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Analyses of energy dissipation of run-off-road wheeled vehicles utilizing controlled soil bin facility environment

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ABSTRACT

Management of nonrenewable energy sources is a worldwide concern particularly some of which refer to the consumption of fossil fuels. There is a great deal of energy loss in terramechanics at soil-wheel interface while the role of rolling resistance as a pronounced factor, was aimed to be assessed in this study under the effect of tire inflation pressure, forward velocity and wheel load in controlled condition of a well-equipped soil bin facility utilizing a single wheel-tester for provision of accuracy. Inflation pressure, velocity and wheel load varied at three, three and five different levels, respectively, forming forty-five treatments each of which with three replicates. The experimental results were analyzed using ANOVA (analysis of variance) and development of multiple regression analysis based model using the stepwise selection technique. Our results showed that increase of velocity led into increment of energy loss where increase of wheel load had paramount effect on the increase of the target parameter. The obtained results indicated that a decrease of inflation pressure from 350 kPa to 250 kPa decreased energy loss, however, further decreasing from 250 to 150 to an underinflated pressure, resulted in significant increment of energy loss.

1. Introduction

Rolling resistance is in essence the parasitic energy dissipated by the constant deflections of traversing tire accompanied by the soil deformation under acting load [1]. The phenomenon is quite complicated due to the elasto-plastic semi-infinite characteristic of soil medium interacted by stochastic wheel dynamics wherein mechanical energy is changed to heat [2]. The converted energy is the summation of the required energy to deform the rubber (elastic deformation) and/or the soil beneath the tire (plastic deformation) in motion added with friction in the bearings of wheel [3]. Rolling resistance performs as a resistive force applied to the wheel against the direction of traversing. Due to sinkage, wheels operating on soft soils must handle much superior resistance leading to greater waste of power. In another term, tire rolling resistance is expressed as the amount of energy required to keep tires rolling at a steady pace, and has a momentous impact on vehicle fuel efficiency. The California Energy Commission conducted a survey on light truck fleets and the impact of low-rolling resistance tires. Results revealed that should all light truck tires in California were changed to low-rolling resistance tires, and then the energy savings could be outstanding, about 1135623.53 m^3/y of gasoline, or approximately one thousand million US dollar [4]. This statistic emphasizes on the consequence of functional management of reduced rolling resistance on energy saving and due to scarcity of investigations in this realm, necessitates the attempts to be made in this regard. There are also some studies dealt with energy system assessments of agricultural vehicles in this regard. An investigation was carried out where inorganic and organic soil N amendments consisting of none, inorganic fertilizer at 100 and 200 kg ha^{-1} N, and SM (stockpiled manure) and RM (rotted manure) at 50 and 100 Mg ha^{-1} (wet weight) were yearly used to corn farms for 18 years [5]. Subsequently, Mouldboard plough draught and tractor fuel consumption were quantified during annual fall tillage in selected years. In Ref. [6], the energy balance and economic analysis between inputs and output of seed corn production in different harvesting systems in Iran was assessed which indicated that the highest total energy input and output corresponded to the two stage harvesting system (using picker-husker) in comparison with other harvesting systems (combine and plot-harvester harvesting). Furthermore, the sustainability and efficiency of corn production with regard to energy consumption in the Fars province, Southwest Iran, was evaluated employing fuzzy modeling and DEA (Data

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Nomenclature

b	width of plate (m)
E_L	energy loss (J)
FV	forward velocity (m/s)
GT	gross traction (N)
k_c	soil sinkage coefficient
k_ϕ	soil sinkage coefficient
l	length of plate (m)
N	normal load (N)
NT	net traction (N)
P	tire inflation pressure (kPa)
P_a	vertical average contact pressure (kPa)
P_{max}	vertical maximum contact pressure (kPa)
P_o	power (W)
R^2	coefficient of determination
RF	resultant of the surface reaction force (N)
RR	rolling resistance (N)
RF_v	vertical component of the surface reaction force (N)
T	input torque acting on wheel (N m)
V	velocity (m/s)
W	wheel load (kN)
W_o	work (J)
z	sinkage of soil profile (m)
z_0	maximum sinkage (m)
ω	tire angular velocity (rpm)

Envelopment Analysis) [7]. Considering a portion belonging to the first selected cluster, it was reported that the current corn production system is not sustainable in the test location.

