

# Impact of Mixed and Pure Stand Eucalyptus Plantations on Soil Quality in Southern China

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Undergraduate Research Thesis

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## ABSTRACT

Since its introduction to China in the late 1800's, the Eucalyptus tree has played a vital role in the country's development by providing a booming timber supply. The trees are grown in pure and mixed stand plantations across China, and there is interest in which plot type facilitates better growth of Eucalyptus trees. Soil quality data from pure Eucalyptus hybrid (*Eucalyptus urophylla* x *E. grandis*) stands and mixed stands (Eucalyptus with *Magnolia glanca* Blume or *Tsoongiodendron odorum* Chun) near Liuzhou and Nanning, China, respectively, were compared to see which plantation type fostered better soil quality for Eucalyptus growth. Circular plots (n= 6 for mixed, n= 9 for pure) were established and each plot was subsequently divided into four quadrants. Two of these quadrants were randomly picked to perform soil analyses. Soil pits were dug to a depth of 40 cm and electrical conductivity, temperature, soil moisture, and pH measurements were taken at 0 cm, 20 cm, and 40 cm. Results show that the two types of plantations vary significantly with their soil temperature and pH, but not with their conductivity or moisture, according to Duncan's multiple range test ( $p= 0.05$ ). The mixed stands had a higher soil temperature and a more acidic pH than the pure stands. These differences can potentially be explained by the documented allelopathic effects of both Eucalyptus and *M. glanca* trees, which may inhibit understory growth and cause soil acidification. Suggestions for future management practices to promote Eucalyptus productivity and ecological functions based on these results will be discussed.

## INTRODUCTION

Eucalyptus plantations have been rapidly increasing in China since their introduction to the area in the late 1800's. Native to Australia, Eucalyptus trees are a popular choice for plantations in tropical and subtropical regions (Jiayu and Siming, FAO). They are fast-growing, drought-tolerant, and the timber can be used for multiple industrial purposes (Liu and Li, 2010). The economic benefits of these trees are met with a range of ecological consequences, however. Commonly reported issues include a loss of soil fertility and forest biodiversity (Liu and Li, 2010).

Researchers have attempted to overcome these negative ecological consequences of monoculture Eucalyptus plantations by growing Eucalyptus trees in tandem with another tree species, both native and non-native. Mixed results have been seen with these pilot plots (Zhang and Fu, 2009; Chu et al., 2014). Native and non-native trees planted with Eucalyptus can have differential results (Chu et al., 2014). Some researchers have also studied the impact of Eucalyptus trees when they are intercropped with agricultural produce (Espinosa-Garcia et al., 2008; Zhang and Fu, 2010; Sasikumar et al., 2001; Fikreyesus et al., 2011). This practice is known as agroforestry. The presence of Eucalyptus had an inhibitory effect on some crops, and a slightly stimulatory effect on others. Chinese cabbage and cucumber were among those crops shown to be good candidates for this type of agroforestry under certain conditions (Zhang and Fu, 2010). Black beans, tomatoes, and pigeon peas were shown to be inhibited at a greater rate and therefore poor choices for intercropping with Eucalyptus trees (Espinosa-Garcia et al., 2008; Sasikumar et al., 2001; Fikreyesus et al., 2011).

Eucalyptus trees can lower the biodiversity and soil quality in the forests they are planted in. They have been shown to have allelopathic effects, which is commonly considered the major

cause of decreased biodiversity in areas where many Eucalyptus trees are grown (Zhang and Fu, 2010; Chu et al., 2014). Allelopathy is the inhibition of one plant or organism by another. Specifically, in the case of Eucalyptus trees, this involves the release of volatile oils and phenolic acids into the soil which inhibit growth of other plants in the surrounding area. These chemicals can come from the leaves and bark of the tree when it falls to the ground as litter, or from root exudates (Zhang and Fu, 2009). One study showed that the allelopathy of *Eucalyptus urophylla* was selective in its inhibition; native trees were impacted, but non-native trees were not (Chu et al., 2014). This differential impact on indigenous versus exogenous species is important to consider when thinking about management practices for future plantations.

Eucalyptus trees can also lower the nutrient level and water quality of the soil surrounding them. Because they grow so quickly, they utilize nutrients and water in the soil more rapidly than other plants (Jiayu and Siming, FAO). The litter, and therefore nutrients, that falls from the Eucalyptus trees and returns to the soil through decomposition may be inhibitory to other plants if it has chemicals that deter growth (Zhang and Fu, 2010).

The issue then arises of the sustainability of Eucalyptus tree plantations. The trees serve a large industrial purpose, supplying materials for paper-making, fiber industries, and fuelwood (Jiayu and Siming, FAO). However, the rapid loss of biodiversity in these areas can detract from the economic benefits. This research focuses on soil quality differences between mixed and pure stand Eucalyptus plantations, with the goal of informing future management practices that will maximize both economic and ecological benefits. The research looks at pure stands (*Eucalyptus urophylla* x *E. grandis*) and mixed stands (*Eucalyptus* spp. with *Magnolia glauca* or *Magnolia odora*) in Guangxi Province in southern China.

