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TRANSPIRATIONAL DRYING OF ENERGYWOOD

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SUMMARY:
Weight loss due to transpirational drying is reported for several tree species being used for energy.

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Introduction

It is well documented that the fuel value of wood is related to the moisture content. Tillman (1978) gives the following relationship of net fuel value for wood (Em) in Btu's per pound as a function of percent moisture content ovendry basis (M): Em = 8800 + 100.28M. Thus, lowering the moisture content enhances the value of wood as a fuel.

Drying the wood by allowing transpiration to remove the moisture from the felled tree is a method of reducing the moisture content of a fuel wood. Transpiration drying, also known as "sour felling," "leaf seasoning," "leaf felling," "biological drying," or "delayed bucking", (McMinn and Taras 1983), is a practice in which trees are felled and left with the crown in tact for several weeks. This drying method has been studied in eucalyptus and slash pine by McMinn and Taras (1983) and McMinn and Stubbs (1985), in red oak and white birch by Patterson and Post (1980), in loblolly pine, white oak, and sweetgum by Rogers (1981), and in Piedmont hardwoods by McMinn (1986).

Transpirational drying was used on an operational basis by a firm harvesting wood for fuel (Watson et al. 1986; Miller et al. 1987).The firm needed assistance in developing an optimal drying schedule for the tree species that were being used in its energywood harvest. The species of interest in these studies, which were conducted to provide optimal schedule for drying, were loblolly pine, the soft hardwoods sweetgum, blackgum, and red maple, and the hard hardwoods dogwood, southern red oak, and water oak. The situation was unique because the trees for energy were being allowed to dry under a canopy of standing trees that was being left for a second-pass harvest of material large enough for use as pulpwood.

Methods

Drying Study I

Trees were felled for this study in south Alabama from late June to mid-August 1985. Stems were felled in weekly intervals over an 8-week period, and transpirational drying was allowed to take place up to the time the stems were chipped. The stems were segregated into bundles by the following 2-inch diameter classes: 1, 3, 5, 7, 9, 11, 13, 15, and 17 inches. The bundles were segregated by species into the pine, soft hardwood, and hard hardwood species groups. A subset of the bundles was weighed as they were felled and reweighed each week. The weighings were performed with the loader on a forwarder and using an electronic load cell to obtain the weight.

Chip Test

Another study involved tree bundles used in a chipping test. These bundles had dried for different lengths of time. As each bundle was chipped in August 1985, a subsample of chips was collected from the stream of chips being blown into the chip van. These chips were sealed in a plastic bag and returned to a lab for moisture content determination.

Drying Studv II

A second drying study was begun in August of 1985 at the same location as Study I by felling three bundles each of the following species: loblolly pine, sweetgum, blackgum, red maple, southern red oak, water oak, and dogwood. These bundles were weighed immediately after felling and were reweighed each week through the month of October 1985. After the final weighing was conducted, sample disks were collected from three trees in each bundle; the disks were then placed in plastic bags and returned to the lab for moisture content determinations.

Starr Forest Drying Study

Another drying study was completed for loblolly pine stems during the months of February to April 1986; four bundles were assembled for this study. The data were collected in the same manner as in the other drying studies. This study was installed on the John W. Starr Memorial Forest in Oktibbeha County, Mississippi.

Weather Data

Weather data were collected for each drying study. The weather data for the Chip Test bundles and Drying Studies I and II came from two sources. The daily rainfall was obtained from the weather station in Wallace, approximately 5 miles from our test sites. The daily temperature data were obtained from the Atmore State Nursery, about 20 miles from our test sites. The weather station at Mississippi State University was used as the source of weather data for the Starr Forest Drying Test.

As a result of this data collection, four blocks of data were formed:

1. Drying Study I (July-August): 150 observations,
2. Chip Test (July-August): 185 observations,
3. Drying Study II (August-October): 199 observations, and
4. Starr Forest Drying Study (February-April): 48 observations on loblolly pine only.

