Evaluation of Moisture Reduction in Small Diameter Trees after Crushing

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(Received 25 July 1990; accepted 15 August 1990)

Abstract

Past studies have suggested that processing small diameter whole trees, like those found on rights-of-way (ROWs), would help reduce transportation costs and increase energy value by lowering stem moisture content. Small stems were crushed by a roller crusher/splitter test bench machine and allowed to dry under field conditions in Alabama. Tests were conducted in winter and summer using softwoods and hardwoods. Crushing facilitated short term field drying during periods when rain was light or absent. Any benefits of crushing are realized within the first five weeks of drying. Under field conditions, there is no guaranteed benefit associated with crushing trees to increase the rate of moisture loss over long drying periods or in times of heavy rainfall.

Key words: Biomass, drying, energy wood, moisture content, small trees.

INTRODUCTION

Two problems are generally encountered when utilizing small diameter trees for energy; the high moisture content and the handling of multiple small stems. An alternative to processing small diameter trees for energy use by whole-tree chipping is roll crushing/splitting (De Sault, 1984; Barnett *et al.*, 1985, 1986). The concept involves the crushing and splitting of stems to expedite field drying, and to facilitate baling for transport and storage at an energy conversion site. This method has been found to be a feasible alternative for processing small stems during harvest of short rotation woody biomass (Stuart *et al.*, 1984). The objective of the present study was to determine if crushing small diameter whole trees would aid in reducing stem moisture content in a simulated ROW environment before further processing. The benefits of a lower tree moisture would be reduced transportation cost, because of lower weight, and higher net BTU output during energy conversion. To determine potential benefits of harvesting biomass year-round, tests were run under both winter and summer conditions in southeastern Alabama. Because most natural stands, including utility ROWs, contain both softwoods and hardwoods, the study included loblolly pine (*Pinus taeda*), sweetgum (*Liquidambar styraciflua*), and oak (*Quercus* sp.). The size of the test trees was limited to large end diameters less than 12·7 cm. Earlier tests of the bench model roll crusher/splitter showed that a stem size range from 2·5 to 12·7 cm was practical for the machine and typical of the tree sizes generally found growing on ROWs (Sirois *et al.*, 1986).

The test was designed

(1) to determine the rate of moisture loss for whole trees processed by the roll crusher/splitter,
(2) to provide general guidelines on how long crushed stems need to remain on a field site before being collected and baled for transport to a conversion facility, and
(3) to determine if the drying rate of crushed trees was significantly different from that of whole, uncrushed trees.

METHODS

For the test to be of practical value, it was decided that drying data should be collected in both winter and summer. The winter test took place from

Bioresource Technology 0960-8524/91/$03.50

January to April, and the summer test from May to August, 1986. The winter test included loblolly pine and sweetgum; the summer test, loblolly pine, sweetgum, and oak.

In both tests, five trees of each species, in each of four diameter classes, from 2·5 to 12·7 cm, were cut and transported to the test site for weighing and treatment. From each group of five trees, three were randomly selected for treatment by crushing, the remaining two untreated stems being experiment controls. All trees were weighed at green weight moisture content on the day they were cut, and those to be processed were crushed on the same day. For each tree, the species and DGL (diameter at ground line) were recorded, and whether or not the tree was crushed. Environmental conditions were obtained from the National Weather Service and summarized on a weekly basis.

After selected trees were processed and weighed, all of the trees were transported a short distance to an open area adjacent to a timber stand. The trees were randomly placed on the ground with no overlapping so that all would be exposed to similar weather conditions. After heavy rains some trees were lying in shallow puddles and some were not. Each individual tree was reweighed every seven days to determine its weight. Weighing continued until no additional weight loss was noted for a 21 day period.

After the study was complete, moisture content percent (oven-dry weight basis) was calculated for each tree.

$$\text{TREEMC\%} = \frac{(\text{green wt of tree} - \text{oven-dry wt of tree})}{(\text{oven-dry wt of tree})} \times 100$$

The oven-dry weight for each tree was calculated using a proportional tree factor based on percent wood. At the end of each drying study, representative wood sample sections were taken from the butt, midsection, top, first limb, and second limb of each tree. These samples were oven dried to determine the percent wood in each section. A proportional weighting factor (W) for each section of the tree sampled was found using the equations:

$$W_{\text{section}} = \frac{\text{DIB}^2_{\text{section}}}{\Sigma(\text{DIB}^2_{\text{all sections}})} \times \text{WDF}_{\text{section}}$$

where DIB = diameter inside bark, and WDF = wood fraction = dry $\text{wt}_{\text{section}}$/green $\text{wt}_{\text{section}}$.

