Monitoring the drying of residue bundles during storage in the forest and at a terminal in Ireland

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Abstract:
Bundles derived from green and brown forest residues from Sitka spruce (Picea sitchensis) were stacked in the forest and at a terminal in a range of treatments between March and August 2010. Pre-storage mean moisture content was 50.8% and 54.0% for green and brown bundles respectively. After 18 to 21 weeks storage all treatments lost weight and dried significantly. In-forest green bundle stack moisture content ranged from 28.3% and 39.2% while brown ranged from 39.5% to 47.5%. Post-storage moisture contents at the terminal ranged from 23.3-25.1% and 28.8-32.4% for green and brown bundles. Covering stack tops had a significant effect on green bundle drying in the forest but not on brown bundle drying in-forest or any bundles stacked at the terminal. Further, stacking bundles in a double rather than single row did not affect drying. Finally, there was no significant difference in observed drying rate between bundles stacked in an exposed compared with a sheltered forest location.

Keywords: forest residues, bundles, storage, drying

1 Introduction

1.1 Study Objectives

In anticipation of the development of a commercial forest residue bundle supply chain in Ireland, an industry/academic partnership met to scope a research project will the objective of assessing the following:

The rate of change in bundle moisture content in storage at a terminal and in the forest.

The difference in drying rate between green bundles, made from fresh brash with leaves still attached and brown bundles, made from seasoned brash that has shed leaves.

The effect on drying of covering the stack with a plastic top cover in order to prevent re-wetting from rain.

The effect on drying of stacking bundles in single width rows, or double width rows. This issue was important for two reasons: bundles could only be stacked singly to a height of three metres, after which the stack becomes unstable; the volume of bundles removed could exceed the available stacking space at roadside if bundles were only stacked in single width rows.

The effect on drying of exposure to the wind on an open clearfell site compared to a sheltered site.

1.2 Impact Of Bundle Storage

The storage and monitoring of moisture in forest residue bundles has not been previously studied in Ireland. Hoyne and Thomas, (1997) observed the change in weight of bundles manufactured with a prototype bundler. Bundles stored between August and December 1996 gained 20% in weight, whereas bundles lost 30% weight in a second storage trial from December 1996 to April 1997. Prior studies on small whole trees and roundwood stored in the forest in Ireland indicated that moisture content would reduce over summer seasoning, particularly if covered, but the rate of drying was highly variable (Kofman & Kent, 2006). Subsequent research indicated that roundwood stored at a terminal would rapidly dry, depending on time of year and covering did not significantly impact the rate of drying but ensured greater homogeneity in moisture content (Kofman & Kent, 2009).

Moisture management, through storage and drying in the supply chain between harvesting and utilization, is key to improving both transportation costs and market values (Jirjis, 1995). Storing forest residue bundles is both a necessity and an opportunity. Pettersson and Nordfjell (2007) acknowledge the logistical challenges of handling and scheduling supply of large volumes of residue material and also indicate the financial benefit of higher energy value through moisture loss during storage. Johansson *et al.* (2006) describe the positive economic impact on the residue bundle supply chain of transporting bundles seasoned so that truck weight limits are not exceeded prior to full volume capacity being reached.

2 Material and Methods

Two storage trials of green and brown residue bundles were constructed in a forest and at a terminal in the south east of Ireland. The trials took place between March and August 2010.

2.1 Pre-storage Methods

All bundles were made with a John Deere 1490D bundler from Sitka spruce (*Picea sitchensis*) residues of shortwood clearfell operations. Brown bundles were transported from a site clearfelled in May 2009. On this site, both harvester and forwarder drove over the brash, which was left loose over winter and bundled in February 2010. On a second site, green bundles were made in March 2010 immediately after the clearfell. All bundles were 70cm in diameter and cut to a standard 2.5m length. Pre-storage moisture content was determined by comminuting 90 green and 63 brown bundles using a Jenz 660AZ chipper/shredder and sampling each individually, taking a cumulative sample of c. 5000g from each bundle for moisture content analysis.

