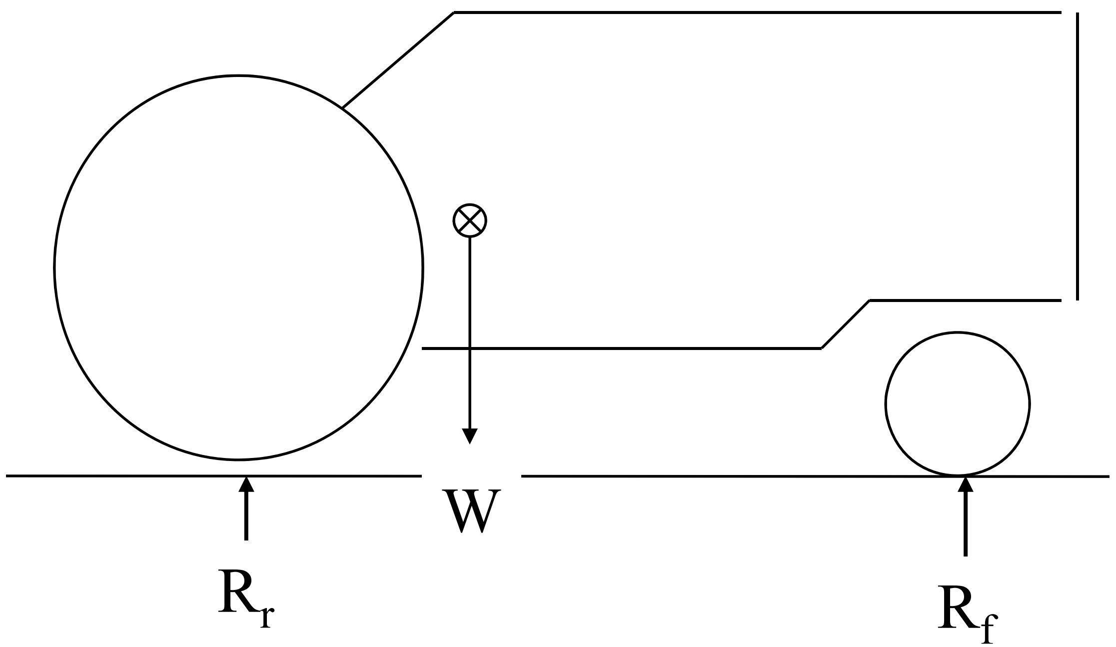
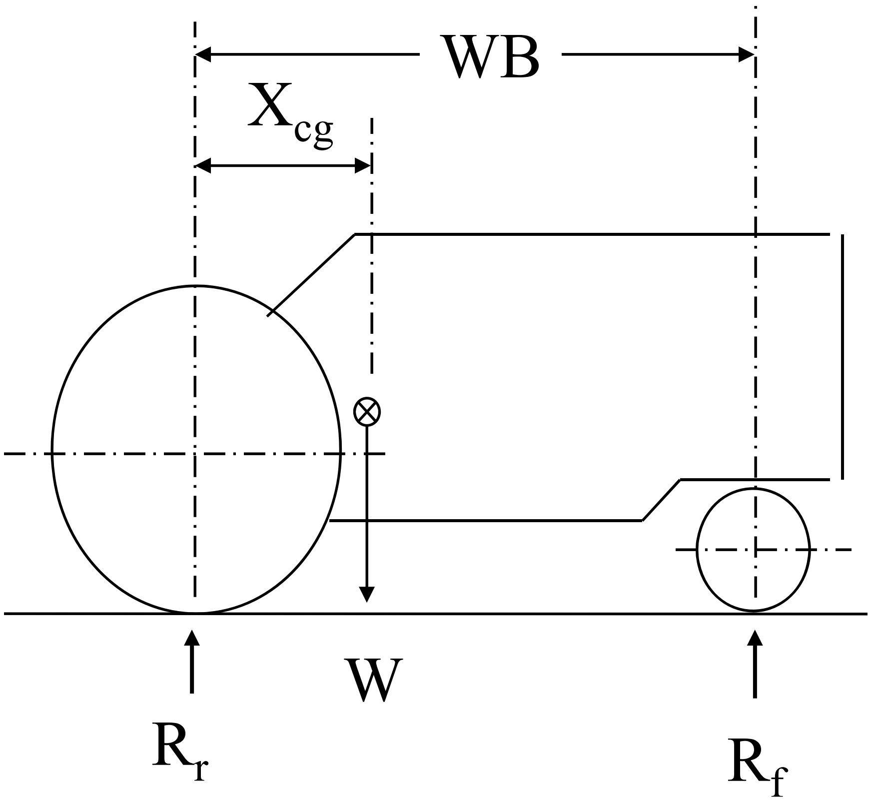
Weight Transfer, Traction & Stability

- Moments and Center of Gravity
  - ⇒ The center of gravity can be determined using moments about any point on the tractor
  - ⇒ For the tractor to be in equilibrium the clockwise moment must equal the anti-clockwise moment
    - Moment = Force * Perpendicular distance to line of force



Center of Gravity



- **Moments about rear axle**

Clockwise Moment = CounterClockwise Moment

$$W*X_{cg} = R_f*WB$$

⇨ $$X_{cg} = R_f*WB / W$$

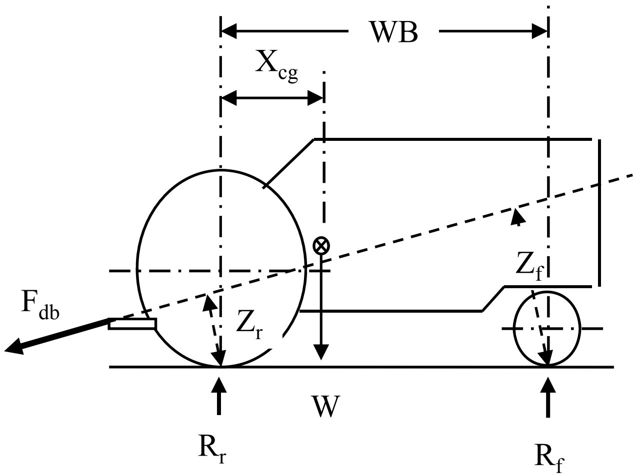
Metric

X_{cg} (mm) = R_f(kN) * WB(mm) / W(kN)

English

X_{cg} (in) = R_f(lb.f) * WB(in) / W(lb.f)

Weight Transfer



Moments about rear axle: Dynamic Front Wheel Reaction

Clockwise Moment = CounterClockwise Moment

$$W*X_{cg} = R_f*WB + F_{db}*Z_r$$

$$\Rightarrow \mathbf{R_f = (W*X_{cg} - F_{db}*Z_r)/WB}$$

Moments about Front axle: Dynamic Rear Wheel Reaction

Clockwise Moment = CounterClockwise Moment

$$R_r*WB = W*(WB-X_{cg}) + F_{db}*Z_f$$

$$\Rightarrow R_r = [W*(WB-X_{cg}) + F_{db}*Z_f]/WB$$

Static Reaction Forces	Dynamic Reaction Forces		Dynamic Weight Transfer
Drawbar Pull = 0	Drawbar Pull = F_{db}	⇨	ΔR= Dynamic Forces - Static
Front	Front		Front
$R_{fo} = (W*X_{cg})/WB$	$\mathbf{R_f = (W*X_{cg} - F_{db}*Z_r)/WB}$	⇨	$\Delta R_f = (R_{fo} - R_f) = -(F_{db}*Z_r)/WB$
Rear	Rear		Rear
$R_{ro} = [W*(WB-X_{cg})]/WB$	$R_r = [W*(WB-X_{cg}) + F_{db}*Z_f]/WB$	⇨	$\Delta R_r = (R_{ro} - R_r) = F_{db}*Z_f/WB$

