Haying Machinery Basics

Dennis Buckmaster
Assoc. Prof. of Agricultural Engineering
Purdue University

Forage Systems Operations

- Mow / condition
- Invert
- Ted
- Rake
- Chop / roll process
- Bale
- Package d transport
- Slack for storage
- Wrap for storage
- Pack into bag
- Blow into silo
- Pack into bunker
- Bulk transport
Presentation Outline

- **Machinery management**
  - Capacity equations
  - Typical systems & costs
  - Custom rates
- Hay Harvest Losses
- Machine features & tractor matching
  - Mower-conditioners
  - Rakes
  - Balers
  - Transport & Storage systems
- Harvest Operations Timing
- Safety Considerations

Machine Capacity

- Potential Limits to Machine Capacity
  - Power
  - Throughput
  - Speed
  - Traction (hopefully not a factor with haymaking equipment)
Machine Capacity
Mower-Conditioner

- Potential Limits to Machine Capacity
  - Power (particularly with disc cutting)
  - Throughput (perhaps of conditioner)
  - Speed (particularly with sickle cutting)

Machine Capacity
Rakes & Inverters

- Potential Limits to Machine Capacity
  - Power (not likely)
  - Throughput (perhaps)
  - Speed (likely excessive loss at high speeds)
Machine Capacity

Balers

- Potential Limits to Machine Capacity
  - Power (possibly)
  - Throughput
  - Speed (exceed suitable speed for the pickup)

Example:
Mow 150 acres in 14 calendar days if 3 of 10 days suitable for working (pwd=.3). 8 h/d available for mowing.

\[
C_{ac/h} = \frac{A_{ac}}{B_{days} \times G_{h/day} \times PWD_{decimal}}
\]

\[
C = \frac{150}{[(14)(8)(0.3)]} = 4.5 \text{ ac/h}
\]
A good dinner or lunch-time debate topic

- What is the pwd for *hay mowing* in our area in late May?
- What is the pwd for *hay raking* in our area in late May?
- What is the pwd for *hay baling* in our area in late May?

PWD Factors

- Operation to be performed
- Geographic/Climatic location
- Time of year
- Soil conditions (slope, type, drainage)
- Probability level (e.g., 50%, 90% of years)
Machine Capacity

\[ C_{ac/h} = \frac{S_{mph} \cdot W_{ft} \cdot E_f}{8.25} \]

Example: 9’ Sickle mower-conditioner at 5.0 mph. Typical field efficiency is 80%

\[ C = \frac{(5.0)(9)(0.8)}{8.25} \]

\[ C = 4.4 \text{ ac/h} \]

Simple Capacity Tool
### Typical Speeds & Field Efficiencies

<table>
<thead>
<tr>
<th>Operation</th>
<th>Typical Speed (mph)</th>
<th>Typical Field Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sickle Mower-Conditioner</td>
<td>5.0</td>
<td>80</td>
</tr>
<tr>
<td>Disc Mower-Conditioner</td>
<td>8.5</td>
<td>80</td>
</tr>
<tr>
<td>Rake</td>
<td>6.0</td>
<td>80</td>
</tr>
<tr>
<td>Small Rectangular Baler</td>
<td>4.0</td>
<td>75</td>
</tr>
<tr>
<td>Large Round Baler</td>
<td>5.5</td>
<td>65</td>
</tr>
<tr>
<td>Large Rectangular Baler</td>
<td>6.0</td>
<td>80</td>
</tr>
</tbody>
</table>

Accounts for: turning, breaks, overlap, anything keeping you from 100% of machine utilization.

### Round Baler Twine vs. Net Step by Step analysis

- Maximum throughput of 30 tons/hour
- 90% maximum field efficiency (turns & breaks)
- Effective maximum throughput of 27 tons/h (54,000 lb/h)
- Bale weight of 1200 lb
- Time to form bale is 80 seconds @ maximum capacity (but who can do that?)
- Time to form bale is 120 seconds at 2/3 max capacity
- Twine wrap, eject, & operator delay time of 40 seconds
- Actual rate is 1200 lb/(120s + 40 s) = 13.5 tons/h
- Utilization rate is 13.5/30 or 45%
Round Baler Twine vs. **Net**
Step by Step analysis

