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Sliding Resistance of Plane Solid Materials Against Arable Soils

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Abstract: A lot of problems have been encountered in the use and maintenance of imported agricultural machinery for crop production in Nigeria, especially the tillage implements. Many appeared not to be suitably designed for certain soils in our country by their poor performance characteristics. There is also increasing need to design and develop soil engaging tools and implements to be able to meet increasing demand for food production. It has therefore become necessary, to evaluate soil/implement design parameters that are often necessary in the design of such tools and implements. Such parameters include soil friction and adhesion. Laboratory investigations were carried out to evaluate friction characteristics of solid materials on sandy clay loam soils. On analyses of data collected the Coefficient of Soil-Interface Friction (CSIF) was obtained for the different solid materials. The major equipment used in the investigation was the sliding shear apparatus. The solid materials investigated were Rubber (RUB), Smooth Steel (SST), Galvanized Steel (GAS) and Teflon (TEF). Results show that the CSIF increased with moisture content to a limit and thereafter decreased. For the materials tested, the range was: 0.28-0.43 for RUB; 0.19-0.39 for SST; 0.16-0.33 for GAS; and 0.14 0.32 for TEF. The variation of the CSIF with moisture content was best described by polynomial functions with very high coefficient of determination (R^2).

Key words: Soil, solid materials, coefficient of interface-friction, adhesion, models

INTRODUCTION

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 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 and Vanden, 1968). It was reported (Ren *et al*., 2001) 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 (Li *et al*., 2004). It was also 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 (Ren *et al*., 2001).

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 (Salokhe and Gee, 1988). 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 and Gee, 1988). In tests with inclined blade, the Teflon coated surface displayed negligible adhesion. 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-

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solution, which was at a rate equivalent to 103 l ha^{-1} (Li *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^{-1}.

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 and 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 study therefore is to present data and information on soil sliding behaviour at the interfaces with plane solid materials for some arable soils in Nigeria.

MATERIALS AND METHODS

Experimental soils and materials: The site was a portion of agricultural land under fallow at the Federal University of Technology, Akure, Nigeria (7^0 15^1N, 5^0 15^1E) and elevation 210 m The soil is Oxic paleustalf (Alfisol) or ferric Luvisol (FAO). A mini soil pit was dug to expose the profile. The site was designated Experimental Soil (ES). Three horizons ES1, ES2 and ES3, from top to bottom respectively were identified and samples taken from each. The thickness of the three horizons from top to bottom was 8, 15 and 15 cm, respectively. The fourth soil was a mixture of proportions in the ratio of the thickness of the three horizons and designated ESM.

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 include: Spring balance of sensitivity 0.1 g; sliders made up of the following surfaces Rubber (RUB), Smooth Steel (SST), Galvanized Steel (GAS) and Teflon, polytetrafluoroethylene (TEF). The slider was rectangular in shape, with a surface area of 314.2 cm^2.

Analytical methods: Particle size analysis of the soils was performed using hydrometer method (Lamb, 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 readings. It was important that the surface was in exactly the same state as before.

The normal load ranged between 250 and 1250g.The procedures were replicated three times and the average taken for the different slider surfaces also noting the corresponding 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:

$$F = CaA + P\tan\delta \qquad (1)$$

where,

Ca = 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)

$\tan\delta$ = Coefficient of Soil-Interface Friction, CSIF

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 at different moisture contents. Regression analysis was applied to fit the best straight line for each set of observation using the

Table 1: Physical properties of the soils

Soil type (Saclo)	Texture Sand%	 Silt%	 Clay%	Bulk density Mg m^{-3}	Sat. hyd. Cond.mm min^{-1}	Clay ratio %	Clay+silt %	Organic C, % w/w
ES1	54	21	25	1.43	1.21	33.3	46	1.41
ES2	54	21	25	1.55	1.22	33.3	46	1.22
ES3	52	17	31	1.39	0.85	44.9	48	0.87
ESM	53	19	28	1.47	1.2	38.9	47	1.19

Saclo = Sandy clay loam

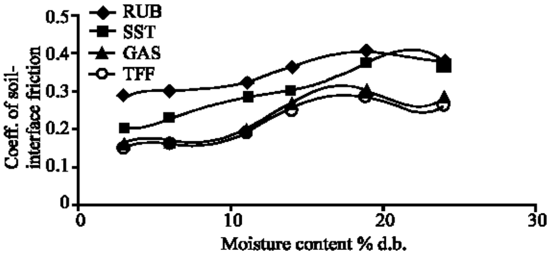

Fig. 1: Effect of moisture content on soil-mareerial interface friction of sandy clay loam (ES1)

