Selecting Forage Machinery

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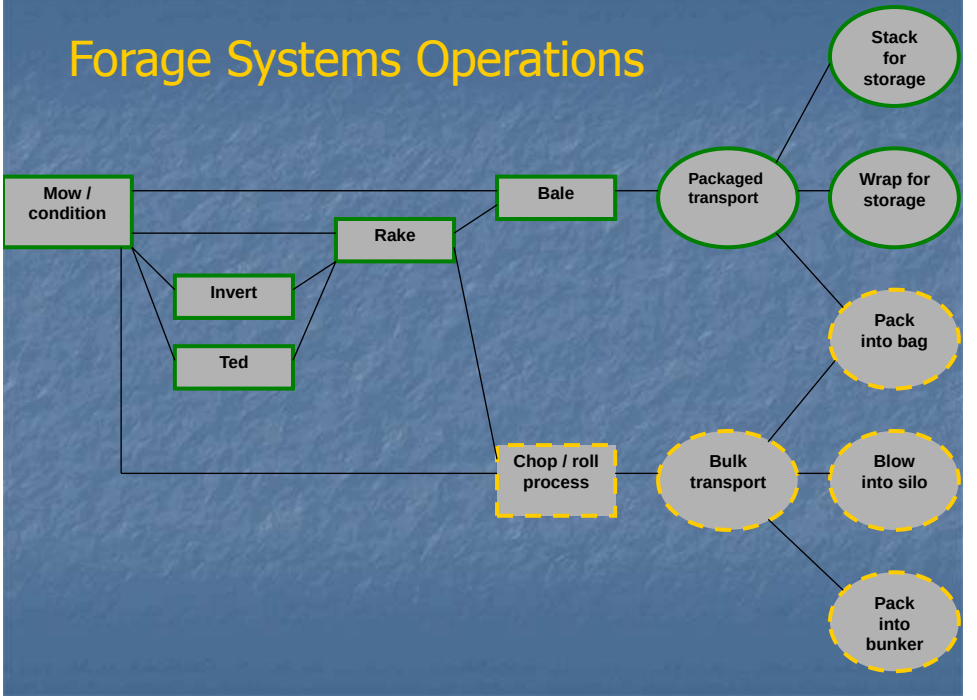
Forage Systems Operations



Presentation Outline

- Making Hay
  - Capacity equations
  - Typical systems & costs
  - Custom rates
  - Machine features & tractor matching
- Making Silage
  - Harvester capacity/power relationship
  - Putting it away (blower, bagger, bunker)
  - Transporter requirements

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)

Required Capacity

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

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 = 150/[(14)(8)(0.3)] = 4.5 ac/h

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)

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?

Machine Capacity

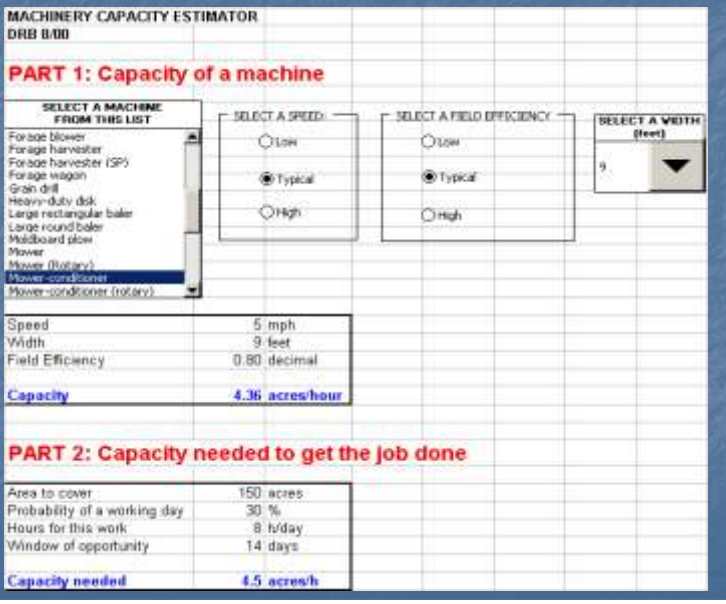
$$C_{ac/h} = \frac{S_{mph}\ W_{ft}\ E_f}{8.25}$$

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

C = (5.0)(9)(0.8)/8.25

C = 4.4 ac/h

Simple Capacity Tool

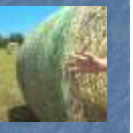


Typical Speeds & Field Efficiencies

Operation	Typical Speed (mph)	Typical Field Efficiency (%)
Sickle Mower-Con		80
Disc Mower-Condi		80
Rake		80
Small Rectangular		75
Large Round Baler	5.5	65
Large Rectangular Baler	6.0	80

