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Evaluation of Soil/Material Interface Friction and Adhesion of Akure Sandy Clay Loam Soils in Southwestern Nigeria

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Abstract

There is the need to develop appropriate and efficient soil engaging tools and implements to optimize energy required to cultivate the land and enhance agricultural productivity and sustainability in Nigeria. Necessary design data which were hitherto scarce for Nigerian soils are therefore required to accomplish the task effectively. Laboratory investigations were carried out to evaluate angle of soil/material friction and coefficient of soil/material friction necessary in the design of soil-engaging tools and implements. Facilities used in the investigation include soil-material friction device or sliding shear apparatus. Three types of soil investigated were sandy clay loam soils. The structural materials' surfaces investigated were rubber (RUB), steel (SST), galvanized steel (GAS) and Teflon (TEF). Results show that the coefficient of soil/material friction increased with moisture content to a limit and thereafter decreased. For the materials tested the range was 0.13 - 0.85 in the three soil textures and can be described by polynomial equations for the purpose of prediction. Rubber had the highest coefficient of soil/interface friction followed by smooth steel, galvanized steel, while Teflon had the least in that order.

Key words: Soil; Coefficient of friction; Materials; Soil/tool interface; Adhesion; Models

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INTRODUCTION

Soil adhesion is a natural phenomenon and is an urgent problem that needs to be solved (Jia, 2004). Draft requirement of soil engaging implements is affected by soil-material friction. By reducing the soil to metal friction, the draft requirement of a soil engaging component can be reduced considerably (Loukanov and Uziak, 2002). Soil sliding resistance is made up of friction and adhesion forces that are brought about between the soil and material interface. It was reported (LI *et al.*, 2004) that sliding resistance of the soil–engaging components affects the working properties, energy consumption, efficiency, and quality of terrain machines. Adhesion of soil to terrain machines components is a universal phenomenon and can be very serious. It can decrease productivity, increase energy consumption and affect the quality of work (Gill & Vanden Berg, 1968). It was reported (Ren *et al.*, 2001; Khan *et al.*, 2010; Qaisrani *et al.*, 2010) that adhesion between soil and solid surfaces was dependent upon the nature and properties of soil, the material properties of the soil engaging components and the experimental conditions or working surroundings. The factors that influence the strength of soil sliding resistance include, soil moisture content, normal stress, static stage in the sliding system, soil texture, porosity, material characteristics, sliding velocity, material type, level of normal stress, stiffness of loading and rigidity of the soil materials and maximum values of the normal stress during the course of the test history (Jian-qiao *et al.*, 2004). Ren *et al.* (2001) reported that soil adhesion was increased as the proportion of clay particles in the soil increased and was highest when the soil moisture content was between plastic limit and liquid limit.

A large proportion of the energy used to operate tillage tools goes to overcome frictional sliding resistance as soil moves over the tillage tools surfaces. One approach to reducing the tillage energy requirements has been to use surfaces with low frictional properties. Values of

coefficient of friction and adhesion have been determined for steel surfaces coated with the various materials including lead oxide, ceramic tile, Teflon sheet/tape, and enamel (Salokhe & Gee-Clough, 1988). In tests with inclined blade, the Teflon coated surface displayed negligible adhesion. Tsubakihara *et al.* (1993) carried out laboratory test on friction between cohesive soils and mild steel using a direct simple shear type of apparatus.

Draught was reduced by 27% at low moisture contents but by 31% at high moisture contents (Shrinivasa et al., 1994). Another approach is to use a lubricating fluid to reduce soil metal friction. With the blade lubricated by a 3% solution of polymer, the average draught reduction was 16% with the appropriate rate of polymer-water-solution, which was at a rate equivalent to 103 l/ha (Jian-qiao *et al.*, 2004) . An average draught reduction in 15 trials on widely varying soils was 22% with an average application rate of 140 l/ha.

Moreover, surface morphology also significantly affects the frictional and adhesion forces. For a rusted surface the coefficient of friction may be as high as the coefficient of internal friction of the soil, and even higher than 0.8. By removing the rust, the friction may be considerably reduced, but a high degree of surface polish will result only in a minor decrease in coefficient of friction (Koolen & Kuipers, 1983).

The soil engaging implement change the soil state and the change produced depends on the nature of the soil and the soil/implement interface. A well-designed soil-engaging implement is one, which performs the manipulation required in the most efficient way, usually with a minimum effort (Spoor, 1969).

