The relationship between some wood physical, chemical properties and decay levels of Pecan logs

Peiyao Zhang, Gerald L. Riskowski*

(Department of Biological and Agriculture Engineering, Texas A&M University, TX, USA,77843)

Abstract: This study was conducted to determine the preferred decay level of Pecan logs for the cultivation of *Auricularia auricular*-judae (wood ear mushroom). Previous research had found some relationship between densities and C/N ratio of hardwood boreal trees in Canada. In this research, the physical (density, moisture content, penetration depth, etc.) and chemical properties (carbon, nitrogen and C/N ratio) of logs were measured from Pecan logs at different levels of decomposition. First, the traditional visual method was used to define the decay levels and they were compared to the log physical and chemical properties to find relationships between them. There was a negative relationship between log densities and decay levels. The more decayed logs had lower densities than new, fresh logs. Densities could be used as a basic standard to represent log decay levels. When the densities of logs were less than 430 kg m^{-3}, the negative relationship was significant between penetration depth and densities of logs. The relationship between C/N ratios and densities of logs was not significant, except for logs that already had mushroom fruiting residue present. Therefore, there was some relationships between log properties and decay levels. These log properties can be useful as parameters to determine the decay level and select the logs with the right decay level for Auricularia mushroom growth.

Keywords: *Auricularia auricula*-judae, Pecan logs, wood decay level, carbon, nitrogen

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1 Introduction

1.1 Auricularia mushroom and Pecan trees

Auricularia auricular-judae, also called wood ear mushrooms, is jelly fungi and basidiomycetes that grow in the tropics and subtropics. It is widely distributed and regarded as a healthy food throughout the world, especially in Asia. Log cultivation of mushrooms is relatively simple and some consumers believe it to be the best method to save nutritional value inside the mushroom. In the natural environment, the mushroom fungus appears to prefer to infect woods which are already partially decomposed.

Pecan trees are common local hardwood trees and wood ear mushrooms are known to grow on them so they could be used for cultivating mushrooms. Cultivating mushrooms on them is an economic and realistic way for local mushroom growers. Hence, finding the right decay level of logs for mushroom growth can save cultivation time, costs and improve mushroom yield for commercial growth. But unfortunately, there is no previous research about this.

However, the physical and chemical properties of logs change during the decay process, and these changes may be related to wood ear mushroom growth. The decay process of logs can be tracked with the changes of these properties. There must be a preferred decay level for wood ear mushroom growth on Pecan logs.

During the decomposition process of logs, the physical and chemical properties of logs are changed by microbial

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***Corresponding author: Gerald L. Riskowski,** Professor and Head, Department of Biological and Agriculture Engineering, Texas A&M University, TX, USA. Tel: 979-845-7619. Fax: 979-847-8627. Email: riskowski@tamu.edu.

activities. The nitrogen, carbon and mineral resources have significant effects on mushroom growth (Jonason and Fasidi, 2001). The ligninase, cellulase and other enzymes make logs become ideal nutrition sources for fungi growth (Luo, 1993). During the wood decay process, the cellulose and lignin contents are lysed by cellulase and ligninase which can be the nutrition resource for the fungus growth. The cellulase and hemicelullase activities could lead to wood degradation. Ligninase activities and acid proteinase activities are also related to wood decomposition. The more soluble carbohydrate produced, the better the wood substrate would be for mushroom growth. Therefore, the wood would become an available nutritional resource for mushroom growth during the decay process.

Many researchers have studied the effects of different carbon sources and nitrogen sources for mushroom growth. But there is no study about how carbon and nitrogen affect the growth of mushrooms. Based on previous research in the literature, the best carbon and nitrogen ratio of logs for mycelium growth was 35:1 for wood ear mushroom (Luo, 1993). The logs came from hardwood trees, but it was not indicated what specialized hardwood trees were used for mushroom growth. In this study, it is hypothesized that wood ear mushroom starts growing on decomposed logs with a specific decay level at particular C/N ratio for Pecan logs.