Reaction Forces

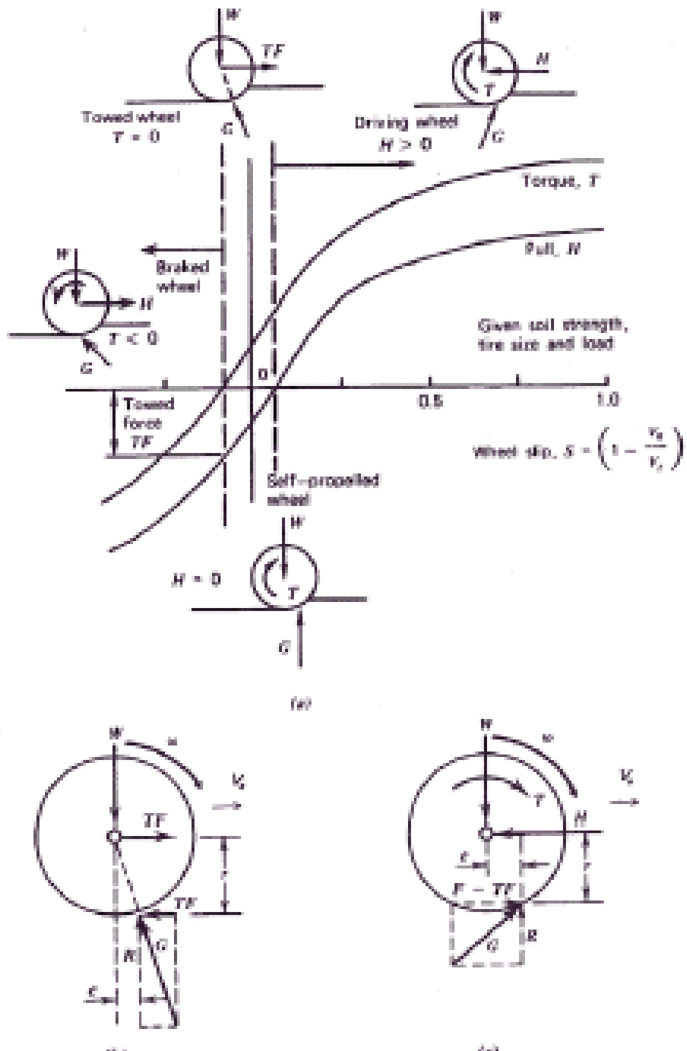


Figure 13.11. (a) Net traction (pull)-torque-slip relation for wheels on soil. (From Wismer and Luth, 1974.) (b) Free body diagram of a towed wheel. (c) Free body diagram of a driving wheel.

Basic Concepts of Traction: Travel Reduction

- Travel Reduction (TR): Reduction in actual forward speed that occurs due to increased slippage when the drawbar load is increased. Theoretically, Slip and Travel reduction are not identical although they are often used interchangeably.

$$TR = 100*(1- S_a/S_o)$$

where: S_a = Actual travel Speed, S_o = Travel Speed on specified surface with no load

- Travel reduction must occur to develop drawbar pull
  - ⇒ Tire lug must compress the soil allowing it to develop tractive force
  - ⇒ Rear movement results in travel reduction

Basic Concepts of Traction: Tractive Force (Wismer-Luth)

- Gross Tractive Force Coefficient (μ_g): Gross Tractive Horizontal Force (F) divided by the Dynamic Weight (Reactive Force) on driving wheel.

$$\mu_g = F/W = 0.75*[1- \exp(-0.3C_nS)]$$

$$C_n = CI\ bd/W \text{ (Wheel Numeric)}$$

- Motion Resistance Ratio (ρ): Horizontal Towing Force (TF) divided by the Dynamic Weight (Reactive Force) on wheel.

$$\rho = TF/W = 1.2/C_n + 0.04$$

$$C_n = CI\ bd/W$$

- Net Tractive Force Coefficient (μ): Net Tractive Horizontal Force (H) divided by the Dynamic Weight (Reactive Force) on driving wheel.

$$\mu = H/W = (F-TF)/W = 0.75*[1- \exp(-0.3C_nS)] - [1.2/C_n + 0.04]$$

$$C_n = CI\ bd/W$$

Basic Concepts of Traction: Tractive Force (Bias Ply)

- Gross Tractive Force Coefficient (μ_g):

$$\mu_g = F/W = 0.88*[1- \exp(-0.1B_n)\ ]\ *[1- \exp(-7.5S)\ ]+0.04$$

$$B_n = [CI\ bd/W]*[(1+5*\delta/h)/(1+3*b/d)]\ \text{(Mobility Number)}$$

$$C_n = CI\ bd/W\ \text{(Wheel Numeric)}$$

$$b/d = \text{Width to Depth Ratio}$$

$$\delta/h = \text{deflection Ratio}$$

- Motion Resistance Ratio (ρ):

$$\rho = TF/W = 1.0/B_n + 0.04 + 0.5s/(B_n)^{1/2}$$

- Net Tractive Force Coefficient (μ):

$$\mu = H/W = (F-TF)/W = \mu_g - \rho$$

Basic Concepts of Traction: Tractive Force (Radial Ply)

- Gross Tractive Force Coefficient (μ_g):

$$\mu_g = F/W = 0.88*[1- \exp(-0.1B_n)] *[1- \exp(-9.5S)]+0.0325$$

B_n = [CI bd/W]*[(1+5*δ/h)/(1+3*b/d)] (Mobility Number)

C_n = CI bd/W (Wheel Numeric)

b/d = Width to Depth Ratio

δ/h = deflection Ratio

- Motion Resistance Ratio (ρ):

$$\rho = TF/W = 0.9/B_n + 0.0325 + 0.5s/(B_n)^{1/2}$$

- Net Tractive Force Coefficient (μ):

$$\mu = H/W = (F-TF)/W = \mu_g - \rho$$

Basic Concepts of Traction: Dynamic Traction Ratio

- Dynamic Traction ratio (DTR) is the ratio of drawbar pull (F_{db}) over the dynamic weight on the driving wheels

$$DTR_{(2\ \text{wheel Drive})} = F_{db} / [\ R_{ro} + \Delta R_r\ ]$$

where: R_{ro} is static weight on rear wheels and ΔR_r is weight transfer

- A high DTR needed for high drawbar pull
  - Improved lug design
  - Radial ply design

- Increase weight will also increase pull at the cost of higher compaction and increased stress on the axles

