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Effect of Soil Moisture, Tillage Speed, Depth, Ballast Weight and, Used Implement on Wheel Slippage of the Tractor: A Review

Amer M. Mamkagh[1*]

[1]*Department of Plant Production, Mutah University, Mutah, Karak, Jordan.*

Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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Review Article

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ABSTRACT

Tractor wheel slippage is a critical parameter for fuel consumption and field performance and should not exceed 15%. Several attempts have been made to study the wheel slippage of the agricultural tractor in order to minimize it to acceptable levels during the tillage operations. There are many different types of implements for soil tillage, each one of them affects the wheel slippage in a different way. Moreover, several studies have found many operating conditions that can affect the wheel slippage significantly such as: soil moisture content, tillage speed, ballast weights and the type of implement used for tillage. This article reviews the relationship between them which gives possibility for further research to focus on the potential solutions to decrease the tractor driving wheel slippage which can positively affect the fuel consumption. Increase the additional mass of the tractor, decrease the air pressure in the tires, avoid tilling the soil that is too wet or too dry and, choose the right implement, speed and depth can decrease the tractor driving wheel slippage.

Keywords: Fuel consumption; field performance; agricultural tractor; soil.

**Corresponding author: Email: mamkag93@yahoo.com, amer_mam@mutah.edu.jo;*

1. INTRODUCTION

Tillage is a very important practice in agriculture [1,2] and is one of the major energy consumers in agricultural production; its efficiency is measured by the power consumption [3,4,5]. 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 for the crop production [6]. One of the major factors that affect fuel consumption is tillage depth. Increasing tillage depth also means more work which needs more fuel [7], therefore the issue of reducing the fuel consumption of the tractor during tillage have been investigated and reported by many researchers [2,8,9,10]. There are many methods to decrease tractor fuel consumption during tillage. One of them is the wheel slippage reduction to the minimum. The wheel slippage is a critical parameter for fuel consumption and field performance [11]. Normally, slippage of drive wheels should not exceed 15% [12]. The research studies show that optimal tractor slippage in soil should be in the range of 8-12% [13]. Loading the tractor with ballast weight can reduce wheel slippage [11] and can improve the tillage depth stability [14].

To till the soil deeply there are many types of plows, the most common are: Moldboard, disk and chisel plows.

The moldboard plow is one of the most important tools used for plowing [15]. It has historically been the most important primary tillage implement in agriculture [16]. Disk plows are well adapted to plowing in extremely hard soil; for cutting, pulverizing, elevating, and inverting furrow slices in primary as well as in secondary tillage [17].

The chisel plow is commonly used for primary tillage operations with minimum soil dispersion, especially for farms having crop residue on the soil surface [18]. It helps prevent wind erosion, water runoff, and promoting water infiltration by breaking soil layers below normal tillage depth [19].

2. WHEEL SLIPPAGE

2.1 Measurement of the Tractor Wheel Slippage

Several attempts have been made to measure the wheel slippage of the agricultural tractor. The most recent study was done by Ashok Kumar et al. [20]. Because they believe that most previous techniques were costly and of unproven reliability for instantaneous measurement of wheel slippage they developed digital system with hall effect sensor to measure wheel slippage and warn the operator with audible and visible warnings if the optimum range of the slippage was exceeded. The system comprised of three hall effect sensors, three magnetic mounted round discs, magnetic pins and LCD display unit, buzzer and LEDs. Based on their test results the developed system can save fuel up to 32% and can be applied to any make and model of 2WD tractors.

2.2 The Effect of Soil Moisture Content

The results from Amponsah et al. [21] Fig. 1 shows a correlation between tractor wheel slippage and soil moisture content and indicates that increasing soil moisture content from 12% to 22% led to an increase in wheel slippage from 10% to 20%. The above results are similar to those found by Jebur H. and Alsayyah Y. [22] which found in their work that reducing soil moisture content caused decreasing slippage percentage and force pull as shown in Fig. 2. The obtained results showed that reducing soil moisture content from 18% - 20 % to 14% - 16 % led to a decrease in slippage percentage by 31.34 % and force pull by 26.14%.

Fig. 3 shows from the work of Tayel et al. [23] how the soil moisture content can affect the wheel slippage. When the soil moisture content increased from 8.6% to 10.4% then to 11.6 % the wheel slippage increased from 12.6% to 18.8% then to 24.7 %.

While results from Mamkagh [24] indicate an inverse relationship between tractor wheel slippage and soil moisture content. When the soil moisture increased from 7% to 15 % the wheel slippage decreased from 20% to 16 % when the moldboard plow was used. The different results may be due to working conditions change like soil structure, tillage speed and type of the implements.

2.3 Effect of Ballast Weight and Air Pressure in the Tires

Increasing the additional mass of the tractor (adding ballast weight) decreases the driving wheel slippage, increases work productivity, but increases fuel consumption and soil compaction [13].

