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SPECIFIC GRAVITY, FIBER LENGTH AND CHEMICAL COMPONENTS OF *CONOCARPUS ERECTUS* AS AFFECTED BY TREE SPACING

RAMADAN A. NASSER
Department of Forestry and Wood Technology, Faculty of Agriculture, Al-Shatby, Alexandria University

ABSTRACT

Conocarpus erectus L. is a fast growing tree, drought resistant and it is widely planted throughout Saudi Arabia around parking lots and along the streets. It constitutes a renewable resource that could be used as a source of raw materials required for several uses. However, no data were available about its wood quality. This study was established to investigate the effect of plant spacing on some wood quality parameters of buttonwood i.e., specific gravity, fiber length and chemical components. In May 2003 the seedlings were planted at three different spacing of 0.7, 1.4 and 2.1 meter either between rows or between seedlings within row. After 3 years, trees were harvested and the chemical analysis of wood was determined. The results of the present study indicate that the variation of extractives, hemicellulose, lignin and ash contents among the plantation density levels were highly significant. Variation of cellulose content was not significant. The effect of spacing levels on specific gravity and fiber length was small, but significant. By increasing spacing from 0.7 to 2.1 m, specific gravity of *Conocarpus* was increased (0.63 to 0.66, respectively). Among the three spacing levels, no trend was obtained for fiber length. In general, this study recommended that wide space resulted in higher lignin content and the utilization of wood is recommended for furniture industry, however, narrow space yielded greater hemicellulose and ash contents and the produced wood is preferred for ethanol production as a biofuel.

Depending on this study, those results will be helpful in the development of plantation management programs.

Key words: *Conocarpus erectus, spacing, narrow space, wide space,specific gravity, fiber length, cellulose, hemicelluloses, lignin, ash.*

INTRODUCTION

As the world demand getting over the wood products, global solid wood material source is being insufficient. So, attempting to fill the gap between wood production and its consumption was done by using short rotation of tree plantations. In the meantime, the silvicultural treatments may play role in the characteristics of produced timbre. It is well known that wood quality is affected by silviculture, which includes factors such as stand density control (spacing) and genetics (Hapla *et al.* 2000, and Koga and Zhang 2002). Roth *et al.* (2007) concluded that tree spacing is a critical management decision, because of its large effect on overall yield per unit are, stem size and tree form. Larson (1969) states "stand density has a tremendous influence on the quality of the wood formed". On the other hand, to meet increasing wood demand for different uses forest service has been trying to adapt fast growing trees species. Research efforts were carried out in the Department of Plant Production, King Saud University, Saudi Arabia by introducing fast growing tree species. These studies have been directed towards the evaluation of biomass production from newly introduced species when they planted at different spacing on *Leucanea leucocephala* and *Acacia salicina* (Aref *et al*, 1999, and El-Juhany, 2003), on *Zizyphus spina-christis* (Aref *et al*, 2004) and on *Conocarpus erectus* (Hegazy *et al*, 2008). However, no studies were carried out herein to evaluate the effect of spacing between trees on the wood quality of these species.

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Conocarpus erectus (buttonwood) is native to the silt shores of coasts and islands of Florida. It is widely distributed on coasts of tropical America and on coasts of west Africa and in Melanesia and Polynesia. Nowadays, it occurs intensively in Saudi Arabia even on the inland areas around Saudi cities for hedges, roadsides, and entertainment (Aref *et al*, 1999). The mature tree may reach heights of 15 meters and 50 cm in diameter. Buttonwood tree is reported to tolerate diseases, insects, salt, and water logging (Little, 1983) and their wood has high calorific value as fuel and it is most widely used for high-grade charcoal (Morton, 1981). Its wood makes a good slow-burning fuel and charcoal (Little, 1983). Alden (1995) reports that the wood of Buttonwood can be used in durable constructions, in addition to fuel and charcoal.