2.2 Forest Storage Trial Treatments And Methods

The storage trial of 857 residue bundles was constructed along a forest road through a recently clearfelled area adjacent to a mature Sitka spruce stand at Listrolin, Piltown, Co. Kilkenny (52°21’50”N 7°14’30”W), at 250m elevation. The trial consisted of 239 green bundles divided between two stacks and 618 brown bundles divided between six stacks. Green and brown bundles were delivered to the forest storage trial site between the 10th and 24th March 2010. The delivered weight of bundles in each stack was determined by driving the trucks transporting the bundles over a calibrated weighbridge on route to the forest storage site.

Each stack tested a particular treatment as follows:

Green bundles with no cover in a single width stack in an exposed location

Green bundles covered on top in a single width stack in an exposed location

Brown bundles with no cover in a single width stack in an exposed location

Brown bundles covered on top in a single width stack in an exposed location

Brown bundles with no cover in a single width stack in an sheltered location

Brown bundles covered on top in a single width stack in an sheltered location

Brown bundles with no cover in a double width stack in an exposed location

Brown bundles covered on top in a double width stack in an exposed location

The cover used was 3m wide, 1000 gauge plastic. Figure 1 shows brown bundles, with no cover, stacked in a sheltered location beside the forest road, under mature trees.

Figure 1: Brown Bundle Stack In A Sheltered Forest Location With No Cover

The stacks were left in situ for five months, until 15th August 2010. Each stack was loaded separately onto trucks and re-weighed on a calibrated weighbridge. Twenty bundles were randomly selected from each stack, comminuted with the Jenz 660AZ and individually sampled for moisture content. The mean post-storage moisture content of each stack was determined as the mean of the 20 sample bundle moisture contents.

2.3 Terminal Storage Trial Treatments And Methods

The terminal was located in the log yard at the Medite (Europe) Ltd. at Redmondstown, Clonmel, Co. Tipperary (52°22'0"N 7°39'02W), at 40m elevation, 28km west of the forest storage trial site. A total of 250 bundles; 125 each of green and brown bundles were transported to the terminal with between 41 and 43 bundles placed in each of six steel frame storage bins, as shown in Figure 2. Each storage bin was lined on the base and sides with MDF sheeting so that only the top and front and back faces of the bundle stack were exposed. The base was further strengthened with a layer of 3m long roundwood. Each bin was placed on four load cells connected to a data-logger which recorded total weight at hourly intervals. The bins were scaled to each contain c. 50m^3 volume. The load cells and data management system were supplied by Eilersen Electric Digital Systems A/S, Denmark. The load cells were zeroed before stacking the bundles for storage. The total bundle weight placed in each storage bin at the terminal was read off the bin load cells and checked against the calibrated weighbridge determination.

Four treatments were trialed at the terminal storage site:

Green bundles with a top cover, replicated in two bins

Green bundles with no top cover, no replication

Brown bundles with a top cover, replicated in two bins

Brown bundles with no top cover, no replication

Bundles were loaded into the bins between 25th March and 9th April 2010. The top covers used were PVC tarpaulins.

Figure 2: Green Bundles Stored At A Terminal In A Weighing Bin

All bins were emptied on the 19th August and the bundles from each bin were comminuted separately with the Jenz 660AZ. A total of 50 point moisture samples per bin were extracted at random during the comminution, with each sample at least 1000g in weight. The bin mean moisture content was applied to the final recorded bin weight to estimate the dry matter weight per bin. The change in bundle moisture content over the storage period was derived from applying the dry weight to the hourly weights recorded hourly over the storage period.

2.4 Weather Conditions During Storage Period

Rainfall and temperature data was gathered at Piltown, Co. Kilkenny, 6 km west of the forest storage site and 22 km east of the terminal storage trial site. Figure 3 presents the total monthly rainfall (mm) and mean daily temperature (^{o}C) for the six months between March and August 2010 compared to the historical mean values. The rainfall over the storage period was 15% higher than the average of 30 years, while the mean daily temperature was 10% higher than the average.