- Maximum throughput of **30** tons/hour
- 90% maximum field efficiency (turns & breaks)
- Effective maximum throughput of **27** tons/h (54,000 lb/h)
- Bale weight of 1200 lb
- Time to form bale is 80 seconds @ maximum capacity (but who can do that?)
- Time to form bale is 120 seconds at 2/3 max capacity
- Twine wrap, eject, & operator delay time of **25** seconds
- Actual rate is 1200 lb/(120s + 25 s) = 14.9 tons/h
- Utilization rate is 14.9/30 or 48%

Round Baler Capacity Utilization

- Depends on:
  - How hard you push the machine
  - Twine or net
  - Maximum capacity of the machine (20 to 50 tons/hour for round balers today)
- Likely in the range:
  - 35-50% with twine wrap
  - 45-60% with net wrap
Typical Hay Equipment Sets

Small Rectangular Bales
100 to 300 tons DM/year
(20 to 60 acres)
- 9’ Mower-conditioner
- Rake
- Small baler
- 2 wagons
- Labor: 1.4 – 2.1 h/t DM
- Cost: $42 – 69 / t DM

Typical Hay Equipment Sets

Small Rectangular Bales
200 to 400 tons DM/year
(40 to 80 acres)
- 8-12’ Mower-conditioner
- Tandem Rake
- Medium baler
- 3 wagons
- Labor: 1.0 – 1.4 h / t DM
- Cost: $36 – 52 / t DM
Typical Hay Equipment Sets

Small Rectangular Bales
300 to 600 tons DM/year
(60 to 120 acres)
- 12-14’ Mower-conditioner
- Tandem Rake
- Large baler
- 4 wagons or automatic bale wagon
- Labor: 0.5 – 1.0 h / t DM
- Cost: $29 – 41 / t DM

Large Round Bales
100 to 300 tons DM/year
(20 to 60 acres)
- 9’ Mower-conditioner
- Rake
- Small baler
- 1 wagons
- Labor: 1.2 – 1.4 h/t DM
- Cost: $44 – 67 / t DM
Typical Hay Equipment Sets

Large Round Bales
200 to 400 tons DM/year
(40 to 80 acres)
- 8-12’ Mower-conditioner
- Tandem Rake
- Medium baler
- 1-2 wagons
- Labor: 0.9 – 1.1 h / t DM
- Cost: $36 – 43 / t DM

Typical Hay Equipment Sets

Large Round Bales
300 to 600 tons DM/year
(60 to 120 acres)
- 12-14’ Mower-conditioner
- Tandem Rake
- Large baler
- 2 wagons or truck
- Labor: 0.7 – 0.9 h / t DM
- Cost: $28 – 33 / t DM
Custom Rates
Mowing-conditioning

- PA: $11.90/acre
- DE: $10.00/acre
- OH: $10.00/acre
- IN: $10.25/acre
- VA: $12.70/acre

Custom Rates
Raking

- PA: $6.30/acre
- DE: $3.70/acre
- OH: $5.00/acre
- IN: $5.00/acre
- VA: $6.75/acre
Custom Rates
Rectangular Baling

- PA: $0.48/bale
- DE: $0.32/bale
- OH: $0.47/bale
- IN: $0.46/bale
- VA: $0.47/bale

Custom Rates
Mow-Rake-Bale-Store
Small Rectangular Bales

- PA: $1.15/bale
- DE: $0.85/bale
- OH: $26/ton ($.80/bale)
- VA: $1.11/bale
Custom Rates
Large Round Baling

- PA: $6.40/bale
- DE: $8.45/bale
- OH: $7.50/bale
- IN: $7.70/bale
- VA: $7.15/bale

Estimating Power Unit Cost

A tractor cost benchmarking relationship (without fuel):

\[ SC_{$/hph} = 200 \ P_{hp}^{0.122} \ I_{dec}^{0.244} \ N_{yrs}^{-0.437} \ H_{hrs/yr}^{-0.958} \]

Reference:
Estimating Power Unit Cost

Example:
80 hp tractor kept 10 years with 250 hrs/yr and 7% interest rate

\[
SC_{$/h} = 200(80)^{0.122}(0.07)^{0.244}(10)^{-0.437}(250)^{-0.958}
\]
\[
= 0.329/hph
\]

Cost_{$/h} = SC_{$/hph} P_{hp} = (0.0359/hph)(80hp)
\[
= $26/hr
\]

The Machinery Portion of hay production costs ...

