Bio-Based Energy Analysis Group

UT Agricultural & Resource Economics

Harvesting, Handling, and Storage Logistics and Economics

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Presentation

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Harvest and Storage Management Issues in Tennessee/Southeast U.S.

- Alternative harvest and storage methods may have certain advantages and disadvantages in a potential switchgrass feedstock supply chain.
  - Dry matter losses during harvest, staging, storage, and transport.
  - Area covered and biomass gathered during harvest window.
  - Density of biomass and costs of transportation.
  - Quality of dry matter (potential ethanol yield).

Presentation Outline

- **Switchgrass bale harvest and storage study.**
- **Switchgrass harvest and storage logistics economic feasibility study.**
  - **Look at potential of an industrial compactor-baler-wrapper from the garbage industry (BaleTech) as a preprocessing step to increase the density and provide protection for feedstock before the storage and transportation functions within the feedstock supply chain.**
- **Current harvest and storage logistics research at the University of Tennessee.**

Bale Harvest & Storage Study

Participants:

- Burton C. English
- James A. Larson
- Donald D. Tyler
- Daniel F. Mooney

Research supported by US DOE Grant Project entitled “UT Switchgrass Project”

Bale Harvest & Storage Study

Objectives:

- Estimate storage dry matter losses under alternative storage methods and weather.
- Estimate chemical composition & ethanol yield of switchgrass bales under alternative storage methods and weather.
- Develop guidelines to visually estimate the quality of stored biomass.
- Correlate ethanol content of bales with weather, % moisture, and storage method.
- Calculate switchgrass harvest and storage costs under alternative storage methods and weather.

Data Collection

- Harvest methods:
  - 5 ft × 4 ft round bales
  - 4 ft × 8 ft rectangular bales
- Storage Covers:
  - Tarp on top
  - No tarp
- Storage Surfaces:
  - Well drained ground
  - Gravel
  - Pallets
- In barn (500 days only)

Methods

- Bales entered storage Jan. 25, 2008.
- Bales were removed from storage every 100 days for 5 sampling periods.
- Bales were weighed, mechanically separated, and photographed.
- Samples were collected based on a visual estimate of weathered areas.
- Wet and dry sample weights and proportions of different weathered areas were used to estimate dry matter losses for each treatment.

