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FIELD TRACTIVE PERFORMANCE OF THREE POPULAR TWO -WHEEL DRIVE TRACTORS IN IRAN

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ABSTRACT

Field tractive performance of the three most commonly used tractors in Iran (Universal 650, Massey Ferguson 285 and John Deere 3140) was compared. Selection of farms and tractors was made according to the stratified random sampling method, in which 30 tractors (10 of each model) were randomly selected. At every site, during mouldboard ploughing, parameters relevant to tractive performance, including drive axle load and power, tire dimensions, deflection and inflation pressure, operating speed, wheel slip and soil cone index of the fields were measured. By using empirical relations, estimates were made of optimum ballasting, drawbar power and ratio of actual to optimum efficiencies at the actual forward speed and at the assumed recommended forward speed of 1.4 m s^{-1} for tractors to operate at optimum conditions. All the tractors tested were under-ballasted and their tires over-inflated and were operating at an average forward speed of 1.17 m s^{-1}. Massey Ferguson tractors had significantly higher wheel slip than the other two types, while other parameters were not significantly different among tractors. The tested tractors were wasting about 57 percent of their available power and the average ratio of actual to optimum tractive efficiencies was estimated to be 0.53. At the assumed operating speed, the average ratio of actual to optimum axle load increased from 0.63 to 0.73, the overall power wastage decreased from 57.3 to 48.1 percent, and the total useable drawbar power improved from 13.55 kW to 16.53 kW, correspondingly.

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KEY WORDS: Drawbar power, Traction, Tractors, Tractive efficiency.

تحقیقات کشاورزی ایران

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ارزیابی عملکرد کششی سه نوع تراکتور دو چرخ محرک متداول در ایران

محمد لغوی و محمد شاکر

به ترتیب دانشیار بخش ماشین های کشاورزی، دانشکده کشاورزی دانشگاه شیراز و پژوهشگر بخش تحقیقات فنی و مهندسی، مرکز تحقیقات کشاورزی فارس، زرقان جمهوری اسلامی ایران،

چکیده

عملکرد کششی سه نوع از متداول ترین تراکتور های مورد استفاده در ایران، (یونیورسال ۶۵۰، مسی فرگوسن ۲۸۵ و جاندیر ۳۱۴۰) مقایسه شد. انتخاب مزارع و تراکتور ها بر طبق روش نمونه گیری طبقه بندی تصادفی انجام گرفت و براین اساس تعداد ۳۰ دستگاه تراکتور (ده دستگاه از هر مدل) بطور تصادفی انتخاب گردید. در هر مزرعه به هنگام شخم با گاو آهن برگرداندار، پارامتر های مرتبط با عملکرد کششی شامل بار وارد بر محور محرک، ابعاد و فشار باد چرخ، سرعت پیشروی، درصد لغزش چرخ های محرک و شاخص مخروطی خاک اندازه گیری شد. با استفاده از روابط تجربی پیشنهاد شده توسط تعدادی از پژوهشگران، تخمینی از سنگین سازی بهینه، توان مالبندی و نسبت بازده کششی واقعی به مطلوب در سرعت پیشروی واقعی و در سرعت فرضی ۱/۴ متر بر ثانیه (توصیه شده برای اجرای عملیات خاک ورزی اولیه در شرایط بهینه) بدست آمد. کلیه تراکتور های مورد آزمایش دارای وزنی کمتر و فشار بادی بیشتر از میزان توصیه شده بودند و در سرعت متوسط ۱/۱۷ متر بر ثانیه کار می کردند. مقایسه میانگین پارامتر های عملکردی نشان داد که تراکتور های مسی فرگوسن دارای لغزش چرخ بزرگتری نسبت به دو نوع دیگر بودند، در حالی که در مورد سایر پارامتر ها تفاوت معنی دار مشاهده نشد. تراکتور های مورد بررسی حدود ۵۷ درصد از توان قابل دسترس را تلف می نمودند و میانگین نسبت بازده کششی واقعی به بهینه در حدود ۰/۵۳ تخمین زده شد. در سرعت پیشروی فرضی، میانگین نسبت بار محوری واقعی به بهینه از ۰/۶۳ به ۰/۷۳، درصد تلفات قدرت از ۵۷/۳ به ۴۸/۱ درصد و توان مالبندی قابل دسترس از ۱۳/۵۵ به ۱۶/۵۳ کیلو وات تغییر یافت.

