# A comparison of kiln-drying schedules and quality outcomes for 4/4–thickness black cherry lumber sawn from small-diameter logs

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## Abstract

With high stumpage prices, many sawmills are interested in the feasibility of processing smaller diameter hardwood logs. Most of these mills do not know the lumber yield, lumber grade, or cost of processing these logs. In this project we investigated the impact of alternative dry kiln schedules on the grade yields and defect occurrence in lumber sawn from small-diameter (logs with small-end diameters of 11 inches or less) black cherry (*Prunus serotina* Ehrh.) logs. The position within the log from which each board was sawn was mapped in relation to the profile of the logs. Every board was examined for end checks, surface checks, shake, twist, bow, cup, crook, and assigned a predrying grade. The lumber was dried using a conventional black cherry kiln schedule published in the *Dry Kiln Operator's Manual* (Simpson 1991) and two modified kiln schedules designed to dry lumber under milder drying conditions compared to the conventional schedule. The modified kiln schedules maintained equilibrium moisture content (EMC) conditions that were comparable to those of the conventional kiln schedules for each of the drying steps. After drying, each board was again examined for end checks, surface checks, shake, twist, bow, cup, crook, and assigned a postdrying grade Modified kiln schedule #1, in which the final dry-bulb temperature was lowered 20 °F from that of the conventional schedule, provided the best drying results in terms of the reduction in defects and minimization of grade loss as compared to the conventional (T4-D8) cherry schedule. Overall, for all three kiln treatments, lumber grade yield increased with increasing log diameter and log grade, and it improved in the direction of pith to bark. This study will provide the hardwood products industry with a better understanding of the feasibility of and approach for processing lumber from small-diameter black cherry logs.

It is commonly thought that small-diameter logs are only capable of producing low-grade (and low-value) wood. Lower quality wood typically is used in the production of pallets, particleboard, pulp, and engineered wood products (Luppold and Bumgardner 2003). Very little data exist detailing the feasibility of processing small-diameter hardwood logs into dry lumber for the production of dimension stock for use in appearance products such as cabinets, furniture, and flooring. Increased handling costs, lower average lumber grades, and drying induced defects are potential problems associated with processing small-diameter hardwood logs into lumber.

Log diameter strongly influences both lumber volume and grade recovery, which is directly related to product value recovery. For example, the expected lumber volume recovered from a Forest Service Grade 3, red oak tree yielding 1-1/2 logs (24 lineal feet of logs) is 60 BF for a tree with a diameter at breast height (DBH) of 10 inches, 122 BF for a tree with a

DBH of 14 inches, and 207 BF for a tree with an 18-inch DBH (based on Table 23, Hanks 1976). Multiplying the expected grade distribution of this lumber (Hanks 1976) by current northern red oak market prices (Hardwood Market Report 2008) indicates that the difference in the lumber recovery potential from these three tree diameters on a value-basis is even greater than the volume difference yielding $15, $49, and $94 in lumber value for the 10-, 14-, and 18-inch DBH trees, respectively.

Only minor attention has been given to grade and volume studies of small-diameter logs in the past. In addition to the Hanks study (1976), cited previously, a small-scale study of logs removed in a thinning operation offers guidance (Emanuel 1983). In this study, 20 small-diameter red oak, hard maple, and yellow-poplar logs removed in a thinning yielded 30 percent, 19 percent, and 15 percent No. 1 Common and Better lumber, respectively (Emanuel 1983).

A recent study of lumber recovery from small-diameter (6 to 10 inches in small-end diameter) red oak logs found that only 35 percent, by weight, of the material produced in a scragg mill operation was solid wood (Perkins et al. 2008a). The majority of the solid wood component consisted of lower-grade cants with the percentage ranging from 72 percent for the 6-inch logs to 54 percent for the 10-inch logs. The remaining solid wood volume was lumber, of which 74 percent was grade 2 A and 3 A Common and only 26 percent was grade 1 Common and Better (Perkins et al. 2008a).

A small-diameter sawing feasibility study that used the scragg mill-based yield results of Perkins et al. (2008a), returned a negative net present value and internal rate of return for all of the sawmill production scenarios that utilized 6- to 10-inch diameter logs (Perkins et al. 2008b). However, when a pallet part operation was paired with the sawmill operation, the sawing of small-diameter red oak logs was profitable when log prices were constrained to no more than $74/m³ ($523 per MBF, Doyle scale) paid for the logs (Perkins et al. 2008b).