Sampling Protocol

Weathering—Uncovered Round Bales

100 Days

200 Days

300 Days

400 Days

Weathering—Uncovered Square Bales

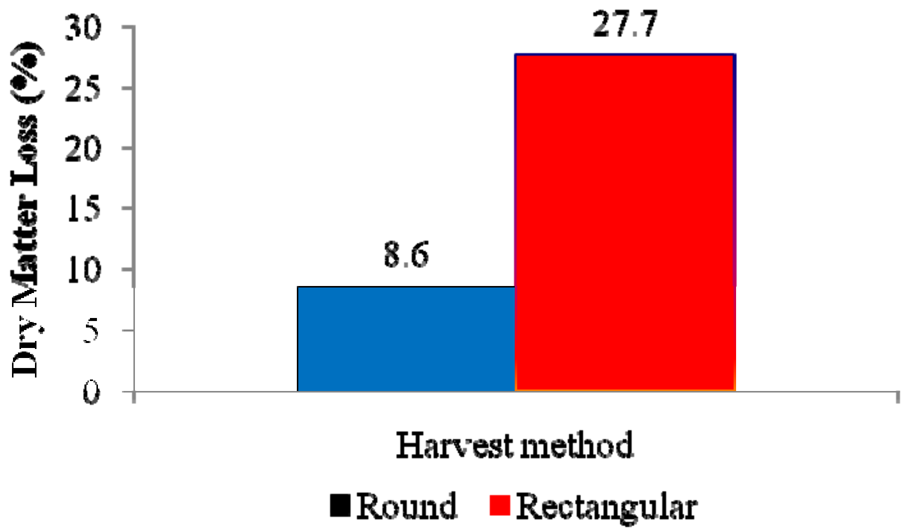
100 Days

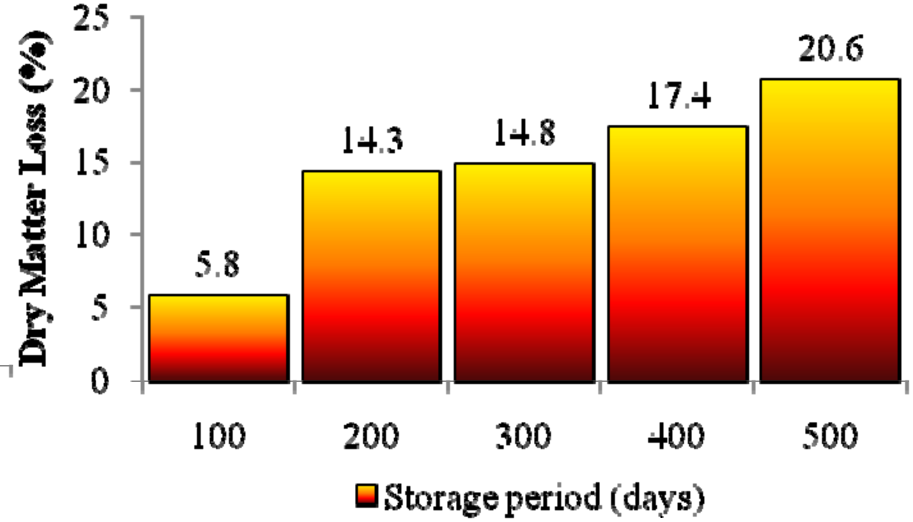
200 Days

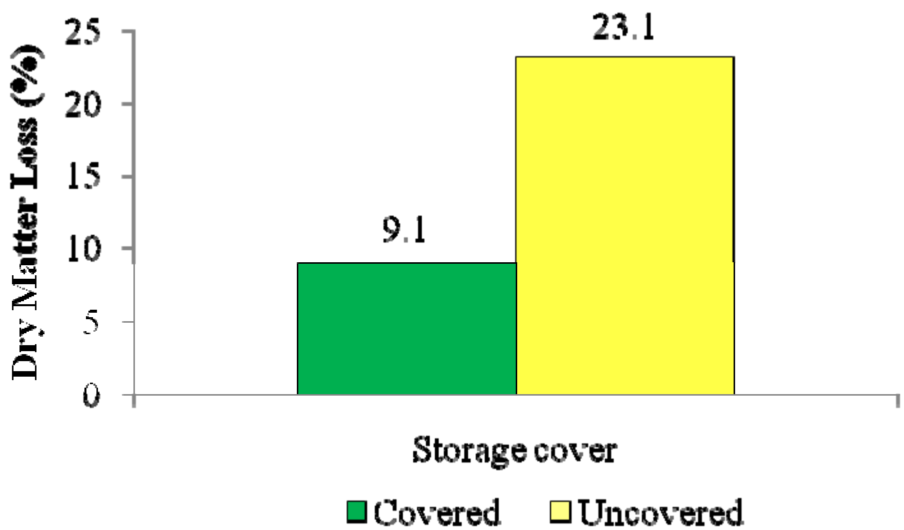
300 Days

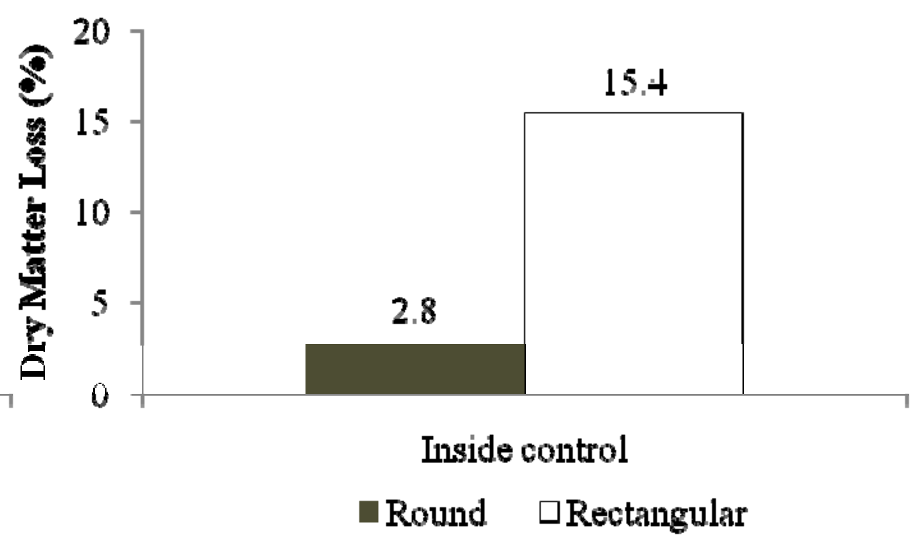
400 Days

Switchgrass Bale Storage Losses

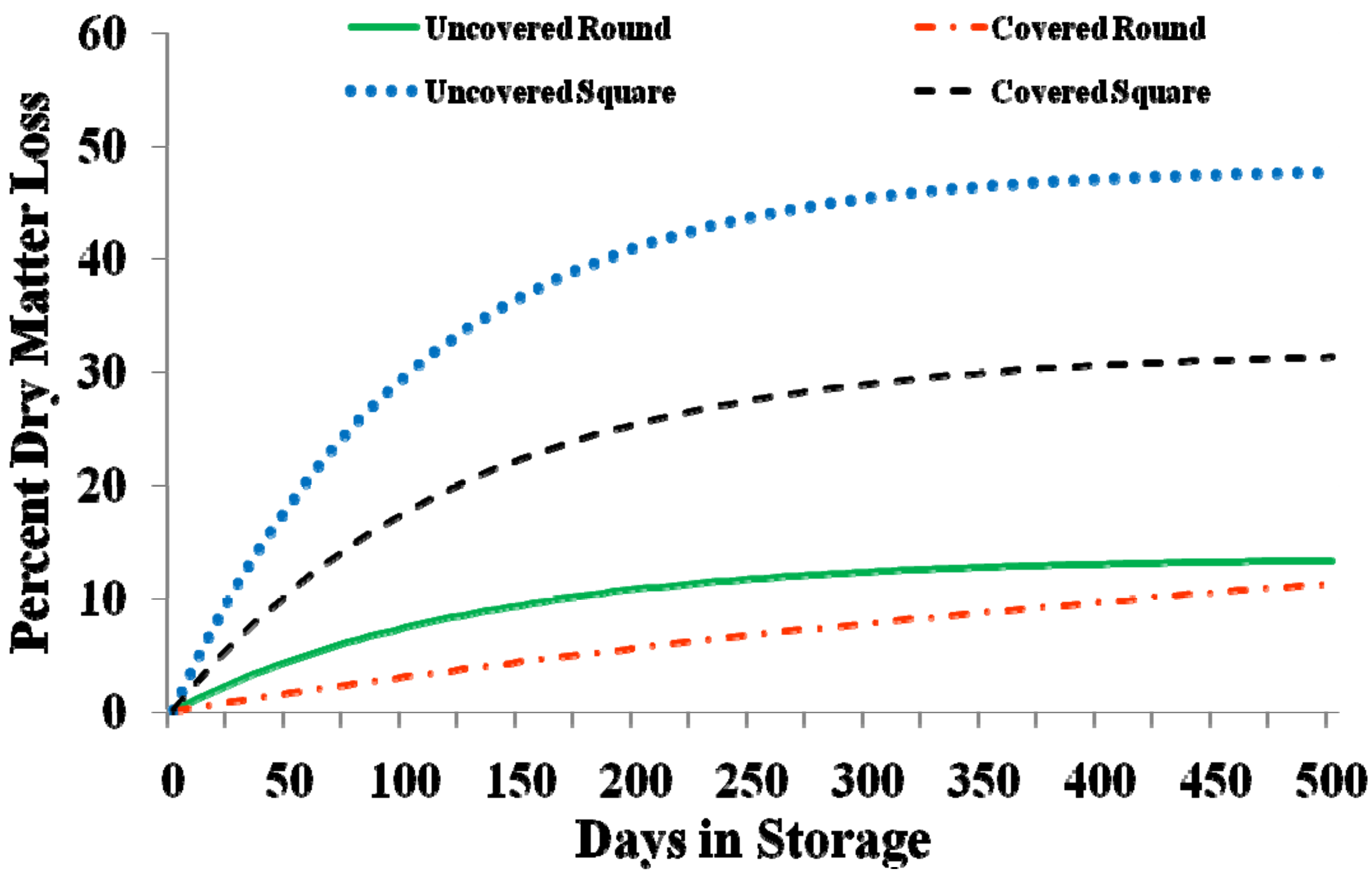




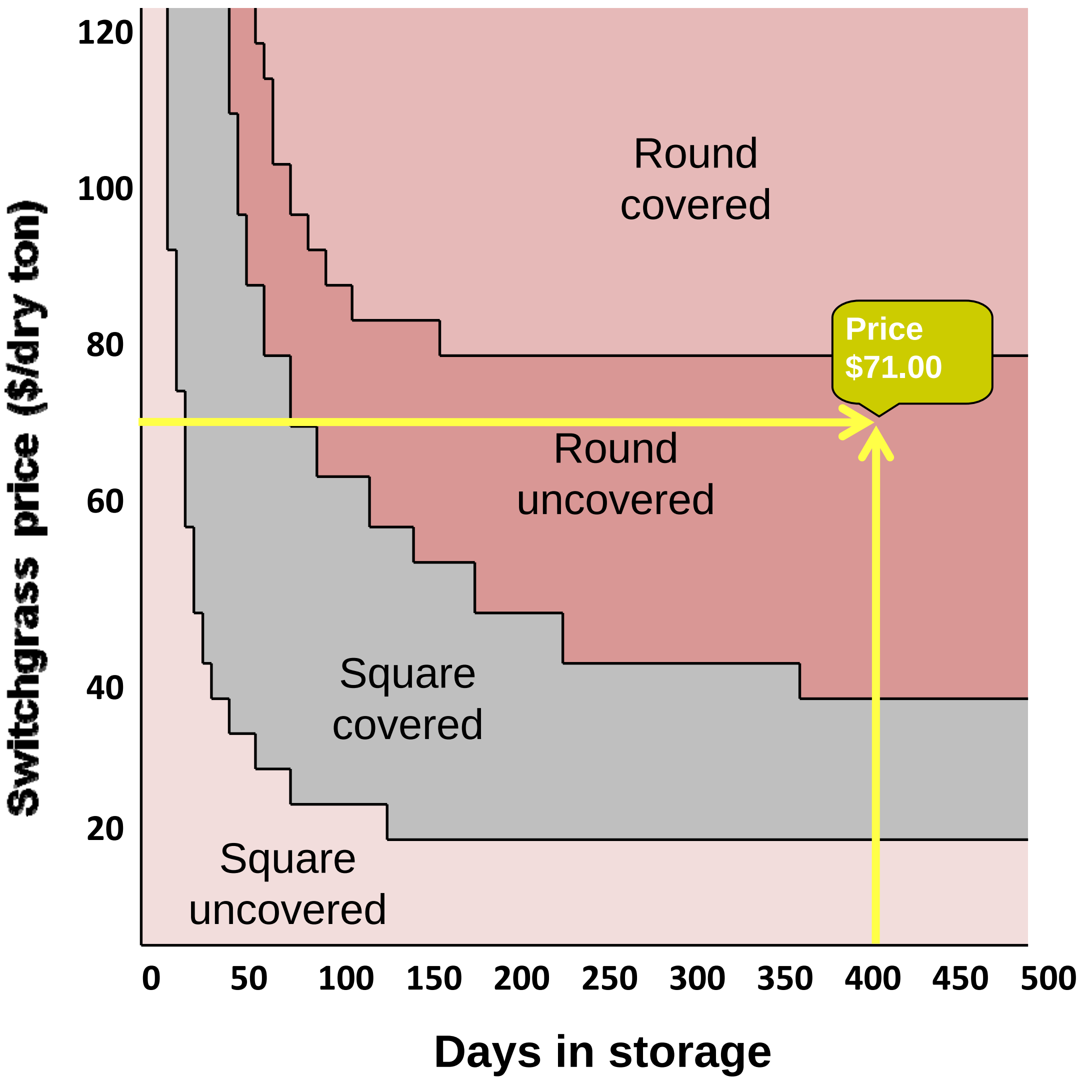




Estimated Dry Matter Losses by Bale Type, Storage Cover, and Days in Storage using a Mitscherlich-Baule Functional Form



Storage Method Profitability Map



- **The map indicates which storage option is most profitable for a given storage period**
- **Longer storage periods imply greater losses**
- **Higher prices increase the "payback" to protective expenditures**
- **Low prices & short storage periods favor square bales**
- **High prices & long storage periods favor round bales**

Switchgrass Harvest and Storage Logistics Economic Feasibility Study

Participants:

- James A. Larson
- Edward Yu
- Burton C. English
- Daniel F. Mooney
- Chenguang Wang

Research supported by Southeastern Sun Grant Initiative Project entitled "Evaluating the Economics of Incorporating Preprocessing Facilities in Biomass Supply Logistics with an Application in East Tennessee."