Wood cell walls are chemically composed of three groups of structural substances i.e., cellulose, hemicellulose, and lignin. Cellulose of wood is the most important single chemical component in the woody cell wall in terms of its volume and its effect on the characteristics of wood (Panshin and DeZeeuw, 1980). It acts as a framework substance and contributes its high tensile strength to the complex of wood structure (Kollmann and Côté, 1968). On the other hand, cellulose constitutes slightly less than one-half the weight of both hardwoods and softwoods. The proportion of hemicellulose varies widely among wood species and it ranged in hardwood species between 15 to 35% based on dry weight of the wall substance. The presence of hemicelluloses in the cell wall has a tremendous influence on certain physical properties of wood especially for pulp and paper making. Lignin is a complex and high molecular weight polymer built upon phenylpropane units (Haygreen and Bowyer, 1989). The most important physical property of lignin is its rigidity and the increased stiffness it imparts to cell walls in which it is located (Panshin and DeZeeuw, 1980). Ash is the residue that remains after complete combustion of the wood material at 575±25 °C. According to Karchesy and Koch (1979), it is composed primarily of inorganic substances such as calcium oxide (CaO), silica (SiO_2) and small percentages of alumina (Al_2O3), iron oxide (Fe_2O_3) and magnesium oxide (MgO).

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In addition to its major chemical components, wood also contains small (but in some cases quite appreciable) quantities of extraneous components (extractives). These extractives exert a diversified influence on the characteristics of wood, wood products, and tissues. They are responsible for colour and durability of wood (Hillis, 1972). Other properties that have been related to extractives include shrinkage (Choong, 1969), specific gravity and compressive strength (El-Osta *et al*, 1980) and bending strength (Arganbright, 1971). The presence of extractives results in corrosion metals in contact with wood, inhibition of cement setting, glue, and finishes (Hon and Nobuo, 2001).

Specific gravity of wood is the measure of the relative amount of solid wall material and is the best index that exists for predicting the strength properties of wood (Panshin and DeZeeuw, 1980). In the meantime, specific gravity of wood is the most important technological properties for wood industry, which profoundly determine and affect the wood quality (Harvey and Tsuneo, 1974 and Haygreen and Bowyer, 1989). Specific gravity of wood is usually used as an indicator for the mechanical properties of wood (El-Osta *et al*, 1980) and the suitability of wood for wood industry (Mohamed, 2004) and charcoal (Hindi, 2001). Fiber length is a wood-quality parameter of important to pulp and paper making (Horn, 1978). Wood fiber is the basic unit of wood especially for fast-growing trees such as *Conocarpus*. Studying the morphological characteristics of fibers should assist in understanding and interpreting the behavior of wood products. It is well known that long fibers are preferred in production of high strength paper (Horn, 1978 and Francis, *et al.*, 2006). The average fiber length at a breast height could give a good estimation for the total tree fiber length (Abo-Hassan and El-Osta, 1982).

It can be concluded from the above that specific gravity, fiber length and chemical components of wood are the most important technological properties for wood industry, which profoundly determine and affect the wood quality. Thus, the wood species with high fiber length and cellulose content with low lignin content are usually preferred for pulp and paper making, while the species rich in extractive materials could have a higher potential for production of certain chemicals such as

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tannin, resin and rubber (Panshin and DeZeeuw, 1980). Therefore, before suggesting proper utilization of wood produced from woody trees, it is essential to evaluate the basic technological properties of its wood.

There is no study exists on the wood properties of *Conocarpus erectus* trees that grown in Saudi Arabia. So the objective of the present investigation was to evaluate the effect of tree spacing among *Conocarpus erectus* on the certain wood parameters quality including specific gravity, fiber length, and the wood of chemical components (extractives, cellulose, hemicellulose, lignin and ash).