Increased handling costs, lower average lumber grades, and drying-induced defects are potential problems associated with processing small-diameter hardwood logs into lumber. Several prior studies have examined alternate processing methods that might be employed to process small-diameter logs economically. These include: curve sawing (Hamner et al. 2006), System 6 (Reynolds et al. 1983), Saw-Dry-Rip (Maeglin and Boone 1988), and inside-out sawing to produce beams (Patterson et al. 2002).

Unlike these other studies, in this research we focus on the lumber grade and quality characteristics of dry lumber sawn from small-diameter hardwood logs in a conventional sawmill and dried in a kiln. The results might provide insight to the many hardwood sawmill managers who are contemplating processing a higher percentage of smaller diameter logs. For those sawmills that have reduced the diameters of the logs they are processing, this study will shed light on alternate drying strategies that might be pursued to minimize quality degradation in the kiln.

The objective of this research project is to develop information on the quality of the lumber produced from small-diameter hardwood logs and to evaluate the quality characteristics of the lumber after it is dried in a kiln using different drying schedules. Specific objectives are:

- Determine the grade yield of lumber sawn from small diameter logs
- Determine the effect of log diameter on postdrying lumber grade
- Determine the effect of log grade on postdrying lumber grade
- Determine the effect of log quality zone on postdrying lumber grade
- Determine the location in small-diameter hardwood logs where the lumber is prone to developing drying defects resulting in a drop in grade
- Determine the effect of two modified kiln schedules on drying defect development
- Determine the severity of warp that develops when sawing lumber from small diameter logs and kiln-drying with conventional and modified kiln schedules

## Experimental procedures

### Log delivery and storage

Logs were obtained from north-central Pennsylvania. The logs were transported to The Pennsylvania State University on a triaxle truck, unloaded and end sealed with wax to prevent end checking and excess moisture loss. The logs varied in length from 8 feet to 23 feet and were bucked to a length of 8 feet 4 inches. The portion of the log that remained after the maximum number of 8-foot 4-inch lengths were recovered was discarded.

### Log breakdown

Two sawing patterns were used to breakdown the logs into lumber: grade sawing and live sawing. In grade sawing the log was rotated each time a higher grade was thought to be on an opposite or adjacent face. This resulted in a number of faces exposed to the sawing plane. Live sawing exposed only the open face and the best quality face. The best quality face was broken down until growth stresses in the tree intensified in the open face after which the opening face was turned into the sawing plane and the remainder of the log was sawn into boards.

Logs were grade sawn or live sawn based on log diameter, percent sweep, and percent crook. Small-diameter logs with sweep, crook, or both could not be repeatedly rotated on the log deck for grade because it was difficult to produce volume yield. These logs were live sawn. The opening face for both sawing patterns was the face opposite the best face, which was the face with the least number of surface defects.

As each board was produced, board and log numbers were marked directly on the board surface. The combination of both the log and board number allowed for each board to be located in a particular log's profile. The location of the board in the log's profile was also assigned to the core center, inner quality zone, and outer quality zone based on U.S. Forest Service log grading rules (Kenna 1981). The inner quality zone was defined as the area between 40 percent and 70 percent of the log's radius (**Fig. 1**).

After sawing, the boards were placed in either a pile awaiting edge sawing or stacked onto a pick-up truck for transport to the dry kiln. The edging process was accomplished through the use of a bull edger. The gasoline-powered edger had one fixed saw with a second maneuverable saw blade.

### Types of defect and predrying inspection

Defects that were recorded in this experiment were end checks, shake, surface checks, bow, twist, crook, and cup. Severe checks through the cross section of the wood are defined as splits. Both surface checks and end checks were scrupulously examined. Even the smallest of checks was recorded in this study (1/32nd to 1/16th of an inch deep). Different amounts of twist, bow, cup, and crook are associated with the low, medium, and high warp categories (**Table 1**).

The predrying inspection of the lumber was conducted within 1 day after sawing and just prior to loading the lumber in the dry kiln. The lumber was graded using National Hardwood Lumber Association (NHLA 2003) grading rules and visually scanned for seven different defects (end checks, surface checks, shake, bow, twist, crook, and cup). The initial predrying grade and surface measure were marked on the board using a green crayon representing the green grade and green surface measure. The cuttings that were used to calculate the green grade were drawn on the board (outlined) in black crayon. Marks were placed on the ends of the boards to indicate the presence of defects of interest; different types of defects were assigned different marks and colors. End markings also were used to indicate the dominant quality zone from which the board originated.

