# COLOUR VARIATION IN TEAK (*TECTONA GRANDIS*) WOOD FROM PLANTATIONS ACROSS THE ECOLOGICAL ZONES OF GHANA

**[1]N. S. A. Derkyi, [2]H. Bailleres, [2]G. Chaix, [2]M. F. Thevenon, [1]A. A. Oteng-Amoako and [1]S. Adu-Bredu**

*[1]Forestry Research Institute of Ghana, Council for Scientific and Industrial Research*
*KNUST P. O. Box 63, Kumasi, Ghana*
*[2]CIRAD-FORET, Montpellier, France*

## ABSTRACT

*The colour of teak wood from plantations in Ghana was characterized by the International Commission on Illumination (CIE) L* a* b* colour measurement system in order to study the variations of wood colour parameters (lightness-darkness, redness-greenness and yellowness-blueness), among the different ecological zones. Teak trees totaling 46 were felled from 8 different plantation stands in four different ecological zones of Ghana (moist semi-deciduous forest, MSDF; dry semi-deciduous forest, DSDF; transition savanna forest; and savanna forest). Colour measurements were made on strips obtained from logs cut from the felled trees. Chemical analyses were performed on soil samples obtained from the rooting zones of the teak trees. Both environmental and tree age effects on colour were observed. However, environmental factors had a stronger effect on the colour of teak heartwood than the stand age. Although there were no significant differences between teak wood colour in moist semi-deciduous forest and transition savanna forest on one hand, and dry semi-deciduous forest and savanna forest on the other hand, in general, environment seemed to be an important factor, with teak wood colour being relatively darker in wetter areas than drier ones. Wood colour parameters showed differing relationships with soil chemical properties ranging from no relation through weak to moderate relations. For instance, soil pH decreased moderately with decreasing L* values (increasing darkness), indicating some evidence that teak wood colour may be predicted from soil pH. However, there was very little evidence that teak wood colour could be predicted from soil exchangeable cations ($Ca^{2+}$, $Mg^{2+}$, $Na^{+}$ and $K^{+}$). The range of observed site quality was rather limited. Nevertheless, richer plantation sites showed a tendency toward darker and less red heartwood.*

***Keywords*: *Tectona grandis,* CIE-L*a*b* colour system, soil chemical properties, heartwood**

## INTRODUCTION

Teak (*Tectona grandis* Linn. f.) is a multi-purpose wood with a wide range of end uses, from general carpentry and joinery to furniture and cabinet making, and from veneers to boat construction (Bailleres and Durand, 2000). It has an appealing golden colour with typical figures as well as its very interesting technological properties: medium specific gravity, high strength without heaviness, dimensional stability and non-corrosion. Besides, this wood is easy to process, has good seasoning behavior and offers very good resistance to weather, termites and decay (Bailleres and Durand, 2000). To satisfy the growing demand teak is increasingly supplied to the international market from plantations established in various countries including Ghana. Furthermore, the development of commercial teak plantations worldwide is encouraged by its high market price.

Colour is a crucial factor in hardwood appearance, and uniformity of colour has a direct impact on the final value of a product (Lu *et al*., 1997; Boardman *et al*., 1992; Janin, 1987). The perception of colour by a human observer is a psychophysical phenomenon that connot be measured with exactitude (Stokke *et al*., 1995). The eyes and the brain tend to automatically adjust to interpret colours correctly based on a given environment (Brunner *et al.*, 1990). Colorimetry provides a rigorous scientific definition of the perception of colour, and makes it possible to translate colour into numeric values. More recently Ledig and Seyfarth (2001) have used a spectrophotometer to measure surface colour in European beech and have successfully characterised the wood colour using the CIELab system.

An object absorbs a part of light from the light source and reflects the remaining light. The light reflected from an object is a mixture of light at various wavelengths. The light of a specific wavelength absorbed by the object is caused by chromophores - the side chains of the pigment molecules (Hon and Minemura 2001).

