

Field performance of an agricultural tractor fitted with rubber tracks on a low trafficable soil

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Abstract

The introduction of rubber tracks on tractors has allowed more engine power per unit weight than with steel-tracked tractors, together with a reduction in soil compaction and higher on-road speeds. Recently, triangular rubber tracks able to be adapted on conventional wheeled tractors have been introduced. In this context, the goal of the paper is to evaluate the performance of a tractor with four triangular rubber tracks with respect to those of a wheeled tractor; the comparative tests consist of ploughing under on low trafficable and workable soil. The results obtained have shown a higher tractive efficiency, lower soil compaction and up to 20% lower specific fuel consumption for the fully tracked tractor. These results are in accordance with previous tests conducted with the triangular rubber tracks on highly trafficable soil, although in the present case, the dynamic traction ratio is markedly lower due to the low trafficable soil. The use of triangular rubber tracks is therefore justified on low trafficable soils and more in general on different soil conditions, since the soil is less compacted by such traction device.

Introduction

In the past 40 years the average farm size has increased in Europe,

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so farmers need more powerful machines in order to increase farm productivity and to reduce production cost (Dieter Kutzbach, 2000; Mattetti *et al.*, 2015). For this reason, tractor manufacturers have developed more and more powerful and therefore heavier machines, which exert high loads on the soil and consequently produce high soil stresses. Soil compaction, which is considered to be one of the biggest causes of agricultural soil degradation, determines a crop yield reduction, an increase in soil erosion, and a higher fuel consumption due to the higher tire rolling resistance (Håkansson and Reeder, 1994; Batey, 2009; Chamen *et al.*, 2015).

Soil compaction can be reduced by controlling tires inflation pressure, tractor ballasts weight and using tractors equipped with traction devices with larger footprints, such as tracks. Tracked tractors allow to increase the drawbar pull and to reduce the vehicle slip with respect to wheeled tractors (Zoz and Grisso, 2003; Schjønning *et al.*, 2008). Tractors with steel tracks are falling in disuse and being substituted by tractors with belted rubber tracks, since the latter allow higher on-road mobility and travelling speed (Renius, 1994). In spite of the lower soil compaction, tracked tractors have higher internal resistance with respect to wheeled ones; these may reduce traction efficiency and, consequently, increase the fuel consumption (Bekker, 1956; Turner *et al.*, 1997; Wong, 2001). Recently, triangular rubber tracks, that can be easily mounted on a conventional tractor to increase the drawbar pull, have become available on the market (Ansoorge and Godwin, 2007, 2008, 2009; Arvidsson *et al.*, 2011; Molari *et al.*, 2012). These tracks increase the flexibility of conventional tractors because they can be installed in case of low trafficable soils to improve the vehicle floating on the soil. This type of tracks might have lower internal resistance because they are manufactured with a lower number of moving parts than belted tracks.

In this context, the goal of the paper is to evaluate the performance and the fuel efficiency of a tractor with four triangular rubber tracks by comparison with those of a conventional wheeled tractor during ploughing under on low trafficable soils.

Materials and methods

The tractors used in the tests were the Case Puma 210 fitted with four driving wheels and set with liquid in wheels and front ballast (TA) and the New Holland T7060 fitted with four triangular rubber tracks (TB) (Figure 1). The two models of the same manufacture, dimensions and technical specifications, were fitted with the same engine and full power shift transmission with 19 forward ranges and 6 reverses.

