1962

Characteristics of a Teflon-covered simple tillage tool

William Robert Fox
Iowa State University

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CHARACTERISTICS OF A TEFLON-COVERED SIMPLE TILLAGE TOOL

by

William Robert Fox

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Dean of Graduate College

Iowa State University
Of Science and Technology
Ames, Iowa

1962
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INTRODUCTION

The plow has long been the symbol of Agriculture. It is said that the early colonists regarded plows as indispensable equipment. The cities did not begin to grow until there were good plows to cultivate the nearby fields and insure a sufficient food supply.

During the early settlement of the West, there were many problems for the pioneer farmer. Probably the greatest was that of breaking the prairie sod. The promising prairie that stretched for miles either way from the Mississippi could be broken only with extreme effort. A giant plow, drawn by a cavalcade of eight to sixteen oxen, inched its slow, laborious way through the grass at a rate of 1½ to 2 acres a day. After the first breaking, the farmer, with his crude iron plow and team of horses or oxen, found his land impossible to turn profitably. The alluvial valley soil clung like paste to the share and had to be scraped away by hand after every few feet of plowing.

The first notable contribution to the problem of scouring was given by John Deere, a blacksmith of Illinois (16). He designed, cut and shaped from a discarded sawmill blade the first successful steel plow.

Since the development of the steel plow, many different materials have been used to improve scouring. The steel moldboard has been covered with such materials as glass, plaster of paris, pigskin, plexiglass, and stainless steel (11, 24). Bacon (1) cites the fact that moldboards covered with pigskin or plaster of paris turned the black soils of Texas better than any other type of moldboard. The steel moldboard has also been removed and replaced with an endless canvas belt which rotated on
two tapered rollers, with a slat type endless belt, with wooden rollers, and with slats (steel, oil-impregnated wood, glass, bronze, and lucite) (11, 24). Kummer (11) states that wood-slat bottoms produced considerably better scouring than steel-slat bottoms, especially in the higher moisture ranges.

The reason for improving the friction and scouring characteristics of a plow or any tillage implement is to reduce the total draft of the implement. Collins (6) estimates that 34 percent of the draft is due to the turning of the furrow slice; but, he did not distinguish the portion due to friction on the moldboard. However, it is felt that the friction force is a significant part of the total draft. It is estimated that the highest percentage of the total tractor energy expended on farms is used in plowing operations.

The friction characteristics of a plastic called "Teflon"* seemed to indicate possibilities for improving the scouring of tillage tools. The coefficient of friction for the "Teflon" was found to be phenomenally low. Bowden and Tabor (3) state that the coefficient of friction between metal and "Teflon" is equal to 0.04 which is comparable to that of ice. However, Pillsbury (21) states that the coefficient of friction varies with different materials. Therefore, one should use only data from tests where circumstances are similar to those of the intended application. Some preliminary tests in Hawaii (24) and Alabama (7) indicate that friction and scouring characteristics are improved by using "Teflon" as a surface cover.

*Registered trademark of a polytetrafluoroethylene plastic developed by E. I. du Pont de Nemours and Company.
Objectives of This Study

The objectives of this study were:

1. To determine soil-"Teflon" friction characteristics for different soils.
2. To determine draft requirements of "Teflon"-covered tools.
3. To determine wear characteristics of "Teflon" when used as a cover for the ground-engaging surfaces of a tillage implement.

Review of Related Studies

As stated previously, Bacon (1) found that moldboards covered with plaster of paris or pigskin did a better job of scouring than any other moldboard. The reason given for the success of the plaster of paris moldboard is that the plaster wears away with the soil, demonstrating that the adhesive force between the soil and the plaster is greater than the cohesive force of the plaster. The reason given for the success of the pigskin is that it has water-repelling qualities. It is believed that the improved scouring is caused by decreased adhesion of the water to the contact surface. Kummer (11) has found results similar to the pigskin by using linseed-oil-impregnated wooden slats for a moldboard.

Nichols (14, 15) has studied the friction of soil and metal in detail and has found that the friction varies with the amount of clay content as well as the moisture content of any given soil. He has divided friction into four phases as follows:

A (Compression)Phase. In a soil when the water does not adhere to the metal and when the bearing power of a soil is less than the pressure, that is, when the weight
D (Lubrication) Phase. Where there is enough moisture present to give a lubricating effect, $\mu'$ varies

1. With the pressure per unit area
2. With the speed
3. With the amount of moisture and viscosity of the solution
4. With the nature of the surface and kind of material of which it is composed.

The practical working range for most tillage operations is in the B phase and first part of the C phase. Nichols states that the friction is dependent upon the speed of sliding in the C phase. However, recent tests by Payne (18) suggest that the angle of soil-metal friction is independent of speed.

Bacon (1) has also shown that heating the moldboard reduces the soil-metal friction. A study by Doner and Nichols (8) shows that high curvature in the path near the share results in increased tendency for the soil to stick to the moldboard. Kummer (11) reports that a belt moldboard was tried on sticky soils but was not a success.

Tribble (24) states that a moldboard plow covered with a sheet of "Teflon" was used successfully to plow soils of volcanic origin. He did not state what percentage in draft reduction one might expect. Cooper and McCreery (7) indicate that preliminary tests of a "Teflon"-covered moldboard plow did a good job plowing a Davidson clay. Davidson clay has a fairly high adhesion but has a low cohesive strength which makes it very difficult to plow. They state that the draft requirement of the "Teflon"-covered moldboard plow was 23 percent less than the steel moldboard plow.
Theory of Friction as Applied to This Study

Notable contributions to the subject of friction were made by Leonardo da Vinci (1452-1519) at the end of the fifteenth century (3). It would seem that da Vinci with his astonishing practical genius and insight was clear about the two basic laws of friction and had verified them experimentally. Bowden and Tabor (4) quote da Vinci as follows:

Friction produces double the amount of effort if the weight be doubled, and the friction made by the same weight will be of equal resistance at the beginning of the movement although the contact may be of different breadth or lengths.

The two basic laws are still valid; namely, friction force is independent of sliding area and proportional to load. The friction force is the force required to shear welded asperity contact areas and the force required to push or plow asperities of one surface through those of the other. Usually this plowing force is very small or negligible, especially for very smooth surfaces.

The more recent view that friction had its origin in surface forces and was due to molecular adhesion between the solids was introduced in 1892 (4). Bowden and Tabor (4) observed that when surfaces are placed together they make contact over the tips of their asperities and the pressures here are extremely high. Over these regions where intimate contact occurs, strong adhesion takes place and the specimens become, in effect, a continuous solid. When relative sliding between them takes place, the bonds may hold fast, while bonds between the like molecules of one of the materials give way. As a consequence shearing occurs within the bulk of the weaker of the two materials, rather than at their inter-
face. Therefore, the coefficient of friction is relatively large.

If one accepts the molecular theory as valid, an understanding of the "Teflon" molecule is necessary to explain the extremely low coefficient of friction. Laboratory analysis of "Teflon" shows that the molecule consists essentially of two chemical elements: carbon and fluorine (5). In "Teflon", the forces binding the carbon and fluorine together provide one of the strongest known chemical linkages.

Consider next the manner in which the individual molecules comprising the "Teflon" fit together. With "Teflon", as with other crystalline plastics, molecules are arranged and bound together in an ordered fashion by attractive forces arising primarily from interactions between neighboring molecules. In some polymers, these intermolecular forces are very high. In the case of "Teflon", they are comparatively low. These forces become effective only when the molecules are packed very closely together (25). "Teflon" molecules show even less attraction for dissimilar molecules, which cannot be packed close to the "Teflon" molecules.