Stacking was accomplished manually. Each board was hand stacked into packs that were 8 feet by 4 feet by 4.5 feet in size. The layers of boards were then separated by oak stickers (3/4 inches by 3/4 inches by 48 inches) to create openings for airflow beneath and above the boards. Stickers were placed 2 feet apart from each other starting at the very edge of the board and aligned with the bolsters under the pack. Following the inspection and stacking processes each pack was loaded into the kiln. The kiln used in this study utilized steam heat and had a drying capacity of 1500 BF. The kiln could accommodate two 750 BF packs of lumber.

### Kiln schedule methodology

A conventional kiln schedule (T8-B4) (Simpson 1991) along with two experimental kiln schedules were used during the project. The black cherry modified kiln schedule #1 was modified from the conventional kiln schedule (T8-B4) published in the *Dry Kiln Operator's Manual* (Simpson 1991). The final dry-bulb (DB) temperature was lowered 20 °F from that of the conventional schedule to 160 °F. The wet-bulb (WB) settings were selected based on an EMC comparable to the conventional kiln schedule (**Table 1**). Black cherry modified kiln schedule #2 altered the conventional kiln schedule in three ways: 1) lower initial DB temperature, 2) lower final DB temperature, and 3) addition of an intermediate step change to gradually ramp the DB temperature from 110 to 140 °F (**Table 1**). The rationale for this schedule was that lumber dried using the lower initial DB setting should result in an increase in the tension set because of the slower drying compared to the other kiln schedules used in the study. An increase in tension set may enable the wood to better resist the forces that cause warp in the later stages of drying.

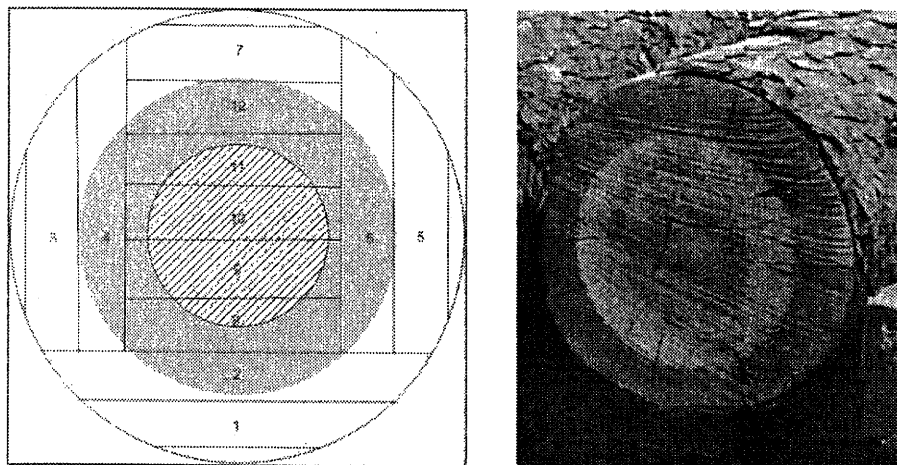In total, four kiln charges of lumber were used in this study. Two



*Figure 1. — Left side: Log profile with board layout and quality zones (outer quality zone – white, inner quality zone – gray, core center – slashes). Right side: spray painted log profile (outer quality zone – dark gray, inner quality zone – unmarked, core center – medium gray).*

Table 1. — Kiln-drying schedules for black cherry lumber sawn from small-diameter logs.

| MC at the start of the step | Conventional kiln schedule | | | Modified kiln schedule #1 | | | Modified kiln schedule #2 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Dry-bulb temperature | Wet-bulb temperature | Equilibrium MC | Dry-bulb temperature | Wet-bulb temperature | Equilibrium MC | Dry-bulb temperature | Wet-bulb temperature | Equilibrium MC |
| (percent) | ----------(°F)---------- | | (percent) | ----------(°F)---------- | | (percent) | ----------(°F)---------- | | (percent) |
| >35 | 130 | 123 | 14.0 | 130 | 123 | 14.0 | 110 | 103 | 14.1 |
| 35 | 130 | 120 | 12.1 | 130 | 120 | 12.1 | 120 | 110 | 12.1 |
| 33 | | | | | | | 130 | 120 | 12.1 |
| 30 | 140 | 125 | 9.6 | 140 | 125 | 9.6 | 140 | 125 | 9.6 |
| 25 | 150 | 125 | 6.9 | 150 | 125 | 6.9 | 150 | 125 | 6.9 |
| 20 | 160 | 120 | 4.3 | 160 | 120 | 4.3 | 160 | 120 | 4.3 |
| 15 | 180 | 130 | 3.3 | 160 | 110 | 3.2 | 160 | 110 | 3.2 |
| E | 180 | 152 | 6.0 | 160 | 131 | 6.0 | 160 | 131 | 6.0 |
| C | 180 | 172 | 12.2 | 160 | 151 | 12.1 | 160 | 151 | 12.1 |

