

Review Paper

Effect of tillage speed, depth, ballast weight and inflation pressure in the tires on the fuel consumption of the agricultural tractor: A review

ABSTRACT (ARIAL, BOLD, 11 FONT, LEFT ALIGNED, CAPS)

Tillage is a very important practice in agriculture and accounts for more traction energy than any other field operation. It consumes up to 59% of all diesel fuel required for the complete technology so reduced tractor fuel consumption during tillage will result in both environmental and agricultural economic benefits.

Several attempts have been made to study the fuel consumption of the agricultural tractor in order to minimize it to acceptable levels during the tillage operations. Moreover, several studies have found many operating conditions that can affect the tractor fuel consumption significantly such as: tillage speed, depth, ballast weight and inflation pressure in the tires of the tractor. This article reviews the relationship between them which gives possibility for further research to focus on the potential solutions to decrease the fuel consumption of the agricultural tractors.

Keywords: Tractor; fuel consumption; speed; tillage depth; ballast weight; inflation pressure

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1. Introduction

Soil tillage is a very important practice in agriculture (Mamkagh, 2009a) and is one of the most energy consuming operation in agricultural production (Moitazi et al., 2013), (Moitazi et al., 2006); its efficiency is measured by the power consumption (Bentaher, 2013), and is the most agricultural practices that consumes fuel (Mamkagh,

2002a), (Mamkagh, 2007). Plowing as a part of tillage also accounts for more traction energy than any other field operation and often determines the size of the suitable tractor. It consumes from 29% to 59% of all diesel fuel required for the complete technology (Egidijus Sarauskis et al., 2016).

Reduced tractor fuel consumption during tillage will result in both environmental and agricultural economic benefits. Therefore, the issue of reducing the fuel consumption of the tractor during tillage have been investigated and reported by many researchers. There are many methods to decrease tractor fuel consumption during tillage. One of them is the wheel slippage reduction to the minimum. Great slippage deteriorates the structure of soil and increases fuel consumption. Therefore, the issue of reducing the tractor wheel slippage during tillage have been investigated and reported by many researchers (Mamkagh, 2009 b and c).

Estimating the amount of fuel consumption of the tractor will help in selection of the best conservation practices for farm equipments. (Abbaspour-Gilandeh et al., 2009)

Implement energy requirements vary greatly with soil type, soil moisture, soil density, previous treatment, ground cover, and operation speed and depth (Michel et al., 1985).

2. Tillage Speed

In general, the faster the speed of field operation, the more fuel is consumed. Tractors should not, however, be driven slowly just to save fuel, because in saving fuel, time required for the operation may be considerably greater. However, if implements are matched to tractor size, then the normal range of operating speeds (4 to 7 MPH) will often produce the most efficient fuel usage (Helsel, 2007).

Tractors using faster field speeds (e.g., 6–7 mph instead of 4–5 mph) have optimal fuel efficiency using slightly less weight because they do not need to pull quite as much load to accomplish an equivalent amount of fieldwork in a given time (Hanna and Sanford S., 2015).

Fig. 1 from the work of Adewoyin and Ajav (2013) shows how much the plowing speed affects the fuel consumption of the agricultural tractor. An increase of tractor speed from 5.5 to 6.5 km.h⁻¹ resulted in an increase of fuel consumption by 4.25 L (21%), while increase in from 6.5 to 7.5 km.h⁻¹ increased tractor fuel consumption by 2.98 L (12%).

Fig. 2 from the work of Tayel et al., (2015) also shows how the tractor forward speed can affect the fuel consumption during tillage operations. When the tractor speed increased from 1.79 km.h⁻¹ to 9.6 km.h⁻¹ the fuel consumption increased from 3.45 L/fed to 7.13 L/fed.

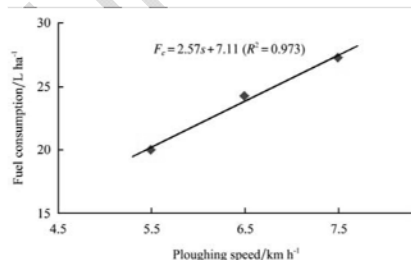


Fig. 1. Tractor fuel consumption as a function of ploughing speed; Adewoyin and Ajav (2013).

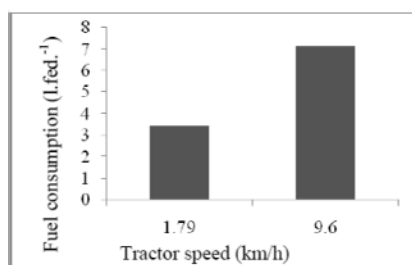


Fig. 2. Effect of tractor speed (km.h⁻¹) on fuel consumption (L.fed⁻¹); Tayel et al. (2015).

