Optimization of Logging Residue Drying for Energy Products

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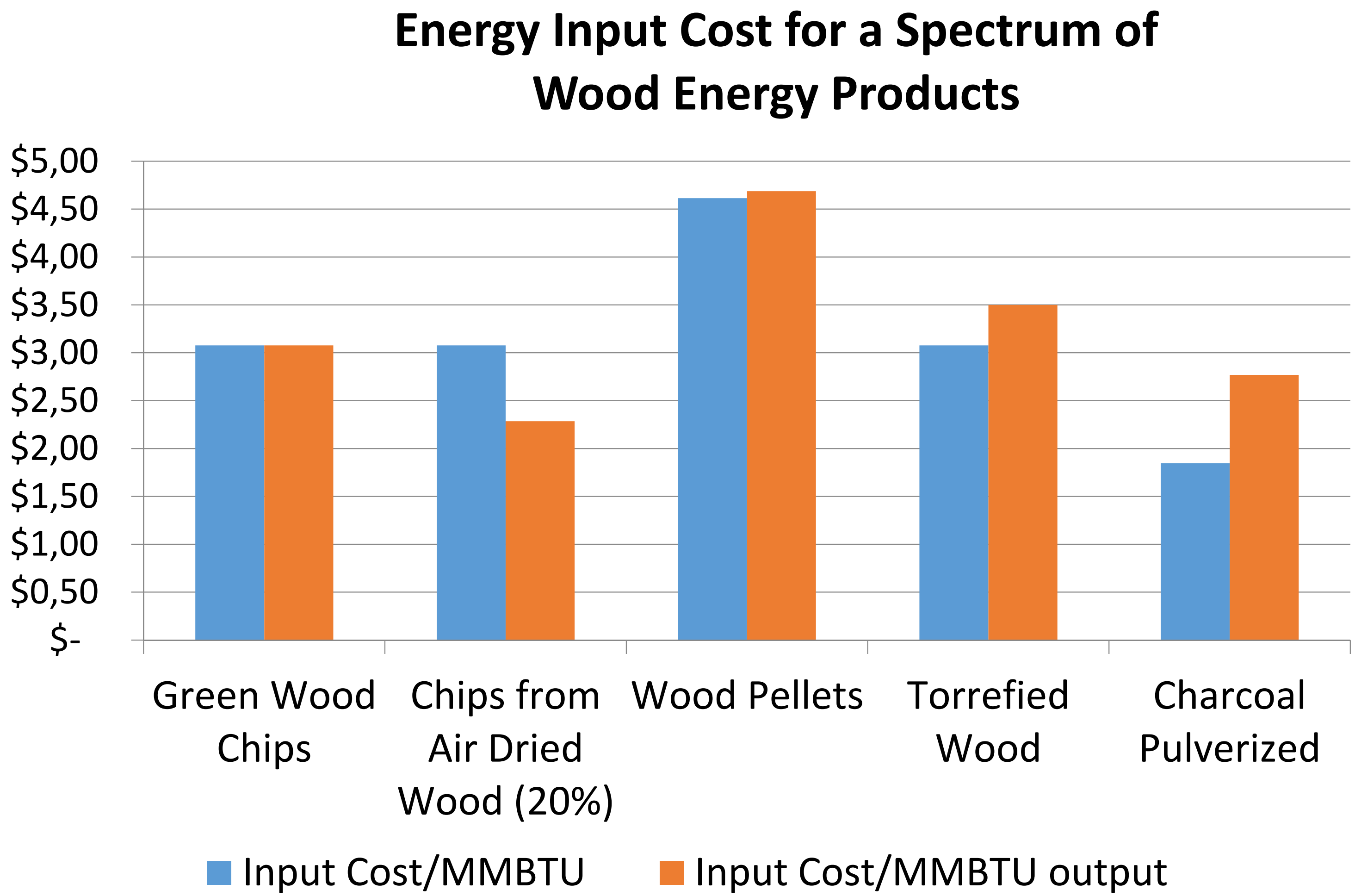
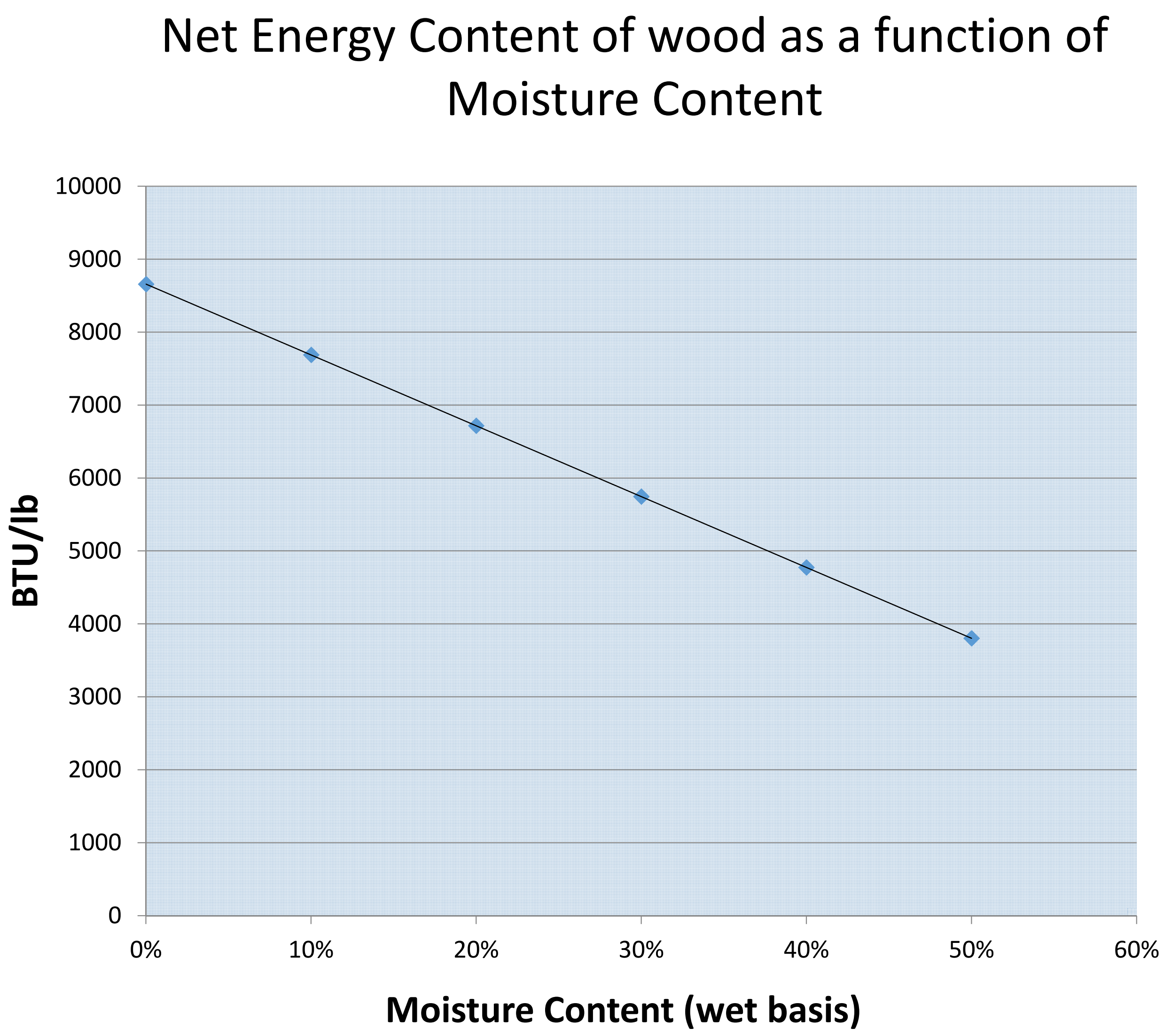
Partners and Funding Sources

