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Effect of Plowing Conditions on the Tractor Wheel Slippage and Fuel Consumption in Sandy Soil

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Abstract: The aim of this research work is study the influence of soil moisture content at plowing tractor speed and plowing depth on tractor wheel slippage and fuel consumption. The field experiments were conducted during two successive seasons 2014 and 2015 in the experimental farm of National Research Centre at El-Nubaria area, El-Buhera Governorate, Egypt. Three levels of soil moisture at plowing (ϴ1=8.60, ϴ2=10.35, ϴ3=11.61(w/w), two plowing speed(Speed 1 = 1.79 kmhr^{-1}and Speed 2 = 9.6 km hr^{-1}) and three plowing depth's (10, 20; 30 cm)were used. Data could be summarized as following: The effect of soil moisture, tractor speed, and plowing depth on wheel slippage and fuel consumption could be put in the following descending orders: ϴ3>ϴ2>ϴ1), (Speed2> Speed1) and (depth30> depth20> depth10 cm). The interaction among factors as following: the maximum and minimum values of wheel slippage and fuel consumption were (significantly at 5%) recorded at ϴ3 x Speed2 x depth30, and ϴ1 x Speed1 x depth10, respectively. In conclusion, it could be noticed that the best conditions for plowing of the studied soil: 8.6 % (w/w) soil moisture content at plowing, 10 cm plowing depth and 1.79 kmhr^{-1} tractor speed.
Key words: Sandy soil, Moisture at Plowing, Plowing Depth, Tractor Speed, Fuel Consumption; Wheel Slippage.

Introduction

Primary tillage is the first mechanical disturbance of the soil after harvest. It is normally done when the soil is moist enough to allow ploughing and strong enough to give reasonable and efficient traction. Secondary tillage on the other hand is any working of the soil after primary one. It is usually less shallow and less aggressive than primary tillage.

Reducing fuel consumption in cropland agriculture is a complex and multifactorial process, where farm management plays a key role[1]. Conventional tillage with ploughs is one of the most energy-consuming processes in plant production[2]. Mouldboard ploughs; tined implements and disc implements are the main implement types for primary tillage[3].The intensity of tillage depends on the number of tillage operations, power transmission (active by PTO or passive by drawbar power), implement geometry, and depth of operation[4,5].

Compared to conventional tillage systems, fuel consumption can be significantly reduced with conservation tillage systems[6,7,8]. Tillage with a high degree of soil disturbance, e.g. ploughing or cultivating, contributes greatly to soil tillage erosion[9,10].

The concept of Wheel slippage in tractors has always been one of the main efficient factors affecting fuel consumption by tractors, for both on-field and off field farm operations. Tractor performance is influenced by traction elements, soil conditions, implement type, and tractor configuration[11].

According to Olatunji, O. M. et al[12], the soil moisture content and shear strength contribute to tillage energy requirement. Operations that involve machinery traffic and soil engaging tools, such as tillage and planting, on agricultural soil is considered tractable if it can develop adequate shear resistance to minimize tire slippage and soil damage and can as well produce soil tilth without the formation of clods[13]. By decreasing soil moisture content, net traction of tractor decreased and resulted in reduced rolling resistance. Fenyvesi L. et al [14] found out that rolling resistance of wheel will increase by reduction of some key soil parameters. According to Ahaneku I. E. et al [15], agricultural tillage involves soil cutting, soil turning, and soil pulverization which thus, demands high energy, not just due to the large amount of soil mass that must be moved, but also due to inefficient methods of energy transfer to the soil. It is known from related research efforts that the draft resistance of ploughs and energy requirement for plowing depend on the plow body parameters and soil properties such as hardness, density, friction and adhesion. [16,17,18] Reported that increasing the plowing depth and traction power causes both the wheel slip and fuel consumption to increase. [19] Reported that in every tillage operation, there are three main factors that should be considered for the achievement of desired results. These factors include personnel (i.e.operators), tillage tools and soils with the most important of them being the soils followed by the tillage tools.

Tractive efficiency is a measure of the ability of the tractor to transfer power from the axle to the drawbar through the tire and soil interface. This implies that tractive efficiency depends on wheel slip, soil and tire conditions as well as drive configurations. In the research work of Inchebron K. et al [20], the measured and calculated parameters were rolling resistance, wheel slip and tractive efficiency. The inference taken from the work revealed that wheel slip might be considered higher for primary tillage than in secondary tillage operations due to the depth of the two different tillage implements (3-bottom disc plough and offset disc harrow) that were used to work on the soil.

