Predicting Tractive Performance using ZOZ Charts

Example: Determine the Drawbar Pull, Drawbar Power, and Actual Travel Speed for an International 5488 Tractor at maximum drawbar power poperating in 9th Gear , with full tractor ballast, semi-mounted plough in firm soil.

Preliminary Calc

Before you can use the ZOZ, chart you need to determine the static rear axle force, no-load speed, and axle power available.

We will use the Nebraska Test #1441 to estimated these values for the drawbar tests on concrete.
Preliminary Data, form Nebraska Test

SRAF = 7035 kg, (15510 lb)
Drawbar Power = 122.91 kW, (164.82 Hp)
Speed = 8.48 km/h, (5.27 mph)
Slip % = 3.52

Calc zero slip speed

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

$\Rightarrow \quad S_o = S_a / (1 - TR/100)$

$= 8.48/(1-3.52/100)$

$= 8.79$ km/hr

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

$= 5.27/(1-3.52/100)$

$= 5.46$ mph

This no-load speed does not change, provide all calculations are in 9th gear, maximum power

Finding the Axle Power for Tractor in 9th Gear

From Chart Read tractive efficiency (TE) to determine the axle power.

At 3.52 % Slip

Project line from 3.52% slip to left until hit the curve for concrete, the project up to the TE (Drawbar Power/Axle Power) axis and read TE (Yellow Line)

$\Rightarrow$ TE = 0.908

Determine Axle Power

$TE = P_{db} / P_a$

$\Rightarrow \quad P_a = P_{db} / TE$

$= 122.91 / 0.908$

$= 135.4$ kW

$TE = P_{db} / P_a$

$\Rightarrow \quad P_a = P_{db} / TE$

$= 164.82 / 0.908$

$= 181.5$ Hp

The maximum axle power and no load speed will be constant for any calculations for this tractor in 9th gear, and any amount of tractor ballast (SRAF), slip or travel reduction, soil conditions or tillage tool.

Using the ZOZ chart to determin Drawbar Pull etc.

Need to know the no-load speed & the ratio of SRAF/axle power
From preliminary calculations

No-load Speed	8.79 km/h,	(5.46 mph)
SRAF	7035 kg,	(15510 lb)
Axle Power	135.4 kW,	(181.5 Hp)

Calculate SRAF/axle power

$SRAF/P_a = SRAF\ (N) / P_a\ (kW)$
$= (7035*9.81) / 135.4$
$= 68{,}943 / 135.4$
$= 509\ N/kW$

$SRAF/P_a = SRAF\ (lb) / P_a\ (Hp)$
$= 15{,}510 / 181.5$
$= 85.5\ lb/Hp$

Now ready to use the ZOZ chart starting at bottom with no-load speed

Start with S_o at Bottom left axis (5.46 mph) projecting a horizontal line to right (Red Line)
⇨ At the correct SRAF/Axle Power ratio in this case 85 lb/Hp show as blue line,
Project a vertical line up the upper right plot to intersect the correct soil/tillage tool combination
⇨ To firm soil, semi-mount curve
Project to left a horizontal line to the correct soil type on the upper left plot in this case firm soil.

From this line

The slip can be read directly off the left hand axis of the right upper plot
⇨ Slip 16%
To determine the Drawbar Pull project a line (red dashed line) down from the relevant family of soil/tillage tool (firm soil / semi mounted) curves to determine ration drawbar pull/SRAF
⇨ drawbar pull/rear axle force = 0.65
To determine the Drawbar Power project a line (red line) up from the relevant soil type curve (firm soil) to detemine drawbar power/rear axle power (TE) from the upper axis
⇨ Tractive Efficiency (0.725)

