NORRIS
Energy Crop Technology

# Determining the Relative Benefits of Different Leaf Collection Strategies, (Based on the Performance of Components in the System).

**Chris Norris**
**Principal Consultant**
**Norris Energy Crop Technology**
**Chris@norrisect.com**

www.NorrisECT.com

# Energy Contained in 1,000 tons of Sugar Cane

(in tons of oil equivalent)




Source: Nastari, Lisbon, 2000

# Sugarcane as an Energy Crop:




- C4 Pathway: Highly efficient at capture and storage of sunlight
- Bagasse alone:
  - 30% OF 1.5 B t/year
  - 7.5MJ/kg @50%MC
  - $9.45 * 10^{18}$ Joules
- Bagasse production in 2004 equated to 4% of energy value of total global coal production.
- Total energy of sugarcane = 12% of global coal production.

NORRIS
Energy Crop Technology

# Options for trash recovery:




NORRIS
Energy Crop Technology

# Trash baling after Chopper Harvesting







NORRIS
Energy Crop Technology

# Other Strategies: Forage harvester for collection of field dried trash.

- +/- 50% of total trash retrieved
- 100 t / machine/day
- Soil in trash an issue





NORRIS
Energy Crop Technology

# Integrated  Trash + Cane delivered to the Factory.

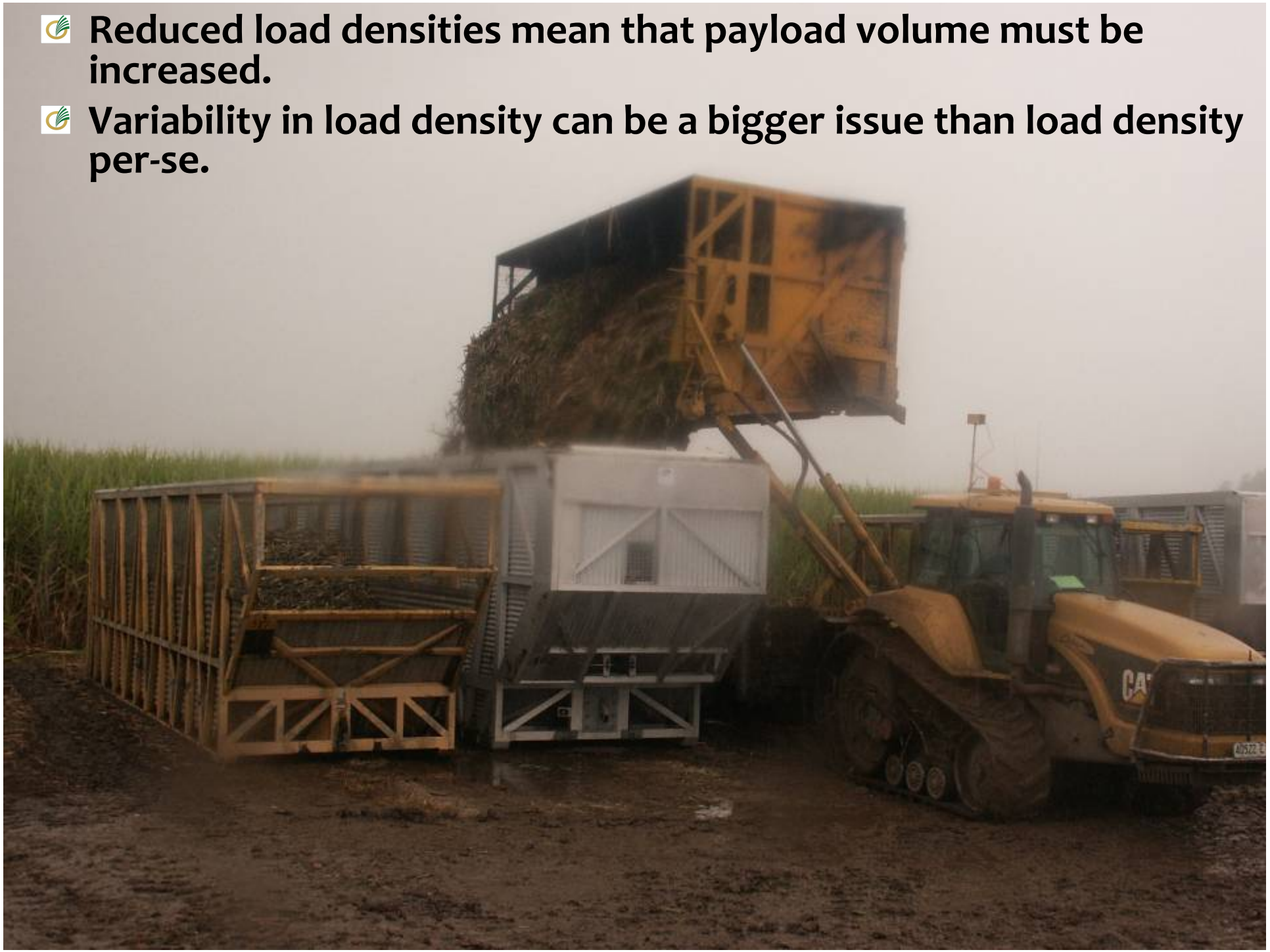


# Integrated Cane + Trash to the Factory:




NORRIS
Energy Crop Technology

- Reduced load densities mean that payload volume must be increased.
- Variability in load density can be a bigger issue than load density per-se.



A system of trash separation is then required at the mill.



NORRIS
Energy Crop Technology

# Ledesma Argentina.








NORRIS
Energy Crop Technology

# Which strategy is best?

- To determine the optimum strategy to recover leaf material for "value adding", analysis of all components of the "system" is required.
- To do this, a number of parameters relating to each situation must be defined:

NORRIS
Energy Crop Technology

# Parameters for Consideration:

- The trash resource:- Total and recoverable;
- Harvester performance parameters;
- Transport implications of different cane and trash strategies;
- Options and performance for trash separation & cleanup;
- Impact of trash levels associated with different strategies on mill performance;
- Economics

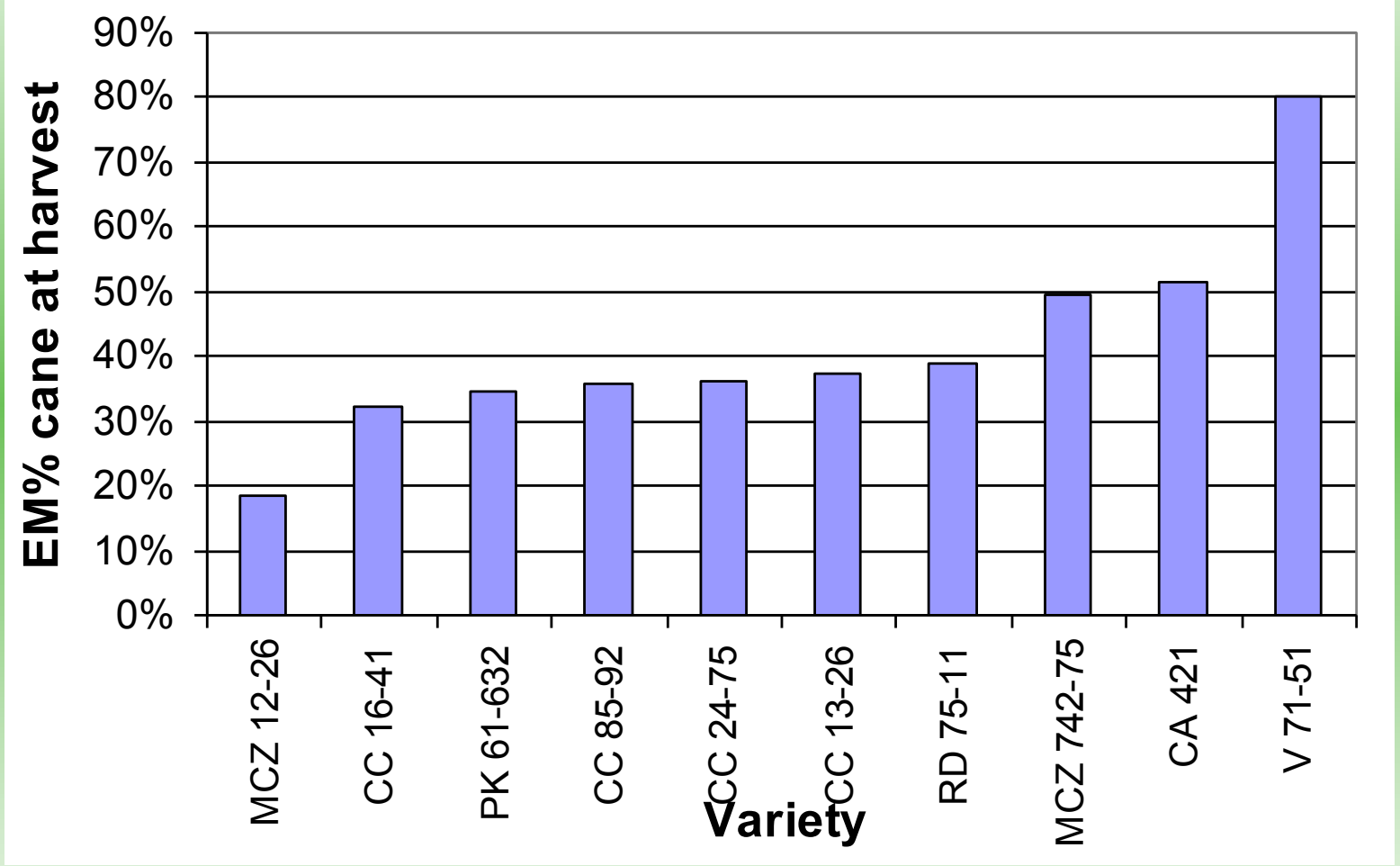
NORRIS
Energy Crop Technology

# Defining the Trash Resource

- Leaf levels associated with a cane crop pre-harvest vary widely, with parameters impacting on absolute levels including:
  - Crop yield;
  - Variety;
  - Cane class;
  - Growing conditions;
  - Maturity & ripening strategy;
  - Levels required to be left in the field for agronomic benefit.

NORRIS
Energy Crop Technology

# Defining the Resource: Variety Effect (Colombia)

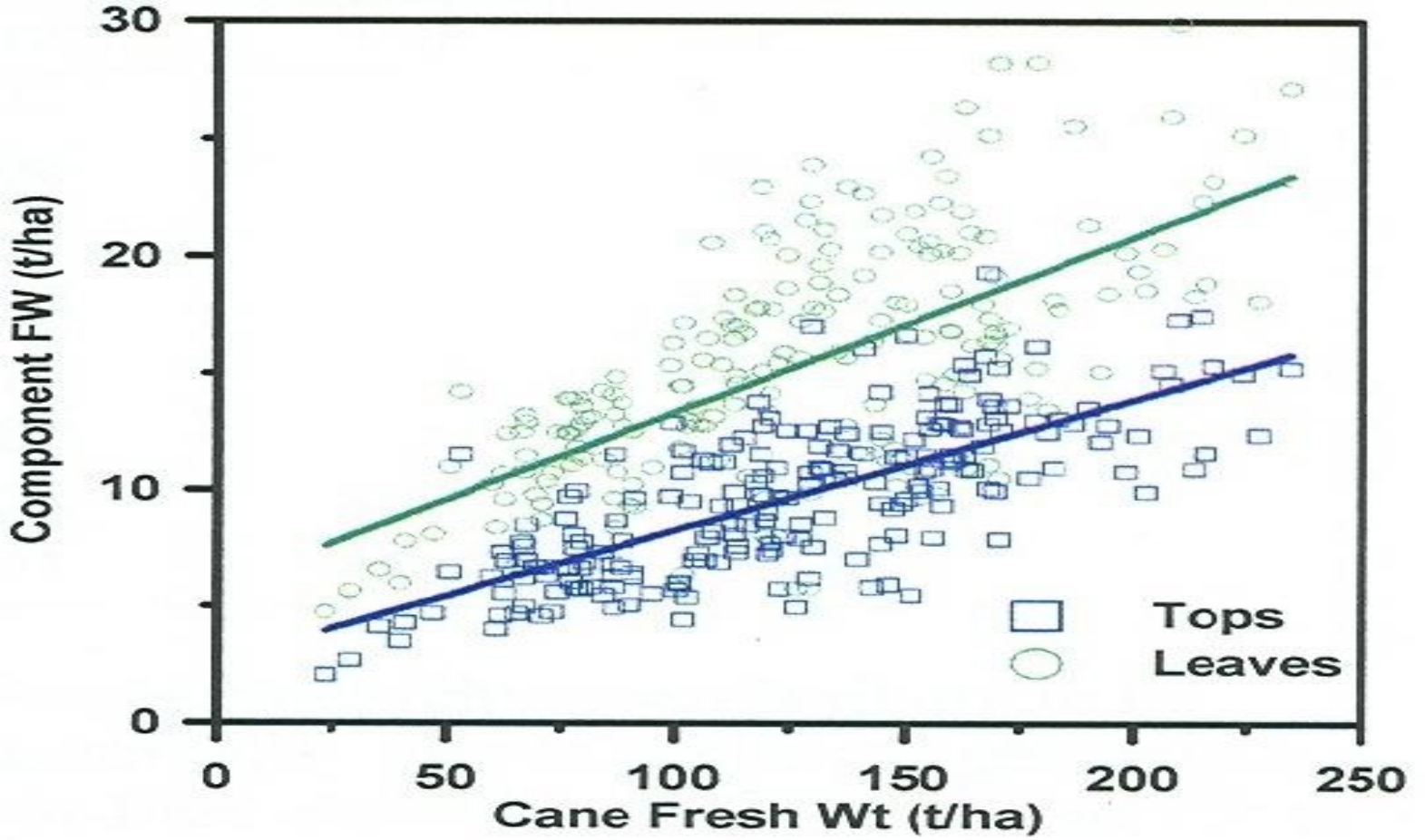



- Brienco etal. Colombia

NORRIS
Energy Crop Technology

# Defining the Resource: Crop yield effect (FW)

- Thurbon etal, Australia.