As stated previously, when sliding occurs shearing may take place within the bulk of the weaker of the two materials, rather than at their interface. In the case of "Teflon", the slight attraction that the molecules exhibit toward dissimilar molecules, combined with the strong bonds within the "Teflon" molecules, gives rise to shearing at the interface. Therefore, the coefficients of friction are extremely low.

The friction of soil and "Teflon" or metal is somewhat different from the ordinary friction of two solids. The presence of the water
molecule acts as a link between the soil molecule and the other material. Nichols (12, 15) has shown that the amount of water present largely determines the friction force required to slide the soil over the surface. Fountaine (9) attributed the adhesion between soils and foreign materials entirely to the water film between the joined surfaces. He has shown that, provided there is sufficient water present in the soil to form a continuous film between the soil and the surface, the normal adhesion is equal to the product of the area and the moisture tension. When there is not sufficient moisture present for this, he believes the same mechanism to hold, though the resulting adhesion may be reduced due to the smaller area of contact. This would explain the increase in friction with an increase in moisture during the adhesion phase as described by Nichols. With an increase in moisture, there would be an increase in area of contact, thereby increasing the friction force. This increase would continue until there was a sufficient amount of water molecules present to provide a shearing action between the water molecules, and not between water and soil molecules or water and metal molecules. This shearing force between water molecules is less than the shearing force between water and soil. The friction force then essentially would be related to the viscosity of the soil water which would serve as a lubricant.
INVESTIGATIONS

Model Equipment

Because of the desire to test the "Teflon" over a wide range of moisture content and clay content, it was decided to use the model tillage equipment developed by Bockhop (2) and modified by McLeod (13). Although this equipment did not simulate field conditions exactly, it was found to approach them, and it did allow the conditions to be changed with the minimum amount of effort.

Figure 1 shows an overall view of the model equipment as used for the draft tests. The basic function of the equipment is to move the soil past a stationary test stand which supports the implement.

The soil was contained in 3 removable boxes that could be placed on a trolley riding on a narrow gauge test track. The boxes were approximately 3 feet by 12 feet and the test track approximately 45 feet long.

The trolley could be moved in either direction by use of a roller chain drive connected to a variable speed transmission driven by a 5 hp electric motor. The drive assembly is shown in Figure 2. The electric motor was controlled by a remote switch at the test stand.

The implement test stand which was constructed of heavy angle iron straddled the track midway along the track. The tool-carrying frame was mounted on the test stand by a shaft extending through a bearing on each side of the stand. The tool-carrying frame in turn supported the tool and load frame. The tool and load frame could be moved across the tool-carrying frame thereby permitting one to utilize the full width of the
Figure 1. Overall view of model test equipment

Figure 2. Variable speed drive unit
soil box for draft tests. Figure 3 shows a view of the tool and load frame.

The tool and load frame was carried in the tool-carrying frame by six load rings. The rings were constructed from 1/2-inch sections of a 2-inch pipe with two clevises diametrically opposed. SR4 electric resistance strain gages were bonded to the load rings so that strain due to loading could be recorded. The strain from the gages was amplified by a Brush Model BL320 Universal Amplifier and recorded on a Brush Model BL222 Oscillograph from which the respective loads could be determined.

A soil-compaction stand shown in Figure 4 was located at the opposite end of the track from the drive assembly. Its main function was to support the equipment used for the soil fitting procedure. The packer wheels were used in the initial compaction stage. They were mounted on a screw adjusted holder which permits easy adjustment. The packer wheels were 10-inch diameter wheels with 1-inch zero pressure rubber tires. The scraper used to level and smooth the surface is supported by bolts and slotted frame to permit adjustment for different elevations of the soil.

Description of Tools

The basic design of the tillage tools used for this study was a flat plate inclined from the horizontal plane. They were constructed of cold-rolled steel plate 1/4-inch thick. The plates were 4 inches wide by 3 inches long. The front edge of the plate was ground from the back side at a 20-degree angle to form a cutting edge for the tool. A 5-3/4-inch length of 1/4-inch steel rod was welded to the back side of the plate.
Figure 3. Tool holder and load frame

Figure 4. The soil-compaction stand
1/2 inch from the trailing edge to form a holder for the tool. Four tools were constructed for the tests. The tools were called the steel tool, the "Teflon" tool, the "Teflon" with glass filler tool, and the strip of "Teflon" tool.

**Steel tool**

The surface of one of the steel plates was ground to a very fine finish. This was finished as smoothly as the surface grinder in the Engineering Experiment Station shop would permit. The steel tool is shown in Figure 5.

**"Teflon" tool**

A thin sheet of "Teflon" plastic was glued to the surface of one of the steel plates. The back side of the "Teflon" was chemically etched so that an adhesive bond would take place. This tool is shown in Figure 6. The narrow strip of "Teflon" along the leading edge of the tool was added after the large section. Initially the tool was constructed with a leading edge of steel. However, in preliminary tests it was found that soil would stick to the steel surface. To eliminate this effect the small strip of "Teflon" was added.

**"Teflon" with glass filler tool**

One of the steel plates was covered by "Teflon" with a glass filler. The amount of glass filings in the "Teflon" was 15 percent by volume. The "Teflon" with glass filler was chosen because of its resistance to wear and abrasiveness. It is more resistant to wear than virgin "Teflon" or "Teflon" with a copper or graphite filler (20). The "Teflon" with glass
Figure 5. The steel tool

Figure 6. The "Teflon" tool
filler tool is shown in Figure 7. Here again it was necessary to add a small strip of "Teflon" with glass filler along the leading edge after the initial construction.

Strip of "Teflon" tool

The fourth steel plate was covered on the leading edge by a 3/4-inch by 4-inch strip of "Teflon". This constituted one-fourth of the total surface area. This tool is shown in Figure 8. The steel surface was ground as smoothly as possible. The strip of "Teflon" tool was tested only in the Colo soil.

Description of Soils

Since Nichols (14) has shown that clay content appears to affect physical characteristics of soils to a greater degree than any other recognized property, the soils were chosen on this basis. The three soils selected for this study and shown in Table 1, provided a considerable range in clay content.

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<th>Percent silt 0.5-0.002mm</th>
<th>Percent clay &lt;0.002mm</th>
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<tr>
<td>Ida silt loam</td>
<td>14.5</td>
<td>64.4</td>
<td>21.1</td>
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<tr>
<td>Colo silty clay loam</td>
<td>27.9</td>
<td>36.5</td>
<td>35.6</td>
</tr>
<tr>
<td>Luton silty clay</td>
<td>12.0</td>
<td>30.8</td>
<td>57.2</td>
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Figure 7. The "Teflon" with glass filler tool

Figure 8. The strip of "Teflon" tool
The Ida silt loam, a loess soil, was obtained from the Western Iowa Experimental Farm near Castana, Iowa; the Colo silty clay loam was obtained from the local Iowa State University farms; and the Luton silty clay was obtained from the Luton Soil Type Experimental Farm, Sloan, Iowa. The Luton soil is a Missouri River bottom-land soil which has presented a considerable number of problems during tillage operations, especially at a high percent of moisture. All three soils were free from foreign material.

