Design, manufacture and evaluation of the new instrument to measure the friction coefficient of soil

Fereshteh Hasankhani-Ghavam[1*], Yousef Abbaspour-Gilandeh[2], Gholamhosein Shahgoli[3], Hadi Rahmanzadeh-bahram[4]

(1. *Graduated Student, Department of Mechanics of Agricultural Machinery, University of MohagheghArdabili, Ardabil, Iran;*
2. *Associate Professor, Department of Mechanics of Agricultural Machinery, University of MohagheghArdabili, Ardabil, Iran;*
3. *Assistant Professor, Department of Mechanics of Agricultural Machinery, University of MohagheghArdabili, Ardabil, Iran;*
4. *Graduated student of department of agrotechnology, college of Abouraihan, University of Tehran, Tehran, Iran.*)

Abstract: Accurate determination of soil parameters such as the coefficient of internal friction, soil adhesion and soil-metal friction is essential for designing agricultural machinery, calculating the draft force and investigating the performance and wear of them. Tillage as the main operation is causing soil displacement and skidding on tillage equipment. Soil friction parameter against the tools that have wide contact surface with soil, increases the operating draft force and consequently energy consumption would be increased.This paper describes the design, fabrication and using a system for measuring the coefficient of soil external friction. Soil box was moved on two parallel rails by the electric motor. For measurement of mentioned coefficients a piece of constant metal was in tangential contact with the soil located inside the soil box during box movement. S-shaped load cell was used to measure the tensile force of the friction force connected to a data logger model DT800 and all data loaded to a laptop computer. Soil textures were sandy-loam soil and loam soil. The result showed that the changes of draft force versus normal load were linear and increasing the moisture and reached to final adhesion phase, increased soil external friction. Also, the results showed that the test system can discriminate between different soil textures and different contact surfaces tested. In general, according to the results the performance of the soil friction coefficient measuring device was acceptable.

Keywords:soil, the coefficient of soil external friction, load cell, draft force

Citation: FereshtehHasankhani-Ghavam. 2015. Design, manufacture and evaluation of the new instrument to measure the friction coefficient of soil. AgricEngInt: CIGR Journal, 17(1):101-109.

1 Introduction

Tillage operation associated with soil displacement and skidding on tillage equipment.Soil friction parameter against the tillage tools that have wide contact surface with soil, increases the required draft force and consequently energy consumption would be increased. According to its definition, friction is the resistance against relative motion of two tangential objects to each other when sliding, resulted by an external force or pressure (Kepner et al., 1978).

Received date: 2013-10-15 **Accepted date:** 2015-01-12
***Corresponding author:FereshtehHasankhani-Ghavam,** Department of Mechanics of Agricultural Machinery, University of MohagheghArdabili, Ardabil, Iran.
E-mail: f.hasankhani2@gmail.com

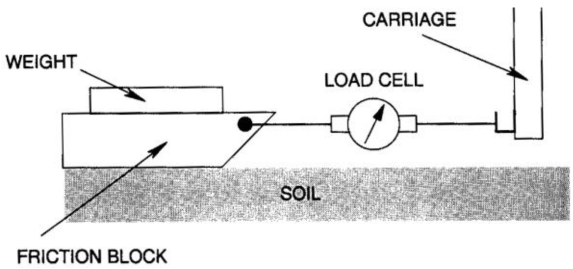
In general, there are types of friction occurs in the studies related to soil dynamic including: a) friction between soil and metal, b) friction between soil with soil c) soil internal friction. The phenomenon of soil-soil friction occurs when the soil is moving as a hard rigid on another soil surface. While the internal friction is manifested in the soil failure under shear force, or when soil fails under shear load. Hence in shear tests, when the soil was broken and started to move, soil-soil friction occurs that is the result of sliding rigid soil on another rigid. Before soil failure, soil internal friction resist versus force (Srivastava et al., 2006, Shahidiand Moghadam, 2008)

Therefore, the soil resistance against cutting is determined by the coefficient of internal friction.

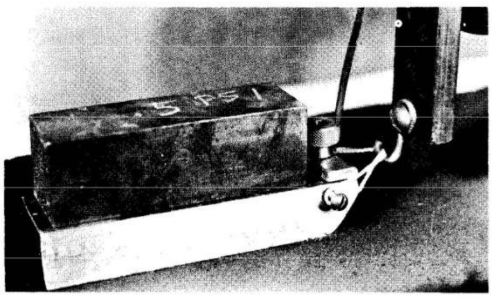
When a part of the soil is replaced with other materials such as agricultural equipment of steel, the soil-metal friction will appears. This friction is that cause’s abrasion plowshare (Shahidiand Moghadam, 2008).