The attempts that have been made to study and reduce friction were to be able to design appropriate and efficient implements that would require minimum draught and produce the required and appropriate soil condition for plant growth.

In Nigeria, this area of research has not been given the much-needed attention and published works are very scanty. There is therefore the need to embark on such research in soil-tillage dynamics and especially in the specialized area of soil/implement interaction, which will provide additional information and data necessary for the design of appropriate soil engaging implements. The objective of this paper therefore was to evaluate soil/material interface friction and adhesion of Akure sandy clay loam soils in southwestern Nigeria.

MATERIALS AND METHODS

Experimental Soils and Materials

The experimental soils were taken from the profile of a fallow arable land of the commercial farm of the Federal University of Technology, Akure, Nigeria (elevation 210m, 7^0 15'N, 5^0 15'E). The soil is Oxic Paleustalf (Alfisol) or Ferric Luvisol (FAO). The site was recovered from three years of bush fallow. The thickness of the uppermost layer or top soil (S1) is 8.0 cm while the middle layer (S2) was 15.0 cm. The third layer (S3) which was thickest was excavated to 15.0 cm. The quantities of soil samples that were removed according to the three layers were stock piled separately. The fourth sample (S4) was a mixture of the three samples in equal proportions. Samples of the soil were analyzed in the laboratory to determine some of their characteristics (Table 1)

Table 1
Physical Properties of the Soils

Soil type	Texture			Plastic limit, ($\%H_2O$)	Liquid limit, ($\%H_2O$)	Clay ratio %	Particle density, Kg/m_3	Organic matter, %
	Sand%	Silt%	Clay%					
Sandy clay loam (S1)	54	21	25	19	31	33.3	2510	4.32
Sandy clay loam (S2	54	21	25	20	34	33.3	2538	2.94
Sandy clay loam (S3)	52	17	31	21	39	44.9	2567	1.43
Sandy clay loam (S4)	53	19	28	20	35	39.0	2540	2.86

In the evaluation of soil/implement frictional parameters, a soil sliding shear apparatus was used, details of description of the apparatus are reported (Manuwa, 2002). Other accessories of the equipment include: spring balance of sensitivity 0.1g; four sliders of different surfaces: rubber (RUB), smooth steel (SST), galvanized steel (GAS) and Teflon- polytetrafluoroethylene (TEF). The sliders were rectangular in shape, with a surface area each of 314.2 cm^2.

Analytical Methods

Particle size analysis of the soils was performed using hydrometer method (Lambe, 1951). Organic matter content of the soils was determined using the dichromate method. Other physical and chemical properties of the soils were also determined using standard methods.

Experimentation

Soil samples were thoroughly mixed together, air-dried

and passed through 2 mm sieve. The tray of the sliding shear apparatus was filled with soil initially in the dry condition compacted and surface smoothed out with a roller. Soil sample was taken and moisture content determined by gravimetric method. Experimental slider was loaded and winched along the tray while the spring balance recorded the frictional effort. Tests were repeated using different normal loads, noting the different normal loads and the spring balance reading. It was important that the surface was in exactly the same state as the previous treatment. The normal load ranged between 250 g and 1250 g. The procedures were replicated for the different slider surfaces and moisture contents.

Data Analysis

When a material surface and soil slide relative to one another, the frictional resistance of the contact surface must satisfy the Coulomb's equation:

$$F = CcA + P\tan\delta \quad (1)$$

where,

C_a = soil-material adhesion (Pa)

δ = angle of soil/material friction (degree)

P = normal force on surface (N)

F = frictional resistance (N)

A = contact area (m^2)

In adhesive soil, the frictional resistance, F, is mainly produced by adhesion and can be minimized if the contact area (A) is reduced (Qian *et al.*, 1999). Values of frictional forces were plotted against the normal loads for particular moisture content. Regression analysis was applied to fit the best straight line for each set of observation using the criterion of the coefficient of determination (R^2). The slope of the best straight line was taken as the coefficient of soil/material friction/adhesion. The series of these coefficients that were obtained at different moisture contents were then expressed in plots of coefficient of soil/material friction versus moisture content. Polynomial functions best fitted the relationships using R^2 as the criterion.