How to define and determine the log decay levels is the key to help mushroom growers select the right Pecan logs for Auricularia mushroom growth. To find a solution to define and determine the decomposition levels of Pecan logs was the objective of this research. The physical and chemical properties of Pecan logs collected from Pecan orchards in Central Texas were measured. The decay levels were first defined by traditional visual methods, then these decay levels were compared to other log physical and chemical properties to find the relationships between them.

1.2 Relationships between log properties and decay levels

1.2.1 Traditional visual decay level measurement

To measure the decay levels of logs, the traditional visual method divides them into five classes based on visual examination (Daniels et al., 1997). In that study, logs from cool mesothermal forests of southwestern coastal British Columbia were used to determine the log decay levels. Those logs were divided into five classes by visual standards: i，ii，iii，iv，v.

i) Freshly fallen logs, with sound bark and wood, and with presence of twigs.

ii) Sound bark and wood mainly, branches are present but twigs are absent.

iii) Logs maintain structural integrity, bark is detached or absent, wood is decayed but still structurally sound.

iv) Logs are oval, bark is absent, and wood is soft due to decay, branch stubs can be removed.

v) Logs lack structural integrity and are being incorporated into the forest floor. Log height over the forest floor > half log diameter.

However, this traditional, visual method is inherently subjective, raising questions about repeatability. Such questions are of particular concern in practice, and the class definitions often fail to clarify how to assign logs that are decomposing in an unusual way (e.g., bark still attached but can be broken by kicking). Therefore, such measurements presumably remain quite variable and inaccurate.

1.2.2 Relationship between physical properties and decay levels of wood

Larjavaara and Muller-Landau (2010) defined wood decay levels by the log densities and hardness. During log decay processes, densities and hardness varied over time. The hardness of logs with different densities were measured by a penetrometer. From the penetration method, the dynamic penetrometer showed a strong relationship between log densities and penetration depth. There was a linear relationship between them (Larjavaara and Muller-Landau, 2010). Mäkipää and Linkosalo (2011) also found a similar linear association between wood densities and penetration depth by using a penetrometer. The density had a negative relationship with penetration depth. These research papers provided a good method to determine the log decay levels and proved to have higher precision and efficiency. However, some variations still existed. Logs with similar densities varied significantly in penetration depth by a dynamic penetrometer. This was not surprising, as hollow logs can be covered in strong bark and solid heartwood can be surrounded by decayed, soft sapwood. But this dynamic penetration method was better and more precise than the traditional visual classification.

1.2.3 Relationships between chemical properties and decomposition levels of wood

During the wood decomposition process, not only the physical properties were changed, but the chemical properties of wood also changed. Especially the carbon, nitrogen and C/N ratio were significantly changed (Hale and Pastor, 1998). Strukelj et al. (2013) measured the chemical transformations during the log decomposition process. The logs were divided into five classes by the traditional method of using visual cues, then they measured the log densities and chemical properties. All the wood samples were ground in a ball mill to pass a 0.5 mm mesh screen before conducting the chemical analyses. Total C and N concentrations were determined by dry combustion using a CNS 2000 analyzer (LECO Corporation, St. Joseph, Michigan). They studied logs from common deciduous and coniferous boreal species, including white birch, trembling aspen, balsam fir, jack pine, white spruce, and black spruce, from the Abitibi region of northern Quebec. Densities of logs ranged from 79 to 469 kg m^{-3}. Despite a general decrease in wood density with log decay classes, densities of adjacent decay classes overlapped for all species, and large variations in wood density were observed within each decay class. The results showed that C concentrations increased significantly with decreasing density for all logs. Nitrogen concentrations in logs also significantly increased with decreasing wood density. But nitrogen concentrations increased more than C concentrations in that research. Hence, the C/N ratios decreased significantly with decreasing wood density. Overall, the chemical properties were changed during the log decomposition process. The relationship between C/N ratios and decay levels were obvious, but the effect of tree species and patterns existed.

1.3 The objective and hypothesis of this research

1.3.1 Define and determine the log decay levels by log physical properties

Densities changed during the log decay process. It was hypothesized that there was a relationship between density and decay levels, so densities could be used to represent the log decay levels. The objective was to measure the changes of physical properties of logs at different stages of the decomposition process, and to find the relationships between these physical properties and decay levels as represented by changes in log density. Hardness also varied during log decomposition process. Therefore, it was hypothesized that a relationship existed between log hardness and log density.