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

$S_a = S_o * (1 - TR/100)$
$= 8.79 * (1 - 16/100)$
$= 7.4\ km/h$

$S_a = S_o * (1 - TR/100)$
$= 5.46 * (1 - 16/100)$
$= 4.6\ mph$

Calculate Drawbar Power $P_{db} = P_a * TE$

$P_{db} = P_a * TE$
$= 135.4 * 0.725$
$= 98\ kW$

$P_{db} = P_a * TE$
$= 181.5 * 0.725$
$= 132\ Hp$

Calculate Drawbar Pull $F_{db} = SRAF * drawbar\ pull/rear\ axle\ force$

$F_{db} = SRAF * 0.65$
$= 68{,}943 * 0.65$
$=44.8\ kN$

$F_{db} = SRAF * 0.65$
$= 15{,}510 * 0.65$
$= 10081\ lb.f$

Check the above calculations: Note Power = Force * Velocity

Drawbar Force =	44.8 kN,	10081 lb.f
Velocity =	7.4 km/h	4.6 mph

Drawbar Power = 44.8 (kN) * 7400 (m/h) / 3600 (s/h)
= 92 kW (This is similar to that found above, error due to slight misreading of chart & small imperfections in relevant chart curves)

Drawbar Power = 10081(lb) * 4.6(mph) * 5280(ft/mile) / [60 (min/h) * 33000({ft.lb/min}/Hp)]
= 124 Hp (This is similar to that found above, error due to slight misreading of chart & small imperfections in relevant chart curves)

Determining Ballast

Example: For the same tractor as in the last example, how much is required for the tector to operate with 20% slip on soft soil in 9th Gear

From Preliminary Calculation in the last example we know

zero slip speed= 8.79 km/hr, 5.46 mph
Axle Power= 135.4 kW, 181.5 Hp

Require 20% Slip Using ZOZ Chart

Starting at the left axis of the top right plot
Start at 20% slip and project a horizontal line (green line) to the correct soil/tillage (soft soil /semi-mounted) tool curve.
Project a line down from this point in to lower right plot.

Now Start at left axis of of lower right plot with no load speed
Start with S_o (5.46 mph) projecting a horizontal line to right (Dotted green line) until intersect with line above, to determine the required SRAF/axle power ratio
Estimate the required ratio from sloping lines
⇨ Required SRAF/axle power ratio 860 N/Kw (metric)
⇨ Required SRAF/axle power ratio 140 lb/Hp

Calculate Required SRAF (Know axle power from above)

Requird SRAF = Axle Power * Ratio
= 135.4(kW)*860(N/kW)
= 135.4(kW)*860(N/kW)
= 116444(N)
= 116444(N)/9.8(N/kg)
= 11,882 kg

Required SRAF = Axle Power * Ratio
= 181.5(Hp)*140(lb/Hp)
= 181.5(Hp)*140(lb/Hp)
= 25,410 lb

