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Field tractive performance comparisons between a tractor operated in the 2WD and 4WD mode

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تقييم و مقارنة أوصاف جرار يعمل بعجلتين أو بأربع عجلات محركة

أجريت في هذا البحث تجارب لتقييم و مقارنة أوصاف جرار يعمل بعجلتين أو بأربع عجلات محركة. المعطيات التجارية التجريبية التي حصل عليها من جدب عمود الجر و الربط تمت فوق خمسة أنواع من التربة. بعد ، قمنا بمقارنة الأوصاف المحصل عليها و ذلك تبعا للتزحلق، للعادل الديناميكي للجر و لعلة الجر. بينت التجارب أن أوصاف الجرار تنقص تبعا لكثرة حرث الأرض و أن أفضلها يحصل عليه لما يعمل الجرار بأربع عجلات عوض عجلتين.

الكلمات المفتاحية : الجرار - التزحلق - العادل الديناميكي - لعلة الجر.

Performance en traction d'un tracteur opérant en 2RM et 4RM

Des essais ont été menés pour évaluer et comparer les performances d'un tracteur en mode opératoire 2 et 4 roues motrices. Les données expérimentales ont été obtenues à partir d'essais de traction sur cinq types de surface. Les performances obtenues ont été comparées en se basant sur les relations caractérisées par le glissement, le coefficient dynamique à la traction et l'efficience à la traction. les résultats ont montré que plus le sol est labouré, plus les performances en traction du tracteur sont réduites. De même, de meilleures performances sont obtenues quand le tracteur est utilisé en mode opératoire 4RM par comparaison au 2RM.

Mots clés: Tracteur - Traction - Efficience du tracteur - Glissement

Field tractive performance comparisons between a tractor operated in the 2WD and 4WD mode

Field tests were conducted to evaluate and compare the tractive performance of a tractor when operated in the two-and four-wheel drive mode. Traction data were obtained form drawbar tests on five different soil surfaces. Tractive performance evaluation were made by comparing the relationships of slip, dynamic traction ratio and tractive efficiency. Results showed the more the soil is disturbed the lowest are the tractive performance. Also, the highest performance was obtained when the tractor was operated in the four-wheel drive mode.

Key words: Tractor - Traction - Tractor efficiency - Slip

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INTRODUCTION

As energy cost increases, its efficient use in agricultural production systems has become a major concern to engineers, farmers and others concerned with agricultural production. Increasing the tractive performance of farm tractors can lead to increased tractor productivity and fuel savings.

Tractive performance of agricultural tractors has been the focus of much research. Osborne (1971) and Dwyer & Pearson (1976) reported that increasing the number of drive wheels by using front-wheel-assist (FWA) or four-wheel-drive (4WD) tractors can improve traction in soft soil.

Ali & Mckeyes (1978) investigated different tire treads. They observed very little improvement in traction with changes in the tire tread. Bashford *et al.*, (1987) compared dual tires to singles for a MFWD tractor. No discernible difference in tractive performance was observed on tilled soil with duals on the rear axle of the tractor.

Dwyer (1984), Plackett (1985) and Upadhyaya & Wulfsohn (1990) summarized different studies aimed at traction prediction and improvement. Most of this research, carried out in Europe and North America, was directed towards agricultural vehicle performance on relatively firm surfaces. The present study, conducted in Morocco, reports field trials data comparing the tractive performance of a tractor when operated in the 2WD and 4WD modes on different soil surfaces. Obviously, for a given MFWD tractor, the operator has a choice of operating in the 2WD or 4WD mode.

The objectives of this research were: (i) to compare the tractive performance of an agricultural tractor when operated in the 2WD and 4WD modes and (ii) to develop equations to describe the tractive performance of the tractor test on different tractive surfaces.

MATERIEL AND METHODS

1. Procedure

A Massey-Ferguson 3080 tractor was instrumented so that drawbar pull, travel speed, engine rpm and transmission output torque could be measured in the field. These variables were measured using respectively a 50 kN load cell, a radar velocity sensor, a magnetic pickup and a wire-less inductive torque meter. A 21-XL campbell Scientific data logger was used to power the sensors and to record their output signals. Specific details of the instrumentation system are given by *Jenane et al.* (1991) and Jenane & Bashford (1991).

