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The most important factors affecting yield of the *Eucalyptus* species

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Abstract: This study was conducted primarily to obtain factors affecting yield for forest plantation *Eucalyptus* spp in Aek Nauli, North Sumatera, Indonesia. The data in this study used 650 rhombic plots consisting of 106 PSPs and 544 inventory plots with several variations of plot size. Stands features referred to diameter, height, merchantable volume, age, species, spacing, site index, basal area, and density of *Eucalyptus* species. Geographical features referred to slope, elevation, rain fall and soil of the study area .The most important factors affecting yield of the E. hybrid*, E. urophylla, and all Eucalyptus* species are rainfall followed by soil group A while for *E. grandis, E. pellita* and mixed *Eucalyptus* are stand density, elevation, interaction site index and age, respectively.

Keywords: Stand, Geografhic, Yield, *Eucalyptus*

1. Introduction

The global forest plantations have increased by nearly 12 million ha/year in 1990s, less than 4 million ha/year compared in 1980s (FAO, 2001; ITTO, 2001). This increase in forest plantations establishment indicates that there is steadily increasing investment in forestry. Therefore, the current problem is not only the availability of the investment but also the ability to plan, manage, control and sell the forest plantations products successfully [2].

Growth modeling of plantation timber species is a vital tool for the prediction of yield from future harvesting and estimating financial returns. One criterion of sustainable forest management is sustainability of yield [3]. These requirements have implications for model design, implementation and use. Reliable predictions depend on reliable models and reliable input data. The yield is dependent on several factors, the most important being the species composition, stand age, site quality, genetic variation, stand density, management regime and environmental conditions [4].

Forest management decisions are predicated on information and projection about current and future resource conditions. Inventories taken at one point in time provide information on current volumes and related statistics. Managers of these plantations require precise and reliable predictions of future stand yield. [3].

There are many complex and interrelated factors that influence the quantity, quality, and distribution of growth in a forest stand. Some of the more important factors are stand age, site quality, genetic variation, stand density, management regime and environmental conditions. Thus the purpose of this study is to obtain factors affecting yield of the *eucalyptus.*

2. Material and Method

2.1. Study Site

The study was conducted in Aek Nauli sector of the Industrial Timber Estate (*Hutan Tanaman Industri* - HTI) namely, PT. Toba Pulp Lestari (PT. TPL), from December 2008 – March 2009. It is in the territorial jurisdiction of

Porsea subdistric, Simalungun regency, North Sumatera Province, Indonesia. The study area has the highest annual rainfalll in October and the lowest in August. Based on its topography, the study area has a rainfall range of 85 – 434 mm/month, it has an elevation range from 350 to 1400 msal and it has top soil depth ranges from 10 to 44 cm. The study area covered an area 189,975 ha with Aek Nauli sector has an area 21341.8 ha.. Geographically, it is located between 02° 40'00" to 02° 50'00" north latitude and 98° 50'00" to 99° 10'00" east longitude .[7]

2.2. Materials

The concerned institutions and organizations were requested to facilitate data gathering for the research. These institutions included agencies in Indonesia such as PT. TPL, National Coordination Agency for Survey and Maping (BAKOSURTANAL , *Badan Kordinasi Survei dan Pemetaan Nasional*), Agency for Meteorology and Geophysics-regional I Sampali , Medan, Agency for Watershed Management in Asahan Barumun, North Sumatera. Secondary data were collected from the libraries and internet-base sources of the institutions/ agencies in the Philippines and Indonesia. Libraries used included SEARCA, College of Forestry and Natural Resources (CFNR), UPLB and University of North Sumatera

The data in this study used 650 rhombic plots consistin of 106 permanent sample plots (PSPs) and 544 inventory plots with several variations of plot size, from 0.02 to 0.04 ha.. PSPs have an area of 3.44 ha. It consisted of 106 plot or 273 observations. Inventory plot has an area of 21.76 ha. It consisted of 544. Thus, the total area of the plots in this study site is 25.2 ha.

The primary data and secondary data were digitally encoded. Field observation was conducted to gather stands and geographic data. Stands features referred to diameter, height, merchantable volume, age, species, spacing, site index, basal area, and density of *Eucalyptus* plantations. Geographical features referred to slope, elevation, rain fall and soil of the study area.