charges were dried using the conventional kiln schedule and the remaining two kiln charges were dried using the two modified kiln schedules (**Table 1**). Four to six kiln samples were used for MC tracking for each kiln charge. Kiln samples were selected using the following criteria: (1) square edged lumber with no wane; (2) representative amounts of heartwood and sapwood; and (3) no knots. If a portion of the board met these criteria it was considered to be a potential kiln sample board. From among those boards that met these criteria, kiln samples were randomly selected.

### Postdrying inspection

After completion of the drying process, the lumber was removed from the kiln. The predrying defects, quality zone, and predrying lumber grade from the labels on the board were recorded on a data collection sheet. The postdrying inspection replicated the procedures used for the initial inspection and introduced new procedures to measure slope of grain and warp, examine cuttings used to calculate green grade, and note the presence or absence of pith. Slope of grain was determined through the use of a stencil. Warp was measured with the aid of a taper gauge for reading actual depth and a flat level surface. All four types of warp (twist, bow, cup, and crook) were measured. Crook was measured first while the board was on its edge. To measure crook the first examiner would apply a force to one end of the board and the other would measure the distance the opposing end of the board deviated from the flat surface. Bow and twist were measured with the board surface closest to the bark facing down (except in cases where more bow or twist was apparent on the opposite side) on the level surface. The corner that visually deviated from the level surface the furthest was measured for twist. Bow was measured at the point along the board's length that visually had the most deviation from the flat plane. The amount of cup was measured at the greatest distance between the surface of the board and a straight edge placed across the board's width.

The same surface measurement used to calculate the green grade was used to determine the dry grade. By standardizing this, the effects of the kiln-drying process on drying defect occurrence was unmasked. Each of the original cuttings (which had been marked on the boards prior to drying) was evaluated for defects and dimensional changes that would potentially lower the board grade. The dimensional changes that were taken into account were width shrinkage (cup/twist), length shrinkage (crook), and thickness shrinkage (cup/twist). Width shrinkage was determined by comparing the green width dimension labeled on the board with the dry width dimension. In cases of severe crook, the width of the edge cutting decreased possibly resulting in a lower board grade. The loss in width was determined by using a Lexan sheet etched with a 1-inch grid pattern. Boards that had a large degree of cup (>3/16th inch) were unable to meet the standard surface thickness for 4/4 lumber and were deemed as falling out of grade.

Table 2. — *Black cherry defect odds ratios for lumber dried under modified kiln schedules compared to the conventional black cherry schedule (T8-B4); defects with higher odds of being present in the modified kiln charges compared to the control charge are shown in bold text.*

| Presence of defect / reason for drop in grade | Modified kiln schedule #1 | Modified kiln schedule #2 |
|---|---|---|
| End checks | 0.45 | 0.47 |
| Surface checks | 0.94 | 0.60 |
| Shake | 0.41 | 0.52 |
| Twist | 0.39 | 0.47 |
| Bow | 0.27 | 0.28 |
| Cup | **1.15** | **1.33** |
| Crook | 0.74 | **1.34** |
| Surface checking (causing drop in grade) | **1.10** | 0.76 |
| Surface checking with pith present (causing drop in grade) | 0.42 | 0.45 |
| Width shrinkage (causing drop in graded) | 0.60 | 0.80 |

### Statistical methods:
### odds ratio and analysis of variance

The odds ratio is the increase or decrease (if less than one) in the odds of a particular outcome happening in a treatment group (black cherry modified kiln schedules #1 and #2) when compared to a control group (black cherry conventional kiln schedule— our control). For example, an odds ratio of 1.15 means that it is 1.15 times more likely for a drying-related defect to occur in a certain modified kiln schedule when compared to the black cherry control charges. In other words, there is a 15 percent increase in a particular drying defect when dried with the modified kiln schedule compared to the control kiln schedule. Conversely, if an odds ratio is equal to 0.41 there is a reduction of 59 percent in the occurrence of a defect dried with a modified kiln schedule compared to being dried with the control kiln schedule. An odds ratio of 2 or higher was considered to be substantial. The odds ratios for the black cherry lumber grade study are found in **Table 2**.