Basic Concepts of Traction: Tractive Efficiency

- Tractive Efficiency (TE) is the fraction of axle power (P_a) that is converted to drawbar power (P_{db}) by the drive wheels

$$TE = P_{db} / P_a$$

$$TE = [F_{db} * V] / P_a$$

Metric

$$TE = [F_{db}(kN) * V(km/h) * 1000(m/km)/3600(sec/h)] / [P_a(kW)]$$

$$TE = [F_{db}(kN) * V(km/h)] / [P_a(kW) * 3.6\ (km/h\ per\ m/s)]$$

English

$$TE=[F_{db}(lb.f) * V(mph) * 5280(ft/m)/60(sec/h)]/[P_a(Hp) * 33000(ft.lb/min\ per\ Hp]$$

Basic Concepts of Traction: Tractive Efficiency

- $TE = P_{db} / P_a$

$\Rightarrow TE = [F_{db} * V_a] / P_a$

$\Rightarrow TE = [F_{db} * V_a] / T\omega$

$\Rightarrow TE = [F_{db} * V_a] / [(F*r)*(V_t/r)]$

$\Rightarrow \quad = [H / F]*[V_a / V_t]$

$\Rightarrow TE = [H / F]*[1-S]$

$\Rightarrow TE = [(H/W) / (F/W)]*[1-S]$

$\Rightarrow TE = [(\mu_g - \rho)/ \mu_g]*[1-S]$

$\Rightarrow TE = [1- \rho /\mu_g]*[1-S]$

$P_{db} = [F_{db} * V_a]$

$P_a = T\omega$ T = Axle Torque

ω= angular velocity

$\omega = V_t/r$ r=rolling radius

$T = F*r$ F = Gross Traction

$F_{db} = H$ (Net Traction)

$V_a / V_t = (1-S)$ S=Slip

Travel Reduction, Drawbar Pull and Maximum Tractive Efficiency

- Drawbar Pull
  - Zero Slip, Zero Drawbar Pull
  - 100% Slip, Max Drawbar Pull
- Dynamic Traction Ratio
  - Zero Slip, DTR=0
  - 100% Slip, DTR=maximum

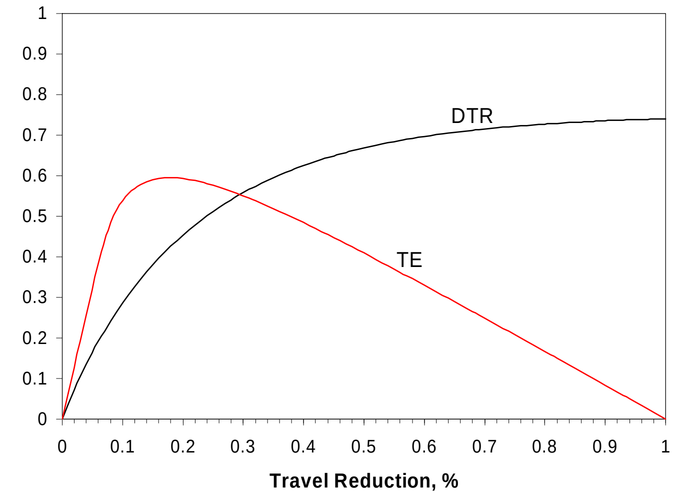


Figure 1: Variation of Tractive Efficiency and Dynamic Traction Ratio with travel reduction for a particular tractor on one specific soil

- Tractive Efficiency

TE=Tractive/axle Power

Tractive Power = Drawbar Force * Velocity

Zero Slip

Velocity=maximum, Drawbar Force =0

⇒ Tractive Power =0, TE=0

100% Slip

Velocity=0, Drawbar Force =maximum

⇒ Tractive Power =0, TE=0

Maximum tractive efficiency occurs at some intermediate slip conditions, generally between 10-15%, but will depend on the conditions.

Traction Performance

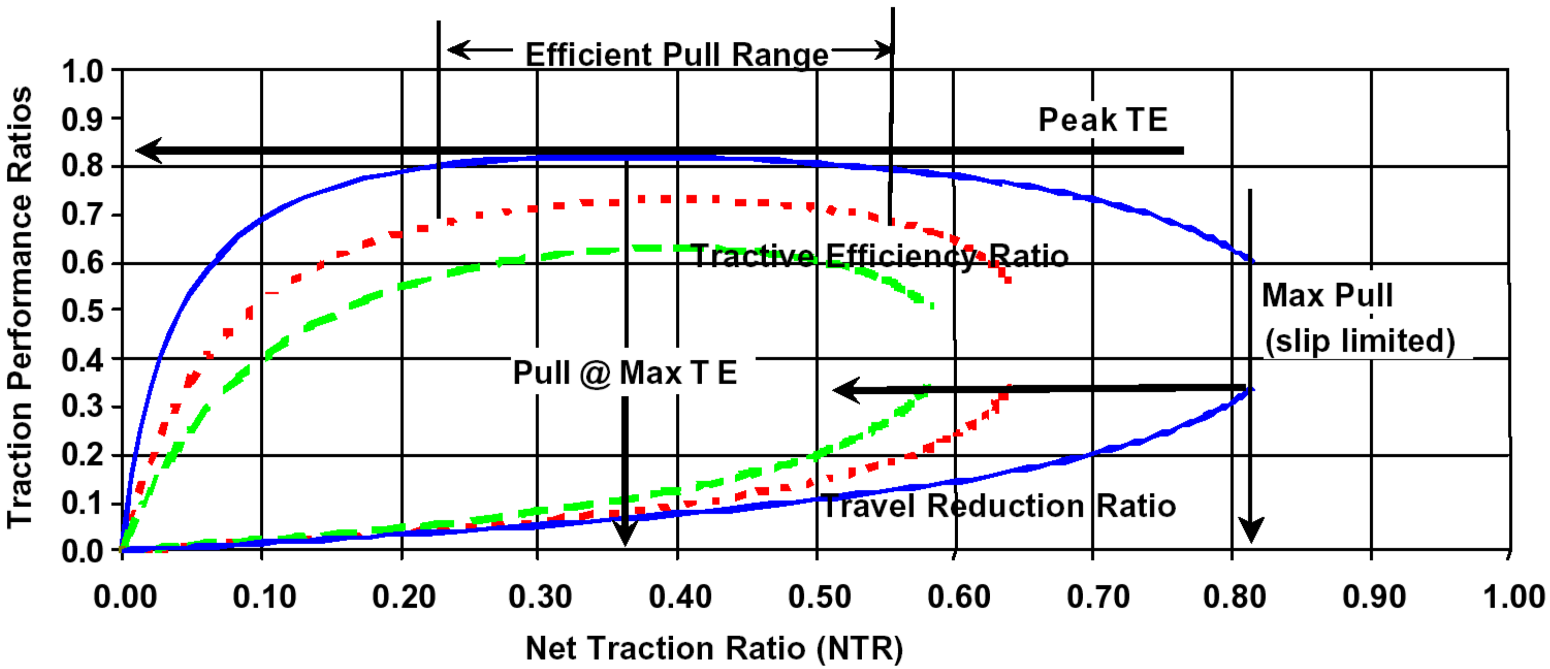


Figure 26. How to interpret traction plots (performance of 20.8R42 dual tires on three surfaces).