- North Carolina State University
- US Endowment for Forestry and Communities
- Carolina Commonwealth
- North Carolina Association of Professional Loggers
- Walki
- Maxiload Scales
- Peterson Corporation

Presentation

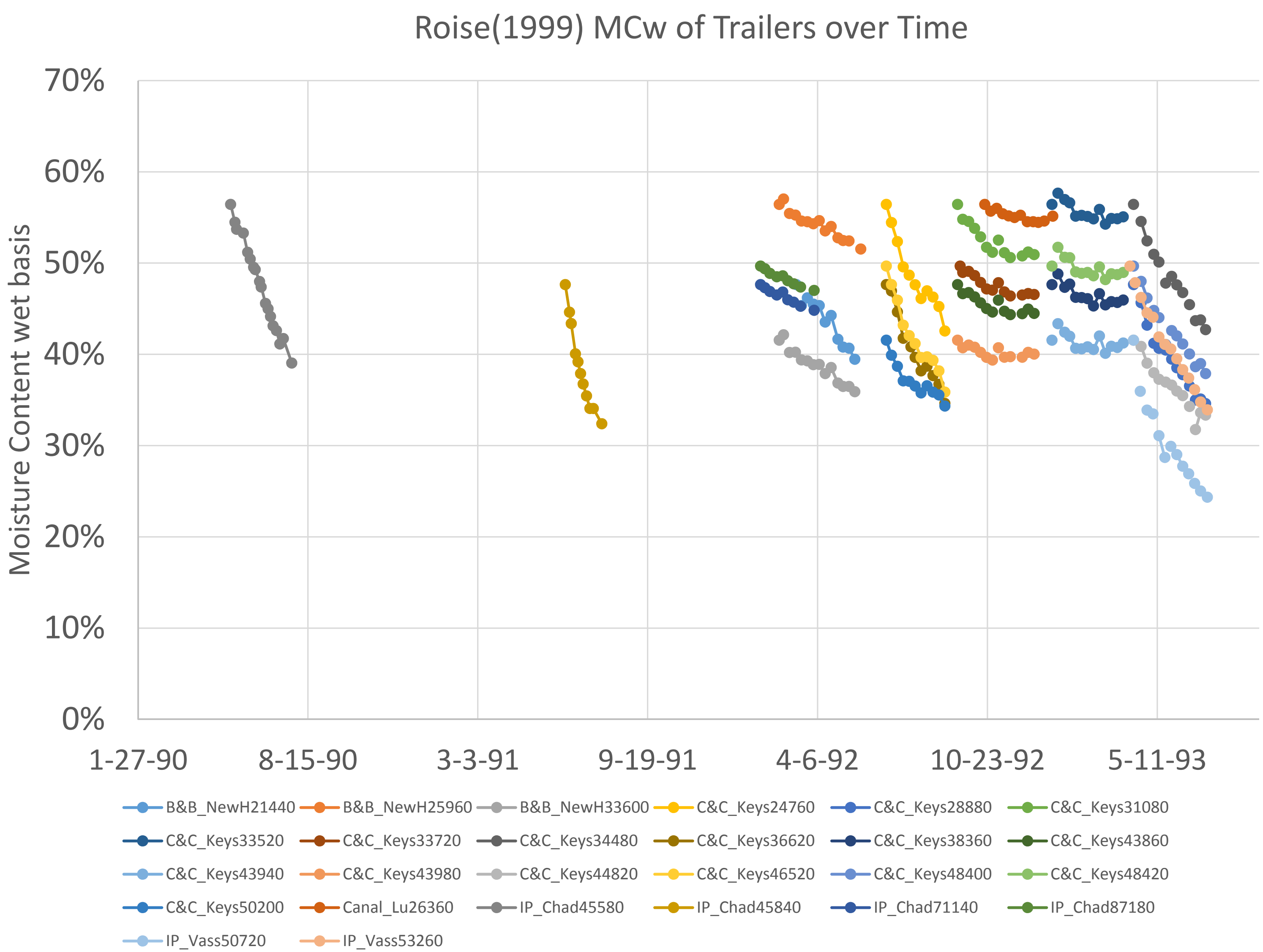
1) Background and justification
2) Data collection
3) Model
4) Results