The colour characteristics of wood depend on the chemical components that interact with light. Typical molecules having chromophore bindings in wood are lignin (below the wavelength of 500 nm), and phenolic extractives such as tannins, flavonoids, stilbenes and quinines (above the wavelength of 500 nm), (Hon and Minemura 2001). Cellulose and hemicelluloses do not absorb light in the visible region. Due to differences in composition of wood components, the colour of fresh, untreated wood varies between different species, between different trees of the same species and even within a tree. Within a species wood colour can vary due to the genetic factors (Rink and Phelps 1989, Mosedale et al. 1996) and environmental conditions (Phelps *et al.* 1982, Wilkins and Stamp 1990).

Due to its high timber qualities, market demand, ease of domestication and cultivation, teak plantations have been widely established throughout the tropics from the 1850s (FAO, 1957). However, no studies exist concerning the colour of teak wood from Ghana and its relation to environmental factors and age. Therefore the objective of this study was to evaluate the variation of teak heartwood colour across the different ecological zones in Ghana and establish relationships between the wood colour and tree age and soil chemical properties.

## MATERIALS AND METHODS

## MATERIALS

Teak trees totaling 46 were felled from eight different plantation stands in four different ecological zones (moist semi-deciduous forest, MSDF; dry semi-deciduous forest, DSDF; transition savanna forest; and savanna forest) of Ghana (Table 1). Three logs, 1 m, 1.3 m and 3 m in length, were crosscut along the length of each tree. The first log (1 m) was cut beginning from the butt of the tree. Approximately 300 g of soil from the rooting zone of each collection site (tree locations) were dug and placed in plastic bags. All soil samples were collected at 0–25 cm depth using a plastic hand trowel.

## TEAK SAMPLE PREPARATION

Each log was sawn into two radial boards through the pith. The boards (~400 mm long) were planed to 25 mm thickness. To gradually dry the samples, 30 mm strips of the heartwood were cut from pith to bark and were conditioned in a humidity- and temperature-controlled oven to achieve 12% moisture content. The strips were subsequently planed and cross-cut to give samples of dimension 25 x 15 x 50 mm as well as 25x15x100 in the radial (R), tangential (T) and longitudinal (L) directions respectively. Colour measurement was performed immediately after planing in order to avoid any aging of the surface.

## COLOUR MEASUREMENT

Colour measurements were performed on the longitudinal-radial and longitudinal-tangential faces of the clear wood samples at 12 % moisture content. The measurements were recorded using a portable spectrocolorimeter Microflash Datacolor at ambient temperature and humidity. A sensor head diameter of 6 mm, illuminant D65 (representing average daylight), and 10° standard observer were the conditions used to measure the wood colour (Hunter and Harold 1987). On each of the 100 mm long test samples 8 measurement points were recorded whilst 4 measurement points were recorded on the 50 mm long test samples. The CIELAB colour parameters L*, a* and b* which respectively denote lightness/darkness, redness/greenness and yellowness/blueness were obtained directly from the measurements. The colour measurements in each test sample were made avoiding knots and other defects and averaged to one recording.

## SOIL CHEMICAL ANALYSIS

Total nitrogen was determined by the Kjeldhal method while organic matter and organic carbon were determined according to Walkey and Black (1934). Concentrations of exchangeable cations were determined by atomic absorption spectroscopy and soil pH was determined with a pH meter using both water and calcium chloride solutions.

## DATA ANALYSIS

Using the SPSS 11.0 software package, Pearson and partial correlations, univariate analysis of variance (ANOVA) and post-hoc pairwise comparisons with the Duncan's multiple range test (DMRT) (at $p = 0.05$) were performed on colour parameters, growing site, soil properties and age of tree.