The TB was fitted with front and rear rubber track devices, characterized by a mass of 1300 kg and 2400 kg respectively. Each front and rear track produced a theoretical contact area of about 0.890 m² and 1.713 m² respectively, instead each front and rear tire produced a theoretical contact area of about 0.116 m² and 0.158 m² respectively (Grečenko, 1995). The characteristics of the two tractors are reported in Table 1 and the two tractors have the same load distribution on the

axles. The tests were performed on a farm in Medesano, Parma, Italy in March 2011. The test field, was not worked for 5 years and was preliminarily worked with a ripper in the previous autumn, to facilitate the soil drainage. The tests were carried on a clay loam soil, according to the United States Department of Agriculture (USDA), soil consistency was evaluated on the basis of the Atterberg's limits (plastic limit = 25% and liquid limit = 43%), the moisture content on dry basis averaged on the first 0.20 m of soil (between 27 and 31%) (ASTM, 2010). The soil in which the tests were performed was therefore a low trafficable soil with

a consistency index included between 0.66 and 0.89 (Müller *et al.*, 1990). For the ploughing, a mouldboard plough with three bottoms, two ways, semi-mounted hitch was used. The mouldboard plough was connected to the tractor through a three-point hitch coupler (ASAE, 2003) on which 3 transducers (HBM, Type U1/10T) were fitted to measure the traction load (Figure 2). To compare the performances of the two different solutions, the ploughing took place at three different depths (h) with the same width (b). For each thesis (2 tractors and 3 depths), 20 repetitions with a length equal to 300 m each, were performed.



Figure 1. Tractors used in the tests: on the left the tracked tractor, on the right the wheeled tractor.

The volume of soil worked for each repetition was calculated by measuring the depth and width on the basis of 14 points of measure. The working time for each repetition was measured; the average speed (v) and the hourly volume of soil worked (V_h) were calculated.

The slip (s) was evaluated according to the Organisation for Economic Co-operation and Development (OECD) code 2 (OECD, 2012). The fuel consumption was measured with a volumetric transducer fitted on the fuel input (model fto-3ax; Flow Technology Inc., Tempe, AZ, USA).

These parameters were recorded with an acquisition card (model e-corder; eDAQ Inc., Colorado Springs, CO, USA) at a frequency of 50 Hz; the average traction load (T) and the average hourly fuel consumption (Q_h) were calculated for each repetition. Finally, the specific fuel consumption (Q_s) and the drawbar power (P_g) were calculated:

$$Q_s = 10^3 \rho_f Q_h V_h^{-1} \quad (\text{g m}^{-3}) \quad (1)$$

$$P_g = 10^{-2} T v \quad (\text{kW}) \quad (2)$$

where fuel density ρ_f was equal to 0.838 g cm^{-3} .

The effect of the vehicles transit on soil compaction was evaluated by measuring the bulk density on dry basis and the cone index (CI) values. The bulk density on dry basis was measured in the topsoil with the cylinder method (diameter 0.050 m, height 0.050 m). The CI was calculated on a depth of 0.150 m with a standard soil cone penetrometer with a head diameter of 0.020 m (ASAE, 1986, 1999). The dynamic traction ratio (A_d) and the slip efficiency (S_e) were evaluated by:

$$A_d = T/m_a \quad (\text{kg/kg}) \quad (3)$$

$$S_e = 1 - s \quad (\text{ms}^{-1}/\text{ms}^{-1}) \quad (4)$$

where m_a is the static load on the driving axles. All the measures were performed in the forward direction of the tractor in correspondence to the marked area before and after the tillage in correspondence of the transit lines not ploughed. The values were calculated on the basis of 20 repetitions for each thesis.

Results and discussion

The results of the tractive tests on working conditions are reported in Table 2, where, besides the length and depth of the ploughed section, the traction parameters as the slip and the traction load, and the operative parameters as the speed and the fuel consumption, are reported.

In the limited conditions indicated, the higher working depth was acquired with the tracked tractor, equal to 0.48 m, while with the wheeled tractor the maximum depth was equal to 0.44 m. At these depths the traction loads were around 80 kN for the tracked tractor and 66 kN for the wheeled one with a slip for the wheeled tractor twice that of the tracked one. In these conditions the slip efficiency was 84% for the tracked tractor and 69% for the wheeled one. For the other two working depths, basically equal for the two configurations, with an equivalent traction load, the slips of the wheeled tractor were three times that of the tracked one.