RESULTS AND DISCUSSION

Some physical and chemical properties of the soils are presented in Table 1. The tangential stress varies with the soil moisture content in the following way: the trend was almost constant as the moisture increased gradually to the lower plastic limit. This is commonly referred to as 'friction phase' Thereafter the tangential stress increased rapidly to a maximum at the upper plastic limit in the region termed 'adhesion phase'. Further increase in moisture from the upper plastic limit caused the shear stress to drop gradually. This region is termed the 'lubrication phase'. At the lower plastic limit the tangential. stress increased rapidly to a maximum as the moisture increased to the upper plastic limit For all the soil textures, it was observed that friction and adhesion increased as moisture content increased until a point at the upper limit consistency of the soil when it reached a maximum and thereafter decreased. It was also observed that the adhesive components were relatively smaller except under certain plastic conditions where a non-scouring condition developed or where the clay ratio was sufficiently high such as in clay soil as reported by Spoor (1969).

Figure 1 shows the effect of moisture content on the coefficient of soil-interface friction of Sandy clay loam soil (S1). The results showed similarity between rubber and smooth steel soil-interface friction characteristics. Also galvanized steel and Teflon had similar characteristics. It is also noteworthy that the values of the coefficient of soil-interface friction peaked when the moisture content was about 22.0% (db). The values of the models that best describe the behavior are also presented in Table 2. Figure 2 presents the effect of moisture content on coefficient of soil-interface friction for S2. The corresponding best fit polynomial models are presented in Table 2.

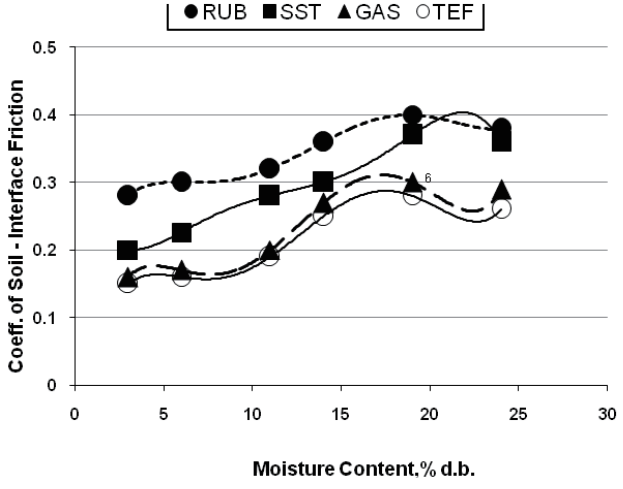

Figure 1
Effect of Moisture Content on Soil/Interface Friction on Sandy Clay Loam Soil (S1)

Table 2
Best Fit Models of Coefficient of Interface Friction in Relation to Water Content

Material Surface	Model	R^2
Soil Texture **S1**	**Models for figure 1**	
RUB	$y=0.0019x^3-0.0202x^2+0.0985x+0.1215$	0.9991
SST	$y=0.0019x^3-0.0188x^2+0.0735x+0.2951$	0.9996
GAS	$y=0.004x^3-0.0402x^2+0.1769x+0.1031$	0.9993
TEF	$y=0.0031x^3-0.0313x^2+0.1382x+0.0564$	0.9999
Soil Texture **S2**	**Models for figure 2**	
RUB	$y=0.0014x^3-0.0158x^2+0.0792x+0.1535$	0.9990
SST	$y=0.0022x^3-0.0233x^2+0.0978x+0.3425$	0.9998
GAS	$y=0.0034x^3-0.0339x^2+0.1513x+0.0660$	0.9994
TEF	$y=0.0024x^3-0.0241x^2+0.1083x+0.0129$	0.9997
Soil Texture **S3**	**Models for figure 3**	
RUB	$y=0.0026x^3-0.0199x^2+0.0657x+0.3648$	0.9993
SST	$y=0.0062x^3-0.0557x^2+0.2342x+0.0941$	0.9998
GAS	$y=0.0067x^3-0.0586x^2+0.2366x+0.1455$	0.9992
TEF	$y=0.003x^3-0.0275x^2+0.1189x+0.0188$	0.9998
Soil Texture **S4**	**Models for figure 4**	
RUB	$y=0.002x^3-0.0201x^2+0.0898x+0.1441$	0.9996
SST	$y=0.0026x^3-0.0259x^2+0.1028x+0.3299$	0.9997
GAS	$y=0.0009x^3-0.0080x^2+0.1028x+0.3298$	0.9984
TEF	$y=-E-05x^3+0.0032x^2-0.0214x+0.1768$	0.9999

