Examination of the potential to reduce water application rates in pine wet decks

HEATH RAYBON, LAURENCE SCHIMLECK, KIM LOVE-MYERS, FINTO ANTONY, JOE SANDERS, RICHARD DANIELS, EDWARD ANDREWS, AND ERIK SCHILLING

ABSTRACT: Wet storage of logs under sprinklers is a common method for maintaining log quality and consistent fiber supply to wood production facilities. Because of increased concerns regarding water use, mills in the southeastern United States are interested in refining water application strategies. To do so, we need to examine how log moisture varies with time and in response to differing water application rates. We used time domain reflectometry (TDR) to examine variation in log moisture of southern pine logs in response to nominal water application (100 mm/day) and a 30% reduction in water use at two woodyards (Santee in South Carolina and Dry Creek in Alabama) over a 15-month period. Initially significant differences between treatments were observed, but differences only existed for a short period, indicating that a 30% reduction in the amount of water applied results in little change in log moisture or quality.

Application: The amount of water applied to pine wet decks can be reduced by at least 30%, with little change in log moisture or quality.

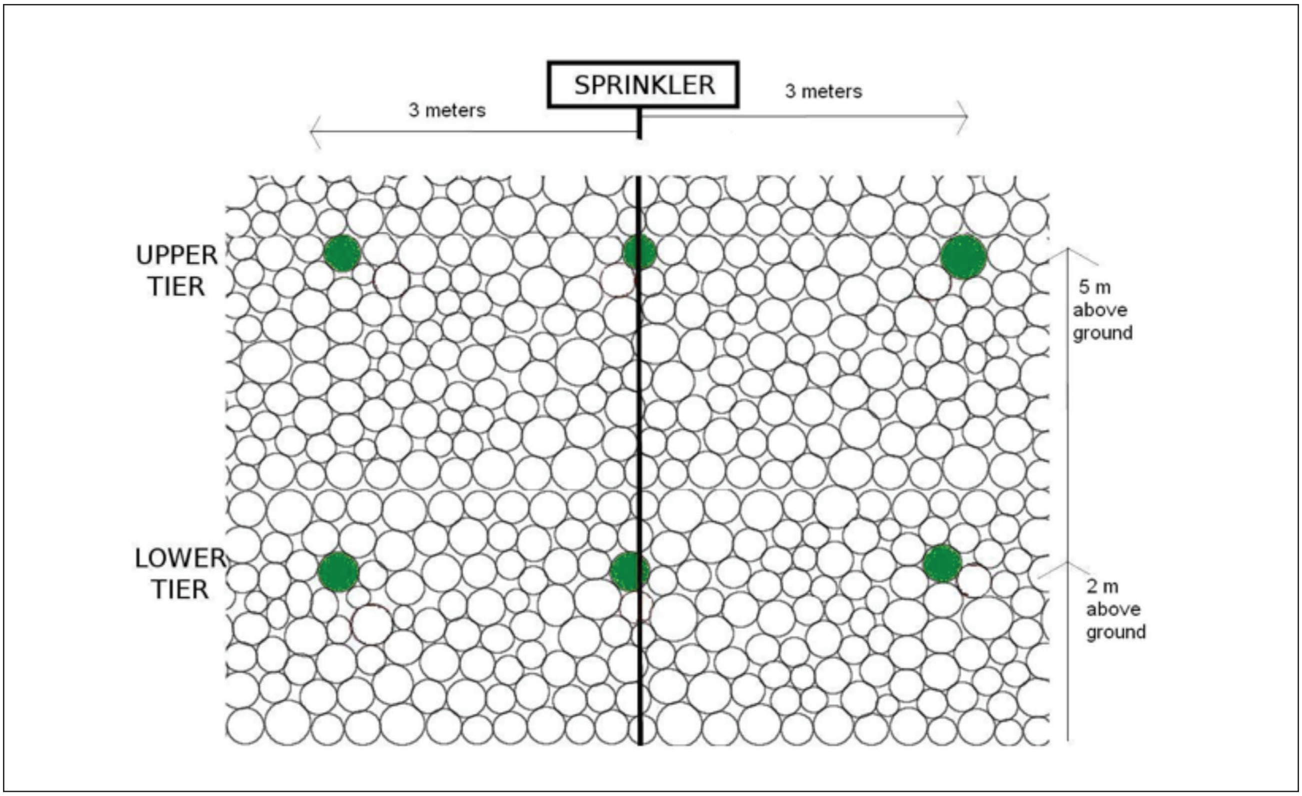
Wet storage of logs under sprinklers is a common method for maintaining log quality and consistent fiber supply to wood production facilities. Water is applied continuously while the logs are stored (which can be up to 1 year), with the aim of achieving a very high moisture content, thereby reducing the risk for fungal decay or damage by insects [1,2]. Moisture contents of greater than 100% (on a dry weight basis) are typical. It is assumed that at such high moisture levels fungi are unable to degrade wood.

