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Ergonomic assessment of drivers in MF285 and MF399 tractors during clutching using algometer

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A B S T R A C T

Tractor as one of the most widely used agricultural machinery should be considered from different aspects. The frequent application of clutch and brake pedals and also the steering wheel within farms, along with the unfavorable working conditions, cause negative effects on the occupational health of the tractor drivers. Thus, in this research, the imposed forces on three engaged muscles including: Gastrocnemius, Trapezius and Quadrate's lumborum of the tractor drivers during clutching have been studied. In this regard, algometer device was used to determine the applied forces on selective muscles of drivers during clutching of MF285 and MF399 tractors. The experiments were performed employing sample of 30 drivers and were conducted on two Iranian frequently used tractors including: MF285 and MF399 models.

The results showed that the clutching forces for MF285 and MF399 tractors were 340 N and 290 N, respectively. The knee angle of the drivers of the two tractors was statistically different at the one percent level of significance. The reduction of pain threshold after 30 and 60 s clutching and also 60 s rest after clutching in MF285 tractor, for all three muscles, were more than those of MF399 tractor. The impact of clutching on the average decreases of pain threshold, for all drivers and all clutching periods, during and after clutching, in the Quadratus lumborum muscle was more than the other two muscles, in both tractors. In order to reduce the clutching force for MF285 tractor some modifications is suggested. In this regard the force transfer joint between the pedal and the clutch release linkage may be replaced with one made of cast iron.

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1. Introduction

Agriculture is one of the important sectors in the developed industrial countries and also developing countries. Hence adequate attention should be paid to the practical application of ergonomic measures and changes of activity in agricultural practices, in order to reduce work-related accidents and illnesses that result in improved living conditions and increased productivity [1]. According to the International

Labor Organization (ILO) about 2.3 million people annually die due to occupational accidents and work-related diseases. Latest estimates based on year 2003 data, indicate that 337 million occupational accidents and 160 million occupational illnesses take place world widely every year. According to a study by the European Commission in 2000, more than four percent of the Gross Domestic Production (GDP) is wasted due to accidents and illness in the world [2,3]. One of the problems in the agriculture sector of the developing countries is the design, construction and assembling of agricultural machineries which not quite match with the users requirements. On the other hand, being exclusive and the lack of competitive environment in manufacturing (monopoly in production) agricultural machineries such as tractors, cause farmers requirements to be ignored. To lessen this, the experts of agricultural machineries and ergonomists should pay more attention on this subject area for understanding the relevant problems and deficiencies.

Reducing the difficulties and the hardship of agricultural activities has always been one of the main reasons for moving towards the mechanized farming [4]. In recent years, due to the widespread use of machinery and equipment in different agricultural operations, it is thought that the work- related costs and diseases have declined. However, some tools and machines which are used in agriculture, for several different reasons, such as mismatch between the machines and the driver (operator) characteristics, crop and climate conditions, lack of suitable adjustment of the device and also the lack of engineering and ergonomic design principles could potentially cause injuries and illnesses and complications arising from their use. In other words, despite the expansion of mechanized and automated processes, Musculoskeletal Disorders (MSDs) associated with the work are still the most important cause of work time loss, increased costs, human injuries which are the greatest occupational health problems in the industrialized countries [5]. These disorders are the most common health hazards arising from inappropriate ergonomic working conditions which affect tens of millions of workers in all working sectors including agriculture [3], and should be considered continuously by the researchers.

One of the jobs in agricultural sector which is directly engaged with tractor and other machinery and implements is tractor driving. According to a study on oil seed production in America, planting and harvesting of crops by agricultural machineries is the most harmful farmers' activity. Damages from these activities were reported in the entire body, especially in the back of person along with general and visual fatigues in the body [6].

In a study on the effect of employing folding cabin for tractor on the comfort of the tractor drivers in three adverse environmental conditions, indicated that the cabin with all closed sides be able to create the most comfortable condition with comfort grade of 8.75 out of 10 in cold conditions. While for warm conditions, a cabin with opened front and back and also providing opened side windows could create the most comfortable condition with the average comfort grade of 7.75 out of 10 [7]. In a study, agricultural tractor drivers' backache illnesses due to the exposure of agricultural tractors drivers to whole body vibration and high-pressure conditions were investigated. The results showed that the prevalence of backache among drivers was more than the other group with no such activities [8].