Species were grouped into *E. hybrid* (*E.*hyb), *E. grandis* (*E.gra*), *E. pellita, E. urophylla* (*E. uro*), mixed *Eucalyptus,* and all *Eucalyptus species.* The data sets derived from 470 *E.* hybrid*, 94 E.grandis*, 23 *E. pellita*, 46 *E. urophylla* and 119 mixed *E*. observations. *E.* hybrid is breeding from E. *urophylla* vs *E. grandis* and *E. pellita* vs *E. grandis*. Mixed *Eucalyptus* observations consisted of *E.*hybrid*, E.grandis*, *E. pellita*, and *E. urophylla species.*

2.3. Data Analysis

To determine the factors that most influence the yield of eucalyptus, partial coefficient determination (R^2) of the final models for Each *Eucalyptus* species was used [8]. The coefficient of partial determination can be defined as the percent of variation. This coefficient is used to provide insight into whether or not one or more additional predictors may be useful in a more fully specified regression model. It helps to provide the proportion of the variance of one variable which is predictable from the other variable. It is a way of measurement which allows determining how clear it can be in making predictions from a certain data provided. [1].

Coefficients of determination (R^2) represent the proportion of SST (Total Sum of Square) that is explained by use of the regression model. It is a measure of how well the regression line represents the data [1]. The computational formula for R^2 as follow:

$$R^2 = \frac{SS\ reg}{SS\ tot} = \frac{b\ SPxy}{SS\ y}$$

Where:

SS reg = the regression sum of squares

SS tot = the total sum of square

Usually, the higher the value of R^2 is, the better the regression model will be. This is because if R^2 is larger, a greater portion of the total error is explained by the included independent variable and a smaller portion of errors is attributed to other variables and randomness. The range of r-square is from 0 to 1. An R^2 = 90%, implies that 90% variation in Y is attributable to the variation in X.

3. Results and Discussion

3.1. Descriptive Statistic for Stand Variables of the Study Area

Stand variables used in this study consisted of merchantable volume in cubic meter per hectare, basal area in square meters per hectare, age in year, diameter at breast height in centimeter, height in meter, site index in meter, stand density in number of tree per hectare, and spacing in square meters.

The summary descriptive statistics of the actual stand variables to develop the models are shown in Table 1. The merchantable volume ranges from 0.0003 to 289.5 m^3/ha. Merchantable volume averages for *E.* hybrid, *E.grandis*, *E. pellita*, *E. urophylla*, mixed *Eucaylptus* and all species observations are 37.532 m^3/ha, 60.965 m^3/ha, 45.408 m^3/ha, 29.557 m^3/ha, 11.726 m^3/ha and 35.796 m^3/ha, respectively. *E. grandis* has the highest average volume (60.965 m^3/ha) and m*ixed Eucalyptus* has the lowest average volume (11.726 m^3/ha).

The study site has a basal area ranges of 0.0128 to 28.064 m^2/ha. The basal area averages for *E. hybrid, E.grandis*, *E. pellita*, *E. urophylla*, mixed *Eucaylptus* and all species are 6.59731m^2/ha, 10.076 m^2/ha, 10.831 m^2/ha, 6.369 m^2/ha, 2.372 m^2/ha and 6.479 m^2/ha, respectively.

The stand ranges in age from 0.17 to 6.7 years. The stand age averages for *E. hybrid, E.grandis*, *E. pellita*, *E. urophylla*, mixed *Eucaylptus* and all species are 2.0 year, 3.1 year, 3.03 year, 2.048 year, 1.34 year, and 2.08 year, respectively. In terms of stand age, *E. hybrid* has both the highest age (6.7year) and the lowest age (0.17 year).

Table 1 indicates that diameter ranges from 0.3438 to

24.80 cm. The average diameter for *E.* hybrid*, E.grandis*, *E. pellita*, *E. urophylla*, mixed *Eucalyptus* and all species observations are 7.274 cm, 11.213 cm, 10.901cm, 7.586 cm, 4.294 cm and 7.424 cm, respectively. In terms of stand diameter, *E.* hybrid has the highest diameter (24.80 cm) and mixed *Eucalyptus* has the lowest stand diameter (0.34 cm).