Unballasted Weight (From Nebraska Tests) 5935 kg, 13085 lb

Calculate Ballast Required

Ballast required = 11882 - 5935
= 5947 kg

Ballast required= 25,410 - 13085
= 12,325 lb

TABLE 16.2 Nebraska tractor test 1441—International 5488 diesel, 18 speed

POWER TAKE OFF PERFORMANCE

Power Hp (kW)	Crank shaft speed rpm	Fuel Consumption gal/hr (l/h)	lb/hp.hr (kg/kW.h)	Hp.hr/gal (kW.h/l)	Temperature °F (°C) Cooling medium	Air wet bulb	Air dry bulb	Barometer inch Hg (kPa)
MAXIMUM POWER AND FUEL CONSUMPTION								
Rated Engine Speed—Two Hours (PTO Speed—1005 rpm)								
187.22 (139.61)	2400	11.555 (43.740)	0.430 (0.262)	16.20 (3.192)	190 (87.7)	61 (15.9)	75 (23.9)	28.873 (97.501)
VARYING POWER AND FUEL CONSUMPTION—Two Hours								
165.46 (123.38)	2496	10.665 (40.371)	0.449 (0.273)	15.51 (3.056)	186 (85.6)	61 (16.1)	76 (24.4)	....
0.00 (0.00)	2614	3.446 (13.045)	....	....	176 (80.0)	60 (15.6)	74 (23.3)	....
84.88 (63.30)	2556	6.935 (26.252)	0.570 (0.347)	12.24 (2.411)	180 (82.2)	60 (15.6)	74 (23.3)	....
186.88 (139.36)	2400	11.517 (43.597)	0.430 (0.261)	16.23 (3.197)	189 (87.2)	60 (15.8)	75 (23.9)	....
42.84 (31.95)	2590	5.184 (19.624)	0.844 (0.513)	8.26 (1.628)	177 (80.6)	60 (15.6)	74 (23.6)	....
125.58 (93.64)	2524	8.841 (33.467)	0.491 (0.299)	14.20 (2.798)	183 (83.9)	61 (16.1)	75 (23.9)	....
Av 100.94 *Av (75.27)*	**2530**	**7.765** *(29.394)*	**0.536** *(0.326)*	**13.00** *(2.561)*	**182** *(83.2)*	**60** *(15.8)*	**75** *(23.8)*	**28.897** *(97.580)*

DRAWBAR PERFORMANCE

Power Hp (kW)	Drawbar pull lbs (kN)	Speed mph (km/h)	Crank-shaft speed rpm	Slip %	Fuel Consumption gal/hr (l/h)	lb/hp.hr (kg/kW.h)	Hp.hr/gal (kW.h/l)	Temp. °F (°C) Cool-ing med	Air wet bulb	Air dry bulb	Barom. inch Hg (kPa)
Maximum Available Power—Two Hours 9th (M3) Gear											
163.44 (121.88)	11642 (51.78)	5.26 (8.47)	2399	3.69	11.545 (43.701)	0.493 (0.300)	14.16 (2.789)	187 (85.8)	55 (12.5)	67 (19.2)	28.915 (97.642)
75% of Pull at Maximum Power—Ten Hours 9th (M3) Gear											
130.87 (97.59)	8798 (39.14)	5.58 (8.98)	2512	2.57	9.949 (37.661)	0.530 (0.322)	13.15 (2.591)	182 (83.4)	56 (13.6)	66 (18.8)	28.951 (97.763)
50% of Pull at Maximum Power—Two Hours 9th (M3) Gear											
89.26 (66.56)	5866 (26.09)	5.71 (9.18)	2549	1.76	7.959 (30.129)	0.622 (0.378)	11.21 (2.209)	179 (81.7)	57 (13.9)	60 (15.6)	28.945 (97.743)
50% of Pull at Reduced Engine Speed—Two Hours 13th (H1) Gear											
89.32 (66.60)	5866 (26.09)	5.71 (9.19)	1530	1.58	6.023 (22.800)	0.470 (0.286)	14.83 (2.921)	181 (82.8)	59 (15.0)	64 (17.8)	28.895 (97.574)
MAXIMUM POWER IN SELECTED GEARS											
154.52 (115.23)	18646 (82.94)	3.11 (5.00)	2400	8.93	6th (L6) Gear			181 (82.5)	56 (13.3)	58 (14.4)	28.940 (97.726)
162.73 (121.35)	16001 (71.18)	3.81 (6.14)	2400	6.06	7th (M1) Gear			185 (85.0)	52 (11.1)	63 (17.2)	28.940 (97.726)
164.58 (122.73)	13536 (60.21)	4.56 (7.34)	2400	4.35	8th (M2) Gear			186 (85.3)	52 (11.1)	62 (16.7)	28.940 (97.726)
164.82 (122.91)	11731 (52.18)	5.27 (8.48)	2398	3.52	9th (M3) Gear			186 (85.6)	53 (11.7)	60 (15.6)	28.970 (97.827)
164.43 (122.61)	9879 (43.94)	6.24 (10.04)	2401	2.92	10th (M4) Gear			186 (85.6)	52 (11.1)	63 (17.2)	28.940 (97.726)
162.54 (121.21)	8373 (37.24)	7.28 (11.72)	2400	2.41	11th (M5) Gear			188 (86.4)	52 (11.1)	64 (17.8)	28.940 (97.726)
160.12 (119.40)	6987 (31.08)	8.59 (13.83)	2400	1.80	12th (M6) Gear			187 (86.1)	52 (11.1)	64 (17.8)	28.940 (97.726)