F.M. Zoz and R.D. Grisso, Traction and Tractor Performance: ASAE Distinguished Lecture # 27,
Agricultural Equipment Technology Conference, 9-11 February 2003, Louisville, Kentucky USA. ASAE Publication Number 913C0403

Traction Performance

- Soil Type
  ⇒ Soft soils decrease in TE

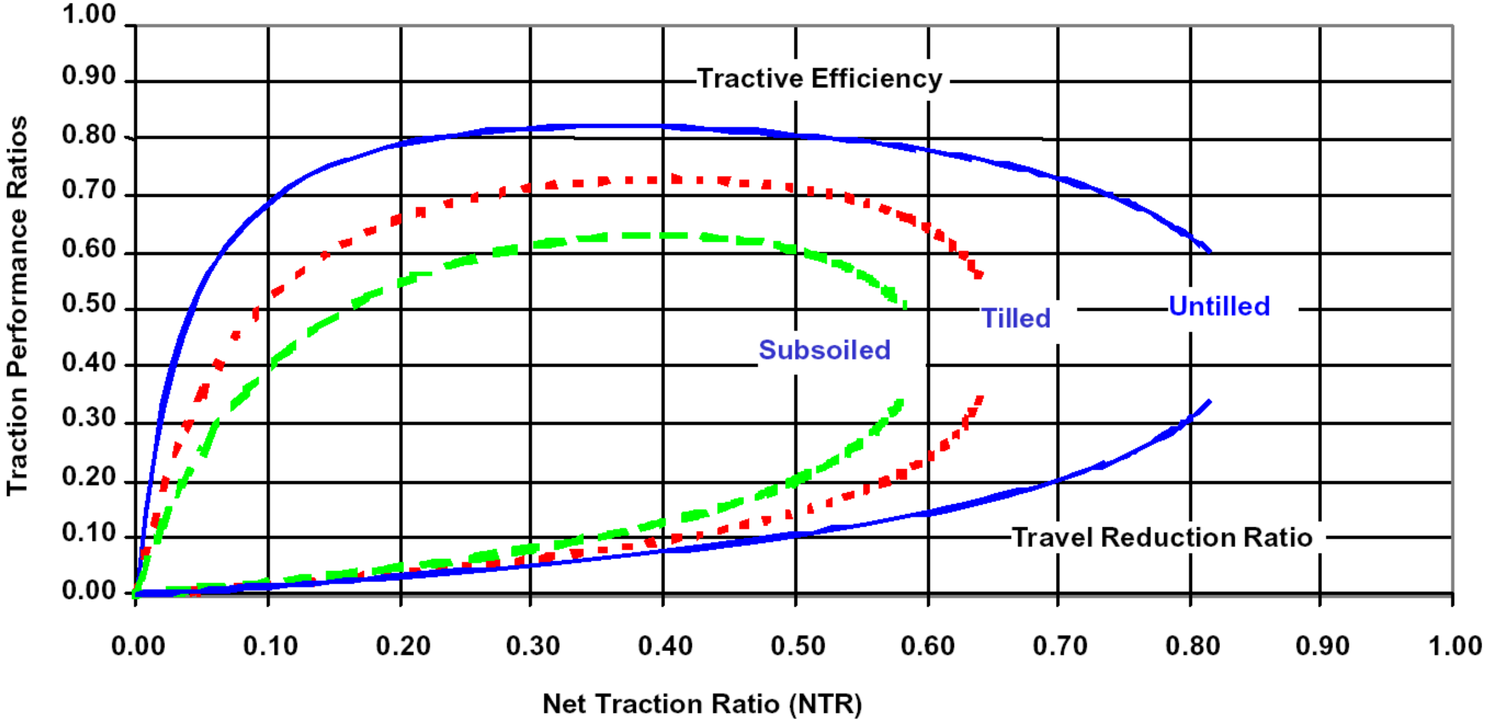


Figure 27. Performance of 20.8R42 dual tires on three surfaces (8300 kg axle load, 83 kPa tire pressure).

F.M. Zoz and R.D. Grisso, Traction and Tractor Performance: ASAE Distinguished Lecture # 27,
Agricultural Equipment Technology Conference, 9-11 February 2003, Louisville, Kentucky USA. ASAE Publication Number 913C0403

Traction Performance

- Tire Pressure
  - ⇒ Over inflation slight decrease in TE

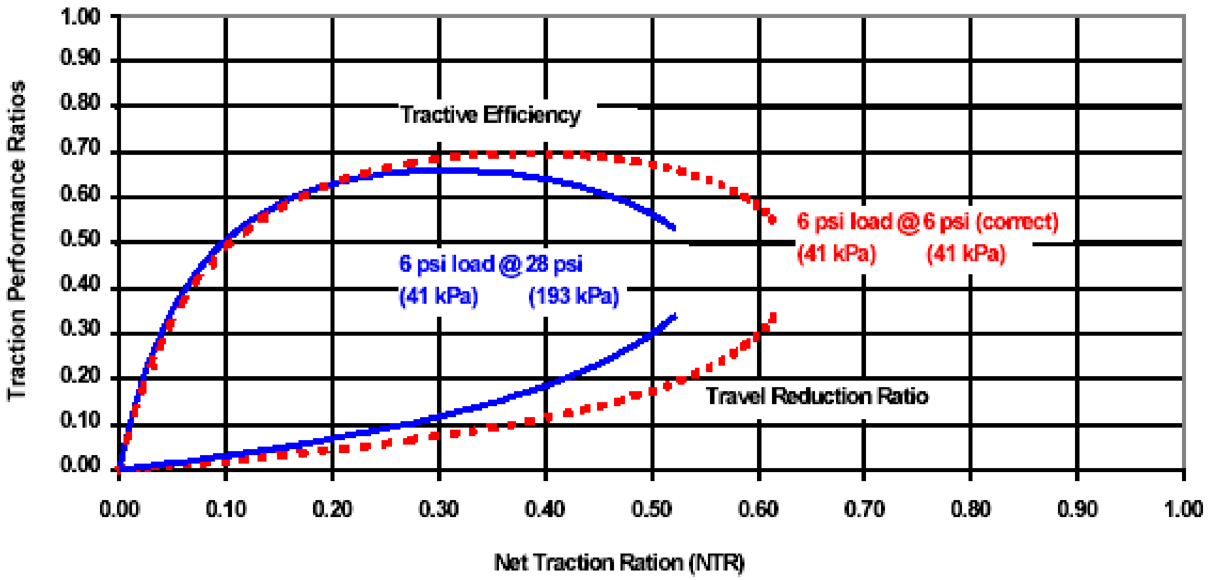


Figure 28. Performance of single tire (Firestone 710/70R38 ATR) at two inflation pressures in tilled (loose) tractive conditions.