The fuel consumption of soil tillage operations varies widely and can be reduced through proper matching of tractor size, operating parameters, tillage implement[21]. Of the average fuel consumption for ploughing (25 L ha-1), only 5 L ha-1 of the fuel energy is used for the drawing of the plough[22], while the remaining fuel consumption is due to efficiency losses in the engine, transmission, and wheel/soil interface[23]. The term “fuel” is used here exclusively to denote diesel fuel. Additional, soil related, parameters, such as soil texture and organic matter content, influence fuel consumption in soil tillage[24,6].

Depending on the soil consistency the fuel consumption increases by 0.5 to 1.5 L ha-1 per centimeter of ploughing depth[25,26]. Moreover, wheel slip as a measure of traction affects field performance and fuel consumption[27].

The improvement of the drawbar pulling efficiency through an all-wheel drive reduced wheel slip during ploughing by 50% and during cultivating by 67% in comparison to a two-wheel drive and resulted in fuel savings of 2 L ha^{-1}, [26]. The working depth in tillage processes also had a large influence on fuel consumption and wheel slip.

The objective of this paper is the studying effect of different soil moisture at plowing, plowing depth, and plowing speeds on wheel slip and fuel consumption.

Materials and Methods

The field experiments were conducted during two successive seasons 2014 and 2015 in the experimental farm of National Research Centre at El Nubaria area, El-Behera Governorate, Egypt to study the influence ofsoil moisture content, tractor speed and plowing depth on tractor wheel slippage and fuel consumption in sandy soil condition. Some physical properties of the studied soil are presented in Table (1).The previous crop in selected site was Common Been, *Phasolus vulgaris*. Sprinkle irrigation system was used.

Table (1): Some physical properties of the soil.

Soil Depth (cm)	Particle Size distribution, %				Texture Class	Soil θ_S(w/w)%			HC (cmh^{-1})	BD (g/cm^3)
	C. Sand	F. Sand	Silt	Clay		F.C.	P.W.P.	A.W		
0-15	8.4	78.6	7.5	5.5	Sand	12.0	4.1	7.9	6.68	1.56
15-30	8.6	78.7	7.3	5.4	Sand	12.0	4.1	7.9	6.84	1.58
30-45	8.5	78.5	7.8	5.2	Sand	12.0	4.1	7.9	6.91	1.63
45-60	8.8	78.7	7.6	5.9	Sand	12.0	4.1	7.9	6.17	1.62

FC= field capacity, P.W= wilting point; AW= available water

A completely randomized and split-split plot design was applied. Three soil moisture content θ (8.60, 10.35 and11.61% w/w), two plowing speed (1.88 and 9.6 km/h) and three plowing depth (10, 20 and 30cm) were used at plowing. The wheel slippage was measured at all treatments. Plowing process was conducted using Chisel plow with 7 fixed tines. The tractor wheel slippage can be described by the following equation.

$S\% = (1 - V_{act} / V_{th}) \times 100$ [28.]
Where S is wheels slip (%), $V_{act.}$ is actual speed with plow tool (km/h), and V_{th} is theoretical speed without plow tool (km/h).
$V_{act.}$orV_{th} = (D / t) * 3.6
Where D = distance meter and t= time (sec.).
The fuel consumption was measured by refilling the tank to full and calculating the amount of fuel consumed (l/fed).

The consumption flow rate (L h-1) is calculated according Equation (1).

$$Q = \frac{f \cdot 3.6}{K_D} \qquad (1)$$

Where, Q is flow rate, L h-1; f is frequency. According to the calibration protocol KD was 161.99 cm^{-3}. The factor 3.6 in Equation (1) is a dimensionless conversion factor.

A two-way analysis of variance was carried out on the data generated with the use of the General Linear Factorial Model in GENSAT Discovery Edit. 3 Software. The software was used in analyzing the % wheel slippage values of the 2WD tractor during the different tillage operations on the different soil surface conditions of the experimental plots. Thereafter, the Least Significant Differences (L.S.D) between the means of % wheel slippage were computed at 5 % level of significance and used to make paired comparisons between the treatment means.

Values of fuel consumption and wheel slippage were subjected to the proper statistical analysis according to Snedecor and Cochran. et al.[29]

Results and Discussions

The concept of wheel slippage in tractors has always one of the main efficiency factors affecting fuel consumption by tractors, for farm operations. The soil moisture content at plowing, soil texture and shear strength contribute to tillage energy requirement.