A tree factor was computed for each tree using $W_{\text{tree}} = \Sigma(W_{\text{section}})$.

The final oven-dry weight of each tree was calculated:

$$\text{oven-dry wt} = W_{\text{tree}} \times \text{final green wt.}$$

RESULTS

Tree characteristics

Table 1 summarizes the characteristics of the 101 trees cut for the test. Of these, 61 were crushed and 40 were not crushed. Uniform DGL distributions were achieved for all species and treatments. The cut diameter of the test trees averaged 7·6 cm (3·0 in) and ranged from 2·0–14·0 cm.

Moisture loss characteristics

Table 2 shows the observed means of initial and final stem moisture content within species and treatments for each diameter class. Trees with smaller diameters initially had a higher moisture content than larger trees. Final moisture content values are for a drying period of 11 weeks.

Table 1. Ground line diameters for green trees

	N[a]	Mean (cm)	SD[b] (cm)	Range (cm)
Winter				
All stems	39	7·7	3·4	2·0–14·0
Crush	23	7·8	3·8	2·8–14·0
No-crush	16	7·6	4·0	2·0–14·0
Pine-all	19	8·2	3·8	2·8–14·0
Crush	11	7·9	3·7	3·6–13·5
No-crush	8	8·4	4·0	2·8–14·0
Gum-all	20	7·3	3·9	2·0–14·0
Crush	12	7·7	3·9	2·8–14·0
No-crush	8	6·7	3·9	2·0–13·7
Summer				
All stems	62	7·7	3·7	2·3–13·2
Crush	38	7·8	3·7	2·3–13·2
No-crush	24	7·5	3·8	2·8–12·7
Pine-all	21	7·9	3·7	3·0–13·2
Crush	12	8·2	3·4	3·0–13·2
No-crush	9	7·5	4·0	3·0–12·7
Gum-all	20	7·7	3·8	2·3–12·7
Crush	13	8·0	3·9	2·3–12·7
No-crush	7	7·3	3·5	2·8–11·7
Oak-all	21	7·5	3·7	2·3–12·7
Crush	13	7·4	3·6	2·3–12·7
No-crush	8	7·7	3·7	2·3–12·7

[a]N = number of observations.
[b]SD = standard deviation.

Table 2. Average moisture content for each species and DGL class[a]

Species	*DGL (cm)*	*Crush*		*No-crush*	
		Initial (%)	*Final (%)*	*Initial (%)*	*Final (%)*
Winter					
Pine	2·5	161·7	36·6	249·1	12·1
	5·1	176·0	26·4	199·1	25·0
	10·2	152·6	12·7	181·8	23·9
	12·7	211·6	34·2	170·5	23·9
Gum	2·5	76·8	42·3	83·8	76·7
	5·1	106·2	8·3	69·7	21·3
	10·2	121·7	21·4	76·9	26·8
	12·7	116·3	24·0	76·7	31·8
Summer					
Pine	2·5	102·0	17·8	115·2	13·8
	5·1	70·9	15·2	59·2	14·8
	10·2	47·9	14·0	108·7	13·0
	12·7	58·9	17·5	77·9	19·9
Gum	2·5	149·5	20·2	96·1	14·0
	5·1	84·5	22·9	83·3	14·0
	10·2	63·2	14·1	65·7	13·4
	12·7	60·6	13·2	62·1	13·4
Oak	2·5	69·6	19·3	87·2	18·2
	5·1	103·2	10·5	64·4	15·6
	10·2	57·2	12·6	58·4	19·3
	12·7	56·6	13·6	62·7	16·9

[a]All moisture content data are calculated on an oven-dry basis.

Tables 3 and 4 summarize the average weekly moisture contents for each test and treatment. A seasonal difference was observed in the moisture content data. For all the trees tested, the initial moisture content was 137% in winter and 80% in summer, a seasonal difference of about 57%. At the end of 5 weeks of drying, the moisture content was 60% in winter and 26% in summer, a seasonal difference of 34%. The difference in moisture content at the end of 11 weeks of drying was about 11% with a final winter moisture content of 27%, and a final summer moisture content of 16%.