According to the World Bank about 85% of the world's farms are less than two hectares which are classified as small farms. The average ownership area (per holding) of agricultural land in some countries such as Iran is also relatively low [9,10]. For example, the average ownership area for peanuts production in Guilan province (Northern part of Iran) is about 0.8 hectares [11]. Driving tractor in such small farms and performing the agricultural activities requires more frequent clutching, braking and steering. With no doubt in such circumstances, physical problems and the fatigue of the driver are the main concerns. So paying attention to any of agricultural equipments in highlighting and identifying the causes of operators' physical problems is required.

It seems there are some methods that can help for assessing and improving the ergonomic aspects of agricultural machineries [12,13,6,14]. A literature review showed that many researchers have reported the valuable application of algometer device in ergonomic studies [15,16], and it has been shown to be an effective tool of quantifying pressure pain threshold [17–19]. However, the application of algometer in ergonomic evaluation of agricultural machineries and tractors has not been investigated yet.

According to the report of Iranian Agriculture Mechanization Development Center, from 245,989 supplied tractors during years 1993–2011, about 67% were MF285 tractor and about 9% were MF399 tractor. In other words these two models of tractors dominate the tractor types in Iran [20]. Considering the above issues, the aim of this study was to investigate the forces imposed on the three engaged muscles of the drivers including Gastrocnemius, Trapezius and Quadratus lumborum arising during clutching of Iranian common tractors of MF285 and MF399 using algometer. Based on the experimental results, some guidelines are also provided to optimize clutching of the tractors for improving the tractor driver's health condition.

2. Materials and methods

2.1. *Sampling method*

The research was conducted in the first half of year 2013 at the College of Agriculture, Ferdowsi University of Mashhad, Iran. The so called Cochran method (Eq. (1)) was employed to determine the sample size of study [21]:

$$n = \frac{N(s \times t)^2}{(N-1)d^2 + (s \times t)^2} \tag{1}$$

$$d = \frac{t \times s}{\sqrt{n}} \tag{2}$$

where t equals to 1.96 (for confidence level of 95%); s, is the pre-estimate of the community's standard deviation; d is the proper probable accuracy; N is population size and n is the sample size [22]. Having known the total number of tractors in the region, the sample size was determined as 30 drivers. Table 1 shows some technical specifications of MF285 and MF399 tractors.

2.2. Force analysis of clutching

In this study, the effect of some independent variables including: Body Mass Index (BMI), height, weight, knee, ankle and hip angles on the pain threshold reduction, as the dependent variable, was examined. The reduction of pain threshold is a measure of the effect of clutching force on the muscle. The higher reduction of pain threshold indicates a greater impact of clutching force on the muscle under consideration. The knee, ankle and hip angles of the driver during clutching were measured using a suitable protractor ruler. The BMI index as a measure of body fitness is calculated as:

$$BMI = \frac{W}{L^2} \quad (3)$$

where W (kg) and L (m) are weight and height of the driver, respectively. If this index is less than 18.5, this means that the person is under weight. The BMI of 18.5–24.9 shows that the person has a normal body. BMI of over 25 and over 30, indicate overweight and obesity, respectively [24].

To determine the pain threshold, an algometer device (Lutheran ModelFG-5005) with 0.01 N resolution and probe cross-section of 44.15 mm^2 was used. Investigations were performed on the three engaged muscles during clutching mainly: Gastrocnemius (in the calf area) (see Fig. 1), Quadratus lumborum (around the waist) (see Fig. 2), and Trapezius (trapezoid muscle in the upper neck line) (see Fig. 3). Gastrocnemius is the calf surface muscle, which its two ends are easily palpable in posterior to the tibia. Quadratus lumborum is the important muscle regarding to the stability of waist joints and during many activities such as flexion (bending forward), extension (bending backwards) and side bending of waist. Trapezius is a muscle in the back area that is composed of three parts and in this study the upper Trapezius was selected for experiments [25–28].

Measurements were performed using the algometer device for each person on each muscle for different clutching mode including: before clutching, 30 s after clutching, 60 s after clutching and after 60 s rest of after clutching. For all drivers, the muscles on the left side (clutch side) have been selected and tested. The measurements were performed in compliance with appropriate time intervals between the measurements. Given that the clutch of tractor MF285 is a two-stage type (the first stage for transmission and the second stage for Power Take off shaft (PTO) which is not used frequently), in order to avoid the possible errors resulting from entering to the second phase of clutching (clutching of power take off shaft), a metal barrier under the clutch pedal was provided to avoid from entering to the second stage of clutching and exerting excessive force beyond the first stage of clutching.