Because of increased concerns in the southeastern United States regarding water use, mills are interested in refining water application strategies. To do so, we need to examine how log moisture varies with time and in response to differing water application rates. Monitoring the moisture content of stored logs is very difficult and dangerous once a wet deck has been built, but recent studies [3,4] have demonstrated that time domain reflectometry (TDR) has the potential to monitor log moisture over an extended period.

TDR has been used to monitor moisture variation in standing trees [5-7]. The measurement of moisture in wet stored logs uses a similar approach. A probe is inserted into a log and connected to a TDR instrument. The probes used in this study were two 3 mm diameter stainless steel rods, 125 mm long, brazed to a copper coaxial cable of known length and cast inside a 30 mm × 30 mm × 60 mm plastic block. A pulse of energy is transmitted through the cable to the probe where it enters the wood and is reflected back to the instrument. The time the pulse takes to return is influenced by the moisture content of the wood, with a higher moisture content slowing the pulse and increasing the apparent length of the cable. Therefore, the longer the apparent length, the higher the moisture content of the wood. The apparent length is read from a waveform trace on an oscilloscope display [3], and an equation is used to convert TDR readings to moisture contents.

Recently, Schimleck et al. [4] used TDR to monitor the moisture variation of 30 wet-stored southern pine logs over an 11-week period in a commercial woodyard. Probes were inserted into each log at 3 m, 4.5 m, and 7.5 m from the butt. The logs were then placed in a standard wet deck under normal operating conditions. The aim was to determine if the probes and cables could withstand being installed into a wet deck, and to examine the effects of probe position in logs as well as the position of the study logs with respect to height and distance from a sprinkler head. The study found that if sufficient care was taken when building a wet deck, probes could survive the harsh environment with no sign of deterioration. The location of probes within each log was potentially important. Schimleck et al. [4] recommended probes be inserted near the butt end of logs and near the center of mass. They suggested that the butt end of logs might dry quicker than the middle in the event that water application is insufficient to maintain an existing moisture content. Log position was important, especially with respect to vertical position, and it was recommended that logs in a lower and upper tier be examined. Horizontal position with respect to the sprinkler was less important, but because the study was placed close to the end of a wet deck, this aspect could not be explored thoroughly.

Further research is required if TDR is going to be used



1. Layout of an experimental stall.

widely for monitoring the moisture content of logs in wet decks. Although Schimleck et al. [4] demonstrated the potential of TDR for this purpose, they did not monitor moisture throughout an entire cycle of four seasons. The objective of this study was to use TDR to monitor moisture variation in southern pine logs over an extended period (15 months) and to determine whether water application rates can be reduced.

MATERIALS AND METHODS

Santee woodyard

Studies were conducted at two woodyards. The first was at the Santee woodyard, near Georgetown, SC, USA, with installation commencing October 9, 2009. Southern pine logs selected for examination were relatively straight with no forks and a diameter greater than 150 mm (to accommodate the 125 mm long probe rods described in Schimleck et al. [3]), 4.6 m from the butt. Logs were prepared for probe installation by removing the bark at 1.5 m and 4.6 m from the butt of each log.

Because of space limitations at the woodyard, only two water level treatments (nominal and 30% reduction) were used, with three replications of each. Each of the six treatment/replication combinations was located in a separate compartment or "stall" that was sprayed with water from a single sprinkler head located at the center of the stall. Sprinklers were 30 m apart (typically the distance is 20 m) to avoid overlap between sprinklers and ensure that target application rates were achieved. A control treatment consisted of the nominal water application rate for the woodyard (estimated to be 100 mm/day). The experimental treatment was an approximately 30% reduction of the nominal rate, which was achieved by shutting off sprinklers 2 days each week (usually Saturday and Sunday, with water shut off to the same three stalls Friday afternoon, and resuming the following Monday).

Each stall contained six logs, with three logs positioned in a lower tier at a height of 2 m and three logs in a second tier at a height of 5 m. One log in each tier was positioned 3 m to the left of the sprinkler head, and another was positioned 3 m to the right. The third log was positioned directly under the sprinkler head (**Fig. 1**). Tier 1 was installed approximately 2 weeks before tier 2, as it took time to build the wet deck to a height of 5 m. Data collection commenced once each tier was installed.

Data collection continued for 9 months, at the end of which 10 logs were removed from the nominal and reduced water level treatments for determination of pulp yield by International Paper. For comparison, 10 freshly delivered (green) logs from an operational wet deck were also pulped using the conditions shown in **Table I**. After 15 months (January 2011) the wet deck was dismantled and logs from the categories described above were again collected for pulping.