1.3.2 Use log chemical properties to describe the log decomposition levels

The objective was to find the relationship between log chemical properties and decay levels as represented by log density. The carbon, nitrogen and C/N ratio of the logs were measured to determine the association between these chemical properties and log density. Differences of carbon, nitrogen and C/N ratio of logs with different densities were analyzed. The relationships between them and log densities were determined.

2 Materials and methods

2.1 Tested logs

2.1.1 Pecan logs with clean surface (no fungus growth history)

A total of 104 Pecan (*Carya illinoinensis*) logs were collected randomly from central Texas. Pecans are common hardwood trees in the southern United States. The logs had slightly different diameters and were cut approximately 30-cm-long (Figure 1). Then they were put in a small lab room at 23℃ and 40% relative humidity for at least one week before starting the measurement of all physical and chemical properties.

Figure 1 Examples of Pecan logs tested for physical properties

2.1.2 Pecan logs with **Auricularia** mushroom residue

To find whether the same relationship existed for logs which already grew mushroom before, 13 Pecan logs with known mushroom residue (dried fruiting body) were also collected from Pecan orchards. These logs were also cut to 30-cm-long pieces and were pre-treated like the 104 logs which had a clean surface with no history of fugus growth. The physical and chemical properties of these 13 logs were measured.

2.2 Decay levels determination by traditional visual method

To estimate the decay levels of Pecan logs, the traditional visual method was used first (Daniels et al., 1997). In this study, the decay levels of the 104 logs with no history of fungal growth and the 13 logs with mushroom residue growth history were measured and divided into five visual decay classes. Most logs were at decay levels from 2 to 5 by the visual method.

2.3 Physical properties measurement

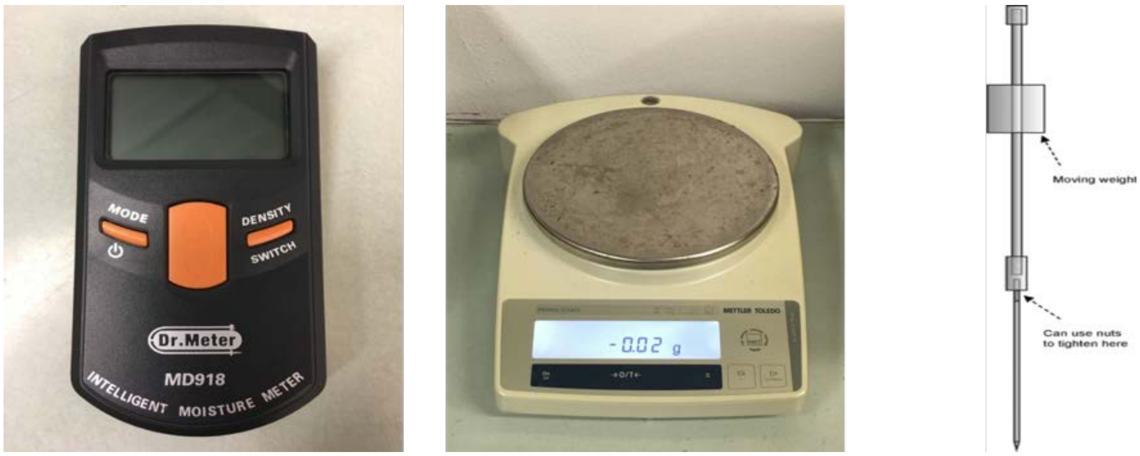
2.3.1 Log density

After pre-conditioning, the log moisture contents were measured with a moisture meter (Dr. Meter®, Intelligent Moisture Meter, model MD918, USA) (Figure 2(a)). The moisture meter directly reads the moisture contents by contacting the wood surface and has a range from 4% to 80% by mass basis. The maximum error was (RH · 1% + 0.5%) and resolution was 0.5%. It was calibrated per manufacturer's instructions to adjust to the external environment.

