نهمین کنگره ملی مهندسی ماشین‌های کشاورزی
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Investigating the effect of dynamic load on rolling resistance of agricultural tractor tire

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Abstract
The interrelation between destructive effect of dynamic wheel load and the resistive and energy-wasting impact of rolling resistance was investigated. A single wheel-tester inside a soil bin facility was used to study the impact of dynamic load on rolling resistance utilizing four horizontal load cells to measure rolling resistance and a vertical load cell to measure dynamic wheel load. Four static wheel loads (i.e. 1, 2, 3, and 4 kN) were used to generate varying dynamic loads at two velocities (i.e. 0.7, 1.4m/s) while traversing the length of soil bin. It was revealed that by slight increase/decrease of wheel load, amount of rolling resistance increased/decreased with higher inclination. A relatively high conformity existed between valleys and peaks of dynamic wheel load and rolling resistance almost at all of tested treatments.

Keywords: Dynamic wheel load; rolling resistance; single wheel-tester; soil bin

Introduction

Wheel is playing an important role in agricultural vehicles since it is used to traverse and bear the weight of vehicle. Moreover, nearly all of forces and moments influencing the motion of vehicle are applied to it. Furthermore, it has very noticeable impact on machine dynamics. Amongst the acting forces on wheel, rolling resistance is the paramount factor considering its resistive effect while initiating a wheel to roll and also its importance in fuel consumption, imposed soil compaction, and reducing the traction. Fuel consumption of tractors is dependent on amount of rolling resistance (Taghavifar and Mardani, 2012). Energy loss in agricultural tires because of inaccurate management was reported to be about 575 million Liters per year in USA (Wulfsohn, 1987). Hence, reduction of rolling resistance to the lowest possible level is of the prominent priorities.

Rolling resistance is a moment applied to wheel against the direction of movement, while a tractive force is required to move the wheel forward (Komandi, 1999). It is basically an unwanted force applied to wheel while starting to roll on a surface caused by the energy required for soil or wheel deformation. Precise measurement of rolling resistance is simply complex work particularly without proper facilities due to effectiveness of many parameters on it simultaneously. Additionally, rolling resistance evaluation seems troublesome when the wheel moves since the condition becomes evidently dynamic during the movement.

Bekkar (1960) scientifically studied and established the relations between wheel and soil in 1960. Based on his equation (Eq. 1), amount of rolling resistance is influenced by variety of parameters may be expressed by:

$$R=\frac{3w^{(\frac{2n+2}{2n+1})}}{(3-n)^{(\frac{2n+2}{2n+1})}(n+1)(Kc+bK\varphi)^{(\frac{1}{2n+1})}d^{(\frac{n+1}{2n+1})}} \tag{1}$$

Kc and Kφ have been yielded from pressure sinkage equation (Eq. 2) as below:

$$P = (\frac{K_C}{b} + K_\varphi)Z^n \tag{2}$$

Where w is vehicle weight, n is sinkage exponent, b is the smaller dimension of the rectangular contact area, Z is the sinkage, and KC and Kφ are the soil condition parameters.

The required energy to compact the soil beneath the wheel during movement for a definite distance is equal with a resistive force against the movement multiplied by the distance. This resistive force (i.e. rolling resistance) is suggested to be as follows (Eq. 3):

$$R = b_w \int_0^{z_{max}} (\frac{K_C}{b} + K_\varphi)Z^n dZ \tag{3}$$

Validity of equation above in order to predict rolling resistance based on soil deformation was offered by Wong (1984) for wheel diameters more than 50cm and sinkage levels less than 15% of wheel diameter.

Hetherington and Littleton (1978) suggested a simple approximate equation for calculation of rolling resistance in terms of geometry, load and accepted soil constants as following:

The proposed model describing rolling resistance of wheel over sand is following as:

$$R = \sqrt[3]{\frac{2W^4}{bd^2 \gamma N_q}} \tag{4}$$

Where R is rolling resistance, W is vertical load acting on wheel, b is width of wheel, d is wheel diameter, γ is bulk density of sand, and Nq is recognized as Terzaghi's bearing capacity solution.

There are numerous parameters affecting rolling resistance comprising wheel diameter, tire inflation pressure, multipass, soil texture, sinkage, wheel slip, wheel load, and velocity. In 1971, the effect of wheel speed on rolling resistance was verified by Pope (1971). Elwaleed et al. (2006) reported the effect of inflation pressure on motion resistance in their experiments. McAllister (1983) studied reduction in the rolling resistance of wheels determining the values of the coefficient of rolling resistance (CRR) for wheels. The results indicated that reductions in CRR can be produced by reducing inflation pressure and vertical load. Coutermarsh (2010) claimed that in dry sand, the rolling resistance has linear relation with velocity until the tire starts to plane, and then it becomes stabilized or decreases.