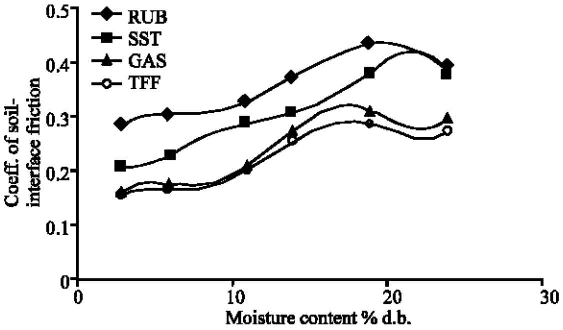

Fig. 2: Effect of moisture content on soil-mareerial interface friction of sandy clay loam (ES2)

criterion of the coefficient of determination (R^2). The slope of the best straight line was taken as the coefficient of soil-material interface friction/adhesion. The various coefficients of soil-material interface frictions that were obtained at different moisture contents were then expressed in plots of coefficient of soil-interface friction versus moisture content. Polynomial functions best fitted the relationships using R^2 as the criterion.

RESULTS AND DISCUSSION

The physical properties of the soils are presented in Table 1. Analysis showed that all the soils belong to the same textural class, which is sandy clay loam, but defer in other soil properties. ES1 and ES2 seem to be the same soil judging from their textural fractions, however they are differed especially in colour, which may be due to the presence of more dead organic material in the ES1 than in the ES2.

Table 2: Regression models of soil- interface friction of sandy clay loam soil (ES1) of Fig.1

Surface material	Model	R^2
RUB	$-0.0007X^3+0.0031X^2–0.0033X+0.2009$	0.9966
SST	$0.0016X^3–0.0082X^2+0.0172X+0.1853$	0.9987
GAS	$-2E-05X^3+0.0002X^2+0.0004X+0.1558$	0.9974
TEF	$-0.000X^3+0.003X^2–0.003X+0.1438$	0.9991

RUB = Rubber, SST = Smooth Steel, GAS = Galvanized steel, TEF = Teflon

Table 3: Regression models of soil- interface friction of sandy clay loam soil (ES2) of Fig. 2

Surface material	Model	R^2
RUB	$0.0019X^3-0.0202X^2+0.0985X+0.1215$	0.9949
SST	$-0.0019X^3+0.0188X^2 – 0.0735X+0.2951$	0.9989
GAS	$0.004X^3-0.0402X^2 +0.1769X-0.1031$	0.9979
TEF	$0.0031X^3-0.0313X^2+0.1382X-0.0564$	0.9992

RUB = Rubber, SST = Smooth steel, GAS = Galvanized Steel, TEF = Teflon

Generally, for all the soils the coefficient of soil-material friction varied with the soil moisture content in the following way: initially, it was more or less constant as the moisture increased gradually to the lower plastic limit. This phase is called 'friction phase' Thereafter, the CSIF increased gradually to a peak (maximum) at the upper plastic limit in the region termed 'adhesion phase'. Further increase in moisture content from the upper plastic limit caused the CSIF to drop gradually. This region is termed the 'lubrication phase' (Fig. 1-4). It was also observed that the adhesive components were relatively smaller in this case, except under certain plastic conditions where a non-scouring condition developed or where the clay ratio was sufficiently high such as in clay reported (Manuwa, 2006).

Figure 1 and 2 show similar trend in the variation of Coefficient of Soil-Interface Friction (CSIF) with increase in moisture content for the solid materials for soils ES1 and ES2. The results showed that Rubber (RUB) had greatest adhesion of all the solid materials followed by Smooth Steel (SST). The maximum coefficient of soil interface friction, CSIF, was 0.43 and 0.38 for rubber and smooth steel respectively. Galvanized steel and Teflon had similar characteristics, however, the CSIF for galvanized steel is relatively higher. It is also noteworthy that the values of the CSIF peaked when the moisture content was about 18.0% (db). The values of the models that best describe the behaviour of polynomial functions in Fig. 1 and 2 are presented in Table 2 and 3 respectively.

Table 4: Regression models of soil- interface friction of sandy clay loam soil (ES3) of Fig. 3

Surface material	Model	R^2
RUB	$-0.0026X^3+0.0199X^2 - 0.0657X+0.3648$	0.9978
SST	$0.0062X^3-0.0557X^2+0.2312X-0.0941$	0.9869
GAS	$0.0067X^3-0.0586X^2+0.2366X-0.1455$	0.99995
TEF	$0.003X^3-0.0275X^2+0.1186X-0.0188$	0.99973

RUB = Rubber, SST = Smooth Steel, GAS = Galvanized Steel, TEF = Teflon

Table 5: Regression models of soil- interface friction of sandy clay loam soil (ESM) of Fig. 4