F.M. Zoz and R.D. Grisso, Traction and Tractor Performance: ASAE Distinguished Lecture # 27,
Agricultural Equipment Technology Conference, 9-11 February 2003, Louisville, Kentucky USA. ASAE Publication Number 913C0403

Traction Performance

- Tire Size
  - ⇒ Larger Dia , higher TE at same slip
  - ⇒ Wider Tire, greater MMR
  - ⇒ Equal maximum pull

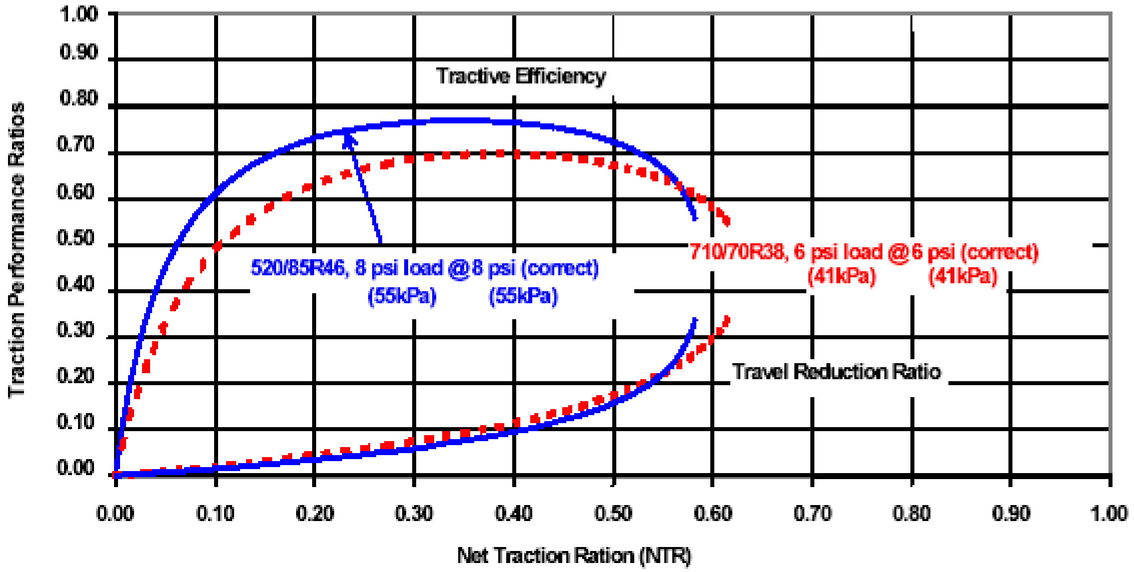


Figure 29. Performance of two sizes of single tires at correct inflation pressures in tilled (loose) tractive conditions.

F.M. Zoz and R.D. Grisso, Traction and Tractor Performance: ASAE Distinguished Lecture # 27,
Agricultural Equipment Technology Conference, 9-11 February 2003, Louisville, Kentucky USA. ASAE Publication Number 913C0403

Traction Performance

- Tire Load
  ⇒ Max TE at equal Net traction ratio

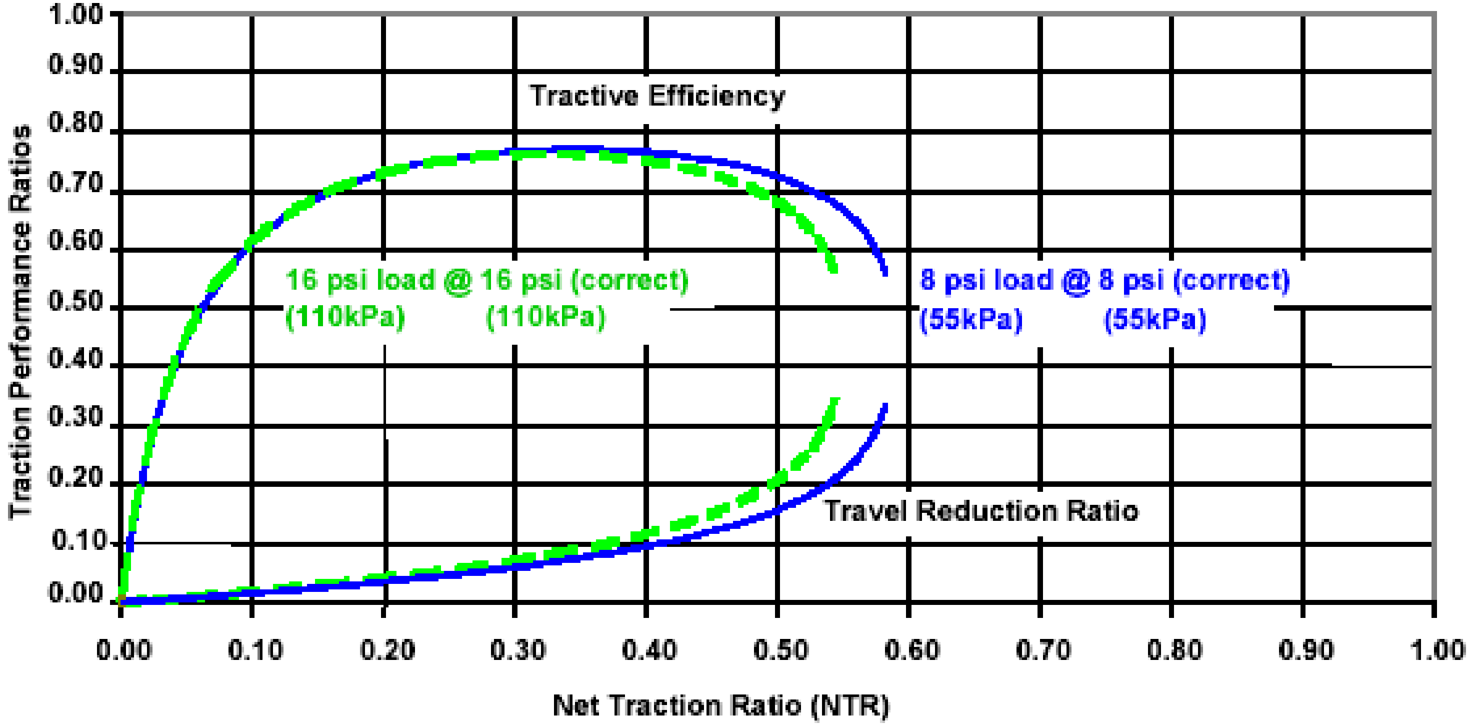


Figure 30. Performance of single tire (Goodyear 520/85R46 DTR) at two weights with correct pressures in tilled (loose) tractive conditions.