## METHODS

### *Study Area*

This study was conducted in two forests in southern China. One forest, located south of Nanning near the village of Lianshan (approximately N22°35' latitude, E108°19' longitude), was intermixed with plantings of *Magnoliaceae glanca* Blume or *Tsoongiodendron odorum* Chun. The other forest, located near Liuzhou (approximately N24°29' latitude, E109°22' longitude), consisted of pure Eucalyptus hybrid plantations (*Eucalyptus urophylla* x *E. grandis*) (Figure 1).

This region is within the subtropical monsoon climate areas of China (Kang et al., 2006). The average yearly temperature in this region is 21.82 °C (71.3 °F). The summers are typically hot and humid with July having a 24-hour mean temperature of 28.4 °C (83.1 °F). In contrast, the winters are damp and mild. The January mean temperature is 12.9 °C (55.2 °F). The relative humidity is usually over 80% from February to August, which is the rainiest season. The mean annual rainfall is 1.31 meters (51.6 in). Snowfall and frost are both very rare. The topography is dominated by low mountains and rolling hills. The soil type is mainly red sandy soils (Zheng et al., 2008). Figure 1 provides a visual of the geographical location of the two study sites within the context of continental China.

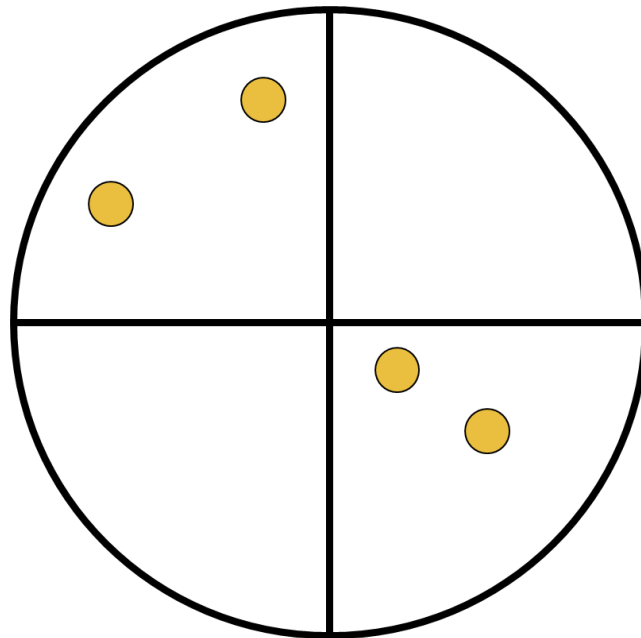


**Figure 1.** The study areas are located near the cities of Nanning and Liuzhou in Guangxi Province, P. R. China.

### *Data Collection*

Six circular 0.05 hectare plots were established in two different mixed Eucalyptus plantations near Nanning in May, 2015. Nine plots were established in three different pure Eucalyptus plantations near Liuzhou during previous years. After designation of the circular plots, they were subsequently divided into four quadrants. This allowed better measurements of all trees within the entire plot. Two out of the four quadrants were selected randomly for soil quality measurements. A 40-cm deep soil pit was dug in each of the two randomly selected quadrants. A Hanna Instruments soil conductivity meter was used to measure the temperature and electrical conductivity (EC) to the nearest 0.1 °C and 0.01 mS/cm, respectively. Soil pH and nutrient content

(Nitrogen, Phosphorous and Potassium) were measured with a soil analyzer probe. The moisture level of the soil was measured using an Extech® digital soil moisture meter to the nearest 0.1%. These parameters were measured at depths of 0, 20, and 40 cm. Additional information on tree growth and forest qualities (density, topography, etc.) was collected and can be found in the attached Appendix.



**Figure 2.** A schematic showing the experimental design. Soil pits were dug in two of the four quadrants. The circular plot and pit locations were each chosen randomly.

## RESULTS

Measurements of electrical conductivity, soil temperature, soil pH, and soil moisture were compared along a depth profile (0, 20, and 40 cm) in both mixed and pure stand plantations. None of the soil parameters showed a significant difference in values at the different depths ( $p = 0.05$ ) (Table 2). The average readings through the depth profile were used to compare the treatment types

(mixed versus pure stand) to each other. Among these averages, electrical conductivity and soil moisture readings showed no significant differences between mixed and pure stands, while temperature and pH were significantly different from each other (Table 1).