Regarding stand height in this study area, the stand height ranges from 31.5 to 0.14 m. The stand height averages for *E.* hybrid*, E.grandis*, *E. pellita*, *E. urophylla*, mixed *Eucalyptus* and all species are 10.234 m, 15.514 m, 12.151 m, 11.227 m, 6.667 m, and 10.449 m, respectively. In terms of stand height, *E. grandis* has the highest average stand height (5.514 m) and mixed *Eucalyptus* has the lowest average stand height (6.667 m).

The study site has a site index ranges from 25.936 to 0.154 m. The site index averages, respectively, for *E.* hybrid*, E.grandis*, *E. pellita*, *E. urophylla*, *Mixed Eucalyptus* and all species are10.323 m, 15.747 m, 16.359 m, 12.255 m, 6.464 and 10.693 m. *E. pellita* have the highest average site index (16.359 m) and mixed *Eucalyptus* have the lowest average site index (6.464 m).

Table 1. *Descriptive statistics for actual stand variables of models E. hybrid, E. grandis, E.pellita, mixed Eucalyptus and all species in Aek nauli sector*

Species	Variables	Max	Min	Average	Variance	Standard Deviation
E. hybrid	Volume(m^3/ha)	289.500	0.0003	37.532	0.710	0.843
	Basal area (m^2/ha)	28.064	0.0128	6.597	0.196	0.443
	Age (year)	6.700	0.1700	2.007	2.225	1.492
	Diameter (cm)	24.800	0.3438	7.274	24.504	4.950
	Height (m)	31.500	0.1385	10.234	0.102	0.319
	Site index (m)	25.936	0.1542	10.323	0.106	0.325
	Density (tree/ha)	1751.000	290.0000	1156.291	0.011	0.107
	Spacing (m^2)	9.000	3.0000	7.293	1.269	1.126
E.grandis	Volume(m^3/ha)	152.307	0.3149	60.965	0.282	0.531
	Basal area (m^2/ha)	20.277	0.4829	10.076	0.067	0.259
	Age (year)	6.120	1.0800	3.119	1.585	1.259
	Diameter (cm)	16.000	2.3938	11.213	12.470	3.531
	Height (m)	25.400	2.6188	15.514	0.047	0.216
	Site index (m)	25.004	4.6322	15.747	0.040	0.200
	Density (tree/ha)	1280.000	575.0000	925.532	0.006	0.079
	Spacing (m^2)	9.000	6.7500	8.928	0.158	0.398
E. pellita	Volume(m^3/ha)	116.005	5.3705	45.408	0.172	0.415
	Basal area (m^2/ha)	20.245	3.6374	10.831	0.040	0.201
	Age (year)	5.010	1.5000	3.029	1.402	1.184
	Diameter (cm)	15.400	5.8217	10.901	8.529	2.921
	Height (m)	19.300	5.5375	12.151	0.040	0.201
	Site index (m)	23.724	8.3147	16.359	0.023	0.152
	Density (tree/ha)	1200.000	675.0000	1047.000	0.003	0.055
	Spacing (m^2)	9.000	9.0000	9.000	0.000	0.000
E.urophylla	Volume(m^3/ha)	135.520	0.0120	29.557	0.584	0.764
	Basal area (m^2/ha)	17.652	0.3000	6.369	0.127	0.356
	Age (year)	5.000	0.6700	2.048	1.346	1.160
	Diameter (cm)	15.278	1.7000	7.586	15.735	3.967
	Height (m)	22.004	2.2693	11.227	0.061	0.246
	Site index (m)	23.539	2.5337	12.255	0.067	0.259
	Density (tree/ha)	1625.000	725.0000	1201.152	0.008	0.091
	Spacing (m^2)	9.000	6.0000	6.799	1.160	1.077
mixed	Volume(m^3/ha)	170.000	0.0600	11.726	0.366	0.605
Eucalyptus	Basal area (m^2/ha)	19.000	0.0320	2.372	0.103	0.321
	Age (year)	6.100	0.4900	1.374	1.678	1.295
	Diameter (cm)	15.900	0.5000	4.294	14.508	3.809
	Height (m)	27.900	0.4000	6.667	0.080	0.283
	Site index (m)	23.350	1.5896	6.464	0.061	0.247
	Density (tree/ha)	1476.000	625.0000	1092.261	0.006	0.078
	Spacing (m^2)	9.000	6.0000	7.412	0.240	0.490
All species	Volume(m^3/ha)	289.500	0.0003	35.795	0.691	0.831
	Basal area (m^2/ha)	28.064	0.0128	6.479	0.187	0.433
	Age (year)	6.700	0.1700	2.080	2.216	1.489
	Diameter (cm)	24.800	0.3438	7.424	24.055	4.905
	Height (m)	31.500	0.1385	10.449	0.097	0.312
	Site index (m)	25.936	0.1542	10.693	0.099	0.315
	Density (tree/ha)	1751.000	290.0000	1116.715	0.010	0.102
	Spacing (m^2)	9.000	3.0000	7.538	1.300	1.140