The results from Damanauskas et al. [13] shown in Fig. 4 illustrates that when ballast mass was increased and inflation pressure in the tires was reduced, slippage of the driving wheels decreased. During the experiment the tractor wheel slippage was varied in the range from 6.5% to 13.5%. When 520kg was added to the tractor with air pressure about 240 kPa in the tires the wheel slippage was decreased from 13.5% to 10.2%. Without adding weights, when the air pressure in the tires was decreased from 240 kPa to 100 kPa the wheel slippage was decreased from 13.5% to 9.0%.

2.4 Effect of the Implement Used

When Arvidsson et al. [25] investigated the specific draught for different implements at different soil water contents they found that wheel slippage was generally higher for the chisel plow than for moldboard plow. They also found that the greater tillage depth was also associated with higher slippage. While the results from Mamkagh [24] showed that the tractor wheel slippage was highest for the moldboard plow and lowest for the chisel plow.

Ranjbarian et al. [26] developed and tested a mobile instrumentation system to study performance of tractor and tillage implements in clay soil where Fig. 5 shows from their work the relationship between the speeds, implement type and wheel slippage and indicates a maximum slippage in chisel plowing and minimum in disk plowing.

Fig. 2 shows from the work of Jebur and Alsayyah [22] how the type of implement can affect the wheel slippage under different levels of soil moisture content at different speeds. As seen from this figure the wheel slippage was higher for the moldboard plow than for the chisel and sweep plows.

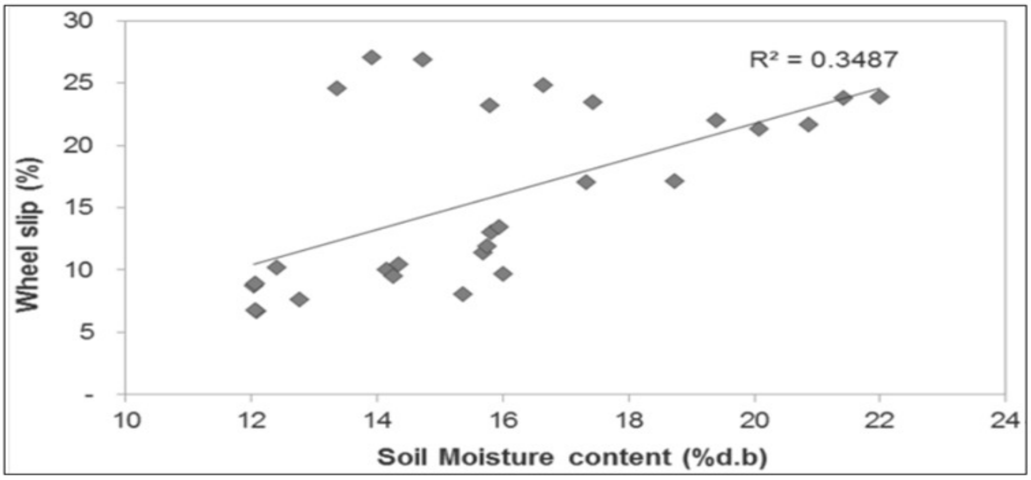

Fig. 1. Correlation between soil moisture content and tractor wheel slippage at harvest; [21]

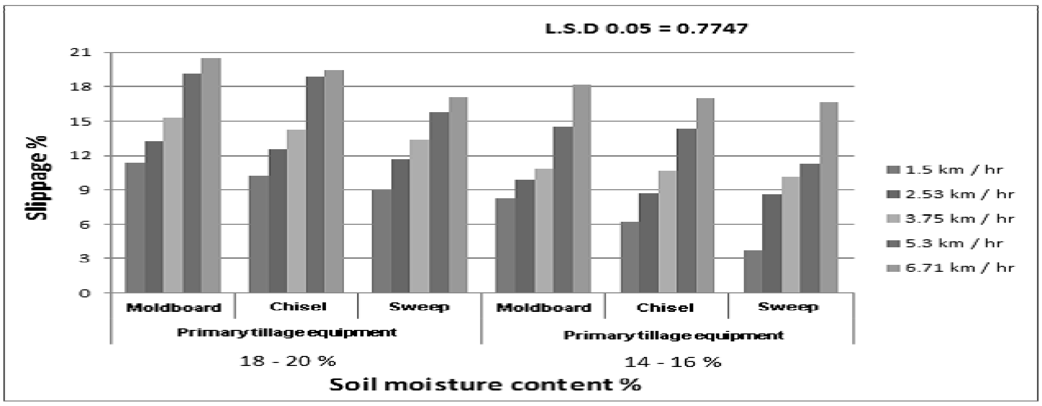

Fig. 2. Effect soil moisture content, tractor speed and equipment type on slippage; [22]