Removal of logs was achieved by wrapping a chain around the butt of selected logs and pulling them out using a hydraulic loader. Whole logs were then chipped, bulked, and a representative chip sample (approximately 30 kg) removed for pulping.

White liquor sulfidity, % active alkali	31
Presteaming	
Time, min	10
Temperature, °C	105
Impregnation	
Effective alkali charge, % Na_2O	15.8
Liquid/Wood ratio, L/kg	4
Temperature, °C	110
Time to temperature, min	15
Time at temperature, min	30
Cooking	
Temperature, °C	170
Time to temperature, min	30
Time at temperature, min	110
Residual effective alkali, g/L Na_2O	6.2
H-Factor	1845

I. Pulping conditions.

Dry Creek woodyard

The second study was conducted at the Dry Creek woodyard, in Prattville, AL, USA, in the lower coastal plain region of the southeastern United States. Installation began on November 5, 2009. The study design was almost identical to the Santee study. Because of limited space, only two replications of two treatments (the nominal rate, again 100 mm/day, and a 30% reduction of the nominal rate) were used. Six southern pine logs were examined per stall and log position was the same as the Santee study (Fig. 1). Tier one was installed approximately 2 weeks before tier two. The study ended in February 2011.

Data analysis

Using the model described in Schimleck et al. [4], TDR readings collected at both woodyards were converted to predicted moisture contents (on a dry weight basis). The predicted moisture contents for each probe were examined and unrealistic extreme values were removed from the dataset before analysis. On a few occasions, probes appeared to have malfunctioned; extreme moisture content predictions were usually related to these probes.

We used mixed effects analysis of variance (ANOVA) models to analyze data from each of the sites. The variables examined for significant effect on moisture content at the study sites included the replication, treatment, tier, position (placement of log with respect to sprinkler head), location (distance of probe from the butt of tree), and day of measurement. All possible interaction effects (up to third order) were considered as part of the model building process. The full statistical model can be written as follows:

$$Y_{iklmn} = \mu + w_i + e_{ij} + t_k + p_l + wt_{ik} + wp_{il} + tp_{kl} + wtp_{ikl} + e^*_{ijkl} + l_m + wl_{im} + tl_{km} + pl_{lm} + wtl_{ikm} + wpl_{ilm} + tpl_{klm} + o_{ijklm} + d_n + wd_{kn} + td_{kn} + pd_{ln} + ld_{mn} + wtd_{ikn} + wdl_{inm} + tdl_{knm} + wdn_{iln} + tpd_{kln} + pld_{lmn} + o^*_{ijklmn}$$

where Y_{iklmn} is the predicted moisture content in percent, μ is the intercept of the model, w_i is the effect of the water treatment (I = nominal or 30% reduced), e_{ij} is the error introduced by replicate j of treatment i, t_k is the effect of tier (k = upper or lower), p_l is the effect of position relative to the sprinkler (l = left, center, or right of sprinkler), e^*_{ijkl} is the error introduced by the log in tier k in position l for replicate j of treatment i, l_m is the effect of location of the probe within the logs (m = 1.5 m or 4.6 m), o_{ijklm} is the error introduced by the probe in location m of the log in tier k in position l for replicate j of treatment i (residual error), d_n is the effect of the day of TDR measurement, wd_{kn} is the interaction effect of water treatment and day, and o^*_{ijklmn} is the error introduced by the day n measurement at location m of the log in tier k in position l for replicate j of treatment i (residual error). Notations involving two or more symbols represent interactions of the factors represented by those symbols.

Because the measurements from each probe were taken over time, we expected to see a correlation between measurements collected at two consecutive time points within probes. The week of measurement was therefore analyzed as a repeated factor with an AR(1) covariance structure to account for correlation between measurements from a single probe over time. This was the most appropriate covariance structure, based on the fit statistics of the resulting model.