For measuring the required clutching force, a mediate spring with initial length of 55 mm was inserted between the operator's bottom foot (Metatarsus) and the clutch pedal. By using a tensile testing machine (Model HTE-5000), the spring was calibrated and by which the clutching force was measured. The differences of angles of knee, ankle and leg and pain threshold reduction were investigated after 30 s, 60 s clutching and also after 60 s resting after clutching. Data were analyzed using JMP8 Software (statistical software from SAS) in the three selected muscles for both models of tractors performing the "t" test i.e. the comparison of means was performed using the Paired Observations method. The detailed information of the software is available from SAS Institute [30].

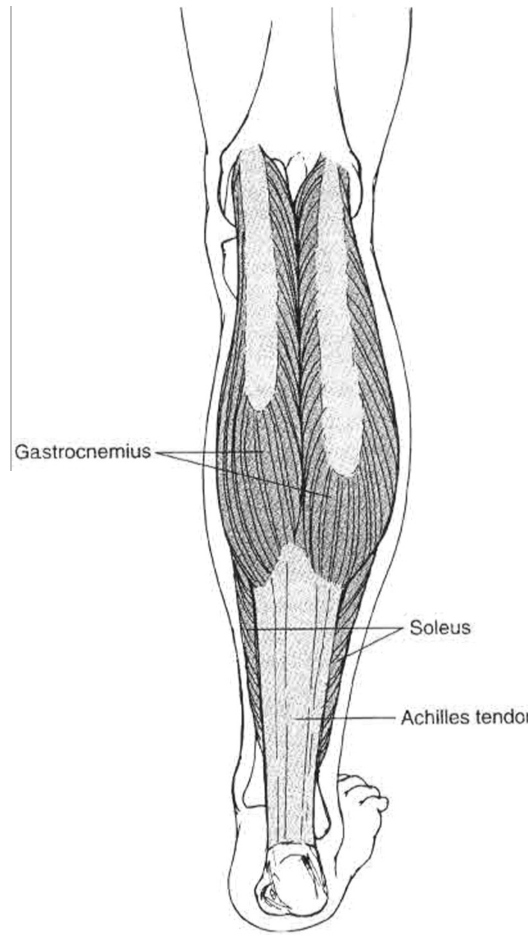

Fig. 1 – Gastrocnemius muscle [29].

3. Results and discussion

The average characteristics of the sample drivers including weight, height and BMI index were calculated as 62.23 kg,

Table 1 – Some technical features of MF285 and MF399 tractors [23].

Specification	MF285	MF399
Engine HP	75	110
The number of cylinders	4	6
Clutch	Mechanical	Mechanical

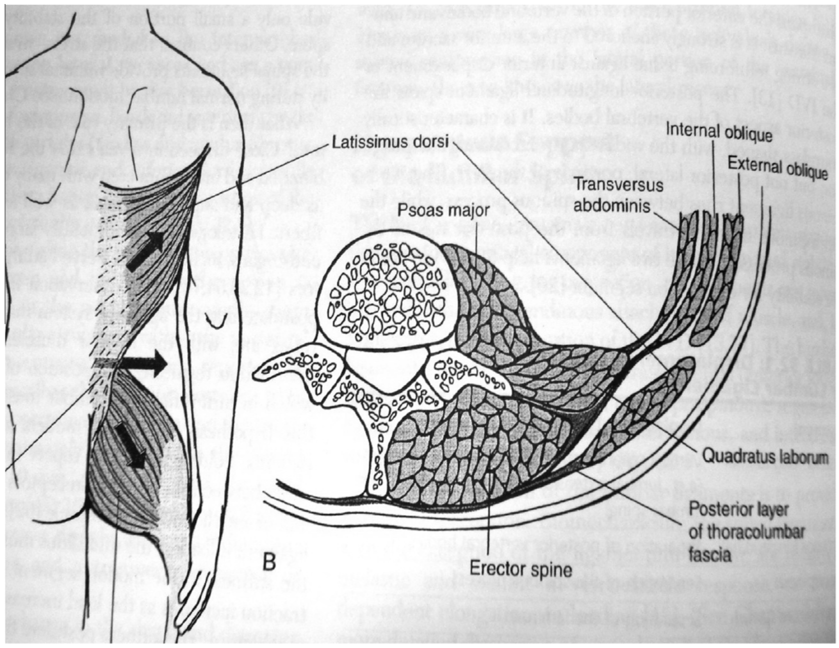

Fig. 2 – Quadrate's lumborum muscle [29].