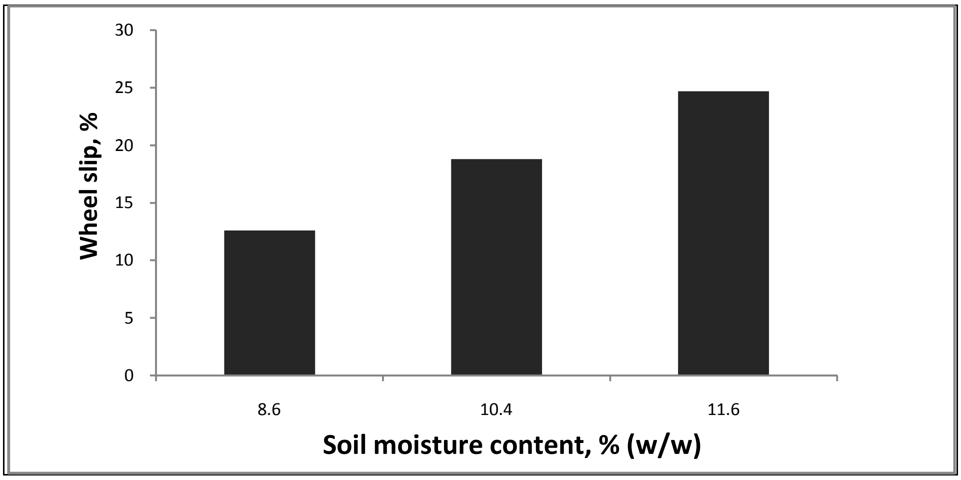

Fig. 3. Effect of soil moisture content on wheel slippage; [23]

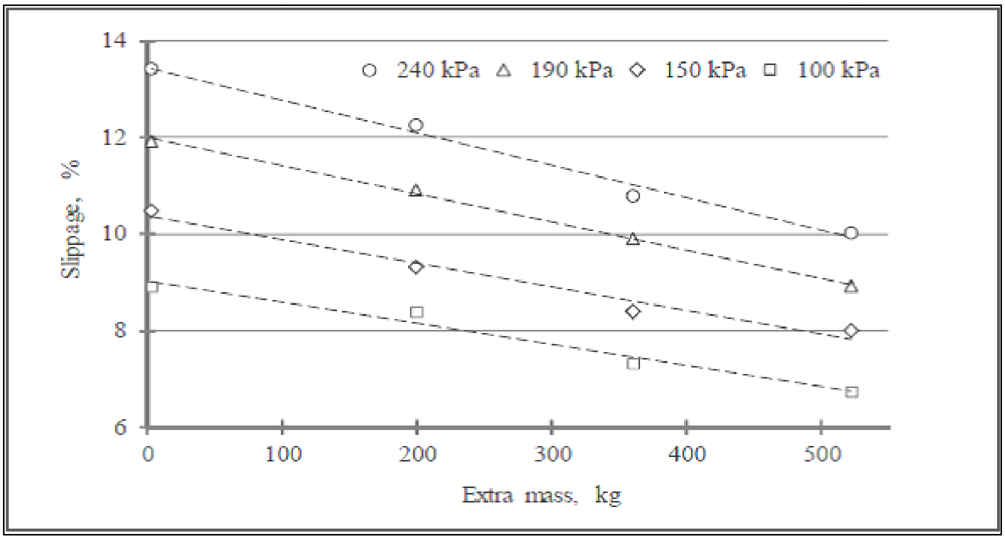

Fig. 4. Tractor fuel consumption per hectare dependences on the extra mass at different tire inflation pressures; [13]

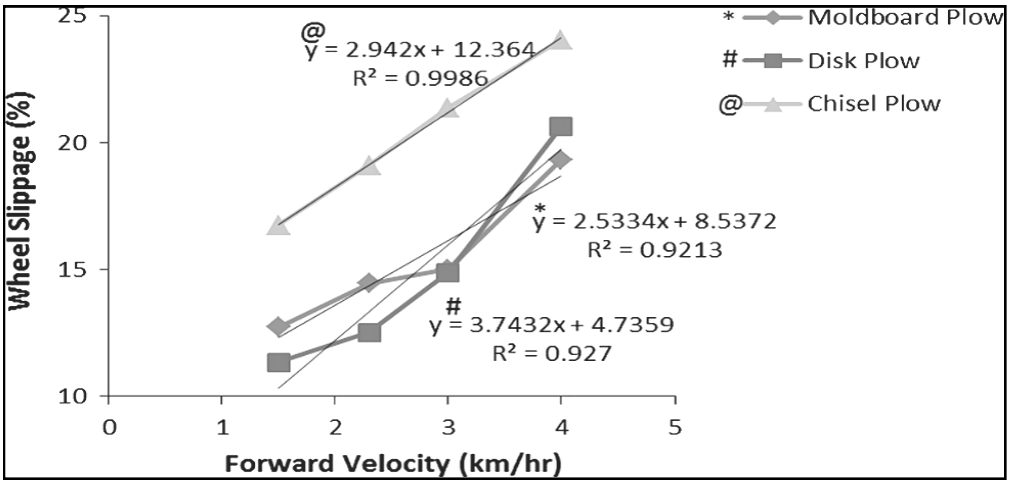

Fig. 5. The relationship between the forward velocity, Implement type and slippage; [25]