## RESULTS AND DISCUSSIONS

The lightness index (L*) ranged from 42.86 to 68.31, redness index (a*) from 6.00 to 16.94, and yellowness index (b*) from 16.84 to 33.32. A larger L*, a* or b* means a lighter, redder and more yellow colour, respectively (Janin, 1994; Wuszecki and Stiles, 1982). Duncan's Multiple Range Test revealed that for each of the colour parameters (L*, a* and b*), some of the means were significantly different whilst others were not (Table 2). In general, teak wood tends to be slightly darker in wetter areas (MSDF, L* = 53.36) than in drier areas (Savana, L* = 59.12) as observed in this study. These differences can be clearly seen in the graph depicting the mean colour parameters of each of the four ecological zones (Figure 1). This is contrary to the findings by Thulasidas *et al.*, (2006) who observed that no significant difference existed among the teak samples collected from wet and dry localities with regard to lightness (L*) and redness (a*) ($p < 0.05$). The differences in the two observations may be attributable to the geographical locations and soil properties and conditions of the two research work.

The results of this work are however similar to that obtained by Tadashi *et al.*, (2003) who also observed that teak wood colour is darker in wetter areas than drier ones. As the colour parameters changed across the ecological zones, so did the chemical properties of the soil. Figures 1 and 2 illustrate these variations of colour parameters and soil chemical properties across the ecological zones, and Table 3 gives the correlations between the parameters. From Figure 3, trees of similar age group but from different ecological zones differ in colour parameters. For instance, trees aged 33 years in the dry semi-deciduous forest (Abofour) and transition savanna forest (Kintampo, C83) have different colour parameters. Thus differences in colour parameters are more pronounced due to location of stand than stand age.

Table 1: Mean chemical properties of soil and plantation age

| Ecological Zone | Plantation Stand | Age (yrs) | Org C % | Total N % | Org M % | Ca (ppm) | Mg (ppm) | K (ppm) | Na (ppm) | pH |
|---|---|---|---|---|---|---|---|---|---|---|
| MSD | Obuasi | 26 | 2.09 | 0.18 | 3.60 | 336 | 112 | 49 | 47 | 4.96 |
| DSD | Abofour | 33 | 1.26 | 0.11 | 2.17 | 976 | 128 | 92 | 39 | 7.00 |
| | Dormaa | 25 | 2.82 | 0.26 | 4.86 | 1536 | 1544 | 166 | 37 | 6.52 |
| | Somanya | 35 | 1.27 | 0.11 | 2.19 | 376 | 120 | 50 | 35 | 4.96 |
| Transition | Kintampo (C83)[ç] | 33 | 0.57 | 0.05 | 0.98 | 384 | 32 | 48 | 58 | 6.41 |
| Savana | Kintampo (C84)[çç] | 44 | 0.59 | 0.05 | 1.02 | 352 | 48 | 139 | 61 | 6.55 |
| Savana | Nuale | 32 | 0.68 | 0.06 | 0.17 | 880 | 160 | 67 | 69 | 6.49 |
| | Wa | 50 | 0.28 | 0.02 | 0.48 | 192 | 32 | 31 | 55 | 5.66 |

ç: Compartment 83; çç: Compartment 84; Org C: organic carbon; Org M: organic matter

Table 2: Differences between ecological zones based on mean Teak colour parameters

| Ecological Zone | L* ± SD | a* ± SD | b* ± SD |
|---|---|---|---|
| MSDF | 53.36 ± 5.37[a] | 12.04 ± 1.58[a] | 24.88 ± 2.85[a] |
| DSDF | 57.61 ± 5.00[b] | 11.32 ± 2.86[a] | 23.30 ± 2.84[b] |
| Transition Savana | 55.38 ± 5.48[a] | 10.23 ± 1.91[b] | 21.40 ± 2.91[c] |
| Savana | 59.12 ± 4.30[b] | 10.29 ± 2.15[b] | 25.16 ± 3.40[a] |

Values bearing the same letter in a column are not significantly different at the 5% level by DMRT