- Hay @ $80/ton with 50 lb bales is worth $2.00/bale.
- At custom rates, machinery (with labor) expense is about $1.00/bale → 50%
- Depending on the system, machinery (with labor) costs are 29 to 69/ton → 40-90%
Presentation Outline

- Machinery management
  - Capacity equations
  - Typical systems & costs
  - Custom rates
- **Hay Harvest Losses**
- Machine features & tractor matching
  - Mower-conditioners
  - Rakes
  - Balers
  - Transport & Storage systems
- Harvest Operations Timing
- Safety Considerations

Typical Forage System Losses

![Diagram showing typical alfalfa dry matter losses](image)
Typical Forage System Losses

![Bar chart showing economic losses per ton of feedable DM]

- Mower-conditioner: $1.90
- Respiration: $1.40
- Rain-induced: $3.40
- Rake: $5.90
- Baler: $4.50
- Forage harvester: $3.50
- Hay storage: $9.30
- Silage storage: $9.80
- Feeding: $4.20

*Economic value of alfalfa losses*

Hay Harvest Losses

- **Mowing-conditioning**
  - 1-5%, mostly leaves
  - Conditioner design/setting has a large effect (trade-off faster drying rate for more loss)
  - Flails cause more leaf loss in legumes
Hay Harvest Losses

- **Raking**
  - Loss increases as crop dries
  - Loss is higher with low yield or after tedding
  - Loss can be up to 20%
  - Wheel & rotary rakes cause more loss than parallel bar rakes
  - Best practice is to rake once, on the day of baling

- **Baling**
  - Loss increases as crop dries
  - Loss occurs at the pickup and in the chamber
  - Typical loss is 2 to 5%, sometimes greater with low moisture or round balers in low yield situations (lots of tumbling)
  - No large difference between in-line versus offset balers
Hay Harvest Losses

- Respiration & Rain
  - Highly variable
  - From 2 to 100% loss
  - Loss of most digestible plant components
- Two strategies
  - Try to always avoid rain
  - Try to optimize annual harvest

Presentation Outline

- Machinery management
  - Capacity equations
  - Typical systems & costs
  - Custom rates
- Hay Harvest Losses
- Machine features & tractor matching
  - Mower-conditioners
  - Rakes
  - Balers
  - Transport & Storage systems
- Harvest Operations Timing
- Safety Considerations
Mower-Conditioners

- Cut type:
  - Sickle
  - Disc
- Conditioner type:
  - Roll, “rubber”
  - Rolls, steel
  - Flail/Impellar
- Other features & options

Cut Type

- Sickle
  - Clean cut
  - Speed limited
  - Low power requirement
- Disc/Rotary
  - Good in lodged crops
  - “Never” plug
  - Higher power requirement
Tractor Requirements

<table>
<thead>
<tr>
<th>Tractor PTO hp</th>
<th>Reasonable Mower Width (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>6</td>
</tr>
<tr>
<td>75</td>
<td>8</td>
</tr>
<tr>
<td>100</td>
<td>10</td>
</tr>
<tr>
<td>125</td>
<td>12</td>
</tr>
<tr>
<td>150</td>
<td>14</td>
</tr>
</tbody>
</table>

- Sickle Mower-conditioners
- Disc Mower-conditioners

Conditioner Type

- “Rubber” rolls
  - Crimp & crush with pressure
- Steel rolls
  - Crimp & crush with pressure
- Flail, Impellar, or Tine
  - Scuffing action
- Regardless of type, more aggressive conditioning increases drying rate and increases loss
Some Mower Features

- Side windrow attachment for wider units
- No tools adjustments (swath width, roll pressure, tine clearance, etc.)
- Split swath on wider units
- Cutterbar angle tilt adjustment
- Variable reel speed
- Suspension of cutterbar

Rakes & Other Swath Manipulation Equipment

- Rake Types
  - Parallel bar
  - Rotary
  - Wheel
- Other Swath Manipulation machinery
  - Tedders
  - Inverters
- Features
Rake Type

- **Parallel Bar**
  - Lowest loss, particularly with legumes
  - Ground or variable speed hydraulic drive

- **Wheel**
  - Higher speed
  - Higher potential for rock collection

- **Rotary**
  - Sometimes dual function (tedder & rake)

Swath Manipulation Features

- Drawbar or hitch mount
- Adjustable swath & windrow width
- Variable speed
- Hydraulic folding
- Windrow inverters & mergers
- Tedders
- Tandem axles
Small Rectangular Balers

- **Sizes & Styles**
  - 14”x18”, 16”x18”, 15”x22”
  - Inline & offset
- **Features**
  - Bale Thrower
  - Hydraulic tension control
  - Pickup heads
  - Pre-pack chamber
- **Tractor Matching:**
  - 35 hp minimum
  - Could use up to 100+ hp