Table 1 indicates that stand density ranges from 290 to 1751 tree/ha. Results show that *E. hybrid* has the highest average stand density (1156.3 tree/ha) and *E. grandis* has the lowest average stand density (925.5 tree/ha).

Spacing in this study site ranges from 3 to 9 m^2. Results show that average spacing for *E.* hybrid, *E.grandis, E. pellita, E. urophylla*, mixed *Eucalyptus* and all species is 7.29 m, 8.923 m, 9.00 m, 6.799 m, 7.41 m and 7.538 m, respectively. In terms of spacing, *E. pellita* observations have the highest average spacing (9 m) and *E. urophylla* observations has the lowest average spacing (6.799 m).

3.2. Descriptive Statistic for Geographic Variables of the Study Area

Geographic variables were obtained and these were top soil depth in centimeter, monthly rainfall in millimeter, slope in percent, elevation in masl, and groups of soil. In regression analysis, the dependent variables are frequently influenced not only by quantitative variables but also by variables of spatial, temporal or qualitative nature. Descriptive statistic about max, min, mean, variance and standard deviation for soil groups were not needed because of a nominal scale. It is no more than giving each feature a name and is thus purely subjective and descriptive in nature. It divides the data based on qualitative considerations. It is usually coded numerically by ones or zeroes to indicates presence or absence of an attribute. Descriptive statistic geographic variables to develop the models are shown in Table 2. Dummy variables for group of soil are shown in Table 3.

Table 2 indicates that top soil depth is from 10 to 44 cm. Results show that average top soil depth for *E.* hybrid*, E.grandis*, *E. pellita*, *E. urophylla*, mixed *Eucalyptus* and all species observations are 23.455 cm, 22.287 cm, 21.957 cm, 21.826 cm, 22.143 cm and 22.956 cm, respectively. In terms of top soil depth, *E.* hybrid observations have the highest average top soil depth (23.455 cm) and mixed *Eucalyptus* observations have the lowest average top soil depth (22.143 cm).

The study area has a rainfall from 85 – 434 mm/month. The average monthly rainfall for *E.* hybrid*, E.grandis*, *E. pellita*, *E. urophylla*, mixed *Eucalyptus* and all species observations are 222.30 mm, 201.46 mm, 154.00 mm, 209.24 mm, 221.05 mm, and 216.61 mm, respectively. Regarding monthly rainfall, Table 2 indicates that *E.* hybrid observations has the highest average monthly rain fall (222.3 mm) and *E. pellita* observations has the lowest monthly rainfall (154 mm).

Table 2 shows that Aek Nauli sector has a field slope of 4 – 45 %. The average field slope for *E.* hybrid*, E.grandis*, *E. pellita*, *E. urophylla*, *Mixed Eucalyptus* and all species observations are 15.51% cm, 15.29%, 28.47%, 14.47%, 11.78% cm and 15.23%, respectively. In terms of field slope, *E. pellita* observations have the highest average field slope (28.47%) and *Mixed Eucalyptus* observations have the lowest average field slope (11.78 %).

Aek Nauli sector has an elevation ranges from 350 to 1400 masl. Elevation in the research area averages for *E. hybrid, E.grandis*, *E. pellita*, *E. urophylla*, mixed *Eucalyptus* and all species observations are 1193.511 masl, 1225.532 masl, 1256.522 masl, 1175.000 masl, 1179.832 masl, and 1196.144 masl, respectively. *Eucalyptus grandis* observations have the highest average elevation.