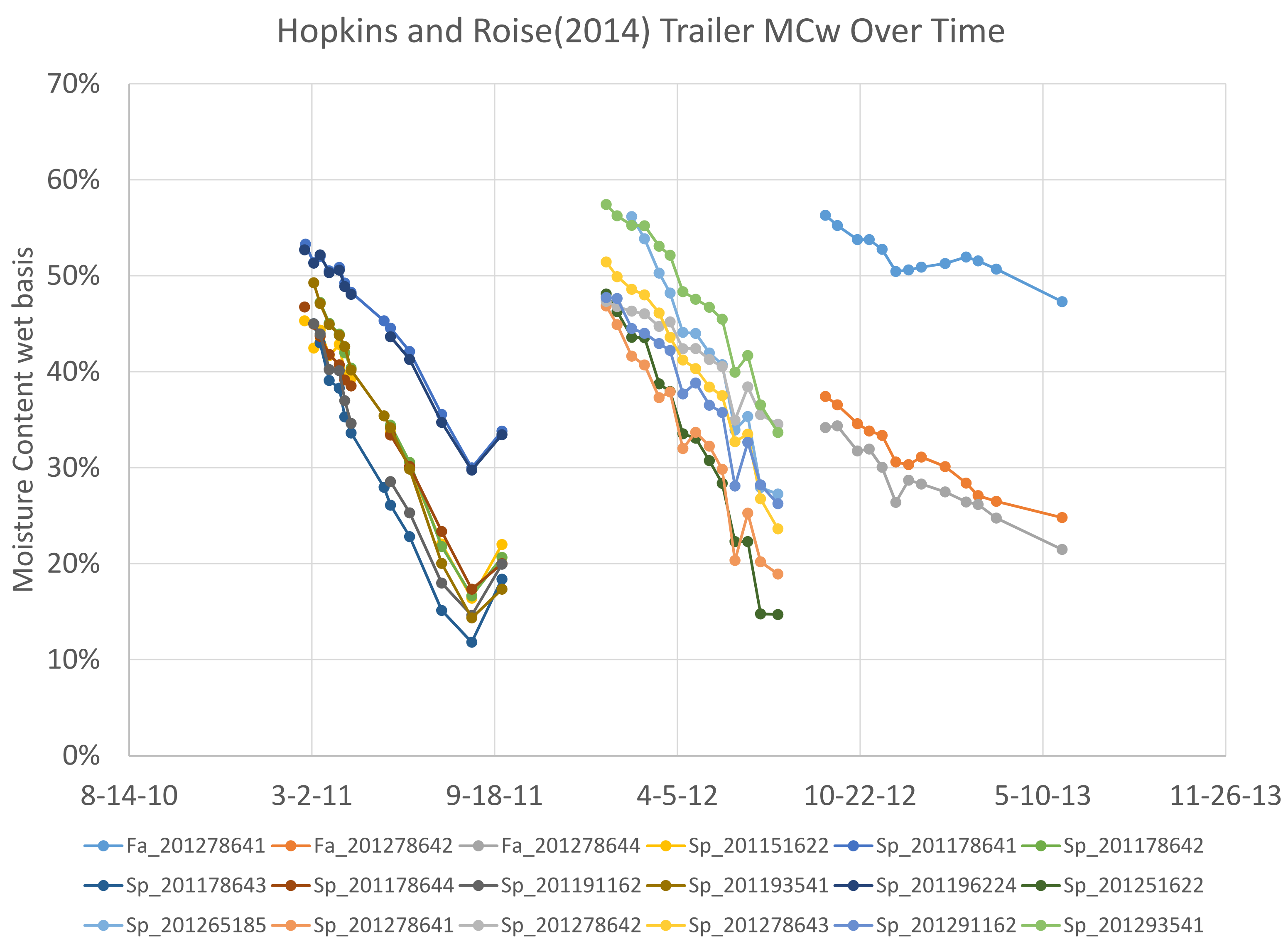

Energy Input Cost for a Spectrum of Wood Energy Products
$5,00
$4,50
$4,00
$3,50
$3,00
$2,50
$2,00
$1,50
$1,00
$0,50
$-
Green Wood Chips
Chips from Air Dried Wood (20%)
Wood Pellets
Torrefied Wood
Charcoal Pulverized
Input Cost/MMBTU
Input Cost/MMBTU output


Net Energy Content of wood as a function of Moisture Content
BTU/lb
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0%
10%
20%
30%
40%
50%
60%
Moisture Content (wet basis)

Objectives:

- Determine an in-Field Drying model to predict Moisture content.
  - Lower energy delivery costs per unit of energy (47%)
  - Increasing the supply of energy from forest resources (by 32%)
  - Decrease the cost of drying prior to pelletizing (75%)
- Convert the industry from measuring tons to measuring energy content.


Roise(1999) MCw of Trailers over Time
Moisture Content wet basis
70%
60%
50%
40%
30%
20%
10%
0%
1-27-90
8-15-90
3-3-91
9-19-91
4-6-92
10-23-92
5-11-93
B&B_NewH21440
B&B_NewH25960
B&B_NewH33600
C&C_Keys24760
C&C_Keys28880
C&C_Keys31080
C&C_Keys33520
C&C_Keys33720
C&C_Keys34480
C&C_Keys36620
C&C_Keys38360
C&C_Keys43860
C&C_Keys43940
C&C_Keys43980
C&C_Keys44820
C&C_Keys46520
C&C_Keys48400
C&C_Keys48420
C&C_Keys50200
Canal_Lu26360
IP_Chad45580
IP_Chad45840
IP_Chad71140
IP_Chad87180
IP_Vass50720
IP_Vass53260


Hopkins and Roise(2014) Trailer MCw Over Time
Moisture Content wet basis
70%
60%
50%
40%
30%
20%
10%
0%
8-14-10
3-2-11
9-18-11
4-5-12
10-22-12
5-10-13
11-26-13
Fa_201278641
Fa_201278642
Fa_201278644
Sp_201151622
Sp_201178641
Sp_201178642
Sp_201178643
Sp_201178644
Sp_201191162
Sp_201193541
Sp_201196224
Sp_201251622
Sp_201265185
Sp_201278641
Sp_201278642
Sp_201278643
Sp_201291162
Sp_201293541


MELLANSKOG

Balancing biomass harvesting and drying tactics with delivered payment practice
Refining woody biomass feedstock logistics

Dr. Joseph P Roise, and others

12/23/2013

http://www.usendowment.org/images/Final_Report_to_the_US_Endowment_on_Field_Drying_Biomass_v5.pdf