NORRIS
Energy Crop Technology

# Defining the Resource: Component v's crop yield (DM)

- Mitchell et.al. (Australia)

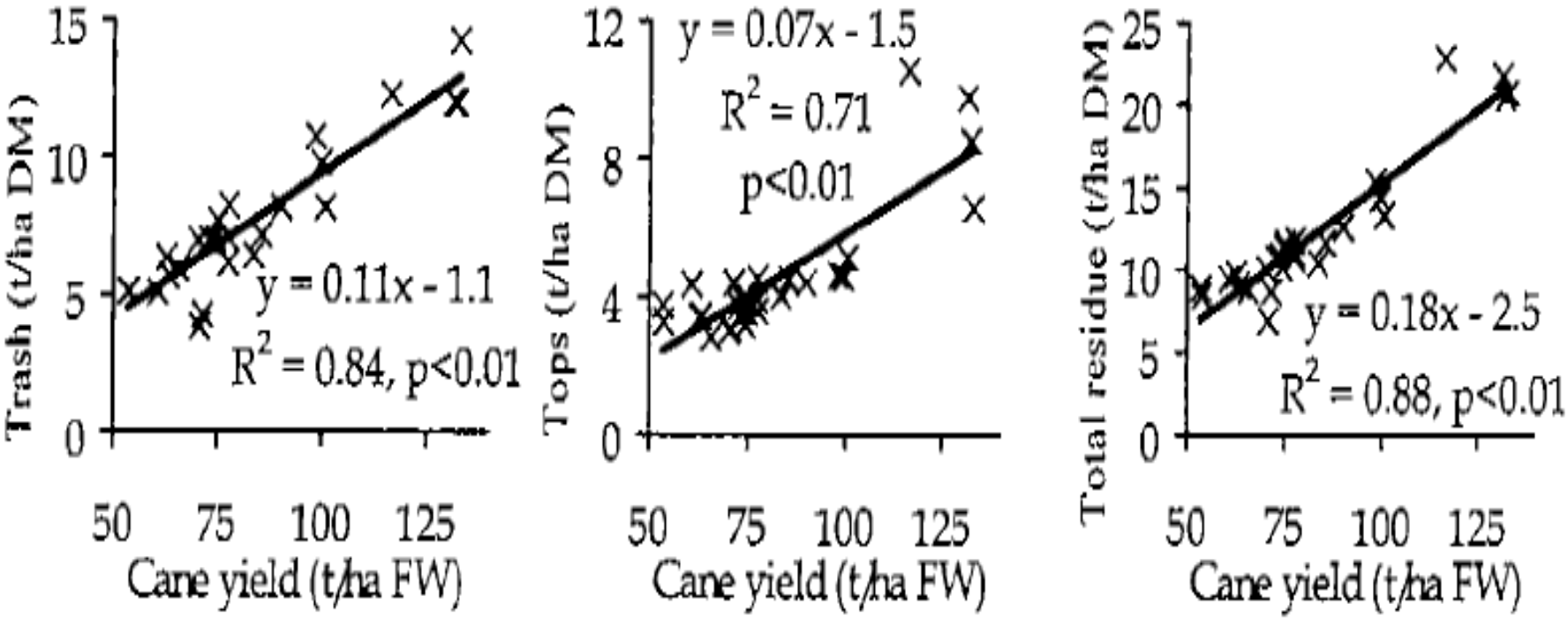
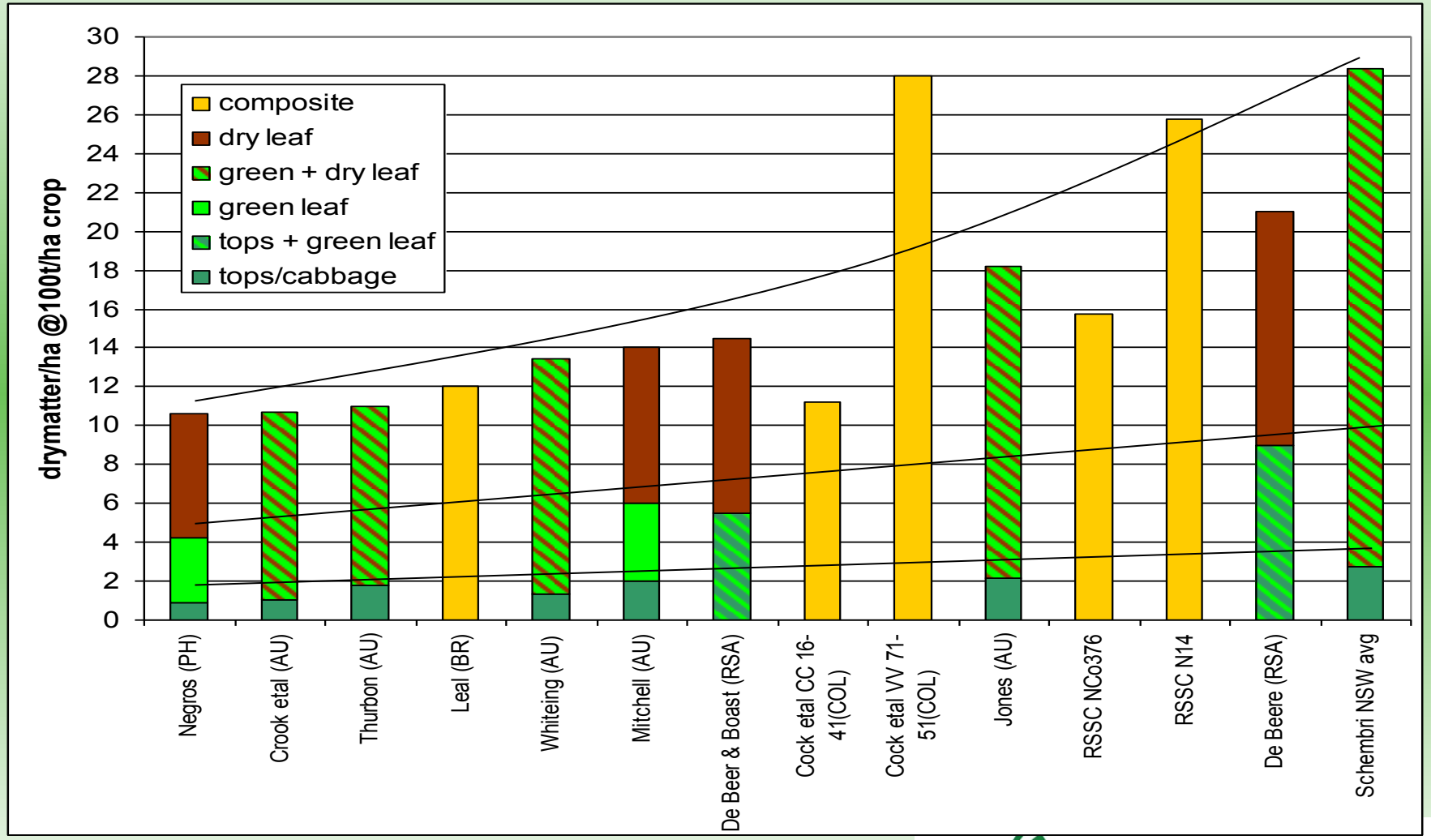



Fig. 1—Quantity of unburnt sugarcane residues (trash, tops and total residue) and mechanically harvested cane yield.

NORRIS
Energy Crop Technology

# Defining the Resource: (DM corrected to 100t/ha)




NORRIS
Energy Crop Technology

# Defining the Resource: "Average" 100t/ha crop

| Component: | Initial Mass (t/ha) | At Time of Harvest: Initial MC% | Energy Content (MJ/kg) LHV | Total Energy (GJ/ha) | Dry-matter (t/ha) |
|---|---|---|---|---|---|
| Clean cane | 100 | | | | |
| Tops | 9.2 | 80 | 1.4 | 13 | 1.8 |
| Green Leaf | 14.0 | 66 | 4.2 | 59 | 4.7 |
| Dry Leaf | 10.8 | 12 | 15.1 | 162 | 9.5 |
| Leaf Only | 24.7 | 42.5 | 8.9 | 221 | 14.2 |
| Composite | 33.9 | 52.5 | 6.9 | 234 | 16.1 |
| Bagasse | 30 | 51 | 7.2 | 215 | 14.7 |

NORRIS
Energy Crop Technology

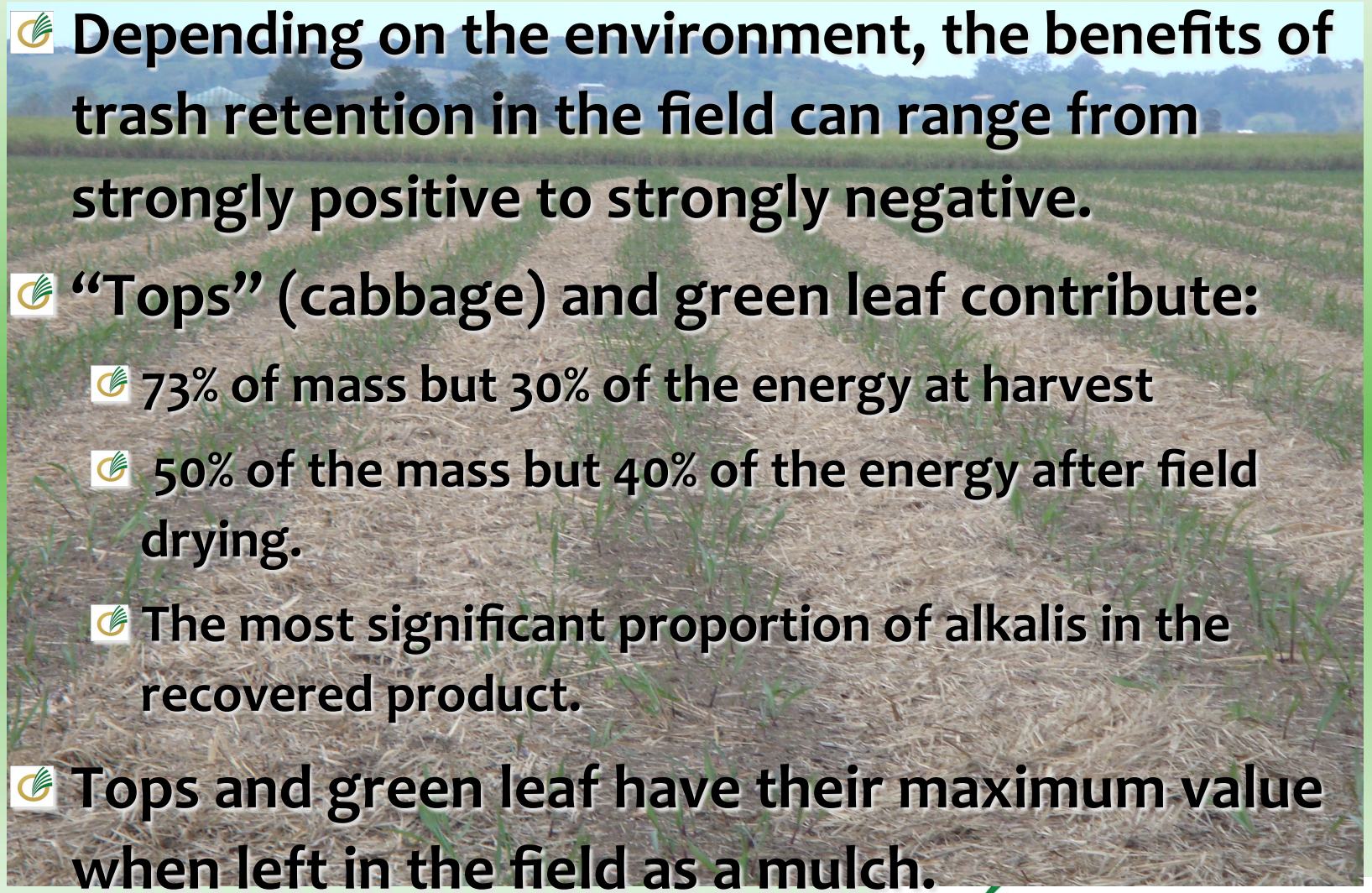
# "Average" 100t/ha crop

| Component: | At Time of Harvest: Initial Mass (t/ha) | Initial MC% | Energy Content (MJ/kg) LHV | Total Energy (GJ/ha) | Dry-matter (t/ha) | After Field Drying to 25%MC: Collection MC% | Available Mass (t/ha) | Energy Content (kJ/kg) LHV | Total Energy (GJ/ha) |
|---|---|---|---|---|---|---|---|---|---|
| Clean cane | 100 | | | | | | | | |
| Tops | 9.2 | 80 | 1.4 | 13 | 1.8 | 42.6 | 3.2 | 8.6 | 28 |
| Green Leaf | 14.0 | 66 | 4.2 | 59 | 4.7 | 36.3 | 7.5 | 10.0 | 75 |
| Dry Leaf | 10.8 | 12 | 15.1 | 162 | 9.5 | 12.0 | 10.8 | 15.1 | 162 |
| Leaf Only | 24.7 | 42.5 | 8.9 | 221 | 14.2 | | | | |
| Composite | 33.9 | 52.5 | 6.9 | 234 | 16.1 | 25.0 | 21.4 | 12.4 | 265 |
| Bagasse | 30 | 51 | 7.2 | 215 | 14.7 | | | | |

- Field drying typically increases potential energy recovery of composite product by 11-14%.

NORRIS
Energy Crop Technology

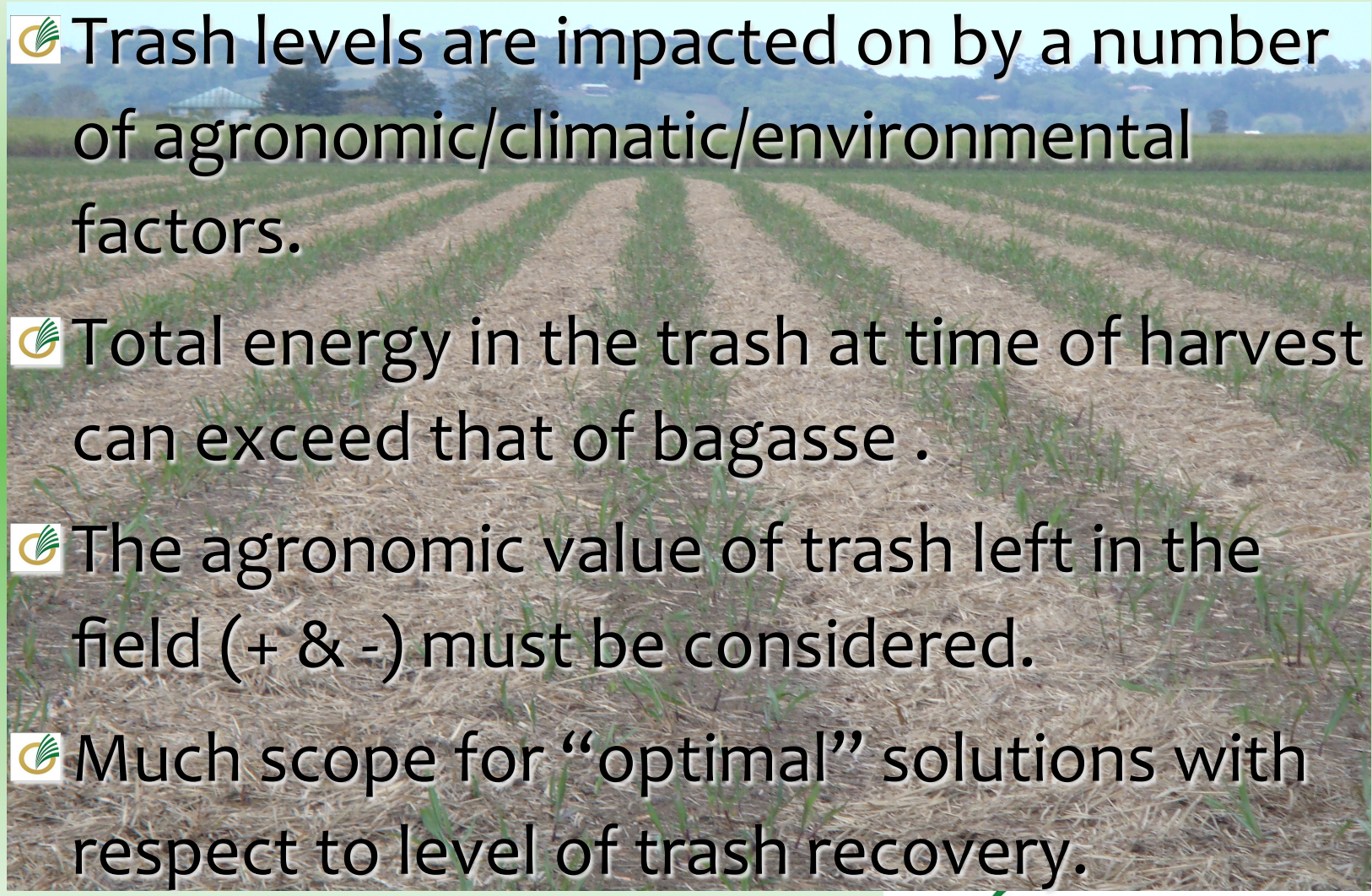
# Trash for Agronomic benefit:



- Depending on the environment, the benefits of trash retention in the field can range from strongly positive to strongly negative.
- "Tops" (cabbage) and green leaf contribute:
  - 73% of mass but 30% of the energy at harvest
  - 50% of the mass but 40% of the energy after field drying.
  - The most significant proportion of alkalis in the recovered product.
- Tops and green leaf have their maximum value when left in the field as a mulch.