LUGGING ABILITY IN 9th (M3) GEAR

Crankshaft Speed rpm	2398	2162	1919	1682	1441	1204
Pull—lbs (kN)	11731 (52.18)	13489 (60.00)	14928 (66.40)	15838 (70.45)	15477 (68.85)	13385 (59.54)
Increase in Pull %	0	15	27	35	32	14
Power—Hp (kW)	164.82 (122.91)	169.56 (126.44)	165.14 (123.14)	152.46 (113.69)	127.90 (95.37)	93.55 (69.76)
Speed—Mph (km/h)	5.27 (8.48)	4.71 (7.59)	4.15 (6.68)	3.61 (5.81)	3.10 (4.99)	2.62 (4.22)
Slip %	3.52	4.35	5.18	5.66	5.50	4.52

Department of Agricultural Engineering

Dates of Test: May 26 to June 8, 1982

Manufacturer: INTERNATIONAL HARVESTER COMPANY, 401 North Michigan Avenue, Chicago, IL 60611

FUEL, OIL AND TIME: Fuel No. 2 Diesel **Cetane No.** 46.6 (rating taken from oil company's inspection data) **Specific gravity converted to 60°/60° *(15°/15°)*** 0.8375 **Fuel weight** 6.973 lbs/gal *(0.836 kg/l)* **Oil SAE** 30 **API service classification** CD/SE **To motor** 4.032 gal *(15.262 l)* **Drained from motor** 3.722 gal *(14.088 l)* **Transmission and final drive lubricant** I.H. Hy-tran fluid **Total time engine was operated** 38.5 hours.

ENGINE: Make International Diesel **Type** six cylinder vertical with turbocharger and intercooler **Serial No.** 467BT2U169510* **Crankshaft** lengthwise **Rated rpm** 2400 **Bore and stroke** 4.30" × 5.35" *(109.2 mm × 135.9 mm)* **Compression ratio** 16.3 to 1 **Displacement** 466 cu in *(7636 ml)* **Starting system** 12 volt **Lubrication** pressure **Air cleaner** two paper elements with aspirator **Oil filter** two full flow cartridges **Oil cooler** engine coolant heat exchanger for crankcase oil, radiator for hydraulic and transmission oil **Fuel filter** two paper cartridges **Muffler** underhood **Exhaust** vertical **Cooling medium temperature control** one thermostat.