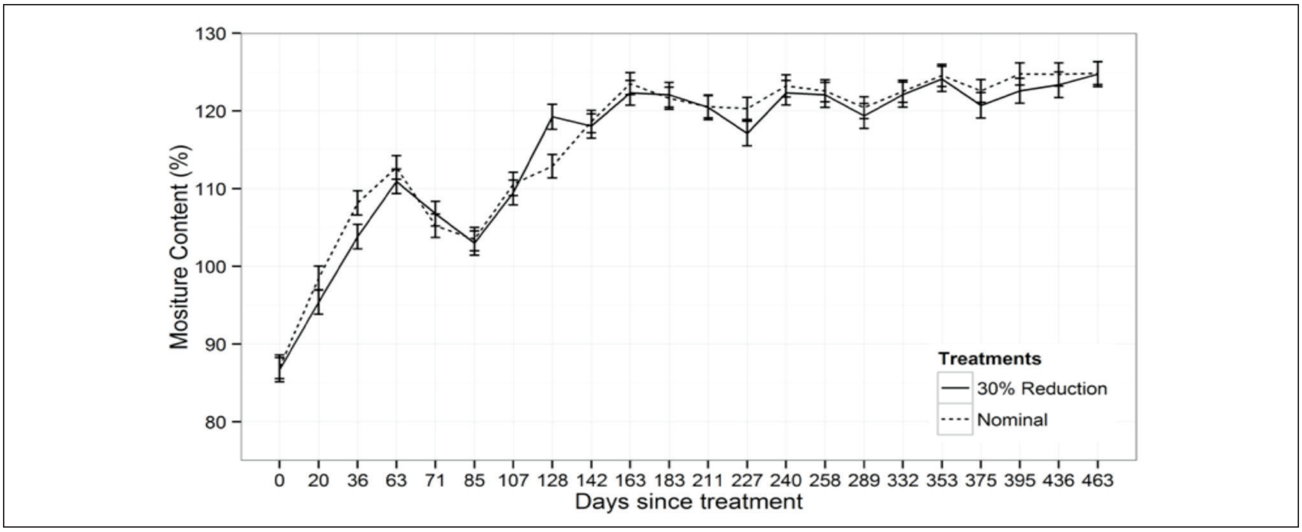
RESULTS

Santee woodyard

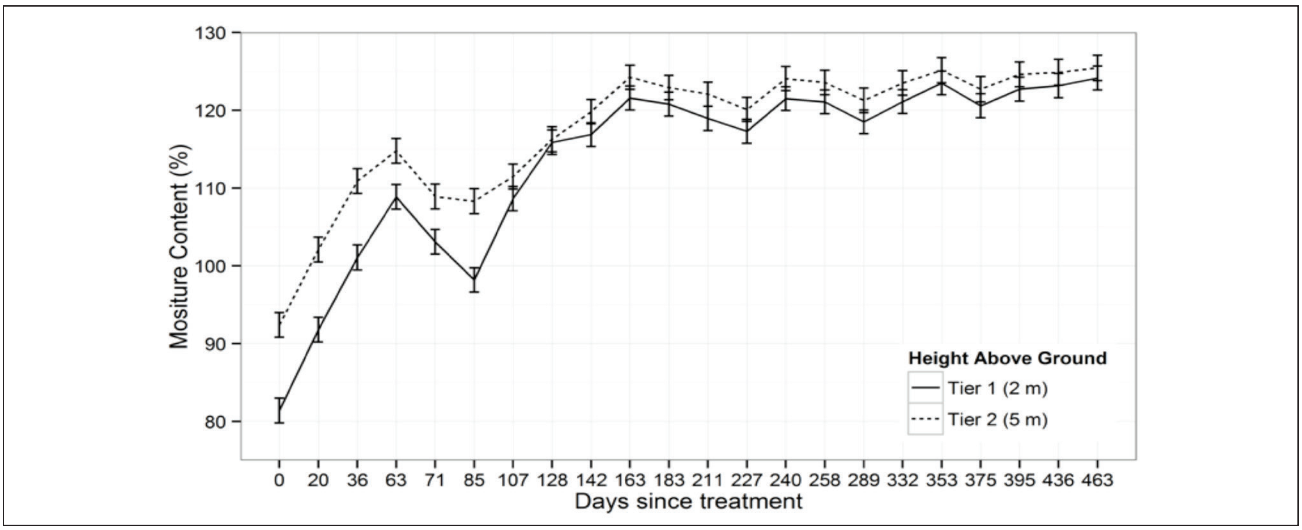
Significant average moisture differences occurred between tiers by day, treatment by day, and location by day. **Table II** lists the significant interactions with their associated p-values.

Effect	Num DF	Den DF	F Value	Pr > F
Treatment	1	3.68	0.26	0.6378
Tier	1	26.8	6.05	0.0206
Position	2	26.3	0.67	0.5193
Location	1	26.1	0.12	0.7329
Tier*Location	1	26	16.67	0.0004
Position*Location	2	25.9	4.34	0.0237
Day	21	953	87.16	<0.0001
Treatment*Day	21	952	1.97	0.0058
Tier*Day	21	953	2.57	0.0001
Location*Day	21	953	4.38	<0.0001

