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Research Article

Soil chemical properties influences on the growth performance of *Eucalyptus urophylla* planted in dryland ecosystems, East Nusa Tenggara

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Abstract: Understanding the relationship between soil chemical characteristics and forest productivity is importantly required to support sustainable forest management, mainly in eucalyptus plantation. This study investigated the influence of soil chemical properties on the growth performance of *Eucalyptus urophylla,* which established in dryland ecosystems, East Nusa Tenggara. Forest inventory was undertaken by N-trees sampling in the priority locations for *E. urophylla* development, located in Buat, Fatukoto1, and Fatukoto2. Four parameters were selected to describe the growth performance of *E. urophylla*, comprising diameter, height, volume, and mean annual increment. In each sampling point, a soil sample was collected at the depths of 0-10, 11-20, and 21-30 cm. Then, the sample was composited before brought to the laboratory for quality analysis. Six parameters were selected to quantify the soil chemical characteristics, namely soil acidity (pH), soil organic carbon (SOC), total nitrogen (TN), available phosphorus (Av-P), exchangeable potassium (Exc-K), and cation exchange capacity (CEC). Results found that soil chemical properties from three locations were significantly different in pH, SOC, Av-P, and CEC. However, this study recorded the content of TN and Exc-K were statistically equal among the three sites. Difference soil chemical properties were also followed by the variation growth of *E. urophylla*, particularly in diameter and height. The highest volume of eucalyptus stand was observed in Fatukoto1 (181.06$\pm$95.46 m^3 ha^{-1}), followed by Buat (142.67$\pm$27.19 m^3 ha^{-1}) and FatukotoII (99.09$\pm$62.46 m^3 ha^{-1}). There were four soil parameters that meaningfully affected the growth performance of *E. urophylla*, i.e. pH, Av-P, Exc-K, and CEC. Among those parameters, Av-P demonstrated a consistent effect on the growth performance of *E. urophylla*. According to these findings, this study concluded that Av-P substantially provided higher effect on the growth performance of *E. urophylla* than other soil chemical parameters.

Keywords*: available phosphorus, eucalyptus plantation, forest productivity, sustainable management*

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Introduction

Soil is the primary component of ecosystems which provide essential roles in espousing plant growth and development (Alam et al., 2020). It supplies water and nutrient which importantly required by the plant for ensuring their physiological process (Guo et al., 2019). In every type of ecosystems, soil characteristics principally diverse due to the effect of specific factors regarding its pedogenesis, such as climate, parent materials, relief, vegetation, and time periods (Catoni et al., 2016). Several studies also report that soil characteristics generally varies, mainly in ecosystems affected by human activities (Maynard et al., 2014; Steffan et al., 2018; Yan et al., 2018), including eucalyptus plantation. In fact, some literature document that the variation of soil characteristics has a direct effect on the gradient productivity of eucalyptus plantation (Vance et al., 2014; Resende et al., 2018; Lu et al., 2020). These explanations confirm that understanding about the relationship between soil properties and the growth performance of eucalyptus is basically required for forest managers to determine the best silviculture treatment in improving the productivity of eucalyptus plantation.

In the context of sustainable plantation forest management, mainly in eucalypts plantation, the availability information about soil characteristics is highly necessary to determine the best strategy for conserving soil fertility and reducing the risk of erosion (Lal, 2015). For example, the application of fertilization using potassium is needed to improve eucalypts productivity which planted in sandy soil (Bassaco et al., 2018). Moreover, the development of agroforestry between leguminaceae species and eucalyptus is also helpful to minimize runoff and erosion (Raj et al., 2016). It also has the potential to increase the content of soil nitrogen since most of leguminaceae plants can fix nitrogen (Forrester et al., 2006). Furthermore, several references publish that soil characteristics can be used as an indicator to assess the environmental condition in eucalyptus plantation (Pulleman et al., 2012).