CHASSIS: Type standard with duals **Serial No.** 2590002U001019* **Tread width** rear 64" *(1625 mm)* to 130" *(3302 mm)* front 62.5" *(1588 mm)* to 86.5" *(2197 mm)* **Wheel base** 111.6" *(2835 mm)* **Center of gravity** (without operator or ballast, with minimum tread, with fuel tank filled and tractor serviced for operation) Horizontal distance forward from center-line of rear wheels 26.9" *(683 mm)* Vertical distance above roadway 38.9" *(988 mm)* Horizontal distance from center of rear wheel tread 0" *(0 mm)* to the right/left **Hydraulic control system** direct engine drive **Transmission** selective gear fixed ratio with partial (2) range operator controlled powershift **Advertised speeds mph *(km/h)*** first 1.5 *(2.4)* second 1.8 *(2.8)* third 2.0 *(3.2)* fourth 2.4 *(3.8)* fifth 2.7 *(4.4)* sixth 3.2 *(5.2)* seventh 3.8 *(6.1)* eighth 4.5 *(7.2)* ninth 5.1 *(8.3)* tenth 6.0 *(9.7)* eleventh 7.0 *(11.3)* twelfth 8.2 *(13.3)* thirteenth 8.6 *(13.8)* fourteenth 10.1 *(16.2)* fifteenth 11.5 *(18.5)* sixteenth 13.6 *(21.8)* seventeenth 15.7 *(25.3)* eighteenth 18.5 *(29.7)* reverse 2.9 *(4.6)*, 3.4 *(5.4)*, 3.9 *(6.2)*, 4.5 *(7.3)*, 5.3 *(8.5)*, 6.2 *(9.9)* **Clutch** wet multiple disc operated by foot pedal with hydraulic power assist **Brakes** wet multiple disc hydraulically power actuated and operated by two foot pedals which can be locked together **Steering** hydrostatic **Turning radius** (on concrete surface with brake applied) right 151.1" *(3.84 m)* left 151.1" *(3.84 m)* (on concrete surface without brake) right 199.5" *(5.07 m)* left 199.5" *(5.07 m)* **Turning space diameter** (on concrete surface with brake applied) right 316" *(8.03 m)* left 316" *(8.03 m)* (on concrete surface without brake) right 412" *(10.47 m)* left 412" *(10.47 m)* **Power take-off** 1005 rpm at 2400 engine rpm.

TABLE 16.2 Continued

TRACTOR SOUND LEVEL WITH CAB	dB(A)
Maximum Available Power—Two Hours	78.0
75% of Pull at Maximum Power—Ten Hours	78.5
50% of Pull at Maximum Power—Two Hours	77.0
50% of Pull at Reduced Engine Speed—Two Hours	73.0
Bystander in 17th (H5) gear	86.5

TIRES, BALLAST AND WEIGHT		With Ballast	Without Ballast
Rear Tires	—No., size, ply & psi *(kPa)*	Inner Two 20.8R38; 10; 12 *(85)* Outer Two 20.8R38; 8; 12 *(85)*	Inner Two 20.8R38; 10; 12 *(85)* Outer Two 20.8R38; 8; 12 *(85)*
Ballast	—Liquid (each inner)	995 lb *(452 kg)*	None
	—Test Equip. (each)	109 lb *(49 kg)*	None
Front Tires	—No., size, ply & psi *(kPa)*	Two 14L-16.1; 6; 28 *(195)*	Two 14L-16.1; 6; 28 *(195)*
Ballast	—Test Equip (each)	130 lb *(59 kg)*	None
	—Cast Iron (each)	40 lb *(18 kg)*	None
Height of Drawbar		21.5 in *(545 mm)*	21.5 in *(545 mm)*
Static Weight with Operator	—Rear	15510 lb *(7035 kg)*	13085 lb *(5935 kg)*
	—Front	4495 lb *(2039 kg)*	4155 lb *(1885 kg)*
	—Total	20005 lb *(9074 kg)*	17240 lb *(7820 kg)*

REPAIRS and ADJUSTMENTS: No repairs or adjustments.

REMARKS: All test results were determined from observed data obtained in accordance with SAE and ASAE test codes or official Nebraska test procedure. For the maximum power tests, the fuel temperature at the injection pump was maintained at 128°F *(53.3°C)*. Seven gears were chosen between stability limit and 10 mph *(16.1 km/h)*.

We, the undersigned, certify that this is a true and correct report of official Tractor Test **1441.**

LOUIS I. LEVITICUS
Engineer-in-Charge

K. VON BARGEN
W. E. SPLINTER
L. L. BASHFORD
Board of Tractor Test Engineers

Source: Reprinted from University of Nebraska Tractor Test Laboratory, Report 1441.