From a seasonal viewpoint, the average moisture loss for 11 weeks was much greater in the winter. This difference was most evident in the pine trees where the average total moisture loss in the winter was more than double that observed in the summer. However, all trees lost about 80% of their original moisture, regardless of the season. It was surmised that some seasonal variations were related to differences between coniferous and deciduous trees, as well as to seasonal differences in weather conditions.

The initial moisture content observed in winter was higher than typically reported, especially for pine. A typical pine has an initial green moisture content in the range 70–140% (Clark, pers.

Table 3. Percent moisture content statistics for winter data

Test week	*N*	*Mean*	*SD*	*Range*
Crush				
0	23	139·7	47·2	22·6–231·3
1	23	81·9	24·2	53·6–148·1
2	23	104·0	29·5	65·3–190·3
3	23	105·6	31·8	55·8–190·3
4	23	74·1	27·8	33·5–135·7
5	23	53·3	20·0	22·6–93·5
6	23	39·6	23·5	17·3–129·8
7	23	60·0	23·2	26·8–110·4
8	23	52·7	20·3	25·9–91·5
9	23	29·8	16·6	9·8–76·2
10	23	36·6	15·8	19·0–91·5
11	23	25·2	17·6	6·6–91·5
No-crush				
0	16	133·8	64·6	31·3–249·1
1	16	92·0	28·4	31·3–130·2
2	16	93·5	26·8	43·8–133·6
3	16	91·2	23·7	56·3–124·2
4	16	80·2	18·3	56·3–108·2
5	16	70·1	17·9	31·3–94·9
6	16	54·8	14·8	25·0–78·1
7	16	56·1	20·3	37·5–126·0
8	16	47·3	9·8	25·0–69·5
9	16	29·2	13·9	1·4–58·2
10	16	33·0	11·7	14·7–69·5
11	16	30·3	26·3	12·1–126·0

Table 4. Percent moisture content statistics for summer data

Test week	*N*	*Mean*	*SD*	*Range*
Crush				
0	38	78·2	36·6	44·1–235·3
1	38	104·6	100·4	21·1–372·6
2	38	101·3	97·8	32·4–445·3
3	38	47·2	17·3	25·4–115·1
4	38	29·6	17·0	11·1–82·9
5	38	22·2	21·5	−28·5–84·0
6	38	20·8	9·9	9·1–67·6
7	38	17·4	11·2	5·7–52·9
8	38	9·8	10·5	−18·7–49·0
9	38	14·9	10·0	−4·6–52·9
10	38	22·4	12·2	−27·3–52·9
11	38	15·5	5·1	7·9–30·4
No-crush				
0	24	81·7	31·4	49·3–184·1
1	24	70·8	148·9	−100·0–387·2
2	24	108·9	81·5	34·9–354·5
3	24	59·4	30·1	27·8–155·7
4	24	42·7	14·6	23·4–73·6
5	24	31·9	14·2	12·0–70·5
6	24	24·1	9·5	−3·9–42·0
7	24	20;9	9·5	−3·9–42·0
8	24	16·5	11·4	−19·9–42·0
9	24	13·0	7·4	−6·7–25·9
10	24	14·2	9·2	−7·2–28·2
11	24	15·6	3·9	11·4–25·3

comm.). The pines measured in winter had initial moisture content values outside this range, averaging 192% for the untreated trees (Table 5). This high figure may have resulted from the small sample size and small size trees.

Table 6 summarizes the recorded weather data for the two study periods. These data were obtained from the National Weather Service in Auburn, Alabama, and were collected within 427 m of the test area. The data show that weather conditions varied more during the winter than during the summer. The range of weather variables was twice as wide during the winter.

The moisture contents calculated for the summer tests frequently had negative values. These are probably due to a combination of invalid weights recorded during the early part of the test and material loss during the course of the test. No analysis was done on the summer data because of the unexplained discrepancies. However, the data is presented because it verifies the general trends observed in the winter data.