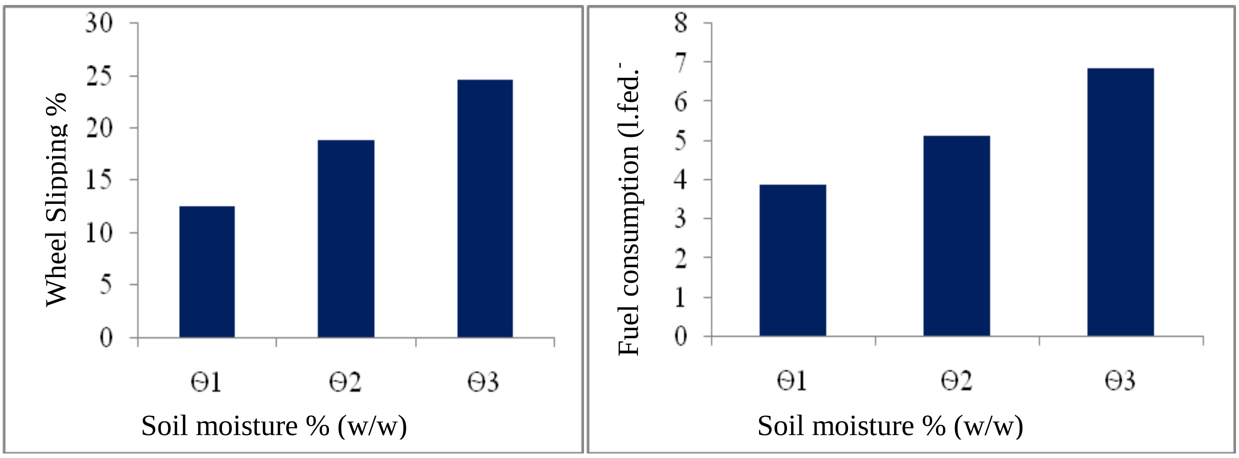
Table (2) and Figures (1, 2 and 3) illustrates the effect of three different soil moisture (ϴ1=8.60%, ϴ2=10.35%, ϴ3=11.61%), two tractor speed's (Speed 1 = 1.79 km/h and Speed 2 = 9.6 km/h) and three plowing depth (10, 20, 30 cm) on fuel consumption and wheel slippage.

Soil consistence comprises the attributes of soil material which are expressed in its degree and kind of cohesion and adhesion forces or in its resistance to deformation or rupture. Consistence phenomena are friability, plasticity, stickiness, and resistance to compression and shear. The mean forces responsible for soil consistence are molecular attraction (cohesion) and surface tension (adhesion).Cohesion molecular attraction is brought about by the charges of the clay particles, by broken bonds at the edges of clay plates and the attraction from particle to another (Vander Waals forces). Consistence as a result of molecular attraction can be large only if the soil particles lie closely together and have relatively large surface area of contacts.

Regardless tractor speeds and plowing depth, the obtained of fuel consumption and soil moisture content could be ranked in the following descending orders: ϴ3 >ϴ2 >ϴ1.Based on these results, decreasing soil moisture content decreased both wheel slippage and fuel consumption that measured fuel efficiency usage and vice versa. Differences in data of wheel slippage and fuel consumption between means of the studied parameters were significant at the 5 % level. While the highest and lowest values of wheel slippages and fuel consumption were achieved under ϴ3 and ϴ1, respectively. Data supported by Schreiber M. et al[23], Olatunji, O. M. et al[12].