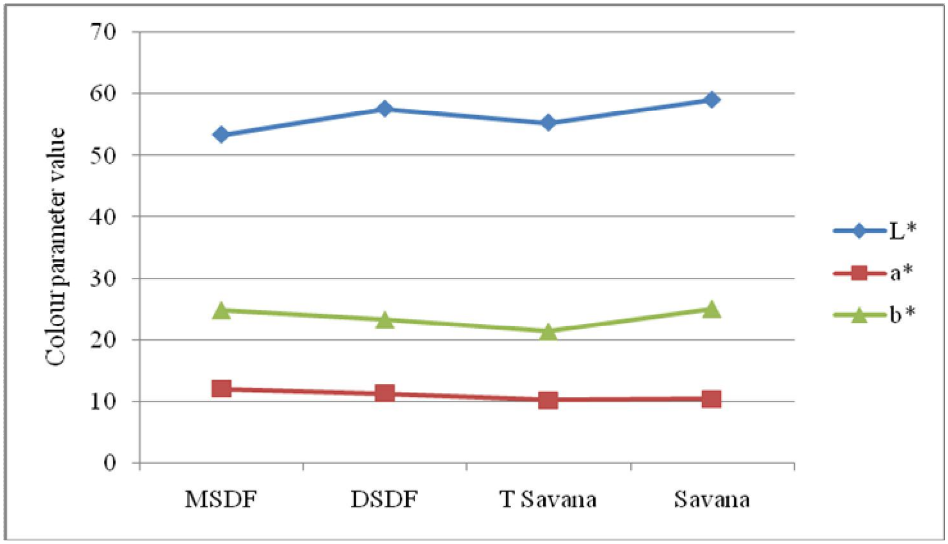


Figure 1: Variation of colour parameters of teak wood across the ecological zones of Ghana

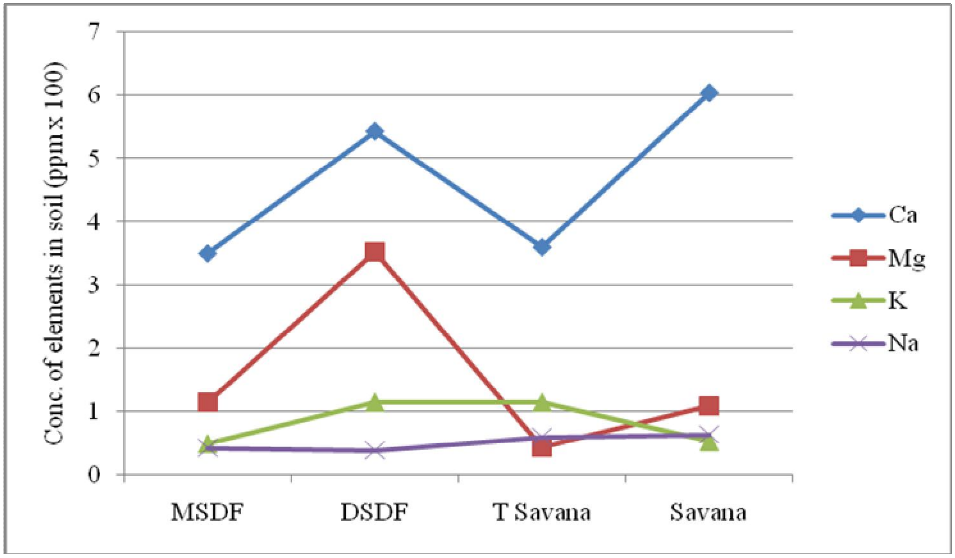


Figure 2: Variation of soil exchangeable cations across the ecological zones of Ghana

Table 3: Relationship between colour parameters, soil chemical properties and tree age