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

Round Baler 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%

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

Typical Hay Equipment Sets

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

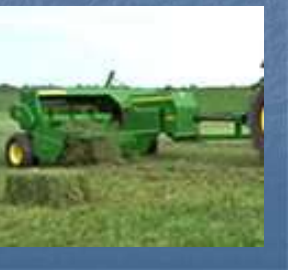
- IN: $12.30/acre
- PA: $13.40/acre
- OH: $11.80/acre
- KY: $11.30/acre

Custom Rates
Raking

- IN: $5.90/acre
- PA: $7.80/acre
- OH: $5.90/acre
- KY: $5.40/acre

Custom Rates
Rectangular Baling

- IN: $0.64/bale
- PA: $0.67/bale
- OH: $0.44/bale
- KY: $0.56/bale



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

- IN: ??
- PA: $1.60/bale
- OH: $32.50/ton
- KY: $1.58/bale

Custom Rates
Large Round Baling

Large Round Baling

- IN: $8.80/bale
- PA: $6.60/bale
- OH: $8.70/bale
  KY: $8.60/bale

The Machinery Portion of hay production costs …

- Hay @ $100/ton with 50 lb bales is worth $2.50/bale.
- At custom rates, machinery (with labor) expense is about $1.60/bale → 64%
- Depending on the system, machinery (with labor) costs are 29 to 69/ton → 40-90%

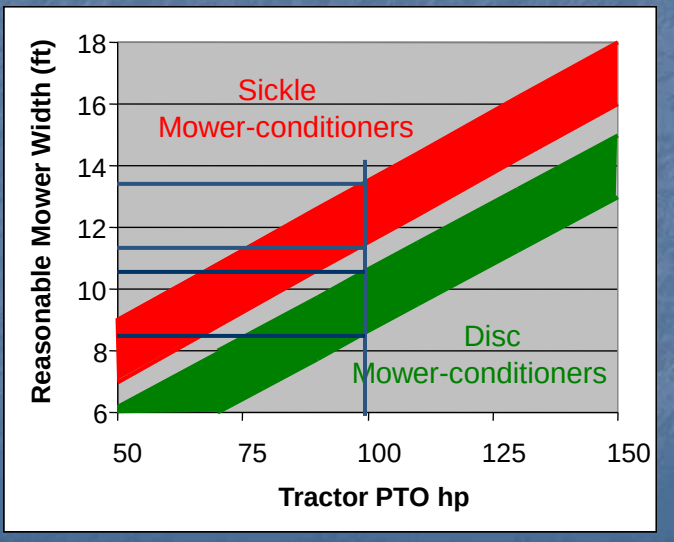
Mower-Conditioners

- 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



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 over 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




Large Rectangular Balers

- Need 90-200 hp
- Very high capacity (50+ tons/hr)

40 tons/hr example

- 2.5 tons/acre yield
- 6 mph
- .85 field efficiency

$$C_{tons/hr} = \frac{S_{mph}\ W_{ft}\ E_f\ Y_{tons/ac}}{8.25}$$

- Requires 26 ft of width
- Would cover 16 acres per hour

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

Bale Handling Equipment

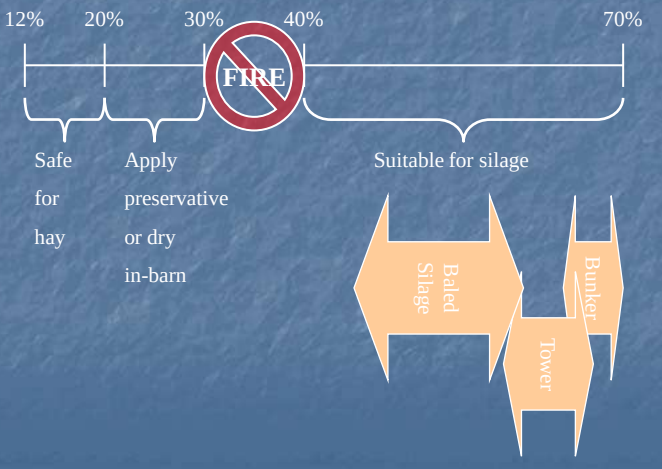







A brief diversion to discuss baled silage

Forage Moisture Continuum



Hay vs Silage

HAY: Low moisture so respiration stops and bacteria, fungi, and yeasts cannot survive.