MATERIAL AND METHODS

Three-years old *Conocarpus erectus* trees were used for the current study, which were planted in May 2003 at the University Experiments Station near Dirab, Riyadh, Saudi Arabia (N.24° 24′ 33″, E.46° 39′ 40″). In the field, the experimental design was complete randomized block design (RCBD) with three blocks. Each block had three experimental plots (three different spacing). The total area of each plot was 49 m^2. The three spacing levels were 0.7 x 0.7 m (high-dense stand 20400 trees ha^{-1}), 1.4 x 1.4 m (dense stand 5100 trees ha^{-1}) and 2.1 x 2.1 m (low-dense stand 2250 trees ha^{-1}). Soil is sandy loam with an average of 61, 23, and 15% of sand, silt and clay, respectively (for more details, see Hegazy *et al*, 2008). Five trees were randomly selected from each plot with total of 45 trees. To avoid the edge effect, the trees on borders were discarded. Trees were felled in May 2006 and one bolt (30-cm in length) was cut from each tree at breast height. For each tree used in the current work, tree growth parameters (total height, diameter at 10 cm above soil surface, and the number of branches), total dry biomass production, and biomass allocation were recorded for each tree (Hegazy *et al*, 2008).

Specific gravity determination:

For the specimens of specific gravity a disc was cut from each tree at breast height, thereafter, small specimens were cut from each disk with dimensions of 2 by 2 by 2 cm^3. Specific gravity was then calculated using the green volume by displacement in water and oven-dry weight.

Fiber length determination:

Samples of fiber length measurements were cut from the area of breast height. Each specimen was prepared and measured according to Franklin (1945). Small segments were randomly taken from the disk then was divided to many chips like match sticks or smaller. For fiber maceration chips were treated in a mixture of glacial acetic acid and 30% hydrogen peroxide (1:1 by volume) in water bath at 60 °C for approximately two days. Thereafter, the material was washed by distilled water and reduced to fibers by mild shaking. The macerated fibers were stained with 2% safranin then thirty fibers were measured to the nearest 0.01 mm using a microscope connecting to TV screen to expose the image.

Extractives content determination

The extractive content of wood was determined according to the ASTM, D1105-84 (1989). Samples of air-dry wood were chipped and ground to pass through 40-mesh screen and retained on a 60-mesh screen. Air-dried wood meal was extracted in a Soxhlet apparatus with ethanol-benzene mixture (in the ratio of 1:2 by volume, respectively) for four hours, followed by extraction with 95% ethanol for four hours, and finally extracted with hot distilled water for four hours with chancing water every one hour. The percentage of extractives was calculated based on the oven-dry weight of wood samples.

Cellulose content determination

Cellulose content was determined by the treatment of extractive-free wood meal with nitric acid and sodium hydroxide: one gram of extractive-free wood meal was treated with 20 ml of a solution of nitric acid 3% in flask and was boiled for 30 min. The solution was filtered in a crucible. The residue was treated with 25 ml of a solution of sodium hydroxide 3% and was boiled for 30 min. The residue was filtered, washed with warm water to neutral filtrate, dried and weighed. The cellulose content was calculated as percentage of residues based on oven dry wood meal weight (Nikitin, 1960).

Hemicelluloses content determination

Hemicellulose content of buttonwood samples was determined by the treatment of extractive-free wood meal (about 1.5 g) with 100 ml sulfuric acid (2%) and boiled for 1 hour under a reflex condenser and filtrated in a crucible. After that the residue was washed with 500 ml of hot distilled water to free of acid, and contents were dried in an oven at 105± 2 °C, cooled in a desiccator and weighed (**Rozmarin and Simionescu**, 1973). Then, the hemicellulose content was calculated based on the oven-dry weight of the spacemen.

Ash content determination

Ash content of wood was determined according to the **Chemical Analysis and Testing Task Laboratory Analytical Procedure** "NREL" (1994). Approximately one gram of oven-dry sample was placed into the crucible. The sample in an uncovered crucible was heated gradually, then ignited at 575±25 °C in muffle furnace for a minimum of three hours, or until all the carbon is eliminated. Ash content was calculated as a percentage of residues based on the oven-dry wood meal weight.