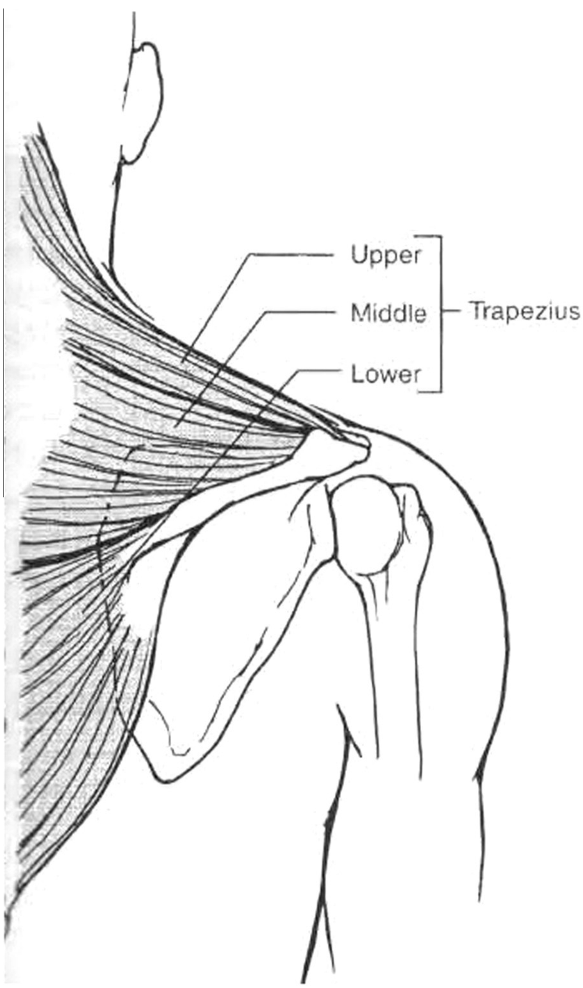

Fig. 3 – Trapezius muscle [29].

177.43 cm and 21.91 kg m^{-2}, respectively. The measured force required for clutching indicated that the clutching force for MF285 tractor was more than MF399 tractor and were 340 and 290 N for the former and latter, respectively. In a study it was reported that the maximum force exerted by the right and left foot were 665 and 613 N, respectively. Accordingly, the maximum stimulus force for brake and clutch were recommended as 330 and 280 N, respectively [31]. Having these, it can be say that both tractor models require more force than the amount recommended in the above report. This means that during clutching of these tractors extra and unusual pressure is imposed to the drivers.

Table 2 displays the comparison of the knee, hip and ankle position angle of the two tractor models. The average position angle of the knee in MF285 and MF399 tractors were calculated as 127.83° and 148.83°, respectively. The difference between the position angles of knee of the two tractor models was significant at the one percent level. The position angles of the hip and ankle in MF285 model were more than the MF399 model. However, the differences in the tractor models were not significant at the one percent level. The MF285 tractor is a four-cylinder with 75 horsepower so less torque is transferred through the clutch and transmission system than the MF399 tractor that has six cylinders with 110 horsepower. Despite of this fact, the MF285 tractor requires more clutching force than the other which is a more powerful model, and hence needs greater attention for clutch modification in the former model.

Table 3 shows the results of the reduction of pain threshold using algometer in three muscles area. The mean reduction of pain threshold in Gastrocnemius muscle after 30 s clutching in MF285 tractor was more than MF399 tractor and they were calculated 3.87 and 3.23 N, respectively. As it is seen the reduction of pain threshold after 30 s on MF285

Table 2 – Means comparison of knee location, thigh and ankle angles of MF285 and MF399 tractors (in degree).