Literature review approves that little attention has been given to effects of dynamic wheel load rolling resistance using a single-wheel tester in a soil bin since it prepares controlled condition to evaluate the effects accurately. The main objective of present study was to investigate the effect of various dynamic wheel loads on induced rolling resistance.

Materials and Methods

A long soil bin was built in 2010 in the Faculty of Agriculture, Urmia University, Iran. This soil bin has 23 m length, 2 m width and 1 m depth (Mardani et al., 2010). This long channel had the ability to hold a wheel carriage, a single-wheel tester, and different tillage tools to be moved altogether in the length of the soil bin. The facility to fill the channel with various soil textures and different moisture contents provided higher advantage in comparison with uncontrolled conditions. A three-phase electromotor of 30hp was used to move a carriage through the length of soil bin by means of chain system along with the wheel-tester when the carriage had the ability to traverse at the speed of about 20 km/hr. The output shaft of the electromotor was connected to the drive shaft of the chains that pull the carriage forward or reverse. An inverter providing variable frequencies was used to supply power of electromotor in order to reach varying velocities. Another advantage of this system is the facility of adjusting braking and starting acceleration of electromotor which results in decrease of inertia forces. Four S-shape transducers with the capacity of 200 kg were calibrated and then were placed at proper places horizontally in parallel pattern between carriage and single-wheel tester and these transducers were interfaced to data acquisition system included a data logger, enabled monitoring the data on a screen and simultaneously, the data were sent to a computer with frequencies of around 30 Hz. A single-wheel tester was assembled to the carriage system with four S-shape transducers to measure the rolling resistance alterations caused by motion of wheel in various treatments being tested. The utilized tire was Good year 9.5L-14, 6 radial ply agricultural tractor tire. The general system set up is shown in Fig. 1.

Figure 1- Soil bin system set up and including carriage and a single wheel-tester

The measured volume of soil bin was assessed to be 46 m^3 and consequently was filled with soil. To initiate the process, the electromotor generated power for the carriage movement based on adjusted velocity by an inverter by connection between the shafts of electromotor and chain system. An optic tachometer was used to measure the speed of carriage while an inverter could produce variety of velocities for the carriage. The movement of carriage by chain system generated traction of single-wheel tester in the soil bin and accordingly, transducers sent signals to the data acquisition system which were indicators of rolling resistance of wheel and eventually, data acquisition system enabled monitoring these data and also transferring them to the computer. Microsoft Office Excel was used to process, evaluate and determine the relation between velocity and rolling resistance. Fig. 2 illustrates the power transmission utilized in the soil bin facility.

Table 1-Summary of experiment conducted

Independent Parameters			Dependent Parameter	
Normal Load (kN)	Inflation Pressure (kP)	Velocity (m/s)		
1	100		0.7	
2			1.4	Rolling Resistance
3				
4				

Table 2- Soil constituents and its measured properties

Item	Value
Sand (%)	34.3
Silt (%)	22.2
Clay (%)	43.5
Bulk density (kg/m3)	2360
Frictional angle (°)	32
Cone Index (kPa)	700

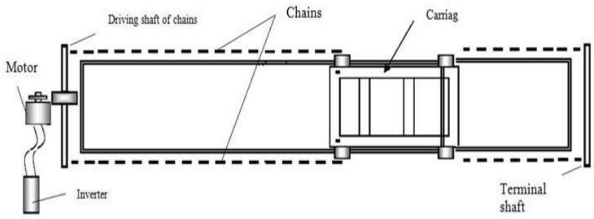


Figure 2- The power transmission system utilized in the soil bin facility

This experiment was conducted with the two velocities of 0.7, and 1.4 m/s at inflation pressure of 100 kPa and four different static loads of 1, 2, 3, 4 kN. Since soil surface is uneven, static load is source of varying dynamic load during the traversing time. Summary of treatments being tested is shown in Table 1.The soil bin was filled with clay-loam soil to simulate the real condition of farms that exists in most of regions in Urmia, Iran. Particular equipment were used to organize soil bed including leveler and harrow since it's very important to have well-prepared soil inside soil bin for acquiring reliable and precise results from this experiment. Soil constituents and its properties are defined in Table 2.

Results and discussion

Static wheel loads of 1, 2, 3, and 4 kN provided vibrating dynamic loads due to the tire non-uniformities and ground unevenness. The general process of dynamic load on tire is demonstrated in Fig.3. The initial excitation of dynamic load was induced and then caused varying rolling resistance. The vertical dynamics of the wheel-tester is strongly influenced by the soft soil inside soil bin facility. Fig. 4 clearly depicts these variations at four levels of static load exciting dynamic loads.