Statistical analysis

The analysis of variance was carried out according to randomize complete block design (RCBD) and the least significant difference at 95% level of probability ($L.S.D_{0.05}$) was used to detect the differences among the means of specific gravity, fiber length and the wood of chemical components (extractives, cellulose, hemicellulose, lignin and ash) according to Neter *et al.*, 1990.

RESULTS AND DISCUSSIONS

1. Effect of tree spacing on wood specific gravity

Analysis of variance showed that the differences among plantation densities (spacing) were small, but significant for specific gravity. It can be seen from Table (1) that the mean values of specific gravity significantly increased (from 0.634 to 0.658) with increasing in tree spacing from 0.70 to 2.10 m. Although there are significant differences between the three levels of plantation densities used in the current study in specific gravity, it can be said that the spacing at which trees were planted did not have noticeable effects on specific gravity. Maximum percentage increase in specific gravity was obtained by decreasing plantation densities from 20400 trees ha^{-1} to 2250 trees ha^{-1} (3.78%) as shown in Table (1).

Similar results were obtained by DeBell *et al.* (2001) for *Eucalyptus saligna* who's concluded that wider spacing (4 x 4 m vs. 2 x 2 m) increased mean diameter by 34% without decreasing, and may have increased, wood density, which ranged from 400 $kg.m^{-3}$ in the densest spacing (2 x 2 m) to 424 $kg.m^{-3}$ in the widest spacing (4 x 4 m). However, they suggest a slight positive trend in wood density with increased spacing. Most researchers reported that the effect of plantation densities (tree spacing) on the specific gravity of wood for many wood species were not significant (Jaakkola *et al*, 2006, and Kayad and Khamis, 2007). Contradictory, Kang *et al* (2004) reported that initial stand spacing has significant effects on wood density, fiber and pulp properties in jack pine. Analysis of the effect of spacing showed significant differences in stiffness, strength, and specific gravity of unthinned loblolly pine among spacing at 8 feet, but did not vary significantly with spacing at 24 or 40 feet (Alexander *et al*, 2008). Kang *et al* (2004) concluded that stand density regulation might improve yield, wood and pulp fiber properties of jack pine. On the other hand, it should be taken in our mind that wider spacing tends to produce slightly lower quality values for most of the wood quality variables because of the increase in juvenile wood formation (Willcocks and Bell, 1995).

Table 1: Effect of tree spacing on the specific gravity and fiber length of 3-years-old *Conocarpus erectus* trees.

Plant spacing levels (m)	Specific gravity	Fiber length (mm)
Narrow (0.7 m)	0.634^{B}	0.894^{B}
Mediate (1.4 m)	0.644^{B}	0.912^{A}
Wide (2.1 m)	0.658^{A}	0.900^{B}
$LSD_{0.05}$	0.011	0.009

Each value is the average of 15 specimens.
Means with the same letters in column are not significant differences at 0.05 level of probability according to LSD test.

2. Effect of tree spacing on wood fiber length

Statistical analysis of variance revealed that the differences among plantation densities were very small, but slight significant differences were observed for fiber length. It can be notice from Table (1) that the plantation density levels had a significant effect on fiber length. However, fiber length didn't appear any trend (Table 1) and it can be seen that planted trees under mediate spacing, 1.4 m had higher average value of fiber length (0.912 mm) than either low or high-stand densities (0.89 mm for each). Although there are significant differences between the three levels of plantation densities used in the current study, it can be said that the spacing at which trees were planted did not have noticeable effects on fiber length especially in young plantations. Maximum percentage of increase in fiber length which obtained by decreasing plantation densities from 20400 trees ha^{-1} to 5100 trees ha^{-1} was 2.01% (Table 1). Many researchers found that thinning and/or tree spacing have no significant effect on fiber length of different softwood and hardwood species. Kayad

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and Khamis (2007) reported that thinning treatments significantly did not effect the fiber length for some hardwood species (*Cordia myxa, Citherxylum quadrangulare,* and *Eugenia cumini*). The same result was found by Donald *et al* (1983) for ponderosa pine as a softwood species after thinning. Watson *et al*, 2008 found that at the widest spacing the outer wood fiber length was significantly shorter than at the four tighter spacing.