The soil friction on tillage equipment usually acts between soil and steel or sometimes between the soil and plastic (in that case the back surface of plow is covered with the plastic) (Kepner et al., 1978).

Soil friction coefficient and mentioned materials (steel and plastic) is measured by using a simple slider system as shown in Figure1. This system includes a slider that was pulled over the soil surface. (See Equation 1)



A



B

Figure 1 A simple slider system to measure soil-metal friction. A) Scheme figure. B) Actual figure

$$\mu' = \frac{F}{N} = \tan\delta \qquad (1)$$

Where:

$\mu' =$ Coefficient of friction, (-)

F=Frictional force tangent to sliding surface, (N)

N= Normal force, (N)

$\psi =$ Angle of friction, (degree).

The slider that shown in Figure 1 may be covered by polytetrafluoroethylene plates or a material that does not adhere to the soil.This simple method of slider has been applied by a group of researchers as a device for measuring the friction of metal and soil (Gill and Berg, 1968a).

Weights are added on metal part in order to supply the essential vertical force (N), and then the apparatus is pulled on the soil by draft force (F). If the test is performed with variant weights, the friction force due to variant vertical pressures will be measured and plotted versus the normal loads. The slope of the resultant line represents the coefficient of friction, and the intercept is C_a.A, where C_a is the adhesion and A is the surface area (Srivastava et al., 2006).

Payne (1956) used a vertical slider for field tests that the coefficient μ' would be measured by this device. This device is similar to a vertical chisel that can be pulled by a moving dynamometer in the soil. The schematic of the apparatus is demonstrated in Figure 2.

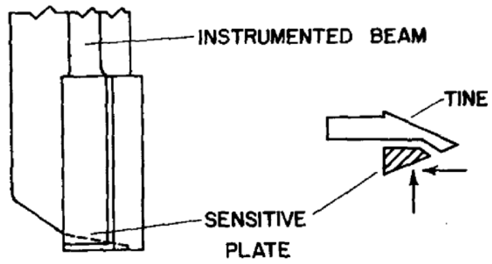


Figure2 The permeable soils are influenced by forces associated with soil sliding

The vertical force on the sliding surface can be altered with changing the angle of approach of the surface or with increasing the velocity of operation. Most of complicated apparatuses have been developed in which a metal ring shaped plate or a spherical disk was used. These are placed on the soil and are turned round in place. Shoehne (1953) has utilized an annulus for this purpose while Rows and Barnes (1961) used a rotary disk.In each apparatus, the contact area between soil and slider was fixed by using similar physical size of slider and therefore load intension did not change during the test. Structural changes present a continuous change in slider surface and almost changes the μ'.

Among the active forces on the reciprocal surfaces of two bodies of different materials, almost a force is needed for pulling two bodies. The attraction force between two different materials is defined as adhesion (Srivastava et al., 2006, Gill and Berg, 1968b).

Adhesion forces between soil and other material are due to the films of their moisture. As soil slides upon metal, adhesive forces between soil and metal have a significant effect on the friction force. Adhesion force effect is the increment in vertical force on the surfaces which increases the tangential friction force (Kepner et al., 1978).

Adhesion has two important forms or behaviors that must be defined in machine and soil relation. First it is related to sliding friction and the second it is related to the stickiness. If soil sticks to variant materials, required forces for tangent motion of soil on surface and vertical to surface will be different (Gill and Berg, 1968). Payne and Fountaine (1954) have supposed the adhesion of the soil as an additional parameter in friction equation of soil and metal (Equation 1). On this base, the equation is formed to Equation 2:

$$\tau_{f\max} = C_a + p\tan\delta \qquad (2)$$

Where:

$\tau_{f\max}$ =Sliding stress, N/m^2

C_a= Adhesion, N/m^2

p= Normal stress of frictional surface, N/m^2

δ = Angle of soil- metal friction, degree

As a general rule, a straight or curve line with slight slope can be created by connecting the acquired points. On the S' axis, normal load value is zero. So the intercept represent adhesion that is desired parameter. The slope of the line expresses the coefficient of sliding friction (Figure 3) (Gill and Berg, 1968a).