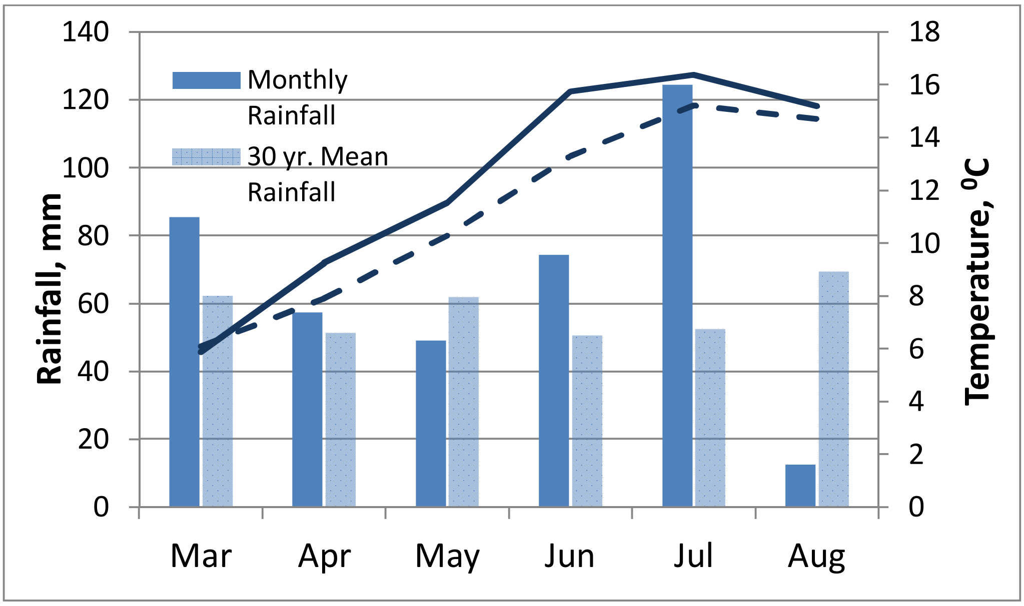

Figure 3: Mean Monthly Rainfall and Mean Daily Temperature During Storage Trial

3 Results

3.1 In-Forest Storage Results

Table 1 below details the change in total weight and moisture content of each stack over the storage period in the forest. Pre-storage, the green and brown bundles had a similar mean moisture content of 50.8% and 54.0% respectively. A feature of the pre-storage green bundles was the high degree of moisture content variation between bundles, compared to the brown bundles. Moisture content reduced in all stack treatments over the storage period to between 28.3% for green bundles stored in a single covered row in an exposed location to 47.5% for brown bundles stored in a single row with no cover in a sheltered location. The post-storage moisture content variation of sampled green bundles had reduced, whereas the variation in moisture content between brown bundles within the same treatment had increased during storage.

Table 1: Total Weight and Mean Moisture Content Of Residue Bundles Stacked In The Forest

Stack ID					No. Bundles	Storage Period [weeks]	Pre Storage Total Wt. [kg]	Post Storage Total Wt [kg]	Pre-storage Moisture [%, total wt.]	Post-storage Moisture [%, total wt.]
1	G	N	S	EX	120	18	36297	28940	50.8 (9.3)	39.2 (5.7)
2	G	C	S	EX	119	18	36456	25900	50.8	28.3 (7.1)
3	B	N	S	EX	49	21	19688	17780	54.0 (3.5)	46.2 (7.4)
4	B	C	S	EX	140	21	51444	36232	54.0	39.5 (10.7)
5	B	N	S	SH	71	21	25428	23048	54.0	47.5 (7.4)
6	B	C	S	SH	184	21	69587	54100	54.0	45.2 (10.2)
7	B	N	D	EX	104	21	37755	32635	54.0	41.9 (7.3)
8	B	C	D	EX	70	21	26224	21485	54.0	40.4 (7.6)

Stack Descriptors: G = green bundles, B = brown bundles, N = no top cover, C = with top cover, S = single row stack, D = double row stack, EX = exposed stack location, SH = sheltered stack location. Standard deviations in brackets.

The effect on bundle drying of the different treatments is shown in the Figures 4, 5 & 6 below. Each column represents a particular stack mean moisture content and the error bars represent the 95% confidence interval of the mean. Figure 4 indicates that moisture reduction during storage was significant for green and brown bundles stacked in a single row in an exposed location. Further, the difference in moisture content reduction between covered green bundles and those with no top cover was also significant, whereas this was not the case for brown bundles.