Analysis

The average daily temperature was calculated over the drying period of each stem bundle by adding all of the minimum and maximum daily temperatures and dividing by 2 times the number of days of the drying period. The rainfall observations were used in two ways. First, the total rainfall in the drying period was determined by adding the total daily rainfall measured in the period since felling. Second, only the total rainfall recorded during the last 7 days of the drying period was determined.

For drying of the samples, a bulk dryer (temperature 122 °F) was used for approximately 6 weeks. The samples were then dried an additional 25 hours in a smaller dryer at a temperature of 212 °F, at which time net weight was measured. The moisture content (MC) was calculated as follows:

$$MC = \frac{\text{wet weight} - \text{dry weisht}}{\text{dry weight}} \times 100\%.$$

Drying Study I

A weight reduction factor was calculated for each bundle for each measurement. This factor describes the reduction in weight (Reduw) as compared with the original weight immediately after felling:

$$Reduw_i = \frac{Weight_i}{\text{Initial Weight}},$$

where $Weight_i$ = weight of the bundle i days after felling, and Initial Weight = weight of the bundle on the day the trees were felled.

Note that $Reduw_i$ ranges from 1 to a number smaller than 1. The following information was known for each Reduw observation:

1. Species group (1 = pine, 2 = soft hardwood, 3 = hard hardwood),
2. DBH.
3. Number of stems.
4. Days since felling.
5. Bundle weight.
6. Weight reduction factor.
7. Average daily temperature since felling.
8. Total rainfall.
9. Last week's rainfall.
10. Original bundle weight.

Chin Test

With the information gathered from the chip samples, the moisture content was calculated for each bundle. The following information was available for each bundle:

1. Species group (1 = pine, 2 = soft hardwood, 3 = hard hardwood).
2. DBH.
3. Number of stems.
4. Wet weight sample.
5. Dry weight sample.
6. Days since felling.
7. Original bundle weight.
8. Average daily temperature since felling.
9. Total rainfall.
10. Last week's rainfall.
11. Ending moisture content.

In the chip tests, 185 observations, (28 pines, 75 soft hardwoods, and 82 hard hardwoods) were available for analysis.

Drvins Studv II

As in the first drying study, the weight reduction factor was calculated over time for each bundle. Because moisture content was calculated for the final measurement, the ovendry weight could be estimated for the bundle. This estimate of ovendry weight was then used to determine moisture content at other times when the bundle had been weighed. There were 199 observations of the following species groups: 30 red maple, 30 blackgum, 30 sweetgum, 30 dogwood, 30 red oak, 29 water oak, and 20 pine.

Each observation contained the following information:

1. Species.
2. Number of stems.
3. Days since felling.
4. Bundle weight.
5. Weight reduction factor.
6. Average daily temperature.
7. Total rainfall.
8. Last week's rainfall.
9. Ending moisture content.
10. Original bundle weight.

Combinations of Data

Because the same information was available in the different data blocks it was possible to combine much of the data. Drying Study I and II were combined. The total number of observations was 349 (71 pines, 142 soft hardwoods, and 136 hard hardwoods). Each observation contained the following information:

1. Species group.
2. Bundle weight.
3. Original bundle weight.
4. Number of stems.
5. Weight reduction factor.
6. Average daily temperature.
7. Total rainfall.
8. Last week's rainfall.

Drying Study II and Chip Test data were also combined. The total number of observations was 205 (30 pines, 84 soft hardwoods, and 91 hard hardwoods). Each observation contained the following information:

1. Species group.
2. Number of stems.
3. Days since felling.
4. Original bundle weight.
5. Average daily temperature.
6. Total rainfall.
7. Last week's rainfall.
8. Moisture content.

The Starr Forest Study was conducted during winter months on pines only. Transpirational drying during this period was very different from that of Drying Studies I and II. Combining these data could not be accomplished, even when weather variables were included in the model.