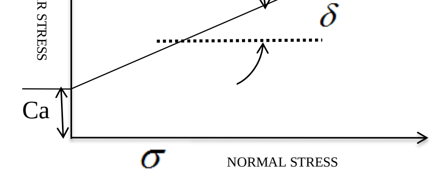


Figure 3 Soil failure envelopes (shear stress versus normal stress)

Therefore Payne and Fountaine (1954) used the Equation 2 as a mathematical model for demonstrating adhesion. An apparent coefficient of friction between soil and steel (due to adhesion force and tangent friction force) usually depends on the soil type, polished of surface of two bodies and the amount of their moisture. This coefficient for sandy-loam is about 0.5-0.7 and for clay soils is about 0.6-0.9 (Shahidiand Moghadam, 2008). Also, Kepner et al. (1978) stated that apparent coefficient of friction in clay soil is more than that of sandy soils. According to different researches, the usual range of this coefficient in soil movement on steel that is usually polished, for sandy soils is 0.2-0.5, for loam soils is 0.2-0.65 and for clay soils is 0.35-0.8.

The general relationship between soil friction on metal surfaces and soil moisture content is presented in Figure 4.It can be seen that initially at low moisture content the friction is due to pure sliding action. As the moisture content increases, friction increases due to increased adhesion.Phase adhesion, moisture layer between the soil particles and metal is expanded, therefore the adhesive forces are created that causes a rapid increment in the apparent coefficient of friction with moisture content increment.As the moisture content is increased even further the friction reduces due to the lubricating effect created by the moisture film (Srivastava et al., 2006, Gill and Berg, 1968b).

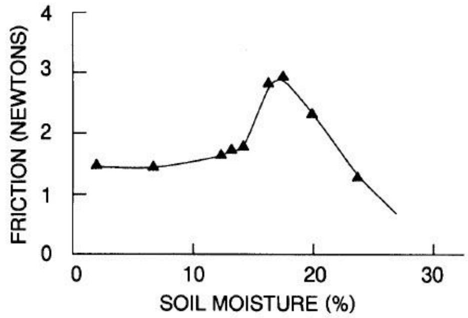


Figure4 Effect of soil moisture on apparent coefficient of friction and classified friction, adhesion and lubrication phase (Seivastava et al, 2006)

Plessis represent that the coefficient of soil - rubber friction is slightly different from the coefficient of soil internal friction; also the adhesion between soil and rubber is less than the internal cohesion of the soil (Plessis, 2005).

Gee et al. (2005) have developed a system which measures the coefficient of friction of parts are tangent to each other. This system can be used in the measuring of the friction properties of variant substances which are in contact with each other. Using of strain gage is the main principle of this system. The vertical force and frictional force have been calculated by the mounted strain gages on the system in specified places and by forming Wheatstone bridge and the friction coefficient of the contact surfaces of materials such as steel, paper, plastic, glass and some thermoplastic objects was calculated as the ratio of frictional force to normal force. The results show that this system can differentiate between different tested materials. This system can be successfully used for measuring frictional features of different materials (Gee et al., 2005).

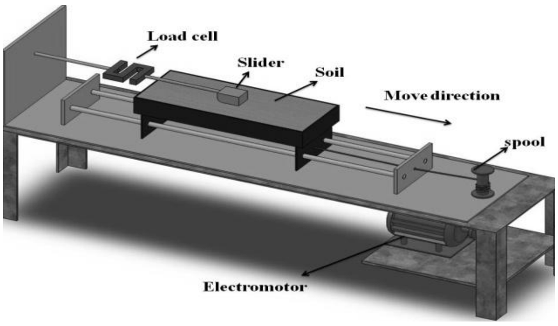
A review is given of the various ways in which humidity and liquid water can influence the friction and wear of metals, polymers, lamellar solid lubricants and ceramics. Compared with dry sliding, water usually reduces friction of materials to a limited extent but wear rates change depending on the materials concerned (Lancaster, 1990).

Ahmadi Moghadamet al. (2006) designed and constructed a simple apparatus for determining the friction of soil and metal. This apparatus was pulled in the soil while was loaded by the vertical forces and the required traction force was measured. The diagram of the traction force changes relative to vertical applied loads was supplied. The tests performed with vertical loads of 1- 5 kg as distributed load and each step was repeated three times for more accuracy. The results showed that increasing the moisture of soil increased the friction coefficient of soil-metal from 35% to 61%.