The masses of the logs were measured by an accurate balance (Mettler Toledo®, model PB3002S, USA) (Figure 2(b)). The maximum capacity of the balance was 3100 g with increments of 0.01g. The volumes were determined by the drainage method in a cuboid shaped tub. Water was added into the tub, and the line of water level was marked. Then each log was wrapped tightly with a thin plastic bag, put into the tub, pushed under the water level, and the water level was marked again. The volume of the log equaled the volume of water between the two lines. The dry masses of logs were calculated by total masses and deducting the moisture content in the logs. Hence, densities were calculated by dividing the dry mass by volume of logs. The densities of all 117 logs (including the 104 logs with no history of fungus growth and the 13 logs with a history of fungus growth) varied from 200 to 800 kg m^{-3}. The logs were divided into six categories by density in increments of 100 kg m^{-3} from 200 to 800 kg m^{-3}. These density categories were labeled by numbers from 1 to 6; 1 being the least dense.

2.3.2 Hardness test

In this study, the hardness of the 104 logs with no history of fungus growth was represented as penetration depth. It was measured by a dynamic penetrometer as described by Larjavaara and Muller-Landau (2010) which was manufactured by the author (Figure 2(c)). The penetrometer was composed of five parts. The moving weight was 1 kg, dropping distance of the moving weight was 250 mm, and the diameter of the pin was 5 mm. The point of the pin was sharpened in the shape of a pencil and the tapering portion had a vertical dimension of 10 mm. The angle between the pin tip of penetrometer and logs surface was 90°. When measuring the log penetration, the moving weight was dropped vertically from 250 mm height for 20 times. After 20 hits, the pin was marked at the location parallel to the log surface. The distance from the pin tip to the marked place was penetration depth. If the penetration depth reached 55 mm in less than 20 hits, then the hit numbers were also recorded. The logarithm of the penetration depth in millimeters per hit numbers was used in the analyses.



(a) (b) (c)

(a) MD918 moisture meter; (b) Mettler Toledo® PB3002S balance; (c) The dynamic penetrometer (Larjavaara and Muller-Landau, 2010)

Figure 2 Experiment equipment

2.4 Chemical properties measurement

In this paper, the carbon, nitrogen contents and C/N ratio of Pecan logs were measured. From the 104 logs with no fungus residue, three logs were selected from each of the density categories. As mentioned earlier, the log densities varied from 200 to 800 kg m^{-3}, and the logs were divided into six categories for every 100 kg m^{-3} interval. Hence, there were 18 logs selected from the 104 logs for chemical properties measurement. The chemical properties of the 13 logs with mushroom residue were also measured. The C and N values of these logs were measured by a Vario MICRO cube elemental analyzer (Elementar, Inc., 2015) (Figure 3).

(a) (b)

(a) Vario MICRO cube elemental analyzer; (b) The column tubes for element analysis, adapted from Elementar, Inc. (2015)

Figure 3 Elemental analyzer

The wood samples were air-dried (20℃ - 25℃) and collected by drilling holes in the logs on the left, right and middle parts to 3-5 cm depth (Strukelj et al., 2013). Each part was done three times in three locations around the log circumference. Samples were taken from these 9 locations on every log. So, nine samples of each log and three logs of each density category were prepared for carbon and nitrogen contents test. For samples taken from the same log, the samples were mixed together. Then they were ground to 40 mesh (0.420 mm) and dried in an oven. Samples were dried at 80℃ for 4 h. After that, they were weighed into 2 mg samples for combustion in the elemental analyzer (Elementar Inc., 2015).

The samples were sealed with aluminum foil and put in the column tubes of the analyzer to analyze the chemical compositions. Samples were fully combusted in the analyzer columns and carbon, nitrogen, sulfur and hydrogen were burned to carbon dioxide, nitrogen dioxide, sulfured dioxide and water. The gaseous compounds were absorbed at element specific columns and one after the other released by a temperature support desorption. All elements were analyzed simultaneously from the one sample. Therefore, the final chemical compositions (carbon, nitrogen, sulfur and hydrogen) were determined.

2.5 Statistic analysis of log properties

After all the physical and chemical properties were measured, the data of this properties was analyzed by JMP software (12^{th} ed., SAS Institute). The one-way analysis of variance (ANOVA) test was used to analyze the relationships. The relationships between these properties and log decay levels were determined.