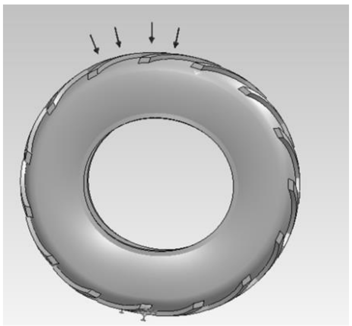
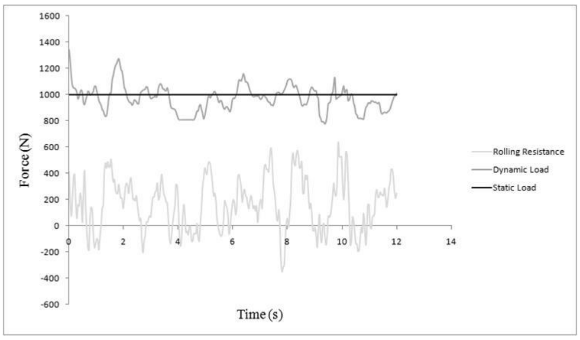


Figure 3- The general process of dynamic load distribution on the tire



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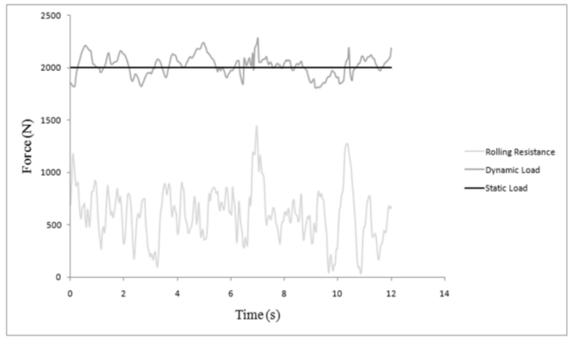

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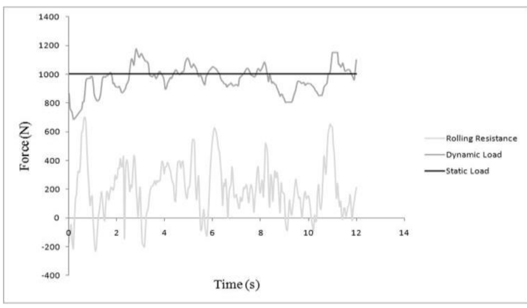

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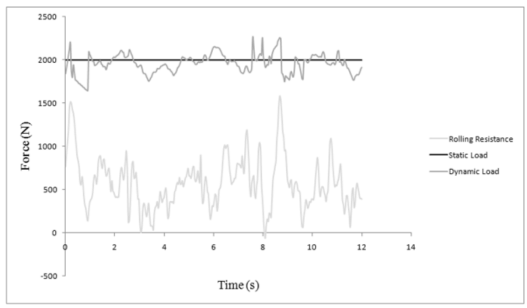
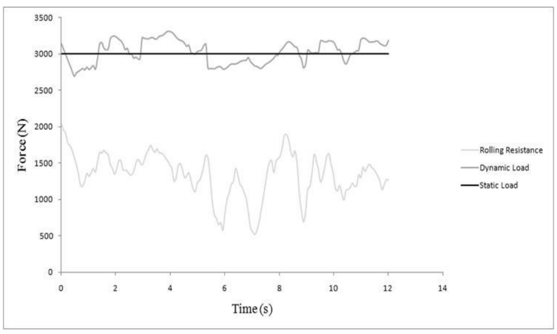


(d)

Figure 4- The variations of rolling resistance effected by varying dynamic load at a) 1 kN static load, b) at 2 kN static load, c) at 3 kN static load, and d) at 4 kN static load, respectively at 0.7m/s velocity



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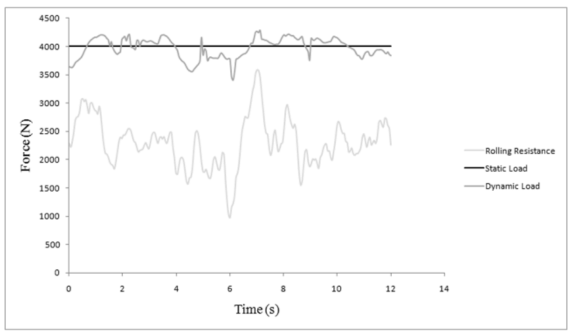