Diffusion Equation for Drying

- Commonly used functional form from both fire science and kiln operation.
- Regression form, k=a*X is determined by environmental variables
- $M_1 = M_0 + (M_0 - M_e) * \delta e^{(a*X)*(t_1 - t_0)}$

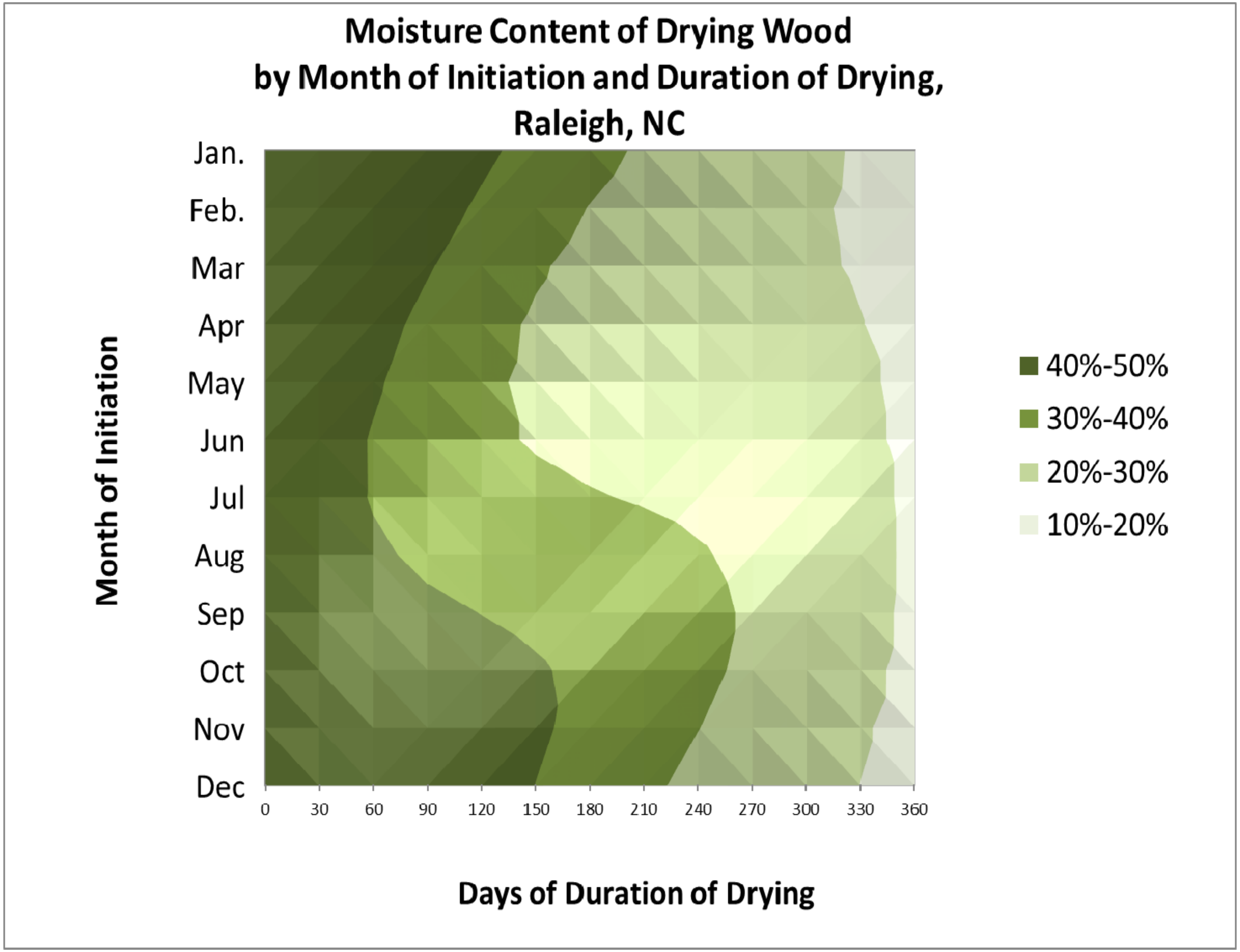
Data Sources for Climate Information

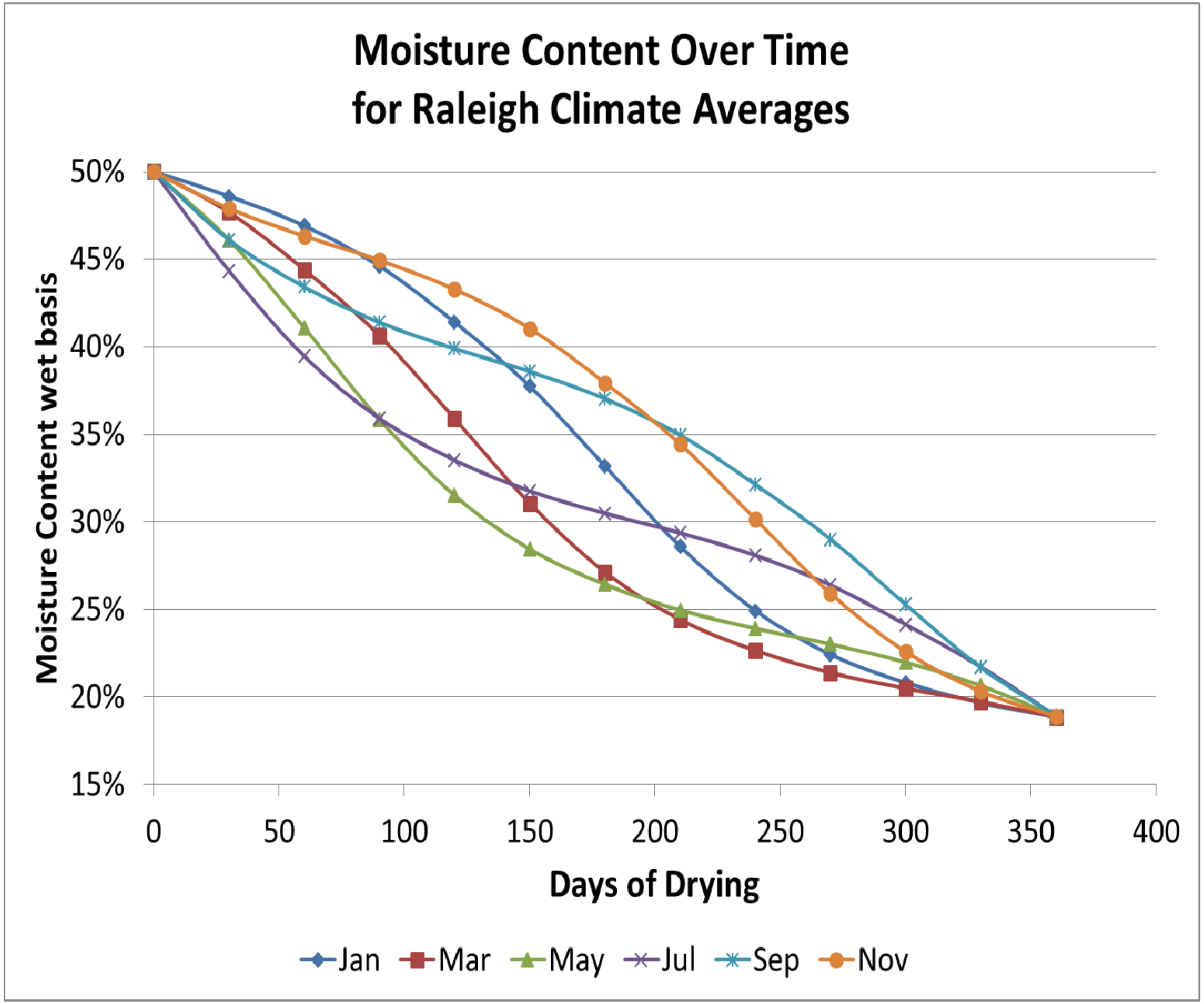
- Hopkins dataset matched to closest weather station (Henderson Oxford Airport weather station (KHNZ station)
  - CRONOS dataset (https://www.nc-climate.ncsu.edu/)
- Roise dataset matched to synthetic data record for precipitation and temperature based on nearest weather stations and on Raleigh humidity record (KRDU station)
  - PRISM dataset (http://www.prism.oregonstate.edu/explorer/, 2015)
  - CRONOS dataset (https://www.nc-climate.ncsu.edu/)

Forecast of Drying rates

- Historical climate normals used to forecast drying for a typical year

	Hardwood		Pine	
Parameter	Tops and Pulpwood	Pulpwood	Tops and Pulpwood	Pulpwood
α (temperature)	0.001265	0.001265	0.001265	0.001265
β (humidity)	-0.00088	-0.00088	-0.00088	-0.00088
γ (precipitation/M_0)	-0.00004	-0.00004	-0.00004	-0.00004
δ (incorporates s, sp, r)	-0.07332091	-0.05402	-0.055712	-0.04104656


Moisture Content of Drying Wood
by Month of Initiation and Duration of Drying,
Raleigh, NC
Month of Initiation
Jan.
Feb.
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
0
30
60
90
120
150
180
210
240
270
300
330
360
Days of Duration of Drying
40%-50%
30%-40%
20%-30%
10%-20%



