. urophylla*, we also presented two histograms which described the trend of biomass and carbon distribution across the diameter class (Altanzagas et al., 2019).

Results and Discussion

The average tree density of *E. urophylla* plantation was 182 trees/ha with a mean diameter of 33.01 cm and a mean height of 29.39 m (Table 3). The basal area ranged from 4.60 to 44.61 m^2/ha depending on the site condition. The distribution of stand volume in this site was extremely varied from 40.36 to 427.81 m^3/ha with the mean annual increment in volume of around 6.82 m^3/year (Table 3).

The growth performance of *E. urophylla* in Timor Tengah Selatan FMU was relatively lower than other eucalyptus plantation in Indonesia. For example, the productivity of eucalyptus plantation in South Sumatra ranged from 16 to 18 m^3/year (Harwood and Nambiar, 2014). In another side, the mean annual increment of eucalyptus plantation in Riau varied from 14-17 m^3/year (Halomoan et al., 2015). In East Kalimantan, the productivity of eucalyptus plantation approached 15-17 m^3/year (Wijaya et al., 2010). The growth performance of *E. urophylla* in Timor Tengah Selatan FMU was relatively lower because it did not receive intensive maintenances from the beginning.

Tabel 3. Growth performance, biomass accumulation, and carbon storage in a commercial *E. urophylla* plantation managed by Timor Tengah Selatan FMU.

Parameter	Unit	Min	Max	Mean	SD	SE
			Growth performance			
Tree density	trees	59	620	182	113	19
Diameter	cm	23.70	43.31	33.01	4.68	0.78
Height	m	24.77	33.44	29.39	2.06	0.34
Basal Area	m^2/ha	4.60	44.61	17.11	9.59	1.60
Volume	m^3/ha	40.36	427.81	150.12	89.55	14.93
MAI	m^3/year	1.83	19.45	6.82	4.07	0.68
			Biomass accumulation			
Root	Mg/ha	6.12	76.24	25.84	15.77	2.63
Stem	Mg/ha	26.55	334.75	112.68	69.05	11.51
Branch	Mg/ha	6.26	70.20	25.33	14.89	2.48
Foliage	Mg/ha	1.13	11.91	4.46	2.57	0.43
Total	Mg/ha	40.86	503.35	171.76	104.34	17.39
			Carbon Storage			
Root	Mg/ha	1.98	23.71	8.23	4.95	0.82
Stem	Mg/ha	7.95	99.59	33.65	20.57	3.43
Branch	Mg/ha	1.96	22.62	8.02	4.76	0.79
Foliage	Mg/ha	0.41	4.23	1.60	0.92	0.15
Total	Mg/ha	12.48	152.28	52.25	31.63	5.27

Note: Min (minimum); Max (maximum); Mean (average); SD (standard deviation); SE (standard error).

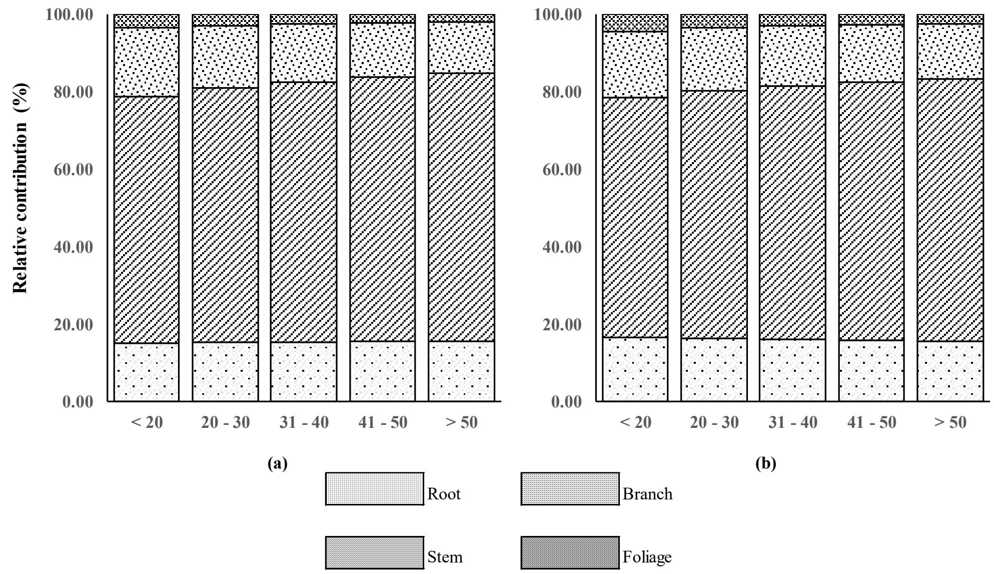

Figure 6. The relative contribution of tree components to (a) total biomass accumulation and (b) carbon storage across diameter class distribution.