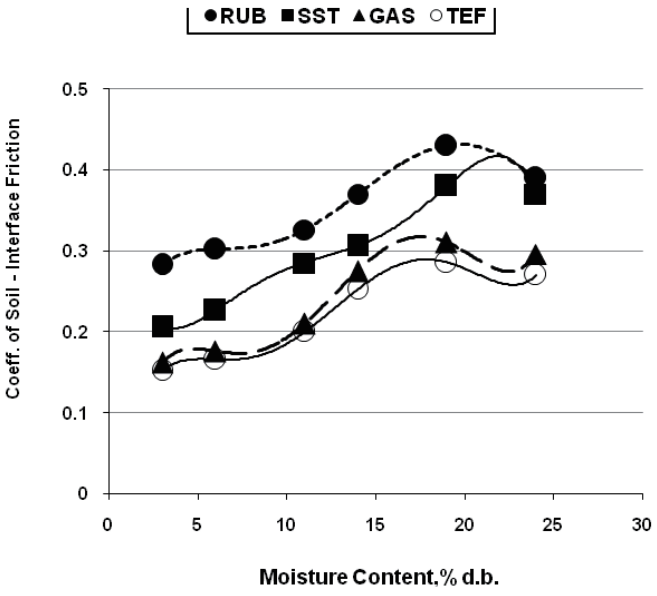

Figure 2
Effect of Moisture Content on Soil/Interface Friction on Sandy Clay Loam Soil (S2)

The peak values for the different materials occurred when the moisture content was about 18.0% (db). With this soil, it was observed that rubber had higher values of soil-interface friction than smooth steel and that the values for GAS and TEF were in a very close range. Figure 3 shows the effect of moisture content on coefficient of soil interface friction for sandy clay loam texture S3.

It was observed here that soil adhesion increased as the proportion of clay particles in the soil increased. Soil interface friction was highest when the soil moisture content was between the plastic limit and the liquid limit. This is similar to that reported by Ren *et al.* (2001). The best-fit polynomial models were also obtained for the curves using regression analysis and their values are presented in the Table 2. Similarly the variation of soil/ interface friction with moisture content for soil texture S4 is presented in Figure 4 and the best fit models presented in Table 2.

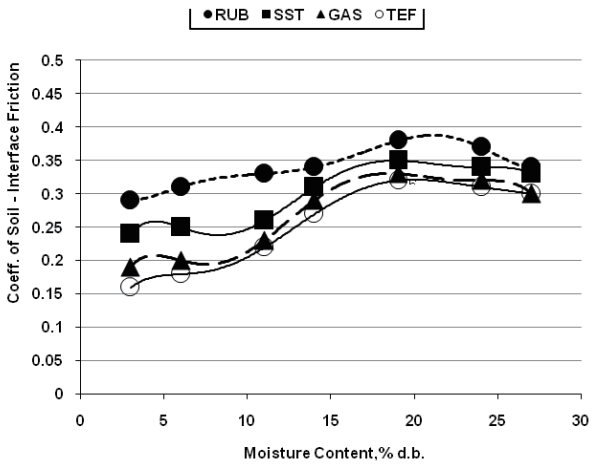

Figure 3
Effect of Moisture Content on Soil/Interface Friction on Sandy Clay Loam Soil (S3)

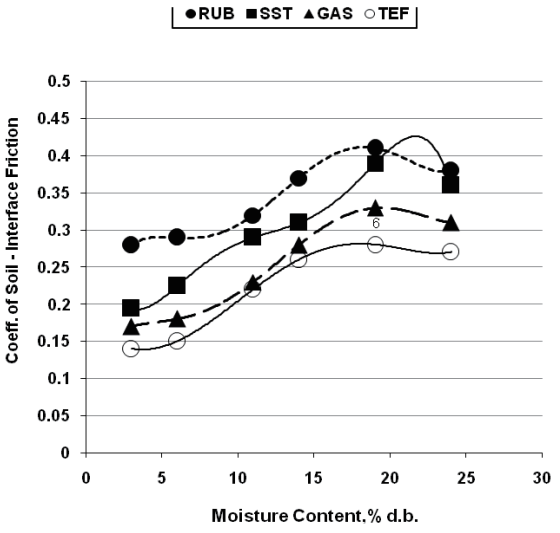

Figure 4
Effect of Moisture Content on Soil/Interface Friction on Sandy Clay Loam Soil (S4)

Generally, in the dry phase, soil-interface friction remained almost constant as the moisture content increased gradually. This trend was similar to that reported by Nichols and Kummer (1932). In the adhesion phase the values of the coefficient of soil-interface friction increased until the lubrication phase when it peaked before it started to decrease rapidly. In the lubrication phase enough moisture was present to cause a low moisture tension and a free water surface to lubricate the soil-material surface and reduce total adhesion (Koolen & Kuipers, 1983). The curves were best fitted with polynomial equations. Generally, the coefficient of soil-interface friction was highest with rubber, followed by smooth steel, then galvanized steel and lastly Teflon. This is expected because Teflon (polytetrafluoroethylene) has non-wetting characteristics and therefore reduced adhesion (Koolen & Kuipers, 1983; Qian *et al.*, 1999; Ren *et al.*, 2001).