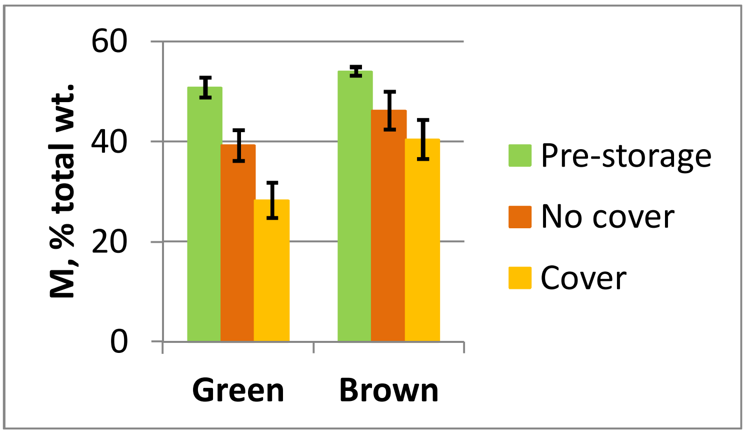

Figure 4: Effect Of Top Cover On Drying In Green And Brown Bundles

Drying in brown bundles stored with and without top cover, stacked in single and double rows in an exposed location was significant, as is shown in Figure 5. There was no significant difference in drying due to stacking in double rows compared to single rows irrespective of whether stacks had a top cover or not.

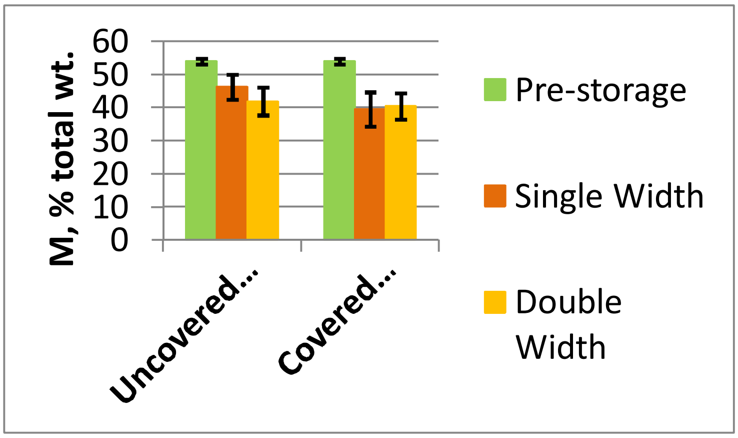

Figure 5: Effect of Stacking Bundles In Single Or Double Rows

Brown bundle drying in a stack was significant over the trial period whether bundles were stacked in an exposed or sheltered location. However, as seen in Figure 6, there was no significant difference in drying rate between the two treatments.

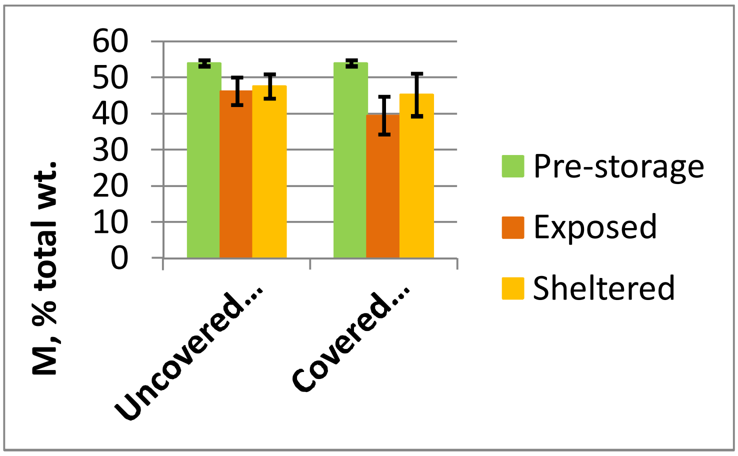

Figure 6: Effect Of Stacking In A Sheltered Compared To Exposed Location

3.2 Results of Storage At Terminal

The start weight of bundle stacks at the terminal ranged from 12815 kg to 16513 kg, as seen in Table 2. After 19 to 21 weeks storage the stacks had each lost c. 5 t in weight. The sampled mean moisture content of each stack after storage was about 24% for the green bundle stacks and 31% for the brown bundle stacks. The sample moisture content variation was low in both green and brown bundle stacks. The estimated dry matter weight of each stack ranged from 5969 kg to 7255 kg. The estimated moisture content of bundles at the start of the storage period, derived from the stack dry weight and total stack weight at the trial start, ranged between 53% and 56%.