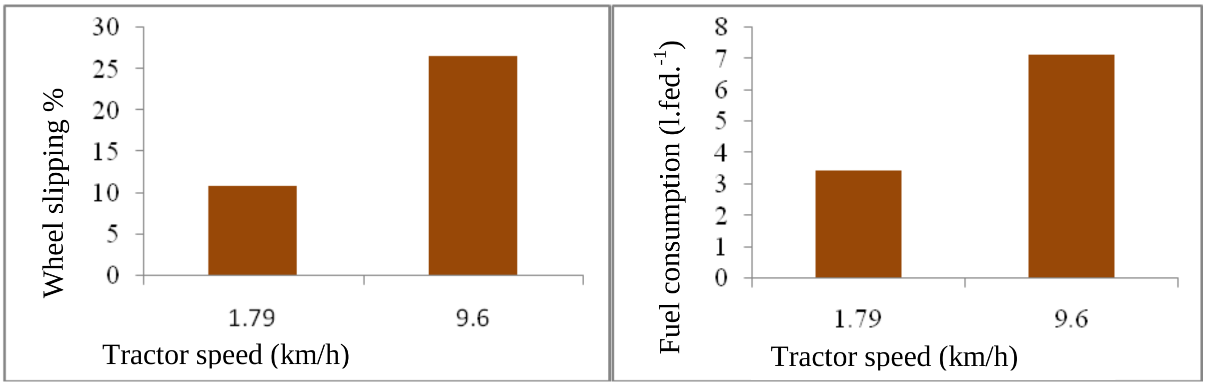
Table (2): Effect of soil moisture, tractor speed and plowing depth on fuel consumption and wheel slippage

Soil Moisture content at plowing w/w%	Tractor speed (km/h)	plowing depth (cm)	Fuel consumption ($L.fed^{-1}$)	wheel slippage (%)
ϴ1 8.60	speed 1 1.79	10	2.2	5.45
		20	2.31	5.87
		30	2.67	7.56
	speed 2 9.6	10	4.86	17.12
		20	5.34	18.99
		30	5.9	20.43
ϴ2 10.35	speed 1 1.79	10	2.88	7.78
		20	3.47	10.68
		30	3.97	12.5
	speed 2 9.6	10	6.21	24.89
		20	6.78	27.78
		30	7.45	29.42
ϴ3 11.61	speed 1 1.79	10	4.05	13.88
		20	4.3	15.76
		30	5.16	18.46
	speed 2 9.6	10	7.89	30.46
		20	8.46	32.45
		30	11.24	37.15
$LSD_{0.05}$			0.44	0.27



(ϴ1=8.60%%, ϴ2=10.35%, ϴ3=11.61%).

Fig. (1) Effect of soil moisture content% (w/w) on wheel slippage (%) and fuel consumption



(Speed 1 = 1.79 km/h and Speed 2 = 9.6 km/h)

Fig. (2) Effect of tractor speed (Km/h) on wheel slippage(%) and fuel consumption (l.fed^{-1}).

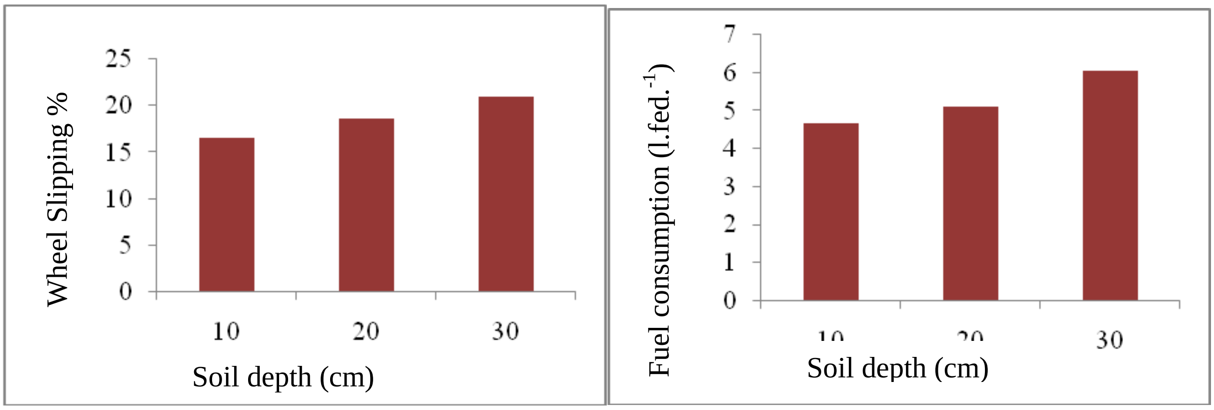


Fig. (3) Effect of soil depth (cm) on wheel slippage(%) and fuel consumption(l.fed^{-1}).

Since in silt and sand soil, the structure is open and both sand and silt particles are nearly spheroid in shape, the soil particles together depends on the presence of the three soil phases, Solid (soil particles), liquid (soil water), and the gaseous one (soil air).