Analysis of variance ($\alpha = 0.05$) was conducted to discern variations in the amounts of crook between board groups dried using the three kiln schedule treatments. The null hypothesis for these tests was that all group means were equal and the alternative hypothesis was that at least one mean was different. The Tukey multiple comparison test ($\alpha = 0.05$) was used to identify dissimilar means for those cases in which the null hypothesis of no difference was rejected. The decision on whether to reject or accept the null hypothesis was made based on the range of the confidence interval. If the confidence interval contained zero, the two population means being compared were said to be statistically similar. However, if the confidence interval did not contain zero, the two population means being compared were determined to be statistically different.

### Results and discussion

The black cherry log sample consisted of 154 eight-foot logs. These logs yielded 991 boards with a total volume of 3,618 BF (based on green dimensions). The average age of the trees sawn was 60 years. The distribution of log diameters ranged from 6 to 11 inches. This project focused on logs considered to be pole logs (logs 5.9 to 11 inches small-end diameter) (McWilliams et al. 2002). **Figure 2** illustrates the distribution of small-end log diameters used in this study. The
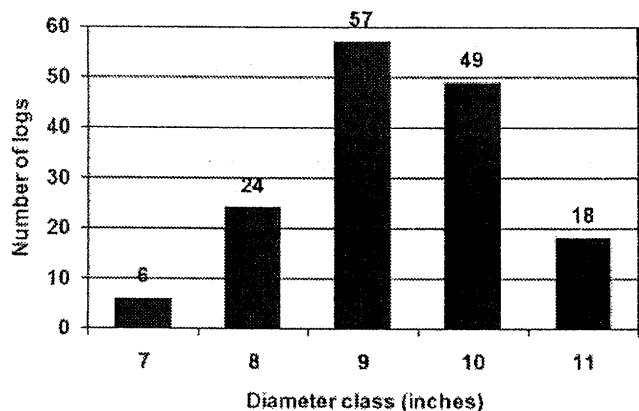
Figure 2. — Black cherry log diameter distribution (small-end diameter inside-bark) for study of lumber grade recovery before and after drying from small-diameter logs.

distribution of U.S. Forest Service log grades (Kenna 1981) in the log sample was: 6 Factory Grade #2 logs, 126 Factory Grade #3 logs, and 25 Cull logs.

The black cherry control kiln schedule had a total drying time of 91 hours with a conditioning period of 3 hours. Black cherry modified kiln schedules #1 and #2 had total kiln-drying times of 117 hours with a 9-hour conditioning period and 110 hours with an 8-hour conditioning period, respectively.

End checks in both black cherry modified kiln schedules were less likely to occur compared to the black cherry control charges. Surface checks were less likely in modified kiln schedule #2 than in modified kiln schedule #1 and the control charge. Black cherry modified kiln schedule #2 had a surface check odds ratio of 0.60, which suggested that there was a reduction in odds of finding a surface check when compared to the black cherry control charges. This may have been the result of the lower initial DB temperatures in the modified kiln schedule #2. Lower initial DB temperatures deliver less heat to the woods surface during the early stages of kiln-drying. This creates less surface tension and more tension set on the board's surface resulting in less surface checking.

Three out of four types of warp (twist, bow, and crook) in modified kiln schedule #1 showed a reduction in odds when compared to the black cherry control charges; twist, bow, and crook had odds ratios of 0.39, 0.27, and 0.74, respectively. Analysis of black cherry modified kiln schedule #2 results indicated that twist and bow were less likely to occur under this schedule as compared to the control schedule (Table 2). The odds ratio for crook increased in modified kiln schedule #2 compared to modified kiln schedule #1. Crook, however, was difficult to control in all kiln charges. The reduction in the odds of occurrence of at least two of the four types of warp in each of the black cherry modified kiln schedules likely is the result of lower DB temperatures in the later stages of kiln-drying. Lower DB temperatures may lessen the rate of warp produced owing to variable shrinkage rates throughout the board. Milder final DB temperatures may also maintain the tension set longer in the board. By maintaining the tension set longer the board may be restricted from warping.

Based on the odds ratios, black cherry modified kiln schedule #2 produced fewer boards with surface checks compared to the control charges. Black cherry modified kiln schedule #1 had lower odds of developing all other forms of drying defects

(the four forms of warp, shake, and end checking), which suggests that modified kiln schedule #1 was the better schedule for kiln-drying this lumber sawn from small-diameter cherry logs.