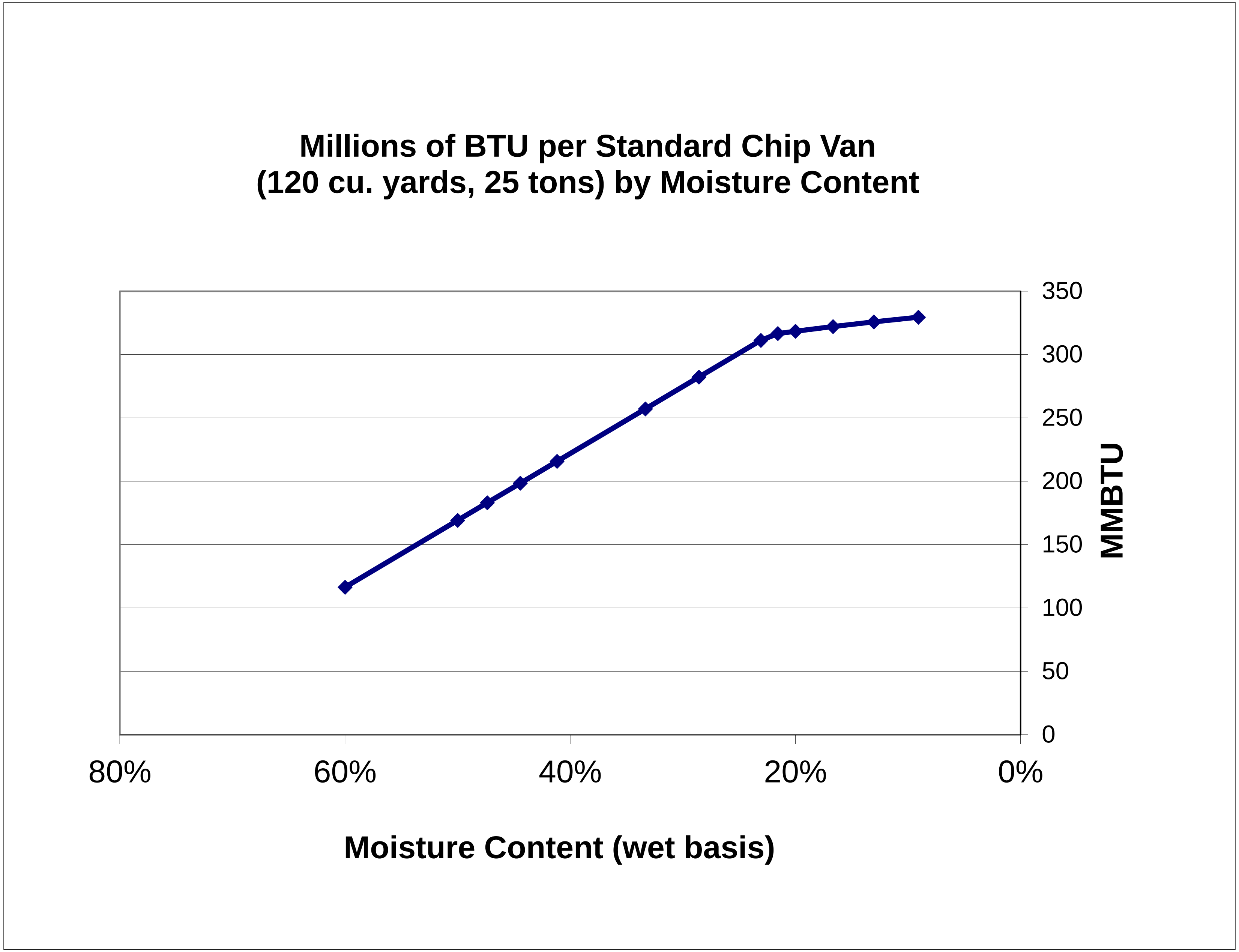
Moisture Content Over Time
for Raleigh Climate Averages
Moisture Content wet basis
50%
45%
40%
35%
30%
25%
20%
15%
0
50
100
150
200
250
300
350
400
Days of Drying
Jan
Mar
May
Jul
Sep
Nov

Financial Optimization

- Incorporate both financial and physical aspects of drying
- π=Revenue-Costs
- $shrinkage\ ratio = \frac{1-.5}{1-M_w}$ accounts for increasing amount of moist biomass to get a given amount of drier biomass
- Price is proportional LHV and price of fresh moist biomass
- $Price_{dry}=Price_{green}*LHV_{dry}/LHV_{green}$
- LHV function of temperature of air and fuel (60˚F), 40% excess air in combustion, 8500 Btu/lb HHV (General Technical Report, 1979).
- LHV=-10255*M_w+8500 Btu