The test tractor was equipped with standard pneumatic radial tires. The size of front tires was 14.9-28 and the size of rear tires was 18.4-38. Both sets of tires had R-1 tread. Care was taken to maintain inflation pressures constant during the tests. The static weight distribution was 40 % front and 60 % rear, for a total vertical load of 43.36 kN. The same ballast was used for the 2WD and the 4WD mode.

Field tests were conducted in a cohesive-frictional partially saturated clay soil. Initial soil moisture content and bulk density were respectively 13.4 % and 1.7 gm/cm^3 for the 0-30 cm soil depth layer. The original tractive surface was a barley-stubble field. From this original surface, four more tractive surfaces were prepared including a moldboard plowed, disk plowed, chisel plowed, and offset disked surface. A 100 m distance was laid off on each tractive surface and flags placed to mark the beginning and end of each test run.

Tractive performance was evaluated over a wide range of slip on the five soil surfaces. The test tractor (MF 3080) was loaded with a load tractor. Illustrated in Figure 1 is the test ractor pulling another tractor which was used to provide the varying drawbar loads.

During the test runs, the load tractor was driven at lower speeds than the test tractor. Thus, different drawbar loads were applied on the test tractor and wheel slip varied from minimum to excessive (0-60% slip).

On each tractive surface, the test tractor was operated in the 2WD and the 4WD mode. In each mode, the tractor operator used two different gears (4th and 6th) and ran the engine at full throttle. The differential lock was kept engaged at all times to insure equal travel reduction at each drive wheel.

Data were sampled at a rate of 50 Hz and averaged over half second intervals, resulting on 120 to 180 data sets for each performance parameter depending on the gear used and the time needed to complete a run. About 300 to 450 data points were obtained for each tractor driving mode and soil surface.

Figure 1. The test tractor pulling the load tractor

2. Equation for calculating tractive performance variables

The slip (sl) was expressed as: $sl = 100x(1-\frac{V1}{V2})$ [1]

where:
V_1 = actual speed measured by the radar,
V_2 = theoritical speed determined on a hard surface at zero drawbar load

From the tractor geometry and drawbar pull field data, the tractor wheel dynamic loads were calculated as (Figure 2):

$$W_f = \frac{1}{a}x(bxW_t - cxp) \quad [2]$$

$$W_f = W_f + \frac{1}{a}x(cxp - bxW_t) \quad [3]$$

Where:
Wt = total weight on the tractor
Wr = dynamic load on the rear axle
Wf = dynamic load on the front axle
a = wheel base, 2700 mm
b = distance from rear axle to center of gravity, 1050 mm
c = drawbar height, 980 mm
P = drawbar pull

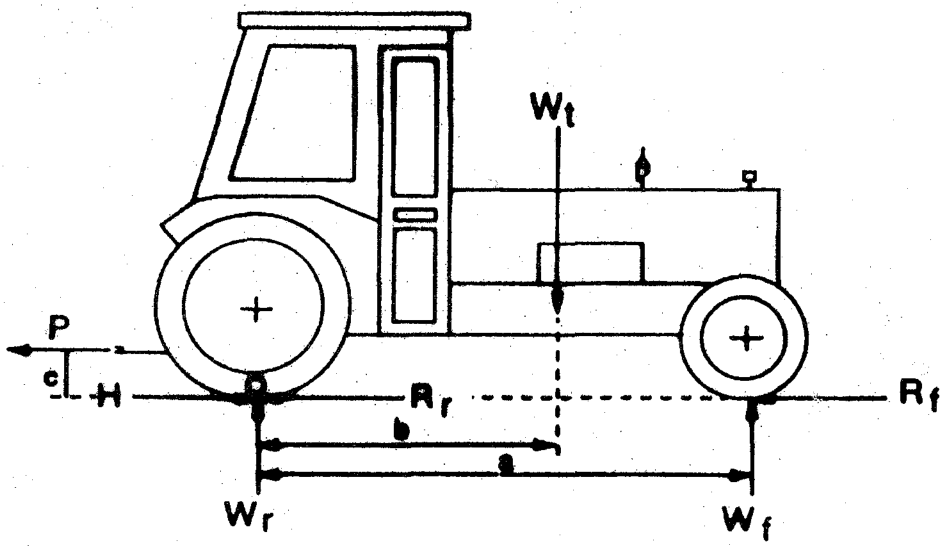


Figure 2. Free body diagram of a tractor and applied forces

The dynamic traction ratio (DTR) was defined as the ratio of the drawbar pull to the dynamic load on the traction devices of the vehicle, which may be written for the 2WD mode as:

$$DTR = \frac{P}{W_r} \quad [4]$$

and for the 4WD mode: $DTR = \frac{P}{W_t}$ [5]