Figure 2. Three-point hitch device coupler.

Table 1. Tested tractor configurations.

Tractor	Max power (kW)	Max torque (Nm)	Total mass (kg)	Static load on the front axle (%)	Front tire	Front track (mm)	Rear tire	Rear track width (mm)
TA	180	984	14,100	42%	Goodyear Optitrac DT818 540/65 R30 (16 kPa)	2334	Goodyear Optitrac DT818 650/65 R42 (16 kPa)	2334
TB	180	984	14,100	40%	Tidue Amfibios 24D18 (belt 610 mm width)	2984	Tidue Amfibios 30/36Q23M (belt 915 mm width)	3015

Table 2. Working parameters.

Tractor		h		b		v		s		T		Q_h	
		M	St.dev.	m	St.dev.	m s^{-1}	St.dev.	%	St.dev.	kN	St.dev.	l h^{-1}	St.dev.
TA	h1	0.39	0.02	1.35	0.01	1.52	0.05	19.8	2.1	47.26	224	39.52	0.53
TA	h2	0.43	0.01	1.35	0.01	1.06	0.04	27.8	1.3	61.67	172	39.58	0.68
TA	h3	0.44	0.02	1.35	0.01	0.95	0.05	31.2	3.1	66.13	323	40.14	0.74
TB	h1	0.38	0.02	1.35	0.01	1.84	0.05	6.2	2.2	47.45	155	39.72	0.75
TB	h2	0.42	0.01	1.35	0.01	1.43	0.05	9.2	1.4	61.88	162	39.79	0.39
TB	h3	0.48	0.01	1.35	0.01	1.01	0.04	16.1	1.8	80.16	220	39.21	0.61

St.dev., standard deviation.

The results in terms of slip and dynamic traction ratio obtained with the tracked tractor on the soil in plastic conditions can be compared with those obtained by Molari *et al.* (2012) with the same tractor on a highly trafficable soil. With reference to the wheeled tractor, while on the highly trafficable soil (Molari *et al.*, 2012), an increasing of the slip around 5% was necessary to obtain the same dynamic traction ratio of

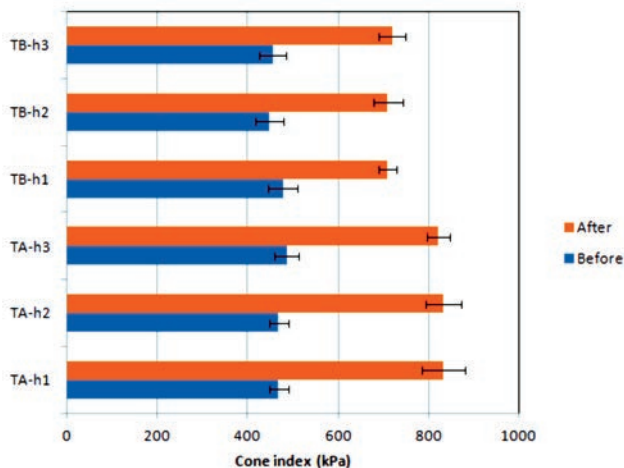


Figure 3. Cone index on dry basis (error bars indicate standard deviation) before and after the passage of the tractor for each test.

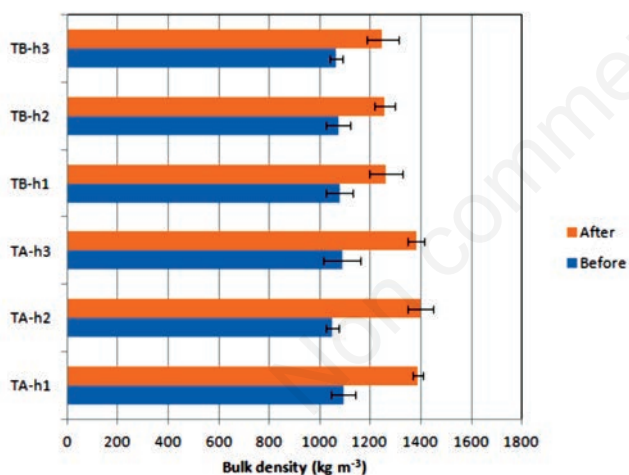


Figure 4. Bulk density on dry basis (error bars indicate standard deviation) before and after the passage of the tractor for each test.

