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Simultaneous comparison of the effects of shaft load and shaft positions on tractor OEE in two soil conditions (cultivated and uncultivated)

Authors

Amin Samiei Far*, Navab kazemi , Majid Rahnama and Mahmood Ghasemi nejad

Dear Author,

After having carefully evaluated your article titled "*Simultaneous comparison of the effects of shaft load and shaft positions on tractor OEE in two soil conditions (cultivated and uncultivated)*" and taken the referees' advice into consideration, the editors came to the conclusion that your paper is suitable for publication in our Journal.

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Yours sincerely,

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Simultaneous comparison of the effects of shaft load and shaft positions on tractor OEE in two soil conditions (cultivated and uncultivated)

Amin Samiei Far[1*], Navab kazemi[2] , Majid Rahnama[2] and Mahmood Ghasemi nejad[2]

1. M-Sc. Mechanization, Engineering, Student of Khuzestan, Ramin Agriculture and Natural Resources University, Khuzestan Iran
2.Assistant Professor, Department of Agricultural Machinery and Mechanization Engineering Khuzestan, Ramin Agriculture and Natural Resources University, Khouzestan, Iran

Corresponding author: Amin Samiei Far

ABSTRACT: one of the main indexes of energy consumption in tillage is overall energy efficiency of tractor. To measure this factor exactly and simultaneously with the other factors affecting it, at first MF 399 tractor was equipped with different kinds of sensors and a data collection system, so factors such as energy consumption, rear wheel slip percentage and overall energy efficiency of tractor during disking, with the data collection speed of 1000 data per second were measured and the data were sent through wireless to a computer 1**.**5 kilometers away and at the same time stored in excel format. The factorial design was accomplished three times and included factors such as: land condition (cultivated T and uncultivated NT), ballast (with ballast B, without ballast UB) and drive shaft (4WD, 2WD). After the analysis, a multistage Duncan test was used. Based on the results, overall energy efficiency of treatments included minimum amount of 9**.**7% associated with cultivated land treatment-two drive shafts, without ballast and maximum amount of 14**.**2% associated with uncultivated land-4 drive shafts with ballast. Minimum and maximum of rear wheels slip 17**.**2% and 40**.**17%, respectively, were associated with four drive shafts with ballast and two drive shafts without ballast. Minimum fuel consumption was determined 22**.**02 liter per hectare in four drive shafts without ballast. Studying the effect of ballast factors and shafts on overall energy efficiency and average rear wheels slip percentage in both conditions was significant in 1%, while fuel consumption per hectare was not significant.

Keywords**:** overall energy efficiency, fuel consumption, MF 399 tractor, tillage, ballast and diskoffset

INTRODUCTION

In the course of a stable development managing optimal energy consumption is a way of achieving stable production, resources supply and energy reduction. So correct management and moving toward exact agriculture causes consumption entities, energy and costs. Constant increase of fuel price has rendered energy consumption to one of the most important issues in agricultural economy.

Many researchers believed the increasing of overall energy efficiency for tractor and implements and correct matching of tractor and agricultural machinery can be effective in decreasing fuel consumption. The overall energy efficiency transferred energy from tractor (for implement launch) per energy equivalent of fuel consumption in different operations (Serano ., 2005). The overall energy efficiency indicated the general condition of tractor performance. This index is more important comparing draft efficiency and specific fuel consumption in survey of tractor performance (Bower, 1989).

Coordination of tractor and farming tools to optimize the operation is affected by the user's accuracy and decision making for using the equipment at his disposal. Including rev, gear, appropriate speed and the proper use of abilities such as lock, differential, 2 or 4 drive shafts, ballasts and speed handle. For example reducing one degree of gear with GUDT (gear up throttle down) can reduce up to 20% of fuel consumption (Toska , 2010). Using one differential and ballasting drive shafts of MF 399 tractor reduces drive shafts slip from 59% to 34.6% and fuel consumption from 31.5% to 27.4% (Soltani and Loghavi, 2007).

Bower (1990) studied overall energy efficiency in different kinds of tillage with several agricultural machineries and during several years and declared the normal limitation of overall energy efficiency to be -10%. Analyzing specific draft and index of OEE in different lands associated with tillage operation with offset disk draft and looking closely at figures inthe tables, it could be seen that OEE offset disk fluctuates from 15.4 to 18 and specific draftchanges from 4.5 to 5.3 kilo Newton per meter width. Measuring index such as OEE and TE, Kheirollah , (2004) showed overall energy efficiency and tensile strength disk offset in uncultivated land in different depths is from 9% to 17% and from 48% to 67% respectively and special energy was 18.5 hour kilowatt per hectare which had a significant difference using disk and moldboard plows with special energy of 34 kilowatt per hour.