F.M. Zoz and R.D. Grisso, Traction and Tractor Performance: ASAE Distinguished Lecture # 27,
Agricultural Equipment Technology Conference, 9-11 February 2003, Louisville, Kentucky USA. ASAE Publication Number 913C0403

Traction Performance

- Belt vs Tire
  - ⇒ Hard conditions little difference, Soft conditions Belts have higher TE
  - ⇒ Wider Belts higher max NTR

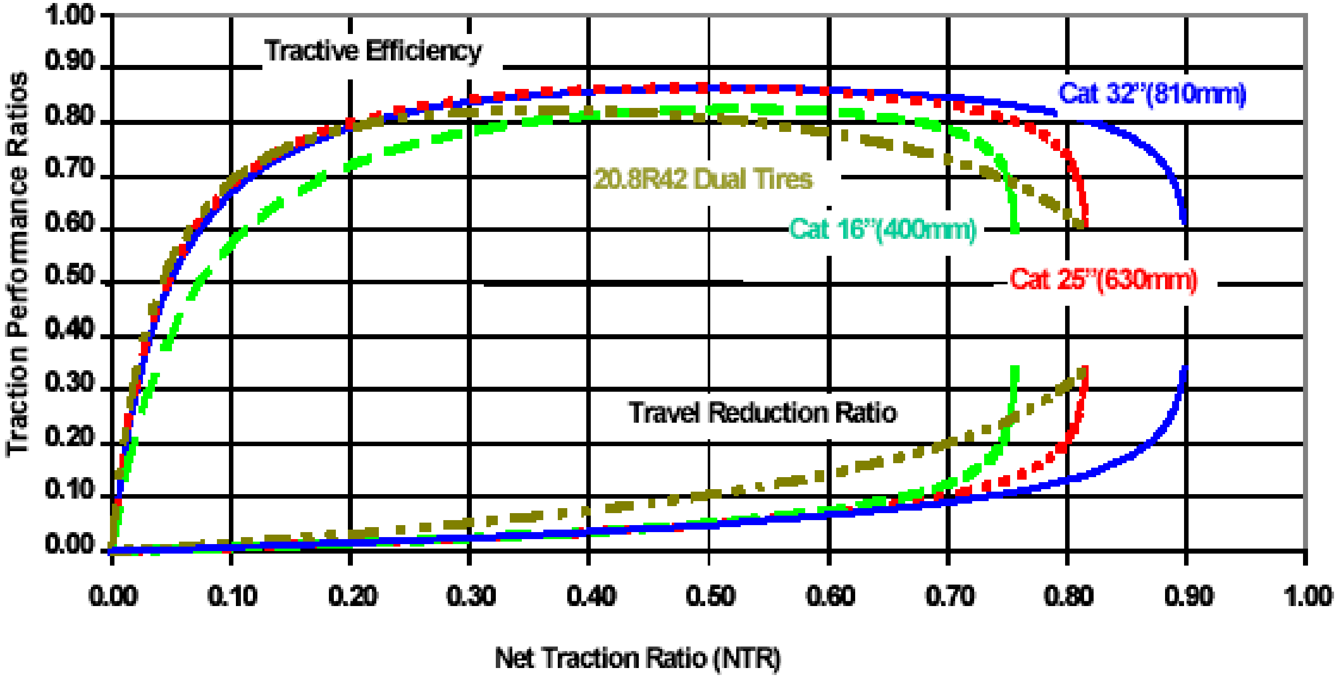


Figure 31. Belt width comparison on firm untilled soil (belted tractor total weight = 12700 kg; wheel tractor axle weight = 8303 kg).

F.M. Zoz and R.D. Grisso, Traction and Tractor Performance: ASAE Distinguished Lecture # 27,
Agricultural Equipment Technology Conference, 9-11 February 2003, Louisville, Kentucky USA. ASAE Publication Number 913C0403

Traction Performance

- Belt vs Tire
  - ⇒ Hard conditions little difference, Soft conditions Belts have higher TE
  - ⇒ Wider Belts higher max NTR

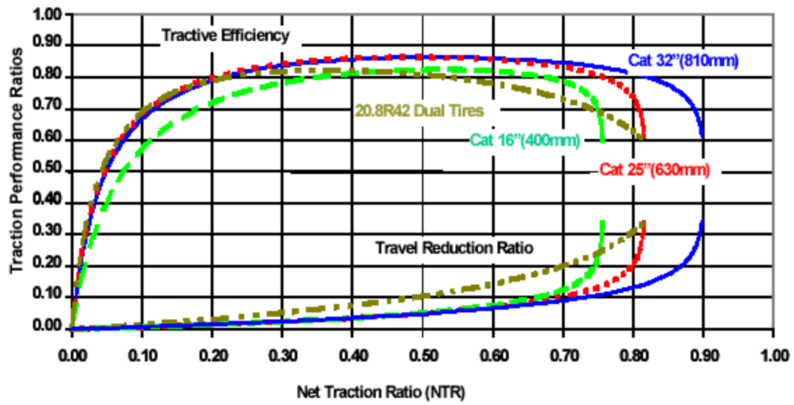


Figure 31. Belt width comparison on firm untilled soil (belted tractor total weight = 12700 kg; wheel tractor axle weight 8303 kg).

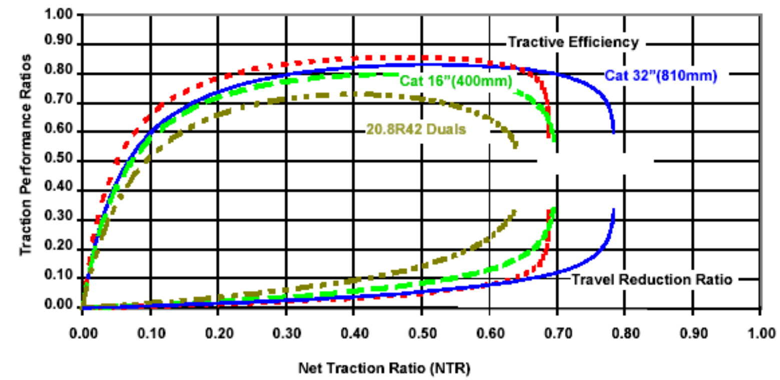


Figure 32. Belt width comparison on tilled soil (belted tractor total weight = 12700 kg; wheel tractor axle weight = 8303 kg).

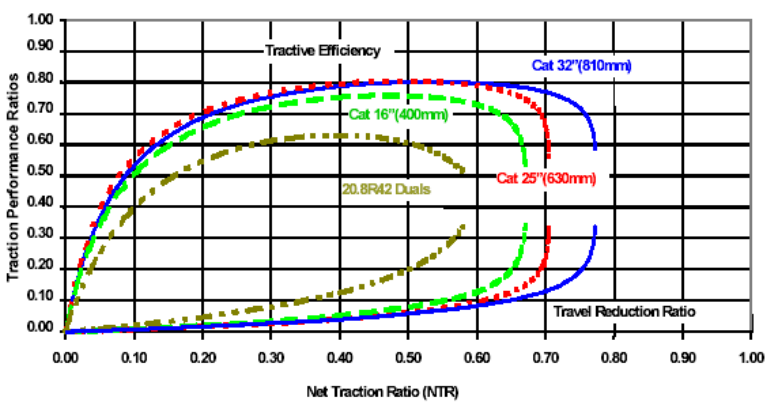


Figure 33. Belt width comparison on subsoiled land (belted tractor total weight = 12700 kg; wheel tractor axle weight = 8303 kg).

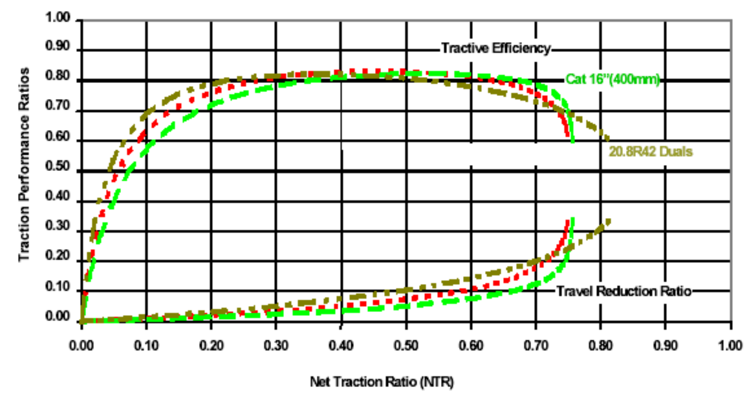


Figure 34. Belt manufacturer comparison on firm untilled soil (belted tractor total weight = 12700 kg; wheel tractor axle weight = 8303 kg).