In Indonesia, eucalypts plantation has been widely established in several provinces, including East Nusa Tenggara. The management of eucalypts plantation in this location is really interesting since it is managed to support rural development, climate change mitigation, and future viability of the industry. Besides having prospective economic value, most eucalypts plants have good ability to absorb carbon emissions from the atmosphere (Cavalett et al., 2018). Higher eucalyptus productivity demonstrates a better contribution to carbon reduction. Nevertheless, the ability of eucalyptus for carbon absorption highly depends on its growth performance (Booth, 2013) wherein the effect of environmental factors, mainly related to soil characteristics, may provide a higher influence on its growth (Rodríguez-Soalleiro et al., 2018). Therefore, this study was designed to evaluate the relationship between soil chemical properties and the eucalyptus stand productivity.

Materials and Methods

Study location

This study was done in *E. urophylla* plantation that managed by Timor Tengah Selatan FMU. It is situated in Timor Tengah Selatan District, around 180 km of Kupang, the capital city of East Nusa Tenggara Provinces. The geographic position of this site is located in 9º50′ to 9º50′ S and 124º15′ to 124º15′ E. The total area of *E. urophylla* plantation in this location is 250 ha which divided into 3 compartments, i.e. Buat, Fatukoto1, and Fatukoto2 (Kurniadi and Pujiono, 2009).

Elevation ranges from 800 to 1,000 m above sea level. The topography is dominated by hilly area with slope level ranging from 15 to 45%. Soil type is categorized as Cambisol, which has a sandy loam texture. The study location is classified as having a humid condition with the mean air humidity of 85.5% and the average daily temperature of 29 ºC. Annual rainfall reaches 1,500 mm $year^{-1}$. Dry periods are noted from 7 months starting from March to September (Kalima et al., 2019)

At the preliminary periods, before the development of *E. urophylla* plantation, the study area was a bare land without trees vegetation. The land cover was dominated by *Imperata cylindrica*. Starting from 1980s, the local government initiated to implement forest and land rehabilitation program by selecting *E. urophylla* as a primary species for reforestation. The effort was made periodically until late 2016 without having commercial objectives. However, after constructing Timor Tengah Selatan FMU and considering the economic benefit of *E. urophylla*, the management objective was transformed into a commercial plantation forest for accelerating the scenario of rural development (Sadono et al., 2020)

Data collection

A field survey was implemented in three priority compartments for *E. urophylla* development, i.e. Buat, Fatukoto1, and Fatukoto2. It was comprised of two important stages, namely soil sampling and stand measurement. In each site, soil sampling was conducted at five different positions randomly to represent the land configuration (Rannestad and Gessesse, 2020). The soil sample was collected at the depths of 0-10, 10-20, 20-30 cm before being composited (Li et al., 2018). Then, the sample was brought to the laboratory for chemical analysis. Six parameters were selected to describe soil chemical properties, including soil acidity (pH), soil organic carbon (SOC), total nitrogen (TN), available phosphorus (Av-P), exchangeable potassium (Exc-K), and cation exchange capacity (CEC). The detail protocols for soil analysis are presented in Table 1.

The stand condition above soil sampling locations was measured using the N-tree sampling method. This approach is a forest inventory technique in which the stage of stand measurement is done at the nearest trees from the centre point (Sadono et al., 2019). In this context, the centre point is assumed as a centre of the sampling plot which is represented by the point of soil sampling position. The main principle of this approach is relatively similar to the point centred quarter method that is frequently used in ecological research, especially for trees vegetation (Haxtema et al., 2012). However, both techniques differ in the number of sample trees. The implementation of point centred quarter method quantified approximately four sample trees while the utilization of N-trees measured around six sample trees (Silva et al., 2017).

Table 1. Protocol of soil analysis for quantifying soil acidity (pH), soil organic carbon (SOC), total nitrogen (TN), available phosphorus (Av-P), exchangeable potassium (Exc-K), and cation exchange capacity (CEC).