3 Results and discussion

3.1 Decay levels and dry weight densities of all 104 logs with no history of fungal growth

The visual decay levels at the different dry weight log densities for the 104 logs with no history of fungal growth are presented in Table 1. There was a negative relationship between decay levels and densities. Logs with high densities had low decay levels and low-density logs had high decay levels. Compared to previous research, the densities can be used as a basic parameter to represent the log decay levels. Hence, densities were used in later experiments to represent the log decomposition levels. The number of logs at each density category were also counted.

Table 1 Wood decay levels by visual method versus densities of clean surface Pecan logs with no history of fungal growth

Density range (kg m^{-3})	Decay levels					No. of logs by density category
	i	ii	iii	iv	v	
200 - 300 (1)	0	0	0	1	5	6
301 - 400 (2)	0	0	3	9	2	14
401 - 500 (3)	0	2	10	8	1	21
501 - 600 (4)	0	2	12	3	0	17
601 - 700 (5)	6	23	8	0	0	37
701 - 800 (6)	6	3	0	0	0	9
No. of logs by decay levels	12	30	33	21	8	104

3.2 Physical properties of all clean surface Pecan logs with no history of fungal growth

The average and standard deviation of log density and logarithm of penetration depths are presented in Table 2.

Table 2 Data of physical properties of all 104 logs with no history of fungal growth

Category	Density (kg m^{-3})	Density average (kg m^{-3})	Density standard deviation	Logarithm of penetration depth Avg. (mm)	Logarithm of penetration depth standard deviation (mm)
1	200-300	273.87	18.70	0.38	0.11
2	301-400	357.06	25.62	0.44	0.35
3	401-500	462.34	24.46	0.20	0.12
4	501-600	549.19	27.04	0.14	0.02
5	601-700	648.63	26.55	0.14	0.02
6	701-800	725.22	18.09	0.13	0.01

3.2.1 Relationship between density and hardness of clean surface logs with no history of fungal growth

The penetration depths had been measured three times for each log; on the left, middle and right part. Figure 4 shows the fit of log density versus logarithm of average penetration depth of all 104 logs with no history of fungal growth.

For the 104 logs, the *p*-value was less than 0.0001, so the linear model between density and logarithm of penetration depths was significant. Hence, a negative relationship significantly existed between density and logarithm of penetration depths.

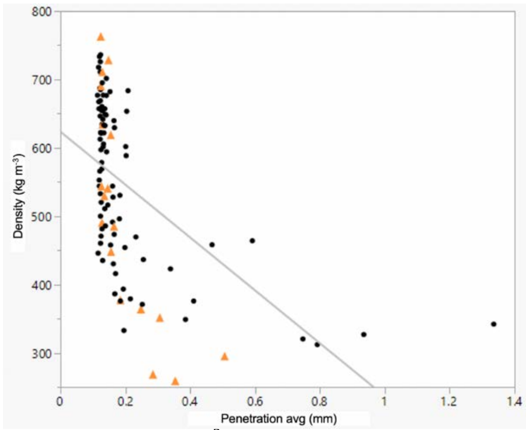


Figure 4 Log densities (kg m^{-3}) versus logarithm of penetration depths (mm) per hit numbers for the clean surface logs with no history of fungal growth.

Note: The orange triangle marks were the 18 Pecan logs from the 104 logs that were selected for the chemical property measurements.

Figure 5 gives the relationship between density and logarithm of penetration of two separate fits which were closer to realistic conditions. It showed that for log densities from 230 to 430 kg m^{-3}, an obvious negative relationship existed. When densities varied from 430 to 800 kg m^{-3}, the first curve showed the penetration depths changed very little at the higher log densities. Hence, the second curve indicated that a strong negative relationship existed between density and the logarithm of penetration depth when densities were below 430 kg m^{-3}.