Financial Optimization Costs

- Assumed microchipping
  - Chipping productivity (tons/hour)=18.5+82.5*M_w (Hopkins, 2013)
  - Chipping cost per ton=\$5*(59.75 tph/(18.5+82.5*M_w) tph) (NCPLA, 2013)
- Transportation
  - 120 yd^3 van, 25 tons load
  - Density (lbs./ ft^3)=10.5+M_w*21
  - At M_w below 23% the truck is limited by volume rather than weight, increasing the cost per ton of transported dried wood.
  - Haul distance is assumed to be 20 miles, \$3.60 per loaded mile
- Harvest and piling \$15/ton


Millions of BTU per Standard Chip Van
(120 cu. yards, 25 tons) by Moisture Content
350
300
250
200
150
100
50
0
MMBTU
80%
60%
40%
20%
0%
Moisture Content (wet basis)

Financial Optimization Profit

- π= Price(M_w(t))*PV(t)* Shrinkage(M_w(t))- Chipping(M_w(t))*PV(t) * Shrinkage(M_w(t))- Transport(M_w(t)*PV(t) * Shrinkage(M_w(t))- Harvesting – Piling
- Discount for PV is 10%
- $\max \pi: set\ \frac{\partial \pi}{\partial t} = 0, solve\ for\ t$

	Month of Initiation											
Days Dryir	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	$ 2.12	$ 2.12	$ 2.12	$ 2.12	$ 2.12	$ 2.12	$ 2.12	$ 2.12	$ 2.12	$ 2.12	$ 2.12	$ 2.12
30	$ 2.46	$ 2.55	$ 2.75	$ 3.05	$ 3.22	$ 3.57	$ 3.72	$ 3.56	$ 3.22	$ 2.88	$ 2.68	$ 2.51
60	$ 2.85	$ 3.11	$ 3.55	$ 3.95	$ 4.38	$ 4.75	$ 4.74	$ 4.36	$ 3.81	$ 3.34	$ 3.02	$ 2.81
90	$ 3.35	$ 3.83	$ 4.33	$ 4.89	$ 5.30	$ 5.48	$ 5.29	$ 4.77	$ 4.16	$ 3.61	$ 3.27	$ 3.15
120	$ 4.01	$ 4.52	$ 5.13	$ 5.62	$ 5.84	$ 5.84	$ 5.54	$ 4.99	$ 4.34	$ 3.80	$ 3.55	$ 3.61
150	$ 4.63	$ 5.23	$ 5.75	$ 6.04	$ 6.09	$ 5.98	$ 5.65	$ 5.09	$ 4.46	$ 4.03	$ 3.94	$ 4.19
180	$ 5.27	$ 5.77	$ 6.08	$ 6.20	**$ 6.16**	**$ 6.01**	$ 5.66	$ 5.14	$ 4.61	$ 4.33	$ 4.44	$ 4.75
210	$ 5.74	$ 6.04	**$ 6.19**	**$ 6.21**	$ 6.14	$ 5.97	$ 5.65	$ 5.20	$ 4.83	$ 4.74	$ 4.91	$ 5.31
240	$ 5.98	**$ 6.12**	$ 6.16	$ 6.15	$ 6.07	$ 5.91	$ 5.64	$ 5.31	$ 5.11	$ 5.11	$ 5.39	$ 5.72
270	**$ 6.00**	$ 6.04	$ 6.05	$ 6.03	$ 5.97	$ 5.86	$ 5.67	$ 5.48	$ 5.37	$ 5.49	$ 5.72	**$ 5.91**
300	$ 5.92	$ 5.93	$ 5.93	$ 5.91	$ 5.86	$ 5.81	**$ 5.72**	$ 5.61	$ 5.62	$ 5.73	**$ 5.83**	$ 5.89
330	$ 5.80	$ 5.80	$ 5.79	$ 5.78	$ 5.76	$ 5.74	$ 5.71	**$ 5.70**	**$ 5.71**	**$ 5.75**	$ 5.77	$ 5.79
360	$ 5.66	$ 5.66	$ 5.66	$ 5.66	$ 5.66	$ 5.66	$ 5.66	$ 5.66	$ 5.66	$ 5.66	$ 5.66	$ 5.66
	1	2	3	4	5	6	7	8	9	10	11	12
end date	October	October	October	Novembe	Novembe	Decembe	May	July	August	Septembe	Septembe	Septembe
Mw end	22%	23%	24%	24%	26%	28%	24%	22%	22%	21%	23%	24%

Discussion

- Increase of profit by allowing time to
- Clustering of optimal times in Fall (9/12 months)
- In process work includes field piled drying and time and motion studies of skidder operation

Questions?

Thanks for coming!