Surface material	Model	R^2
RUB	$0.002X^3-0.02X^2+0.089X+0.144$	0.9999
SST	$-0.0026X^3+0.026X^2-0.103X+0.329$	0.9989
GAS	$+0.0009X^3-0.008X^2+0.033+0.121$	0.99998
TEF	$-2E-05.X^3+0.0032X^2-0.0214X+0.1768$	0.99978

RUB = Rubber, SST = Smooth Steel, GAS = Galvanized Steel, TEF = Teflon

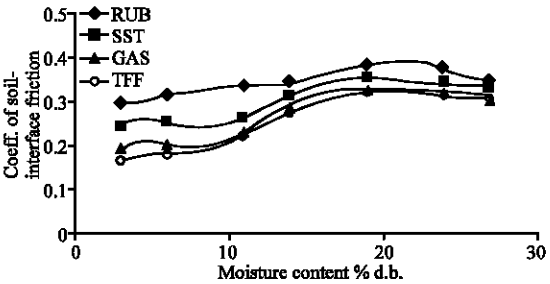

Fig. 3: Effect of moisture content on soil-marerial interface friction of sandy clay loam (ES3)

Figure 3 presents the effect of moisture content on coefficient of soil interface friction for sandy clay loam (ES3) of horizon 3. It is seen here that soil adhesion increased as the proportion of clay particles in the soil increased. It was highest when the soil moisture content was about the plastic limit (20 % db). Other researchers (Ren *et al.*, 2001) reported similar results. The best-fit polynomial models were also obtained for the curves using regression analysis and their values are presented in Table 4.

The parameters of soil ESM are presented in Fig. 4 and the governing regression equations are presented in Table 5.The maximum values of CSIF of this soil texture are 0.41, 0.39, 0.33 and 0.27 for RUB, SST, GAS and TEF respectively.

Generally, in the dry phase, soil-interface friction remained almost constant as the moisture content increased gradually. 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 and Kuipers, 1983).

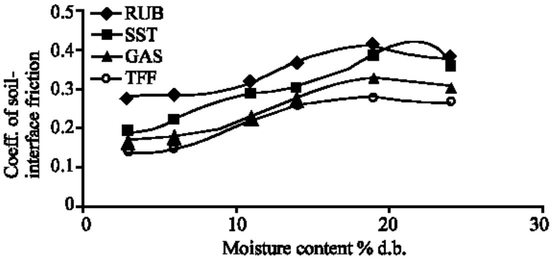

Fig. 4: Effect of moisture content on soil- marerial interface friction of sandy clay loam (ES4)

Generally, the coefficient of soil-interface friction was highest with rubber, followed by smooth steel and then galvanized steel and least for Teflon. This is expected because Teflon (polytetrafluoroethylene) has non-wetting characteristics and therefore reduced adhesion (Ren *et al.*, 2001; Koolen and Kuipers, 1983; Qian *et al.*, 1999).

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 is available for appropriate design of soil-engaging tools and implements. The coefficient of soil-interface friction was highest with rubber followed by smooth steel, then galvanized steel and least with Teflon for a sandy clay loam soil. The curves were best fitted with polynomial equations.

REFERENCES

Gill, W.R. and Vanden G.E. Berg, 1968. Soil dynamics in tillage and traction. Handbook 316, Agricultural Research Service, U. S. Department of Agriculture, Washington, D. C.

Koolen, A.J. and H. Kuipers, 1983. Agricultural Soil mechanics. Springer-Verlag. New York, pp: 171-280.

Lambe, T.W., 1951. Soil Testing for Engineers John Wiley: 165.

LI Jian-qiao, SUN Jiu-rong, REN Lu-quan, CHEN Bing-cong, 2004. Sliding Resistance of Plates with Bionic Bumpy Surface against Soil. J. Bioncs Eng., 1: 207-214

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.

Manuwa, S.I., 2006. Determination of the coefficient of soil material friction for selected materials. Proc. 7th Int. Conf. 28th Ann. General Meeting, Nigerian Inst. Agric. Eng. A.B.U. Samaru-Zaria, Nigeria, 28: 33-36.

Qian, C., R. Luquan, C. Bingcong and Y. Beizhan, 1999. Using characteristics of Burrowing Animals to reduce soil-tool Adhesion. Trans. Am. Soc. Agric. Eng., 42: 1549-1556.

Ren, L., J. Tong, J. Li and B. Chen, 2001. Soil Adhesion and Biomimetics of Soil-engaging components: A Rev. J. Agric. Eng. Res., 79: 239-263.

Salokhe, V. M. and D. Gee-Clough, 1988. Coating of cage wheel lugs to reduce soil adhesion. J. Agric. Eng. Res., 41: 201-210.

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

Spoor, G., 1969. Farm Machine Design Engineering, 3: 22-25.