The type of soil in Aek nauli sector is shown in Table 3, majority of the areas has type soil C(55.85 %) followed by and soil type A (26.33%), soil type E (10.77%), soil type D (5.32%) and soil type B (1.73%)

Table 2. *Descriptive statistics for geographic variables of the models E. hybrid, E. grandis, E. pellita, mixed Eucalyptus and all species*

SPECIES	VARIABLES	MAX	MIN	AVERAGE	VARIANCE	STANDARD DEVIATION
E. hybrid	Top soil (cm)	44.000	10.000	23.455	0.010	0.098
	Rain fall (mm/month)	434.000	85.000	222.300	0.028	0.168
	Slope (%)	45.000	4.000	15.512	0.094	0.307
	Elevation (masl)	1400.000	350.000	1193.511	0.025	0.159
E.grandis	Top soil (cm)	35.000	15.000	22.287	17.669	4.203
	Rain fall (mm/month)	361.000	105.000	201.457	0.029	0.170
	Slope (%)	45.000	4.000	15.298	0.098	0.313
	Elevation (masl)	1400.000	350.000	1225.532	0.016	0.125
E. pellita	Top soil (cm)	30.000	12.000	21.957	0.008	0.090
	Rain fall (mm/month)	275.000	105.000	154.000	0.039	0.196
	Slope (%)	45.000	4.000	28.478	0.088	0.297
	Elevation (masl)	1400.000	850.000	1256.522	0.022	0.149
E.urophylla	Top soil (cm)	35.000	15.000	21.826	0.008	0.090
	Rain fall (mm/month)	434.000	89.000	209.239	0.039	0.196
	Slope (%)	45.000	4.000	14.467	0.088	0.297
	Elevation (masl)	1400.000	350.000	1175.000	0.022	0.149
Mixed	Top soil (cm)	35.000	10.000	22.143	0.009	0.094
Eucalyptus	Rain fall (mm/month)	356.000	89.000	221.050	0.031	0.176
	Slope (%)	45.000	4.000	11.782	0.070	0.264
	Elevation (masl)	1400.000	350.000	1179.832	0.019	0.139
All species	Top soil (cm)	44.000	10.000	22.956	0.009	0.096
	Rain fall (mm/month)	434.000	85.000	216.609	0.029	0.172
	Slope (%)	45.000	4.000	15.227	0.095	0.308
	Elevation (masl)	1400.000	350.000	1196.144	0.022	0.150

Table 3. *Number and proportion of geographic variables on ranking type of soil for all species in Aek Nauli sector*

Dummy –Soil Group			Frequency	Percent
Soil A	1	Rating = 1	198	26.330
	0	otherwise	554	73.670
Soil B	1	Rating = 2	13	1.729
	0	otherwise	739	98.271
Soil C	1	Rating = 3	420	55.851
	0	otherwise	332	44.149
Soil D	1	Rating = 4	40	5.319
	0	otherwise	712	94.681

Where:
Soil A : for group of soil dystrandepts, hydrandepts
Soil B : for group of soil dystropepts, dystrandepts
Soil C : for group of soil dystropepts, hapludults
Soil D: for group of soil dystropepts, humitropepts

3.3. Factors Affecting Yield

Large areas of *Eucalyptus* plantations have the potential to alter the diversity of plant across landscapes. The effects of plantations differ strongly based on the characteristics of the surrounding landscapes and management regime (especially understory vegetation control) [11]

The main target of sustainable management of *Eucalyptus* plantations is maintaining long-term productivity of the land [4]. As the *Eucalyptus* plantations area expands, rotation lengths shorten, and inappropriate plantation establishment and management techniques are applied. Based on the final models for each eucalyptus species, there are several factors affecting the yield of *Eucalyptus* plantations which can be shown in Table 4.

The most important factor affecting yield of the *E.* hybrid is rainfall (R^2 = 89.94%), followed by dummy soil group C (R^2 = 89.86%) and top soil (R^2 = 89.40%). Partial coefficient Determination (R^2) for rainfall is equal to 89.94 %, it means that error sum of square (ESS) can be reduced by 89 % if rainfall is added to the regression model already containing age, top soil and dummy soil group C .

Stand density is the most important factor affecting yield of the *E. grandis* followed by site index, because it had the highest partial R^2 = 0.9808. It means that error sum of square can be reduced by 98.08 % if stand density is added to the regression model already containing basal area, top height, and age. The final model of *E. grandis* had the regression coefficient for stand density - 0.00054. It means that there is a decrease in volume by0.00054 per unit increase in stand density holding other independent variables constant. Stand density is a measure of how many trees are growing per unit area. Together, site and density tell us how much timber we can produce, as well as what kind of wood quality we can expect at harvest time.