Table 5. Percent moisture content summary by species for winter data

Species	*Week of test*	*Crush*				*No-crush*			
		N	*Mean*	*SD*	*Range*	*N*	*Mean*	*SD*	*Range*
Pine	0	11	176·7	32·0	138·9–231·3	8	191·7	29·0	161·9–249·1
	1	11	98·6	24·4	70·2–148·1	8	114·6	9·1	103·5–130·2
	2	11	120·1	31·5	90·1–190·3	8	116·7	8·6	105·7–133·6
	3	11	122·8	32·9	83·3–190·3	8	112·8	8·2	99·8–124·2
	4	11	88·3	23·8	62·8–135·7	8	95·9	7·8	85·9–108·2
	5	11	64·7	15·6	39·6–93·5	8	82·7	9·3	67·5–94·9
	6	11	41·9	13·6	26·8–67·0	8	60·5	15·3	33·8–78·1
	7	11	61·9	25·5	26·8–104·4	8	54·2	9·2	43·3–68·0
	8	11	58·0	21·8	26·8–90·5	8	48·4	6·3	43·3–63·0
	9	11	31·7	13·6	17·2–55·7	8	24·1	13·8	1·4–38·0
	10	11	35·6	12·5	19·0–54·5	8	28·0	7·0	14·7–39·5
	11	11	26·7	10·9	10·5–46·5	8	22·7	7·4	12·1–33·8
Sweetgum	0	12	105·7	29·7	22·6–136·1	8	75·9	20·8	31·3–98·2
	1	12	66·7	10·2	53·6–91·5	8	69·3	21·9	31·3–112·4
	2	12	89·2	18·5	65·3–129·8	8	70·4	15·3	43·8–98·2
	3	12	89·9	21·8	55·8–129·8	8	69·6	8·6	56·3–84·1
	4	12	61·2	25·3	33·5–129·8	8	64·6	9·8	56·3–84·1
	5	12	42·7	18·1	22·6–91·5	8	57·5	15·5	31·3–84·1
	6	12	37·4	30·4	17·3–129·8	8	49·2	12·7	25·0–69·5
	7	12	58·2	21·8	38·6–110·4	8	58·1	28·1	37·5–126·0
	8	12	48·0	18·5	25·9–91·5	8	46·2	12·9	25·0–69·5
	9	12	28·1	19·4	9·8–76·2	8	34·4	12·7	12·5–58·2
	10	12	37·5	18·9	22·4–91·5	8	38·0	13·7	25·0–69·5
	11	12	23·8	22·6	6·6–91·5	8	37·8	36·1	12·5–126·0

Table 6. Weather data[a]

	Units	*N*	*Mean*	*SD*	*Range*
Winter					
Cumulative weekly rainfall	cm	11	2·8	3·8	0·0–10·7
Average weekly temperature	°C	11	13·2	4·9	4·4–20·6
Average weekly solar energy	W m^{-2}	11	4 304·0	1 295·1	2 533·0–6 086·0
Average weekly pan evaporation	cm	11	0·41	0·15	0·18–0·58
Summer					
Cumulative weekly rainfall	cm	11	2·0	2·0	0·0–5·3
Average weekly temperature	°C	11	27·2	2·3	21·1–29·4
Average weekly solar energy	W m^{-2}	11	6 054·0	615·1	4 959·0–6 730·0
Average weekly pan evaporation	cm	11	0·69	0·10	0·51–0·86

[a]From National Weather Service, SE Agricultural Weather Service Center, Auburn University, AL.

The average moisture content data (weighted by a diameter squared term) are plotted against drying time in Figs 1a, 1c, 2a, and 2c for each season, species, and treatment. Figures 1b and 2b show the total recorded rainfall for each 7 day period preceding the day of weighing for each test. These plots show that crush stems, exposed to rain after partial drying, experienced greater moisture gain than no-crush stems. Rainfall reduced the positive effects of crushing in expediting moisture loss. In the winter test, when weekly rainfall exceeded 7·6 cm, the moisture content levels of the crush stems took 2 to 3 weeks to drop below the pre-rain level. The no-crush stems were less affected by rainfall.