In conclusion and based on unclear trend in literature reviews about the impact of plantation densities (tree spacing) on specific gravity and fiber length of wood, the current study showed that there was a small increase, but significant with decreasing plantation density of *Conocarpus* trees. We confirmed that increasing plantation spacing from 0.7 to 2.1 m did not give negative effect on specific gravity and fiber length. Subsequently, it can be concluded that spacing did not affect the suitability of *Conocarpus* for pulping industry. It is important to conduct studies on the effect of increasing the plantation densities on wood characteristics, and the quality of wood pulp obtained from *Conocarpus* trees.

3. Effect of tree spacing on wood chemical components

Wood cell walls are composed of three groups of structural substances cellulose, hemicellulose, and lignin. In addition, wood also contains small quantities of extraneous components called extractives. Statistical analysis of the data show that the differences between plantation densities in the chemical components (extractive, hemicellulose, lignin and ash contents) of *Conocarpus erectus* were highly significant, while no significant differences were obtained for cellulose content.

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Table 2: Average values* of wood chemical components as affected by tree spacing.

Levels of Tree spacing (m)	Content of (%)				
	Extractive	Cellulose	Hemicellulose	Lignin	Ash
Narrow (0.7 m)	8.642^{A}	48.314	20.402^{A}	21.725^{B}	2.750^{A}
Mediate (1.4 m)	7.209^{B}	48.489	19.803^{B}	22.101^{B}	2.410^{B}
Wide (2.1 m)	8.902^{A}	48.664	19.108^{C}	24.497^{A}	2.175^{C}
$LSD_{0.05}$	0.4.9	NS	0.521	0.633	0.141

* Each value is the average of 15 specimens.
Means with the same letters in column are not significant differences at 0.05 level of probability according to LSD test.

3.1. Extractives content as affected by tree spacing

Our results in Table (2) and Figure (1) indicates that, the high and low-stand densities gave the higher values of extractive content (8.642 and 8.902%, respectively) while, mediate stand had the lowest average value (7.21%), this means that there isn't consistent relationship between tree spacing treatments and extractive content. This result is in agreement with finding of many researchers. Harvey and Tsuneo (1974) and Adam *et al.* (2006) reported that the fertilization and thinning treatments had no significant effect on the average extractive levels of trees. On the other hand, Abdel-Aal and Kayad (2007) concluded that heavy thinning gave higher value of extractive content while moderate thinning had the lowest extractive content value on *Cordia myxa*, *Citharexylum quadrangular* and *Eugenia cumini.*

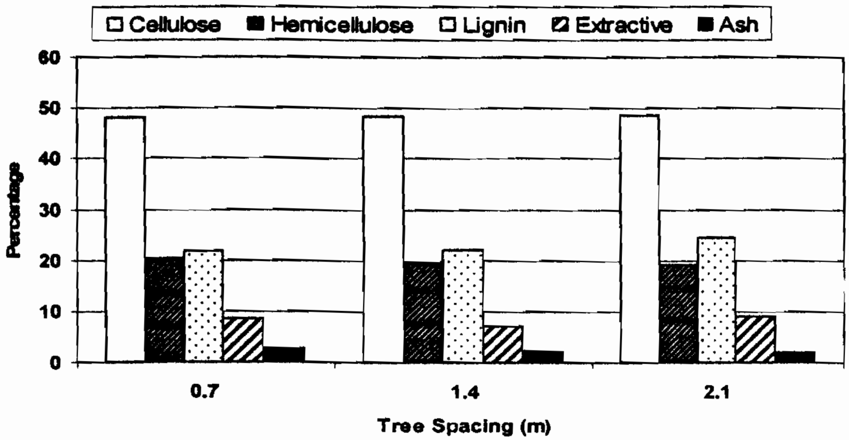

Fig. 1. Wood chemical components of *Conocarpus erectus* as affected by tree spacing.