No	Soil characteristics	Symbol	Units	Analysis method	References
1	Soil acidity	pH	-	pH meter	Suryanto et al. (2017)
2	Soil organic carbon	SOC	%	Walkley and Black	Sato et al. (2014)
3	Total nitrogen	TN	%	Kjeldahl	Sáez-Plaza et al. (2013)
4	Available phosphorus	Av-P	ppm	Olsen	Silva et al. (2015)
5	Exchangeable potassium	Exc-K	cmolc(+) kg^{-1}	Flame Photometer	Estefan et al. (2013)
6	Cation exchange capacity	CEC	cmolc(+) kg^{-1}	Ammonium Acetate	Behera et al., (2016)

The shape of the sampling plot generated by N-trees sampling method was circular (Figure 1). But, the plot size (Ai) was basically different from each others depending on the radius between the sixth tree and centre point (r_6). In this context, the sixth tree was the furthest tree situated from the centre point. Then, the radiuses of each sampling plot (Ri) and plot size (Ai) were counted following these equations (Haxtema et al., 2012; Silva et al., 2017; Sadono et al., 2020):

$$Ri = r_6 + \frac{1}{2} d_6 \quad (1)$$

$$Ai = \pi Ri^2 \quad (2)$$

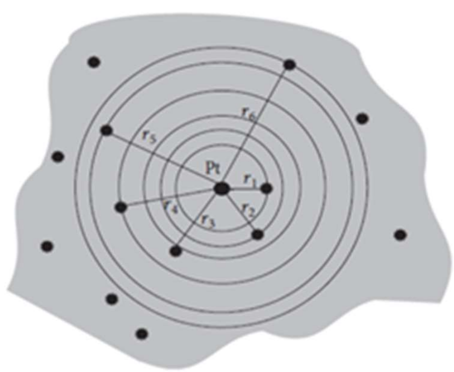

Figure 1. Visualization plot resulted by N-trees sampling method. *Pt* was a centre point of sampling plot while r_n signified the radius between trees and centre point (Silva et al., 2017).

Where d_6 is tree diameter of the sixth tree in meter unit while π is a constant of 3.14 that commonly used for calculating the area of the circular plot. Some literature also confirms the use of N-trees sampling method for facilitating forest inventory demonstrates an equal accuracy with other approaches as long as it is applied in a plantation forest with monoculture species (Basiri et al., 2018; Mirzaei and Eslam, 2016).

Several parameters were used to evaluate the individual tree dimension in each plot, such as diameter at breast height (d), tree height (h), and tree volume (v). The measurement of tree diameter was done by diameter tape at 1.3 m from aboveground. The estimation of tree height was measured by hypsometer from aboveground to top crown. Afterwards, individual tree volume (v) was quantified by the formula:

$$v = 0.25\pi\, d^2\, h\, f \quad (3)$$

where f is a form factor from *E. urophylla* of 0.4 (Susila and Darwo 2015). The value of stand volume (V) was estimated by converting the sum of volume in every plot into hectare unit. Afterwards, the mean annual increment (MAI) was calculated following this equation:

$$MAI = V/t \quad (4)$$

where: t is the age of stand which estimated from year of establishment to measurement time.

Data analysis

The process of data analysis was conducted using software R version 4.0.2 with a significant level of 5%. The package agricolae was selected to facilitate the statistical analysis. The descriptive test was conducted to describe the summarized results of the forest inventory for every parameter, including minimum, maximum, mean, standard deviation, and standard error. Normality of data was examined using Shapiro-Wilk test.

Homogeneity variance of data was evaluated by Fligner-Killen test. Comparison of soil chemical characteristics and the growth performance of *E. urophylla* among compartment were analyzed separately for every parameter using Kruskal-Walls test and followed by Kruskal-Nemenyi test. A hierarchical clustering using heat map diagram was used to assess the similarity of soil chemical characteristics among location. Then, the effect of soil chemical characteristics on the growth performance of *E. urophylla* was tested using stepwise regression.

Results and Discussion

Soil chemical characteristics among surveyed area relatively varied wherein there was a significant difference in pH, SOC, Av-P, and CEC from three compartments (Table 2). In contrast, the content of TN and Exc-K from three sites were statistically equal. The majority of soil chemical characteristics in Fatukoto1 had the lowest value than other sites, except for TN. It happened because Fatukoto1 had higher altitude and slope than Buat and Fatukoto2 thus the risk of erosion in this location was greater than other sites.