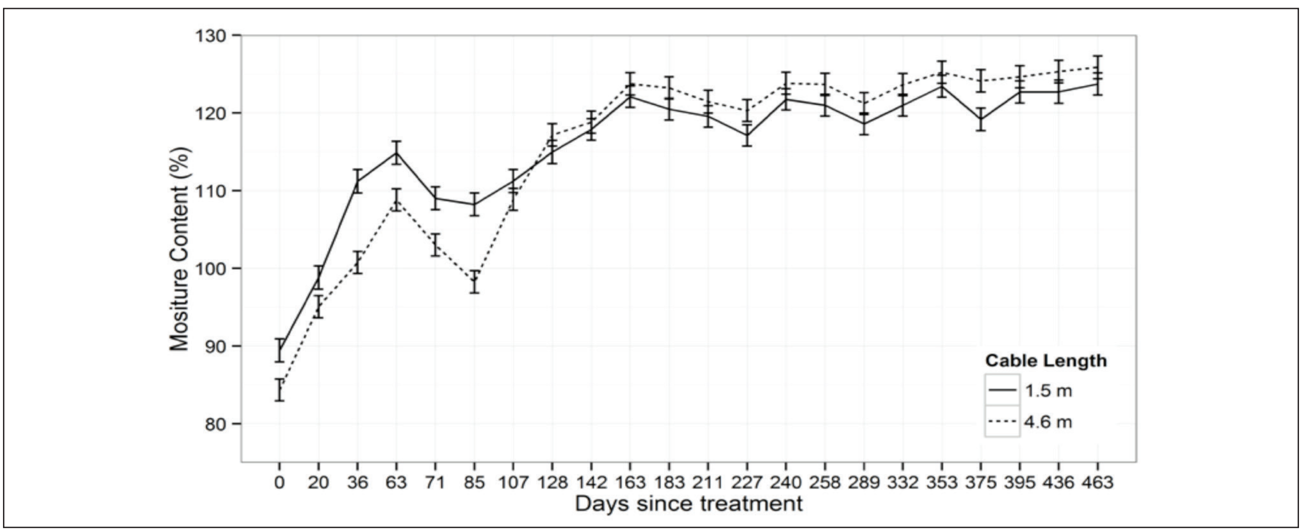
II. Type 3 tests of fixed effects for the Santee woodyard data analysis. (Num DF = Numerator degrees of freedom; Den DF = Denominator degrees of freedom; Pr > F = the p-value associated with the F statistic.)



2. Interaction of treatment and day for logs stored at the Santee woodyard. Error bar indicates ±1 standard error.



3. Interaction of tier and day for logs stored at the Santee woodyard. Error bar indicates ±1 standard error.



4. Interaction of location and day for logs stored at the Santee woodyard. Error bar indicates ±1 standard error.

Figure 2 shows that the logs in the two different treatments differ in average moisture content only sporadically throughout the study. Despite the occasional significant differences, average moisture contents of both treatments were similar and averaged around 120% at the end of the study.

The average moisture contents of logs in tier one were lower than those of tier two for the entire study (**Fig. 3**), but the difference was only significant from day 0 to day 85. The same can be said for the interaction between location and day (**Fig. 4**), where probes located 1.5 m from the butt end of the logs had higher moisture contents from day 0 to day 85 than did probes located 4.6 m from the butt.

Table II also shows that average moisture contents differ between tiers by location. For tier 1, lower moisture contents were observed 4.6 m from the butt end of the log than 1.5 m from the butt. In addition, there is a position by location effect (i.e., moisture contents are variable in different positions by location). Again, with both interactions, the significance of effects is mainly limited to the initial phase of the study. The interactions were not a major factor affecting stored log quality; the average moisture content of logs was sufficiently high to prevent decay.

Logs	Screened Yield, %
Green (woods run)	100.0
Nominal (9 months)	101.2
Nominal (15 months)	101.7
30% reduction (9 months)	99.0
30% reduction (15 months)	99.4
Operational (9 months)	96.7
Operational (15 months)	97.8

III. Screened pulp yield for green and operational logs and logs from the nominal and reduced water treatments.

Effect	Num DF	Den DF	F Value	Pr > F
Treatment	1	1.78	0.22	0.688
Tier	1	19.5	6.06	0.0232
Location	1	21.1	5.65	0.027
Day	17	513	70.3	<0.0001
Treatment*Day	17	513	3.37	<0.0001
Tier*Day	17	514	2.79	0.0002
Location*Day	17	513	3.76	<0.0001