NORRIS
Energy Crop Technology

# The Trash Resource :



- Trash levels are impacted on by a number of agronomic/climatic/environmental factors.
- Total energy in the trash at time of harvest can exceed that of bagasse .
- The agronomic value of trash left in the field (+ & -) must be considered.
- Much scope for “optimal” solutions with respect to level of trash recovery.

NORRIS
Energy Crop Technology

# Harvester Performance




NORRIS
Energy Crop Technology

# Harvester Performance

- As with any separation process, “perfect” component separation is not possible.
- The design of the harvester extractor system by nature incorporates a number of constraints which limit performance, including:
  - Presentation of the material
  - Airflow patterns
  - Size constraints on the system
- Even under ideal conditions, performance is compromised.

NORRIS
Energy Crop Technology

# Harvester Testing: Controlled conditions



Whiteing etal, BSES

NORRIS
Energy Crop Technology

# Harvester Testing - Weighing Cane Before Test



- Cane stripped & weighed
- Weighed trash added to get 10% & 15% EM levels
- Cane and trash recombined on conveyor which fed material into harvester throat.
- Pour rate (80 tph & 140 tph) controlled by amount of cane/ trash on conveyor and conveyor feed rate

Whiteing etal, BSES

NORRIS
Energy Crop Technology

# Conveyor system feeds harvester

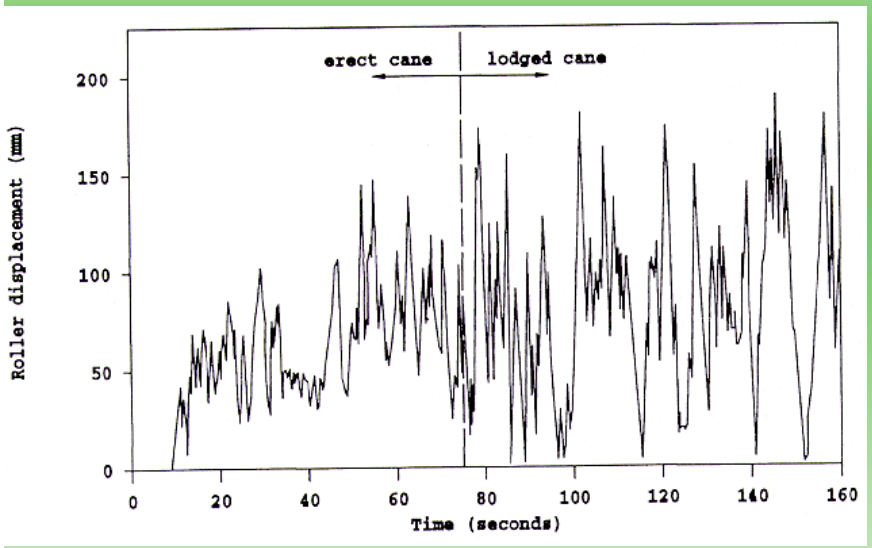



Whiteing etal, BSES

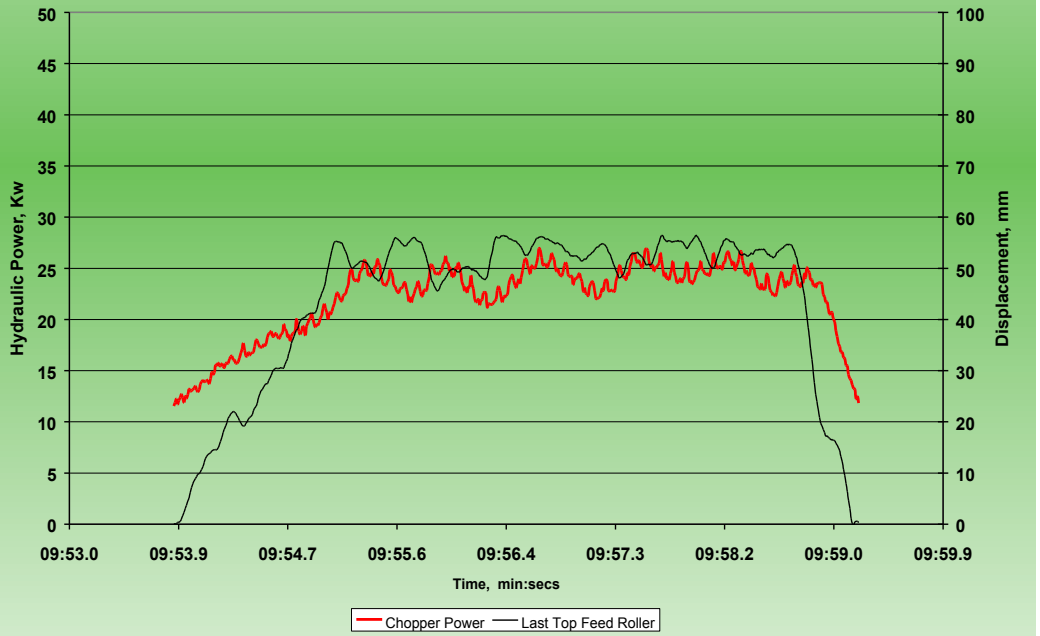
NORRIS
Energy Crop Technology

# Feed even compared with field trials:

Schembri etal, field trials




Typical conveyor feed results




NORRIS
Energy Crop Technology

# Collection of material






Whiteing etal, BSES

# Results – Cane Loss Trends

| | Cane Loss | | |
|---|---|---|---|
| **Fan Speed** (rpm) | **80 TPH** | **140 TPH** | **Mean** |
| 1000 | 1.9% | 2.9% | **2.4%** |
| 1200 | 4.6% | 4.2% | **4.4%** |
| 1400 | 10.4% | 7.8% | **9.1%** |

This equates to a best possible case-
- Pre-stripped dry trash
- Trash & cane mixed, not trash layer at bottom

Whiteing etal, BSES

NORRIS
Energy Crop Technology

# Results – Key Points

This equates to a best possible case for the harvester;-

- Pre-stripped dry trash;
- Trash & cane mixed, not trash layer at bottom;
- Even feed of material

"Scrap" cane from the extractor was collected and weighed:

- Typically less than 20% of cane mass loss was found, i.e.
- 80% of loss was "invisible"
- Similar results from other researchers

NORRIS
Energy Crop Technology

# Results – Extraneous Matter

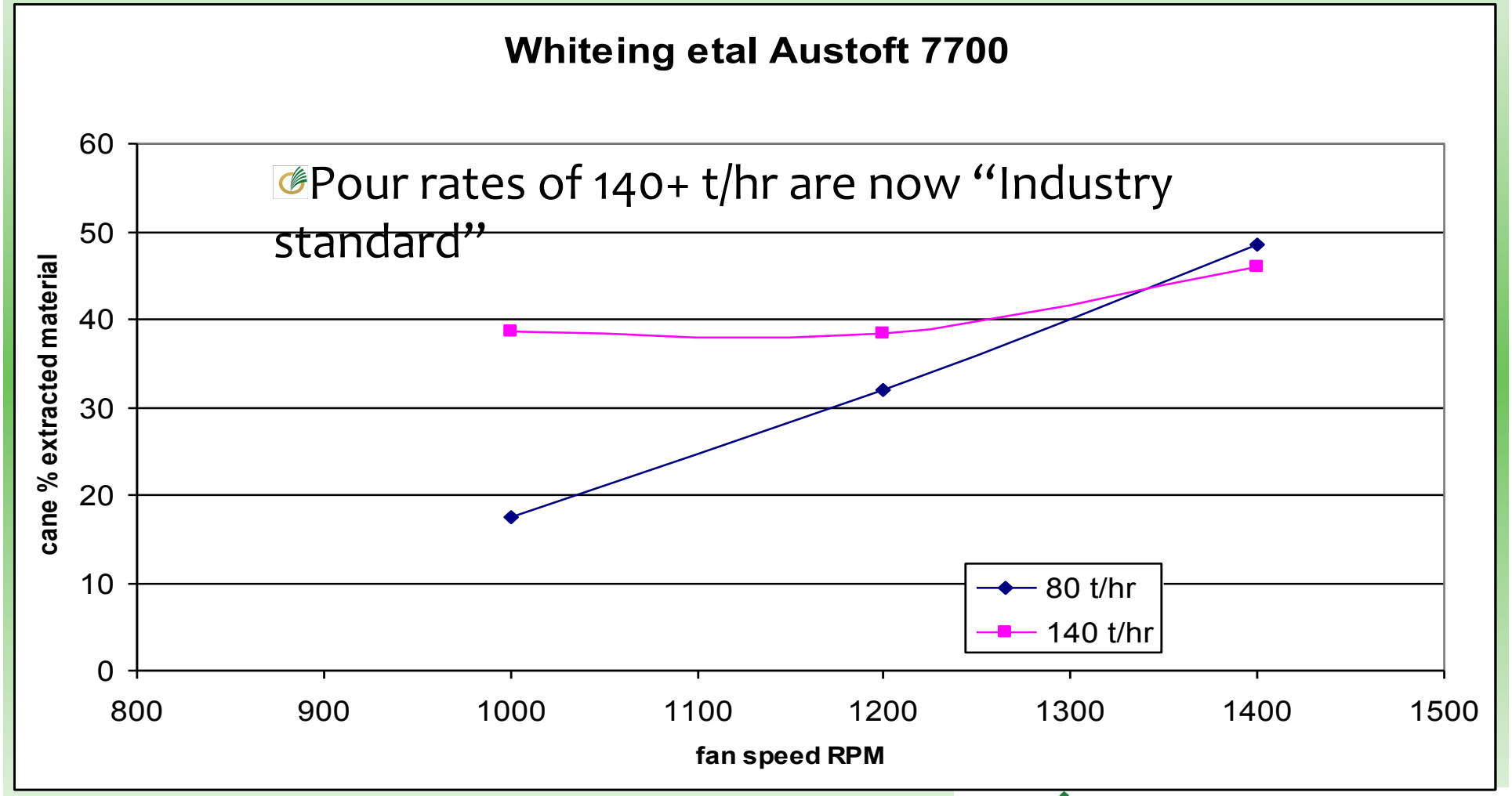
- Pour rate had a significant effect on EM levels

| | Leaf Material | |
|---|---|---|
| **Fan Speed (rpm)** | **80 TPH** | **140 TPH** |
| 1000 | 3.1% | 7.6% |
| 1200 | 2.3% | 5.5% |
| 1400 | 1.1% | 3.1% |

Best possible case-
- Pre-stripped dry trash
- Trash & cane mixed, not trash layer at bottom