F.M. Zoz and R.D. Grisso, Traction and Tractor Performance: ASAE Distinguished Lecture # 27,
Agricultural Equipment Technology Conference, 9-11 February 2003, Louisville, Kentucky USA. ASAE Publication Number 913C0403

Traction Performance

- Belt vs Tire
  - ⇒ Hard conditions little difference, Soft conditions Belts have higher TE
  - ⇒ Wider Belts higher max NTR

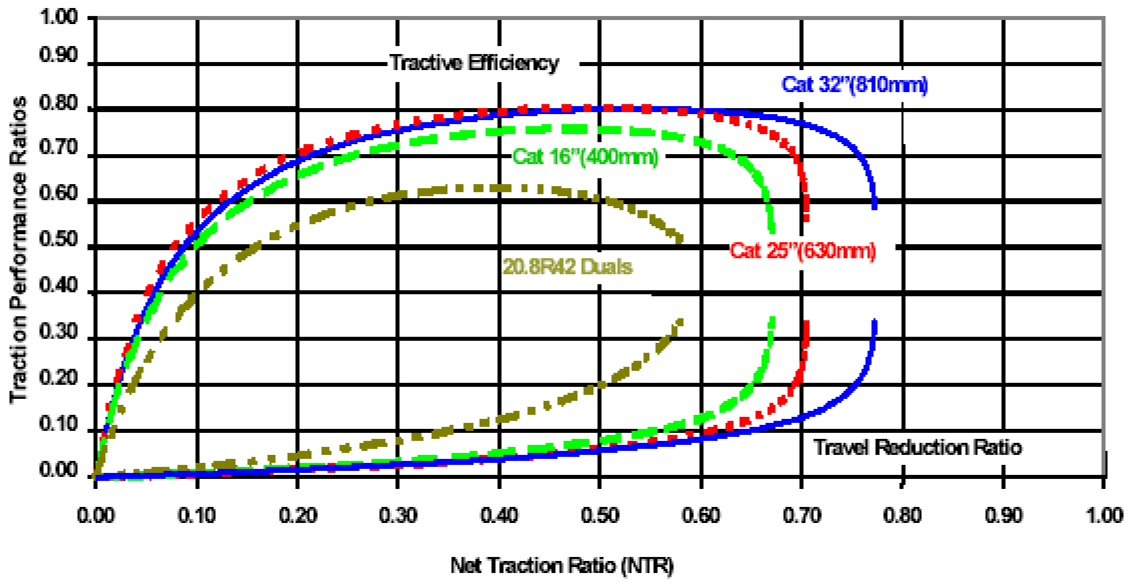


Figure 33. Belt width comparison on subsoiled land (belted tractor total weight = 12700 kg; wheel tractor axle weight = 8303 kg).

F.M. Zoz and R.D. Grisso, Traction and Tractor Performance: ASAE Distinguished Lecture # 27,
Agricultural Equipment Technology Conference, 9-11 February 2003, Louisville, Kentucky USA. ASAE Publication Number 913C0403

Traction Performance

- Belts, Duals, Triples
  - ⇒ Soft Soils, Flotation, Increase in Net Traction, Gross Traction Equal
  - ⇒ Triples no effect

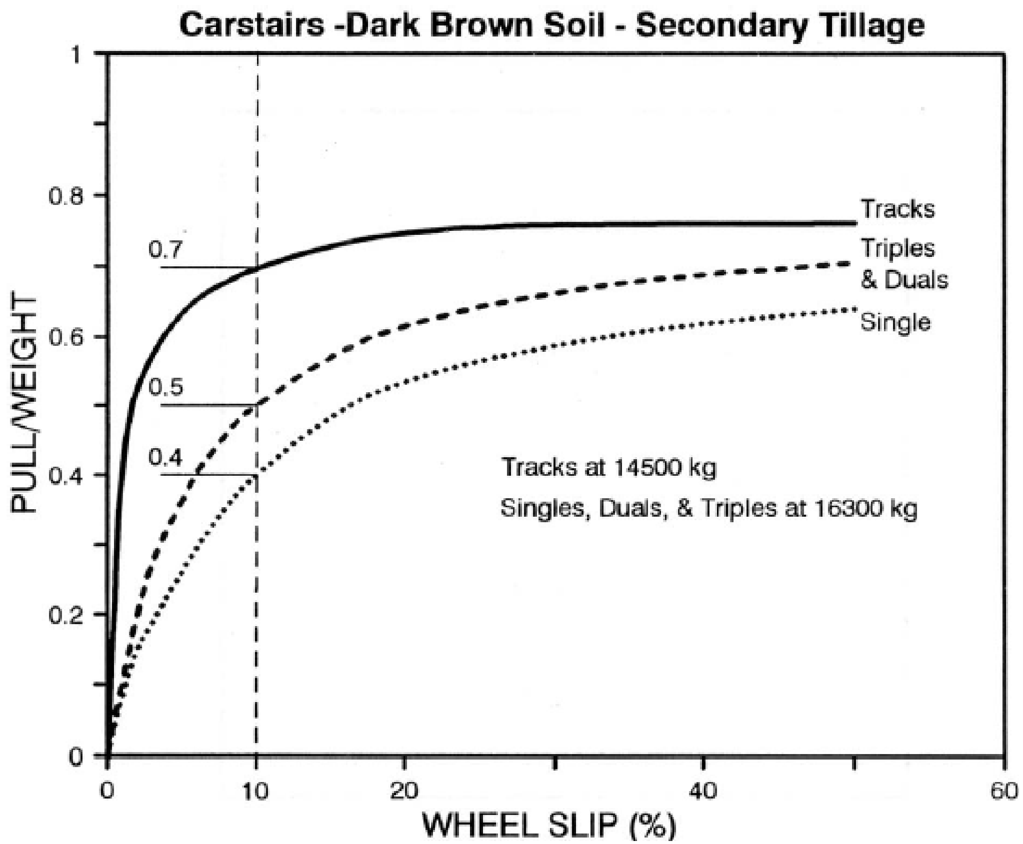


Figure 1. Effect of number of tires on pull at high ballast weight.

