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Differences in tractor performance parameters between single-wheel 4WD and dual-wheel 2WD driving systems

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Abstract

Vertical wheel load and tire pressure are both easily managed parameters which play a significant role in tillage operations for limiting slip which involves energy loss. This aspect to a great extent affects the fuel consumption and the time required for soil tillage. The main focus of this experiment was to determine the effect on the wheels' slip, the fuel consumption and the field performance of a tractor running in a single-wheel 4WD driving system and in a dual-wheel 2WD driving system, due to the variations in air pressure of the tires as well as in the ballast mass. With no additional mass, the lowest fuel consumption was reached by a tractor with the least air pressure in the tires and running in a dual-wheel 2WD driving system. It was determined that for a stubble cultivation with a medium-power (82.3 kW) tractor running in a dual-wheel 2WD driving system, the hourly fuel consumption was by 1.15 L h^{-1} (or 7.3%), the fuel consumption per hectare by 0.35 L ha^{-1} (or 7.9%) and the field performance by 0.05 ha h^{-1} (or 1.25%) lower compared to a single-wheel 4WD driving system, when driving wheels' slip for both modes was the same, i.e., at 8–12%.

Keywords: Tractor; Slip; Fuel consumption; Ballast weight; Tire pressure; Single-wheel; Dual-wheel; Driving system

1. Introduction

Tractors for farming are used throughout the year, with diverse implements to conduct different field operations. Tractors are considered the main machines that generate power for field operations in agriculture. Draft of a wheeled tractor, which is an important index of power efficiency, is a result of stress–strain interaction between the tractor wheels and the topsoil. Research shows that 20–55% of tractor's power can be lost in the process of interaction between the tires and the topsoil because of the slip and the rolling resistance (Taghavifar and Mardani, 2014a; Taghavifar et al., 2014; Šmerda and Čupera, 2010; Muhsin, 2010). This is not simply a wasted power – it creates a soil compaction, which may be detrimental to crop production (Grečenko and Prikner, 2014; Patel and Mani, 2011). Traction ability of any tractor depends on the following main factors: tractor's mass, contact area between traction tires and the soil surface, hitch points, type of mounted implements, traction control and other relevant systems, and, naturally, the soil strength (Battiato and Diserens, 2013; Molari et al., 2012; Zoz and Grisso, 2003). Agricultural tractors commonly employ fo ur-wheel-drive/mechanical-front-wheel-drive (4WD/MFWD) transmissions. Four-wheel drive tractors with front wheels smaller than the rear wheels are known as MFWD. Since the traction performance of a tractor has a major impact on both fuel consumption and the time required for soil til lage, optimizing this performance is clearly of crucial impor tance in tillage management (Damanauskas et al., 2015; Backman et al., 2013; SAE, 2006).

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Fuel consumption of the tractor is highly dependent on the engine speed and load characteristics. In most cases, the most productive and cost-effective work is obtained when the engine load is less than 80% of its rated power and the engine speed does not exceed 80% of its rated speed (Zoz and Grisso, 2003; Janulevičius et al., 2013). In order to reach maximum economic efficiency of farming works, tractors with higher pulling power are unavoidable for usage. Narrow operational speed ranges are recommended for the tractors that perform agricultural operations. Deviations from the operational speed deteriorate quality of work and increase power consumption. Example, when recommended speed (8–10 km/h) is exceeded for soil tillage, the dynamic effect on the soil increases, which adds to power consumption (Barbosa and Magalhaes, 2015; Vantsevich, 2014; Moitzi et al., 2013; Hashemi et al., 2012). In order to effectively use the engine power and not to deviate from the operational speed, the engine has to be loaded with higher traction force, i.e., working width has to be increased. As a rule, when a tractor is loaded with high traction force, the slip of driving wheels increases. Usually, driving wheels' slip should not exceed 15–16%. Anything above results in lower field performance, less economy, and increased disruption of the soil structure (Battiato et al., 2013; Grečenko, 2010). Too low slip (less than 5–7%) of drive wheels in the soil is also unacceptable. Low slip occurs when the drive wheels are under excessive force of gravity. In this case, power is wasted on carrying excess weight and pressing the soil which can lead to increase in fuel consumption of up to 15%. Fuel consumption for carrying excess weight increases significantly when working speed is increased (Janulevičius and Giedra, 2008; Taghavifar and Mardani, 2014). Analysis of research materials shows that optimal tractor slip in soil should be in the range of 8–12% (Damanauskas et al., 2015; Moitzi et al., 2013; Battiato et al., 2013). The wheel slip is a critical parameter for the fuel consumption and the field performance.