The average temperature in mixed stands, throughout the soil depth profile, was 26.24 °C, while the pure stand soil averaged 21.95 °C. The pH of the mixed stand plantation was lower than the pure stand plantation, with readings of 6.11 and 7.16, respectively. The soil moisture content was slightly over 17% for both types of plantations, and the electrical conductivity was 3.8 and 2.9 mS/cm for the mixed and pure stands, respectively.

**Table 1. The mean<sup>1</sup> soil attributes for pure Eucalyptus forests and Eucalyptus forest planted with other species (mixed).**

<b>Forest type</b>	<b>Electrical conductivity (mS/cm)</b>	<b>Temperature (°C)</b>	<b>Soil moisture (%)</b>	<b>pH</b>
Mixed stands	0.038 a	26.24 a	17.06 a	6.11 a
Pure stands	0.029 a	21.95 b	17.34 a	7.16 b

<sup>1</sup> Means with the same letters are not significantly different within each soil attribute, p=0.05, Duncan's multiple range test.



**Table 2.** The measured<sup>1</sup> soil attributes for pure and mixed Eucalyptus forests down a depth gradient from 0 to 40cm.

	Electrical conductivity (0.01 mS/cm)		Soil Temp (°C)		pH		Soil Moisture (%)					
	0cm	20cm	40cm	0cm	20cm	40cm	0cm	20cm	40cm			
Mixed stands	0.057 a	0.033 a	0.025 a	27.67 a	25.78 a	25.27 a	6.03 a	5.97 a	6.35 a	7.54 a	4.72 a	4.10 a
Pure stands	0.030 a	0.027 a	0.031 a	23.23 b	21.59 b	21.03 b	7.15 b	7.18 b	7.13 b	7.25 a	5.56 a	4.53 a

<sup>1</sup>Measurements with the same letters are not significantly different, p=0.05, Duncan's multiple range test.

## DISCUSSION

### *Parameter Variations*

Results show that the soil temperature and soil pH vary significantly between the mixed and pure stand plantations. The electrical conductivity and soil moisture were not statistically different. Mixed stands had a higher soil temperature, which can potentially be explained by the reduced canopy closure (Appendix A). Magnolia trees grow more slowly than Eucalyptus trees, which is a potential cause of the lower canopy cover in the mixed plantations. The sun's rays can more easily penetrate to the forest floor when the canopy is less full.

The mixed stands had a lower soil pH than the pure stands. There are several reasons the pH profile could be different between the two sites, including but not limited to: different soil types, varying microbial communities, differential leaf litter amounts, and/or root exudates. One factor that should be considered when attributing different pH measurements is that Magnolia trees are also known to produce allelopathic substances that reduce seed germination, root growth, and shoot growth of other plants (Abdelgaleil and Hashinaga, 2007). There is research into their potential as herbicides (Rathinasabapathi et al., 2005; Abdelgaleil, and Hashinaga, 2007).

### *Parameter Influence on Growth*

Higher temperatures (30°C) and pH 7 are generally better for Eucalyptus growth (Hawkins and Sweet, 1989; Department of Primary Industries, 2010.). However, pH levels down to approximately 5.5 are well tolerated by *Eucalyptus* spp. (Hawkins and Sweet, 1989). The soil pH measurements in both mixed and pure stands both fall within the range that Eucalyptus species can grow well. They can grow on nutrient deficient acid soil if there is sufficient soil depth and moisture (Schönau,sts 1984). A lower pH does not result in a significant decrease in growth, while

a lower temperature does (Stoneman and Dell, 1993). Therefore, when considering management practices specifically targeted at increasing Eucalyptus growth, the soil temperature should be of greater importance than the soil pH.

Eucalyptus trees are generally tolerant to salinity, which is analogous to electrical conductivity. Trees irrigated with saline water grew well past the levels of salinity measured in our study (Rodriguez de Souza, 2015). In response to high salt, Eucalyptus trees can reduce the number of leaves in order to lower transpiration levels (Rodriguez de Souza, 2015). No statistical difference was seen in the mixed and pure stand plantations in regards to electrical conductivity readings. Eucalyptus trees are a drought-tolerant species (Liu and Li, 2010). Their ability to control transpiration levels would be an additional adaptation to help with low water content in the soil. No statistical difference was seen between the two plantation types in regards to soil moisture content.

#### *Drawbacks of our study*

There are various limitations to this study that should be considered when analyzing available data on this subject. The mixed and pure stand study locations were not adjacent to each other, which could lead to variations based on climate and biogeography. They were also conducted in different years. This could lend insight to a temporal investigation of the forests, but leads to more variation in the attempt at a direct comparison of the different sites. The short duration of the research trips, combined with the strenuous work conditions, meant that the sample size for mixed stands was low. More statistical power would arise if the sample sizes were higher.

Additionally, measurements were not made on other variables that could contribute to the variations in soil parameters. This includes soil type (silt, clay, and sand content), microbial

community composition, and/or direct measurement of allelopathic exudates from different parts of the tree. It is important to consider how these other variables may influence both the economic and ecological impacts of mixed and pure stand Eucalyptus plantations moving forward. Additional research on these factors would complement this study.