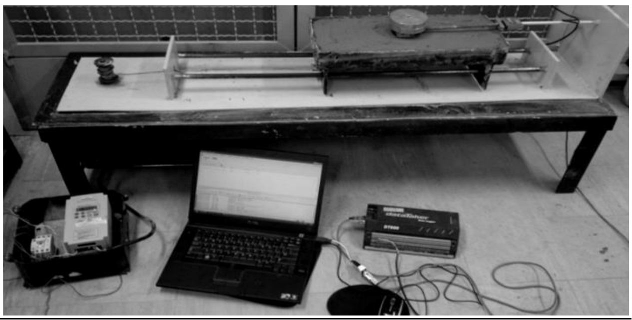
Hao used two physical models or friction simulators for measurement of friction, that these models were developed based on the stretching of a strip around a pin, to characterize sheet metal forming friction (Hao et al., 1999). In comparison to other test devices which use measurements of strain to infer friction forces, these device utilized direct measurements of forces. Effects of strain, stretching speed, lubrication, and pin radius and wrap angle upon the friction coefficient were determined.

2 Materials and methods

To measure the coefficient of external friction, a measurement system was developed that a scheme of the system has been shown in Figure5. This measuring system, which is the developed version of those previous systems used by some of the researches for the purpose of measuring soil apparent friction coefficient, has been designed in SolidWorks environment and fabricated at the University of MohagheghArdabili workshop; the generated system can measure and record the external friction coefficient automatically on the computer memory or data logger connected to it.



A



B

Figure5A) A scheme of the system used to measure the coefficient of soil external friction**. B)** The general view of applying apparatus

The design and the architecture of this system can be considered in two separate functional sections, Mechanical and Electronic.

2.1 Mechanical section

The system consists of chassis, the main body including soil reservoir on rails, and the parts and pieces having contacts with the soil situated inside the reservoir. There are some holes at the underneath part of the reservoir for rails to cross and the reservoir to move on the rails. Cubic pieces of metal made of steel and rubber with dimensions of 5×5×0.5 cm.

In order to having a smooth motion on the soil, the anterior part of the contacting pieces curved slightly upward. The metal part which is connected to the dynamometer will be stable on soil box. The movement of soil box on two parallel beams producing the force due to soil metal contact measured by the data measurement system. S-shaped load cell was used to measure the tensile force connected to a data logger model DT800 and all data loaded to a laptop computer.

The required power to move the soil box is provided by a helical gearbox with a reduction ratio of 1 to 80, powered by a three-phase alternative current electromotor with 180 watt power embedded on the chassis. A 5mm towing cable and a special spool which was on the electro motor's shaft were used to connect the reservoir to the electromotor.

2.2 Electronic section

Electronic measuring system consists of a set of measuring tools which are used for evaluating, controlling and processing of the measured quantities. Electronic part consists of a load cell and data processing set; data processing set consists of signal processing and data recording (on the computer memory) unit.

For collecting and storing data of the load cell, a multipurpose Data logger model of DT800 made in Data Taker Company was used with the capability of programming. Load cell output connected to the input channel of data logger based on the manufacturer's instruction.

To supply the revolution speed required for the tests, revolution speed was controlled by an inverter (SS-021-1.5K). With adjustment frequency, experiments were conducted at an average velocity of 0.025 m/s.

2.3 Experimental soils

Considering that in the area no significant action has been conducted to determine the soil friction coefficient and adhesion and on another side soil has been considered as material for researcher involved in soil mechanic and dynamics. Determining soil mechanical properties was vital for researchers; hence, two samples of Ardabil region soil were analyzed.

The texture of the soil was determined in the laboratory by hydrometric method. One of the soils includes 25.008% clay, 29.33% silt and 45.666% sand that is classified as loam soil. The second sample of the soil includes 9% clay, 17.5% silt and 73.5% sand that is classified as sandy-loam soil. A certain amount of water was added to the soil using a sprinkler in order to have three different levels of moisture in each soil sample, and the soil moisture level was determined in every phase. After setting the system, soil box filled with wet soil and its surface was flat with a handy trowel. In first series of experiments two types of material were examined. They were steel and rubber. In addition friction measurements were carried out on two soil textures. The normal load on the slider was applied using weights of 15-25 N and soil box pulled by the electric motor. Required draft force measured by a load cell and recorded in the computer memory. To increase the accuracy of the tests were conducted with three replications.The average of the data was recorded as a main data.After each replication for a treatment the soil surface was flat again with a handy trowel.