Background

- Regional biomass preprocessing facilities as a part of the supply chain feeding into a biorefinery (Carolan, Joshi, and Dale , 2007) .
- Potential preprocessing facility functions:
  - Cleaning, separating and/or sorting;
  - Chopping, grinding, and/or mixing/blending;
  - Moisture control;
  - Densification and packaging of feedstock before it is placed into storage or transported to the biorefinery.
- The key question is whether the potential saving in storage and transportation costs more than offset the investment in preprocessing technologies.

Objectives

- **To analyze the cost of various logistic methods of switchgrass, ranging from conventional hay methods to the potentially more capital intensive preprocessing option, using enterprise budgeting and GIS methods.**
- **This study evaluates tradeoffs in dry matter losses during storage, investment and operating costs of equipment and facility, and the potential savings in transportation costs among different methods.**

Biorefinery Assumptions

- **Annual capacity of 25 million gallon per year of ethanol.**
- **Ethanol conversion rate of 76 gallons/dry ton of switchgrass (Wang, Saricks, and Santini, 1999).**
- **Biorefinery requires ~329,000 dry tons of biomass annually.**
- **Single harvest system between Nov 1 and Mar 1:**
  - **1/3 of harvested biomass directly brought to plant during harvest window for conversion to ethanol.**
  - **2/3 of harvested biomass placed into storage.**
  - **Inventory in storage was assumed to be uniformly delivered to the plant from March through October.**

Feedstock Logistics Scenarios

1. **Harvest using a large round baler and storing the feedstock on-farm;**
2. **Harvest using a large rectangular baler and storing the feedstock on-farm; and**
3. **Harvest using a forage chopper and hauling to a preprocessing facility for densification and packaging using an industrial compactor-baler-wrapper before being placed in on-site storage at the facility.**

Operations Sequence by Harvest & Storage Method

Operation	Round Bale	Rectangular Bale	Compactor Baler Wrapper
Mow	1	1	1
Rake	2	2	2
Bale	3	3	----
Chop	----	----	3
Truck to preprocessing facility	----	----	4
Dump in holding area	----	----	5
Front-end load into conveyer	----	----	6
Compact/Bale/Wrap	----	----	7
Front end load to storage	4	4	8
Store	5	5	9
Front-end load to truck	6	6	10
Haul by semi-truck to biorefinery	7	7	11