1.1. Adjustment of wheels slip

To adjust the slip, various ways are pointed out in terramechanics. One way is to increase tractor's mass by adding ballast weight. Ballast weight can be added to the tractor in different ways: by fitting front ballast weights; by fitting weight on the front hydraulic lift of the tractor; weights can be mounted on tractor's wheels; weights can be mounted to the bottom of the tractor; tires can be filled with liquid ballast. In tillage works draft can be increased by up to 15% depending on the value of ballast weights and the place where they are mounted (Muhsin, 2010; Serrano et al., 2009, 2007). But this method has a very important drawback – a danger always remains of excessive compacting of the soil and damaging its structure at great depths (much deeper than it is tilled), which can reduce soil productivity (Grečenko and Prikner, 2014; Barbosa and Magalhaes, 2015). Too much ballast weight on the tractor means wasting fuel due to increased rolling resistance, increasing wear of drive train and pressing the soil. When the ballast weight is less than optimal, it means the tractor will waste fuel due to excessive tire slip, which also will cause premature tire wear (Lacour et al., 2014; Pranav and Pandey, 2008).

The other way to adjust the slip is to increase the contact area between tires and the supporting surface. Currently, more and more tractor performance researchers recommend reducing the air pressure in the tires (Šmerda and Čupera, 2010; Battiato and Diserens, 2013) or using dual wheels (Molari et al., 2012; Damanauskas et al., 2015), thus increasing contact area between the tires and the ground. It means that tractor's weight is spread across a larger area, reducing pressure on the soil. Driving wheels less "sink" into the soil, tracks are not so deep and the rolling resistance is reduced (Nam et al., 2010). Depending on the tractor, tire size and type, the pulling force may be increased by up to 8% (Sumer and Sabanci, 2005; Elwaleed et al., 2006; Taghavifar and Mardani, 2013). However, if 4WD tractor performs pulling works with low pressure in the tires, the risk of disproportionate deformation of the tires increases. Disproportionate deformation of tires changes the rolling radiuses, creates kinematic mismatch of the driving wheels, and changes the front-wheels' lead (Molari et al., 2012; Vantsevich, 2014; Janulevičius et al., 2013, 2014; Stoilov and Kostadinov, 2009). When the tractor was used with higher air pressures in the tires, slight reduction in working productivity (3–5%) and a significant increase in fuel consumption per hectare (10–25%) was obtained, even for good traction conditions as demonstrated by the interval of slip values (7–15%) Serrano et al., 2007; Zoz et al., 2002.

The advantages of dual wheels for agricultural tractor are obvious: more pulling power, reduced compaction of soil, greater fuel efficiency and less wear of tractor parts. For four-wheel drive tractors, dual tires increased the pull/weight ratio at a given slip level when compared to singles. When operating with duals instead of singles, overall tractor efficiency was increased by 15%, while specific fuel consumption was decreased by averagely 13% (Zoz and Grisso, 2003; Sumer and Sabanci, 2005).

The wheels' slip can be also reduced with a traction control and other relevant systems. The research shows that traction control system for work with plough reduces the fuel consumption by 10–12% (Moitzi et al., 2013; Serrano et al., 2007).

1.2. Weight distribution between the axles

Not just overall weight of the tractor, but also the weight distribution between the axles has a huge impact on tractor performance. Optimal distribution may vary considerably for different tractor types, hitch points and mountings of implements. MFWD tractors require more weight on the front axle than 2WD tractors to provide traction for the powered front wheels. In case of 2WD tractors, the front