## Pre- and postdrying lumber grade

The last three rows in Table 2 present odds ratios for the three leading reasons why boards dropped in grade. The likelihood of a board dropping in grade because of surface checking was higher in black cherry modified kiln schedule #1 than in modified kiln schedule #2. This may be related to lower initial DB temperature in the kiln-drying schedule. Surface checking with pith present and shrinkage across the board's width were less likely in both black cherry modified kiln schedules when compared to the control black cherry kiln schedule. National Hardwood Lumber Association grading rules (2003) were applied to each board before and after drying. The predrying grade of the board was compared to the lumber grade after drying (postdrying grade). If a drop in grade was noticed, the reason for the drop in grade was recorded.

The pre- and postdrying grade results are presented in Table 3. It is clear that for all kiln schedules, lumber grade exhibited a waterfall effect with many high-grade boards falling into midgrade classes and midgrade boards falling into low-grade classes after kiln-drying. Modified kiln schedule #1 resulted in a smaller proportion of higher grade boards (No. 1 Common and better) dropping grade compared to the other black cherry kiln schedules. Only 14 percent of the higher grade boards (which originally made up 11 percent of all boards based on green grade) dropped in grade under the modified kiln schedule #1 treatment (Table 3). By comparison, 34 percent of the higher grade boards (which originally made up 9 percent of all boards based on green grade) dropped in grade under the control treatment. The lumber dried using modified kiln schedule #2 was intermediate in this regard, with 21 percent of the higher grade boards being reduced in grade to No. 2 A Common or Below as a result of the drying process.

While many sectors of the hardwood industry have found viable uses for No. 3 A Common lumber, No. 3B Common and Below Grade or "Outs" lumber typically is of such poor quality that it rarely is used for anything other than low-value industrial products, wood chips, or local use lumber. Looking at these two lowest lumber grades and the change in the proportional distribution of lumber in these grades after drying compared to before drying, it is evident that a higher percentage of the boards dried using the control schedule fell into these lowest quality categories as compared to the two modified kiln schedules. The increase in the number of No. 3B Common and "Outs" boards after kiln-drying was approximately 17 percentage points compared to increases of 13 and 12 percentage points for the boards dried using the modified #1 and #2 kiln schedules, respectively (Table 3).

## Reasons for lumber grade reductions after drying

Table 4 summarizes the reasons why the black cherry boards dropped in grade postdrying. In all three dry-kiln treatment groups, more boards dropped in grade due to shrinkage across the width of the board than for any other reason (Table 4). This occurrence is easily explained. The smallest legal cutting, as defined by NHLA grading rules, must be at least 3 inches in width for boards to make a grade of No. 3 A

Table 3. — Lumber grade distribution, based on board count, of black cherry lumber sawn from small-diameter logs pre and postdrying under one of three dry kiln schedules (in percent).

| Grade | Control | | Modified #1 | | Modified #2 | |
|---|---|---|---|---|---|---|
| | Pre-drying | Post-drying | Pre-drying | Post-drying | Pre-drying | Post-drying |
| FAS | 0.13 | 0.13 | 0.39 | 0.39 | 1.65 | 1.24 |
| FIF | 0.64 | 0.38 | 0.39 | 0.39 | 0.41 | 0.41 |
| Select | 1.27 | 0.64 | 4.33 | 3.94 | 2.07 | 2.48 |
| No. 1 Common | 7.13 | 4.84 | 5.91 | 4.72 | 7.44 | 4.96 |
| No. 2 A Common | 24.84 | 16.94 | 24.80 | 17.72 | 31.40 | 23.14 |
| No. 2B Common | 0.25 | 0.38 | 0.00 | 0.00 | 0.00 | 0.00 |
| No. 3 A Common | 34.78 | 28.92 | 43.70 | 39.37 | 35.95 | 35.12 |
| No. 3B Common | 21.66 | 34.65 | 20.47 | 33.46 | 20.66 | 31.82 |
| Out | 9.30 | 13.12 | 0.00 | 0.00 | 0.41 | 0.83 |

Table 4. — Reason for drop in grade of black cherry lumber sawn from small-diameter logs after kiln-drying using one of three kiln schedules (in percent).

| Reason for drop in grade | Control | Modified #1 | Modified #2 |
|---|---|---|---|
| No reason / no drop in grade | 65.84 | 79.92 | 77.69 |
| Surface checking | 3.29 | 3.54 | 2.48 |
| Surface checking with pith present | 10.49 | 4.72 | 4.96 |
| End checking | 0.21 | 1.18 | 0.41 |
| Shrinkage (width) | 16.87 | 10.63 | 13.64 |
| Shrinkage (crook) | 0.41 | 0.00 | 0.00 |
| Shrinkage (SST[1]) | 2.26 | 0.00 | 0.00 |
| Shake | 0.62 | 0.00 | 0.83 |
| Total that dropped in grade | 34.16 | 20.08 | 22.31 |

[1] SST = standard surface thickness.