Soil water content control the shape (concave or convex) of water films around soil particles and subsequently the forces of bonding soil particles. While surface tension (film forces per unit area of contact is greatest when the meniscus s curved the most as in soil of limited moisture content of the contact is fairly small under these conditions. As the soil water increases, the area of contact increases while surface tension per unit area only little and subsequently consistence increases. At a certain point in the wet range surface tension/unit area has become so small that even the increase contact area fails to compensate for it.

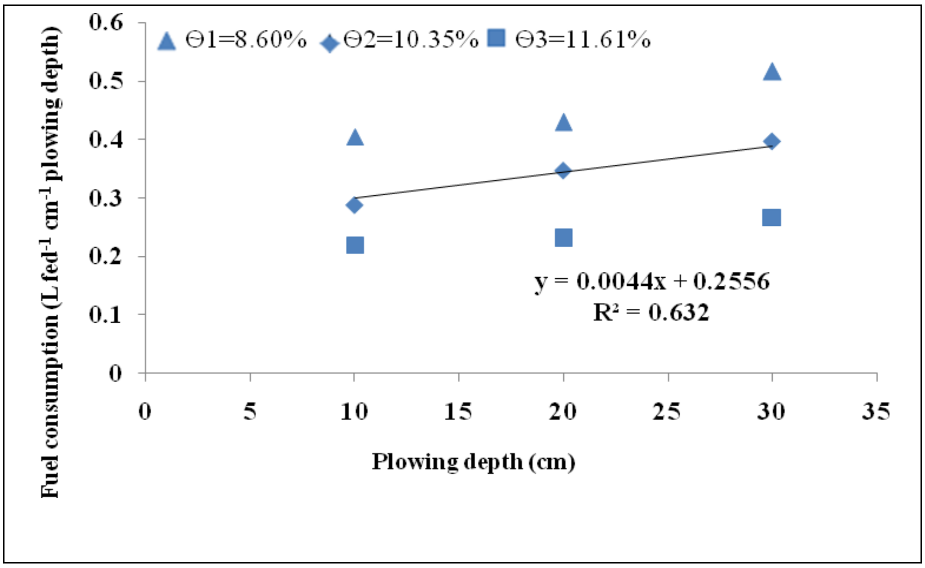
In the case of moist sandy soil (unsaturated) the surface tension causes an a aberrant consistence. This consistence disappears in both dried and saturated sandy soil.The increase in tractor speed decreases the time of wheel contact with the soil. Although, the increases in tractor speed increases the field capacity, fuel consumptive and wheel slippage, it decreases soil deformation and rupture.The increase in plowing depth increases both wheel slippage and fuel consumption may attribute to the overburden pressure of the top soil layers on the subsoil ones and the decrease in soil organic matter content with depth.

Table (3): Main effect of soil moisture content (w/w), tractor speed and plowing depth on fuel consumption and wheel slippage.

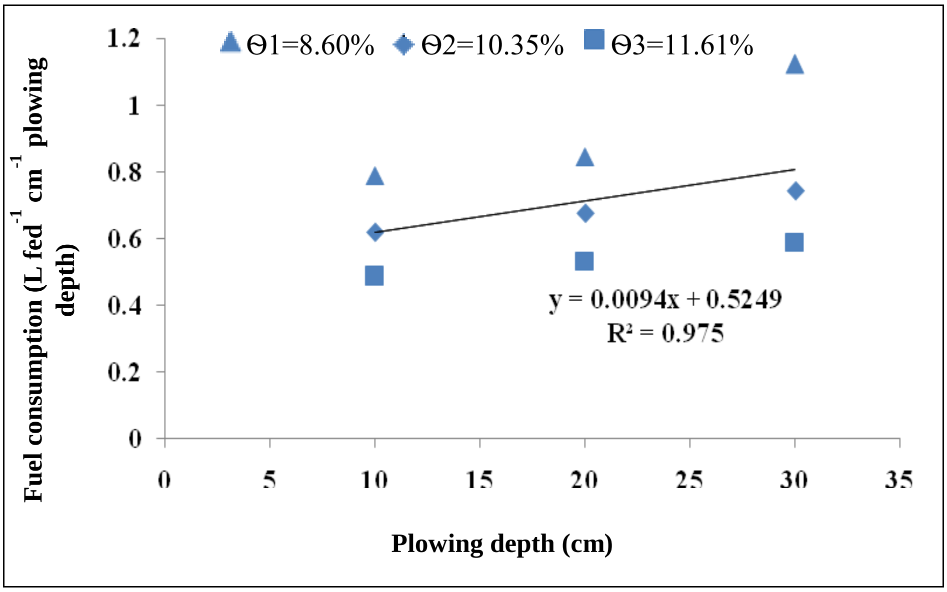
Treatment	Fuel consumption (L/fed)		Wheel slippage (%)	
Soil moisture content (Θ1=8.60%).	3.880	a	12.570	a
Soil moisture content (Θ2=10.35%).	5.127	b	18.842	b
Soil moisture content (Θ3=11.61%).	6.850	c	24.693	c
Tractor speed (S1= 1.79 km/h).	3.446	a	10.882	a
Tractor speed (S2= 9.6 km/h).	7.126	b	26.521	b
Plowing depth (d1 = 10cm)	4.682	a	16.597	a
Plowing depth (d1 = 20cm)	5.110	b	18.588	b
Plowing depth (d1 = 30cm)	6.065	c	20.920	c