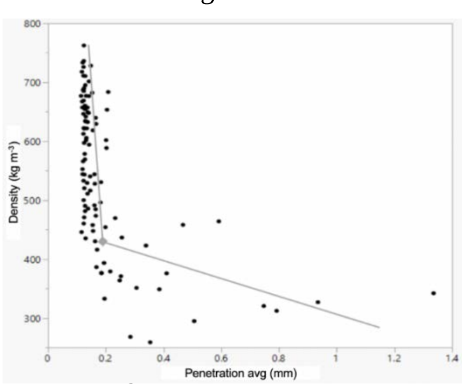


Figure 5 Density (kg m^{-3}) versus logarithm of penetration depth (mm) per hit numbers of all 104 logs with no history of fungal growth

3.3 Physical and chemical properties of selected 18 logs

Table 3 shows the data of densities, logarithm of penetration depth and C/N ratio of the 18 logs that were selected from the 104 logs with no history of fungal growth for chemical analysis. Three logs were selected randomly from each of the density categories. Table 3 The physical and chemical properties of the 18 logs selected for chemical analysis

Category	Density range (kg m^{-3})	Density Avg. (kg m^{-3})	Density standard deviation	Logarithm of penetration depth Avg. (mm)	Logarithm of penetration depth standard deviation	C/N Avg.	C/N standard deviation
1	200-300	273.87	18.70	0.38	0.11	93.57	68.42
2	301-400	363.86	12.83	0.25	0.06	91.85	56.21
3	401-500	474.18	23.13	0.15	0.02	112.38	13.14
4	501-600	537.58	7.44	0.14	0.01	107.52	20.43
5	601-700	647.42	37.67	0.14	0.02	107.13	20.09
6	701-800	733.72	26.40	0.13	0.01	60.44	16.27

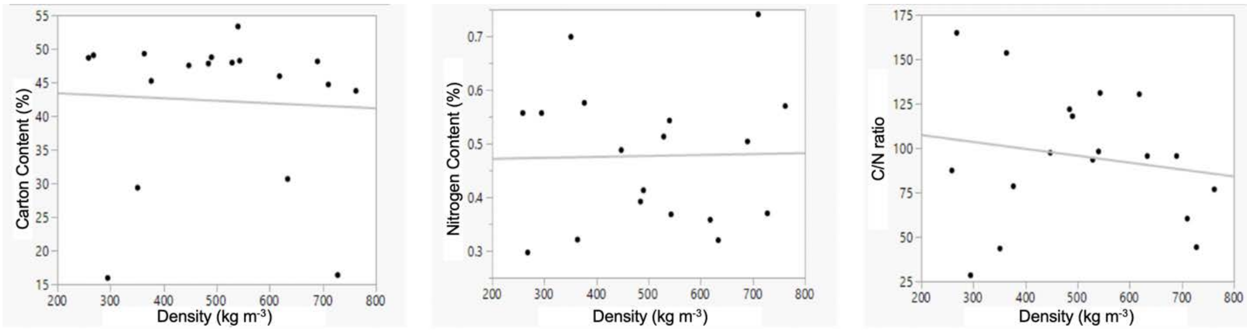
3.3.1 Variations of chemical properties during log decay process of 18 logs

In this research, the carbon and nitrogen contents were also measured for the 18 logs that were selected from the 104 logs. Based on the statistical analysis, the relationship between chemical properties and log decay process was determined.

From Figure 6(a), the linear relationship was not satisfied for carbon content versus log densities. The R squared was 0.0028 and *p*-value was 0.8327 based on ANOVA analysis. Hence, the linear relationship was not significant for carbon contents versus densities of these logs. There was a slight trend but the data had wide variations for most of the logs, so the carbon content decreased slightly when the densities increased.

There was no significant linear relationship between nitrogen content and density, Figure 6(b). The R squared value was 0.0005 and *p*-value was 0.9303. There was a slight trend where the nitrogen increased slightly with increasing density for most logs.

The C/N ratios of the 18 logs were also determined, Figure 6(c). The R square was only 0.028 in the ANOVA analysis, and the p-value was 0.5 which was much larger than 0.05. There was no strong linear relationship between C/N ratio and densities, although C/N decreased slightly with increasing density.