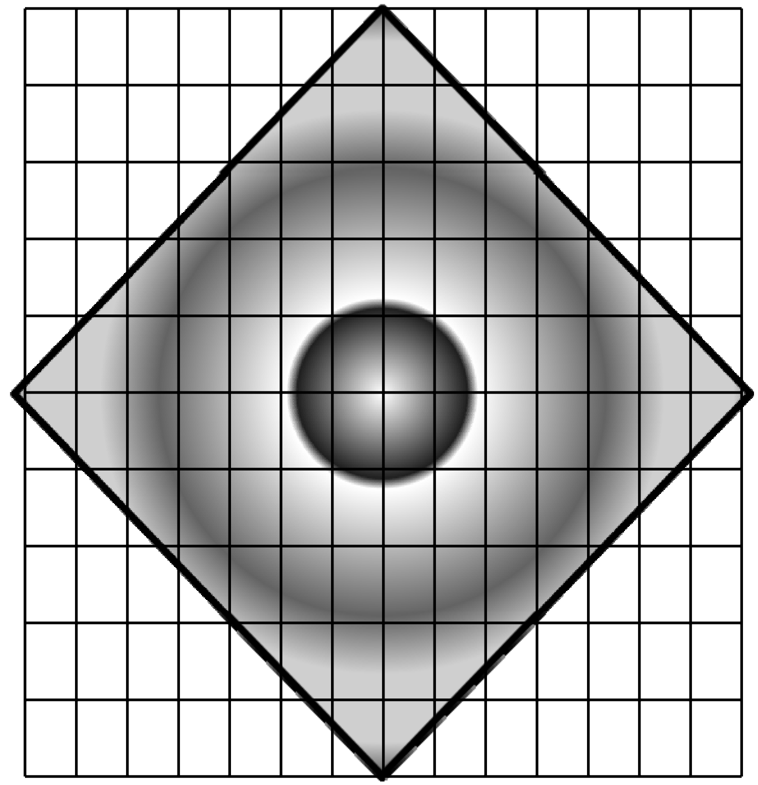
Estimated Harvest Time

Item	Month*				Total
	Nov	Dec	Jan	Feb	
Available Time	-------------------------Days/Hours-----------------------				
Days	14	14	13	12	53
Hours	86	82	78	79	325

*Estimated harvest days assuming that 70% of the days per month when precipitation was less than 0.01 inches were available for harvest operations (Knoxville, TN, precipitation data). Available harvest hours assume an average 60% of daylight hours (Knoxville, TN, daylight hours) of harvest time per available harvest day (Sources: Dry days, NOAA, U.S. Department of Commerce, Daylight hours, U.S. Naval Observatory).

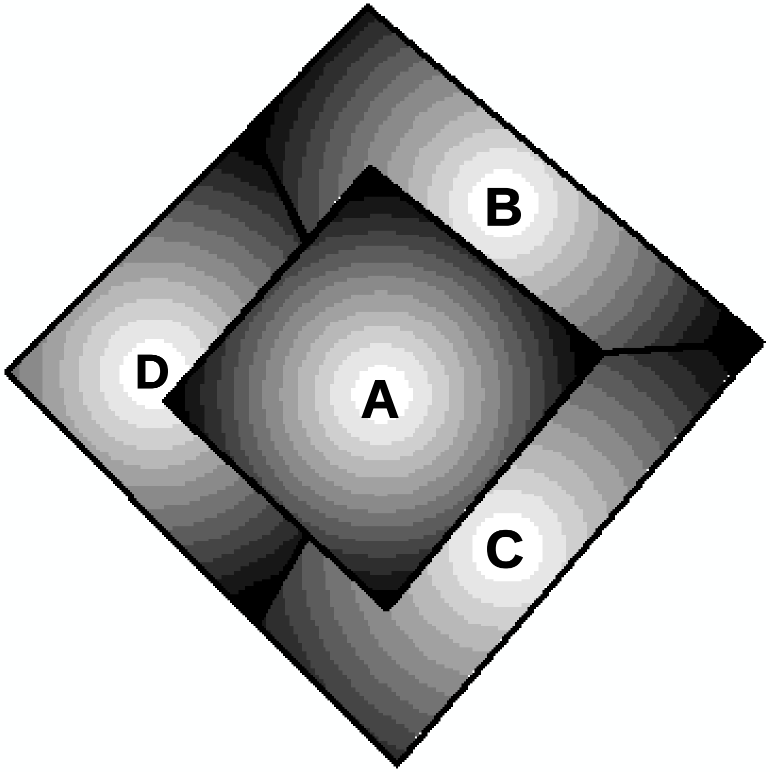
Feedstock Draw Area

- Circles typically used to represent feedstock area in bioenergy analysis.
- Typical road system can be represented by an east-west, north-south grid system.
- Loci of points that are equidistant from a processing plant will form a diamond shaped area (English, Short, and Heady, 1981).
- Assumed feedstock draw area is diamond shaped with a maximum shipping distance of 50 miles.
- For round and rectangular bale systems, average distance from farms to biorefinery is 35.5 miles.