### *Suggestions*

Based on the data gathered in this study, the author suggests mixed stand Eucalyptus plantations with trees that are unaffected by Eucalyptus allelopathy. This may be a native or non-native tree, such as *Albizia lebbbeck* (Chu et al., 2014). Native trees would better support native fauna and understory flora, but may be more heavily impacted by the allelopathic effects of Eucalyptus (Chu et al., 2014). Mixed stands will also provide two types of timber than can be used for different industrial processes, and therefore widen the market for the plantations. Mixed stands had a lower pH, but a higher soil temperature. Because Eucalyptus trees are still able to grow well at a lower pH, but can be inhibited by low soil temperatures, mixed stands that create these conditions are the best options to support efficient Eucalyptus growth.

It is important to note that although this study gives insight into potential abiotic factors that may vary between mixed and pure stand Eucalyptus plantations, it does not provide the full story. Instead, the research provided here-in should act as a stepping stone for further research into other potential factors influencing Eucalyptus growth. Soil pH and electrical conductivity can be influenced by a multitude of other factors, including the age and type of soil, microbial processes, anthropogenic run-off, and understory flora. Further research should be conducted to more accurately answer the question of whether mixed or pure stand plantations have the higher combined economic and ecological benefits.

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## APPENDIX AND SUPPLEMENTARY INFORMATION

**Appendix A.** The mean attributes of two-year-old pure and mixed<sup>a</sup> Eucalyptus (*Eucalyptus urophylla* x *E. grandis*) forests used in this study located near Nanning and Liuzhou, Guangxi, P.R. China.

Stand type	N <sup>b</sup>	Trees per hectare	Basal area (m <sup>2</sup> /ha)	Dbh (cm)	Total height (m)	Aspect (azimuth)	Slope (%)	Canopy closure (%)
Pure	9	1273	8.3	8.9	11.7	199.9	18.8	91.6
Mixed	6	1027	6.6	6.7	9.2	206.7	55.8	84.0

<sup>a</sup> Eucalyptus was intermixed with plantings of *Magnoliaceae glanca* Blume, and *Tsoongiodendron odorum* Chun.

<sup>b</sup> N = the number of sample plots

The diameter-at-breast-height (dbh) was recorded for each tree in the circular plots. The slope percent was measured with a clinometer from the plot center, while the aspect was measured with a compass. The canopy closure was measured using a spherical densiometer. Densiometer readings were taken from the plot center looking north, east, south, and west, and the four readings were averaged for a final percent canopy closure.

Two trees from each quadrant (for a total of 8 per plot) were randomly selected for more detailed measurement. The crown diameter was measured and defined as the quadratic mean of the longest crown diameter and the diameter normal to that axis. Total tree height and height to live crown was measured to the nearest 1.0 meter with a clinometer.



**Appendix B.** Tree attribute prediction equations<sup>a</sup> for Eucalyptus (*Eucalyptus urophylla* x *E. grandis*) trees located in southern Guangxi province, P. R. China.

Tree attribute	Species	N	Equation coefficients			
			a	b	RMSE	R <sup>2</sup>
Total height	Eucalyptus	60	1.9227	2.3320	2.502	0.9858
Height-to-live crown	Eucalyptus	60	1.2022	2.4266	3.5416	0.9486
Crown diameter	Eucalyptus	60	1.0260	1.4077	0.7626	0.9696

<sup>a</sup> Model form:  $Y = a(\ln D)^b$ , where Y = total height, height to live crown, or crown diameter (m); D = dbh (cm.); and ln = natural logarithm.

Twelve Eucalyptus trees from 2-5-year-old Eucalyptus stands were felled to measure the actual total height and height-to-live crown of the tree to minimize bias introduced by the clinometer. The manually determined lengths were used to calculate standard error of the clinometer measurements. The resulting margins of error were found to be  $\pm 0.90$  meters and  $\pm 1.68$  meters ( $p = 0.05$ ) for total height and height-to-live-crown, respectively.

Data from the randomly selected trees was used to create equations to estimate the total height, height-to-live-crown, and crown diameter of the remaining trees in each plot based on the measured dbh. The model:

$$Y = a(\ln D)^b \quad (1)$$

where Y = either total height, height-to-live crown, or crown diameter (m), D = dbh (cm), and ln = natural logarithm, was used to develop prediction equations. The coefficients were estimated with Non-Linear Procedure, Gauss-Newton method in SAS software, version 9.2 (SAS Institute Inc., 2008) and are presented in Appendix B. The quadratic mean of the major and minor axis

measurements was used to define the crown diameter. The equations were applied to all trees in the original circular plots for which height and crown diameter were not originally recorded.