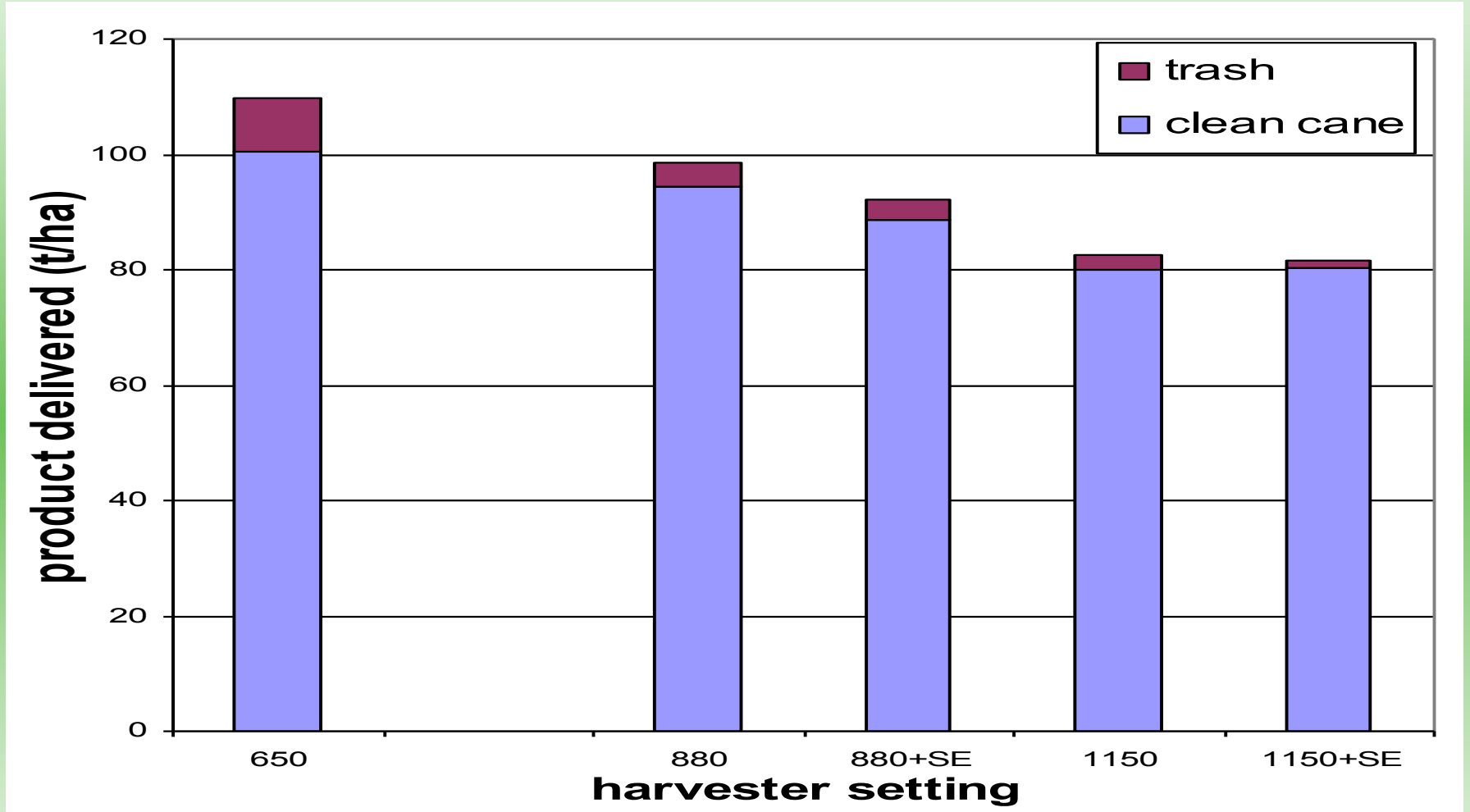
NORRIS
Energy Crop Technology

# Results – Cane loss & trash extraction




NORRIS
Energy Crop Technology

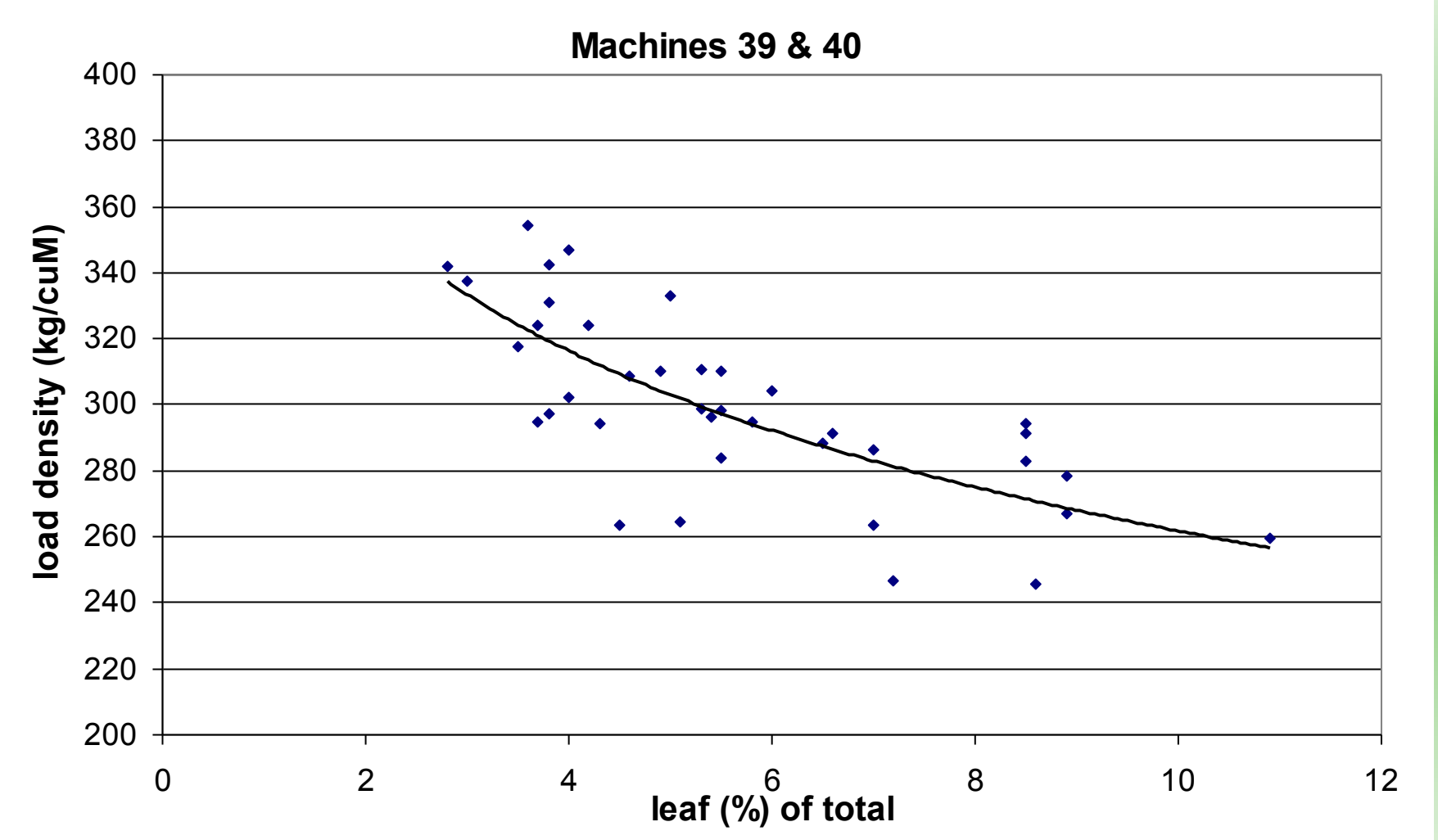
# Cane Loss Trials: New Guinea May 2010




- Increasing harvester fan-speed reduced trash levels and cane recovery.
- Cane fragments in the material from the extractor indicated cane loss of 2-3 t/ha.

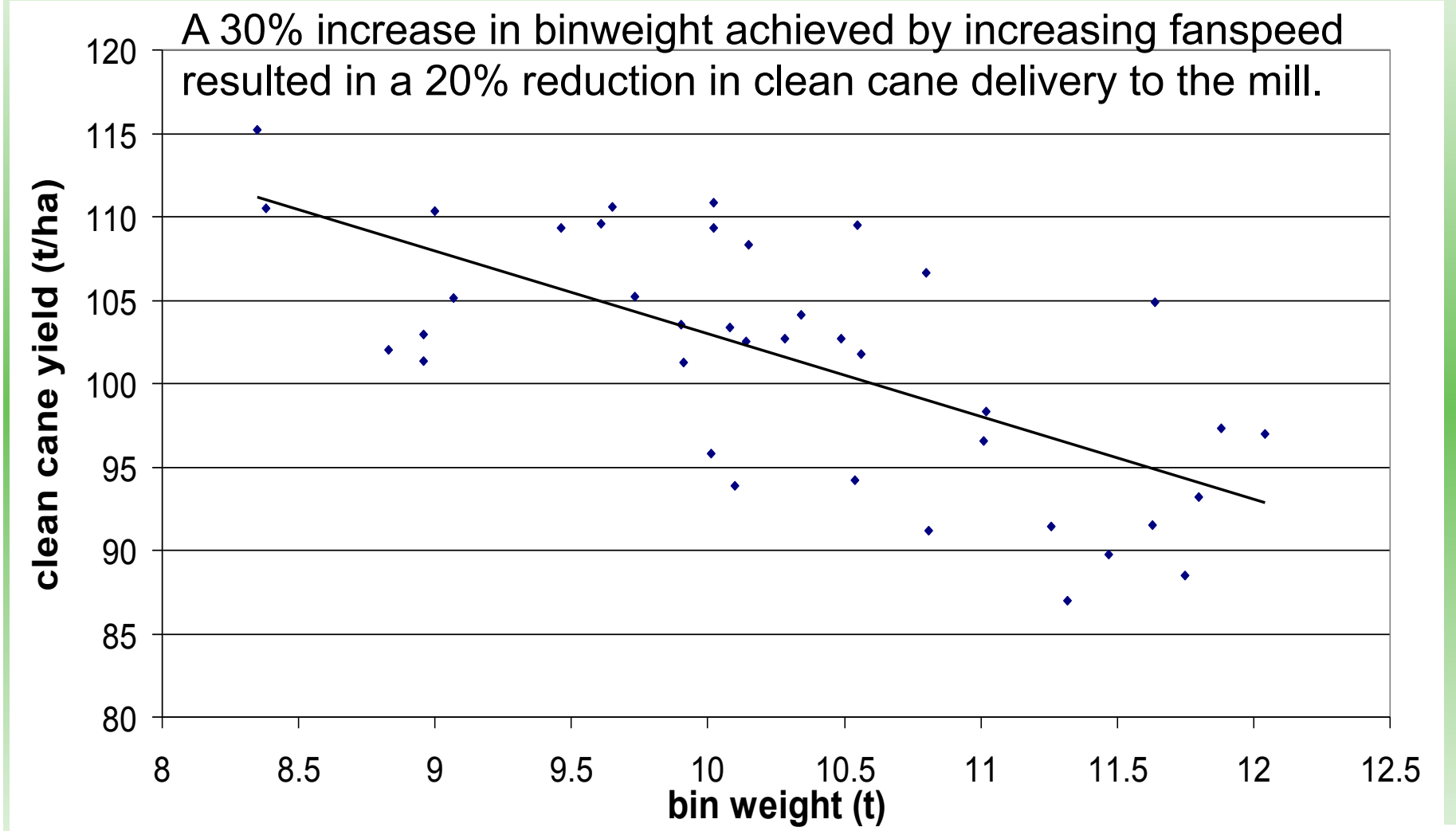
NORRIS
Energy Crop Technology

# Impact of leaf% on load density: (Ramu Fan speed trial May 2010, 2 harvesters)




NORRIS
Energy Crop Technology

# Impact of fan speed on load density: (Ramu Fan speed trial May 2010, 2 harvesters)




NORRIS
Energy Crop Technology

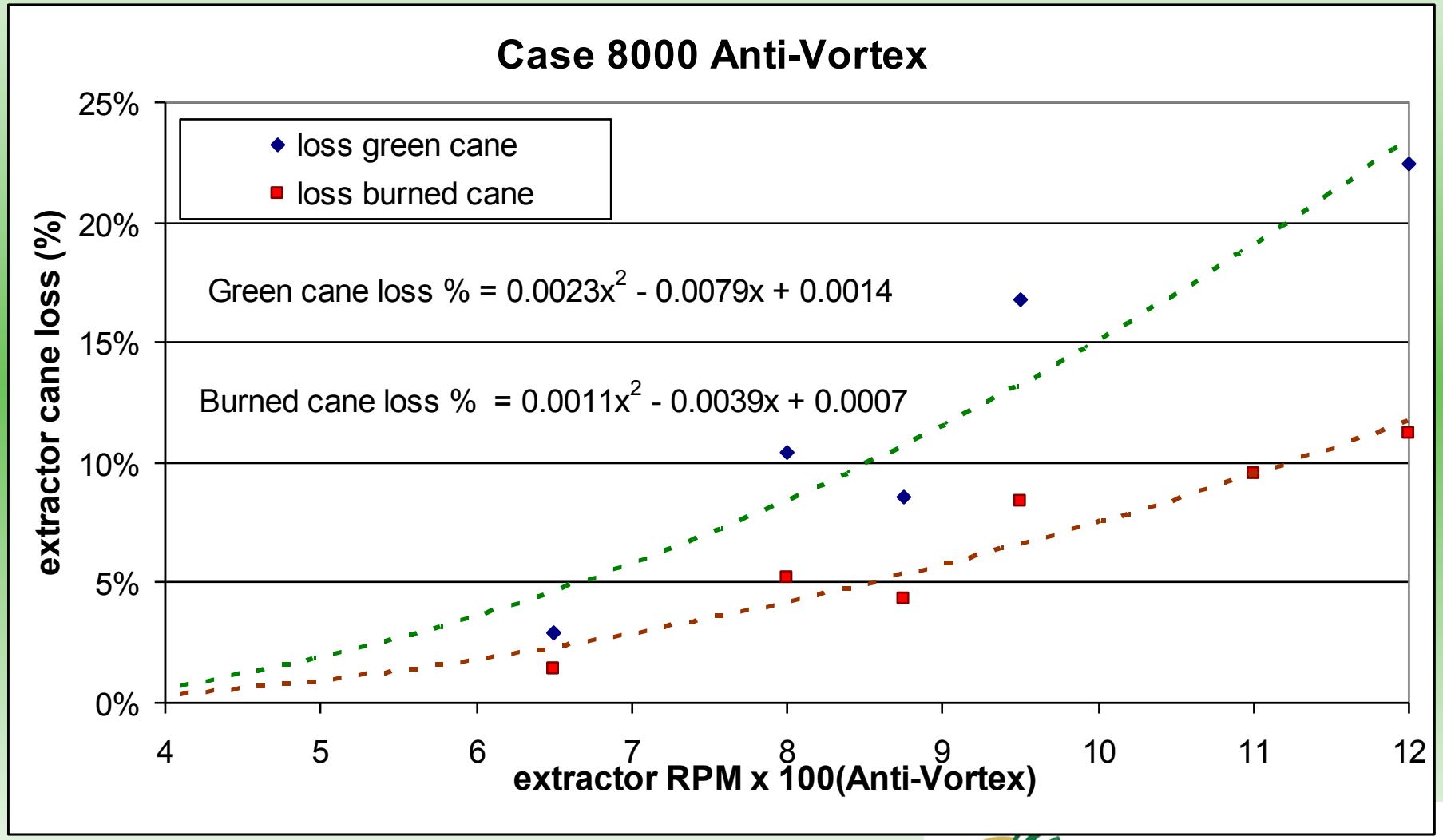
# Cane loss in burned cane:

Extractor cane loss can also be very significant in burned cane.