Satellite Preprocessing Facilities Feedstock Draw Areas

Zone	Travel distance to ethanol refinery	Travel distance within the zone
A. Conversion facility	15.6 miles	15.6 miles
B. North preprocessing	30 miles	17.7 miles
C. Southeast preprocessing	26 miles	18.8 miles
D. West preprocessing	30 miles	16.0 miles



Center zone A will chop and deliver directly to the conversion facility the during the harvest season and has about a 1,667 square mile draw area.

Remaining area is split into three equal area regions each with a draw area of about 1,111 square miles each.

Satellite Preprocessing Facility

- 15 acre industrial park site with road and utility access ($25,000/acre).
- Storage shed capable of holding 2 days inventory of chopped biomass.
- BaleTech Compactor-Baler-Wrapper:
  - $1.4 M investment cost/machine,
  - 88 days operated during season,
  - 16 hours/day,
  - 60 dry ton/hour capacity,
  - Produces 2 ton (dry) bale, and
  - Negligible storage dry matter losses.
- Chopper (14/Compact Baler):
  - 20 dry tons/hour capacity, and
  - 6 tandem axel trucks/chopper.

Round & Rectangular baler Harvest Costs

- Round baler:
  - Lowest initial investment among baler options.
  - 5.5 dry ton/hour harvest capacity (Mooney et al., 2009).
- Large rectangular baler:
  - Higher initial investment—2 to 3 times more than round baler.
  - Larger tractor requirement.
  - 12 tons/hour harvest capacity (English et al., 2008).
- Staging and stacking:
  - Bale loader/spear: 1 rectangular or 2 round bales per trip.
  - Uncovered round stored store in a end-to-end row.
  - Covered round stored in 3-2-1 pyramid.
  - Covered rectangular stored in 2-2-1 pyramid.

Enterprise Budgeting

- Budgets for the equipment, materials, and labor for the establishment, annual maintenance, harvest, storage and transportation of switchgrass were from UT Department of Agricultural and Resource Economics (English Larson, and Mooney, 2008; Gerloff, 2008; Mooney et al., 2009; Wang, 2009).
- Costs were calculated assuming a 5 year contract and an average harvested yield of 6 dry ton/acre.
- Opportunity cost on land used for switchgrass production was $22/acre, the pastureland/hayland rental rate reported by the Tennessee Agricultural Statistics Service (Tennessee Agriculture 2009).
- Cost calculated on available harvest time during a 4 month season and estimated dry matter losses during storage using a Mitscherlich-Baule Functional Form.

Results

- Harvest season capacities for each system.
- Selected costs going into storage.
- Costs to produce, harvest, store, and deliver switchgrass using the round and rectangular bale systems to a biorefinery for different storage periods.
- Comparison of weighted average costs of traditional bale systems with the preprocessing system:
  - Cost per dry ton at the plant gate, and
  - Initial investment.

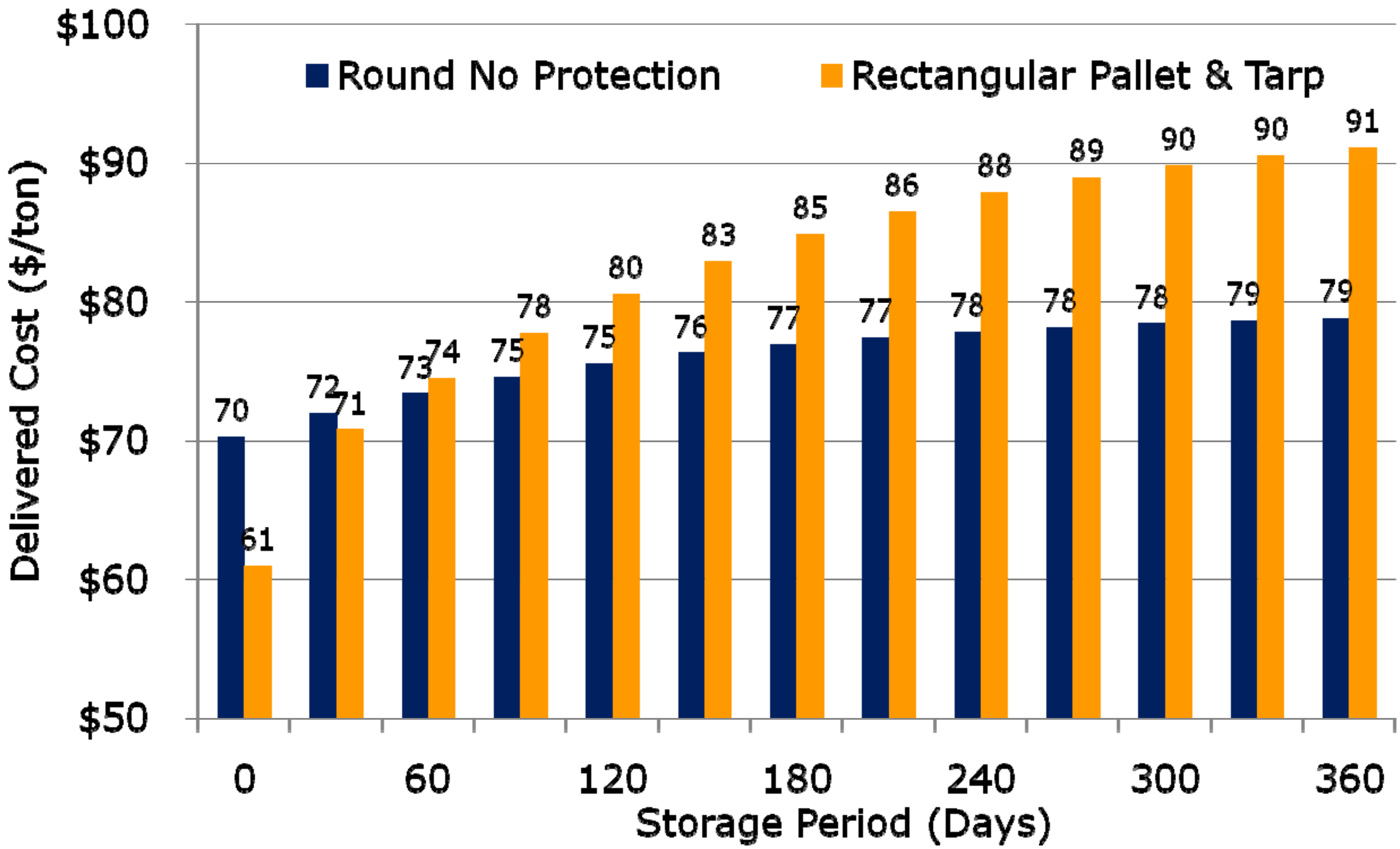
Estimated Land Area Covered and Biomass Harvested