Reed J. Turner, 1993. SINGLE, DUAL AND TRIPLE TIRES AND RUBBER BELT TRACKS IN PRAIRIE SOIL CONDITIONS ASAE Publication Number 93-1516

Traction Performance

- Belts, Duals, Triples
  - ⇒ Soft Soils, Flotation, Increase in Net Traction, Gross Traction Equal
  - ⇒ Triples no effect

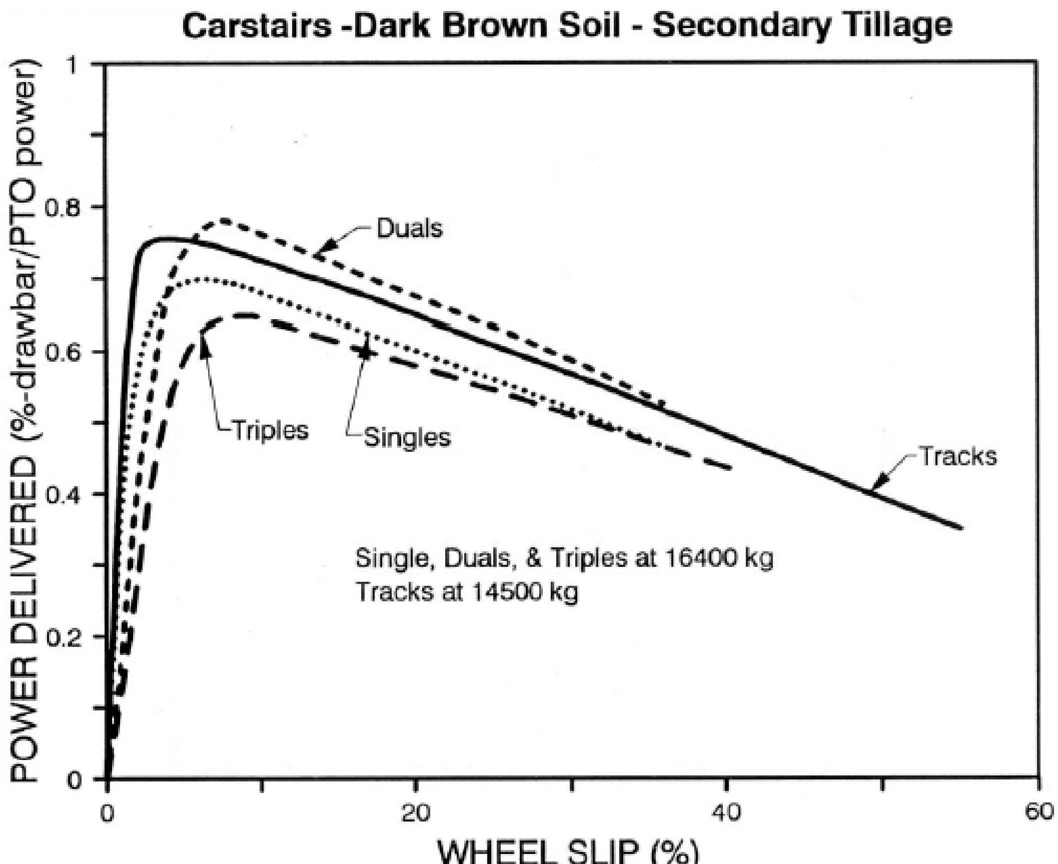


Figure 5. Power Delivery Efficiency at 16,000 kg total tractor weight.

Reed J. Turner, 1993. SINGLE, DUAL AND TRIPLE TIRES AND RUBBER BELT TRACKS IN PRAIRIE SOIL CONDITIONS ASAE Publication Number 93-1516

Traction Performance

- Radial / Bias
  - ⇒ Radial about 10% increase in effeciency

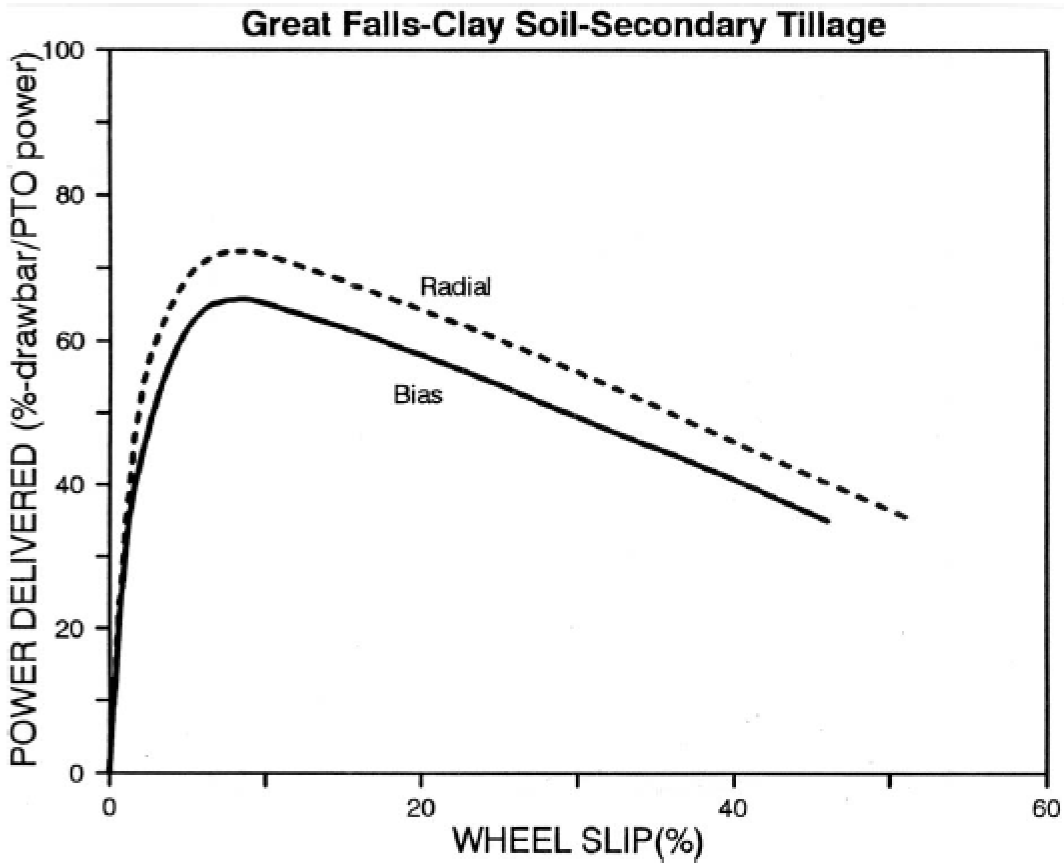


Figure 7. Power Delivery Efficiency for Bias Duals and Radial Duals.

Reed J. Turner, 1993. SINGLE, DUAL AND TRIPLE TIRES AND RUBBER BELT TRACKS IN PRAIRIE SOIL CONDITIONS ASAE Publication Number 93-1516

Traction Performance

- Soil Type
  - ⇒ Max TE at NTR of 0.4
  - ⇒ Max TE at higher slip values for soft soils
- Tire Pressure
  - ⇒ Over inflation slight decrease in TE
- Tire Size
  - ⇒ Larger Dia , higher TE at same slip
  - ⇒ Wider Tire, greater MMR
  - ⇒ Equal maximum pull
- Tire Load
  - ⇒ Max TE at equal Net traction ratio
- Belt vs Tire
  - ⇒ Hard conditions little difference, Soft conditions Belts have higher TE
  - ⇒ Wider Belts higher max NTR
- Belts, Duals, Triples
  - ⇒ Soft Soils, Flotation, Gross Traction Equal, Increase in Net Traction,
  - ⇒ Triples no effect
- Radial vs Bias
  - ⇒ Radial 10% increase in TE at same slip