Table (2) and Figures (1, 2 and 3) show the effect of the studied parameters, it could be ranked in following descending order: Speed 2 > Speed1. Differences in wheel slippage were significant at the 5 % level. While the highest and lowest values under Speed1 and speed2 were achieved at Speed2 and Speed2, respectively.

The effect of plowing depth on wheel slippage and fuel consumption, it could be ranked in following descending order: depth3 > depth2 > depth 1. Differences in wheel slippage and fuel consumption were significant at the 5 % level. This effect may be attributing to decrement tractive efficiency by increasing the soil depth, [30]. So, the highest and lowest values of wheel slippage and fuel consumption were achieved at depth 3 and depth 1, respectively. As it is obvious, increasing the soil moisture content and tillage depth increase wheel slippage and fuel consumption due to decreased the tractive efficiency, [31].



A:



B:

Fig. (4) The effect of soil moisture content, plowing speed and plowing depth on fuel consumption efficiency

Table (3)and Figures (1, 2 and 3)show that the interaction among the studied factors: The maximum and minimum values of wheel slippage and fuel consumption were recorded in Ө3 x Speed2 x depth30, and Ө1 x Speed1 x depth10, respectively, differences in the obtained data among interactions were significant at the 5% level. The data supported by [24], [13], [15], [32]. Data obtained could be explained on the basis of sandy soil consistence. This consistence is due to molecular attraction (Cohesion) and surface tension (Adhesion). Soil structure of sandy is open. This means that each sand particle contacts six other particles since sand particle is nearly spherical in shape the contact will be only in six points. On the other wards, the adhesion force will be in both wet and dry soil, and this will increase wheel slippage and fuel consumption.

Figure (4 A and B) depicts the effect of both soil moisture content at plowing and plowing speed on fuel consumption per cm plowing depth per fed (4200m^2). Data on hand revealed that plowing the sandy soil at 8.6 % (w/w) and 1.79 Km.hr^{-1} caused an increase in fuel consumption ranged from 0.22 to 0.27 litre.fed.cm^{-1} plowing depth.I the case of 10.35 % (w/w), fuel consumption varied from 0.288 to 0.397 and from 0.621 to 0.745 liter cm^{-1} depth fed^{-1} at plowing speed 1.79 and 9.6 Km hr^{-1}, respectively. Concerning soil contain 11.61 % (w/w), fuel consumption varied from 0.405 to 0.516 and from 0.789 to 1.79 liter cm^{-1} depth fed^{-1} at plowing speed 1.79 and 9.6 Km hr^{-1}, respectively. Thus, the suitable conditions for tillage the studied soil are 8.6 % (w/w) plowing speed 1.79 Km hr^{-1} and plowing depth 10 cm for both fuel consumption and wheel safety.

Conclusion

The slippage in tillage operation is an important factor for analysis of fuel consumption. Fuel consumption and wheel slippage of tillage operation with a given implement is greatly affected by soil moisture, tractor speed and the working depth. Wheel slippage and fuel consumption increase with increasing soil depth, tractor speed and soil moisture values under study. The interaction between factors as following: the maximum and minimum values of wheel slippage and fuel consumption were (significantly at 5%) recorded at Ө3 x Speed2 x depth30, and Ө1 x Speed1 x depth10, respectively.

In this study, could be conclude that a very efficient way of saving fuel is to choose the time which will be available good soil conditions (soil moisture content 8.60% at plowing), in addition to10 cm plowing depth and 1.79 km/h, tractor speed during tillage operation.

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