(a) (b) (c)

Figure 6. Densities versus chemical properties of the 18 logs; (a) The carbon content (%) versus density (kg m^{-3}); (b) The nitrogen content (%) versus density (kg m^{-3}); (c) C/N ratio versus density (kg m^{-3})

3.4 Physical and chemical properties of Pecan logs with mushroom residue

The data of physical and chemical properties measured for the Pecan logs with mushroom residue are shown in Table 4. The densities of all logs (total of 13 logs) with mushroom residue varied from 200 to 600 kg m^{-3}, which put them in log density categories of 1, 2, 3 and 4.

Table 4 The data of physical and chemical properties of 13 Pecan logs with known mushroom fruiting body residue based on density categories

Category	Density range (kg m^{-3})	Density Avg. (kg m^{-3})	Density SD	Logarithm of penetration depth Avg. (mm)	Logarithm of penetration depth SD	C/N Avg.	C/N SD
1	200-300	255.00	3.51	0.76	0.40	172.52	117.53
2	301-400	309.85	0.77	0.39	0.08	137.51	45.58
3	401-500	428.88	17.66	0.14	0.01	110.88	35.09
4	501-600	536.10	30.64	0.16	0.03	61.47	15.22

3.4.1 Relationship between density and hardness of logs with mushroom residue

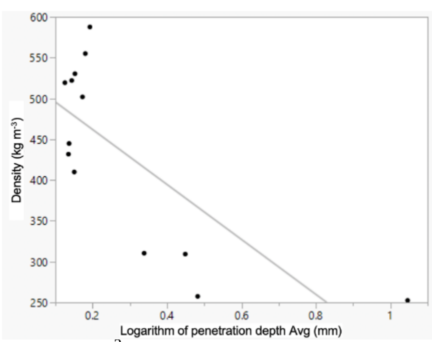


Figure 7 Density (kg m^{-3}) versus logarithm of penetration depth (mm) per hit numbers of 13 logs with mushroom residue

The relationship between density and logarithm of penetration depths was significant for Pecan logs with fungal residue (Figure 7). The p-value was only 0.0032 based on ANOVA analysis.

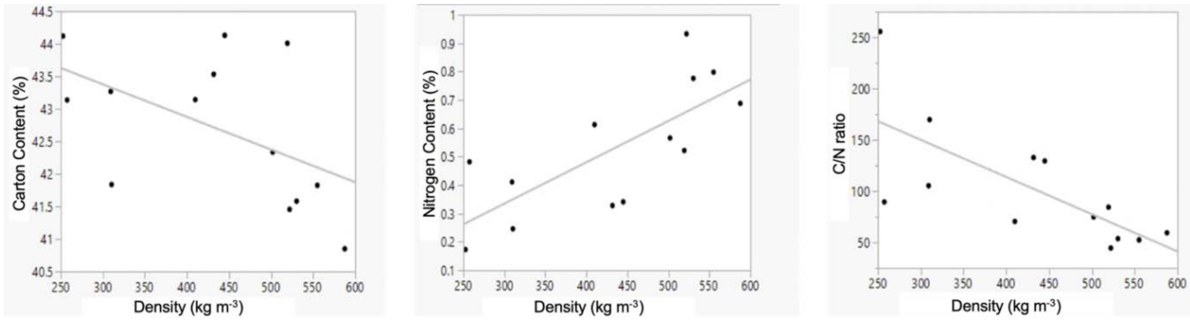
3.4.2 Chemical properties of logs with mushroom residue

Figure 8 shows the relationships between chemical properties and density of logs with mushroom residue. The plot indicated that carbon contents decreased with increasing densities, in Figure 8(a), so there was a trend where carbon contents increased during the log decomposition process for these logs. However, p-value was 0.07 which was larger than 0.05. Hence, the relationship was not significant. This trend was the same as for the Pecan logs with no history of fungal growth.

There was a positive relationship between nitrogen contents and densities. The nitrogen contents increased with increasing densities (Figure 8(b)). The$p$-value was 0.0037. Hence, the relationship was significant. The nitrogen content decreased significantly during log decomposition. And the nitrogen content also decreased during the decay process for the logs with no history of fungal growth.

From Figure 8(c), a linear fit was satisfied for the relationship between density and C/N ratio for the 13 logs with mushroom residue. The p-value was 0.0061 which was less than 0.05. The linear relationship was significant and it was negative relationship. The C/N ratio increased during log decay process. This trend was the same compared to the logs with no history of fungal growth.