Pearson Correlations

| Interactions | Coefficient | Interactions | Coefficient | Interactions | Coefficient |
|---|---|---|---|---|---|
| L* - pH | 0.33 (<0.001)§§ | a* - pH | 0.23 (<0.001)§§ | b* - pH | 0.20 (0.01)§§ |
| L* - Ca | 0.23 (<0.001)§§ | a* - Ca | nsc | b* - Ca | nsc |
| L* - Mg | nsc | a* - Mg | nsc | b* - Mg | nsc |
| L* - K | nsc | a* - K | nsc | b* - K | -0.26 (<0.001)§§ |
| L* - Na | 0.14 (0.02)§ | a* - Na | -0.27 (<0.001)§§ | b* - Na | nsc |
| L* - Total N | -0.20 (<0.001)§§ | a*- Total N | 0.23 (<0.001)§§ | b*- Total N | nsc |
| L* - Organic C | -0.21 (<0.001)§§ | a*- Organic C | 0.24 (<0.001)§§ | b*- Organic C | nsc |
| L* - Organic M | -0.23 (<0.001)§§ | a*- Organic M | 0.26 (<0.001)§§ | b*- Organic M | nsc |
| L* - Age of tree | 0.13 (0.03)§ | a* - Age of tree | -0.20 (0.01)§§ | b* - Age of tree | -0.24 (<0.001)§§ |
| L* - a* | -0.57 (<0.001)§§ | L* - b* | nsc | a* - b* | 0.55 (<0.001)§§ |

Number in bracket indicates *p*-value

nsc: No significant correlation

§. Correlation is significant at the 0.05 level (2-tailed)

§§. Correlation is significant at the 0.01 level (2-tailed)

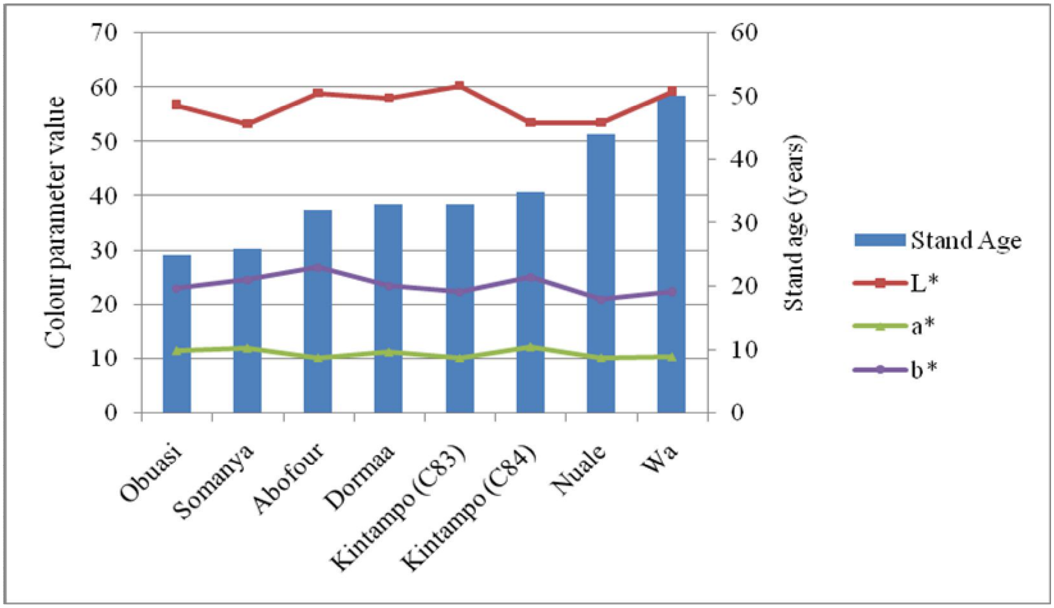


Figure 3: Relationship between age of teak stand and colour parameters

In Pearson correlation while there are no hard and fast rules about the degree of relationship, the general rule of thumb is that $r$ values greater than 0.50 indicate a strong correlation, $r$ values around 0.30 indicate a moderate correlation and $r$ values less than 0.20 indicate a weak correlation. Therefore, from Table 3 it can be deduced that there is a weak positive relationship between lightness of teak colour and sodium content of the soil on which the teak is grown ($r$ = 0.14, $p$ = 0.02), and a moderate positive relationship between lightness of teak colour and soil calcium content and soil pH ($r$ = 0.23, $p$ <0.001 and $r$ = 0.33, $p$ < 0.001 respectively). Thus, a higher degree of lightness in teak colour is related to a higher degree of sodium content, calcium content and pH of soil, but the latter two give a much stronger relationship. However, there is no relationship between lightness of teak colour and potassium and magnesium contents of the soil.