Results

All the data files mentioned in the previous section were analyzed using regression analyses. Both moisture content (MC) on the ovendry basis and weight reduction factors (Reduw) were predicted. The variables considered were: days since felling (Dcut), original weight of the bundle (Oweight), average daily temperature (^{o}F Temp), DBH of the stems in the bundle (Stem), total rainfall (Totrain), and last week's rainfall (LWrain). A new variable was created by the number of days (TDay).

For the different data sets, the following equations were developed with all variables significant at the 0.05 significance level:

Drying Study I

Pine:

$$Reduw = 0.946 - 0.0173\ Dcut + 0.000260\ Dcut^2 + 0.000150\ Oweight \qquad (1)$$
$$R^2 = 63.5\%$$

$$Reduw = 0.946 - 0.00216\ TDay + 4.033 \times 10^{-8}\ TDay^2 + 0.00150\ Oweight \qquad (2)$$
$$R^2 = 63.4\%$$

Soft hardwoods:

Reduw = 1.06 - 0.0245 Dcut + 0.000459 $Dcut^2$ - 0.0135 DBH (3)
R^2 = 79.2%

Reduw = 1.06 - 0.000304 TDay + 7.059 x 10^{-8} $TDay^2$ - 0.0133 DBH (4)
R^2 = 79.3%

Hard hardwoods:

Reduw = 0.991 - 0.0148 Dcut + 0.000569 $Dcut^2$ - 0.0212 Totrain
t 0.0144 LWrain (5)
R^2 = 64.6%

Reduw = 0.994 - 0.000162 TDay + 5.83 x 10^{-8} $TDay^2$ 0.0103 Totrain (6)
R^2 = 61.2%

Chip Test

Pine:

MC = 82.3 - 0.605 Dcut (7)
R^2 = 32.7%

MC = 82.4 - 0.00757 TDay (8)
R^2 = 32.9%

Soft hardwoods:

MC = 55.1 t 3.54 DBH - 0.236 DBH^2 - 0.932 Dcut + 1.14 Totrain (9)
R^2 = 44.2%

MC = 55.1 t 3.54 DBH - 0.236 DBH^2 - 0.0114 TDay t 1.09 Totrain (10)
R^2 = 44.3%

Hard hardwoods:

MC = 45.0 t 2.07 DBH - 0.255 Dcut (11)
R^2 = 57.9%

MC = 45.1 t 2.07 DBH - 0.00320 TDay (12)
R^2 = 58.0%

Drying Study II

Pine:

Reduw = 0.994 - 0.0166 Dcut t 0.000325 $Dcut^2$ - 2.14 x 10^{-6} $Dcut^3$ (13)
R^2 = 88.4%

$$Reduw = 0.969 - 0.000208\ TDay + 2.164 \times 10^{-8}\ TDay^2 + 0.189\ Totrain \quad (14)$$
$R^2 = 88.7\%$

Soft hardwoods:

$$Reduw = 0.970 - 0.0227\ Dcut + 0.000537\ Dcut^2 - 0.000004\ Dcut^3 \quad (5)$$
$R^2 = 57.9\%$

$$Reduw = 0.973 - 0.000293\ TDay + 8.929 \times 10^{-8}\ TDay^2 - 8.925 \times 10^{-12}\ TDay^3$$
$R^2 = 58.4\%$

For the different soft hardwood species the equations were:

Red maple:

$$Reduw = 1.19 - 0.0171\ Dcut + 0.000383\ Dcut^2 - 0.000003\ Dcut^3 - 0.000275\ Oweight \quad (17)$$
$R^2 = 83.6\%$

$$Reduw = 1.19 - 0.000220\ TDay + 6.349 \times 10^{-8}\ TDay^2 - 6.188 \times 10^{-12}\ TDay^2 - 0.000275\ Oweight \quad (18)$$
$R^2 = 84.1\%$

Blackgum:

$$Reduw = 0.968 - 0.0192\ Dcut + 0.000459\ Dcut^2 - 0.000004\ Dcut^3 \quad (19)$$
$R^2 = 78.3\%$

$$Reduw = 0.971 - TDay0.008250\ TDay + 7.710 \times 10^{-8}\ TDay^2 - 7.969 \times 10\text{-}12 \quad (20)$$
$R^2 = 79.0\%$