Common and higher. In our postdrying inspection, it was common to find boards with cuttings that shrunk in width to a dimension less than 3 inches. If a 3-inch cutting shares its borders with the edge of the board and a defect (knot, pith, rot, check, etc.) prior to kiln-drying, the shrinkage incurred during kiln-drying will result in an illegal cutting (having an insufficient width dimension) for boards with a grade of No. 3 A Common and higher. The observed amount of shrinkage across the width of a cutting after kiln-drying was approximately one-quarter to one-half inch. The loss of a cutting frequently was substantial enough to lower the board's overall postdrying grade. This was especially true of flat sawn boards. Flat-sawn boards have a larger tangential face and therefore tend to shrink more across the width than do quarter-sawn boards.

The percentage of boards that dropped in grade due to shrinkage across the board's width was highest for boards dried using the control kiln schedule (Table 4). Lower final DB temperatures in the two modified kiln schedules may have resulted in less shrinkage in the later stages of kiln-drying such that the shrinkage in width did not affect the grade to the same extent in these two kiln treatments. Forty-six percent of the boards that dropped in grade in the control treatment because of width shrinkage were sawn from the outer quality zone. Boards sawn from the outer quality zone have a large tangential surface.

Surface checking with the pith present was the second most important reason why boards dropped in grade after kiln-drying (Table 4). When boards were graded before kiln-drying the pith was sometimes not visible because it often ran through the center of the thickness of the board. The NHLA grading rules allow unrestricted lengths of pith to be present in boards in the No. 2 A Common and lower lumber grades provided the pith is not included in the clear-face cuttings. The kiln-drying of boards with pith present caused a large number of boards to check and cup along the pith. Cuttings that were initially laid over these areas were in some cases no longer valid cuttings and in other cases, reduced in size such that the loss of cutting units was considerable enough to throw the board into a lower grade.

The percentage of boards that dropped in grade because of surface checking with pith present was highest for boards in the control treatment (Table 4). Lower initial dry-bulb temperatures used in modified kiln schedule #2 may have resulted in less tensile stresses and, therefore, less surface checking (with and without the pith present) during the early stages of kiln-drying. As expected, the core center of the log had the highest percentage of boards that dropped in grade because of surface checking with the pith present in each of the black cherry kiln schedule.

## Differences in lumber grade based on log quality zone

Hardwood factory log quality zones published by the United States Department of Agriculture Forest Service are helpful in identifying locations of varying lumber quality within a log (Fig. 1) (Kenna 1981). Lumber quality differences for lumber cut from the outer quality zone, inner quality zone, and core center of the logs were evident. For example, there were 189 low-grade boards (No. 3B Common and "Outs") before drying and 93 of these boards (49%) were sawn out of the core center of the log. After drying, the grade distribution deteriorated such that there were 341 low-grade boards (80% more) of which 151 (44%) were derived from wood in the core center of the log (these results are for all three drying treatments combined). Our working definition of log quality zones describes the core center as the area delineated by a circle with a radius equal to four-tenths of the log's total radius. Given this definition, the core center comprised only 16 percent of the cross sectional area of the logs yet it produced more than 40 percent of the lowest grade lumber. Looking at the other end of the lumber quality spectrum, only 3 of the 118 No. 1 Common and Better black cherry boards (2%) sawn in this study were derived from the core center regions of the logs (based on green lumber grade).

Also of interest with regard to log quality zones was whether lumber sawn from different zones was more or less apt to lose grade after being dried in the kiln. We had expected that lumber sawn from the core center would be more likely to deteriorate upon drying due to the presence of pith-related defects and juvenile wood. This was not borne out by the results,

however. The percentage increase in the lowest grades of lumber (No. 3B Common and *"Outs"*) overall, across all three drying treatments, was 100 percent for lumber sawn from the outer quality zone, 97 percent for lumber sawn from the inner quality zone, and only 62 percent for lumber sawn from the core center.

## Log size and lumber quality

We see two lumber grade trends for material derived from logs in the different size classes. First, the percentage of lumber (based on the number of boards) that grades as No. 1 Common and Better from each log-size class tends to increase with increasing log size with the 7-inch diameter logs not yielding any No. 1 Common and Better lumber, the 11-inch logs yielding 29 percent No. 1 Common and Better lumber (based on green grade), and the 8-, 9-, and 10-inch log-size classes yielding intermediate amounts of the higher grade lumber. The second trend concerns the percentage of lumber that grades as No. 3B Common or lower. Based on the green lumber grade, 38, 41, 35, 29, and 20 percent of the lumber sawn from the 7-, 8-, 9-, 10-, and 11-inch logs falls into these lowest grades.