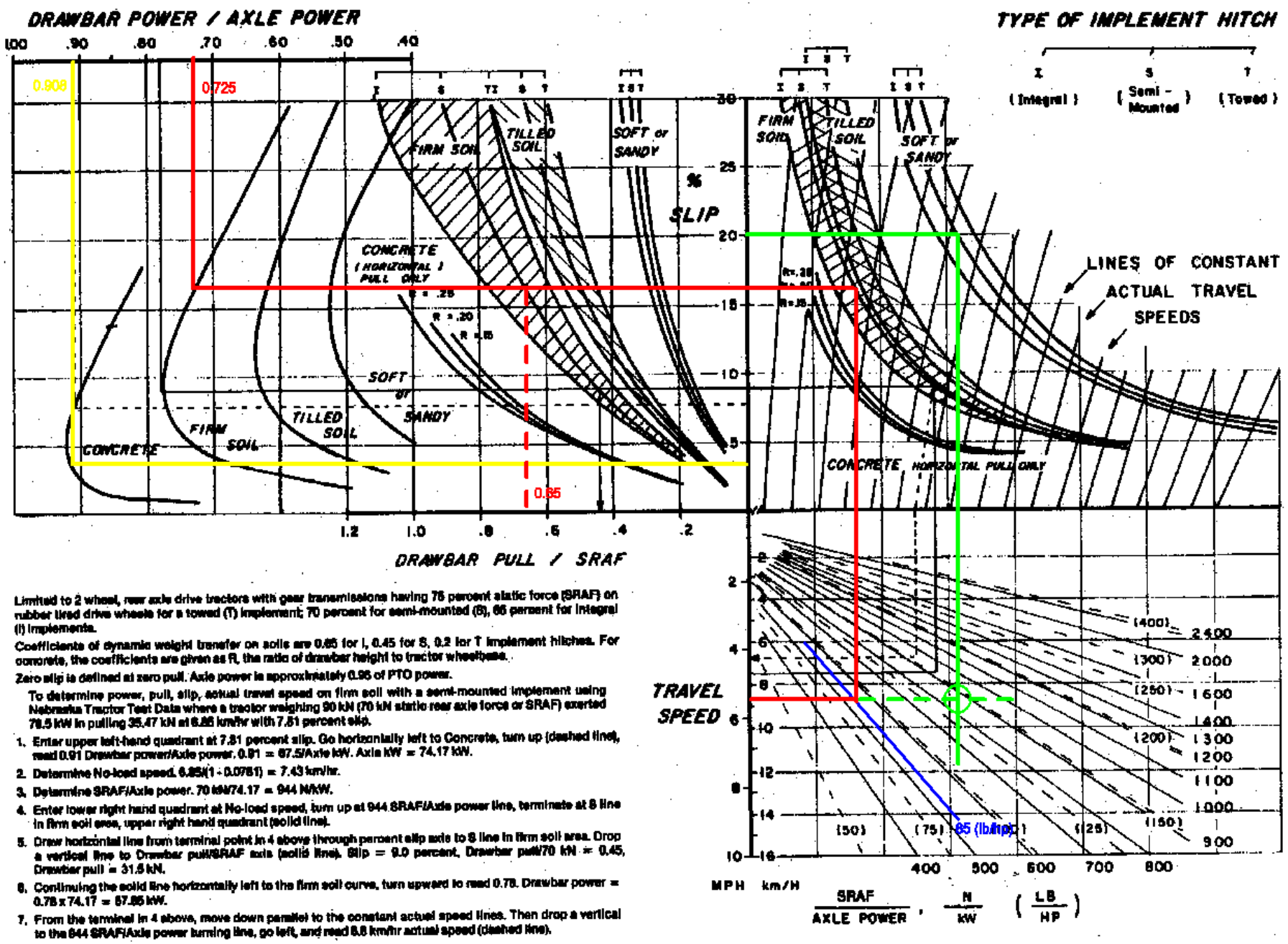

FIGURE 16.9 Traction prediction chart (Reprinted from ASAE Data D230.4, *Agricultural machinery management*, revised December 1983)