Soil Preparation

The basic objective of the process of soil preparation was to produce a soil mass as homogeneous as possible and to simulate field conditions as nearly as possible. The soil was free from foreign material which is not the case in field conditions. However, the ability to prepare the soil under a controlled procedure made it possible to conduct tests of the different tools operating under similar soil conditions which is desirable in comparing the performance of the tools.

The procedure followed during the tests was the following:
1. Add the required amount of moisture.
2. Mix the soil thoroughly.
3. Compact the soil.
4. Level or scrape the soil surface.

The water was added by a pressure spray and the soil thoroughly mixed by a handrake and hoe. Enough water was added to raise the percent moisture approximately 3 percent. The soil was then allowed to stand for
a minimum of 10 hours or until the soil moisture was equally distributed. The percent moisture was determined by oven drying a soil sample and determining the loss of water by weight. The percent moisture was calculated on a dry basis.

Immediately prior to each test, the soil was remixed and was leveled by the scraper. The packer wheels were then moved to one side of the soil box and lowered to a 1-inch depth and the soil box was moved under the wheels. The wheels were then moved across the soil compaction stand to the opposite side and another pass was made. The packer wheels were then lowered to a 2-inch depth from the original soil surface and the soil box again moved underneath the wheels. At the 2-inch depth passes were made in the two previous lateral positions and in six other positions so that the entire soil surface was covered in the eight lateral positions of the wheels.

After the compaction by the wheels, the slight ridges left by the wheels were removed by the scraper. The soil was then further compacted by use of a modified proctor hammer. The modified proctor hammer was constructed by fastening a 7-3/8-in by 10-5/8-inch piece of 1-inch plywood to the base of a standard proctor hammer. The hammer was dropped five times at a particular position and then moved to another position until the entire soil surface was covered.

After the compaction by the proctor hammer, the top 1/8 inch of the soil was removed by the scraper. The scraper was tilted from the horizontal plane at the same angle as the tillage tools. It also was sharpened at a 20-degree angle from the backside. It was felt that the
top soil surface that was used for the friction tests would then be approximately the same as the surface of the soil in contact with the tillage tools used in the draft tests.

The previously stated soil preparation procedure was adopted to give similar conditions after each preparation for all of the tests (13). However, the soil bulk density did vary somewhat. This variation would be expected for different moisture contents. The average bulk density for the Ida soil was 82 lbs/ft$^3$; for the Colo soil, 80 lbs/ft$^3$; and for the Luton soil, 65 lbs/ft$^3$. The bulk density was determined by weighing a specified volume of soil. The sample was taken by using a thin cylindrical tube to extract the small volume of soil from the total volume in the soil boxes.

Test Procedure

Determination of angle of friction and adhesion

Payne (18) has shown that the frictional properties of soil, at least over the range of moisture content at which tillage operations can be carried out, may be represented by an equation similar to the Coulomb equation (19). The equation is as follows:

$$S = A + N \tan \mu$$

where $S$ = tangential shear stress at the interface, force per unit area

$A$ = apparent adhesion, force per unit area

$N$ = normal stress on interface, force per unit area

$\mu$ = angle of friction (soil-to-tool surface)
The A and \( \mu \) are not constant properties even for a given soil type. However, they may be measured for any given soil.

To determine the necessary properties for the previously stated equation, it was necessary to measure different shear stresses for different normal stresses. Payne and Fountaine (19) developed a cylindrical shear device for measuring the resistance to shear of a column of soil. It is essentially a device for measuring the torque required to twist off the column of soil. By knowing the relation between torque and shearing stress, the shear stress is easily found.

McLeod (13) has extended this same line of reasoning to a circular friction plate. It is then a matter of measuring the torque required to twist the circular plate on the surface of the soil.

The device used for measuring the resisting torque of the friction plate is shown in Figure 9. It consisted of an inner shaft on which the friction plate was fastened. The shaft could move axially within an outer shaft, but it could not twist relative to the outer shaft. To apply different normal stresses, it was necessary only to add the required load on the top end of the inner shaft. The outer shaft was supported on a 3-legged frame and was rotated by means of a worm gear and pinion. The plate was rotated at a constant rate which was an average tangential speed of 5.0 ft/min. However, there was no detectable difference for shear stresses at speeds both above and below the given speed. The shear stresses were not investigated at extremely high speeds.

The torque required to twist the friction plate was measured by use of SR4 electric resistance strain gages. The gages were mounted on the
outer shaft in the established manner for measuring strain due to a torque. The strain was then recorded on the previously mentioned oscillograph. To calibrate the device known values of torque were applied and the corresponding pen deflections on the oscillograph were noted and recorded. By plotting several different deflection values and torque values it was easy to obtain a calibration constant.

The friction plates used for this study were constructed of a flat circular steel plate 5.92 inches in diameter with an attachment to fasten onto the shaft of the torsional device. The "Teflon" plate is shown in Figure 10. The parallel marks on the surface of the "Teflon" are processing marks acquired at the factory. The "Teflon" with glass filler plate was constructed similar to the "Teflon" plate. The material in question was glued to the steel plate. The plate used for the soil-metal friction was ground to the same finish as the steel tool used in the draft tests.

By assuming that the shear stress is independent of the distance from the plate center, the following equation may be developed

$$S = \frac{3T}{2\pi r^3}$$

where r is the radius of the plate. McLeod (13) shows this derivation. To check if this was a valid assumption, a plate was constructed consisting of a ring or circular band only in contact with the soil. The ring had an outside diameter of 5.92 inches and an inside diameter of 4.92 inches. If the shear stress is dependent on the distance from the center, one would expect only a slight variation over the area at the distances given.
Figure 9. Torsional device used in friction tests

Figure 10. The "Teflon" friction plate
An analysis of variance as described by Snedecor (23) shows no significant difference at 95 percent confidence between the shear stress of the ring plate and the shear stress of the solid plate for the same normal stress. The data and analysis for this test are given in Appendix A. In view of the above, the assumption of a constant shear stress over the interface was accepted as valid.

A total of sixteen normal stresses and the corresponding shear stresses were measured and recorded for each of the different types of previously described tool surfaces. The measurements were randomly taken over the ends and middle portions of the soil surface in the soil boxes. The area covered was approximately ten square feet. By plotting shear stress and normal stress, the apparent adhesion and angle of friction could be determined.

**Determination of draft**

The basic objective of the draft test was to determine the draft of each different tool for the various soils at different moisture contents.

The soil was prepared according to the procedure previously stated. The tests were begun when sufficient water was added so that the soil was just moist enough to cling together to form a ridge. After the friction measurements were taken, the soil boxes were used for the draft tests. The portion of the soil surface used for a draft test was approximately 24 square feet.

To eliminate the side effect of the soil on the flat plate used as a tool, a ridge was prepared in the soil box. One of the ridges is shown
in Figure 11. To prepare the ridge a 4-inch section of metal was placed on the soil surface and a trench 1-1/4-inch deep and 2-inches wide was dug on each side of the strip. This was done very carefully to insure a ridge 4-inches wide from the top to the bottom. Therefore, the actions involved in the draft test of the tool were the shearing of the soil; the lifting of the soil; and the sliding of the soil block over the tool surface. Figure 12 shows one of the tools and the ridge of soil during a test run.