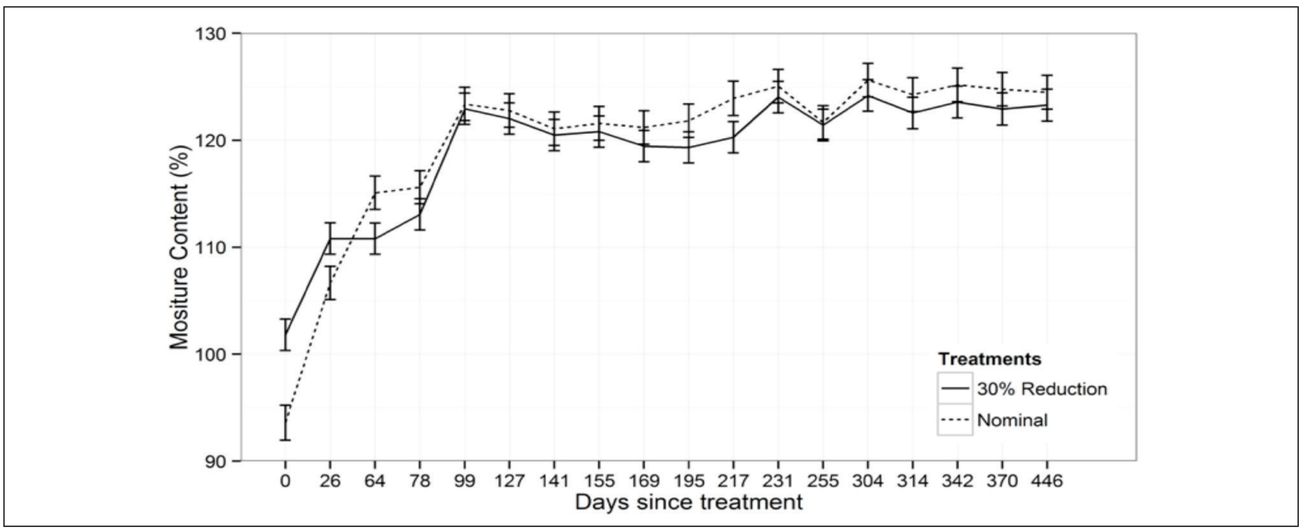
IV. Type 3 tests of fixed effects for the Dry Creek woodyard data analysis. (Num DF = Numerator degrees of freedom; Den DF = Denominator degrees of freedom; Pr > F = the p-value associated with the F statistic.)

Table III shows pulp data for logs collected from the two treatments, an operational deck at the time of sample collection and green at 9 and 15 months for the Santee woodyard. For comparison, the pulping results are reported as a percentage of the baseline green material. Table III indicates that there is little change in screened pulp yield at 9 and 15 months if water application rates are reduced by 30%.

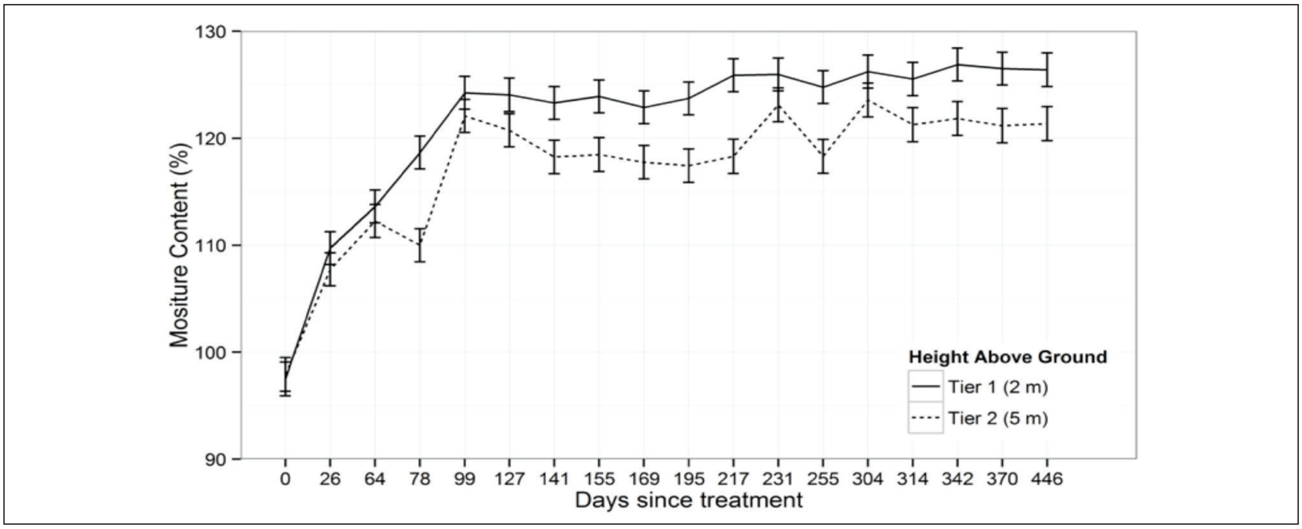
At the completion of the Santee study, samples were collected from test logs and moisture contents were determined gravimetrically. Average moisture content (116.5%) compared well with average TDR predicted moisture content (123.0%).