CONCLUSION

The following conclusions can be drawn from this study. The coefficient of soil-material friction has been evaluated for the following materials: rubber; smooth steel; galvanized steel; and Teflon. The data provide technical information for appropriate design of soil-engaging tools and implements for sandy clay loam soils in Nigeria and similar soils elsewhere. The coefficient of soil/material-interface friction was highest with rubber followed by smooth steel, then galvanized steel and least with Teflon. The curves were best fitted with polynomial equations.

REFERENCES

[1] Gill, W. R. & Vanden Berg, G. E. (1968). *Soil Dynamics in Tillage and Traction* (Agriculture Handbook 316). Washington D. C.: Agricultural Research Service, U. S. Department of Agriculture.

[2] Jia, X. (2004). Theoretical Analysis of the Adhesion Force of Soil to Solid Materials. *Biosystems Engineering, 87*(4), 489-493.

[3] Khan, M. A., Qaisrani, R. & Jian-qiao, L. (2010). The Techniques of Reducing Adhesion and Scouring Soil by Bionic-Review of Literature. *Advances in Natural Science*, *3*(2), 41-50.

[4] Koolen, J. & Kuipers, H. (1983). *Agricultural Soil Mechanics* (pp.171-280). New York: Springer-Verlag.

[5] Lambe, T. W (1951). *Soil Testing for Engineers* (pp.165). John Wley.

[6] LI Jian-qiao, SUN Jiu-rong, REN Lu-quan & CHEN Bing-cong (2004). Sliding Resistance of Plates with Bionic Bumpy Surface against Soil. *Journal of Bioncs Engineering*, *1*(4), 207-214

[7] Loukanov, I. A. & J., Uziak (2002). Performance Evaluation of an Enamel Coated Animal Drawn Mouldboard Plough. *International Scientific Conference, Rousse, Bulgaria, 04-06, April 2002.*

[8] Manuwa, S. I.(2002). *Development of an Equipment for Soil Tillage Dynamics and Evaluation of Tillage Parameters*. Unpublished PhD Thesis in the Department of Agricultural Engineering, The Federal University of Technology, Akure, Nigeria.

[9] Nichols, H. L. & Kummer, T. H. (1932). The Dynamic Properties of Soil IV. A method of Analysis of Plough Mouldboard Design Based upon Dynamic Properties of Soil Agricultural Engineering, *13*, 279-285. In Gill and Vanden Berg. (1968).

[10] Qaisrani, R., Jian-qiao, L., Khan, M. A., Rashid, I. (2010). Soil Adhesion Preventing Mechanism of Bionic Buldozing Plates and Mouldboard Ploughs. *Advances in Natural Science*, *3*(2), 100-107.

[11] Qian, C., R. Luquan, C. Bingcong, Y. Beizhan (1999). Using characteristics of Burrowing Animals to reduce soil – tool Adhesion. *Transactions of the this American Society of Agricultural Engineers,* Vol. 42 (6), 1549 – 1556.

[12] Shrinivasa, K. U., Chancellor, W.J., Perumpral, J. V.(1994). Advances in Soil Dynamics. American Society of Agricultural Engineers, Michigan.

[13] Spoor, G. (1969). *Farm Machine Design Engineering* (Vol. 3, pp. 22-25). Design Engineering Publications.

[14] Ren, L., Tong, J., Li, J. & Chen, B. (2001). Soil Adhesion and Biomimetics of Soil-engaging Components: a Review. *Journal of Agricultural Engineering Research*, *79*(3), 239-263.

[15] Salokhe, V M, Gee-Clough D. (1988). Coating of Cage Wheel Lugs to Reduce Soil Adhesion. *Journal of Agricultural Engineering Research*, *41*(3), 201-210

[16] Tsubakihara, Y, Kishida, H. & Nishiyama, T. (1993). Friction Between Cohesive Soils and Steel. *Soils and Foundation, 33*(2), 145-156.