SILAGE: Create anaerobic environment and reduce pH to a level where bacteria, fungi, and yeast growth is inhibited.

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 sealedd 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.

Wrappers & Tubers

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?

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Potential Capacity Limiters

- Throughput capability
- Power
- Traction
- Speed
- Waiting on others

Hopefully well-matched

Ideally reasonably minimized

Waiting …

- Requires analysis of each system component and their interactions
- First … individual components

Harvester

- Whole-plant corn silage
  - Top-end long-term ca
    - tons/h = HP/2.5
    - OR 2.5 hp h/ton
- Haycrop silage
  - Top-end, long-term capacity
    - tons/hour = HP/4.0
    - OR 4.0 hp h/ton

EXAMPLE:
300 hp
300/2.5 = 120 tons/h corn
300/4 = 75 tons/h haycrop

Blower

- Whole-plant corn silage
  - 180 tons/h likely max
  - Some idle time (~25%
    - 1.6 hp h/ton
- Haycrop silage
  - 110 tons/h likely max
  - Some idle time (~25%)
    - 2.1 hp h/ton

EXAMPLE:
200 hp
200/1.6 = 125 tons/h corn
95 tons/h avg w/ idle time
200/2.1 = 95 tons/h haycrop
70 tons/h avg w/ idle time

Bagger

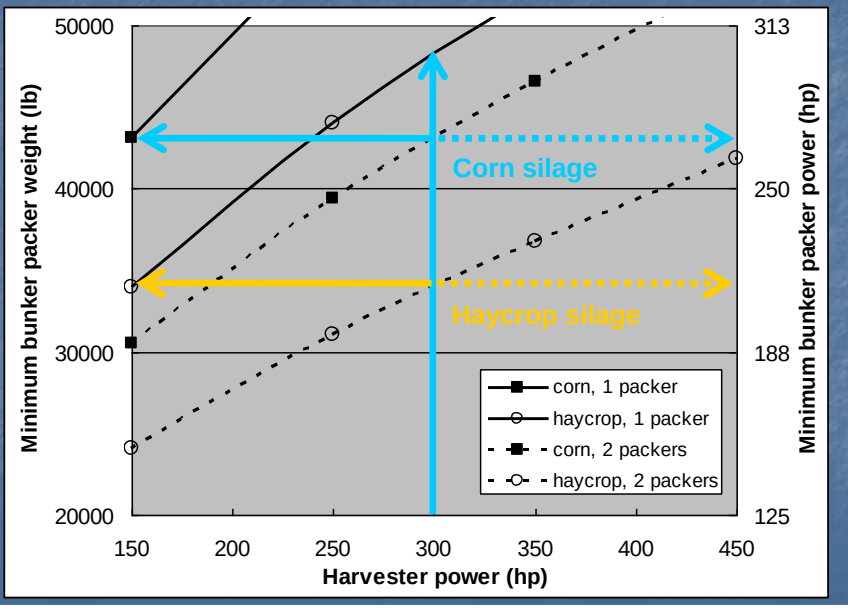
- Whole-plant corn silage
  1 hp h/ton
- Haycrop silage
  1.5 hp h/ton

EXAMPLE:
120 hp
120/1 = 120 tons/h corn
120/1.5 = 80 tons/h haycrop

Bunker Packer

- Holmes & Muck (WI) model
  - 65% moisture
  - 6” layers
  - Target density of 16 lb DM/ft^3
  - Continuous packing
  - 160 lb/PTO hp maximum practical ballast limit
  - … summary chart …