Dry Creek woodyard

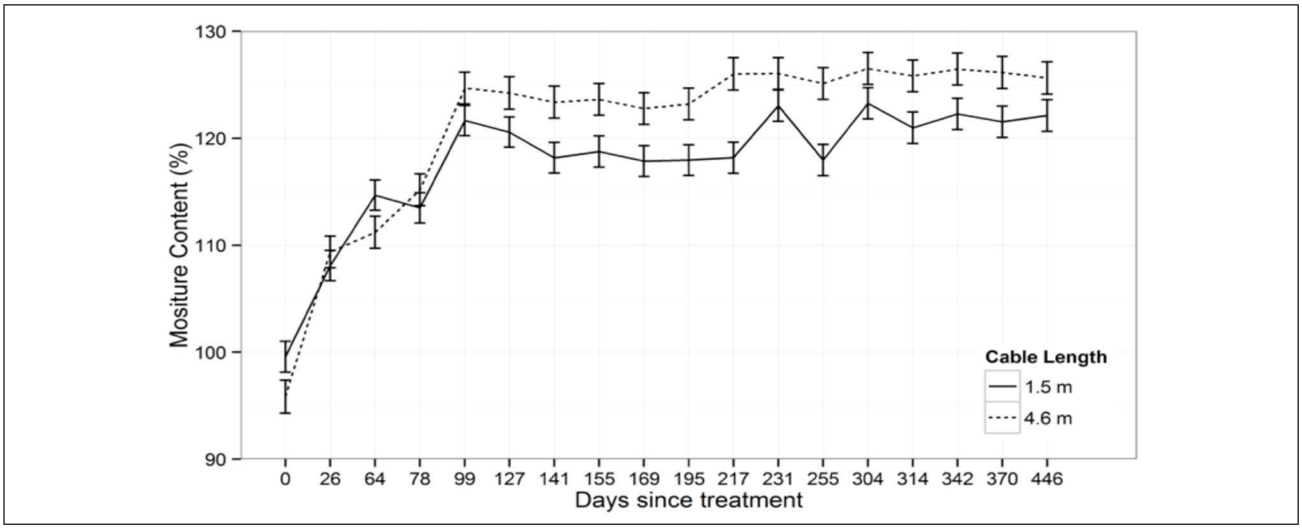
Data analysis revealed several important interactions at the Dry Creek woodyard (**Table IV**). A treatment by day effect occurred at the initiation of the study. We saw a significant difference in moisture contents of logs in different treatments, depending on data collection day. After installation, logs in both treatments gained moisture and reached nearly equivalent moisture contents quickly (**Fig. 5**).



5. Interaction of treatment and day for logs stored at the Dry Creek woodyard. Error bar indicates ±1 standard error.



6. Interaction of tier and day for logs stored at the Dry Creek woodyard. Error bar indicates ±1 standard error.



7. Interaction of location and day for logs stored at the Dry Creek woodyard. Error bar indicates ±1 standard error.

The two tiers at Dry Creek had different average moisture contents at various data collection times during the study, but generally they were not statistically significant. The differences were noticed across both treatments, and were not present at the initiation of the study, as with the treatment effect. Instead, the differences were apparent on seemingly arbitrary measurement days. In general, the average moisture content of tier 2 was lower than tier 1 (**Fig. 6**). This is the reverse of the tier effect occurring at Santee, where the upper tier had higher average moisture content than the lower.

Probes at the two locations within each log occasionally had significant differences in average moisture content (**Fig. 7**), but the difference in average moisture content observed between probe locations was not significant until the upper moisture range was reached after 100 days. At that time, the significance was sporadic, with average moisture contents fluctuating around 120%.

At the completion of the Dry Creek study, samples were collected from test logs to compare gravimetric and TDR predicted moisture contents. Average gravimetric moisture content (125.2%) agreed well with average TDR predicted moisture content (123.9%).

DISCUSSION

The goal of this study was to determine if water application rates at commercial woodyards could be reduced while avoiding fungal degradation in southern pine logs by maintaining sufficiently high moisture content. The data collected from the Santee and Dry Creek woodyards indicate that water application rates can be reduced by at least 30%, with little to no increase in the potential for log degradation. Although moisture content was affected by treatment at Santee and Dry Creek, the effect was only seen at the outset of both studies, before stable moisture contents were achieved. This might be an indication that the two treatments take different amounts of time to bring the logs to a maintenance level, but once that level is reached, each is equally effective. In-house pulping trials conducted by International Paper using Santee woodyard logs stored for 9 and 15 months found that treatment had no effect on pulp yield.

Moisture content was also affected by the tier in which logs were located. Significant differences were recorded only at the beginning of the Santee study, but appeared throughout the Dry Creek study on otherwise arbitrary days (possibly resulting from strong winds blowing water away from the wet deck). Comparing and contrasting the studies at the two woodyards indicates that the effect of tier location, when present, might be specific to the site of the woodyard. Therefore, if it is of concern in a particular woodyard, it should be monitored with particular attention to the direction of the effect (whether the upper or lower tier tends to retain greater moisture content).