Table 2: Total Weight and Mean Moisture Content Of Residue Bundles Stacked At The Terminal

Stack ID			Storage Period [weeks]	Start Weight [kg]	End Weight [kg]	End Moisture Content [%, total wt.]	End Dry Matter Wt. [kg]	Start Moisture Content [%, total wt.]
1	G	C	19	13688	8196	25.1 (3.6)	6139	55
2	G	N	19	12815	7782	23.3 (2.9)	5969	53
3	G	C	19	14858	8729	24.2 (2.3)	6617	55
4	B	C	21	15146	9864	32.4 (5.6)	6668	56
5	B	N	19	16513	10545	31.2 (6.1)	7255	56
6	B	C	19	14978	9625	28.8 (4.7)	6853	54

Stack Descriptors: G = green bundles, B = brown bundles, C = with top cover, N = no top cover, standard deviations in brackets.

The individual stack weight change over the storage period at the terminal is graphed below in Figure 7. The use of load cells to monitor weight changes over the storage period assumes that the changing weight is wholly a result of changing moisture content of the stored material.

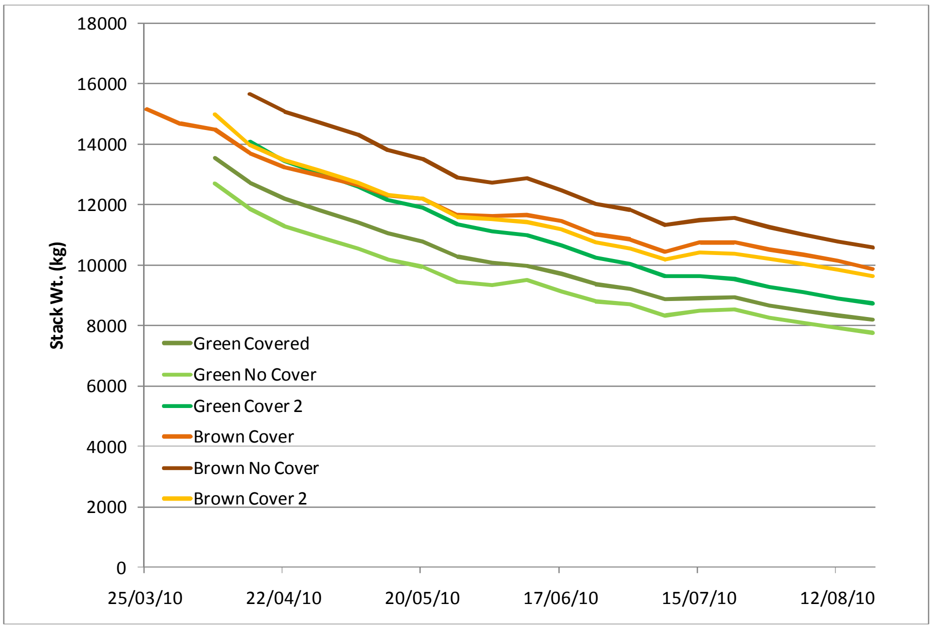

Figure 7: Stack Weight Change Over Storage Period At Terminal

Figure 8 shows the estimated change in stack moisture content at the terminal over the storage period. All stacks displayed a similar rate of moisture content decline, interrupted by two periods of increase around the start of June and mid-July 2010. These moisture increases correspond to periods of heavy rain, with 45mm of rain falling in one day (8th June) and over 80mm falling in the week 13th-19th July. The graph demonstrates that gained moisture departed rapidly from the stacks.