Three ridges were made through the soil boxes with the exception of the Colo soil box in which four ridges were constructed. The ridges were divided into two sections which gave two replications of draft data for each tool. To eliminate the side and end effects of the soil boxes, the particular location in the soil box for each tool was randomly selected. This would give six different measurements for draft at each percent moisture with the exception of the Colo soil which had eight different measurements. The length of run that was used to determine an average draft measurement was 4 feet.

Each tool was run at a depth of 1 inch. This was slightly above the bottom of the side trenches. The tool was operated at an angle of 45° from the horizontal plane, and the speed of forward travel was a constant 0.5 ft/sec.

The draft of each tool was determined by use of the load rings previously mentioned. The strain due to loading (the horizontal draft of the tool) was recorded on the oscillograph. To calibrate the load rings, known values for draft and the corresponding values for pen deflection
Figure 11. View of the ridge in the soil box prior to test

Figure 12. View of the ridge and tool during a test run
were noted and recorded. From this, it was possible to determine draft in relation to the pen deflection for a particular test.

After a particular draft test, water was added to the soil to increase the percent moisture. The soil was then remixed and prepared according to the soil preparation procedure. Altogether nine complete sets of draft tests were conducted for each soil with the exception of the Ida soil in which ten sets of draft tests were made.

The tests were continued until the soil became so wet that it was impossible to prepare the soil with the hand tools. However, the moisture range covered was much wider than the range over which normal tillage operations are practiced.

**Determination of resistance to wear**

Since the "Teflon" is a plastic, one might expect considerable wear when used on tillage tools. This is especially true when the soils contain a high percent of sand and gravel. However, the soils that present scouring or friction problems usually contain a relatively small amount of abrasive material.

To determine wear, one usually measures the amount of material worn away by either volumetric or weight measurements. Since facilities for very precise weight measurements were available, the differential weighing method was utilized. The material was weighed on an analytical balance capable of 0.1-milligram accuracy.

Since wear resistance of steel tillage implements were fairly well known, the wear resistance of the "Teflon" was determined in relation to steel (22). Therefore the results will be a relative comparison and not
an absolute value for wear.

To produce the wear effect, the respective surface on a circular plate was rotated against the soil surface. The plates used for this test are shown in Figure 13. The normal load on each plate was 10.5 lbs.

The device for rotating the plates is shown in Figure 14. The plate was driven by a right-angle drive connected to a flexible shaft. The shaft in turn was rotated at 155 rpm by an electric motor. The support shaft on which the drive unit is fastened is permitted to move vertically. This was adopted to maintain a constant normal load on the circular plate.

The soil used for the test was the Colo soil. This soil was chosen because it contained the most sand of the three soils. The soil during the test was at the 8.7 percent moisture level. It was felt that this was the worst abrasive condition for the Colo soil.

The procedure followed for the actual test is given below. The tools were first run for a short time for a break-in wear test. This was done before any measurements were taken. After this break-in wear, wear is generally a linear relation with time (10). The plates were then weighed before and after a particular test run. The time for a test was either a 5 or 10 minute interval. However, the plate was shifted onto "new" soil every minute. Photographs were taken at various time intervals to provide a visual comparison of the different tool surfaces.
Figure 13. Circular plates used in wear test

Figure 14. Device for rotating the plates used in the wear test
RESULTS AND DISCUSSION

The results will be presented similar to the test procedure. However, the discussion of the different tests will begin with the Ida soil which has a low clay content and continue through the Luton soil.

Results of Friction and Adhesion Tests

The value for torque of any particular test was read from the oscillograph chart and the shear stress computed from the relation previously given. Since the sliding friction was of primary interest, the values taken from the chart was that value at which the torque trace reached a stabilized value. The "Teflon" did not exhibit a "stick-slip" characteristic such as the steel did. "Stick-slip" is a combination of static (stick) friction and kinetic (slip) friction. It predominates when static friction is the larger. This means that at the beginning of sliding the friction force will be greater than it will be during sliding.

To determine the properties $A$ (apparent adhesion) and $\mu$ (angle of friction) or $\tan \mu$ for a particular soil, the values for shear stress as a function of normal stress were plotted. The data for shear stress and normal stress for the different tools are given in Appendix B. A sample diagram for the shear and normal stress is shown in Figure 15. The equation

$$S = A + N \tan \mu$$

was determined by the method of least-squares as outlined by Snedecor (23). The computations were performed by use of an IBM 650 computer.
Figure 15. Sample determination of friction properties
LUTON SOIL
"TEFLON" WITH GLASS FILLER
MOISTURE 22 %

\[ S = 0.005 + 0.205 \ S_n \]
The program used was the well-known one for determining a linear regression by the method of least-squares.

**Ida soil**

The results of the friction and adhesion tests in the Ida soil are given in Table 2. The apparent adhesion for this soil is negligible except for the high percent moisture. The values are very close to zero or negative. Only the apparent adhesion for the steel at the two highest moisture contents was statistically significant. Payne (18) suggests that a possible explanation of the apparent negative adhesion is that, where the applied normal stress was relatively small, it was carried entirely by the pore water which built up a pressure in the vicinity of the interface. Where, however, the applied normal load exceeded a critical value, the pore water drained sufficiently to permit the excess normal stress to be carried by the soil particles and so the tangential stress commenced its linear increase. The extremely low negative values could also be due to the experimental error in collecting the data. However, at high moisture contents the apparent adhesion for the steel tool was significant which is evident in Table 2. During the test run, the soil was observed to actually stick to the steel surface at the higher percent moisture.

The results of friction as a function of percent moisture are also shown in Figure 16. Note that the steel follows the same general pattern as given by Nichols. In order to produce a graph with the most clarity, the curves for "Teflon" and "Teflon" with glass filler were plotted separately with the curve for steel as a base for comparison. The
Table 2. Computed friction and adhesion results for tests in Ida soil