3.2. Cellulose content as affected by tree spacing

The results of variance show that the differences in cellulose content among plantation density levels (tree spacing) used in the present work were not significant. However, it can be seen from Table (2) and Fig. (1) that there was an increase in cellulose content with increasing plant spacing from 0.7 m to 2.1 m (48.31 to 48.66%, respectively). This result was in agreement with the finding of **Shupe** *et al.* (1996) who found that lower stand densities yielded greater cellulose mean values on Loblolly pine wood (*Pinus taeda*). Contrarily, this result was in disagreement with those obtained by **Abdel-Aal and Kayad** (2007) who reported that thinning treatments (20000, 10000 and 6800 trees ha^{-1}) were highly significant but the trend was similar where they found that the more spacing, the more cellulose content occurs. Heavy thinning (low-stand density) had the highest average value (44.97%) followed by moderate thinning (44.68%) and the least average value of cellulose was for control (43.28%). **Russell** *et al.* (2005) also concluded that there is an effect of thinning on crystallite width of cellulose for *Eucalyptus globulus*, which increased with thinning intensity.

3.3. Effect of tree spacing on hemicellulose content

Statistically in the current study, the analysis of variance shows that differences among tree spacing levels in hemicellulose content were highly significant. Table (2) and Figure (1) indicate that increasing the spacing between trees resulted in decreasing in hemicellulose content. Narrow distance had the highest average values (20.40%) followed by medium distance (19.80%) and wide distance had the lowest average value (19.11%) with significant differences between the three spacing treatments.

The decreased in hemicellulose content was in agreement with those obtained by Abdel-Aal and kayad (2007) who found that narrow space between trees gave higher values of hemicellulose. The same result was obtained by Poo *et al.* (1995) on some hardwood species i.e., autumn olive, black locust, eastern cottonwood and sycamore. They concluded that the narrowly spaced trees gave higher values for pentosan content (main component of hemicellulose for hardwood). Shupe *et al.* (1996) reported that lower stand densities yielded greater holocellulose and cellulose contents, which mean that hemicellulose content was decreased.

3.4. Lignin content as affected by plantation densities

Statistical analysis of data reveals highly significant effect on lignin contents of buttonwood when trees planted under different plant spacing. Table (2) and Figure (1) indicate that the spacing treatments increased lignin content. Planted trees at wider space (2.1 m) between trees had the highest average value (24.50%) followed by mediate spacing (22.10%) and the least value was obtained with narrow spacing (21.73%). Wide distance had the highest lignin content, while narrow distance gave the lowest one.

Our results in lignin content were in agreement with those obtained by Abdel-Aal and kayad (2007) who found that the wide spacing was the highest in lignin content, while the narrow spacing was the lowest. Shupe *et al.* (1996) concluded that lower stand densities resulted in higher Klason lignin contents. Poo *et al.* (1995) found that the widely spaced trees gave higher values for lignin.

3.5. Ash content as affected by tree spacing

Statistically, differences in ash content of Buttonwood among plant spacing treatments were highly significant. It can be seen from Table (2) that ash content was decreased with decreasing plant spacing. Narrow spacing had the highest ash value (2.75%) followed by mediate spacing (2.41%) and the lowest average value of ash was recorded with wide spacing (2.17%). These results are in agreement with the data obtained by Poo *et al.* (1995) and Abdel-Aal and kayad (2007). This result means that planting buttonwood (*Conocarpus erectus*) at low-stand density will be solve the problem of ash in most industrial situations especially for fuel and charcoal because it is considered an undesirable material for these industries. Furthermore, this information should be taken in consideration when planting *Conocarpus erectus* for fuel and charcoal. Depending on this study, those results will be helpful in the development of plantation management programs for wood quality control.