Item	Month Nov	Dec	Jan	Feb	Total
Land Area Covered	------------------Acres------------------				
Round Baler	79	75	72	72	298
Rectangular Baler	173	164	157	157	651
Forage Chopper	288	273	261	262	1,084
Biomass Harvested	----------------Dry tons----------------				
Round Baler	475	451	431	432	1,789
Rectangular Baler	1,036	983	940	943	3,903
Forage Chopper	1,727	1,639	1,567	1,572	6,505

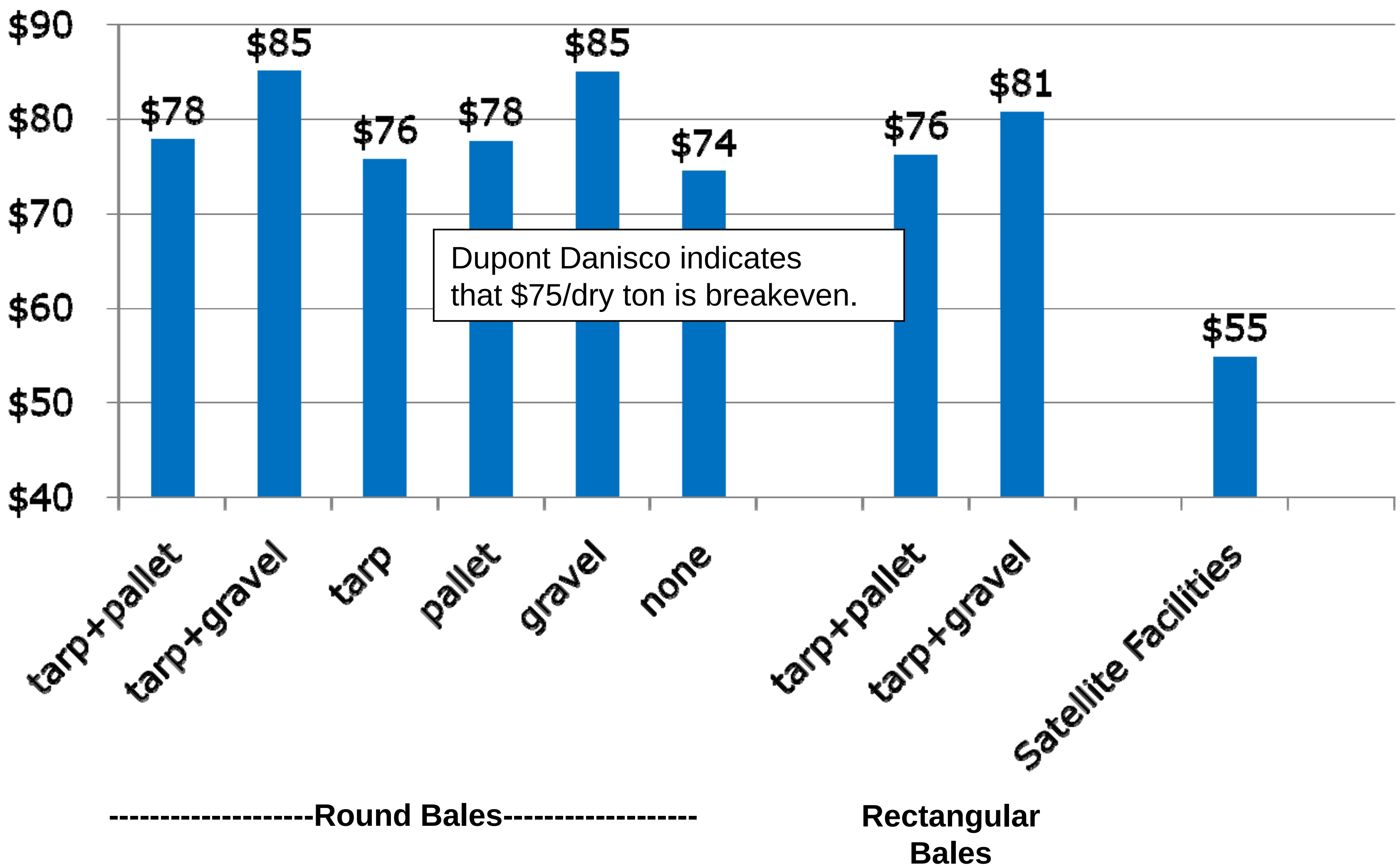
Selected Costs ($/dry ton) going into Storage