<table>
<thead>
<tr>
<th>Tool</th>
<th>Percent moisture (M)</th>
<th>Friction (tan ( \mu ))</th>
<th>Apparent adhesion (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Teflon&quot; with glass filler</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.20</td>
<td>0.351</td>
<td>-0.010</td>
<td></td>
</tr>
<tr>
<td>12.90</td>
<td>0.370</td>
<td>-0.050</td>
<td></td>
</tr>
<tr>
<td>15.40</td>
<td>0.370</td>
<td>-0.010</td>
<td></td>
</tr>
<tr>
<td>14.80</td>
<td>0.381</td>
<td>-0.058</td>
<td></td>
</tr>
<tr>
<td>16.80</td>
<td>0.393</td>
<td>-0.014</td>
<td></td>
</tr>
<tr>
<td>17.50</td>
<td>0.405</td>
<td>0.008</td>
<td></td>
</tr>
<tr>
<td>18.50</td>
<td>0.436</td>
<td>0.034</td>
<td></td>
</tr>
<tr>
<td>20.40</td>
<td>0.455</td>
<td>-0.005</td>
<td></td>
</tr>
<tr>
<td>20.90</td>
<td>0.475</td>
<td>0.022</td>
<td></td>
</tr>
<tr>
<td>23.90</td>
<td>0.405</td>
<td>0.085</td>
<td></td>
</tr>
<tr>
<td>Steel</td>
<td>12.20</td>
<td>0.451</td>
<td>-0.020</td>
</tr>
<tr>
<td>12.90</td>
<td>0.482</td>
<td>-0.005</td>
<td></td>
</tr>
<tr>
<td>15.40</td>
<td>0.492</td>
<td>0.088</td>
<td></td>
</tr>
<tr>
<td>14.80</td>
<td>0.514</td>
<td>-0.025</td>
<td></td>
</tr>
<tr>
<td>16.80</td>
<td>0.537</td>
<td>0.055</td>
<td></td>
</tr>
<tr>
<td>17.50</td>
<td>0.530</td>
<td>0.077</td>
<td></td>
</tr>
<tr>
<td>18.50</td>
<td>0.579</td>
<td>0.068</td>
<td></td>
</tr>
<tr>
<td>20.40</td>
<td>0.562</td>
<td>0.067</td>
<td></td>
</tr>
<tr>
<td>20.90</td>
<td>0.505</td>
<td>0.183*</td>
<td></td>
</tr>
<tr>
<td>23.90</td>
<td>0.424</td>
<td>0.197*</td>
<td></td>
</tr>
<tr>
<td>&quot;Teflon&quot;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.20</td>
<td>0.312</td>
<td>-0.010</td>
<td></td>
</tr>
<tr>
<td>12.90</td>
<td>0.321</td>
<td>0.030</td>
<td></td>
</tr>
<tr>
<td>15.40</td>
<td>0.381</td>
<td>-0.032</td>
<td></td>
</tr>
<tr>
<td>14.80</td>
<td>0.367</td>
<td>-0.012</td>
<td></td>
</tr>
<tr>
<td>16.80</td>
<td>0.400</td>
<td>-0.019</td>
<td></td>
</tr>
<tr>
<td>17.50</td>
<td>0.404</td>
<td>0.031</td>
<td></td>
</tr>
<tr>
<td>18.50</td>
<td>0.420</td>
<td>-0.015</td>
<td></td>
</tr>
<tr>
<td>20.40</td>
<td>0.414</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>20.90</td>
<td>0.427</td>
<td>0.025</td>
<td></td>
</tr>
<tr>
<td>23.90</td>
<td>0.407</td>
<td>0.011</td>
<td></td>
</tr>
</tbody>
</table>

*Significant at 5 percent level of probability.
Figure 16. Tan $\mu$ vs. percent moisture for Ida soil. The two curves for steel are identical. The 95 percent confidence limits for tan $\mu$ are less than $\pm 0.05$. 
moisture range was sufficient to cover the adhesion phase and the lubrication phase. The 95 percent confidence limits on the values of \( \tan \mu \) as plotted are less than ±0.05. The curves for the "Teflon" and "Teflon" with glass filler are not significantly different. However, they are approximately 25 percent less than the steel curve, particularly through the adhesion phase.

A note of interest is that the particular value of percent moisture at which the lubrication phase begins for the two "Teflon" curves is shifted to the right of the percent moisture of the lubrication phase for the steel curve. A possible explanation for this is that the bond between the "Teflon" and water molecules at 19 percent moisture is less than the bond between water molecules. As the amount of water in the soil is increased to a higher percent moisture, the total bond between the water and "Teflon" becomes stronger than the bond between water molecules.

Note also that the steel curves tend to approach the "Teflon" curves as the percent moisture is increased. Since \( \tan \mu \) essentially represents lubrication at the high values of moisture content, one might expect the \( \tan \mu \) for the three surfaces to be represented by a single curve.

Colo soil

The results of the friction and adhesion tests in the Colo soil are given in Table 3. Here, again, the apparent adhesion may be considered negligible with the exception of steel at high moisture contents. Only the apparent adhesion for the steel tool at the two highest moisture contents was statistically significant. The soil was observed to stick to
Table 3. Computed friction and adhesion results for tests in Colo soil

<table>
<thead>
<tr>
<th>Tool</th>
<th>Percent moisture (M)</th>
<th>Friction (tan (\mu))</th>
<th>Apparent adhesion (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Teflon&quot; with glass filler</td>
<td>17.70</td>
<td>0.256</td>
<td>-0.026</td>
</tr>
<tr>
<td></td>
<td>18.60</td>
<td>0.288</td>
<td>-0.016</td>
</tr>
<tr>
<td></td>
<td>19.20</td>
<td>0.281</td>
<td>-0.038</td>
</tr>
<tr>
<td></td>
<td>20.40</td>
<td>0.289</td>
<td>-0.001</td>
</tr>
<tr>
<td></td>
<td>22.40</td>
<td>0.359</td>
<td>-0.040</td>
</tr>
<tr>
<td></td>
<td>23.10</td>
<td>0.403</td>
<td>-0.046</td>
</tr>
<tr>
<td></td>
<td>24.00</td>
<td>0.410</td>
<td>-0.020</td>
</tr>
<tr>
<td></td>
<td>26.70</td>
<td>0.527</td>
<td>0.035</td>
</tr>
<tr>
<td></td>
<td>27.70</td>
<td>0.473</td>
<td>0.101</td>
</tr>
<tr>
<td>Steel</td>
<td>17.70</td>
<td>0.327</td>
<td>-0.033</td>
</tr>
<tr>
<td></td>
<td>18.60</td>
<td>0.546</td>
<td>0.015</td>
</tr>
<tr>
<td></td>
<td>19.20</td>
<td>0.617</td>
<td>-0.060</td>
</tr>
<tr>
<td></td>
<td>20.40</td>
<td>0.585</td>
<td>0.082</td>
</tr>
<tr>
<td></td>
<td>22.40</td>
<td>0.581</td>
<td>0.051</td>
</tr>
<tr>
<td></td>
<td>23.10</td>
<td>0.581</td>
<td>0.141</td>
</tr>
<tr>
<td></td>
<td>24.00</td>
<td>0.563</td>
<td>0.041</td>
</tr>
<tr>
<td></td>
<td>26.70</td>
<td>0.537</td>
<td>0.201*</td>
</tr>
<tr>
<td></td>
<td>27.70</td>
<td>0.507</td>
<td>0.148*</td>
</tr>
<tr>
<td>&quot;Teflon&quot;</td>
<td>17.70</td>
<td>0.281</td>
<td>-0.043</td>
</tr>
<tr>
<td></td>
<td>18.60</td>
<td>0.288</td>
<td>-0.012</td>
</tr>
<tr>
<td></td>
<td>19.20</td>
<td>0.300</td>
<td>-0.007</td>
</tr>
<tr>
<td></td>
<td>20.40</td>
<td>0.320</td>
<td>-0.016</td>
</tr>
<tr>
<td></td>
<td>22.40</td>
<td>0.338</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>23.10</td>
<td>0.388</td>
<td>0.036</td>
</tr>
<tr>
<td></td>
<td>24.00</td>
<td>0.404</td>
<td>0.046</td>
</tr>
<tr>
<td></td>
<td>26.70</td>
<td>0.534</td>
<td>0.005</td>
</tr>
<tr>
<td></td>
<td>27.70</td>
<td>0.442</td>
<td>0.100</td>
</tr>
</tbody>
</table>

*Significant at 5 percent level of probability.
the steel plate during the test run.

The results of friction as a function of moisture content are also shown in Figure 17. In order to clarify the graph, the two curves for steel are identical. The adhesion phase and lubrication phase can be observed as two distinct phases for the steel curves. However, only the adhesion phase is prevalent for the two "Teflon" curves. Since the steel curve was approaching the "Teflon" curves at high moisture levels, it is believed that the "Teflon" curves were approaching the point that would distinguish the lubrication phase.

There is no significant difference between the "Teflon" curve and the "Teflon" with glass filler curve. However, they are both considerably lower than the steel curve. The 95 percent confidence limits on the values of tan $\mu$ as plotted are less than $\pm 0.06$.