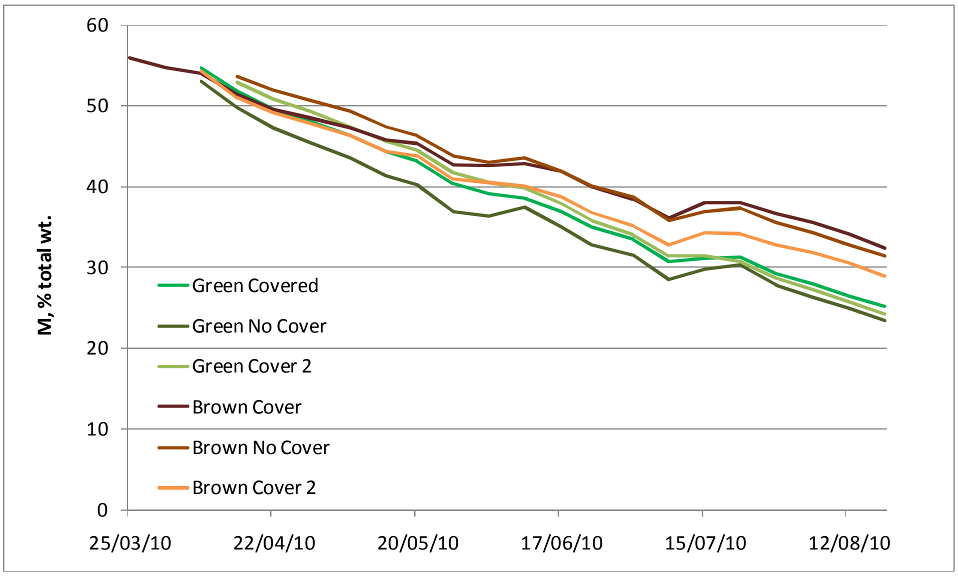

Figure 8: Stack Moisture Content Change Over Storage Period At Terminal

4 Discussion

These storage trials took place between March and August 2010, during the months with typically the best climatic conditions for drying. These results could not be applied to bundles in storage during other times of the year. Repeating the storage trials over the September to February period would be useful in order to derive recommendations on length of storage desirable to optimize the supply chain.

4.1 In-Forest Storage of Bundles

Drying was effective in all treatments trialed in the forest storage study. The resulting reduction in weight will reduce the road haulage cost of the bundles, and seasoned bundles will provide a better quality fuel with higher energy content. It was found in the trial that the green and brown bundles had similar initial mean moisture content but that the green bundles dried better during storage. The green material was bundled soon after harvesting, while the brown bundle material had been driven on by harvester and forwarder and left on the ground over winter. The brown residues may have benefited from preparation in anticipation of bundling during the harvesting operation, whereby residues were not driven on and were piled to allow air flow and drying.

Placing a cover on top of the bundle stacks improved drying significantly in green bundles, but not brown bundles. No significant difference in drying was observed in double width stacks. Stacking bundles in double rows on the forest road may have several benefits like improving the forwarder and road transportation productivity, making more efficient use of the available space and increasing stack stability. Storage in a sheltered environment next to standing trees compared to the exposed environment of a clearfell made no significant difference to drying in this trial.

A number of bundles disintegrated while being loaded for transport by truck after storage. A total of 22 out of 857 bales were lost in the trial. The disintegration of these bundles was due in part to the multiple handling required for measurement taking in this study. Only the brown bundles, which were made with sessile twine, disintegrated. The green bundles were made using nylon twine, and no bundles were lost from the green stacks. It was observed that bundle disintegration tended to occur mostly in bundles in ground contact.

4.2 Storing Bundles at the Terminal

The use of load cells to monitor weight change in bundles stacks during storage and the relation of this weight change to moisture transfer was demonstrated. Monitoring moisture content changes over time was achieved without disturbing the stacks and destructively sampling during the storage period. Overall the moisture content achieved was lower at the terminal than the forest storage trial. The bundles at the terminal showed less variation in moisture content at the end of the storage period than the stacks in the forest trial. It is thought that because the stacks in the forest trial were in direct contact with the ground, they had absorbed ground moisture and rain runoff, whereas the terminal stacks were raised off the ground. Using logs under the stacks in the forest may promote better, more even drying, based on the drying achieved at the terminal. In addition, the forest micro-climate may differ to that of the industrial terminal. Capturing site-specific climatic data would inform this view.

No difference in drying rate between the covered and uncovered stacks was observed in the stacks stored at the terminal. This is contrary to the outcome in the forest trial where an improvement in drying was found in the green bundles.

5 Acknowledgements

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