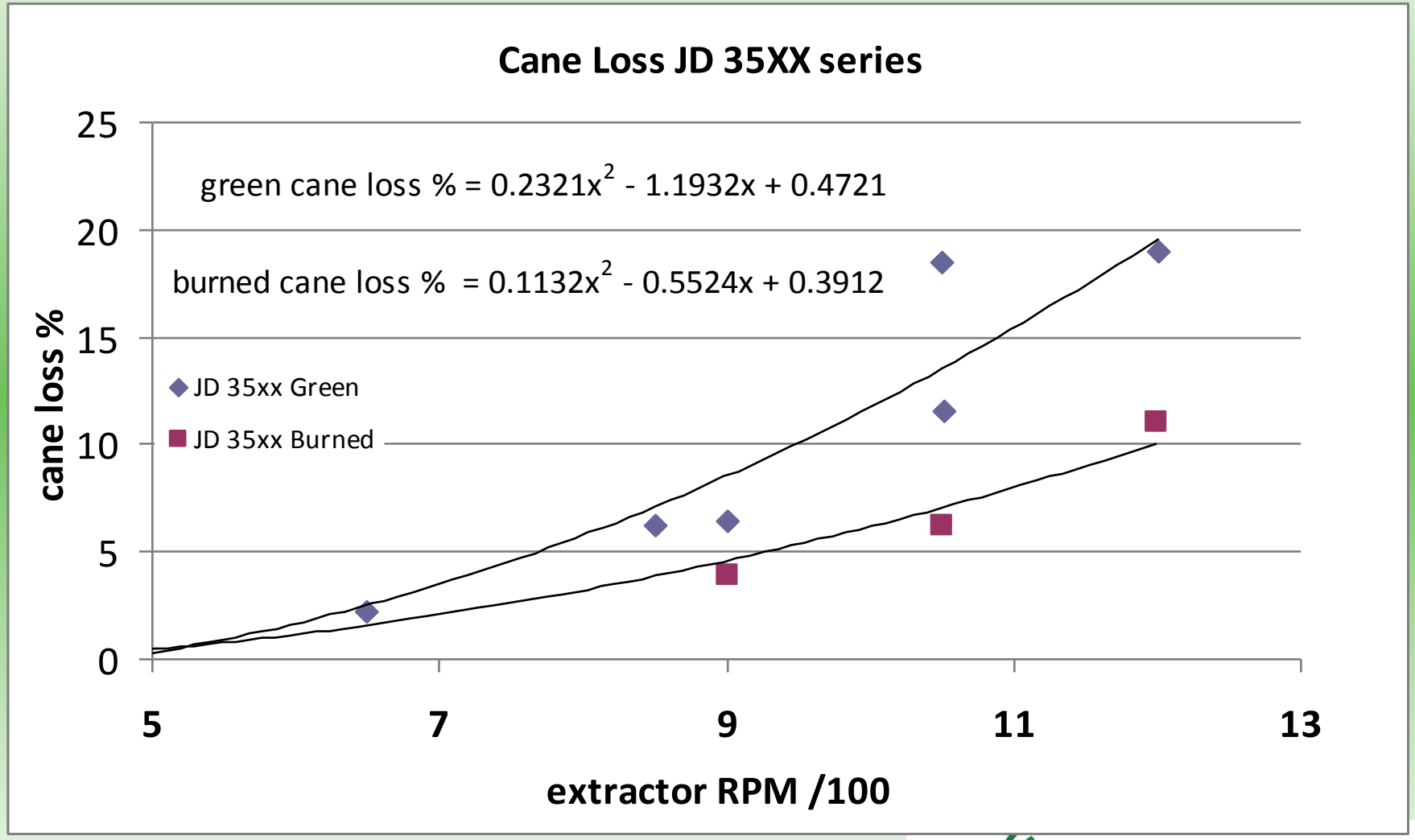
NORRIS
Energy Crop Technology

# General performance: 100t/ha semi-erect



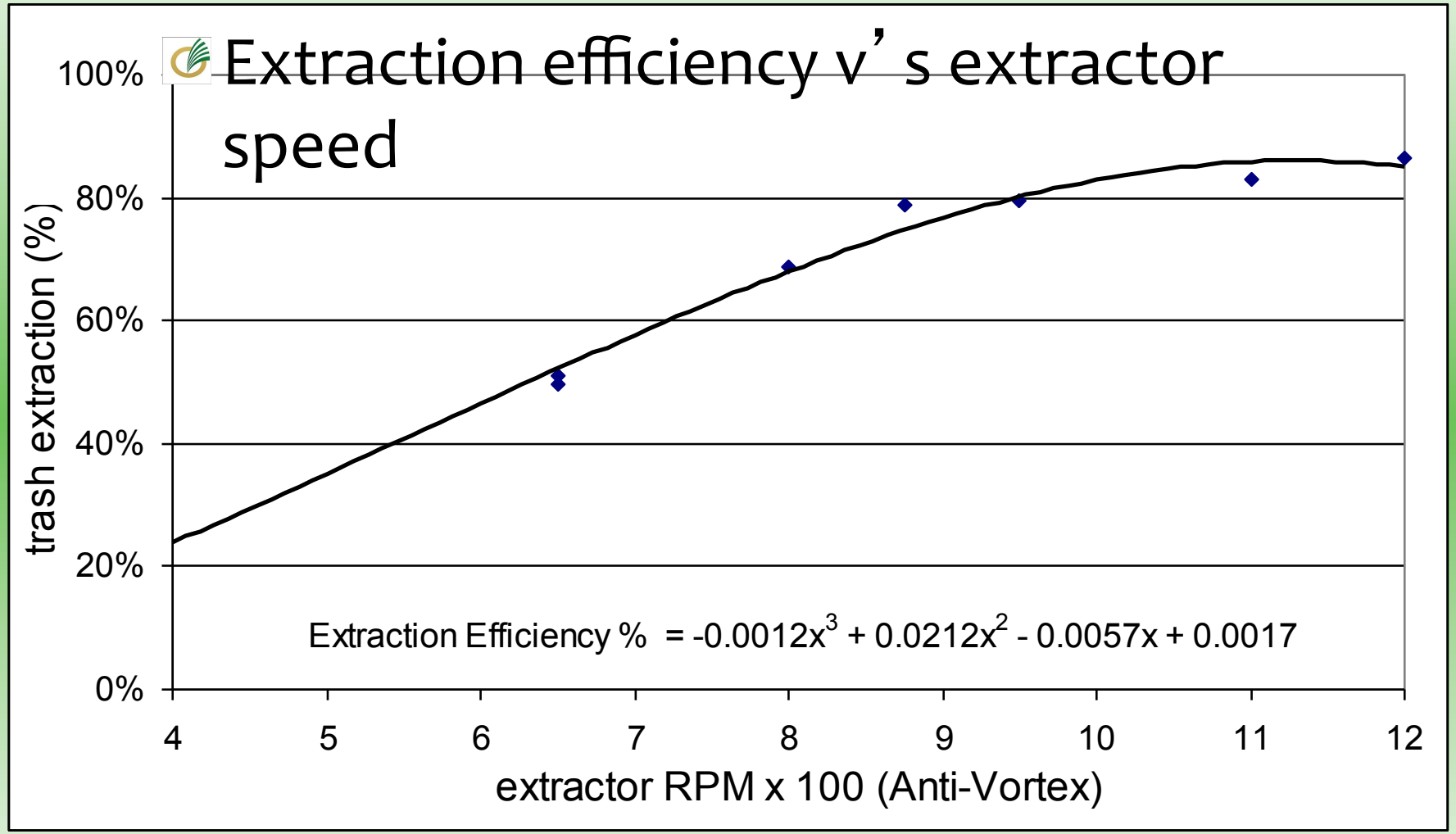

NORRIS
Energy Crop Technology

# General performance: 100t/ha semi-erect



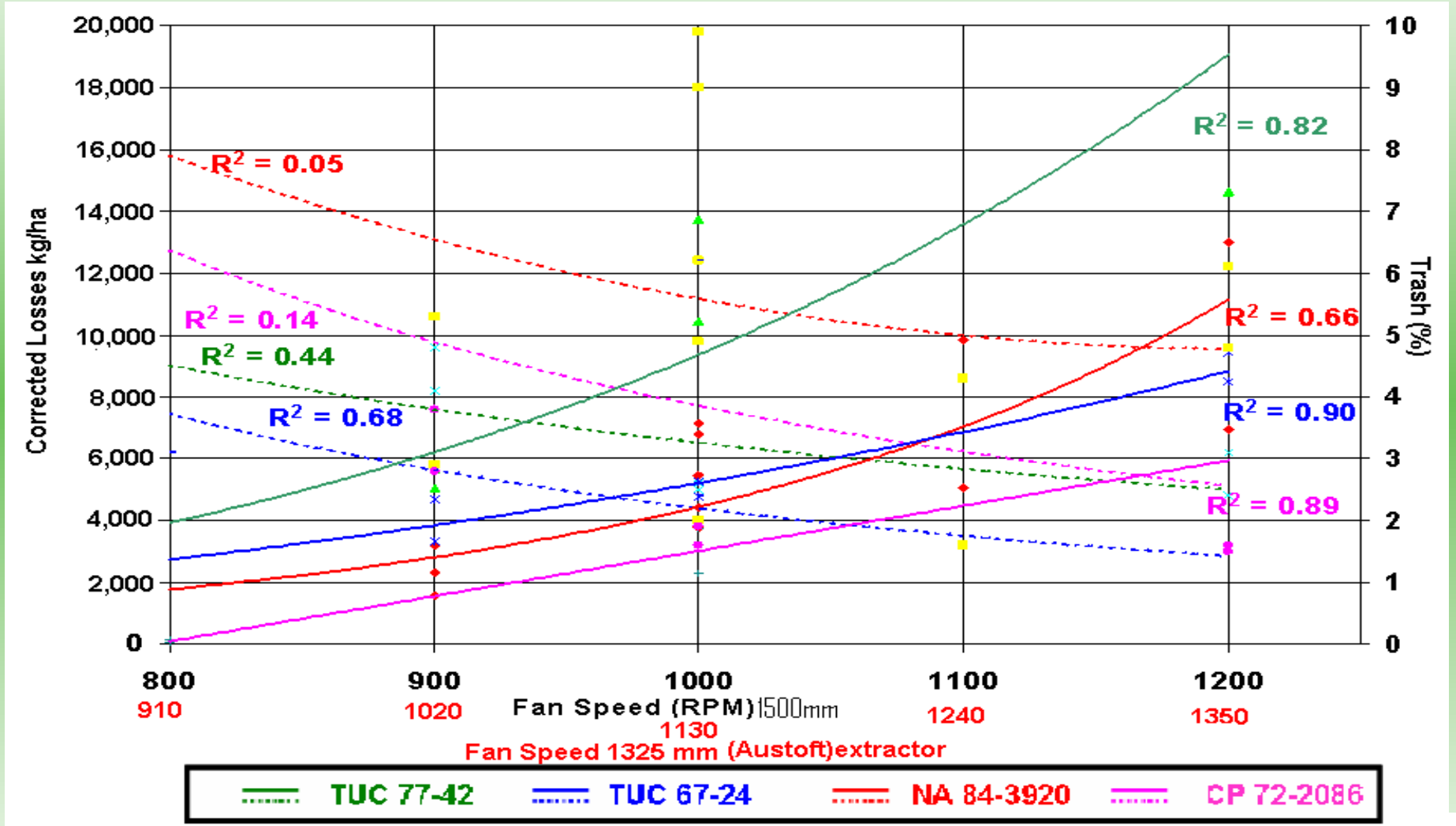

NORRIS
Energy Crop Technology

# General performance: 100t/ha semi-erect



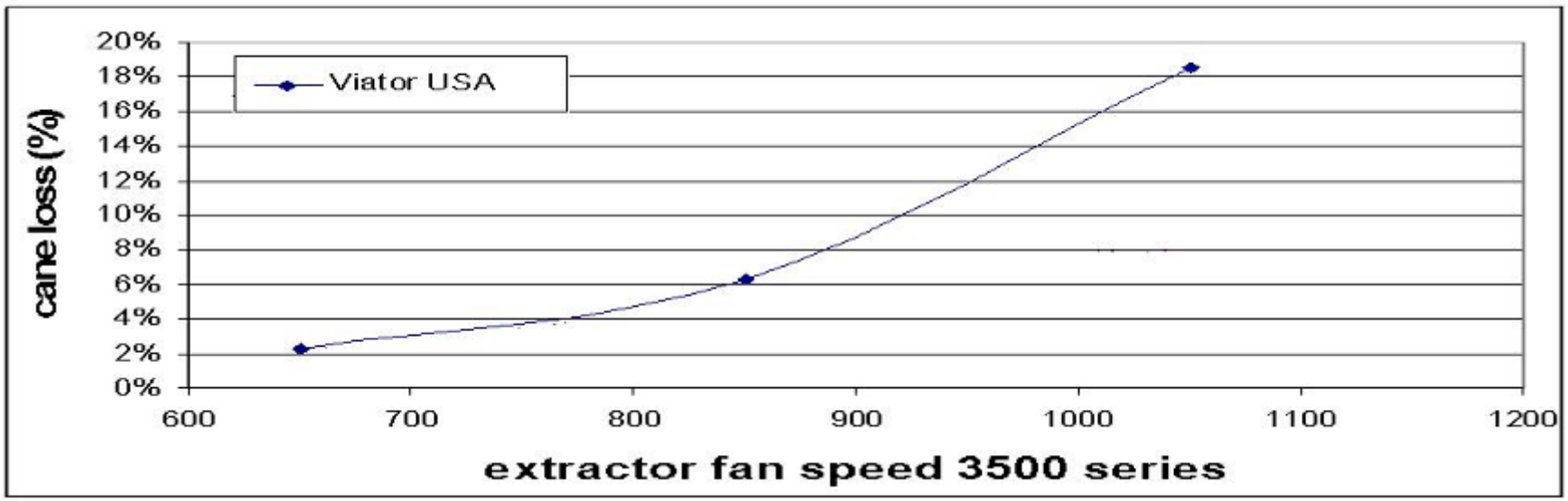

NORRIS
Energy Crop Technology

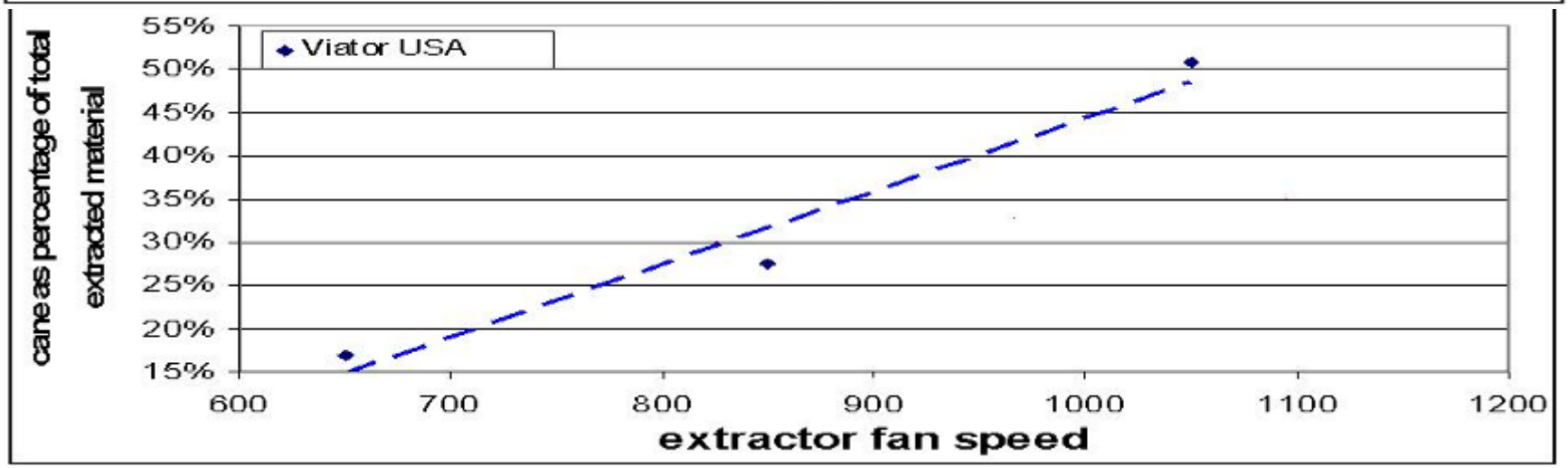
# Cane Loss JD 3500 Argentina




NORRIS
Energy Crop Technology

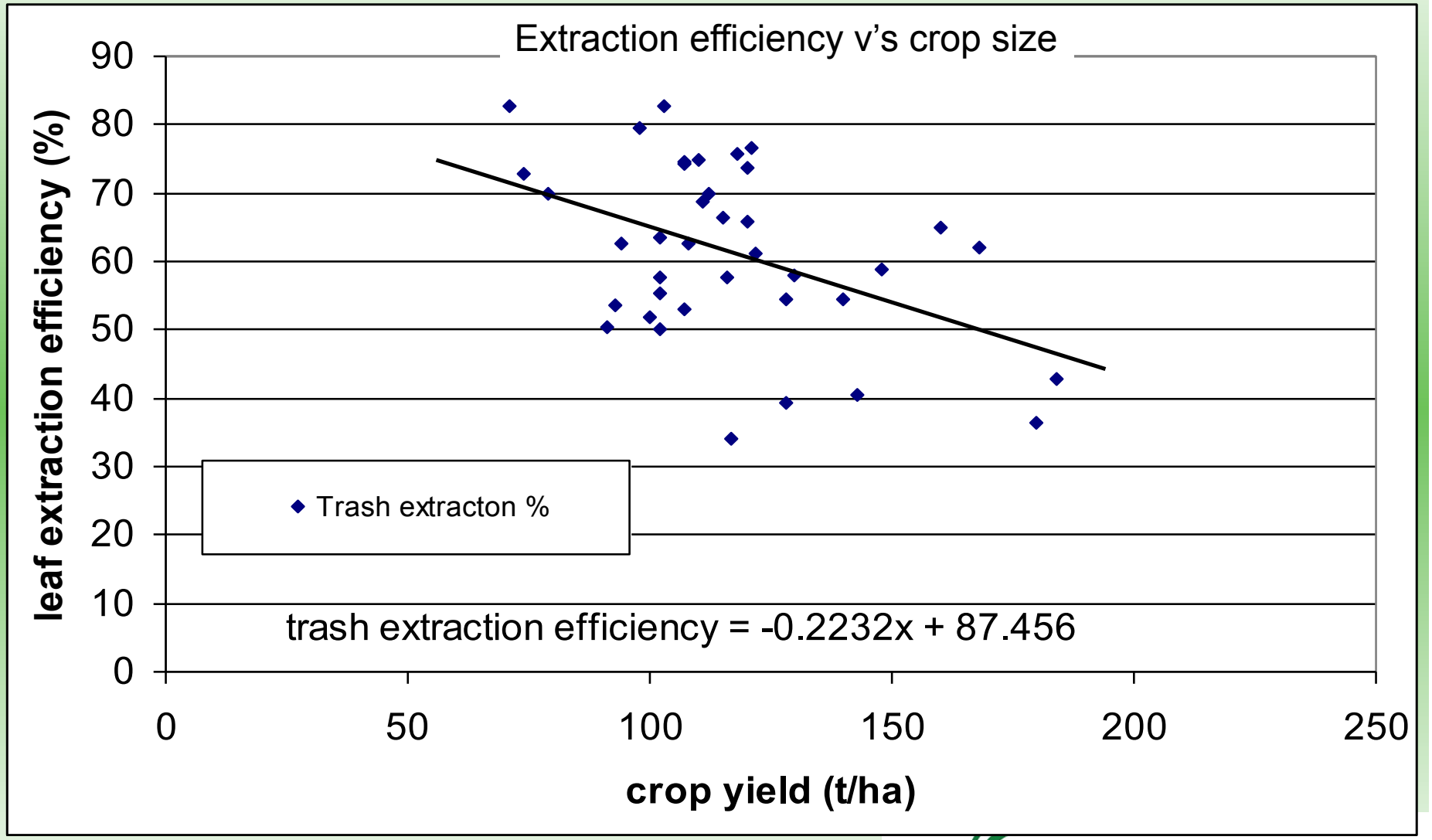
# Cane Loss: JD 3510.
## Louisiana average of trials over 2 years