INTRODUCTION

Tractors have a prime importance and play a crucial role in today's mechanized agriculture. The population of functional tractors in Iran is presently estimated at about 114000. Tillage operations on over 75% of the 14 million hectares of cultivated land in Iran is performed by tractor. The three most popular tractor types are Universal 650, Massey Ferguson 285 and John Deere 3140 with 48.5, 56 and 73 kW rated engine powers, respectively. In many cases, it is observed that in spite of the adequate tractor brake power, its axle power can not be converted to useful drawbar power efficiently. Research results throughout the world show that from 20 to 70% of the energy delivered to the drive wheels of tractors is wasted at the soil-tire interface (3, 10). The resulting soil compaction created by a portion of this energy may be detriment to soil physical conditions and crop production.

In order to optimize the output of a wheel tractor performing a draught operation, there has to be a proper matching of tractor power, weight, speed and draught force or wheel slip (8). Many researchers (2, 4, 5, 11, 13, 14) have tried to develop relationship etween the above - mentioned parameters for optimum performance.

Development of Tractive Performance Equations

Freitag (6) using dimensional analysis, ı ı and wheel parameters affecting the tractive performance of a wheeled tractor are functions of a single dimensionless term M, which he called " mobility number" and defined it as:

$$M = \left(\frac{Cbd}{W}\right)\left(\sqrt{\frac{\delta}{h}}\right) \qquad [1]$$

in which C is soil cone index (kPa), b and d are tire width and diameter (m), respectively, W is dynamic weight on the tire (kN), δ is tire deflection under load on a hard surface (m) and h is tire section height (m). Turnage

(12) suggested a modified mobility number which includes the effect of tire width to diameter ratio as:

$$M = \left(\frac{Cbd}{W}\right)\left(\frac{\sqrt{\frac{\delta}{h}}}{\left(1+\frac{b}{2d}\right)}\right) \quad [2]$$

An empirical prediction of tractor-implement field perfortnance was suggested by Gee-Clough *et al.* (8), using the results of various traction tests in 170 different field conditions in U. K. They described maximum coefficient of traction [$(C_t)_{max}$], a rate constant (k) and coefficient of traction (C_t) in terms of the mobility number (M) as:

$$(C_t)_{max} = 0.796 - \frac{0.92}{M} \quad [3]$$

$$k(C_t)_{max} = 4.838 + 0.061M \quad [4]$$

$$C_t = (C_t)_{max}\left[1 - \exp(-ks)\right] \quad [5]$$

where s is wheel slip (decimal). They recommended average wheel slip of 10% for maximum efficiency.

Dwyer (5) used average values from field tests of tractive performance to derive a curve of the form:

$$\frac{W}{P} = \frac{1.79}{V} \quad [6]$$

This curve which matches dynamic weight W (kN) on the drive tire, drive axle power P (kW) and forward speed V (m s^{-1}) to optimize traction performance, was also verified by Gee-Clough *el al.* (7). They also showed that the following equation existed between the three nondimensional ratios as:

$$\frac{\eta}{\eta_{opt}} = \left(\frac{W}{W_{opt}}\right)\left[\frac{(C_t)}{(C_t)_{opt}}\right] \quad [7]$$

where η and η_{opt} are actual and optimum tractive efficiencies, respectively, W_{opt} is the weight required on the rear axle for optimum performance (kN) and $(C_t)_{opt}$ is coefficient of traction under optimum conditions. Mahmood and

Gee-Clough (10) used the preceding equations and procedure to evaluate the field performance of tractors in Pakistan.

In this study, the field tractive performance of the three most common tractors in Iran were evaluated and compared.

MATERLALS AND METHODS

The study was conducted following wheat harvest at various farms of Zarghan district located about 30 km north east of Shiraz, I.R. Iran. The soil type was ranging from silty clay loam to clay loam with an average moisture content of about 10% dry weight basis in the top 15cm soil layer. Selection of farms and tractors was made according to the stratified random sampling method, by which, among the three most common tractors in the area (Universal 650, John Deere 3140 and Massey Ferguson 285), 30 tractors (10 of each model) were randomly selected. At every site, during mouldboard ploughing, data on several parameters relevant to tractive performance, were collected as follows:

1. Tractor drive (rear) tire width (b), outer diameter (d), section height (h) and tire deflection (δ) on a hard surface.
2. Inflation pressure of the rear tires using a tire pressure gauge. The average value of the pressure readings of the two rear tires was recorded.
3. Rear axle load by using a compression load cell mounted on an alligator jack. The static load on the real axle with the mounted implement (a three-bottom mouldboard plough) raised was measured as an approximation to the dynamic load (10).
4. Tractor forward speed using markers, measuring tape and stop-watch.
5. Drive wheel slip by measuring tractor advance per 10 wheel revolutions with and without drawbar load, according to the Regional Network for Agricultural Machinery (RNAM) test code (1).
6. Tractor axle power "P" in Eq. 6 is the total axle power available (7), which is not necessarily equal to the axle power in the field condition. So, a p.t.o. power test was conducted and the resulting curve of p.t.o power vs. engine speed was plotted. Then by entering the average value of the tractor engine rpm during draft operation in the field test, the

available power was read on the curve and it was converted to axle power by the following relation suggested by Zoz (14).

Axle power= (0.95)*p.t.o.* power [8]

7. Cone penetrometer resistance was measured by using a Bush recording soil penetrometer model SP 1000. The average of 15 penetrometer readings at 1 cm depth increments was considered as the penetration resistance of each insertion. The total average of penetration resistances of five randomly selected points along each test site was divided by the cone base area and was used as the cone index of that site. Then by using mean values of the measured parameters, as given in Table 1 and the empirical relations [2] through [7], the following performance parameters were calculated. The results are listed in Table 2.

Weight on Rear Axle for Optimum Performance (W_{opt})

By replacing tractor actual forward speed (V_{ac}) and axle power (P_{ax}) as V and P, respectively, in Eq.[6], the weight required on the rear axle for optimum performance (W_{opt}) was determined for each tractor.

Tractor Power Loss in Tractive Operation (P_{wst})

By using Eqs. [2] to [5], coefficient of traction (C_t) for each tractor was calculated. The actual tractor drawbar power (P_{db}) in the field was estimated by using the following relations:

$$\text{Pull} = C_t\, W_{ac} \quad [9]$$

$$P_{db} = (\text{Pull})\, V_{ac} \quad [10]$$

Where W_{ac} is actual weight on rear axle (dynamic load) and V_{ac} is actual forward speed of the tractor. Finally, percent of tractive power loss for each test tractor was determined by Eq. [11].

$$P_{wst} = \left[\frac{(P_{ax} - P_{db})}{P_{ax}}\right]100 \quad [11]$$

Tractive Efficiency

The ratio of actual to optimum tractive efficiencies [η/η_{opt}] was calculated using Eq. [7]. The method of calculating the coefficient of traction at optimum condition, $(C_t)_{opt}$ was similar to C_t by using Eqs. [2] to

Table 1. Mean values of some measured parameters relevant to tractive performance of the test tractors.

Tractors type	Rear tire dimensions			Tire						Cone
	Diameter (m)	Width (m)	$\delta/h^{\dagger}$	Inf. pr. (kpa)	$p/p^{\S}_{re}$	V_{ac} (m s^{-1})	Slip (%)	P_{ax} (kW)	W_{ac} (kN)	index (kp_a)
JD¶ 3140	1.53	0.47	0.11	181.66	1.32	1.23	8.7	33.31	35.70	1951
MF 285	1.43	0.47	0.10	118.92	1.44	1.03	15.7	32.34	25.84	2012
U 650	1.47	0.36	0.15	158.91	1.77	1.26	8.7	29.36	28.10	2317
Overall mean	1.48	0.43	0.12	153.16	1.51	1.17	11.0	31.67	29.88	2096

† δ= Tire deflection on hard surface, h=tire section height

§ P= Tire inflation pressure (actual), p_{re}= recommended pressure. P_{re}= 137.6, 82.6 and 89.8 kpa for JD, MF, and U tractors, respectively.

¶ JD= John Deere, U= Universal, MF= Massey Fergusen.

Table 2. Estimated mean values of tractive performance parameters of the test tractors.