It is recommended to use all the motor power with ballasts. Tractors that work with a power less than the determined power need less ballasts. Soltani Ghalejughi and Mohammad Loghavi (2007) studied the effect of ballast and MF 399 tractor drive shaft positions on fuel consumption, farming capacity, specific draft and plowing operation, and concluded that 2WD positionwith ballast reduces wheel slip from 59% to 34.6% in high deep cultivation and from 20% to 16% in low deep cultivation in comparison with 2WD without ballast. While 4WD without ballast holds slip from 12.5% (low depth) and 15.2% (high depth). So with 4WD without ballast, there is no need for ballast. With regard to fuel consumption, 4WD without ballast with 22.84 liter was less than 2WD without ballast with 27.42 liter per hectare and 2WD with ballast with 31.5 liter per hectare. Also MF399 tractor draft without ballast was reported to be 36.5% in comparison with 53% in a condition with ballast. In comparison with JD 4230 tractor, no difference was seen in specific draft. Moradkhanlu , (2006) studied the effect of ballast in 9 different conditions on MF285 and ITM tractors slip and found it significant. An increase of 1150 Kg on rear wheel shaft would reduce fuel consumption up to 15.6% and slip up to 60%. It also increases drawbar force up to 36.3%, but speed had not significance in drawbar force.

Gaisarani (1996) reported that correct ballasting reduces slip, fuel consumption, tire erosion and costs, in a way that proper use of ballasts could cause 33-%26 reduction in fuel. Minimum specific fuel consumption in slip occurs from 10% to 30% and tractor should be applied in maximum draft from 70% to 90% (Sayjenan , 1996).

Looking closely at the methods applied by researchers specifically in Iran, it became clear that for measuring important parameters such as slip percentage, fuel consumption, draft and real speed, none were run simultaneously, because it requires the use of tools and equipment with its special software to collect data according to the changes in land in different lengths and depths. Changes in fuel consumption and power directly influences overall energy efficiency index based on the definition and its computing relations, and these factors are also affected by other parameters such as farming capacity, percentage of all wheel slips, real forward speed, drive shaft and so on. These changes might happen spontaneously in real conditions due to land characteristics and operator.

MATERIALS AND METHODS

This study (2014) was performed in research farms of Ramin University of Agricultural and Natural Resources in Khuzestan located in thirty kilometers to Ahwaz with roman textural clay soil and the apparent specific gravity of 1.43 grams per cubic centimeter, and in fallow. Tillage was done by heavy disk and MF399 tractor which had the accurate tool of RTPM (remote tractor performance monitor) collecting data spontaneously and according to the algorithm of figure (1), all parameters required to calculate overall energy efficiency by the frequency of 3 data per second and finally, each plot data in Excel based on the sample (Fig. 2) is stored and analyzed using SAS statistical software.

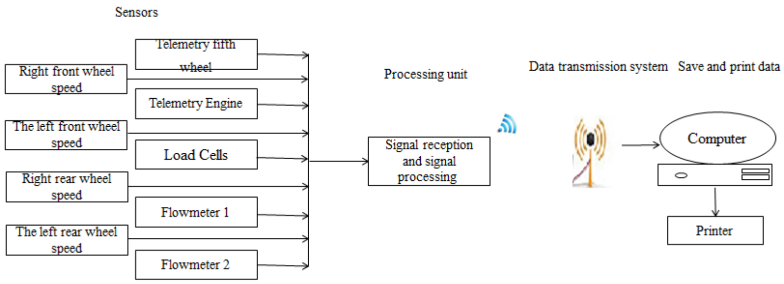
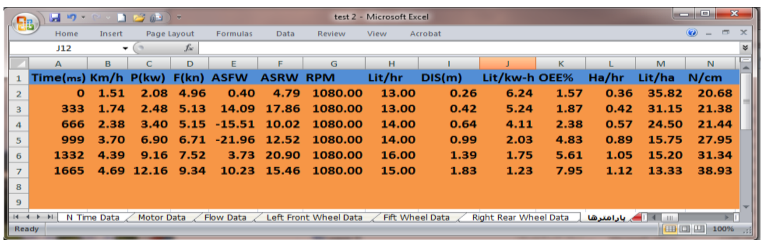


Figure 1. Block diagram of the system for collecting and presenting data to the remote

Pilot project for treatments was performed with a combination of 3 factors, the shaft load (with and without ballast), the shafts (two and four-wheel drive) and soil conditions (intact and plowed with heavy disk) as a factorial experiment in three repetitions. After storing all the data, researchers used Excel to compute the mean for each repetition and by entering them into SAS 9.2 software, the results of the analysis of variance and post ANOVA (slicing) were extracted.