	MF285 (STD)	MF399 (STD)	*t* statistics	*p*-value
Kneeangle	127.83 (10.78)	148.83 (8.36)	−8.67*	0.0001
Thigh angle	94.70 (13.14)	93.70 (10.88)	0.31	0.759
Ankle angle	108.77 (12.40)	112.57 (8.62)	−1.53	0.136

* Significant at the one percent level.

tractor was more than MF399 tractor and the difference between their thresholds was significant at the five percent level. The decrease of pain threshold after holding the clutch for 60 s in MF285 and MF399 tractors were 6.30 N and 4.30 N, respectively. As it can be seen, the mean reduction in pain threshold after 60 s on MF285 tractor was more than MF399 tractor and the difference between the two tractors was significant at the one percent level. The results imply that clutching in MF285 tractor will lead the operator feels the pain threshold in the Gastrocnemius muscle in a shorter time than the MF399 tractor. Our results indicate that the reduction in pain threshold after 60 s clutching in MF285 tractor is more than MF399 tractor and this reduction was significant at the five percent level. The reasons of being more reduction in pain threshold on Gastrocnemius muscle in MF285 tractor than MF399 tractor might be due to more required clutching force in MF285 tractor and also significant difference in operator's knee position angle during clutching in this model of tractors.

The results of measurements on the Trapezius muscle are also presented in Table 3. The reduction in pain threshold after 30 s clutching in MF285 and MF399 tractors were 3.50 and 2.73 N, respectively. The reduction in pain threshold after 30 s clutching on this muscle, like Gastrocnemius muscle, in MF285 tractor was more than MF399 tractor. The difference between the pain threshold reductions in the Trapezius muscle after 30 s clutching in these two tractors was significant at the ten percent level. The reduction in pain threshold after 60 s clutching and resting 60 s after clutching in MF285 tractor was more than MF399 tractor, but these differences were not statistically significant.

The pain threshold on Quadratus lumborum muscle was assessed and the related results are given in Table 3. It is seen that the decreased pain threshold on Quadratus lumborum muscle after 30 s, 60 s clutching and resting 60 s after clutching on the operators of MF285 tractor was more than MF399 tractors. However, only the difference in reducing muscle pain threshold after 60 s clutching in two tractors was significant at the five percent level.

The mean decrease in pain threshold during and after clutching in three muscles is given in Table 4. The results indicate that the Quadratus lumborum muscle has the pain threshold reduction more than the two other muscles after 30 s, 60 s clutching and 60 s of rest after clutching. Clutching was more effective on this muscle in decreasing the pain threshold. However, based on the previous studies, this muscle when bending forward (flexion) and the rest did not been relaxed [32], and in some activities that can be done either manually by the farmers, the waist area have been reported as the common musculoskeletal disorders [33]. The second muscle that is affected by clutching with more decrease in the pain threshold is the Gastrocnemius muscle (see Fig. 4). This muscle plays a key role in plantar flexion of ankle (component that is engaged in clutching) [26]. The Trapezius muscle takes up the least amount of impact by clutching during and after clutching than the other two muscles. As it is seen in Fig. 4, reducing the pain threshold after 30 s clutching in Gastrocnemius and Quadratus lumborum muscles is the lowest and after 60 s clutching, the reduction of pain threshold reaches the highest of its amount. Resting 60 s after clutching, the diminished pain threshold is still more than the lowered pain threshold after clutching of 30 s, but it was shown a significant reduction of pain threshold after clutching after 60 s. It seems that a little rest leads to a reasonable recovery in the muscles. But in Trapezius muscle, the average reduction of pain threshold after 60 s clutching is the highest amount and then the reduction of pain threshold after 30 s of rest is the most value. This suggests that the Trapezius

Table 3 – Means comparison of the decrease of pain threshold after 30 s and 60 s clutching and 60 s rest after clutching of MF399 and MF285 tractors.

Muscle	DPTM[a]	MF285 (*N*)	MF399 (*N*)	*t* statistics	P-value
Gastrocnemius	30 s	3.87	3.23	*−2.52	0.018
	60 s	6.30	4.27	**−7.68	0.000
	60 s rest	4.20	3.07	*−2.70	0.011
Trapezius	30 s	3.50	2.73	−2.02	0.053
	60 s	5.20	4.60	−1.5	0.144
	60 s rest	3.33	2.73	−1.34	0.189
Quadratus lumborum	30 s	4.30	3.53	−1.60	0.118
	60 s	8.47	6.83	*−2.56	0.016
	60 s rest	5.63	4.77	−1.47	0.153

*,** Significant at the 5 and 1 percent levels, respectively.

[a] The decrease of pain threshold in muscle after.