Tractor type	Ct	$(C_t)_{opt}$	At actual speed					At 1.4 m s^{-1} speed				
			W_{opt} (kN)	W_{ac}/W_{opt}	P_{db} (kN)	P_{wst} (%)	η/η_{opt}	W_{opt} (kN)	W_{ac}/W_{opt}	P_{db} (kN)	P_{wst} (%)	η/η_{opt}
JD† 3140	0.34	0.42	51.13	0.75	15.23	54.3	0.60	42.59	0.83	16.96	49.6	0.67
MF 285	0.51	0.46	57.95	0.46	13.65	57.8	0.50	41.35	0.62	18.55	42.6	0.68
U 650	0.36	0.45	44.27	0.68	11.78	59.8	0.50	37.54	0.75	14.07	52.1	0.60
Overall mean	0.40	0.44	51.11	0.63	13.55	57.3	0.53	40.50	0.73	16.53	48.1	0.65

† JD= John Deere, U= Universal, MF= Massey Fergusen.

[5], except that here values of 0.2 and 0.1 (10%) were replaced for δ/h and s in Eqs. [2] and [5], respectively.

The significance of performance differences among the three tractor types were investigated using analysis of variance. Duncan's multiple range test (DMRT) was used for mean comparisons.

RESULTS AND DISCUSSION

Analysis of variance for the effect of tractor type on wheel slip, forward speed, tractive power loss and ratio of actual to optimum tractive efficiency as shown in Table 3, indicated that the three types of tractors studied had significantly different wheel slips, while their other performance parameters were not significantly different among tractors. Comparison of mean values of the above-named four parameters using DMRT (Table 4) indicated that Massey Ferguson tractors had significantly higher wheel slip than the other two tractors. The average wheel slip for MF 285 was more than 50% larger than the optimum value (10%).

Table 3. Analysis of variance for tractor wheel slip, forward speed, percent of tractive power loss and ratio of actual to optimum tractive efficiency.

Source	Degree of freedom	Wheel slip	Forward speed	Tractive loss	Actual to optimum tractive efficiency
Tractor type	2	106.94†	0.16^{ns}	68.42^{ns}	0.03^{ns}
Error	27	38.29	0.06	312.58	0.05
Total	29				

† Significant at P<0.05.

ns Not significant.

The drive axle load is the most important factor affecting wheel slip. The higher wheel slip of MF 285 tractors could be attributed to their lowest actual to optimum axle weight ratio compared to the other two brands as given in Table 2.

Table 4. Comparison of mean values of tractor wheel slip, forward speed, percent of tractive power loss and ratio of actual to optimum tractive efficiency.

Tractor type	Wheel slip (%)	Forward speed	Tractive power loss (%)	η/η_{opt} §
JD 3140	8.670b†	1.23 a	54.27a	0.604a
MF 285	15.680a	1.03a	57.78a	0.504a
U 625	8.710b	1.26a	59.86a	0.500a

† Means followed by the same letter within each column are not significantly different at P= 0.05 (DMRT).

§ η/η_{opt}= Ratio of actual to optimum efficiency.

Tire Inflation Pressure

As illustrated in Table 1, the overall average rear tire inflation pressure was about 153 kPa, which is 51% greater than the average recommended pressure for these tractors. The ratio of measured to recommended pressure was highest (1.77) and lowest (1.32) for univeral 650 and John Deere 3140 tractors, respectively. The effect of over-inflation on decreasing tractive performance could be observed in Table 2, as the tractors with the highest over-inflation have correspondingly the highest power wastage (P_{wst}) .

Tractor Forward Speed

The actual average forward speeds at which the tractors were operating in the field are given in Table 1, with an overall average of 1.17 m s^{-1}. The recommended forward speed for mouldboard ploughing ranges from 1.33 to 1.55 ms^{-1} (9) Therefore, there was still room for increasing the tractor forward speed, as this would reduce the weight required on drive axle for the same power output (as indicated by Eq. [6]). Hence an attempt was made to analyze the situation assuming that all the tractors were operating at 1.4 ms^{-1} (average recommended speed for mouldboard ploughing) and keeping all the other parameters unchanged.

At the assumed operating speed, the ratio of actual to optimum axle weight has increased for all tractor types, with an average of 0.63 to 0.73. The overall power wastage in the soil-tire interface has decreased from 57.3 to 48.1 percent. Also, the total average useable drawbar power (P_{db}) has improved from 13.55 kW to 16.53 kW, correspondingly. The reason for P_{db} of MF tractors being slightly greater than those of JD tractors as indicated in Table 2 is that P_{db} is a function of C_t and V_{ac} as given by Eqs [9] and [10]. The same operating speed was assumed for both tractors, but MF tractors had greater C_t as a result of their higher wheel slip due to the fact that they were over-loaded while JD tractors were under-loaded.