Sweetgum:

$$Reduw = 0.967 - 0.0319\ Dcut + 0.000766\ Dcut^2 - 0.000006\ Dcut^3 \quad (21)$$
$R^2 = 87.0\%$

$$Reduw = 0.971 - 0.000410\ TDay + 1.269 \times 10^{-7}\ TDay^2 - 1.259 \times 10\text{-}11\ TDay3 \quad (22)$$
$R^2 = 87.7\%$

Hard hardwoods:

$$Reduw = 0.863 - 0.0241\ Dcut + 0.000475\ Dcut^2 - 0.000003\ Dcut^3 + 0.0156\ Totrain + 0.000174\ Oweight \quad (23)$$
$R^2 = 76.7\%$

$$Reduw = 0.866 - 0.000302\ TDay + 7.753 \times 10^{-8}\ TDay^2 - 7.081 \times 10\text{-}12\ TDay^3 \times 0.0151\ Totrain + 0.000174\ Oweight \quad (24)$$
$R^2 = 76.9\%$

For the different hard hardwood species the equations were:

Dogwood:

$$Reduw = 0.971 - 0.0291\ Dcut + 0.000534\ Dcut^2 - 0.000004\ Dcut^3 + 0.0238\ Totrain \qquad (25)$$
R^2 = 90.0%

$$Reduw = 0.973 - 0.000362\ TDay + 8.424 \times 10^{-8}\ TDay^2 - 7.351 \times 10^{-12}\ TDay^3 \times 0.0232\ Totrain \qquad (26)$$
R^2 = 90.1%

Red Oak:

$$Reduw = 0.581 - 0.0160\ Dcut\ t\ 0.000392\ Dcut^2 - 0.000003\ Dcut^3\ t\ 0.000558\ Oweight \qquad (27)$$
R^2 = 82.5%

$$Reduw = 0.583 - 0.000207\ TDay\ t\ 6.537 \times 10^{-8}\ TDay^2 - 6.872 \times 10^{-12}\ TDay^3\ t\ 0.000558\ Oweight \qquad (28)$$
R^2 = 85.5%

Water Oak:

$$Reduw = 0.8882 - 0.0120\ Dcut + 0.000493\ Dcut^2 - 0.000004\ Dcut^3\ t\ 0.000124\ Oweight$$
R^2 = 87.9%

$$Reduw = 0.885 - 0.000271\ TDay\ t\ 8.186 \times 10^{-8}\ TDay^2 - 7.978 \times 10^{-12}\ TDay^3 + 0.000123\ Oweight$$
R^2 = 88.6%

Combination of Drying Studies I and II

Pine:

$$Reduw = 0.952 - 0.0135\ Dcut\ t\ 0.000128\ Dcut^2\ t\ 0.000085\ Oweight \qquad (31)$$
R^2 = 67.6%

$$Reduw = 0.953 - 0.00017\ TDay\ t\ 2.0721 \times 10^{-8}\ TDay^2 + 0.000085\ Oweight \qquad (32)$$
R^2 = 67.7%

Soft hardwoods:

$$Reduw = 0.975 - 0.0268\ Dcut\ t\ 0.000610\ Dcut^2 - 0.0000046\ Dcut^3\ t\ 0.00739\ Totrain \qquad (33)$$
R^2 = 70.1%

$$Reduw = 0.977 - 0.000339\ TDay\ t\ 9.936 \times 10^{-8}\ TDay^2 - 9.823 \times 10^{-12}\ TDay^3 + 0.00697\ Totrain \qquad (34)$$
R^2 = 70.4%