Time(ms)	Km/h	P(kw)	F(kn)	ASFW	ASRW	RPM	Lit/hr	DIS(m)	Lit/kw-h	OEE%	Ha/hr	Lit/ha	N/cm
0	1.51	2.08	4.96	0.40	4.79	1080.00	13.00	0.26	6.24	1.57	0.36	35.82	20.68
333	1.74	2.48	5.13	14.09	17.86	1080.00	13.00	0.42	5.24	1.87	0.42	31.15	21.38
666	2.38	3.40	5.15	-15.51	10.02	1080.00	14.00	0.64	4.11	2.38	0.57	24.50	21.44
999	3.70	6.90	6.71	-21.96	12.52	1080.00	14.00	0.99	2.03	4.83	0.89	15.75	27.95
1332	4.39	9.16	7.52	3.73	20.90	1080.00	16.00	1.39	1.75	5.61	1.05	15.20	31.34
1665	4.69	12.16	9.34	10.23	15.46	1080.00	15.00	1.83	1.23	7.95	1.12	13.33	38.93

Figure 2. Sample recording and storing data of performance parameters during tillage by system RTPM

The first factor, according to the study of the most important factors affecting different performance parameters and consequently overall energy efficiency, is the shaft load through ballasts which was selected at two levels, tractor with ballast (B) and without ballast (UB) respectively.

Tractor was ballasted through adding water into four wheels and according to tractor manual, each wheel was filled with water from 70% to 75%. Firstly tires became flat, then drive shaft was put on a jack to the height for filling the wheels with water and finally based on the instructions mentioned in the tractor manual, the amount of air for wheels filled with water is ¼ bar in front wheels and 1.1 bar in rear wheels. Weight distribution on shafts is illustrated in table (1).

Table 1. The amount of weight added in the ballasting tractors

	Front Axle Weight (kg)	Rear axle weight (kg)	The total weight of the tractor (kg)
ballasting	1300	3040	4340
Un ballasting	980	2470	3450
Added weight	320	570	890

MF399 tractor was used in two positions of drive shafts, because of its importance and role in draft, as the second factor in 2WD and 4WD in treatments. The third factor was environment or work level because disking is usually performed in two conditions of first cultivated land and then uncultivated land. So the third factor in two levels was cultivated land or tillage (T) and uncultivated land or none tillage (NT). The main parameter in this study was overall energy efficiency (OEE) that according to equation number 1 was calculated. Looking closely at its elements, it includes three variables of draft, real forward speed and fuel consumption. Since data collection system collects data for these three factors simultaneously and spontaneously. Adding equation (1), overall energy efficiency was also computed and stored.

In this equation, V_a is real forward velocity in terms of km/hr, Dr is draft in terms of KN, FC is fuel consumption in terms of liter per hour and OEE is overall energy efficiency in terms of percentage, 10.2 is calorific value of diesel fuel (in terms of diesel fuel produced in Iran, $kw\text{-}hr^{-1}$). Whileother important parameters or variables such as all wheels slip percentage indirectly influence OEE.

$$OEE = \frac{V_a D_r}{10.2 * FC} * 3.6 \qquad (1)$$

Average slip rear wheels percentage

Slip percentage (+S% or –S%) for each wheel to actual ground velocity (V_a, km/h) was measured with RTPM and system software based on the simple equations mentioned below calculated and stored average slip rear wheels percentage.

$$\%S = 100 * \left[1 - \frac{V_a}{V_t}\right]$$

$$ASRW = \frac{SRRW\,\% + SLRW\,\%}{2}$$

ASRM: average slip rear wheels; SRRW: slip right rear wheel; SLRW: slip left rear wheel.

Required draft equals power of $PTOP_{eq}$: To know what required draft of tillage tool in operation equals what percentage of maximum tractor power in terms of PTO, the following equations were used:

$$P_{eq} = \frac{P_{db} * 100}{TE * 0.96 * MAX\ P_{pto}} \qquad (4)$$

$$P_{db} = \frac{Va * W}{3.6} \qquad (5)$$

Where P_{eq} in terms of percentage, TE is draft in terms of percentage and P_{db} is the required draft by means of tillage in terms of kw, 0/96 is the efficiency for transferring power to drive shafts of tractors.