NORRIS
Energy Crop Technology

# Harvester Performance v's crop size




NORRIS
Energy Crop Technology

# Harvester Performance: Trash extraction

- Design constraints mean that the performance of harvester extractor systems is generally limited.
- Trash extraction efficiency is impacted on by many factors:
  - Lodged v's erect
  - Field conditions
  - Harvester pour rates
- To maximise trash extraction, and so load density, most harvesters throughout the world operate at maximum fan speed.
- This is particularly the case in operations where the cane is being processes by diffusers.

NORRIS
Energy Crop Technology

# Harvester Performance: Cane Loss

- Cane loss is real, and is mainly “invisible”.
- As fan speed increases, extraction systems become less selective with respect to trash extraction and cane loss increases dramatically.
  - High fan speeds = high cane loss
- Cane loss through the extractor system of harvesters is a major issue both financially and environmentally.

NORRIS
Energy Crop Technology

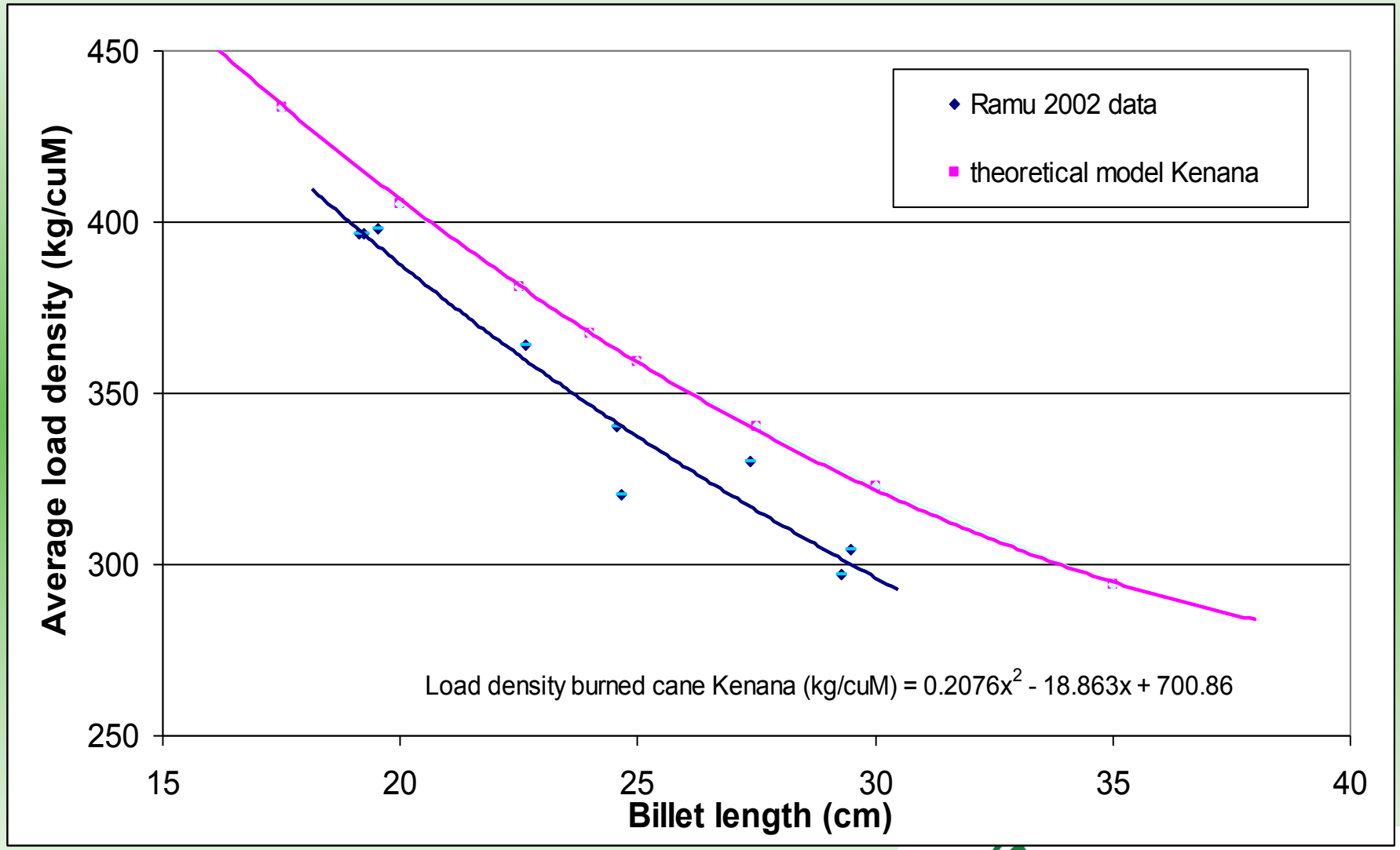
# Billet Length and Billeting Losses



- Manipulation of billet length is the primary strategy to control load density, and thus transport costs with chopper harvested cane .
- Initially with chopper harvesting burned cane, billet lengths of 300mm or greater were targeted, primarily because of deterioration considerations.
- Transport costs consideration have driven industries to shorter billet lengths, generally without consideration of the total cost.