Hard hardwoods:

$$\text{Reduw} = 0.937 - 0.0172\ \text{Dcut} + 0.000370\ \text{Dcut}^2 - 0.0000028\ \text{Dcut}^3 \quad \text{t}\ 0.000079\ \text{Oweight} \qquad (35)$$
R^2 = 72.9%

$$\text{Reduw} = 0.938^{-12} - 0{,}000218\ \text{TDay}\ \text{t}\ 6.033 \times 10^{-8}\ \text{TDay}^2 - 5.849 \times 10^{-12}\ \text{TDay}^3\ \text{t}\ 0.000080\ \text{Oweight} \qquad (36)$$
R^2 = 73.1%

Combination of Chip Test and Drying Study II

Pine:

$$MC = 78.7 - 0.393\ \text{Dcut} \qquad (37)$$
R^2 = 22.1%

$$MC = 79.1 - 0.00515\ \text{TDay} \qquad (38)$$
R^2 = 23.1%

Soft hardwoods:

$$MC = 65.5 - 0.116\ \text{Stem} - 0.428\ \text{Dcut} \qquad (39)$$
R^2 = 44.3%

$$MC = 65.9 - 0.115\ \text{Stem} - 0.00557\ \text{TDay} \qquad (40)$$
R^2 = 44.3%

$$MC = 62.3 - 0.423\ \text{Dcut} \qquad (41)$$
R^2 = 39.2%

Hard hardwoods:

$$MC = 57.9 - 0.268\ \text{Dcut} - 0.231\ \text{Stem}\ \text{t}\ 0.00269\ \text{Oweight} \qquad (42)$$
R^2 = 50.0%

$$MC = 58.0 - 0.230\ \text{Stem} + 0.00271\ \text{Oweight} - 0.00346\ \text{TDay} \qquad (43)$$
R^2 = 49.9%

$$MC = 55.4 - 0.271\ \text{Dcut} + 0.00234\ \text{Oweight} \qquad (44)$$
R^2 = 31.8%

Starr Forest Dry-ins Study

Pine:

$$\text{Reduw} = 1.014 - 0.00369\ \text{Dcut}\ \text{t}\ 0.0000162\ \text{Dcut}^2 \qquad (45)$$
R^2 = 85.5%

$$Reduw = 1.011 - 0.0000741\ TDay + 0.00000001\ TDay^2 \quad (46)$$
$$R^2 = 85.4\%$$

Discussion

Moisture content predictions (equations 7 through 12 and 37 through 44) explained the least variation. In the case of equations 37 through 44, the low R^2's were attributable in part to the foliage being lost as the bundles dried. However, even with the foliage loss accounted for, moisture content exhibited great variability.

Most of our data were more conducive to analysis of the reduction in weight. Note that days since felling (Dcut) accounted for about the same amount of variation as temperature-days in all cases. We were able to analyze the pine data for drastic temperature changes between summer and winter and found that the temperature-days variable did not adequately explain the differences in the drying process that were taking place between the summer and winter months. Thus, separate equations for the different times of the year were appropriate.

Figure 1 is a plot of equations 31 and 45, the best predictors of weight reduction as a function of days. Note that the pine stems were only beginning to stabilize in weight reduction after approximately 50 days of drying. Using equation 37, we would predict the moisture content to be 59 percent on the ovendry basis at this point in time.

Figure 2 is a plot of equation 33, which is weight reduction of soft hardwood as a function of days since being felled and total rainfall since felling. Note that the weight begins to stabilize at 30 days for the soft hardwoods. According to equation 41, the bundles would have a moisture content of almost 50 percent on the ovendry basis at 30 days.

Figure 3 is a plot of equation 35, which is the weight reduction of hard hardwoods as a function of days since felling and original weight of the bundle. These bundles were beginning to stabilize in weight at 40 days. According to equation 42, a bundle of hard hardwoods with an initial weight of 1,000 pounds and average DBH of 12.5 inches would have a moisture content of 47 percent on the ovendry basis at 40 days.

Drying the hardwood species 40 days in the summer should give ample time for all transpirational drying to take place. Drying this length of time should reduce the moisture content of the wood to between 45 and 60 percent on the ovendry basis.