Adhesion and the coefficient of soil-metal friction were determined using Mohr-coulomb’s failure concept. (See Equation 3, Equation 4 and Equation 5)

$$\tau = C_A + \sigma \tan\delta \tag{3}$$

$$\frac{F}{A} = C_A + \frac{N}{A}\tan\delta \tag{4}$$

$$F = C_A.A + N\tan\delta \qquad (5)$$

Where:

τ = Shearing stress, (N/m^2)

σ = Normal stress of frictional surface, (N/m^2)

A= Contact surface (area), (m^2)

F=Shear force,(N)

N=Normal force perpendicular to surface,(N)

C_A= Adhesion, (N/m^2)

δ =angle of soil-metal friction, (degrees**)**

Shear stress versus the normal stress diagram was drawn in which the slope of line indicate the coefficient of soil- metal friction and line intercept from X axis shows adhesion.

3 Results and discussions

Table 1 and Table 2 represent the results of experiments at two soil textures, three soil moisture levels under different vertical loads at a forward velocity of 0.025m/s. As it can be inferred from Table 1 and Table 2, with increasing the soil moisture content, the amount of required draft force is increased(Srivastava et al, 2006).

Table 1The amount of draft force and normal load in loam soil (steel)

Normal load (N)	Draft force in loam (N)		
	Moisture content of 11%	Moisture content of 16%	Moisture content of 21%
15	10.027	11.80	18.62
20	12.38	14.80	22.60
25	15.042	17.95	26.25

Table 2The amount of draft force and normal load in loam-sand soil (steel)

Normal load (N)	Draft force in loam-sand (N)		
	Moisture content of 7%	Moisture content of 13%	Moisture content of 24%
15	9.244	14.158	15.093
20	11.045	16.755	18.093
25	13.052	19.921	21.3054

From Figure 6, it can be observed that increment of moisture content increases the slope of draft force graph versus the applied vertical load. As mentioned above, the coefficient of soil external friction is dependent to the soil moisture content (Shahidiand Moghadam, 2008).

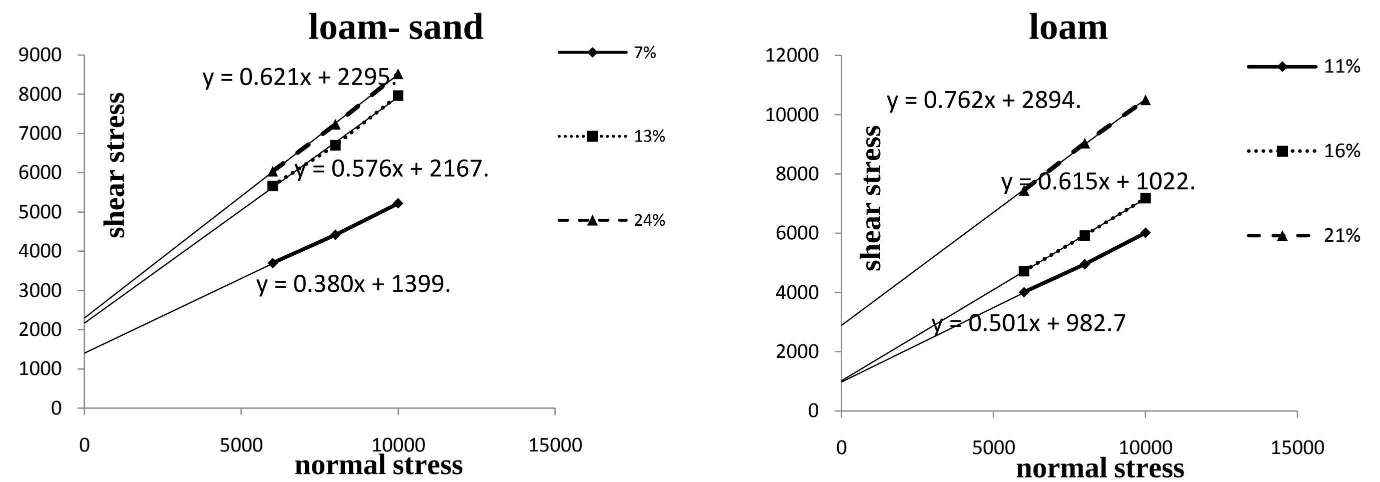


Figure 6 Changing in shear stress against normal stress at different soil moisture contents and two soil textures including loam-sand and loam using steel contact fragment

Shear stress versus normal stress loads for each of soil samples for steel slider (Figure 5) showed that trend line was linear at all levels of moisture content which indicated the good performance of measuring system. The slope of these lines is the friction coefficient of soil-metal friction and also their intercept represents the soil adhesion.