**Luton soil**

The results of the friction and adhesion tests in the Luton soil are given in Table 4. As with the two previous soils, the apparent adhesion was negligible with the exception of steel at the highest moisture content. The apparent adhesion for the steel tool was statistically significant only at the highest moisture content of 30.8 percent where soil was observed sticking to the steel tool.

The results of friction as a function of moisture content are also shown in Figure 18. Here, again the two curves for steel are identical which gives a base for comparison. The adhesion phase for all the tools is the only phase covered by the range of moisture contents given. From the given data, it is not possible to state at which moisture content the
Figure 17. Tan $\mu$ vs. percent moisture for Colo soil. The two curves for steel are identical. The 95 percent confidence limits for tan $\mu$ are less than $\pm 0.06$. 
<table>
<thead>
<tr>
<th>Tool</th>
<th>Percent moisture (M)</th>
<th>Friction (tan μ)</th>
<th>Apparent adhesion (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Teflon&quot; with glass filler</td>
<td>19.10</td>
<td>0.225</td>
<td>0.006</td>
</tr>
<tr>
<td></td>
<td>22.00</td>
<td>0.205</td>
<td>0.005</td>
</tr>
<tr>
<td></td>
<td>21.60</td>
<td>0.217</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>22.90</td>
<td>0.210</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>25.30</td>
<td>0.273</td>
<td>0.006</td>
</tr>
<tr>
<td></td>
<td>26.50</td>
<td>0.297</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td>28.40</td>
<td>0.360</td>
<td>0.040</td>
</tr>
<tr>
<td></td>
<td>30.40</td>
<td>0.564</td>
<td>0.010</td>
</tr>
<tr>
<td></td>
<td>30.80</td>
<td>0.516</td>
<td>0.055</td>
</tr>
<tr>
<td>Steel</td>
<td>19.10</td>
<td>0.494</td>
<td>-0.010</td>
</tr>
<tr>
<td></td>
<td>22.00</td>
<td>0.600</td>
<td>-0.056</td>
</tr>
<tr>
<td></td>
<td>21.60</td>
<td>0.546</td>
<td>-0.056</td>
</tr>
<tr>
<td></td>
<td>22.90</td>
<td>0.646</td>
<td>0.066</td>
</tr>
<tr>
<td></td>
<td>25.30</td>
<td>0.673</td>
<td>-0.056</td>
</tr>
<tr>
<td></td>
<td>26.50</td>
<td>0.688</td>
<td>0.009</td>
</tr>
<tr>
<td></td>
<td>28.40</td>
<td>0.695</td>
<td>0.004</td>
</tr>
<tr>
<td></td>
<td>30.40</td>
<td>0.700</td>
<td>0.067</td>
</tr>
<tr>
<td></td>
<td>30.80</td>
<td>0.619</td>
<td>0.133*</td>
</tr>
<tr>
<td>&quot;Teflon&quot;</td>
<td>19.10</td>
<td>0.223</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>22.00</td>
<td>0.260</td>
<td>0.057</td>
</tr>
<tr>
<td></td>
<td>21.60</td>
<td>0.256</td>
<td>-0.015</td>
</tr>
<tr>
<td></td>
<td>22.90</td>
<td>0.275</td>
<td>-0.040</td>
</tr>
<tr>
<td></td>
<td>25.30</td>
<td>0.295</td>
<td>-0.010</td>
</tr>
<tr>
<td></td>
<td>26.50</td>
<td>0.329</td>
<td>0.008</td>
</tr>
<tr>
<td></td>
<td>28.40</td>
<td>0.382</td>
<td>0.020</td>
</tr>
<tr>
<td></td>
<td>30.40</td>
<td>0.492</td>
<td>-0.006</td>
</tr>
<tr>
<td></td>
<td>30.80</td>
<td>0.450</td>
<td>0.031</td>
</tr>
</tbody>
</table>

*Significant at 5 percent level of probability.
Figure 18. Tan $\mu$ vs. percent moisture for Luton soil. The two curves for steel are identical. The 95 percent confidence limits for tan $\mu$ are less than $\pm0.06$
C PHASE

LUTON SOIL
- "TEFLON"
- STEEL
- "TEFLON" WITH GLASS FILLER

\[ \tan \theta \]

PERCENT MOISTURE

0 18 20 22 24 26 28 30 32
lubrication phase, if any, will occur.

Again, there is no significant difference between the "Teflon" curve and the "Teflon" with glass filler curve. However, they are approximately 50 percent less than the steel curve. The 95 percent confidence limits on the values of \( \tan \mu \) as plotted are less than \( \pm 0.06 \).

From the results of the friction tests, it is observed that the maximum value of \( \tan \mu \) (beginning of the lubrication phase) for steel and soil is related to the clay content of the soil. With an increase in clay content, the maximum value of \( \tan \mu \) also increases. This value represents the moisture film strength when a maximum number of films (due to an increase in surface area of soil particles) of maximum strength are in contact with the steel (15). Likewise, the value of moisture content at which the lubrication phase begins is increased with an increase in clay content. Nichols (15) states that this variation with clay content is due to the amount of hygroscopic moisture absorbed by the clay before a moisture film becomes evident.

A similar trend of increased maximum values with an increase in clay content is also observed for the \( \tan \mu \) for "Teflon" and soil or "Teflon" with glass filler and soil. However, they do not increase as much as the maximum values of the \( \tan \mu \) for steel and soil. Therefore, the difference between the maximum values of \( \tan \mu \) for steel and soil and the \( \tan \mu \) for "Teflon" and soil is more pronounced in soils of higher clay contents. This indicates that "Teflon" or "Teflon" with glass filler is of more value in reducing friction and improving scouring in soils of high clay content.
Results of Draft Tests

As stated previously, the strain due to the draft was recorded on an oscillograph chart. With the known calibration for draft and the pen deflection, the draft was determined directly from the oscillograph chart.

Since the soil yields to the implement in a succession of shear failures, the recorded draft forces of an implement pulled through the soil will reflect an oscillating pattern (17). It is estimated that the draft will decrease approximately 30 percent after each shear failure.

Since the average rather than the peak value for draft was of primary interest, a particular area under a section of the draft trace on the oscillograph chart was integrated by using a polar planimeter and dividing by the chart length to obtain an average draft. The data for the draft tests are given in Appendix C.

Ida soil

The results of the draft test in the Ida soil scattered considerably when the draft was plotted as a function of moisture content. In order to determine an equation expressing this relationship, a linear regression by the least-squares method was again utilized. A linear equation appeared to fit the data as good or better than a curvilinear relation over this range of moisture content. The equations determined were of the form

\[ D = a + b M \]

where \( D \) = draft in lbs. and \( M \) = percent moisture.
The equations representing the tests in the Ida soil are shown in Table 5.