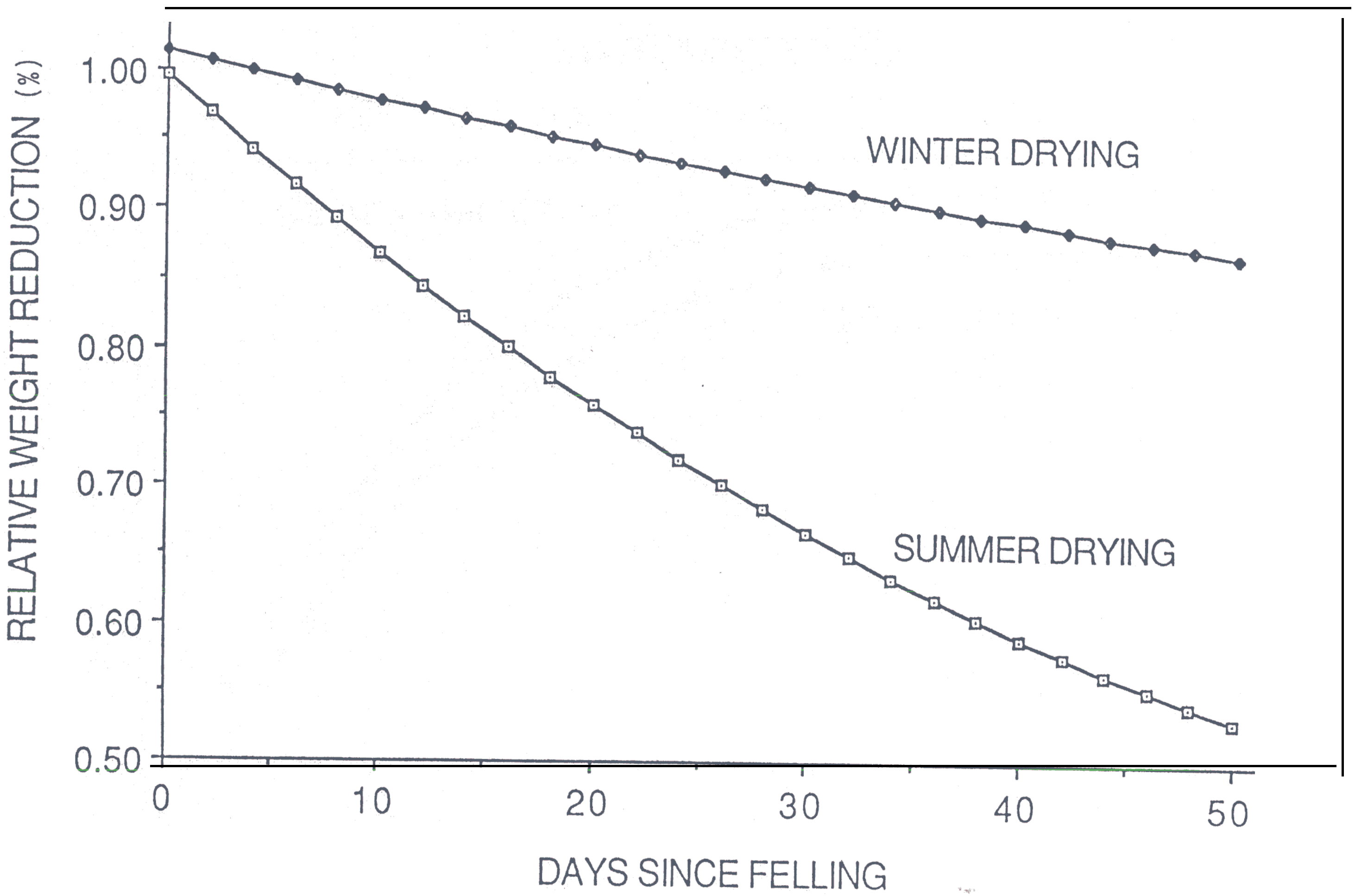

Figure 1. Relative reduction in weight for southern pine species.