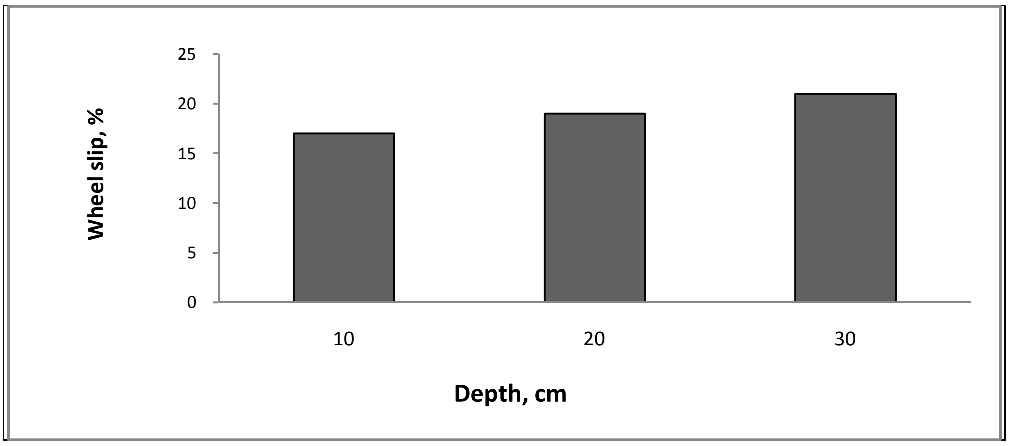

Fig. 6. Effect of soil depth on wheel slippage; [23]

2.5 Effect of Tillage Speed

Normal speed of a tractor in field operations ranges from 0.8 ms^{-1} to 4.2 ms^{-1} (3 km/h-15 km/h). Unfortunately, such speeds fall into the range where the wheel slippage gets its maximal value [11,27]. The results from some studies show that tractor wheel slippage increases with tillage speed [28].

When Tayel et al. [23] studied the effect of plowing conditions on the tractor wheel slippage they found an increase in wheel slippage about 10% to 26% when the tillage speed was increased from 1.79 to 9.6 km/h.

Also from the results of Jebur and Alsayyah [22] and Ranjbarian et al. [26] it was found that the slippage increased significantly as forward speed increased as shown in Fig. 2 and Fig. 5.

2.6 Effect of Tillage Depth

In their work Ashok Kumar et al. [20] they did a comparison between measured and obtained tractor wheel slippage values when the tillage was accomplished by moldboard, cultivator and disk harrow where the depth was varied from 15 to 30 cm for moldboard plow, 9 to 15 cm for cultivator and 8 to 12 cm for disk harrow. From the results it was shown that the slippage always increased with tillage depth with moldboard, cultivator and disk harrow and ranges between 13.5% and 41.68% when measured by the slippage indicator and ranges between 12.9% and 42.37% when measured by manual measurement.

Results from Tayel et al. [23], Fig. 6 shows that as tillage depth increases wheel slippage increases. When the depth increased from 10 to 20 then to 30 cm the wheel slippage increased from 17% to 19% then to 21%.

2.7 Wheel Drive Effect

When Moitzi et al. [29] studied the effect of tillage systems and wheel slippage on fuel consumption they found a reduction in wheel slippage from 6% to 3% during plowing and from 15% to 5% during cultivation with a heavy cultivator when tractor was operated at four wheel drive comparing to the two wheel drive.

3. CONCLUSION

The tractor wheel slippage is a critical parameter for fuel consumption and field performance and optimally it should be in the range of 8-12% and should not exceed 15%. Generally, reducing tillage speed and soil moisture content caused decreasing slippage percentage, but sometimes an inverse relationship between tractor wheel slippage and soil moisture content can be observed. This can be happened if the working conditions change like soil structure, tillage speed and type of the implements. Of the solutions available to decrease the tractor driving wheel slippage is to increase the additional mass of the tractor (adding ballast weight) and decrease the air pressure in the tires, avoid tilling soil that is too wet or too dry and choose the right implement, tillage speed and depth.

Engaging the four wheel drive when using the tractor for tillage operations also can decrease the wheel slippage. However, in any case fuel consumption must be taken into consideration.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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