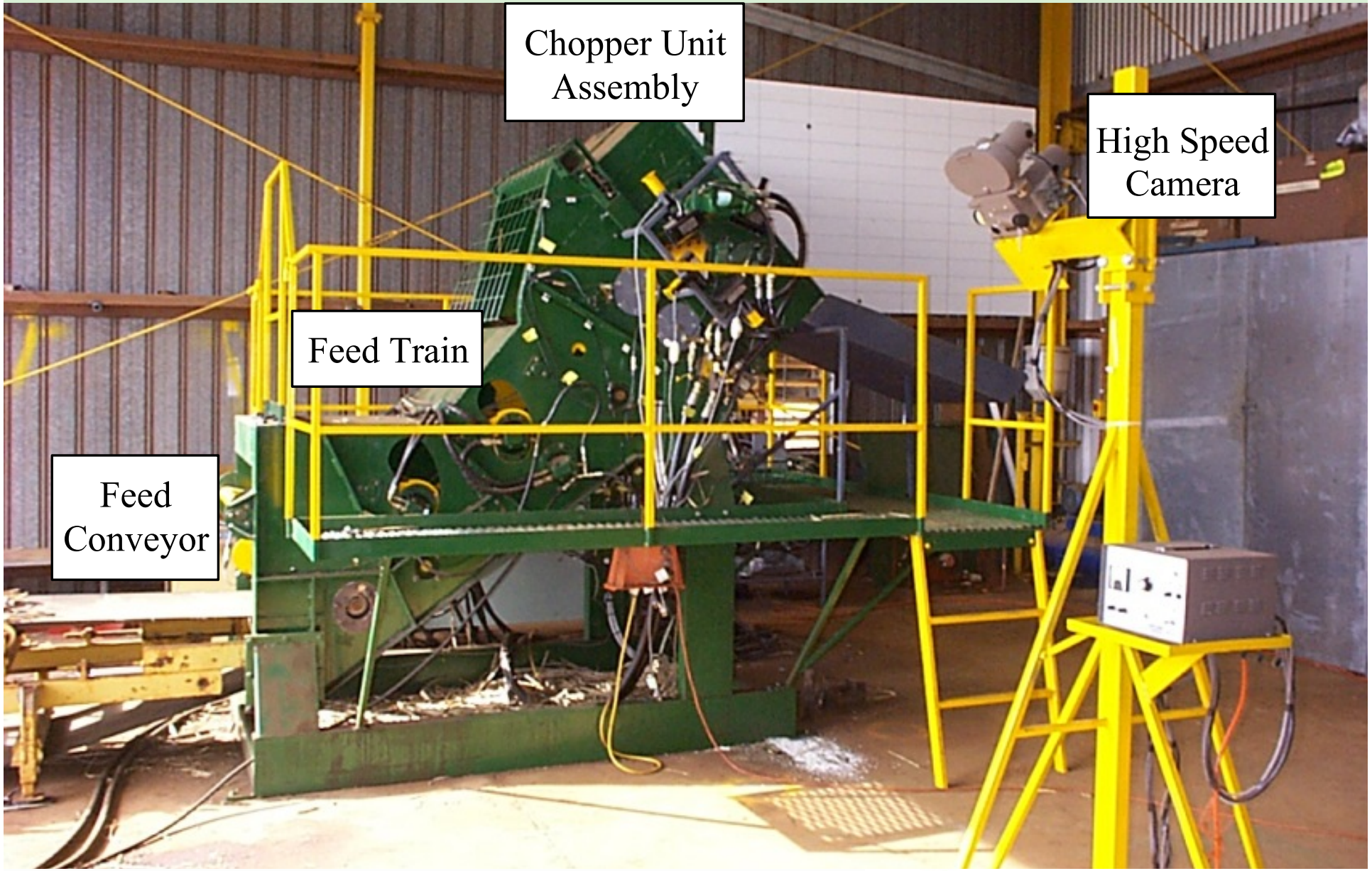
NORRIS
Energy Crop Technology

# Impact of billet length on load density

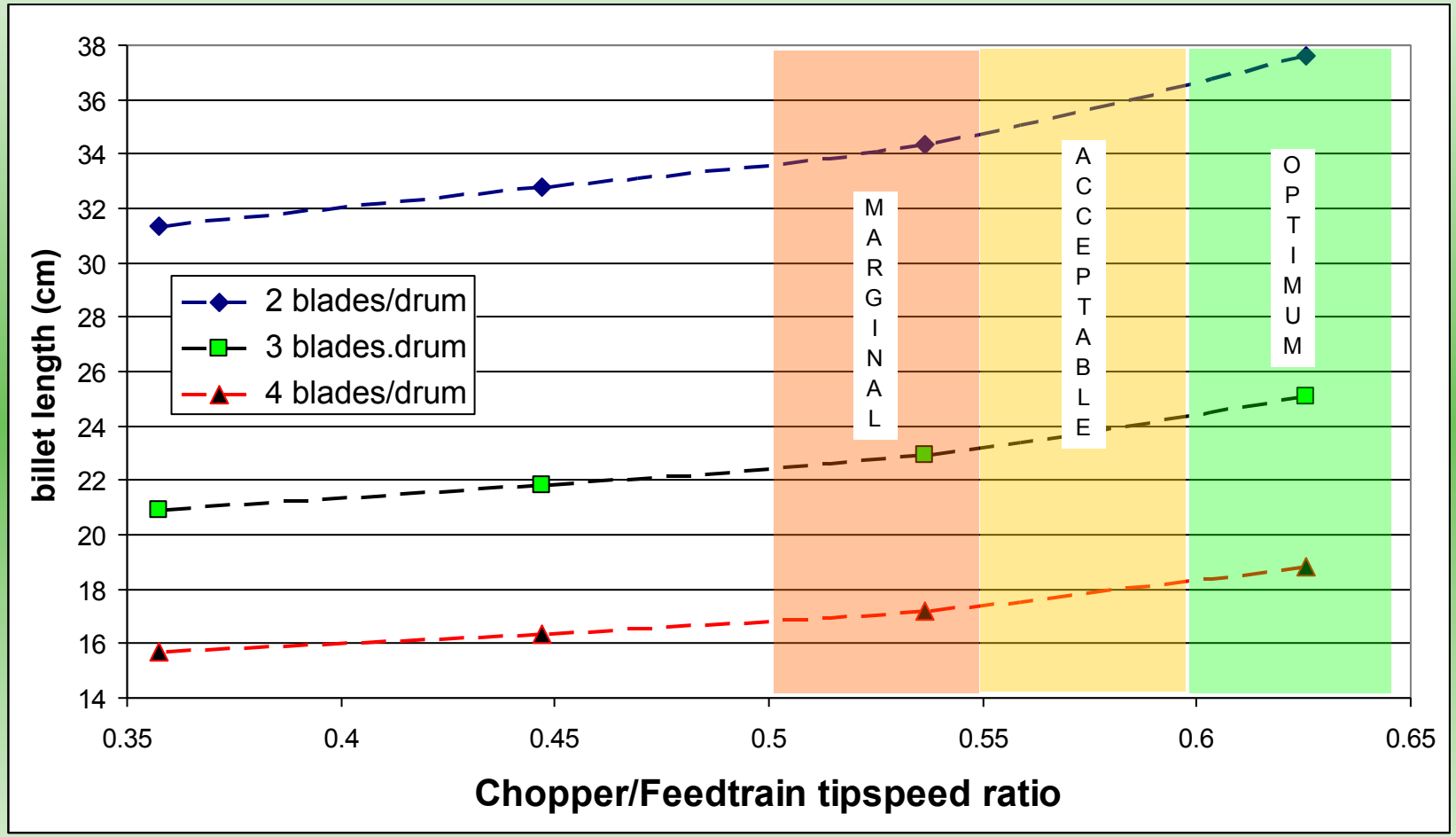



NORRIS
Energy Crop Technology

# Billet Length and Billeting Losses

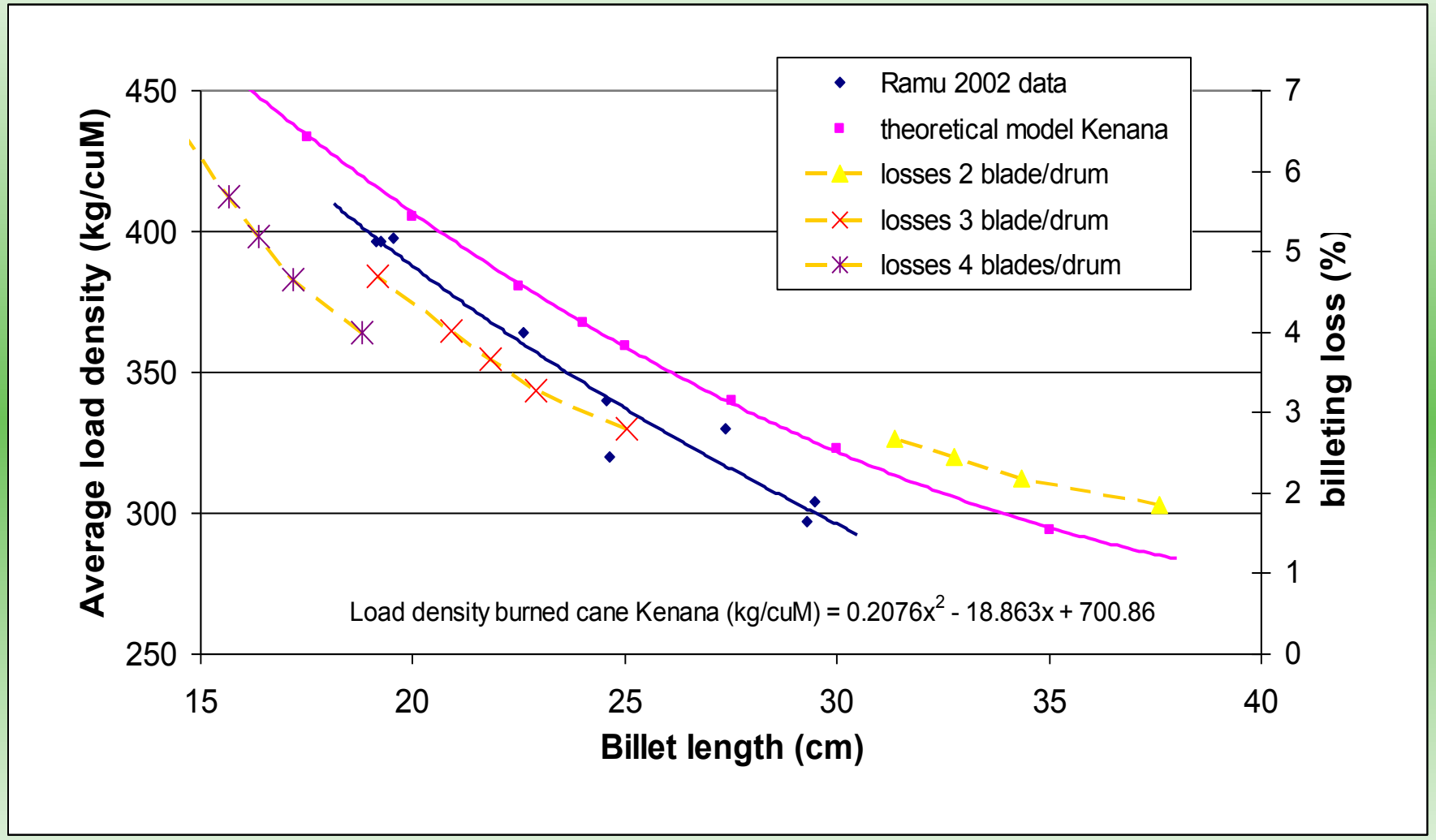


# Billet Length and Billeting Losses




NORRIS
Energy Crop Technology

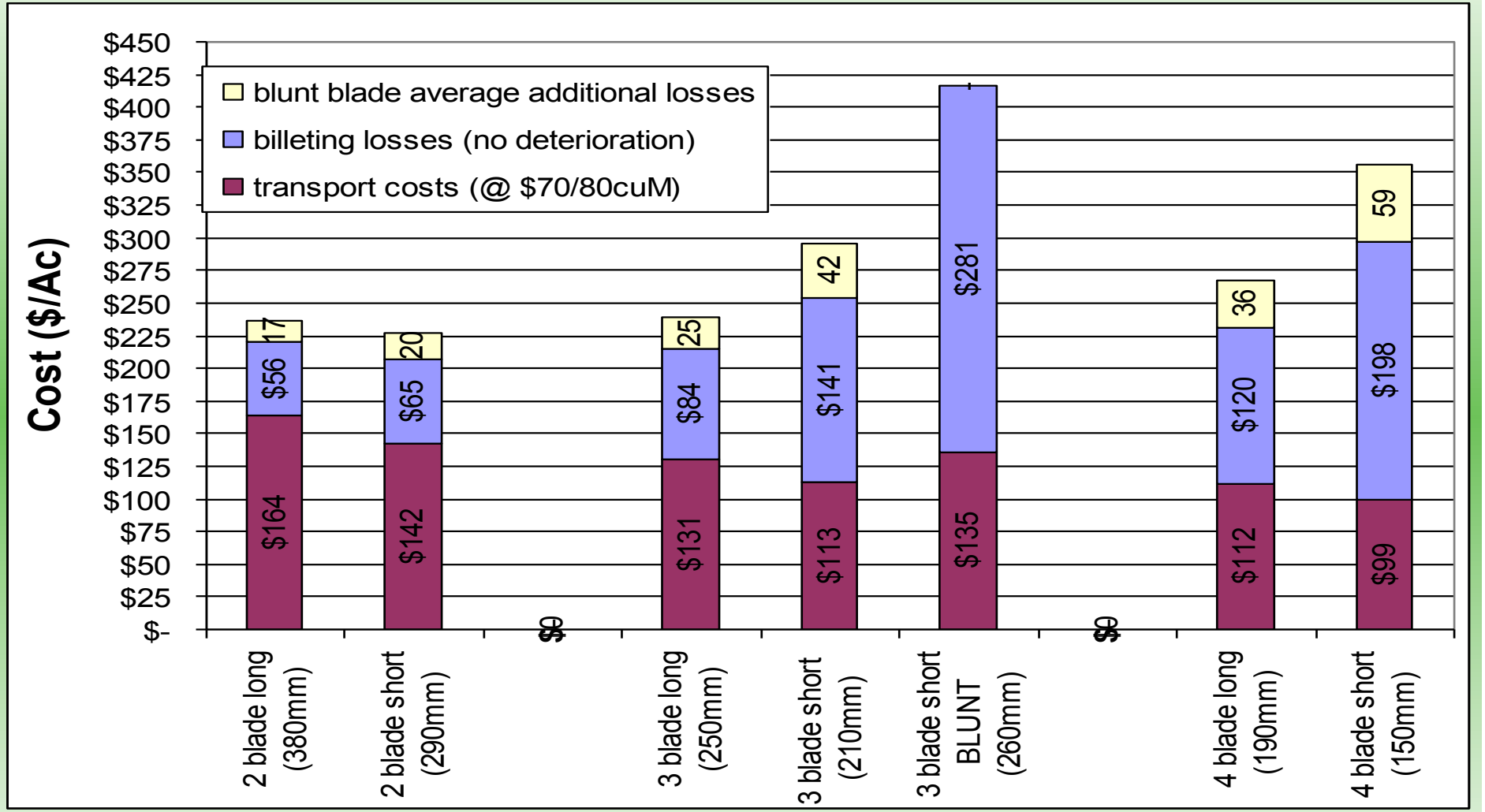
# Billet length v's load density and billeting losses




Billeting Losses: BSES Chopper Test Rig

NORRIS
Energy Crop Technology

# Billet length v's load density and billeting losses




Kenana Sugar Company, Sudan

NORRIS
Energy Crop Technology

# Billet Length and Billeting Losses



Reducing billet length also impacts on damage and rate of deterioration.

- Deterioration is generally lower with green cane, however losses must still be considered.

NORRIS
Energy Crop Technology

# Trash baling after Chopper Harvesting







NORRIS
Energy Crop Technology

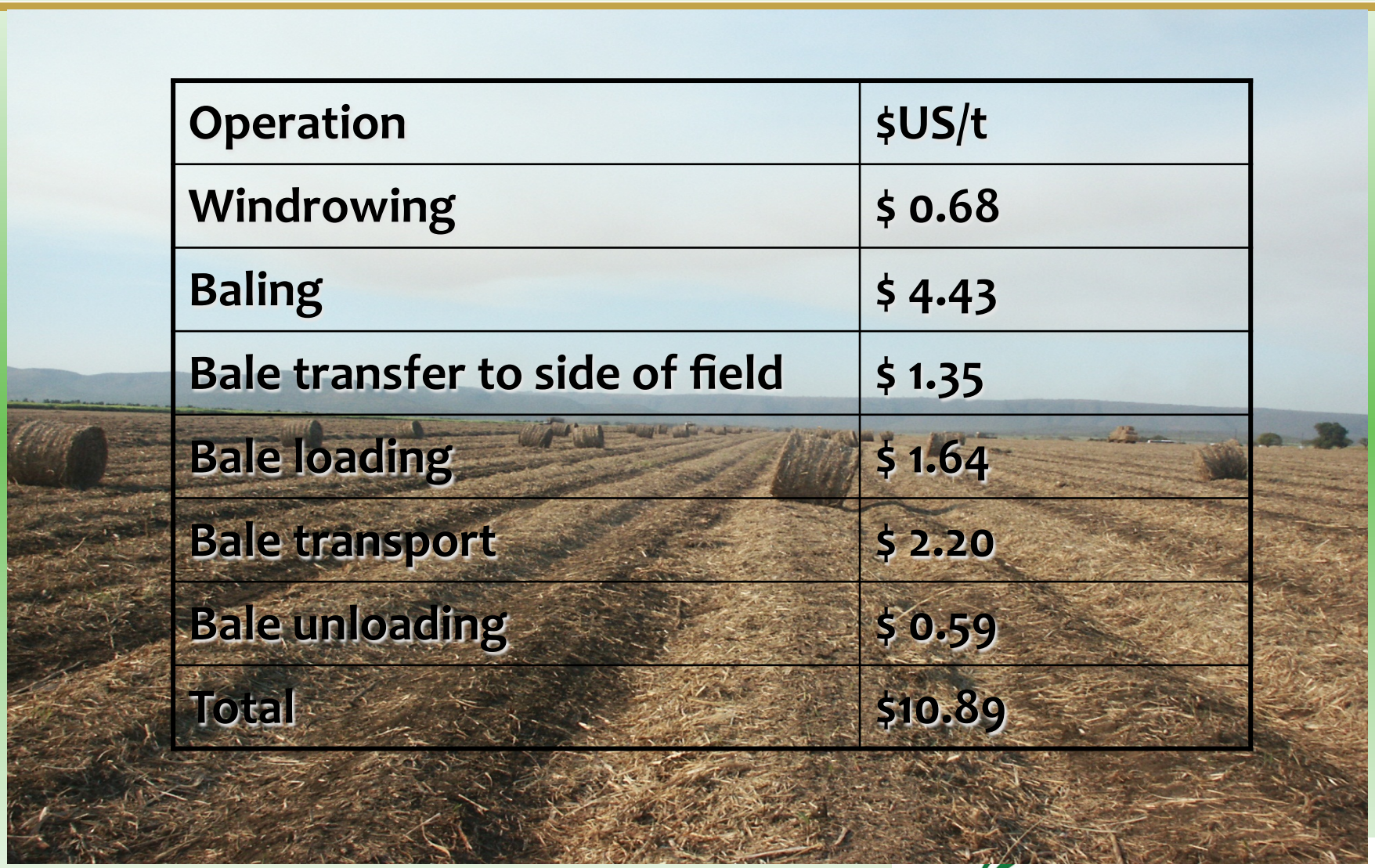
# Capital equipment



# Capital equipment



# Trash baling in the field.



| Operation | $US/t |
|---|---|
| Windrowing | $ 0.68 |
| Baling | $ 4.43 |
| Bale transfer to side of field | $ 1.35 |
| Bale loading | $ 1.64 |
| Bale transport | $ 2.20 |
| Bale unloading | $ 0.59 |
| Total | $10.89 |

# Trash baling in the field.



- There is no “selectivity” in the collection of material, e.g bales have cane stalk, tops and other material.
- Wet conditions after harvest dramatically impact on baling operations.
- Whilst collection efficiencies of >70% have been nominated, most commercial operations achieve <<60%.
- Baling and other trash collection operations often require subsequent operations in the field to re-distribute trash and alleviate compaction.

# Transport Considerations




- Increasing load volume and load density are the standard ways to reduce transport costs.
- Single trailer transport costs between $US 80 and $US 160 / load for a single trailer transport system.
- Actual payload has limited impact on cost/load.

NORRIS
Energy Crop Technology

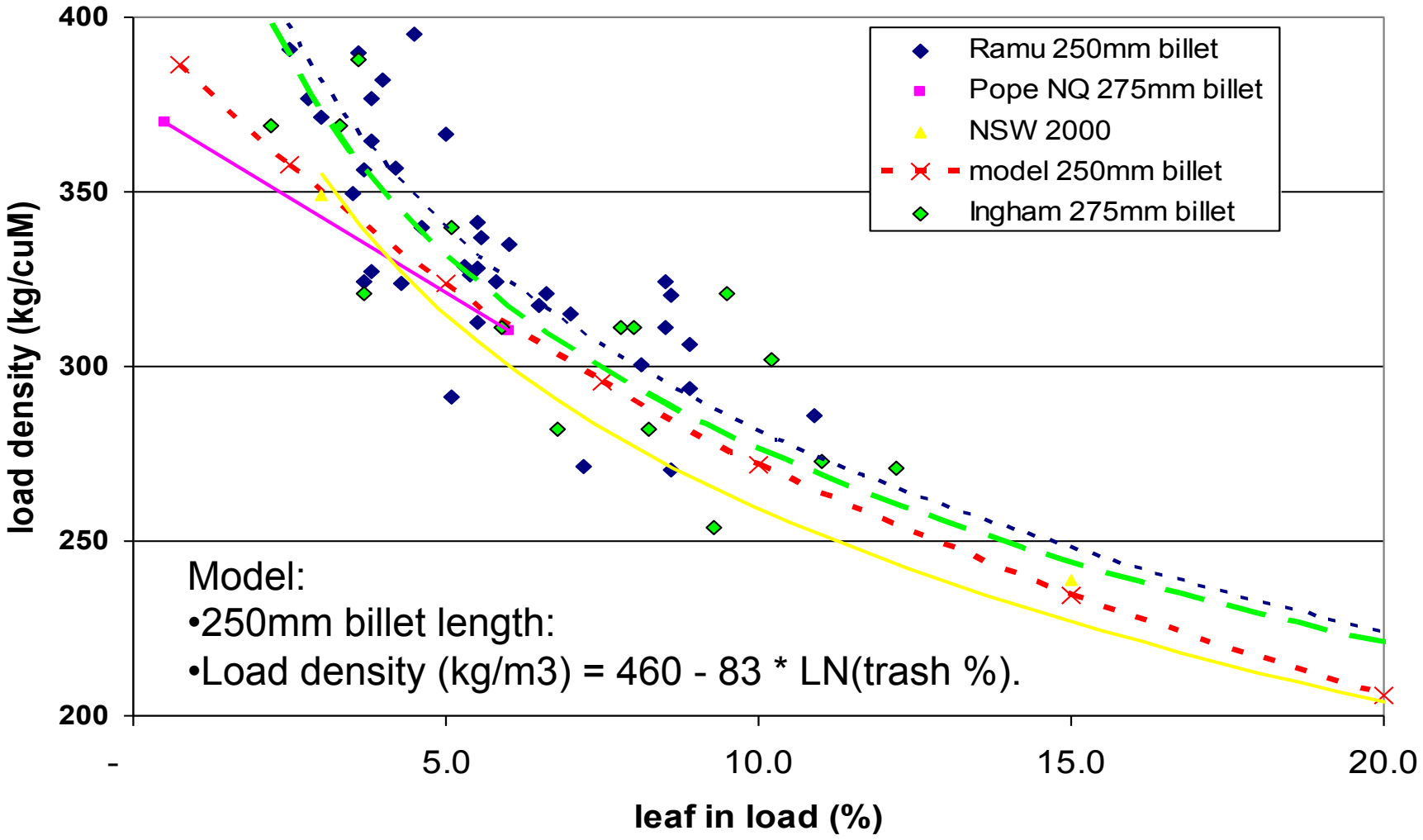
# Transport Considerations

Changes in load density associated with high trash levels has significant impact on transport systems.