Tractive efficiency (TE) is the drawbar power as a percentage of the power available at the driving axles, which may be expressed as:

$$TE = \frac{\text{Drawbar Power}}{\text{Axle Power}} = \frac{P \times V_1}{T_a \times w_a} \quad [6]$$

Where:
T_a = axle torque
w_a = axle rotational speed
P and V_1 are as before

The equation above may be rewritten as:

$$TE = \frac{P \times v_1}{T_{ot} \times \eta \times \omega_{ot}} \quad [7]$$

where:
T_{ot} = transmission output torque
w_{ot} = transmission shaft output angular velocity.
η = drive gear, differential and planetary transmission efficiency (≈ 98.6 %)

Based on Wismer & Luth (1973) empirical equations for traction, the dynamic traction ratio and the tractive efficiency were respectively predicted from the following expressions (Bashford *et al.*, 1987):

$$\frac{P}{W} \times A \times (1 - e^{E \times sl}) + C \quad [8]$$

$$TE = (1 - sl) \times (1 - \frac{D}{1 - e^{E \times sl}}) \quad [9]$$

where, A, B, C, D and E are soil and tire related constants.

RESULTS AND DISCUSSION

A least-squares curve fitting technique (Gauss-Newton method) for estimating non-linear parameters was used to determine the constant terms of equations [8] and [9]. Coefficient estimates 95% confidence intervals and coefficient of correlation (r^2) for the non-linear regression are given in Tables 1 and 2.

Table 1. Dynamic traction ratio coefficients and 95% confidence intervals for the five tractive surfaces - Equation [8]

Tractive surface	Tractor mode	A Estimate (conf. int.)	B Estimate (conf. int.)	C Estimate (conf. int.)	r^2
Stubble	2WD	1.006 (0.945,1.067)	-4.870 (-5.978,-3.762)	-0.167 (-0.232,-0.103)	0.92
	4WD	1.029 (0.982,1.076)	-6.179 (-7.299,-5.060)	-0.198 (-0.263,-0.134)	0.90
Moldboard plowed	2WD	0.685 (0.627,0.744)	-2.979 (-3.973,-1.985)	-0.055 (-0.110,-0.001)	0.88
	4WD	0.845 (0.789,0.901)	-7.547 (-8.591,-6.503)	-0.265 (-0.335,-0.195)	0.94
Disk plowed	2WD	0.714 (0.671,0.756)	-3.639 (-4.643,-2.635)	-0.095 (-0.158,-0.032)	0.88
	4WD	0.736 (0.701,0.772)	-5.006 (-5.951,-4.061)	-0.121 (-0.168,-0.074)	0.91
Chisel plowed	2WD	0.840 (0.799,0.881)	-4.487 (-5.268,-3.707)	-0.184 (-0.248,-0.119)	0.93
	4WD	0.969 (0.897,1.041)	-8.433 (-9.856,-7.011)	-0.351 (-0.445,-0.257)	0.92
Offset disked	2WD	0.879 (0.835,0.923)	-3.627 (-4.382,-2.872)	-0.136 (-0.189,-0.084)	0.93
	4WD	0.994 (0.906,1.082)	-8.034 (-9.519,-6.549)	-0.377 (-0.492,-0.262)	0.90

Table 2. Tractive efficiency coefficients and 95% confidence intervals for the five tractive surfaces - Equation [9]