A study reported by Kurniadi and Pujiono (2009) documented that the altitude of Fatukoto1 varied from 900 to 1,000 m asl with slope level ranging from 15-25%. This condition was relatively in contrast to Buat and Fatukoto2, which has an elevation ranging from 900 to 950 m above sea level with a slope gradient of around 8-15%. Several studies reported that higher altitude and slope level principally increase the risk of erosion in which it becomes a fundamental factor to accelerate the process of nutrient leaching (Charan et al., 2013; Rezaei et al., 2015; Wubie and Assen, 2020). The occurrence of erosion has the potential to reduce soil fertility since it leaches the amount of nutrient in the surface layer (Kandari et al., 2018; Novara et al., 2018). It clearly answered why the soil quality of Fatukoto1 was relatively lower than other sites.

In forest ecosystems, both in natural and plantation forests, the variation of soil chemical characteristics can be affected by several factors like topography, climate, and vegetation (Scholten et al., 2017). The effect of topography and climate on soil diversity is generally related to erosion and leaching. For example, at the site having a high slope level, soil quality is slightly lower than the site which has flat condition due to the impact of runoff and erosion (Dessalegn et al., 2014). The risk of erosion will be also greater in the location which has high rainfall intensity because the rain water is the primary factor which causes runoff and erosion (Mohamadi and Kavian, 2015). The effect of vegetation on soil diversity is primarily related to litter accumulation that provides a meaningful influence on soil chemical properties (Jahed et al., 2014). When the litter is decomposed, nutrients will be released into the soil (Ge et al., 2013). Therefore, at the location having high litter accumulation, soil fertility is better than a site with low litter accumulation.

This study documented that there were some similar soil characteristics among three priority compartments for cajuput development (Figure 2). Based on the outcome of heatmap dendrogram, there were two clusters of soil diversity in the study area. The first cluster was membered by Buat and Fatukoto2 while the second cluster was only occupied by Fatukoto1. It indicated that soil characteristics in Buat and Fatukoto2 were relatively more similar compared to Fatukoto1.

Table 2. Comparison of soil characteristics and stand attributes (Mean±SD) among priority compartments for eucalypts development.

Parameter	**Location**			***P-value***
	Buat	**Fatukoto1**	**Fatukoto2**	
Soil characteristics				
pH	5.00±0.44 a	4.19±0.67 b	6.24±0.59 c	0.003^{**}
SOC (%)	1.82±0.50 a	1.00±0.23 b	0.84±0.35 b	0.017^{**}
TN (%)	0.81±0.34 a	0.65±0.38 a	0.59±0.39 a	0.690^{ns}
Av-P (ppm)	40.73±0.77 a	29.26±0.59 b	41.79±0.68 c	0.004^{**}
Exc-K (cmolc(+) kg^{-1})	1.15±0.66 a	0.58±0.59 a	0.70±0.46 a	0.431^{ns}
CEC (cmolc(+) kg^{-1})	35.11±0.45 a	33.01±0.41 b	34.51±0.59 a	0.006^{**}
Stand attributes				
D (cm)	40.01±2.08 a	33.18±1.73 b	28.39±2.68 c	0.001^{**}
H (m)	18.2±0.16 a	17.54±0.19 b	16.89±0.45 c	0.001^{**}
V (m^3)	142.67±27.19 a	181.06±95.46 a	99.09±62.46 a	0.453^{ns}
MAI (m^3 $year^{-1}$)	6.49±1.24 a	8.23±4.34 a	4.50±2.84 a	0.453^{ns}

** indicated a significant difference according to Kruskal-Walls test; ^{ns} signified non-significant different based on Kruskal-Walls test; the similar letter in a row showed non-significant different referring to Kruskal-Nemenyi test.