NORRIS
Energy Crop Technology

# Transport considerations: Impact of leaf %




NORRIS
Energy Crop Technology

# Transport considerations: Impact of leaf %

Variability of leaf % significantly impacts on load density.

- This has significant impact on transport logistics.
- Management of trash level can be critical:
  - Modulate trash levels to manipulate binweight
  - Where possible aim to leave tops and green leaf in the field .
  - Load densification potentially a viable option.

NORRIS
Energy Crop Technology

# Transport considerations: Load densification

Partial shredding looks to be a promising strategy for load densification.



NORRIS
Energy Crop Technology

# Burning cane impacts on sucrose recovery:

## Ledesma, Argentina, Gomaz etal

| | Losses Due To | Burnt Sugar yield (t/ha) | Green Sugar yield (t/ha) |
|---|---|---|---|
| Processing Losses | Burning | 0.30 | 0.00 |
| | Billeting | 0.20 | 0.07 |
| | Trash Content | 0.49 | 0.67 |
| | Total processing | 1.00 | 0.75 |
| Infield losses | Primary Extractor | 0.45 | 1.03 |
| | Pick up losses | 0.40 | 0.36 |
| | Total infield | 0.85 | 1.39 |
| | Total | 1.84 | 2.13 |
| Measured Yields | Potential TSH | 11.18 | 11.84 |
| | Actual TSH | 9.33 | 9.71 |

NORRIS
Energy Crop Technology

# Impact of Trash on Mill Performance:

- Increasing trash levels in the cane supply impact on many systems in the milling operation:
  - Trash increases fibre levels which impacts on milling train performance, including extraction, power consumption, wear rate, processing rate and final bagasse moisture;
  - Trash increases non-Pol loading which increases loss to molasses;
  - Components in trash impact on final sugar quality (ash, colour).

NORRIS
Energy Crop Technology

# Impact of Trash on Mill Performance:

- Whilst mills have adapted to higher levels of trash from chopper harvested cane, there is an accepted cost.
- Generally attempts at milling “cane + trash” have not been successful because of the magnitude of losses associated with the high trash loading.

NORRIS
Energy Crop Technology

# Impact of Trash on Mill Performance:

- Work at Condong Mill in Australia in 2009 by Kent etal[1] indicated:

- **"The results showed sugar recovery reduced by 0.9 units for each 1.0 unit increase in cane fibre content caused by increased trash content. The sugar analysis showed increased ash and colour, and some evidence of decreased filterability. The results indicated that the reduced sugar recovery was caused by greater Pol losses in molasses, bagasse and mud, in that order of importance."**


- [1] Kent,G.A., Moller, D.J., Scroope, P.D., Broadfoot, R., (2010) The Effect of Whole Crop Processing on Sugar Recovery and Sugar Quality. Proc of Aust Soc Sugarcane Technol V32, pp 559-572.


NORRIS
Energy Crop Technology

# Improving cane quality: Supplementary cleaning.

- Cuba 2010.



- "Supplementary" leaf separation at transloading sites was introduced in Cuba to compensate for limited performance of the harvesting fleet, by further cleaning of the cane prior to transport to the mill.

# Supplementary Cleaning:



- Apparently over 900 of these facilities still operate.

NORRIS
Energy Crop Technology

# Leaf Separation at the Factory

- For effective separation of trash loadings associated with “integrated cane + trash”, carrier based systems are typically required:
- High extraction efficiency (typically> 80% leaf extraction in a single stage system);
- Much lower power consumption than “table” based systems;
- Very low cane loss, (<0.3% )even lower with billet reclaiming from the trash stream.

NORRIS
Energy Crop Technology

# NorrisECT System, JDW Mills Pakistan.



NORRIS
Energy Crop Technology

# Effect of carrier based system, Ledesma. (Argentina)






NORRIS
Energy Crop Technology

# Fuel Quality Considerations:

- Leaf delivered with the cane will typically have lower soil levels than baled material.
- Leaf from trash separation does not contain “tops” or cane stalk.
- The proportion of green and brown leaf will be determined by the topping efficiency of the harvester:
  - Lodged cane, topping efficiency =0%
  - Erect cane, topping efficiency approaching 80%
- The ideal scenario is for green leaf to be left in the field as it has low energy and is high in alkalis.

NORRIS
Energy Crop Technology

# Trash Quality: Relative slagging potential

An argument is that with dry leaves only as a supplementary boiler fuel, dangerous levels of alkalis are unlikely to be encountered, however trash analysis should be undertaken under a range of conditions and safe levels determined.

NORRIS
Energy Crop Technology

# Economics of different strategies

- Strategies:
  - Burnt cane harvesting at low & high extractor fan speeds.
  - “Typical” green cane harvesting at different fan speeds. Trash baled and delivered separately.
  - “Whole cane” harvesting, with different fan speeds to modulate trash delivered with the cane.

NORRIS
Energy Crop Technology

# Economics of different strategies

- Key considerations:
  - Crop size and trash resource in field.
    - 100t/ha crop, assume 14% recoverable sucrose.
    - Residues:

| | | |
|---|---|---|
| Green leaf | 14.0 t/ha, | 25% Fibre |
| Tops/cabbage | 9.2 t/ha | 20% Fibre |
| Dry leaf | 10.8 t/ha | 65% Fibre |

NORRIS
Energy Crop Technology

# Economics of different strategies

- Key considerations:
  - Harvesting cost ($/t clean cane):
    - Burnt cane $4.00/t
    - Green cane harvesting $5.00/t
    - “Whole cane” harvesting. $5.50/t
    - (reduced haulout capacity)
  - Harvester billet length setting 250mm

NORRIS
Energy Crop Technology

# Economics of different strategies

- Key considerations:
  - Baling & transport cost for baled residues $10/t
  - Load cost and volume for cane transport.
    - $100/load, 80cuM
  - Trash separation & processing costs:
  - $0.10/tc separation cost
  - $1.00/t trash shredding cost

NORRIS
Energy Crop Technology

# Economics of different strategies

- Key considerations:
  - Sucrose content of cane in field: 14%
  - Sucrose content after burning: 13.2%
  - Sugar value: $800/t
  - Value of trash delivered to the mill based on coal displacement @: $150/t

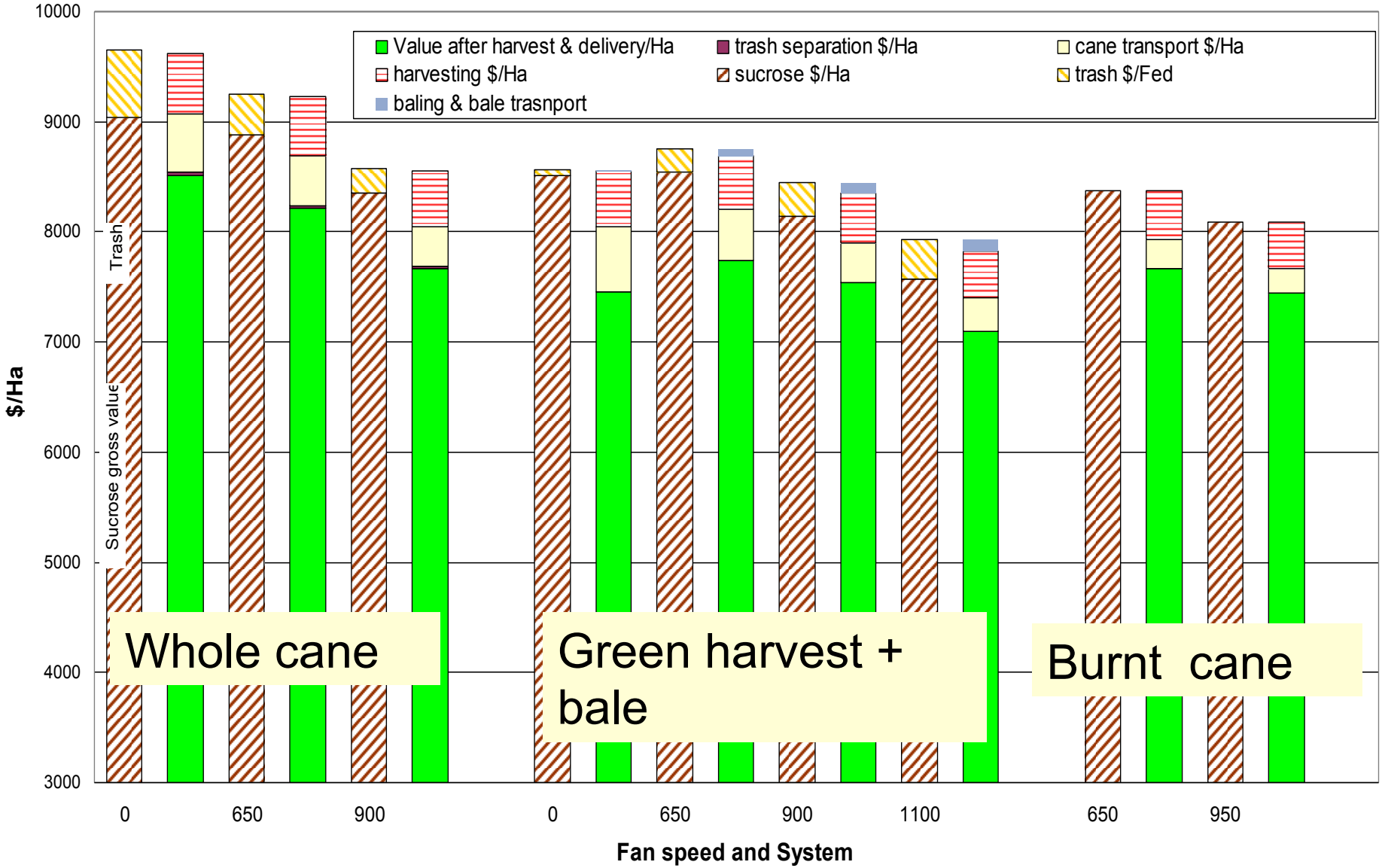
NORRIS
Energy Crop Technology

# Model output

| | Green cane + Mill Separation | | | Green cane + bale trash | | | | Burnt Cane | |
|---|---|---|---|---|---|---|---|---|---|
| Extractor fan speed | 0 | 650 | 900 | 0 | 650 | 900 | 1100 | 650 | 950 |
| Value of Sucrose recovered ($/Ha) | $ 9,042 | $ 8,884 | $ 8,349 | $ 8,516 | $ 8,543 | $ 8,139 | $ 7,573 | $ 8,370 | $ 8,089 |
| Value of Trash recovered ($/Ha) | $ 609 | $ 371 | $ 221 | $ 47 | $ 210 | $ 313 | $ 358 | | |
| *Gross Product Value ($/Ha)* | *$ 9,651* | *$ 9,255* | *$ 8,570* | *$ 8,563* | *$ 8,752* | *$ 8,453* | *$ 7,932* | *$ 8,370* | *$ 8,089* |
| Harvesting costs ($/Ha) | $ 547 | $ 536 | $ 504 | $ 498 | $ 488 | $ 458 | $ 424 | $ 443 | $ 426 |
| Transport Cost ($/Ha) | $ 529 | $ 460 | $ 359 | $ 597 | $ 460 | $ 359 | $ 304 | $ 259 | $ 220 |
| Trash Baling etc ($/Ha) | $ - | $ - | $ - | $ 14.32 | $ 64.62 | $ 96.51 | $ 110.42 | $ - | $ - |
| Trash Separation ($/Ha) | $ 31 | $ 23 | $ 18 | | | | | | |
| *Product Recovery Costs $/Ha* | *$ 1,108* | *$ 1,019* | *$ 881* | *$ 1,109* | *$ 1,012* | *$ 914* | *$ 838* | *$ 702* | *$ 646* |
| **Nett product value after delivery** | **$ 8,543** | **$ 8,236** | **$ 7,689** | **$ 7,454** | **$ 7,741** | **$ 7,539** | **$ 7,094** | **$ 7,668** | **$ 7,443** |

NORRIS
Energy Crop Technology

# Model output: Visual



# Conclusions: Product Value & Recovery.

- The most significant factor in the analysis is the increase in income associated with any strategy to reduce cane loss.
- The contribution of trash (for cogeneration) to the total product value/ha is modest. The collection of trash via the baling option appears to be of marginal value.
- High trash levels in cane to be milled significantly impact on sucrose recovery and have significant impact on other aspects of the milling operation (e.g diffuser binding).

NORRIS
Energy Crop Technology

# Conclusions.

- Whilst “Whole cane” options dramatically increase harvest and transport costs, in the overall analysis these costs are small compared with the potential gains.
- The “whole cane + trash” separation at the mill gives the best outcome, primarily because of the reduction in cane loss on the harvester can then be capitalised on by increased recovery at the mill.
- Other benefits over green cane harvesting will be sugar quality benefits because of reduced trash in the product being milled.

NORRIS
Energy Crop Technology

NORRIS
Energy Crop Technology

www.NorrisECT.com

NORRIS
Energy Crop Technology


NORRIS
Energy Crop Technology


NORRIS
Energy Crop Technology

# Trash Quality: Relative slagging potential

| Summary | Data: CTC Publications | | | | | |
|---|---|---|---|---|---|---|
| | Total Potassium | MC% | DM% | g/kg DM | LHV MJ/kg | mg/MJ |
| Cane tops | 2670 | 70 | 30 | 8.90 | 4000 | 2.23 |
| Cane stalk | 323 | 75 | 25 | 1.29 | 3000 | 0.43 |
| Dry leaves | 3370 | 15 | 85 | 3.96 | 15000 | 0.26 |
| Green leaves | 8000 | 50 | 50 | 16.00 | 8000 | 2.00 |

An argument is that with dry leaves only as a supplementary boiler fuel, dangerous levels of alkalis are unlikely to be encountered, however trash analysis should be undertaken under a range of conditions and safe levels determined.

NORRIS
Energy Crop Technology


NORRIS
Energy Crop Technology