RESULTS AND DISCUSSION

Using all the results of variance analysis in this study and a complete and comprehensive look at them, effects of the two main factors of drive shafts and shaft load on overall energy efficiency and the most important parameters on OEE, i.e. ASRW and FChr, the results were illustrated in Table (3) and overall energy efficiency and other features in the study in two levels of cultivated and uncultivated were also shown in Table (2). The figures in this Table came from the Tables for variance analysis W*B/W, W*B/B in two environments of T and NT. Accuracy in overall energy efficiency showed a significant difference in both conditions, 2WD and 4WD. In both levels the amount of overall energy efficiency with 4WD was more than 2WD, especially in cultivated land this difference is at its most, and this is because slip reduces from 36% to 17% and the required power gets close to the maximum power of tractor, but in an uncultivated land slip reduces from 20% to 11% and the required power does not become significant.

Table 2. Average total energy efficiency variables related to tillage and no-till farm

Average	NO	OEE	PEQ	ASRW	FChr
NT- 2W- UB	3	13.41	69.71	26.31	24.46
NT- 4W- UB	7	15.01	47.03	12.26	20.73
NT- 4W- B	8	15.10	68.80	11.04	26.29
NT-2W- B	4	15.18	72.56	18.94	25.49
T- 2W- UB	11	9.37	64.63	40.45	49.33
T- 2W- B	4	12.00	65.72	25.96	25.33
T- 4W- UB	7	13.21	55.77	17.19	23.24
T- 4W- B	8	13.4	61.43	14.42	11.9

NT: no- tillage, T: tillage, B: Ballasting, UB: UN ballasting, the drive shaft 2w and 4w.

When the tractor gets ballasts, in both levels it causes improvement in OEE. However, this improvement becomes significant in uncultivated land. It is clear that the effect of ballast in 2WD is much more. In other words, ballasting tractor in uncultivated land cause improvement in 2WD condition.

Table 3. Comparison of the 3 main variables influencing the overall energy efficiency of tractor and tillage

		Unballasting Un ballasting ballasting	ballasting MS	MS	WD**2**	4WD	MS
	NT	14/3	16	26/55**	14/6	15/7	۱۴/3**
	T	11/98	12/14	^{ns}4/5	9/9	14/22	221**
ASRW	MS	85/6**	150/4**		258/12**	29/7**	
	T	29/97	22/7	619/2**	35/۶	17/59	4۰74/8**
	NT	17/5	13/65	186/8**	20/22	11	1018/44**
PEQ	MS	1837/3**	1001/6**		2856/8**	443/6	
	T	59/8	63/8	186/4**	59/3	64/2	286/55**
	NT	63	66/8	^{ns}176/6	66	63/8	^{ns}54/18
FChr	MS	^{ns}120/1	^{ns}112				
	T	23/81	25/5	38/6**	24/7	24/6	^{ns}0/2
	NT	23/7	24/12	^{ns}1/65	23/7	24/1	^{ns}2/3
OEE	MS	^{ns}0/019	25/66**		^{ns}12/8	^{ns}2/6	

OEE total energy efficiency, ASRW average slip rear wheels, PEQ percentage of the maximum power of PTO, FChr fuel consumption (lit / hr) B Ballasting, UB without ballasting

With regard to the analysis of variance table comparing effective factors on performance parameters of MF399 tractor, generally the achieved amounts of OEE for the treatments include minimum amount, i.e. 7.43 related to the treatment of cultivated land with 2WD and ballast and maximum efficiency, i.e. 18.16% related to the treatment of uncultivated land with 4WD and ballast. The limitation (7.43 – 18.16) achieved in this study in comparison with studies of Bower (1990) done in several years on tillage machineries had OEE of 15% to 19.4% and Yahya Azimi (2006) for disk offset in uncultivated land reported OEE of 9% to 17%. This shows that in the best condition OEE was about 20% and if the management factors are not chosen correctly by the operator this percentage declines up to 7%. It seems the cause of ballast effectiveness in uncultivated land is that in both levels ballast reduces slip, but in cultivated land due to soil softness and more sinking of wheels, rolling resistance increases and this difference could be seen in draft.

Mutual effect of ballast in NT condition is much more than T condition and mutual effect of W in T condition is much more than NT condition. With regard to the importance of two factors of ballasts (B and UB) and the position of drive shafts (2WD and 4WD) as well as slip, in figure (1) columnar curve was drawn for average slip percentage next to average OEE percentage of tractor tillage in two cultivated and uncultivated lands as well as in general for two conditions and for treatment combinations including 2WD-UB, 2WD-B, 4WD-UB and 4WD-B. Looking closely at figures and change trends, it could be concluded that firstly the slope of OEE is in the opposite of slip. It means when slip reduces, OEE improves and this trend is seen in both conditions. Its most extreme condition refers to the cultivated land when OEE is 9%, slip is 42%, and when slip reduces to 15%, OEE becomes 14.2%. However, with respect to ballast factors and drive shaft, curves in both figures (3) and (4) shows that in each condition changes in OEE is in a way that minimum OEE in both conditions is related to the 2WD-UB, after that 2WD-B, then 4WD-UB and finally maximum percentage is related to 4WD-B.