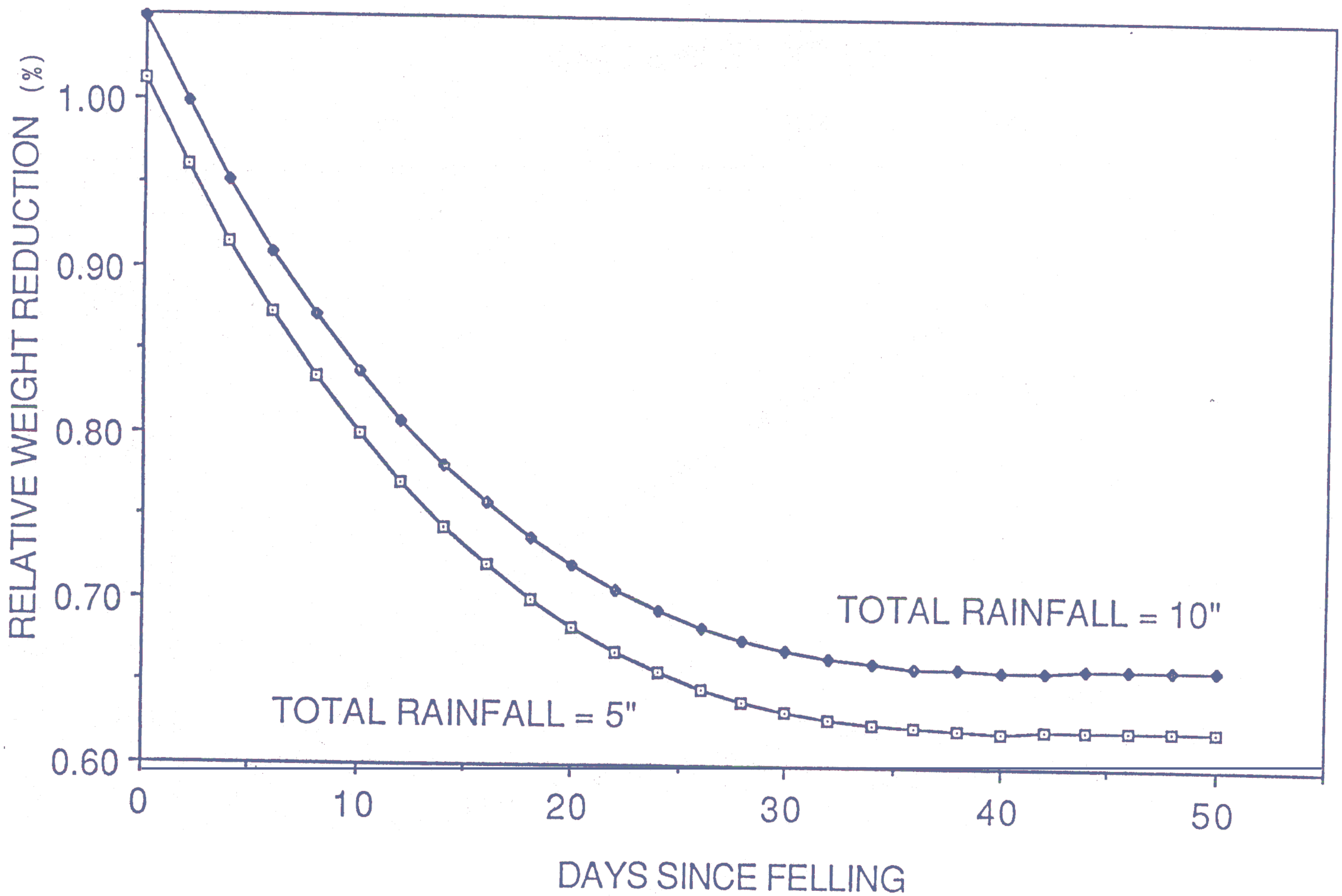

Figure 2. Relative reduction in weight for the soft-hardwood species.