Table 4 – The average decrease of pain threshold after 30 s and 60 s clutching and 60 s rest after clutching of MF399 and MF285 tractors.

Muscle	DPTM[a]	Average (N) (standard deviation)
Gastrocnemius	30 s	3.55 (3.10)
	60 s	5.30 (3.41)
	60 s rest	3.63 (2.50)
Trapezius	30 s	3.12 (1.54)
	60 s	4.90 (1.75)
	60 s rest	3.03 (1.71)
Quadratus lumborum	30 s	3.92 (2.40)
	60 s	7.65 (3.16)
	60 s rest	5.20 (2.74)

[a] The decrease of pain threshold in muscle after the time.

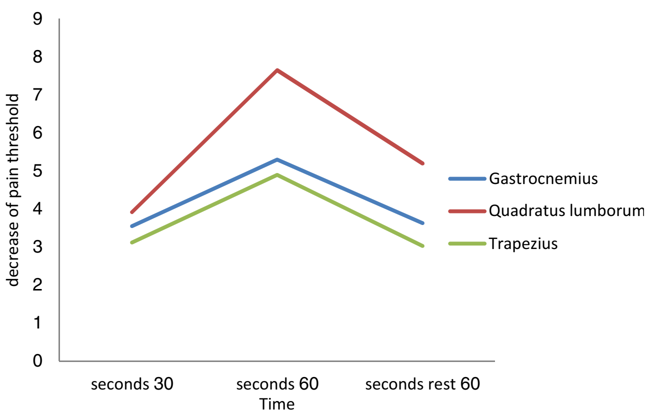

Fig. 4 – The average decrease of pain threshold after 30 s and 60 s clutching and 60 s rest after clutching of MF399 and MF285 tractors.

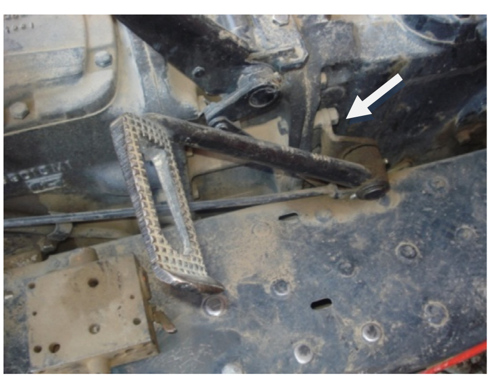

Fig. 5 – The pivot pin of the clutch release linkage and the way in which is currently attached to the gearbox casing of MF285 tractor.

muscle reaches to its original condition faster than the other two muscles and it is less affected by the clutching pressure during clutching. Since the function of this part of the muscle is picking up the Sternoclavicular joint, and picking up, closing and rotating the scapula, therefore, it is appear that this muscle is more affected during steering action and working for a long period of time [10].

4. Conclusions and recommendation

The results of this study shows that the clutching mechanism in both models of tractors is in such a way that the required clutching force is much more than the allowable recommended amount, however, this problem in the MF285 tractor is worse than MF399. So during the experiments, some investigations were made on clutching mechanism of MF285 tractor and it was found out that the pivot pin of the clutch release linkage is attached to the tractor gearbox casing via a bracket made of low carbon steel. During clutching and when the force is applied on the pedal, this bracket is subjected to an unwanted deformation, so the change in bracket configuration causes to change the direction of the force on the clutch release mechanism. As a result the required clutching force is increased. The change in the direction of clutching force causes the movement and rotation of the pivot pin with more friction. Based on this finding, and in order to reduce the clutching force of MF285 tractor and provides more comfort of drivers, necessary rearrangements should be done. Given that, this tractor is considered as lightweight tractors and its production rate and its usage in Iranian agricultural sector is far more than MF399 tractor, paying attention to its optimization will have more effect on occupational health of agricultural drivers. As an introductory suggestion, it is recommended that the bracket of the pivot pin of clutch release linkage (see Fig. 5) is replaced with one made of cast iron. Because the deformability of cast iron is much less than the steel, so during exerting clutching force, its state will not change significantly. Preliminary tests showed that with this modification on the clutch mechanism of MF285 tractor the required clutching force may be reduced up to 70 N. Finally, it is recommended to do more comprehensive studies for improving the ergonomic condition of agricultural machineries drivers using algometer. Moreover, it might be better to do experimental work in farm.

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