CONCLUSIONS

According to the results obtained from the current study, the following conclusions may be drawn:

1- Although there are significant differences between the three levels of tree spacing used in the current study in specific gravity, the spacing at which trees were planted did not have noticeable effects on specific gravity. Specific gravity increased from 0.634 to 0.658 as the tree spacing increased from 0.70 to 2.10 m.

2- The levels of tree spacing had a significant effect on fiber length and no clear trend was obtained. Increasing tree spacing from 0.7 to 2.1 m did not give negative effect on specific gravity and fiber length of wood.

3- Planted trees at narrow and wide distances gave the higher values of extractive content (8.642 and 8.902%, respectively). Cellulose contents were not significantly different between tree spacing. Increasing the spacing from 0.7 to 2.1 m resulted in decreasing in hemicellulose content from 20.40 to 19.11%, respectively. Planted trees at low-stand density had the highest lignin average value (24.50%) and the lowest value was obtained with high-stand density (20.40%).

4- These results are very important to chemical technologists and wood scientists working on wood quality parameters in hardwoods.

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الملخص العربي

الثقل النوعي، طول الألياف والمكونات الكيميائية لخشب أشجار الكونوكاربس (*Conocarpus erectus* L.) وتأثرها بمسافات الزراعة

رمضان عبد السيد ناصر
قسم الغابات وتكنولوجيا الأخشاب، كلية الزراعة، الشاطبي، جامعة الاسكندرية

شجرة الكونوكاربس *Conocarpus erectus* L. واحدة من الأشجار سريعة النمو المتحملة للجفاف وتنتشر بشكل واسع في المملكة العربية السعودية في الطرقات وحول الحدائق العامة ويمكن اعتبارها مصدراً متجدداً لعديد من الاستخدامات الخشبية، ومع ذلك لا توجد دراسات محلية حول جودة الخشب الناتج منها. لذا اجريت هذه الدراسة لدراسة تأثير مسافة الزراعة بين الأشجار على بعض صفات الخشب مثل الثقل النوعي، طول الألياف والتركيب الكيميائي للخشب. استخدمت في الدراسة ثلاث مسافات زراعة بين الصفوف وداخل الصف الواحد وهي 0.7، 1.4 و 2.1 م والتي تعادل كثافة شجرية قدرها 20400 ، 5100 و 2250 شجرة للهكتارعلى التوالي. ودلت نتائج هذه الدراسة على تأثر المكونات الكيميائية للخشب من مستخلصات، هيميسليلوز، لجنين ورماد بالكثافة المنزرعة عليها الأشجار بصورة عالية المعنوية بينما تأثر محتوي الخشب من السليلوز بصورة معنوية فقط. أما بالنسبة للثقل النوعي وطول الألياف فكان التأثير ضئيلاً ولكنه معنوي حيث يزداد الثقل النوعي كلما زادت مسافة الزراعة بين الأشجار في حين لا يمكن تحديد اتجاه محدد لتغير طول الليفة. وبصفة عامة توصي الدراسة الحالية باستخدام أخشاب الأشجار المنزرعة على مسافات واسعة في صناعة الأثاث نظراً لزيادة نسبة اللجنين والثقل النوعي للخشب الناتج، في حين توصى الدراسة باستخدام الأخشاب الناتجة من الأشجار المنزرعة على مسافات ضيقة في إنتاج عجائن الورق والورق وكحول الايثايل لزيادة نسبة الهيميسليلوز والرماد في الخشب. وبناءً علي ذلك فأن نتائج تلك الدراسة سوف تساعد في تطوير برامج إدارة الزراعات الشجرية للكونوكاربس للتحكم في نوعية الخشب الناتج.