Bunker Packer



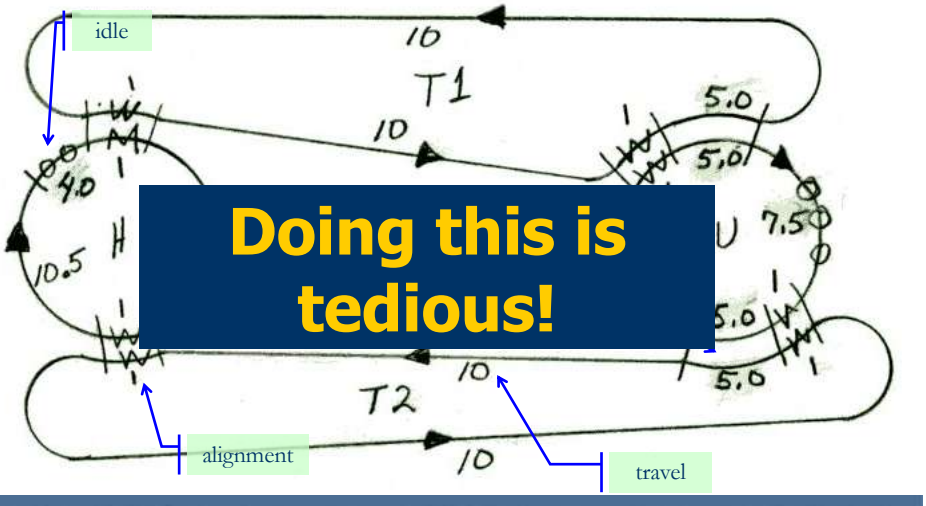
Transport Needs

Cycle Analysis

Where I'm going …

- Graphical example: Pull-type harvester
- Spreadsheet implementation results
  - Pull-type harvester examples
  - SP harvester aid

PT Harvester Cycle Diagram



Doing this is tedious!

PT Harvester – haycrops

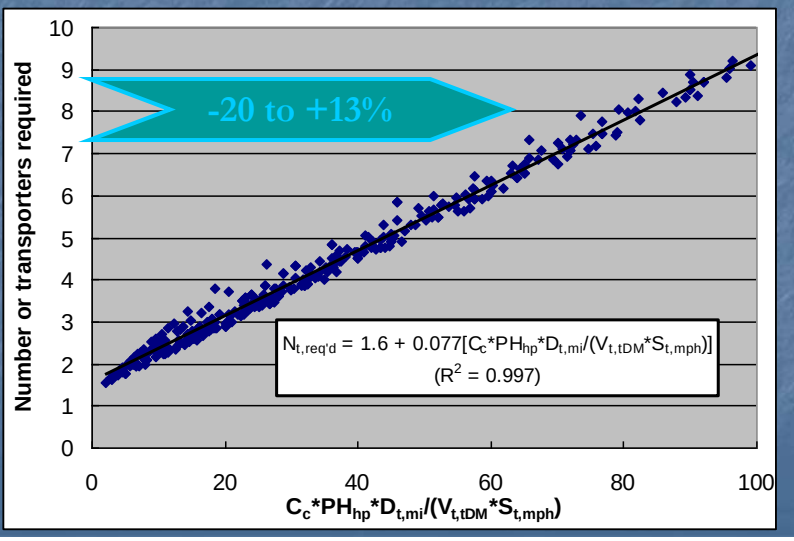
Harvester Power (hp)	Round Trip Distance (mi)	Wagons required to keep harvester busy (or very nearly so)	Capacity with harvester busy (tons/hr)	Capacity with one less wagon (tons/hr)
150	2	3	30	19
150	4	3	30	26
200	**2**	**3**	**39**	**21**
200	**4**	**4**	**39**	**29**
250	2	4	46	23
250	4	3	45	30

46% decrease
26% decrease

Transport Needs via Cycle Analysis

- Worked "backwards" can yield number of transporters needed to keep the harvester busy
- Simulation mode of operation
  - Harvesters harvest directly into transport units (trucks)
  - Harvester power was varied from 200 hp to 575 hp
  - Maximum field efficiency of the harvester (system non-limiting) was 85%
  - Round trip transport distance was varied from 1 to 7 miles
  - Capacity of transport units was varied from 2 to 4 t DM
  - Speed of transport units was varied from 10 to 25 mph

Transport Needs with large SP harvesters



Transport Needs with large SP harvesters

$$N_{t,req'd} = 1.6 + 0.077[C_c*PH_{hp}*D_{t,mi}/(V_{t,tDM}*S_{t,mph})]$$

- EXAMPLE:
- 350 hp harvester
- Haycrop silage (C_c=1)
- 4 miles round trip
- 30 mph average transport speed
- 2 tons DM per load

$$N_{t,req'd} = 1.6 + 0.077[1*350*4/(2*30)] = 3.4$$

Transport Needs with large SP harvesters

Base scenario (350 hp with haycrop silage)

$N_{t,req'd} = 1.6 + 0.077[1*350*4/(2*30)] = 3.4$

6 miles round trip

$N_{t,req'd} = 1.6 + 0.077[1*350*6/(2*30)] = 4.3$

Corn silage, 5 miles round trip

$N_{t,req'd} = 1.6 + 0.077[1.6*350*5/(2*30)] = 5.2$

Thank you for your attention.

For a limited time at:

http://cobweb.ecn.purdue.edu/~dbuckmas/ICFS

- This presentation
- Simple capacity tool
- Article regarding tractor cost and tool
- Cycle analysis reference and tool