Cut trees are expected to dry rapidly at first and then progressively less as drying time increases. The potential for drying decreases as the

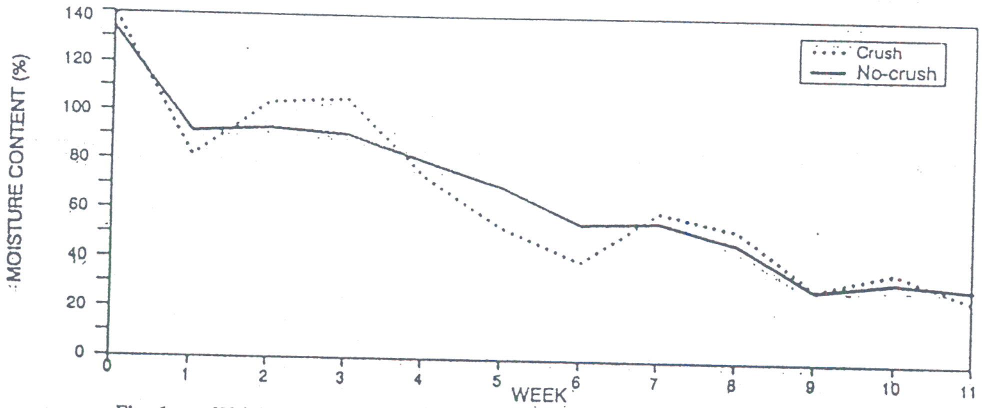

Fig. 1a. Weighted average moisture content versus drying time (winter test).

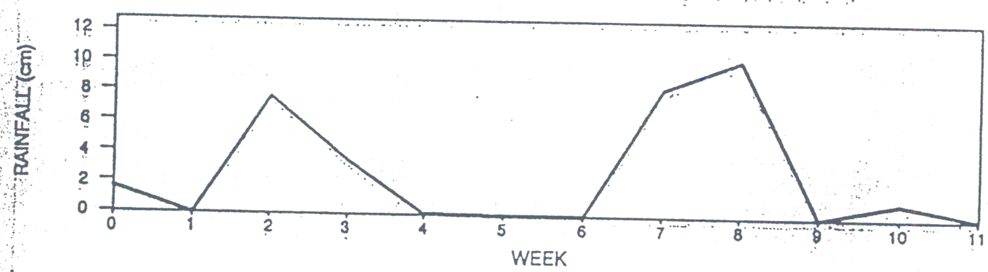

Fig. 1b. Rainfall (winter test).

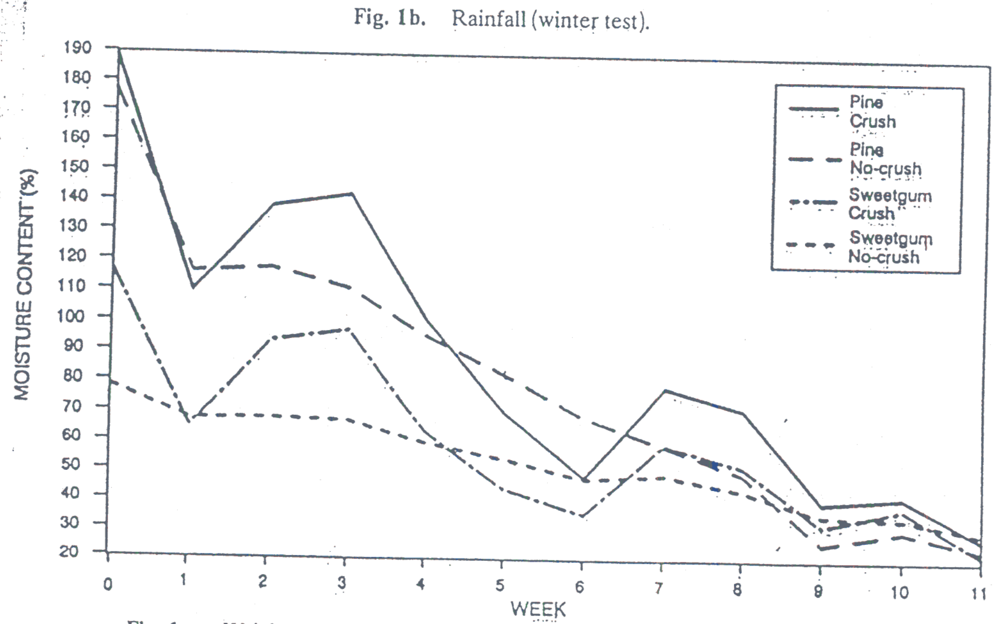

Fig. 1c. Weighted average moisture content versus drying time (winter test).