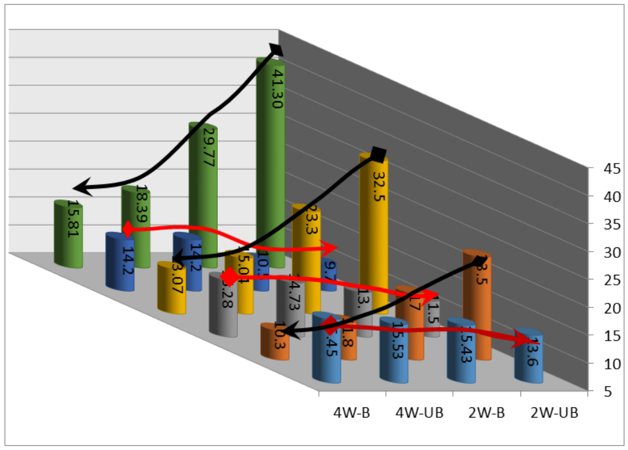


Figure 3. The rear wheel slip with the total energy efficiency in the different treatments. Asrw and black lines to reduce red tape to reduce the OEE

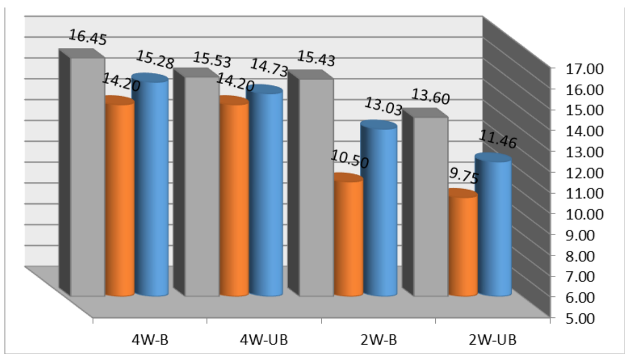


Figure 4. Average slip and energy efficiency all treatments in every situation and in combinationConsidering the studies done and based on the findings of Kheirollah (2004), it could be mentioned that specific energy for disk offset is 18.5 KWh ha and considering that the amount of energy of each diesel fuel is 10 KWh per liter, so for each hectare tillage operation with disk offset 1.85 liter diesel fuel per hectare is needed

Table 4. Comparison of actual fuel consumption and fuel losses by taking energy efficiency of tractors MF 399

Factors	Un Ballasting	Ballasting		4WD
	2WD	4WD	2WD	
OEE%	9.7	14.2	10.5	14.2
FcHa	30.8	22.02	27.2	22.4
The actual fuel consumption	19.07	13.02	17.61	13.02
Energy losses	11.72	9	9.58	9.38

Based on the figures in table (4), a relationship was clearly found between ballast parameters and shaft positions on the amount of fuel consumption and loss. The amount of actual fuel consumption and loss for providing the energy needed for the operation was related to 2WD position without ballast was 19.07 and 11.72 liter per hectare respectively. The cause of this increase in the amount of fuel consumption was related to slip amounted to 35.6% and other factors. In other words, considering OEE, minimum amount of actual fuel consumption and loss related to 4WD without ballast was 13.02 and 9 liter per hectare, which is in accordance with the findings of Soltani Ghale and Mohammad Loghavi (2007) and it does not need ballast.

Conclusion

With respect to the treatments observed, it was seen that in treatment with ballast in comparison to without ballast, 4WD in comparison to 2WD in both conditions of cultivated and uncultivated lands causes increase of OEE. Applying ballast and in shaft positions, considerable results in 4WD and 2WD were achieved that showed a significant difference in OEE and the amount of rear wheel spin. In each condition changes of OEE was in this way that minimum OEE and maximum wheel spin percentage in both cultivated conditions related to treatment of 2WD-UB was 9.7% and 41.3%, respectively, and after that 2WD-B and 4WD-UB, and finally maximum OEE related to 4WD-B was 14.2%. Maximum amount of fuel consumption related to cultivated land in 2WD-UB was 49.33 liter per hectare and minimum amount of fuel consumption in cultivated land in 4WD-B was 11.9 liter per hectare.

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