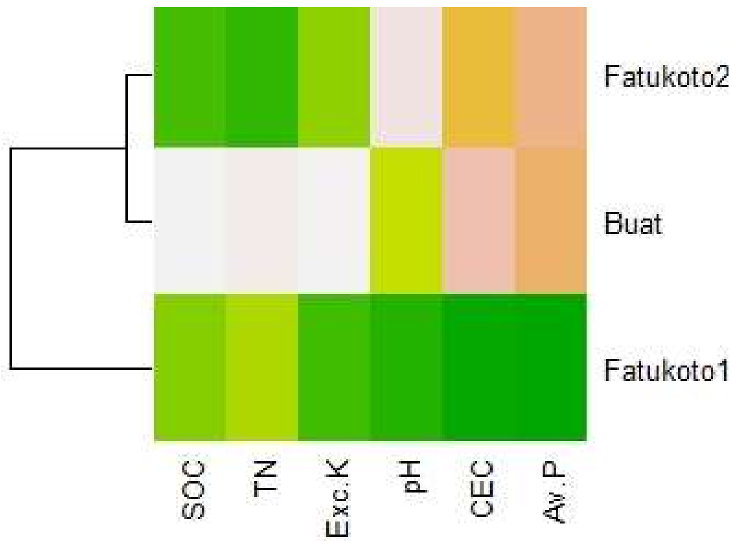

Figure 2. Heatmap dendrogram to identify the similarity of soil chemical characteristics among priority sites for *E, urophylla* development.

In the context of sustainable eucalypts plantation management, the stratification of soil diversity is required to support the best practice maintenance since it correlates to the investment cost, particularly for fertililzation. When the number of sites is classed in an identical cluster, it signifies that the soil characteristics among sites are similar; thus, it can be managed using the same silviculture treatments. The different soil chemical characteristics in every compartment were also followed by the variation of eucalypts growth performance. This study noted the growth performance of eucalypts among three locations significantly differed in height and diameter. However, there was no significant difference in stand volume and mean annual increment (Table 2). Our study recorded the highest eucalypts productivity was observed in Fatukoto1 (181.06±95.46 m^3 ha^{-1}), followed by Buat (142.67±27.19 m^3 ha^{-1}) and Fatukoto2 (99.09±62.46 m^3 ha^{-1}). Interestingly, this study found there were several soil parameters that provided a significant influence on the growth performance of eucalypts stand, i.e. pH, Av-P, CEC, and Exc-K (Table 3). Among those soil parameters, Av-P demonstrated a significant effect on all stand attributes of eucalypts. It indicated that the eucalypts species in this site is very responsive to the availability of phosphorus in soil (Crous et al., 2015; Tng et al., 2014; Wirabuana et al., 2020). Many references also confirmed that phosphorus is the primary nutrient needed by eucalyptus (Amezquita et al., 2018; Bassaco et al., 2018; Wirabuana et al., 2019), especially in acid soil with low availability of phosphorus (Wang et al., 2015). Several previous studies in other locations also documented that the practice of phosphate fertilizer provides a positive effect on the eucalypts productivity (Gotore et al., 2014; Melo et al., 2016; Wirabuana et al., 2020). However, even though most eucalypts species highly require phosphorus, the excessive amount of phosphorus in soil can hider the plant growth. Our study noted that the content of Av-P in each site was very high (Table 2) and provided a negative effect on the growth performance of eucalypts stand (Table 3).

Table 3. Results of the stepwise regression for identifying the effect of soil chemical characteristics and the growth performance of *E. urophylla.*

Parameters	Equations	R-squared	RSE	*P-value*
Diameter	$Y = -208.12^{**} - 4.74pH^{**} - 0.62Av\text{-}P^{**} + 8.52CEC^{**}$	0.861	0.806	$<0.001^{**}$
Height	$Y = -11.01^{**} - 0.40pH^{**} - 0.10Av\text{-}P^{**} + 1.01CEC^{**}$	0.834	0.792	$<0.001^{**}$
Volume	$Y = 346.91^{**} - 7.13Av\text{-}P^{**} + 73.80Exc\text{-}K^{**}$	0.478	55.890	0.021^{**}
MAI	$Y = 15.77^{**} - 0.32Av\text{-}P^{**} + 3.35Exc\text{-}K^{**}$	0.478	2.54	0.021^{**}

** indicated significant results.

Conclusion

Soil chemical characteristics affected the growth performance of *E. urophylla* in dryland ecosystems at East Nusa Tenggara. There were four soil parameters which demonstrated a meaningful effect on the growth performance of *E. urophylla*, i.e. soil acidity, available phosphorus, exchangeable potassium, and cation exchange capacity. Among those soil parameters, available phosphorus consistently showed a significant effect on all stand attributes of *E. urophylla.*

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