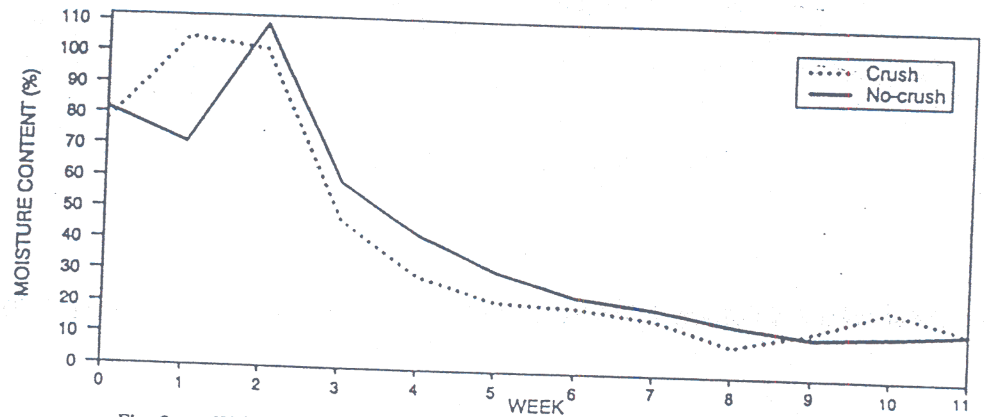

Fig. 2a. Weighted average moisture content versus drying time (summer test).

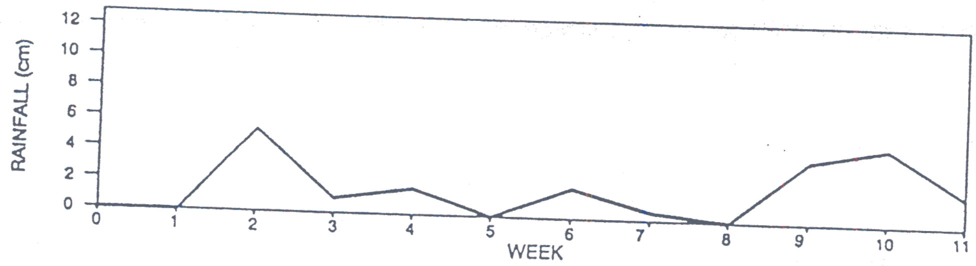

Fig. 2b. Rainfall (summer test).

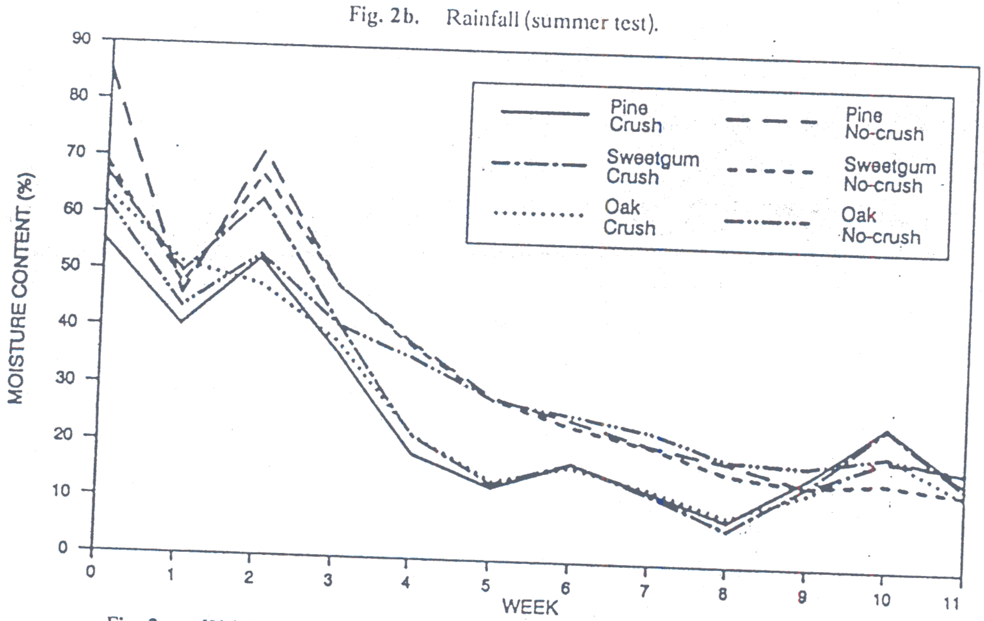

Fig. 2c. Weighted average moisture content versus drying time (summer test).

moisture content of the tree approaches the moisture holding capacity of the air.