Drive Axle Load and Power

The average actual weights on rear axle of JD 3140, MF 285 and U650 tractors were 75, 46 and 68% of the weight required for optimum performance, respectively, with an overall average of 63%. These figures clearly indicate that, on the average, all of the tractors working in the area studied were under-ballasted. This is also quite evident from Fig. 1, in which, all of the points representing the observed values on the test sites are located below the optimum ballasting curve [Eq. 6]. It is clear that in some cases, particularly when the forward speed is too slow, the extra weight required on rear axle for optimum performance is quite large and not practically feasible.

The appropriate total weight required on the rear axle of a tractor may be calculated using Eq. [6] for a known axle power and forward speed. This weight on the rear axle with the implement raised, will give the extra ballast required for optimum performance. The extra weight needed should be provided by rear wheel weights and/or liquid ballasting techniques. Also, depending on the soil type and physical conditions, ploughing depth should be adjusted at a level that results in about 10% rear wheel slip. This will ensure the operation at maximum possible tractive efficiency.

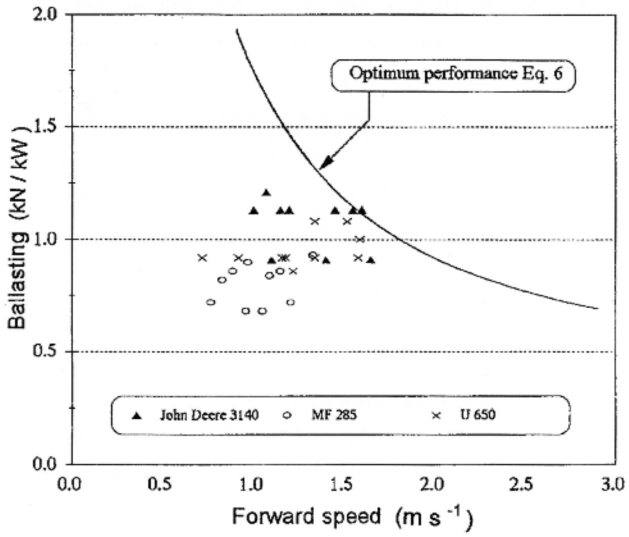

Fig. 1. Actual ballasting of tractors compared to optimum ballasting requirement.

The values of tractor axle power (P_{ax}) in Table 1 are not maximum axle power, but the estimated available power at the engine speed measured during the field tests. The reason for the estimated P_{ax} Of MF 285 tractors being close to those of the more powerful JD 3140 tractors is that, JD tractors were under-loaded while MF tractors were working near their maximum available power.

Tractor Power Wastage (P_{wst})

On the average, the most commonly used tractors in Zarghan area, under actual operating conditions were wasting about 57 percent of their axle power during mouldboard ploughing (Table 2). Under the assumed operating speed of 1.4 m s^{-1} the situation was slightly improved and the average power loss was decreased to about 48 percent.

Tractive Efficiency Ratio

The ratios of actual to optimum tractive efficiencies for the three tractor types tested in the area are tabulated in Table 2. On the average, JD tractors had higher tractive efficiency, followed by MF and Universal tractors, though their mean differences were not significant according to DMRT (Table 4). The overall ratio of 0.53 indicates that tractors in the area were not converting their available axle power to useful work efficiently. This could be attributed to under-ballasting, low forward speed, excessive wheel slip or a combination of all. Under the assumed operating speed of 1.4 m s^{-1}, the efficiency ratio was improved to 0.65.

CONCLUSIONS

Results of this study showed that farmers in Zarghan district of Fars province, were not utilizing the available power of their tractors in tillage operations efficiently, due to the following main reasons:

1. Tractors rear tire inflation pressure was over 50% greater than the value recommended for field work.
2. The actual forward speed at which the tractors were operating in the field was often too slow.
3. Almost all of the tractors were under-ballasted.

In order to improve the tractive performance of tractors, the following recommendations are suggested:

1. Tractor manufacturers and distributors should offer front end and rear wheel weights as a standard feature with their tractors.
2. Guidelines for proper operating speed, inflation pressure and optimum ballasting of tractors should be developed.

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