Hanna and Schweitzer (2014) studied the effects of energy management techniques on tractor fuel consumption during spring and fall field operations where the fuel measurements during chisel plowing were made at three different travel speeds as in Table 1. It shows a linear correlation between tractor travel speed and fuel consumption during chisel plowing.

Table .1. Chisel plowing at different travel speeds; Hanna and Schweitzer (2014)

Operation	No. of replications	Trt travel speed, mph	Gal/acre
Chisel plowing	3	4.6	0.91
	3	5.1	0.96
	3	5.5	1.10
LSD $\alpha=0.05^a$			NS ^b

^aLeast significant difference between treatments at a 95% confidence level.

^bNo significant difference at the 95% confidence level.

Abbaspour-Gilandeh et al. (2006) investigated the energy requirement of site-specific and conventional tillage as affected by tractor speed and soil parameters. The results indicate that the draft force increased with an increase in tractor speed in all soil types. Also, the results showed a strong correlation between the tractor speed and fuel consumption (L/ha⁻¹) in each soil types.

When the effect of speed, tillage and tilt angles on fuel consumption during disk plowing was studied by Mamkagh (2002b) it was found that the fuel consumption was increased from about 16 to 18 Liter/hectare when forward speed increased from 5.5 km.h⁻¹ to 9 km.h⁻¹.

3. Tillage Depth

Another important factor that affects fuel consumption is tillage depth. Increasing tillage depth also means more work which needs more fuel (Hunaiti and Mamkagh, 2003), (Helsel, 2007). With increasing working depth, the drawbar pull rises and also the tractor wheel slippage thus increase the tractor fuel consumption (Fathollahzadeh et al., 2010).

However, the tillage depth had the greatest effect on the draft and drawbar power than the tractor speed. The draft force increased as the travel speed increased in all soil types but the tillage depth had greater effect on the draft and drawbar power than the tractor speed during tillage (Abbaspour-Gilandeh et al., 2006).

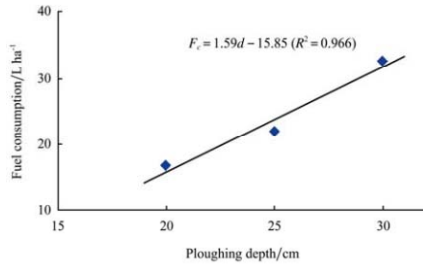


Fig. 3 Tractor fuel consumption as a function of ploughing depth; Adewoyin and Ajav (2013).

From the work of Adewoyin and Ajav (2013) fig. 3 shows how the plowing depth affects the fuel consumption of the tractor. The fuel consumption value increased by 5.23 L (31%) when plowing depth increased from 20 to 25 cm and it increased by 10.65 L (48%) when depth increases from 25 to 30 cm.

Table 2. Fuel consumption measured for two moldboard bottom types at different depths at a width setting of 450 mm on a Sainte-Rosalie clay soil; Plouffe et al. (1995), part of table II.

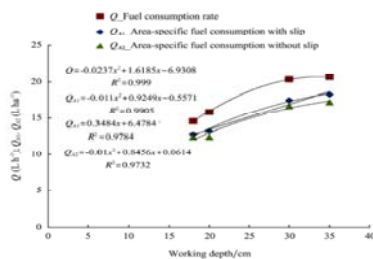
Set depth (mm)	Fuel consumption (L.h ⁻¹)	
	Short bottom	Long bottom
139	23.6 a	21.0 a
170	24.2 b	22.8 b
189	25.1 c	23.8 c
201	26.3 d	25.0 d
223	29.3 a	27.8 e

Means followed by same letter in the same row and the same column are not significantly different (Duncan new multiple range test at $\alpha=0.1$).

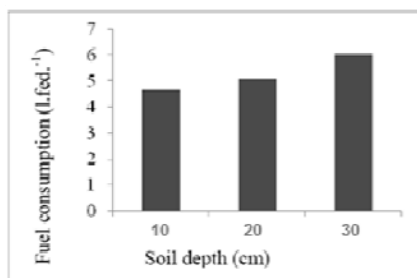
Table 2 shows, from the work of Plouffe et al. (1995), the effect of tillage depth on the measured tractor fuel consumption when the moldboard plow was operated with two bottoms one long and one short. This demonstrates that tillage depth has a significant effect on tractor fuel consumption and the consumption between the two bottom types was significantly different. Results also indicate that the long bottom reduced the fuel consumption by 6% relative to the short model.

Figure 4 from results of Moitazi et al. (2014) shows the effect of working depth on fuel consumption rate, area-specific fuel consumption with wheel slippage and area-specific fuel consumption without wheel slippage. The figure clearly demonstrates that all amounts of fuel consumed were increased with the increase in the depth of tillage.