Figure 7 shows the changing range of coefficient values of soil external friction for two different types of sliders. According to the results, it can be seen in both soil types, the values of friction coefficient between soil and rubber were less than those between steel and soil. Therefore the material type contacted to soil affects the coefficient of soil external friction. These results indicate that this device make a response to different contact surfaces (Shahidiand Moghadam, 2008, Gee et al., 2005).

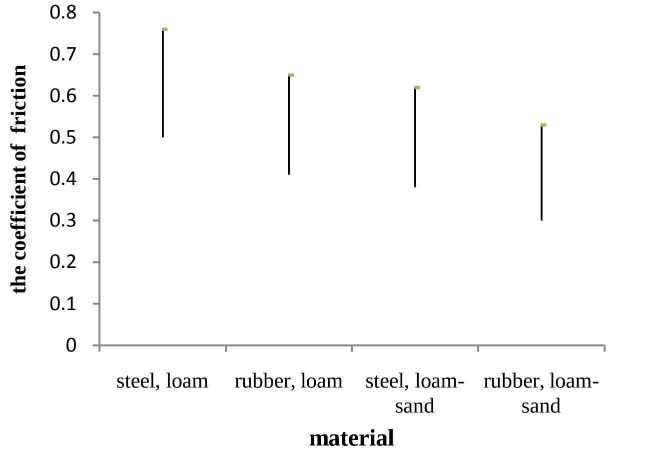


Figure7 The range of coefficient of friction values between soil and used materials

The values were obtained by the system for the coefficient of soil external friction (Table 3), was in the range between 0.4 and 0.7 for loam- sand soil and between 0.5 and 0.76 for the loam soil which included more clay than loam-sand soil (Shahidiand Moghadam, 2008).

Table 3 Effect of the kind of slider on the coefficient of soil-metal friction

The kind of slider	Moisture content in loam-sand			Moisture content in loam		
	7%	13%	24%	11%	16%	21%
Steel	0.38	0.57	0.62	0.50	0.61	0.76
Rubber	0.30	0.42	0.53	0.41	0.55	0.65

Figure 8 shows that increasing in soil moisture from 11% to 32% in loam soil, loam-sandy soil from 6% to 29% and in sandy-loam soil from 7% to 32%, the average of external friction coefficient was increased significantly.