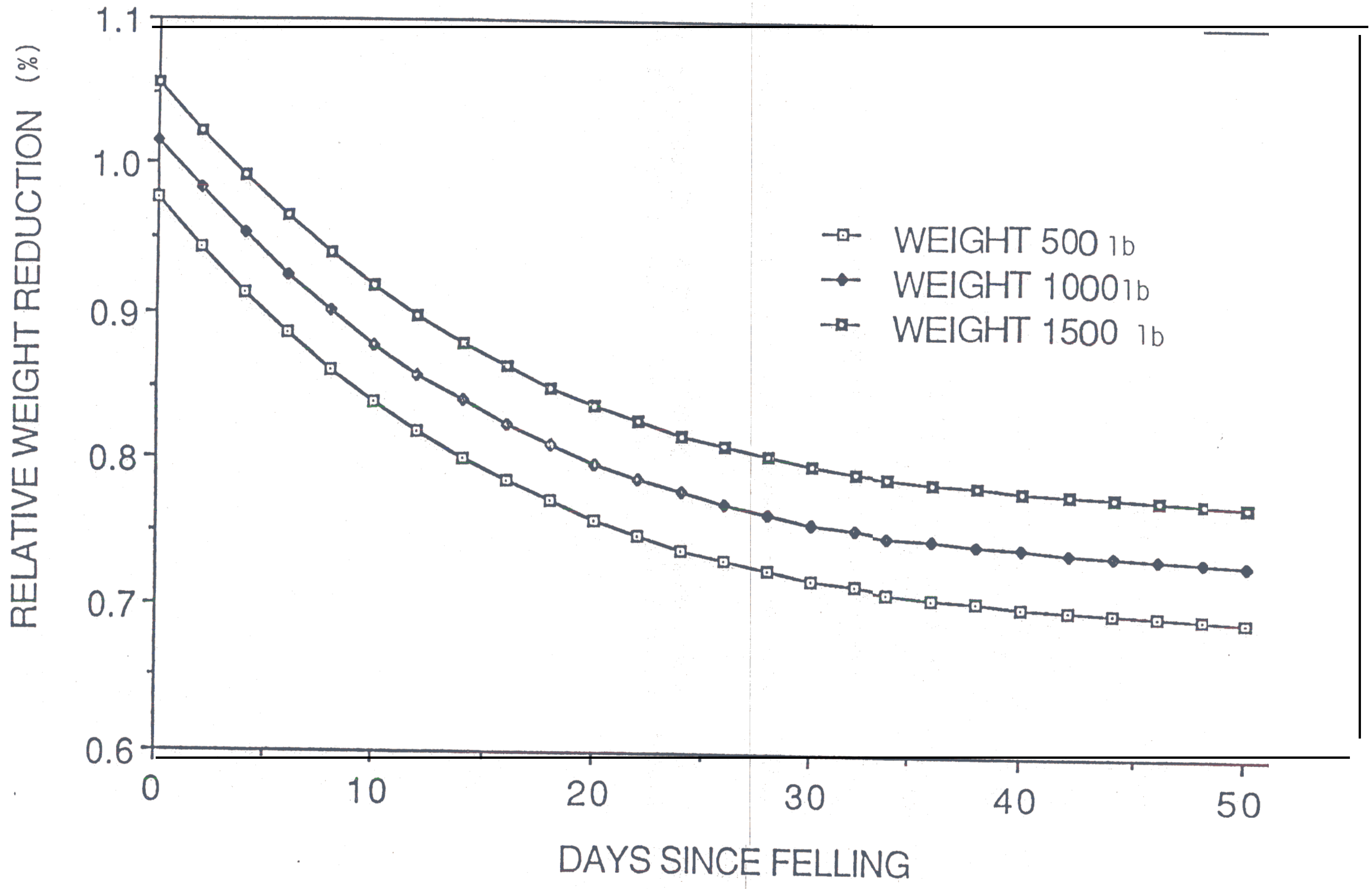

Figure 3, Relative reduction in weight for hard-hardwood species.

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