Moisture content predictions were compared with measured moisture contents of sample logs at both locations, with favorable results. At Santee, a small difference was observed, which might be accounted for by the warm, windy weather at the time samples were collected and a delay of approximately 30 min between collection and weighing. At Dry Creek, samples were cut and immediately weighed, and the difference between TDR predicted and calculated moisture was small (1.3%). The similarity of the two sets of results shows that TDR can be used for monitoring moisture in wet-stored logs over long periods.

Because of space restrictions, the two studies were reduced to two treatments and only three replications at Santee and two replications at Dry Creek. Ideally, more treatments with greater reduction in application rates would have been installed, with three or more replications of each. The issue with additional treatments and replications is that the scale of these studies is massive. For both sites, the studies were nearly ended months before their scheduled completion. A sudden increase in demand for pulp, coupled with rainy weather across the south, decreased log supply to the point where the woodyards were empty of all logs but those being used for our research. International Paper maintained both studies, at considerable cost, during this time. If a greater volume of logs had been committed, owing to more treatments and replications, at least part of a larger study likely would have been terminated.

An important question is: How much can water application

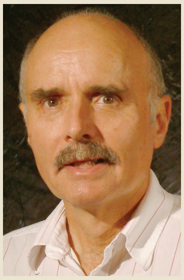
ABOUT THE AUTHORS

We became interested in this topic because lack of knowledge regarding wet deck watering strategies was identified by industry as an important question. This study compliments an earlier study we published in *TAPPI JOURNAL* [4]. In our more recent study, the duration of data collection is much longer and reducing the amount of water applied is investigated.

The most difficult aspects of the study were the long drive to both study sites and collecting data while the wet deck was frozen during extremely cold weather. The most interesting finding was how stable log moisture content was once the logs were fully saturated.

Mills will benefit from this information as it will help them develop strategies for reducing water use on wet decks. Our next steps include honing water application strategies and improving the accuracy of time domain reflectometry (TDR) readings.


Antony


Sanders


Daniels


Love-Myers


Andrews


Raybon


Schilling


Schimleck

Antony was research statistician, Sanders was research coordinator, and Daniels is professor, Warnell School of Forestry and Natural Resources, University of Georgia, Athens, GA, USA. Love-Myers is associate director, University of Georgia Statistical Consulting Center, University of Georgia, Athens, GA, USA. Andrews is forester, USDA Forest Service, Southern Research Station, Athens, GA, USA. Raybon is procurement forester, International Paper, Prattville, AL, USA. Schilling is senior research scientist, NCASI, Aubrey, TX, USA. Schimleck is professor and head, Department of Wood Science and Engineering, College of Forestry, Oregon State University, Corvallis, OR, USA. Email Schimleck at Laurence.Schimleck@oregonstate.edu.

rates be reduced before wood degradation begins? Literature on what a suitable target might be is limited; however, Huisman et al. [8] suggest that moisture contents greater than 80% are sufficient. It is clear from this study that further refinement in water application rates is possible and should be analyzed, but the difficulty in this research lies in the potential economic losses if less than the minimum amount of water is applied for too long. Hundreds of thousands of dollars of logs could be susceptible to fungal decay and might be useless for pulp or saw timber production. The answer is complex because each woodyard will have certain aspects that affect the overall water application requirements. These aspects include pump pressures, water application methodology, wet deck design, and weather patterns in different wet yard locations.

Another issue relates to determining the best method to achieve a reduction in the amount of water that is applied. It is difficult to turn off the pumping system to an entire wet deck. Perhaps the most useful method would be to turn off certain sections at varying times of the day or night. There are endless possibilities for reducing the water applied to logs, and many need to be explored with careful observation at each wet deck to tailor a watering schedule that uses the optimum amount of water. For example, once a target moisture content is achieved, water may only be applied when it is observed that logs are losing moisture. During cool or wet weather, the application of water might be unnecessary for several weeks or even months, saving a considerable amount of water and money.

Schimleck et al. [4] noted several benefits of using TDR to monitor moisture in wet stored logs. Included were the ability to monitor moisture above the fiber saturation point, to track moisture variation within logs located at any position within the wet deck, and to remotely observe moisture variation within the wet deck, increasing safety. In addition to these benefits, this study has demonstrated that TDR can be used to monitor moisture variation over an extended period.

CONCLUSIONS

TDR was successfully used to monitor moisture variation in two pine woodyards over a period of 15 months. At both woodyards, log moisture content was similar, even when water application rates were decreased by 30%. Further reductions are possible. Additional research is needed to determine to what level water application rates can be reduced. **TJ**

ACKNOWLEDGEMENTS

This research was supported by the National Council for Air and Stream Improvement (NCASI). The authors also gratefully acknowledge support from the Wood Quality Consortium of the University of Georgia and from International Paper for allowing access to their Santee and Dry Creek woodyards and for evaluating the pulp quality of logs stored for 9 and 15 months at the Santee woodyard.

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