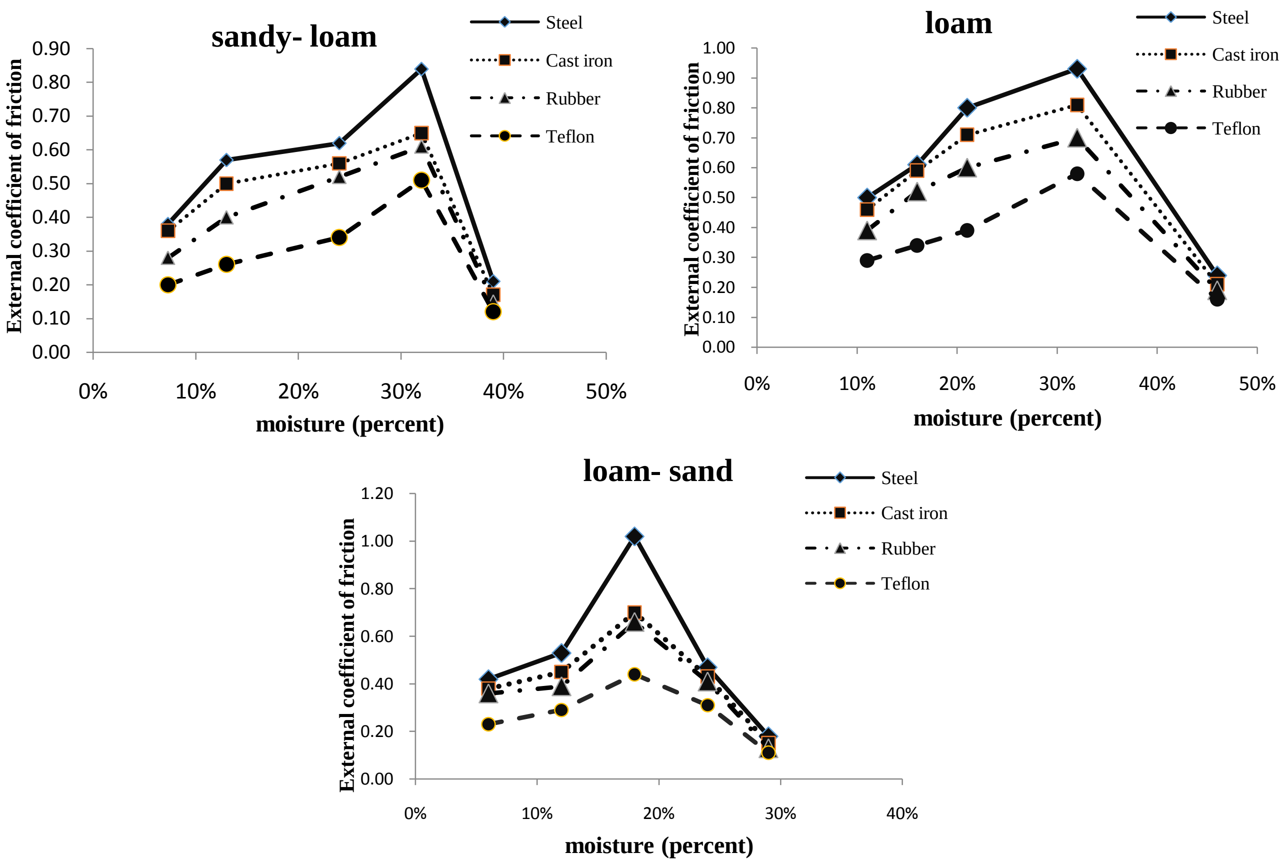


Figure 8Effect of soil moisture on the coefficient of soil- metal friction for 4 pieces at rate 0.025 m/s

Results of the investigation of the effect of the soil moisture content on the coefficient of external friction, with the results obtained by Ahmadi Moghaddam et al. (2006) are consistent. They investigated the effect of five levels of soil moisture content until lubrication limit on the coefficient of soil external friction and found that the coefficient of soil external friction increased significantly until moisture reached to a lubrication limit.

Such reasoning, by water increment the moisture layers extend between the soil and the slider and adhesion increases.

The adhesive force increment operates as an increment in the weight of the slider, therefore adhesive forces cause to the rapid increment in the apparent coefficient of friction with moisture content (Gill and Berg, 1968).

By adding more water when soil moisture content was 46% for loam soil, 39% for sandy loam, 29% loam sand in which soil moisture was at the lubricated limit, draft force decreased per 4 pieces. Whereas in this stage soils moisture content reached a limit in that soil was lubricated and in this condition the coefficient of friction decrease by water increment (Figure 7). The result is consistent with Nichols (1931).

As seen in Figure 8, the amount of moisture to reach to the final limit of friction phase of was different at different textures for each of four test pieces. However, they had the same process.

For three textures of experimental soils, with increasing moisture the coefficient of external friction also increased and passed from frictional phase and adhesion phase.

By adding more moisture it passed from the frictional phase limit and entered to lubricating phase for all three textures.

These results are consistent with the results of Haines (1925) research in which the effect of soil moisture was investigated on the coefficient of soil-metal friction in both sandy and clay soils (Figure 9).

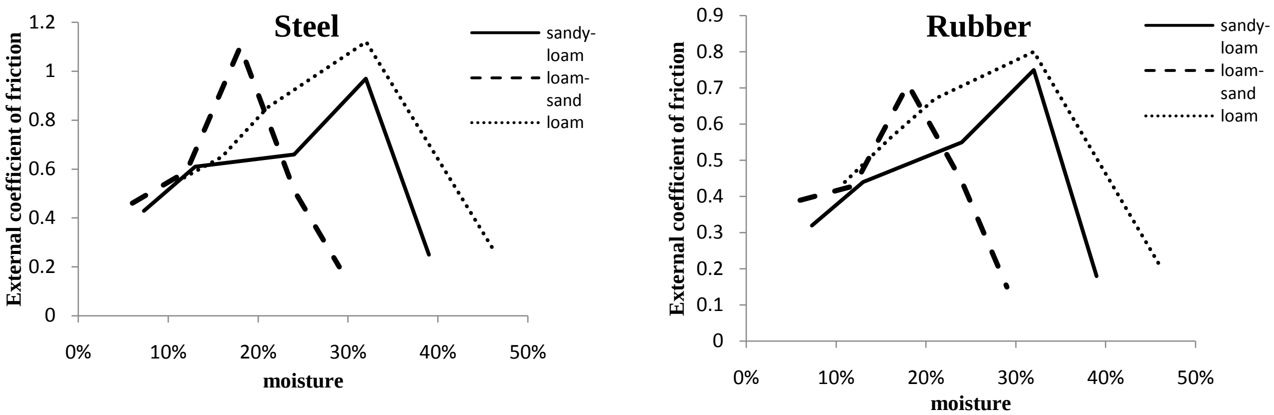


Figure9 Effect of the soil moisture content on the coefficient of soil- metal friction in 3 soil texture and at the rate of 0.025 m/s

This measuring system, which is the developed version of those previous systems used by some of the researches for the purpose of measuring soil apparent friction coefficient, the generated system can measure and record the external friction coefficient automatically on the computer memory or data logger connected to it. That's why, the data processing machine dropped its error and also it was much easier to use.Finally, the values obtained by this device are in close agreement with values obtained by other researchers in the past.