Table 5. Regression equations obtained from tests in Ida soil

<table>
<thead>
<tr>
<th>Draft of respective tool</th>
<th>Regression equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>( D = -2.575 + 0.398M )</td>
</tr>
<tr>
<td>&quot;Teflon&quot;</td>
<td>( D = -0.794 + 0.256M )</td>
</tr>
<tr>
<td>&quot;Teflon&quot; with glass filler</td>
<td>( D = 0.179 + 0.202M )</td>
</tr>
<tr>
<td>Difference. Steel-&quot;Teflon&quot;</td>
<td>( D = -1.773 + 0.141M )</td>
</tr>
<tr>
<td>Difference. Steel-&quot;Teflon&quot; with glass filler</td>
<td>( D = -2.198 + 0.169M )</td>
</tr>
</tbody>
</table>

It is obvious that the same linear relationship does not exist for draft and moisture content from the zero percent moisture up to the range of tests. A possible explanation for the negative intercepts is given as follows. Nichols (15) found that at low percent moisture the coefficient of friction is independent of moisture. This range is approximately from 0 to 10 percent moisture. Since the tools were operated at the same speed and the same depth, the total pressure between the interface should remain the same. Therefore, the friction coefficient for the 0 to 10 percent moisture should remain constant.

Since no record of shearing or cutting the soil slice as a function of moisture content was found in the literature review, it is not possible to state how the cutting force would change. However, since the friction relation does change over the high range of moisture, one might expect a
different relation for draft in the low range from that found in the higher range of moisture contents. The results found in this study indicate that the two relationships are different.

The results of the draft tests in Ida soil are shown in Figure 19. In order to clarify the graph, it was separated into two parts. The two steel curves which give a base for comparison are identical. The draft increased with increasing moisture content even though the tan $\mu$ decreased at the high moisture content. However, the apparent adhesion for the steel was significant at these moisture contents; and, the total shear stress is the important consideration when one considers the draft. Also, the decrease in the tan $\mu$ for the two "Teflon" tools at the higher moisture contents was not appreciable.

To determine if there was a significant difference between the draft of any two tools, the following procedure was followed. Since the data for the different tools were taken at the same time and under the same conditions, the difference of draft between any two tools may be plotted as a function of moisture content. These results are shown in Figure 20. Whenever the lower confidence limit is above zero, one may state that there is a statistical difference. It is observed that there is no significant difference for the draft of the steel tool and the draft of the two "Teflon" tools at moisture contents below approximately 16 percent moisture.

From the figure, it is also observed that the draft of the "Teflon" tool is not significantly different from the draft of the "Teflon" with glass filler tool. The two curves for the confidence limits are for all
Figure 19. Draft vs. percent moisture for Ida soil. The two curves for steel are identical.
IDA SOIL

- STEEL
- "TEFLON"
- "TEFLON" WITH GLASS FILLER

DRAFT (LBS.)

PERCENT MOISTURE

10 15 20 25
Figure 20. Difference between draft of the steel and the other tools vs. percent moisture for Ida soil
IDA SOIL

DIFF. STEEL-"TEFLON" WITH GLASS FILLER

- - - - - 95% CONFIDENCE LIMIT

DRAFT (LBS.)

DIFF. STEEL-"TEFLON"

- - - - - 95% CONFIDENCE LIMIT

PERCENT MOISTURE

0 10 15 20 25
practical purposes identical.

A check at the midpoint of the moisture range (17 percent) with the appropriate confidence limits shows a possible 6 to 25 percent reduction of draft.

From the results of these draft tests, it is seen that there is an advantage of using the two "Teflon" tools over the steel tool especially when the soil is sticking to the steel tool. At this point scouring becomes a problem.

Colo soil

The regression equations obtained from the draft tests in Colo soil are given in Table 6.

The results of the draft tests in the Colo soil are shown in Figure 21. Note the two steel curves are identical. The curve representing

<table>
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<tr>
<th>Draft of respective tool</th>
<th>Regression equation</th>
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</thead>
<tbody>
<tr>
<td>Steel</td>
<td>D = -12.424 + 1.019M</td>
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<td>&quot;Teflon&quot;</td>
<td>D = -9.379 + 0.774M</td>
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<tr>
<td>&quot;Teflon&quot; with glass filler</td>
<td>D = -10.386 + 0.810M</td>
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<td>Strip of &quot;Teflon&quot;</td>
<td>D = -11.158 + 0.901M</td>
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<td>Difference. Steel-&quot;Teflon&quot;</td>
<td>D = -3.038 + 0.245M</td>
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<tr>
<td>Difference. Steel-&quot;Teflon&quot; with glass filler</td>
<td>D = -1.922 + 0.205M</td>
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<tr>
<td>Difference. Steel-Strip of &quot;Teflon&quot;</td>
<td>D = -0.844 + 0.118M</td>
</tr>
</tbody>
</table>
Figure 21. Draft vs. percent moisture for Colo soil. The two curves for steel are identical.
COLO SOIL

- STEEL
- "TEFLON"
- "TEFLON" WITH GLASS FILLER

DRAFT (LBS)

PERCENT MOISTURE

0 15 20 25 30
the draft of the strip of "Teflon" tool, if shown, would lie between the
curve for the steel tool and the curve for the "Teflon" tool. However,
for the sake of clarity, it was not included.

To determine if a significant difference between the draft of the
different tools existed, the same procedure as previously described was
followed. These results are shown in Figure 22. Here, again there was
no significant difference between the draft of the "Teflon" and the
"Teflon" with glass filler tools. However, the draft of the two "Teflon"
tools was significantly different from that of the steel tool.

From the figure, it is also seen that the draft of the strip tool is
not significantly different from the draft of the "Teflon" tools. How­
ever, the slope of the curves representing the different tools is quite
different. A check at the midpoint of the moisture range (22.2 percent)
with the appropriate confidence limits shows a possible 11.2 to 25 per­
cent reduction of draft for the strip tool; whereas, either of the
"Teflon" tools would give a possible 16 to 34 percent reduction of draft.

Luton soil

The regression equations obtained from the draft tests in the Luton
soil are given in Table 7.

The results of the draft tests in the Luton soil are shown in Figure
23. Here, again, the two steel curves are also identical.

Figure 24 shows the results for the difference in draft of different
tools. A test for significance again shows no difference for the draft
of the "Teflon" and "Teflon" with glass filler tools. However, there was
a significant difference for the draft of the steel tool as compared to
Figure 22. Difference between draft of the steel and the other tools vs. percent moisture for Colo soil
COLO SOIL

DIFF STEEL - "TEFLON" WITH GLASS FILLER
--- 95% CONFIDENCE LIMIT

DIFF STEEL - STRIP OF "TEFLON"
--- 95% CONFIDENCE LIMIT

DRAFT (LBS.)

DIFF. STEEL - "TEFLON"
--- 95% CONFIDENCE LIMIT
DIFF. STEEL - STRIP OF "TEFLON"
--- 95% CONFIDENCE LIMIT

PERCENT MOISTURE
Figure 23. Draft vs. percent moisture for Luton soil. The two curves for steel are identical.
LUTON SOIL
- STEEL
- "TEFLON"
- "TEFLON" WITH GLASS FILLER

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PERCENT MOISTURE

0 18 20 22 24 26 28 30 32
Figure 24. Difference between draft of the steel and the other tools vs. percent moisture for Luton soil
LUTON SOIL

- DIFF STEEL - "TEFLON" WITH GLASS FILLER
- 95% CONFIDENCE LIMIT

DRAFT (LBS.)

DIFF STEEL - "TEFLON"
- 95% CONFIDENCE LIMIT

PERCENT MOISTURE

0 10 20 30 40 50 60

0 1 2 3 4 5 6 7
Table 7. Regression equations obtained from tests in Luton soil

<table>
<thead>
<tr>
<th>Draft of respective tool</th>
<th>Regression equation</th>
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<td>$D = -2.138 + 0.183M$</td>
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that of the two "Teflon" tools.