Operation	Round Bale	Rectangular Bale	Compactor Baler Wrapper
Pre-harvest	21.33	21.33	21.33
Harvest	28.55	20.30	18.21
Stage to storage at side of the field	14.88	14.88	----
Haul by truck to preprocessing facility	----	----	7.16
Compact-Bale-Wrap	----	----	8.81
Store			
No protection	0.00	0.00	----
Tarp + Pallet	7.75	5.64	----
Total before storage or delivery			
Bale: *without protection*	57.12	50.04	----
Bale: *tarp + pallet*	64.80	55.63	----
Compactor-Baler-Wrapper	----	----	54.66
Transportation to biorefinery	11.95	9.84	5.10

Costs to Produce, Harvest, Store, and Deliver Switchgrass to a Biorefinery for Different Storage Periods



Weighted Average Costs ($/dry ton) for Alternative Harvest and Storage Systems



Investment in each System

Operation	Round Bale	Rectangular Bale	Compactor Baler Wrapper
Harvest equipment	4,586,000	7,808,500	4,078,000
Preprocessing facilities			
Compactor-Baler-Wrapper	----	----	4,200,000
Buildings	----	----	1,790,827
Land	----	----	72,823
Subtotal	----	----	6,131,150
Vehicles			
Tractors/front-end loaders	26,169,000	12,012,000	6,073,500
Tandem axle trucks	----	----	2,940,00
Semi-trucks and trailers	1,200,000	960,000	480,000
Subtotal	27,369,000	12,972,000	9,426,000
Total	31,955,000	20,780,500	19,635,150

Required Operating Cash Flow for each Harvest & Storage System[a]

		Annual Operating Cash Flow		
	Initial	Discount Rate		% Round
System	Investment	10%	20%	System
Round	$31,955,000	$5,200,529	$7,621,995	100%
Rectangular	$20,780,500	$3,381,931	$4,956,622	65%
Compact	$19,635,150	$3,195,530	$4,683,430	61%

[a] Operating Cash Flow=Net Income +Depreciation.

Conclusions & Future Research

- **Industrial baler system reduced delivered costs over conventional hay methods for a 25 million-gallon-per-year biorefinery in East Tennessee**
  - **Up to 32% without considering dry matter losses during storage.**
  - **Up to 40% because of potential reduction in dry matter losses.**
- **Operating cash flow to meet a given rate of return on the initial investment was 35% to 39% lower than for the traditional harvest and storage systems.**
- **Need to field test assumptions to prove technology:**
  - **Can a the technology consistently make a 2-3 dry ton switchgrass bale under field conditions?**
  - **Do dry matter throughput assumptions hold up under real world conditions?**
  - **Are storage dry matter losses negligible compared to traditional hay systems?**

Second Phase Harvest & Storage Study, Vonore, TN (2010-2012)

Sample Points (days)	Bale Tech				Round			
	Wet Plastic	Wet Mesh	Dry Plastic	Dry Mesh	Mesh	Twine	Mesh Tarped	Bale Total
0[a]	-28	-28	-28	-28	-28	-28	-28	-196
25[b]	4	4	4	4	4	4	4	28
50[b]	4	4	4	4	4	4	4	28
100[b]	4	4	4	4	4	4	4	28
200[b]	4	4	4	4	4	4	4	28
300[b]	4	4	4	4	4	4	4	28
400[b]	4	4	4	4	4	4	4	28
500[b]	4	4	4	4	4	4	4	28

[a] The number of bales going into storage on day zero for each treatment assuming four replications for each treatment. Each bale will be sampled for dry matter (8-10 cores or grab samples per bale) before placed into storage.

[b] The number of bales removed from storage at each sampling point for each treatment assuming four replications for each treatment.

Simulation, Mathematical Programming, and GIS Optimization Framework

- Tennessee and the southeast US:
  - Road networks,
  - Railroad networks,
  - Industrial park locations, and
  - Production modeled on a 5 mile grids.
- Evaluate alternative feedstock supply chains.