This condition was relatively different from other eucalyptus plantation in Riau, South Sumatra, and East Kalimantan that directly managed for commercial objective. In this context, the practice of intensive silvicultural prescriptions in those sites, such as spacing arrangement, weed control, and fertilization provided a meaningful contribution to increasing eucalyptus plantation productivity. Several studies also documented the relationship between silvicultural treatments and productivity of eucalyptus plantation (Xue et al., 2011; Aggangan et al., 2013; Mughini et al., 2014; Van Bich et al., 2019; Wirabuana et al. 2019). Unfortunately, those similar activities were not conducted in Timor Tengah Selatan FMU at the previous time.

Our study recorded that the stand structure of *E. urophylla* plantation in the study area followed normal distribution wherein the majority of trees occupied in diameter class 20-30 cm (Figure 5). Total biomass accumulation and carbon storage content by *E. urophlla* plantation in the study area approached 171.76 and 52.25 Mg/ha (Table 3). These results indicated approximately 30% of total biomass in *E. urophylla* plantation was composed of carbon element. It was considerably different with other studies which reported that the carbon content in eucalyptus plantation biomass ranging from 46 to 50% (Latifah and Sulistiyono, 2013; Li et al., 2015; Viera and Rodríguez-Soalleiro, 2019). More than 80% of biomass and carbon in *E.urophylla* were distributed in above ground. The highest relative contribution of tree components to biomass was recorded in stem (66.33%), followed by branch (15.32%), root (15,31%), and foliage (2.74%). Interestingly, the relative contribution of root to carbon storage in *E. urophylla* was slightly higher than the branch even though it did not differ statistically (Table 4).

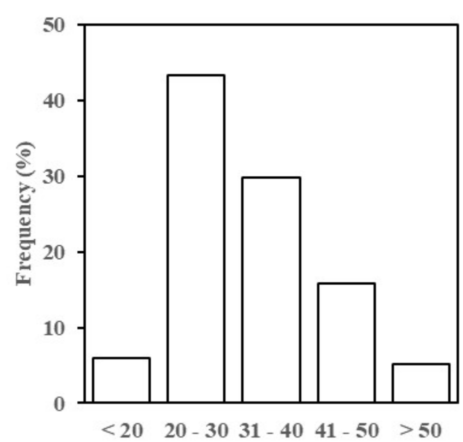

Figure 5. Stand structure of *E. urophylla* based on the diameter class distribution.

The relative contribution of stem improved with the diameter class increased while the dissimilar pattern was recorded in root, branch, and foliage (Figure 6). These trends were similar to other species in a different type of forest ecosystems (Mendoza-Ponce and Galicia, 2010; Zeng and Tang, 2012; Nam et al., 2016; Dong et al., 2018;

He et al., 2018; Altanzagas et al., 2019). The relatively more biomass was distributed to the stem for accelerating translocation process. It was consistent with the previous studies (Zeng and Tang, 2012; Dong et al., 2018; He et al., 2018).

Table 4. The relative contribution of tree components to total biomass accumulation and carbon storage in *E. urophylla.*

Component	Biomass (%)	Carbon (%)	Symbol
Root	15.31	16.02	A
Stem	66.63	65.02	B
Branch	15.32	15.72	A
Foliage	2.74	3.24	C

Note: a similar letter indicated not a significant difference according to HSD Tukey test.

Our study evidenced that the development of *E. urophylla* plantation in Timor Tengah Selatan FMU provided an important role in enhancing the dryland ecosystems productivity in East Nusa Tenggara from bare land condition to fully forest cover with having a good biomass accumulation and carbon storage. However, the forest managers had to apply more silvicultural prescriptions for improving the productivity of *E. urophylla* in the context of commercial plantation forest management.

Conclusion

This study documented that the development of *E. urophylla* plantation implemented by Timor Tengah Selatan FMU, provided a potential contribution to enhancing the productivity of dryland ecosystems in East Nusa Tenggara. However, the performance of *E. urophylla* stands in this site was considerably lower than commercial *E. urophylla* plantation in other sites. Based on these findings, more intensive silvicultural prescriptions were suggested to improve the productivity of *E. urophylla* stand in the context of commercial plantation forest.

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