A check at the midpoint of the moisture range (25.2 percent) with the appropriate confidence limits shows a possible 17 to 38 percent reduction of draft.

From the results of the draft tests, it is observed that "Teflon" used as a surface cover can be of value in reducing the draft of a tillage implement. By using "Teflon" or "Teflon" with glass filler, it was possible to reduce the draft by 6 to 38 percent. The amount of reduction depends upon the clay content and moisture content of the soil. The value of "Teflon" or "Teflon" with glass filler used as a surface cover is especially good when scouring becomes a problem at high moisture contents.

Results of Wear Tests

As previously stated the amount of wear was measured by determining the loss in weight for a particular time interval. However, the volume
loss of material was of primary interest in this study. This is especially true since the materials used are of different densities. Since the density of the respective material was known, it was relatively easy to convert the weight loss to volume loss of material. The data for the wear tests are given in Appendix D.

Figures 25 and 26 show the relation of material loss as a function of time. Note that the two curves for steel are identical. A t-test for significance (23) shows that there is no difference between the rate of wear of the "Teflon" and that of the "Teflon" with glass filler.

A check of the slope with the appropriate confidence limits for the "Teflon" curve as compared to that of steel shows that the "Teflon" may be expected to wear away 8 to 10 times as fast as steel. The same may be said for the "Teflon" with glass filler.

The "Teflon" with glass filler seems to be more resistant to scratches caused by sand particles. This is noted in Figures 27 through 29, which show that the "Teflon" has quite noticeable grooves. Since most soils consist of some sand or gravel, it is therefore suggested that the "Teflon" with glass filler be used for soil engaging surfaces on field implements.

**Limitations of This Study and Suggestions for Future Research**

As stated previously, this study was limited primarily to the performance of model tools. Therefore, the results are not directly applicable to field conditions. However, Bockhop (2) and McLeod (13)
Figure 25. Rate of wear for the steel and the "Teflon"
O "TEFLON"
△ STEEL
NORMAL LOAD 10.5 LBS.
Figure 26. Rate of wear for the steel and the "Teflon" with glass filler.
"TEFLON" WITH GLASS FILLER

STEEL

NORMAL LOAD
10.5 LBS.

WEAR (CU. CENT. $\times 10^{-2}$)

TIME (MIN.)
Figure 27. View of wear plates before the wear test. The one on the right is the "Teflon".

Figure 28. View of the same material after 45 minutes had elapsed during the test run.

Figure 29. View of the same material at the end of the wear test.
have shown that the principles of similitude may be used to predict field results from laboratory results. The results of this study which was conducted on simple tillage tools will differ slightly from the results of tests on more complicated shapes of tillage implements.

There is need for future research on the following related aspects of this study:

1. A study to determine the influence of relatively high speeds on the angle of friction when using "Teflon".

2. A study to determine the influence of moisture content on the shearing strength of soils.

3. A study in actual field conditions of a full-scale implement using the "Teflon" with glass filler as a surface cover.

4. A study to determine how many acres a farmer would need to till before the "Teflon" with glass filler surface can be replaced economically.
SUMMARY AND CONCLUSIONS

Since the beginning of civilization, man has tried to reduce the amount of energy required to till the soil. Many attempts have been made to reduce the draft necessary to move an implement through the soil. Possibly one way to reduce the total draft is to reduce the force required to slide the soil over the surface of the implement.

The purpose of this study was to determine the characteristics of "Teflon" used as a cover for soil-engaging surfaces of tillage implements as an aid in reducing the draft of the implement in question.

The tests were made on model tools in soil boxes. The soil boxes were carried on a trolley riding on a narrow gauge test track. The trolley could be propelled in either direction at various speeds by use of an electric motor driving a roller chain through a transmission.

The basic function of the model equipment was to move the soil past a stationary test stand which supports the implement. The implement was supported by 6 load rings. SR4 electric resistance strain gages were bonded to the load rings so that strain due to loading could be recorded on an oscillograph.

The tool used for this study was a 3-inch by 4-inch flat steel plate. The leading edge of the tool was ground to a 20-degree angle from the back side. A 5-3/4-inch length rod was welded 1/2 inch from the trailing edge in order to hold the tool at a 45-degree angle from the horizontal plane during travel. The tools studied included a steel surface, a "Teflon" surface, a surface of "Teflon" with glass filler, and a steel surface
partially covered with "Teflon".

The three soils used for this study were Ida silt loam, Colo silty clay loam, and Liton silty clay loam. Prior to the tests, the soil was mixed and compacted by use of a scraper and small packing wheels. The tests covered the range of moisture that is normally found in tillage operations.

The friction properties of the tools were determined by use of a torsional shear device. With the relation of shear stress and applied normal stress at the interface known and an equation similar to the Coulomb equation for shear strength of soils, the apparent adhesion and angle of friction for the soil were easily found.

The draft tests were conducted on 4-inch ridges that were made by removing the soil on each side of the ridge. The draft was determined from the strain recordings on the oscillograph charts.

The wear of the respective material was accomplished by rotating a flat circular plate on the soil surface. The amount of wear was determined by the weight loss for a particular time interval.

This study showed the following:

1. The general friction results for the "Teflon" and "Teflon" with glass filler were similar to those obtained for the steel. However, the values of friction were at a reduced magnitude. The amount of reduction depends upon the clay content and the moisture content of the soil.

2. The draft of a tillage tool may be reduced by reducing the angle of friction (soil-to-tool surface). By using "Teflon" or
"Teflon" with glass filler, it was possible to reduce the draft by 6 to 38 percent. This amount of reduction likewise depends upon the clay content and the moisture content of the soil.

3. The "Teflon" or "Teflon" with glass filler may be expected to wear away 8 to 10 times as fast as steel. However, the "Teflon" with glass filler appears to be more resistant to scratches from sand and gravel particles than the virgin "Teflon".

The results of this study show that "Teflon" with glass filler can be of value as a surface cover for tillage tools that are used in soils of high clay content and high moisture content. There were no scouring problems when the "Teflon" with glass filler tool was used; however, the soil was observed to stick on the steel tool.

When the cost of "Teflon" with glass filler is further reduced, the cost per acre of tillage operations with "Teflon" as a cover on soil-engaging surfaces may become competitive with the cost of ordinary steel surfaces.
LITERATURE CITED


12. ______ and Nichols, M. L. The dynamic properties of soil. VII. A study of the nature of physical forces governing the adhesion between soil and metal surfaces. Agricultural Engineering. 19:73-78. 1938.


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Thanks are due the author's wife, Mary, whose patience and help made possible the completion of this study.
APPENDIX A

Preliminary Investigation Data
Table 8. Data for check of ring plate and solid plate shear stress in Ida soil at 8.7 percent moisture

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Analysis of variance:

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*Significant at 5 percent level of probability.
APPENDIX B

Shear and Normal Stress Test Data
Table 9. Shear and normal stress data for tests in Ida soil

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\(^a\)G refers to "Teflon" with glass filler.

\(^b\)S refers to steel.

\(^c\)T refers to "Teflon".
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bT refers to "Teflon".

CS refers to steel.
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aG refers to "Teflon" with glass filler.
bT refers to "Teflon".
cS refers to steel.
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APPENDIX C

Draft Data
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APPENDIX D

Wear Data
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*The values given are cumulative loss in cu. cent. x 10^{-2}.*