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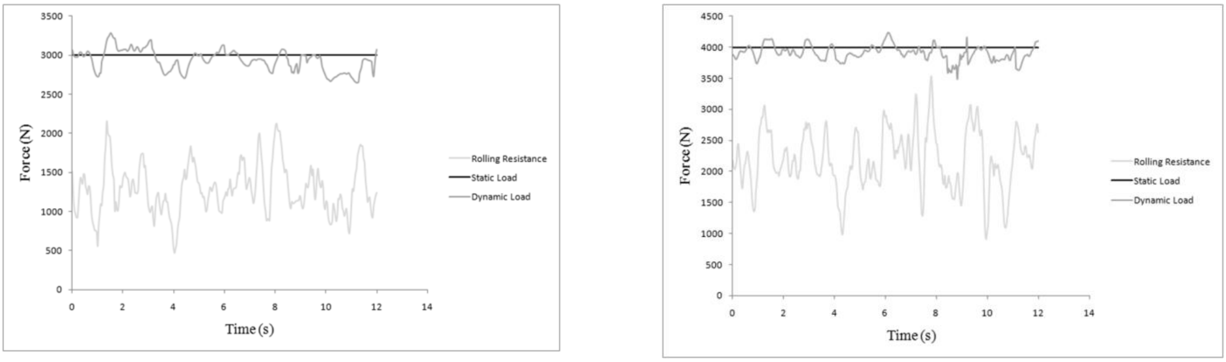

(c) (d)

Figure 5- The variations of rolling resistance effected by varying dynamic load at a) 1 kN static load, b) at 2 kN static load, c) at 3 kN static load, and d) at 4 kN static load, respectively at 1.4 m/s velocity

It is noticeable that small increase of dynamic wheel load causes more intensified vibrations of rolling resistance is not a function of velocities conducted in this study. Relative conformity between amplitude alterations exists between wheel dynamic load and induced rolling resistance. Amount of dynamic vibrations demonstrated for each of measurements are the sum of four horizontal load cells while the two upper ones were pulled and the lower were compressed. The small inclination of dynamic load brings about increased inclination changes of rolling resistance. It can be inferred that amount of dynamic wheel load was higher than rolling resistance almost at all of treatments. The valleys and peaks are nearly conforming while small excitation of dynamic load caused sudden change in rolling resistance. The observation indicates that the relation between wheel load and rolling resistance is non-linear while this relation is possibly better interpreted by polynomial with order of two suggested by Wismer and Luth as follows:

$$R = \frac{1.2}{CI.b.d} \times W^2 + 0.04W \tag{5}$$

Where W is vertical load, CI is cone index, b is width of tire, and d is wheel diameter. Furthermore, Fig.4 approves that rolling resistance increases by adding wheel load.

Fig.5 represents the same process in the case of second tested velocity at the same wheel loads generating dynamic wheel load. The same results can be inferred by observing Fig.4. The valleys and peaks are in conformity but with higher intensity of amplitude for rolling resistance vibrations. It should be noted that negative values of rolling resistance imply that the sum of forces’ direction is against the other ones. These results imply that in order to reduce rolling resistance and fuel consumption, dynamic load should be controlled by use of dampers and dashpots since any slight change in dynamic load generates intensified disadvantage of rolling resistance.

Conclusions

Single wheel-tester in a soil bin was utilized to investigate the influence of dynamic loads on induced rolling resistance. Each treatment was performed for the wheel passing through the length of soil bin while transferring data to the computer by four horizontal load cells and one vertical load cell to transmit dynamic wheel loads generated by non-uniformity of tire and unevenness of ground. It was revealed that by slight increase/decrease of wheel load, amount of rolling resistance increased/decreased with higher inclination. A relatively high conformity existed between valleys and peaks of dynamic wheel load and rolling resistance almost at all of tested treatments.

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بررسی اثر بار دینامیکی بر روی مقاومت غلتشی تایرهای تراکتور

چکیده

اثر متقابل بین بار دینامیکی روی چرخ و مقاومت غلتشی مورد مطالعه قرار گرفت. یک آزمونگر تک چرخ درون انباره خاک برای دستیابی به داده های تجربی استفاده شد و برای سنجش مقادیر بار دینامیکی روی چرخ و مقاومت غلتشی از لودسل های عمودی و افقی نصب شده بین حامل و آزمونگر تک چرخ استفاده شد. بارهای استاتیک در چهار سطح ۱،۲،۳و ۴ کیلو نیوتن و تحت سرعت های ۰/۷ و ۱/۴ متر بر ثانیه بر روی چرخ اعمال شد و در حین حرکت، تغییرات بار روی چرخ سنجش و ثبت گردید. نتایج نشان داد که تغییرات مقاومت غلتشی دارای تطابق با تغییرات بار روی چرخ می باشد.

واژه‌های کلیدی: بار روی چرخ، مقاومت غلتشی، آزمونگر تک چرخ، انباره خاک