4 Conclusions

A new effective test system has been developed to measure the external friction coefficient. The system was based on the use of transducer and Electronic- Digital data acquiring system.

Experiments on different soil moisture levels showed that the friction coefficient was increased by increasing the moisture, due to increasing adhesion.

The results of experiments showed that the soil texture was affective on the friction coefficient. And it was found that the friction coefficient between soil and rubber was less than the coefficient of friction between soil and steel.

According to the results of experiments, it can be concluded that the system performed properly and also it was easy in operating. And it can be used for determining the coefficient of external friction for different types of soils and metals in different soil moisture levels and speed rates. And with using this device the effects of moisture content, speed rate, soil texture and types of material contacting to soil can be investigated.

References

Ahmadi,Moghadam, P., P. Ataeiyan, and S. Azimi.2006. Design, construction and evaluation of soil internal friction angle and soil adhesion measurement device. Proceedings of the Fifth National Congress of Agricultural Machinery Engineering and Mechanization, Mashhad, Iran, (in farsi).

Gee, M.G., P. Tomlins, A. Calver, R.H. Darling, and M. Rides. 2005. A new friction measurement system for the frictional component of touch.*Wear*,259(2005.02.053): 1437–1442.

Gill, W.R. and G.E. Vanden Berg. 1968a. Assessment of the Dynamic Properties of Soils. Chapter 3 in Soil Dynamics in Tillage and Traction, Agriculture Handbook No. 316, pp. 55-116.Washington, D.C.:U.S. Government Printing Office.

Gill, W.R. and G.E. Vanden Berg.1968b. Dynamic Properties of soils. Chapter 2 in Soil Dynamics in Tillage and Traction, Agriculture Handbook No. 316, pp. 14-116.Washington, D.C.:U.S. Government Printing Office.

Hao, S., B.E. Klamecki, and S. Ramalingam.1999. Friction measurement apparatus for sheet metal forming.*Wear*, 224(1) 1-7.

Haines, W.B. 1925. Studies in the physical properties of soil. I. Mechanical properties concerned in cultivation. *Journal of Agricultural Science.*, 15(2):178-200.

Kepner RA, Bainer R, Barger EL. 1978. Principles of Farm Machinery, third ed. AVI Publishing Company Inc., West Port, CT, pp. 112–134.

Lancaster, J.K. 1990. A review of the influence of environmental humidity and water on friction, lubrication and wear. *Tribology International*, 23(6): 371-389.

Nichols M.L. 1931. The dynamic properties of soil II, Soil and metal friction. Journal of Agricultural

Engineering, 12, 321-324.

Payne, P.C.J. 1956. A field method of measuring soil-metal friction. *Journal of Soil Science*, 7(2): 235-241.

N. I. A. E. Technical Memorandum, Issues 96-129. Front Cover. National Institute of Agricultural Engineering (Great Britain), National Institute of Agricultural

Payne, P.C.J. and E.R. Fountaine.1954. The mechanism of scouring for cultivation implements. *National Institute of Agricultural, Technical Memorandum,* 116, 11 pp.

Plessis, H.L.M. 2005. The tractive performance of a friction- based prototype track. Chapter 2.University of Pretoria.

Rows, R.J. and K.K. Barnes.1961. Influence of speed on elements of draft of a tillage tool. *American Society of Agricultural Engineering Trans.*, 4(1): 55-57.

Shahidi, K.S. and P. Ahmadi Moghadam.2008. Soil and machine. Academic Jihad, 35-40 (in farsi).

Shoehne, W. 1953. Friction and cohesion in arable soils. *Grundlagen der Landtechnik* 5(3): 64-80.

Srivastava, A.K., C.E. Goering, R.P. Rohrbach, and D.R. Buckmaster.2006. Soil tillage. Chapter 8 in Engineering Principles of Agricultural Machines, 2nd ed, 169-230. St. Joseph, Michigan: ASABE. Copyright American Society of Agricultural and Biological Engineers.