Tractive surface	Tractor mode	D Estimate (conf. int.)	E Estimate (conf. int.)	r^2 Estimate (conf. int.)
Stubble	2WD	0.028 (-0.017,0.074)	-1.578 (-4.276,1.119)	
	4WD	-0.201 (-0.258,-0.142)	15.196 (12.670,17.723)	
Moldboard plowed	2WD	0.282 (0.228,0.306)	-6.333 (-7.272,-5.394)	0.52
	4WD	0.138 (0.122,0.155)	-5.191 (-6.023,-4.459)	0.80
Disk plowed	2WD	0.233 (0.206,0.259)	-5.044 (-5.926,-4.161)	0.55
	4WD	0.237 (0.217,0.256)	-10.496 (-12.079,-8.914)	0.42
Chisel plowed	2WD	0.156 (0.137,0.174)	-3.759 (-4.363,-3.155)	0.78
	4WD	-0.044 (-0.098,0.011)	1.335 (-0.222,2.890)	0.65
Offset disked	2WD	0.215 (0.195,0.235)	-6.339 (-7.263,-5.415)	0.53
	4WD	-0.065 (-0.103,-0.027)	1.785 (0.859,2.712)	0.75

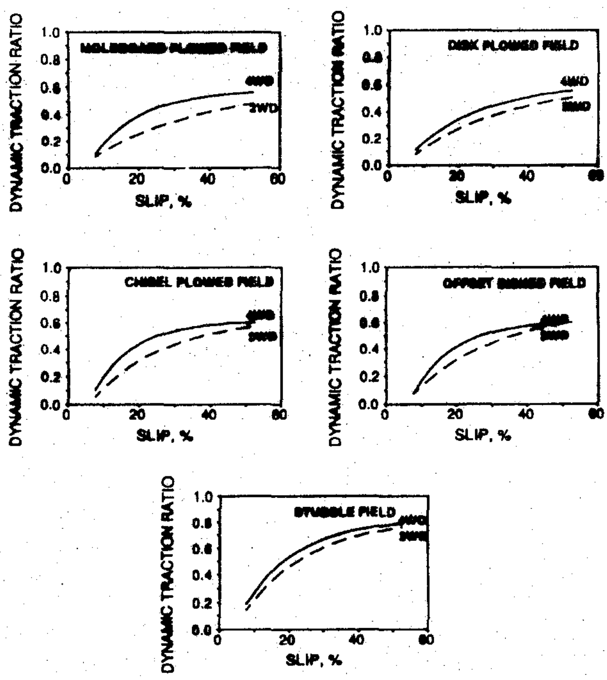
The relationships between the dynamic traction ratio and slip as determined using equation [8] are illustrated in Figure 3. As expected, discernible differences were observed between the two driving modes. In all test the highest dynamic traction ratio occurred when the tractor was operated in the 4WD mode. At 20% slip, the dynamic traction ratios observed for the 4WD mode ranged from 0.39 on a moldboard plowed field to 0.53 on a stubble field. Corresponding figures for the 2WD mode were between 0.25 to 0.46. Thus depending on the soil surface, the resulting increase in the dynamic traction ratio varied between 13 to 36%. Also, the results indicate that the rate of increase of the dynamic traction ratio is highest in more disturbed soil surfaces (moldboard and disk plowed fields) as compared to hard soil surfaces (stubble field).

Comparing the constant terms of equation [8] for the pull/weight ratio developed in 2WD and 4WD modes (Table 1), for the stubble, disk plowed, and offset disked fields, the constant A was within mutually 95% inclusive intervals. The coefficient C was within mutually inclusive intervals for the stubble and disk plowed field. The coefficient B was in general within 95 % exclusive intervals. This result confirm the dynamic traction ratio differences observed between the 2WD and 4WD.

Tractive efficiency data as determined from equation [9] are illustrated in Figure 4. The results indicate that the 4WD developed higher tractive efficiency at less slips than the 2WD on the five tractive surfaces. On tilled soils, and for a slip of 20%, the 2WD mode achieved tractive efficiencies ranging from 0.45 to 0.59. The 4WD mode allowed for the same slip value, tractive efficiencies ranging from 0.60 to 0.70; an increase of 15 to 25%.

The highest tractive performance were observed on the stubble surface (Figures 5 to 8). Also, the tractor performance was better in the chisel plowed and offset disked fields when compared to the moldboard and disk plowed fields. This may be related to the soil shear strength. The moldboard and disk plow inverted the soil, resulting in a more friable state and reducing to a greater extent its shearing strength. Thus, for a given tractor wheel slip, the increase in the dynamic traction ratio is lower in comparison to the chisel plowed or offset disked fields.