the tracked tractor, in the soil of the present study, an increasing of the slip of about 18% was necessary to achieve the same dynamic traction ratio of the tracked tractor.

With respect to the speed, for the wheeled tractor a relevant reduction from the depth h1 to the depths h2 and h3 with a reduction upper than 30% was evident, while for the tracked tractor the decreasing speed was more graduated on the three levels with a reduction of 22% between h1 and h2, and of about 29% between h2 and h3. In any case it is evident that the working speeds of the tracked tractor are on average higher than those obtained with the wheeled tractor. The comparison of the traction power in the two configurations show a difference of about 20% in favour of the tracked tractor (Table 3).

The theoretical working capacity measured in terms of hourly volume worked, showed a difference of about 15% in favour of the tracked tractor in the first depth and of about 25% on the second one. For the third depth, the difference was around 15% always in favour of the tracked tractor, despite being obtained with a higher depth. These differences were reproduced in the same way for the specific fuel consumption, with a difference for the tracked tractor up to 20% in three working conditions.

The analysis of the interaction between the locomotion systems and the soil is strictly connected with the plastic condition of the soil and the moisture content of around 30%. Indeed the consistency status was confirmed by the CI values of the soil before the transit of the tractors, included between 450 and 480 kPa without significant differences in the different thesis (Figure 3).

With reference to the aggregation status of the soil before ploughing, values between 1050 and 1090 kg m⁻³ were recorded without significant differences between the different theses (Figure 4).

As expected and coherently with the results obtained in other experimental conditions (Arvisson *et al.*, 2010; Molari *et al.*, 2012), the soil compaction obtained after the passage of the fully tracked tractor was consistently lower than that obtained with the wheeled tractor. Indeed with reference to the CI the average value obtained with the tracked tractor was around 710 kPa with respect to 830 kPa for the wheeled one. While the average bulk density was 1250 kg m³ for the tracked tractor and 1390 kg m³ for the wheeled one.

Conclusions

The results obtained from the performance comparison between a fully tracked tractor and a wheeled tractor in field tests on a low trafficable soil show a higher performance for the tracked tractor in terms of tractive efficiency, soil compaction and fuel consumption. In these conditions the tracked tractor allows to realise higher traction loads with respect to the wheeled tractor and with the same traction load it shows a slip three times lower. Moreover the tracked tractor realised lower

Table 3. Results obtained in the different configurations tested.

Tractor	<i>h</i>	<i>A_d</i>	<i>P_g</i> (kW)	<i>V_h</i> (m ³ h ⁻¹)	<i>Q_s</i> (g m ⁻³)
TA	h1	0.33	71.8	2881	11.5
TA	h2	0.43	65.4	2215	15.0
TA	h3	0.47	62.8	2031	16.6
TB	h1	0.37	87.3	3398	9.8
TB	h2	0.44	88.5	2919	11.4
TB	h3	0.57	81.0	2356	13.9

fuel consumption up to 20% than the wheeled tractor.

The tests performed confirm the performances obtained in previous experiences with the tracked tractor on a trafficable soil with a consistent reduction of the dynamic traction ratio that justify the use of these systems on low trafficable soil. The results obtained in these soil conditions show an increasing of the speed and a higher availability of traction power for the tracked tractor with respect to the wheeled one.

In conclusion, the installation of rubber triangular tracks on conventional tractors, especially on low trafficable soils, is a good practice to increase the traction efficiency and to reduce the fuel consumption.

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