Similarly, there is moderate positive relationship between redness (a*) of teak and soil pH, and a negative moderate relationship between teak redness and sodium content of soil. There is no relationship between teak redness and calcium, magnesium and potassium content of soil. Again, there is moderate positive relationship between yellowness (b*) of teak and soil pH, and a negative moderate relationship between teak yellowness and potassium content of soil. There is no relationship between teak yellowness and calcium, magnesium and sodium content of soil. Thus, while soil pH is related to all the colour parameters, magnesium content of soil is not related to any of them. Furthermore, while there is moderate negative relationship between teak lightness index L* and soil total nitrogen, organic carbon and organic matter, there is moderate positive relationship between teak redness index a* and soil total nitrogen, organic carbon and organic matter but no relationship between teak yellowness index b* and these three soil properties (total nitrogen, organic carbon and organic matter).

There is a weak positive relationship between the age of plantation teak and lightness of teak colour ($r$ = 0.13, $p$ = 0.03), and a moderate negative relationship between the age of plantation teak and redness and yellowness of teak colour ($r$ = 0.20, $p$ = 0.01 and $r$ = 0.24, $p$ = 0.00 respectively). Thus, increasing teak age is related to a higher degree of lightness in colour, redness and yellowness of teak wood colour, but the latter two give a much stronger relationship with age. There exists very strong relationships between colour components of teak wood, mainly for the components L*/a* and a*/b*. Strong relationships between colour components of wood have also been found for other hardwoods like beech wood (Liu et al., 2005).

Wood colour may vary greatly within a given species due to different environmental conditions and silvicultural treatment (Nelson et al. 1969; Sullivan 1967; Wilkins and Stamp 1990). Mosedale *et al.* (1996) found that the greatest differences in most colour parameters of European oak occurred between sites rather than between species. Our results indicate that soil properties are associated with wood colour of teak independent from effects of tree age as observed by Nelson *et al.* (1969) for walnut wood. Richer sites (indicated by higher N, Na, organic carbon and organic matter) showed a tendency toward darker and less red heartwood (Tables 1 and 3). This is probably due to availability of more soil minerals to the wood that eventually interact with its (wood) chromophores in such a way as to absorb more light, thus reflecting less light and hence the wood appearing darker. From a core sample, it is possible to measure colour at different positions between the pith and bark and on different planes in order to obtain a colour distribution (Bailleres and Durand, 2000). Advantage could be taken of this fact in tree improvement programmes for sustainable teak management for the desired wood colour.

## CONCLUSIONS

In our study, it was observed that ecological variation is important to explain the differences in colour parameters displayed by teak even within the same age group. This suggests that environmental factors had a stronger effect on the colour of teak heartwood than the age of stand.

Teak wood colour tends to be darker in wetter areas than drier ones. From a core sample, it is possible to measure colour at different positions between the pith and bark and on different planes in order to obtain a colour distribution. Advantage could be taken of this fact in tree improvement programmes for sustainable teak management for the desired wood colour. Wood colour parameters show clear relationships with soil chemical properties ranging from no relation through weak to moderate relations. For instance, soil pH decreases with decreasing L* values (increasing darkness) moderately, indicating some evidence that teak wood colour can be predicted from soil pH. However, there is very little evidence that teak wood colour can be predicted from soil exchangeable cations ($Ca^{2+}$, $Mg^{2+}$, $Na^{+}$ and $K^{+}$). Richer plantation sites (indicated by higher N, Na, organic carbon and organic matter) showed a tendency toward darker and less red heartwood.

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