Both 2WD and 4WD configurations resulted in similar tractive performance for the chisel plowed and offset disked surfaces. The less disturbance of soil by these implements accounted for the similar results. A higher performance was obtained in the moldboard plowed field when compared to the disk plowed field in the 4WD mode. Opposite results were obtained by using the 2WD mode. No apparent reason may be given for this result.



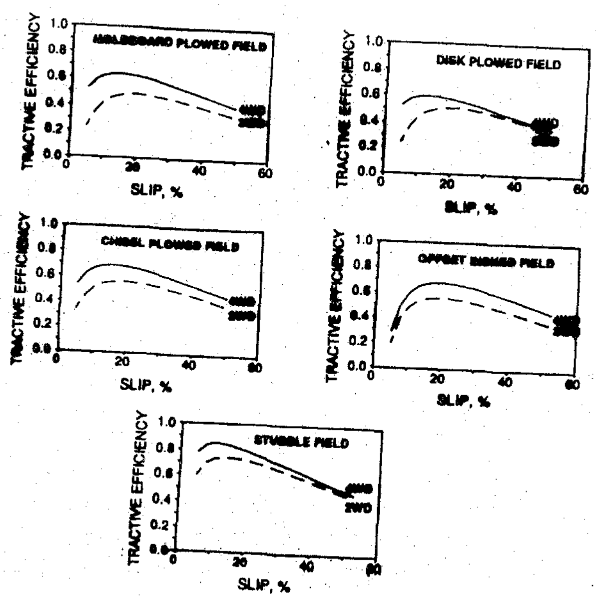


Figure 3. Slip versus dynamic traction ratio comparison for the 2WD and 4WD

Figure 4. Slip versus tractive efficiency comparison for the 2WD and 4WD modes

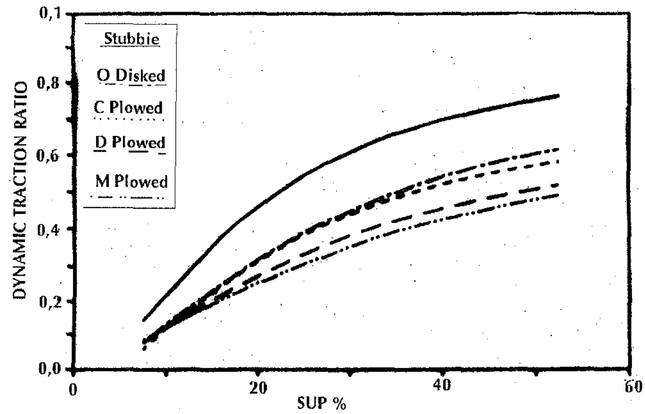


Figure 5. Slip versus dynamic traction ratio on five tractive surfaces in two-wheel drive mode

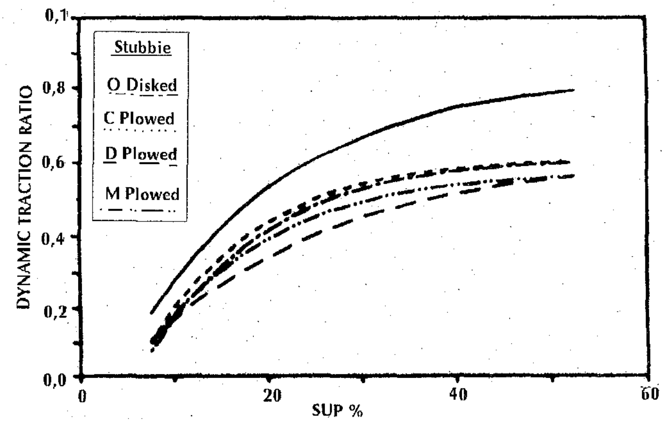


Figure 6. Slip versus dynamic traction ratio on five tractive surfaces in four-wheel drive mode