The wood shrinks as it dries and the cells become less likely to absorb additional moisture as drying time increases. Crush trees have more surface area exposed for moisture absorption than no-crush trees. As drying time increases, weather conditions have less influence on the moisture content of cut trees.

DATA ANALYSIS

Analysis of variance (ANOVA) tests were used to see which variables, if any, had a significant effect on the weekly observed moisture content data for the winter test.

Variables included in the ANOVA of moisture content (MC) were: treatment, drying time, collected weather data, species, and diameter.

Variables considered in the analysis were:

Quantitative:

MC = dry basis moisture content, %
WEEK = accumulated drying time elapsed since study began, wk
RAIN = total measured precipitation for week preceding day of weighing, cm
TEMP = average weekly temperature, °C
SOLAR = average weekly solar energy, W m^{-2}
EVAP = average estimated weekly pan evaporation, cm
DGL = diameter at ground line of each tree, cm.

Qualitative:

CRUSH/NO-CRUSH = stem treatment
SPECIES = pine, sweetgum, or oak.

Winter test

The ANOVA results of the winter data (Table 7) show that the length of drying time has the greatest effect, followed by species and tree size. The treatment by crushing did not make a significant difference for an extended drying period. None of the weather related variables were significant when drying time was considered. The moisture content values were weighted by weekly variance within species and treatment.

Summer test

Examination of the summer data (Figs 2a and 2c) shows that the observed data were erratic during the first few weeks. No plausible explanations for the extreme fluctuations in moisture content could be determined. Therefore, the summer data were not analyzed because the changes in moisture content may have been the result of inaccurate measuring devices or higher rates of transpiration than were observed in the dormant winter condition.

SUMMARY

This study shows that roll crushing/splitting small diameter whole trees for extended drying in field conditions may not have all the benefits projected from earlier work (De Sault, 1984). The earlier test of drying crushed trees was optimal in that the test samples were four foot bolts and these were placed on pallets after crushing. The crushed bolts were exposed to nearly complete air circulation and were protected from rainfall.

The current study was designed to approximate field drying conditions for an extended time period. Crushing whole-tree stems has conditional drying benefits and may even be detrimental to moisture reduction under field conditions if heavy rainfall occurs. The drying benefits of crushing whole trees diminish as drying time increases.

Ground contact reduces air circulation and rate of drying. Rainfall is readily absorbed and lost by exposed wood fibers of crushed stems during the first three to four weeks of drying. As drying time is increased, however, moisture fluctuations from rainfall diminish. During the winter test the no-crush trees showed less evidence of regaining moisture than the crush trees.

The summer drying test showed that both the crush and no-crush trees exhibited dynamic moisture fluctuations during the first four weeks of drying. One reason for this may have been the 'live' condition of the trees during the summer growing season producing a higher rate of transpiration than in the dormant winter condition.

CONCLUSIONS

The drying rate of small cut trees can be accelerated by crushing. The benefits gained, however, can be severely reduced if rainfall occurs, especially heavy rainfall, because exposed fibers

Table 7. ANOVA for the winter moisture content data[a]

Source	*df*	*SS*	*MS*	*F*	*Pr> F*
Week	10	88 677 904·82	8 867 790·48	47·59	0·000 1
DGL	4	18 338 624·98	4 584 656·25	24·61	0·000 1
Species	1	3 444 628·30	3 444 628·30	18·49	0·000 1
Crush	1	11 824·28	11 824·28	0·06	0·801 2
Species × crush	1	487 313·54	487 313·54	2·62	0·106 6
Error	411	76 578 881·2	186 323·3		
Total	428	234 095 302·0			

[a]Moisture content values weighted by weekly variance within species and treatment.

readily absorb moisture. However, after wetting, crush material redries faster than no-crush material. Other potential benefits include an increase in the flexibility of the stems for baling or other processing for transport and storage at an energy conversion site. The greatest potential benefit of roll crushing/splitting is generally achieved during the first 5 to 6 weeks of drying.

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