When they studied the effect of plowing conditions on fuel consumption Tayel et al. (2015), similar results were found as shown in figure 4.



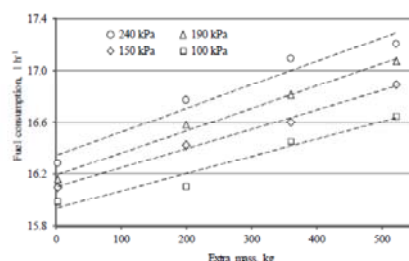
143 Fig. 4. Fuel consumption and ($L.h^{-1}$) and area specific fuel consumption ($L.h^{-1}$) as a function of
 144 working depth for ploughing; Moitazi et al. (2014).
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146 Fig. 5. Effect of depth (cm) on fuel consumption ($L.fed^{-1}$); Tayel et al. (2015).
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149 4. Effect of ballast weight

150 Loading the tractor with ballast weight can reduce wheel slippage (Algirdas
 151 Janulevicius and Vidas Damanauskas, 2015) and can improve the tillage depth stability
 152 (Mamkagh, 2008). But it is not recommended overweighting the tractor because if the
 153 drive wheels are loaded with too big weight force the power is used to carry the excess
 154 mass and press the soil, and fuel consumption may increase by 15% (Bris et al., 2011).
 155



156 Fig.5a. Tractor hourly fuel consumption dependences on the extra mass at deferent
 157 tire inflation pressures: Vidas Damanauskas et al. (2015).
 158
 159

160 The results from Vidas Damanauskas et al. (2015) shown in fig. 5a illustrates that when
 161 ballast mass and inflation pressure in the tires were increased the tractor hourly fuel
 162 consumption also increased. When inflation pressure in the tires was 240 kPa, after
 163 increasing the ballast mass from 0 to 520 kg hourly fuel consumption increased from
 164 about 16 L/h to about 17L/h.

165 The results of Lyne et al. (1984) also shows an increase in fuel consumption when the
 166 static load was added to farm tractor during a field operation.
 167

168 5. Effect of inflation pressure in the tires

169 To improve the tractive performance and fuel economy of a tractor in the field low
 170 tire inflation pressure has been recommended, but on paved roads higher inflation
 171 pressure appears to result in better performance. To determine the effect of inflation
 172 pressure on fuel consumption during the tractor transport operations Udompetaikul et
 173 al. (2011) conducted a study using a John Deere 7810 MFWD tractor equipped with
 174 Infinitely Variable Transmission (IVT), single front 600/65R28 tires, and single rear
 175 710/70R38 tires and operated at $40 km.h^{-1}$ on pavement. Three different inflation
 176 pressures (62, 110, and 158 kPa) and four different levels of trailer mass were used
 177 during their tests. During each test, drawbar load, wheel angular velocity, forward

speed, total fuel consumption, and CAN bus-reported fuel consumption rate were obtained using sensors and data acquisition systems. The results indicated that fuel consumption rate decreased linearly as inflation pressure increased at all load levels. They found that the fuel economy in terms of distance traveled per unit fuel consumed increased from 7.3% to 11.4% when the inflation pressures increases from 110 kPa to 159 kPa.

Lyne et al. (1984) studied the variation in tractor specific fuel consumption resulting from changes in tire inflation pressure with different loads on the tractor. Fig. 6 shows that more inflation pressure in the tires decreases the specific fuel consumption of the tractor during field operations. The figure shows that the minimum specific fuel consumption was obtained when the inflation pressure in the tires was around 62 kPa.

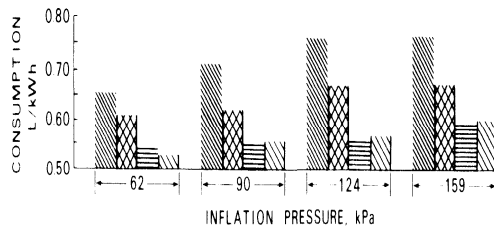


Fig. 6. Effect of inflation pressure on specific fuel consumption with different loads (16, 19, 23 and 26 kN) on the tractor with radial ply tires; Lyne et al. (1984), this figure is a part of the original figure.

6. Conclusion

Reduced tractor fuel consumption during tillage will result in both environmental and agricultural economic benefits. Generally, reduced tillage speed, depth and weight of the tractor caused decreasing fuel consumption during field operations. It also decreased as inflation pressure in the tires increased at all load levels added on the tractor. Of the solutions available to decrease the tractor fuel consumption during tillage is to decrease the additional mass of the tractor and increase the inflation pressure in the tires, also the proper selection of tillage speed and depth.

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