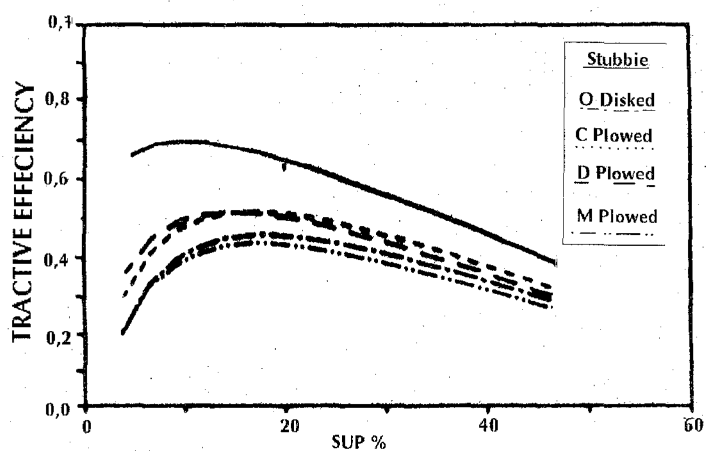


Figure 7. Slip versus tractive efficiency on five tractive surfaces in two-wheel drive mode

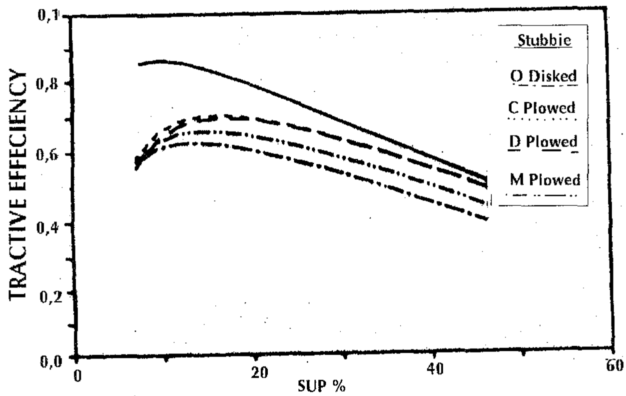


Figure 8. Slip versus tractive efficiency on five tractive surfaces in four-wheel drive mode

CONCLUSIONS

The 4WD mode provided higher tractive performance than the 2WD mode on all the tractive surfaces tested. Depending on the soil surface, an increase of 15 to 25% of tractive efficiency was observed by using the 4WD mode. When comparing the dynamic traction ratio at maximum tractive efficiency, the 4WD has a higher performance than the 2WD. With respect to this performance, it may be concluded that a 4WD will provide a higher draft and a faster speed in comparison to the 2WD. Therefore, it is likely taht the work rate will be increased.

Also, it may be concluded that when operating a MFWD tractor, the tractor should be used with the front-wheel drive engaged while working in the field on any type surface.

However during transport on hard surface roads, the front-wheel drive should be disengaged. Obviuously the tractor cannot be optimally ballast for both 2WD and 4WD operating modes without changing the relative location of the ballast.

The equations developed resulted in a good fit to the measured data. The dynamic traction ratio and tractive efficiency were predicted with reasonable accuracy as demonstrated by their respective coefficient of correlation

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REFERENCES CITED

Osborne L.E. (1971) A field comparison of the performance of two- and four-wheel drive and tracklaying tractors. *Journal of Agricultural Engineering Research* 16(1):46-61

Dwyer M.J. & Pearson G. (1976) A field comparison of the tractive performance of two- and four-wheel drive tractors. *Journal of Agricultural Engineering Research* 21:77-85

Ali O.S. & Mckeyes E. (1978) Traction improvement in lugged tires for farm vehicles. *ASAE Paper*, No. 78-1038

Bashford L.L., Bargen K.V., Way T.R. & L. Xiaoxian (1987) Performance comparisons between duals and singles on the rear axle of a front wheel assist tractor. *Transactions of ASAE* , Vol. 30(3):641-645

Dwyer M.J. (1984) The tractive performance of wheeled vehicles. *Journal of Terramechanics*, Vol 21(1):19-34

Plackett C.W. (1985) A review of force prediction. *Journal of Agricultural Engineering Research*,Vol. 31:1-29

Upadhyaya S.K. & Wulfsoln D. (1990) Review of traction prediction equations. *ASAE Paper* , No. 90-1573

Jenane C., Bashford L.L. & Knetchge H. (1991) A measuring instrumentation system for tillage energy research in Morocco. *Actes Inst. Agron. Vet.* (Maroc), Vol. 11

Jenane C. & Bashford L.L. (1991) Field evaluation of tractive efficiency using a wire-less torque meter. *Journal Applied Engineering in Agriculture*, Vol. 8(2):141-145

Wismer R.D. & Luth H.J. (1973) Off-road traction prediction for wheeled vehicles. *Transactions of the ASAE*, Vol.17:8-10,14