The acting forces are illustrated schematically in order to achieve a better insight into on-the-go condition of an off-road wheel. According to Fig. 1, the GT (gross traction) is the summation of NT (net traction) and RR (rolling resistance) [8]. It is noteworthy that the initiating of wheel movement is provided by the applied torque powered by the engine to form tractive force in contrast to rolling resistance. Furthermore, Bekker [9] laid foundation on quantification of rolling resistance from mechanical strength of soil viewpoint and assumed that at the tire-soil contact patch, wheel typifies a continuously penetrating plate up to a depth of soil equal to formed rut depth of wheel under applied loading. Equations (1)–(7) proposed by Bekker [9] deal with calculation of energy loss as following.

$$P_a = \left(\frac{k_c}{b} + k_\phi\right)Z^n \tag{1}$$

where P_a is the vertical average contact pressure, z is sinkage of soil profile, b is width of plate, and k_c and k_ϕ are soil sinkage coefficients and n is a sinkage exponent derived from sinkage tests. Hence, the work required to penetrate the plate into soil may be described by:

$$W_o = bl\int_0^z P\mathrm{d}z \tag{2}$$

Inserting Eq. (1) in Eq. (2):

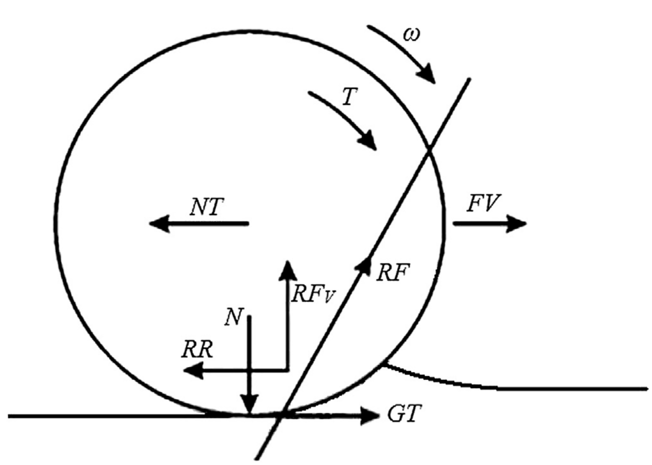

Fig. 1. Basic velocities and forces on a wheel, including resultant soil reaction force [8].

$$W_o = bl\left(\frac{k_c}{b} + k_\phi\right)\int_0^z z^n\mathrm{d}z = l\frac{\left(k_c + bk_\phi\right)}{n+1}z_0^{n+1} \tag{3}$$

where W_o is the representative of work for the load of N (kN) acting on the plate at the maximum sinkage of z_0:

$$N = blP_{max} \tag{4}$$

where P_{max} is the vertical maximum contact pressure. By replacing Eq. (1) in Eq. (4),

$$N = bl\left(\frac{k_c}{b} + k_\phi\right)z_0^n \tag{5}$$

Hence,

$$z_0 = \left[\frac{N}{l\left(k_c + bk_\phi\right)}\right]^{\frac{1}{n}} \tag{6}$$

Replacing Eq. (6) in Eq. (3) we can attain wasted energy as deformation of soil profile as:

$$W_o = \frac{l\left(k_c + bk_\phi\right)}{n+1}\left[\frac{N}{l\left(k_c + bk_\phi\right)}\right]^{\frac{n+1}{n}} \tag{7}$$

However, this can be a simplified description of real-term energy dissipation as a result of rolling resistance since tire deflection should also be considered for dynamic and on-the-go condition.

In literature, numerous attempts have been made to further contribute the qualification and quantification of rolling resistance so far experimentally and analytically. However, mathematical equations are afflicted to unavoidable simplifications, as previously mentioned, and overlooking some factors (e.g. bearing friction), thus approaching to correct insight to energy loss underlies the extensive experimentations. Hence, the authors of the present study in a previous experimental attempt were encouraged to study the effect of tire parameters on rolling resistance and related the amount of rolling resistance to contact area which could be an applicable index for determination of rolling resistance [10]. Coutermarsh in a hybridized analytical and experimental work presented data from rubber tire rolling resistance measurements in three depths of uniform-density dry sand at velocities from 2.1 up to 18 m/s and three load ranges from 4.53 to 10.26 N [11]. He mentioned that in dry sand the rolling resistance increases with velocity until a peak and then it levels off or is controlled by wheel load. Kurjenluoma et al. [1] investigated the correlation between