Elevation is the most important factor affecting yield of the *E. pellita* followed by age, because it had the highest partial R^2 = 0.9952. It means that error sum of square can be reduced by 99.52 % if elevation is added to the regression model already containing basal area, top height, and age. The final model of *E. pellita* had the regression coefficient for elevation - 0.00023. It means that there is an increase in yield by 0.00023 per unit decrease in elevation holding other independent variables constant. Elevation affects on plants are mostly indirect, because they modify other site factors especially climate and soil. A rise in elevation is accompanied by a fall in temperature. Since the distribution of plants is limited by temperature, elevation likewise sets boundaries on species distribution [9]

Rainfall is the most important factor affecting yield of the *E. urophylla, followed by* elevation, because it had the highest partial R^2 = 0.9224. It means error sum of square can be reduced by 92.24 % if rainfall is added to the regression model already containing basal area, top height, and elevation. The final model of *E. urophylla* had the regression coefficient for rainfall 0.00351. It means that there is an increase in yield by 0.00351 per unit increase rainfall.

Interaction site index with age is the most important factor affecting yield of the mixed *Eucalyptus,* followed by stand density because it had the highest partial R^2 = 0.9153. It means that error sum of square can be reduced by 91.53 % if site index and age are added to the regression model already containing basal area, age, stand density and top soil. The final model of mixed *Eucalyptus* had the regression coefficient for interaction site index with age 0.81678. It means that there is an increase in yield by 0.81678 per unit increase in interaction site index with age holding another independent variables constant.

Likewise, result of analysis for all *Eucalyptus* species show that rainfall is the most important factor affecting the yield followed by soil group A, because it had the highest partial R^2 = 0.9032. It means that error sum of square can be reduced by 90.32 % if rainfall are added to the regression model already containing basal area, top height, age, spacing, top soil and dummy soil group A. The final model of the *E.* all species had the regression coefficient for rainfall 0.00103. It means that there is an increase in yield by 0.00103 per unit increase rainfall. So, in general, rainfall is most important factor affecting yield of the *Eucalyptus* plantation in study site.

Table 4. *Partial coefficient determination (R^2) of the final models for Each Eucalyptus species.*

Species	Model	Independent Variables	R^2
E. hybrid	2	Interaction basal area and top height	0.3892
		Age	0.6191
		Top soil	0.8940
		Rainfall	0.8994
		Dummy soil group C	0.8986
E grandis	1	Basal area	0.6611
		Age	0.8927
		SI	0.9224
		Stand density	0.9808
E.pellita	2	Interaction basal area and top height	0.4486
		Age	0.9667
		Elevation	0.9952
E. urophylla	2	Interaction basal area and top height	0.3150
		Rainfall	0.9224
		Elevation	0.9218
Mixed *Eucalyptus*	3	Interaction basal area and age	0.7975
		Age	0.8515
		Interaction site index and age	0.9153
		Stand density	0.8869
		Top soil	0.8789
All species	2	Interaction basal area and top height	0.3598
		Age	0.6504
		Site index	0.8659
		Spacing	0.8821
		Top soil	0.8982
		Rainfall	0.9032
		Dummy soil group A	0.9027

Rainfall is the primary of water in the forest plantations. The amount of rainfall actually reaching the forest floor depends on the characteristics of the canopy, rain, and other climatic factors. Rainfall in *Eucalyptus* plantations plays two major roles, namely: as a factor causing soil detachment, dispersal and transport and a supplier of moisture to the soil. Water is considered to be a vital factor in the life of *Eucalyptus* plantations affecting growth and reproduction of the various organisms found therein

4. Conclusions

The most important factors affecting yield of the E. hybrid, *E. urophylla, and all Eucalyptus* species are rainfall followed by soil group A while for *E. grandis, E. pellita* and mixed *Eucalyptus* are stand density, elevation, interaction site index and age, respectively. The main target of sustainable management of *Eucalyptus* plantations is maintaining long-term productivity of the land. Resource managers and decision makers should consider the most important factors affecting the yield namely; for, *E. urophylla, and E.* all species are rainfall followed by soil group A while for *E. grandis, E. pellita* and mixed *Eucalyptus* is stand density, elevation, interaction site index and age, respectively.

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