The degree to which these percentages change after drying does not seem to be dependent on the sizes of the logs from which the lumber was sawn. In general, the No. 1 Common and Better lumber proportion falls by a few percentage points (0 to 8) and the No. 3B Common and below proportion increases by a larger amount (1 to 12 percentage points). However, the change in grade proportions is not consistent and predictable based on the size of the logs from which the lumber was sawn.

## Analysis of lumber warp between kiln schedules

The average amount of twist in the black cherry control charges was 0.196 inch or just less than 13/64 of an inch. The average amount of bow and cup was 0.287 (9/32 of an inch) and 0.070 (just less than 5/64 of an inch) inch, respectively. Average crook was 0.365 inch or just less than 3/8 of an inch.

The average amount of warp for the black cherry lumber dried using modified kiln schedule #1 was comparable to the average amount of warp in the black cherry control kiln schedule. Twist had an average measurement of 0.195 inch. The average bow measurement was 0.257 inch. The average cup and crook measurements were 0.068 inch and 0.366 inch, respectively.

The average measurement of twist and bow for boards dried using the black cherry modified kiln schedule #2 was 0.217 inch and 0.236 inch, respectively. The average amount of cup was 0.079 inch. Crook had an average measurement of 0.452 inch.

Analysis of variance ($\alpha = 0.05$) conducted on the twist results for lumber from the three kiln schedule treatments indicated no difference among means. The comparison of bow measurements for the boards in the three drying treatments pointed to a difference in bow among the groups. The Tukey multiple comparison test ($\alpha = 0.05$) indicated that the average bow of boards dried under the control schedule was statistically different than the bow measurements for boards dried using modified kiln schedule #2. Analysis of variance conducted on the cup measurements also indicated a difference among lumber groups. The Tukey test for cup showed that the differences in cup for boards dried using modified kiln schedules #1 and #2 were significant. Crook means also were found to be significantly different with the average crook measured on boards dried using modified kiln schedule #2 being different from both the average crook in the black cherry control schedule and modified kiln schedule #1.

## Summary and conclusions

In this research we focused on the lumber grade and quality characteristics of dry lumber sawn from small-diameter hardwood logs in a conventional sawmill and dried in a kiln. There was a common trend that defined the relationship between log diameter, log grade, log quality zone, and lumber grade post-drying. As log diameter and log grade increased, so did the lumber grade yield. Lumber quality differences for lumber cut from the outer quality zone, inner quality zone, and core center of the logs were evident. Forty-nine percent of the lumber that graded as No. 3B Common and below was derived from the core center of the log which makes up only 16 percent of the log's cross sectional area.

The two leading reasons for boards dropping in grade after drying were surface checking with pith present and shrinkage across the width of the board. Surface checking with pith present was concentrated in the core center of the log. Black cherry modified kiln schedules #1 and #2 decreased the percentage of total boards that dropped in grade because of surface checking with the pith present The modified black cherry kiln schedules reduced the total percentage of boards that dropped in grade because of shrinkage across the board's width as compared to the control (conventional) schedule.

Odds ratios were used to determine the effect of modified kiln schedules on drying defect development when compared to the control kiln schedule. An odds ratio of two was considered to be substantial. All drying defect categories (end check, surface check, shake, twist, bow, cup, and crook) were below two for both of the black cherry modified kiln schedules. The likelihood of cup increased slightly in both of the black cherry modified kiln schedules. There also was a slight increase in the odds of crook developing in black cherry modified kiln schedule #2 compared to the control schedule. The development of crook was difficult to control when kiln-drying.

Black cherry modified kiln schedule #1 was less likely than modified schedule #2 to develop six of the seven drying defects based on defect odds ratios that use the control treatment as the baseline for comparison.

For those sawmills that have reduced the diameters of the logs they are processing, this study will shed light on alternate drying strategies for black cherry lumber sawn from these smaller logs. Modified kiln schedule #1, in which the final DB temperature was lowered 20 °F from that of the conventional schedule and the wet-bulb settings maintained an EMC comparable to the conventional schedule, is particularly noteworthy for the reduction in defects and minimization of grade loss that it produces as compared to the conventional (T4-D8) cherry schedule.

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