Large Round Balers

- **Sizes & Types**
- **Tractor Matching**
- **Features**
Large Round Balers

- Typical Sizes (width by max diameter):
  - 4’x39”
  - 4’x4’
  - 4’x5’
  - 5’x5’
  - 5’x6’

- Types
  - Fixed chamber (soft core, high density outside)
  - Variable chamber (uniform bale density)

Large Round Balers

- Tractor Requirements:
  - 4’ width – 45 to 65 hp (more with silage specials)
  - 5’ width 70-100 hp
Large Round Balers Features

- Twine or net wrap
- Hydraulic pickup (variable speed & reversible)
- Silage special (heavier bales, “sticky” crop)
- Bale slicers

Large Round Balers Features

- Tandem axles, wider tires
- Automatic controls
- Automatic lubricators
- Integrated plastic wrapping
Baled silage checklist

- **Bale Moisture**: Proper moisture for baleage is 45 to 60%.
- **Bale Density**: Bale density should be as high as possible.
- **Bale Sealing**: If wrapped, bales should be wrapped with four layers of plastic with 50% overlap. Seal holes with proper tape.
- **Bale Seal Delay**: Bales should be sealed within a few hours of baling.

Baled silage checklist

- **Storage site**: The storage site should be constructed to minimize punctures, standing water, and rodent or bird damage.
- **Bale Stacking**: Avoid stacking of bales and, if possible, place them on their ends.
- **Forage Quality as Baled**: Forage should not be overly mature or have experienced significant rain damage.
- **Additive Use**: Inoculants should be used when wilting temperatures are cool and wilting time is short.
Large Rectangular Balers

- Need 90-150 hp
- Very high capacity
- Many features beyond a “basics” presentation

Packaged Hay Transport

- Small package options
  - Stack on wagon
  - Throw to wagon
  - Drop then collect
- Large package options
  - Loader & wagon or trailer
  - Auto-loading transporters
Presentation Outline

- Machinery management
  - Capacity equations
  - Typical systems & costs
  - Custom rates
- Hay Harvest Losses
- Machine features & tractor matching
  - Mower-conditioners
  - Rakes
  - Balers
  - Transport & Storage systems
- Harvest Operations Timing
- Safety Considerations

Timing the Operations

- Mowing-conditioning
  - Is the crop ready?
  - Check the weather (but don’t be too risk-averse)
- Raking
  - At 35 to 45% moisture
  - Best on the day of baling
  - Perhaps after rain
- Other swath manipulation
  - Tedding after mowing (or start of 2nd day)
  - Tedding or swath inversion after rain
- Baling
  - Determined by moisture
Presentation Outline

- Machinery management
  - Capacity equations
  - Typical systems & costs
  - Custom rates
- Hay Harvest Losses
- Machine features & tractor matching
  - Mower-conditioners
  - Rakes
  - Balers
  - Transport & Storage systems
- Harvest Operations Timing
- **Safety Considerations**

Hay-making Safety Considerations

- Shield disc mowers properly (knife tip speeds are 160 to 190 mph); always use a tractor with cab
- Never stand behind conditioning rolls or flails
- Remember that baler flywheels and hydraulic accumulators store energy
- Keep fingers out of moving knotters (even if they are temporarily manually powered)
- Do not ride the wagon when a bale thrower is used
- Handle bales safely
Hay-making Safety Considerations

- Keep equipment “harvest ready”
- Keep guards & shields in proper order
- Securely block hydraulically-raised equipment before working around or under the machine
- Disengage power and shut off engine before unplugging
- Keep a fire extinguisher on all powered equipment
- No kids or other riders
WRAP-UP

A Useful Model -- IFSM

The Integrated Forage System Model
- Simulates multiple years, driven by historical weather data
- Growth models (grass, alfalfa, corn, small grains)
- Harvest models (machinery, drying, operations, labor, fuel, timing)
- Storage models (hay, silage)
- Feed utilization & conversion (beef, dairy, commercial hay)

http://pswmru.arsup.psu.edu/software/ifsm.htm
If I were making hay (for a living)

- Disc mower-conditioner for capacity
- Roll conditioner with legumes, flail conditioner with grasses
- Parallel bar rake with legumes, rotary rake with grasses
- Small square baler for flexibility
- Bale accumulator and loader grapple system
- Trailers, not wagons
- Can you talk me out of this system?