Therefore, the same trends existed between chemical properties and decay levels of the logs without mushroom growth and the logs with mushroom fruiting residue.



(a) (b) (c)

Figure 8 Densities versus chemical properties of logs with mushroom residue; (a) The carbon content (%) versus density (kg m^{-3}); (b) The nitrogen content (%) versus density (kg m^{-3}); (c) C/N ratio versus density (kg m^{-3})

3.5 Comparison of the changes of chemical properties in this research with previous research during log decay process

The chemical properties of wood changed significantly during the decay process in previous research conducted by Strukelj et al. (2013). For boreal hardwood trees grown in Canada, they found that carbon and nitrogen contents were both significantly increased during the log decay process. However, nitrogen increased more significantly than carbon. Therefore, the C/N ratio decreased significantly during the decomposition process.

In this research, the chemical properties of Pecan trees were measured in Central Texas. The carbon content was also increased with the decay process which was the same as found by Strukelj et al. (2013). However, the nitrogen content decreased at higher levels of decay. Hence, the C/N ratio increased for the logs with higher levels of decay which was opposite of the trends reported by Strukelj et al. (2013). However, the changes in carbon, nitrogen and C/N ratio for Pecan logs were very slight and did not show strong relationships between these criteria and log decay levels. In fact, they were not significant for the logs without a history of fungal growth and only the nitrogen and the C/N ratio had a significant relationship with log density for the logs with a history of fungal growth. Differences in results between this research and that done by Strukelj et al. (2013) may be due to different tree species and growth conditions, and possibly the history of fungal growth may have modified element contents.

3.6 The significance of variations of carbon, nitrogen and C/N ratio for wood decomposition process

During the wood and forest decomposition process, wood was attacked and decomposed by wood-destroying fungus (Rayner and Boddy, 1988). The changes of chemical properties of wood were significant, and carbon and nitrogen have been used as parameters to describe the decay process. Especially the nitrogen content was believed to affect the decomposition process of logs and organic matter (Fog, 1988). Wood-destroying fungi grow on wood as the sole source of nutrients so they obtain N from the wood. There is evidence that the N content that occurs naturally in wood is less than optimal for wood destroying fungi which was provided by observation that adding a small amount of amino or ammonia N accelerates the decay rate of wood (Cowling and Merrill, 1966). However, the contrary results had also been reported (Cowling and Merrill, 1966). The idea that C/N ratio governs the rate of decomposition of the organic matter is well known and reported in textbooks on soil science by Blume et.al (2010) and Alexander (1977). These textbooks also conclude that the addition of ammonium or nitrate to straw or other nitrogen deficient substrates greatly enhanced decomposition (Fog, 1988). However, the opposite situation also existed. Therefore, more research is needed on the relationships of carbon and nitrogen contents to wood decomposition for specific wood species and other relevant conditions.

4 Conclusions

4.1 The relationship between log decay levels and physical properties

Fresh Pecan logs generally had higher densities and moisture contents and older, decayed Pecan logs had lower densities and moisture contents. Log density could possibly be used as a basic standard to represent wood decay levels, but the relationship would have to be determined for each tree species.

Pecan log hardness (as determined with a penetrometer) could be used to describe Pecan log decay levels at lower log densities There was no significant relationship between log densities and penetration depths when the Pecan log densities were higher than 430 kg m^{-3}. However, the penetration depths significantly increased with decreasing log densities when the log densities were below 430 kg m^{-3}.

The dry densities of the 13 logs that had a history of mushroom residue varied from 200 to 600 kg m^{-3}, which put them in the lower log density categories of 1, 2, 3 and 4.

4.2 The variation of chemical properties during the log decomposition process

The relationships between log decomposition levels and chemical properties were not significant. For the clean surface Pecan logs with no history of fungal growth, there were no significant relationships found between log density and C content, N content, or C/N ratio.

For the Pecan logs with known mushroom residue, there was no significant relationship found between log density and C content. However, there was a significant positive relationship found between log density and N content. There was a significant negative relationship found between log density and C/N ratio.

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