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To the Graduate Council:

I am submitting herewith a thesis written by Rudragouda Fakiragouda Patil entitled "Friction Characteristics of Soil and "Teflon" Tetrafluoroethylene Resins for Use in Agricultural Machinery". I recommend that it be accepted for eighteen quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Engineering.

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Dean of the Graduate School

**FRICTION CHARACTERISTICS OF SOIL AND "TEFLON", TETRAFLUOROETHYLENE
RESINS FOR USE IN AGRICULTURAL MACHINERY**

A THESIS

**Submitted to
The Graduate Council
of**

**The University of Tennessee
in**

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for the degree of
Master of Science**

by

Rudragouda Fakiragouda Patil

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CHAPTER I

INTRODUCTION

Agriculture is the oldest of all industries. The first practice of the art of tillage marked the beginning of the introduction of tillage machinery. The earliest tools were crude chopping or digging implements of wood, stone, shell or bone. The application of animal power for tillage followed the invention of the crooked-stick plow used to stir the soil. Since then a wide variety of tools have been developed. The process of improvement of the tillage machinery is never ending. In spite of the rapid progress made in recent years, there are still many problems to be solved in the field of tillage machinery. According to Todd (19), the consideration of the continual improvements to machinery is necessary, not only for new installations, but also for those already in use.

Tillage and Power

The use of cultivation implements to prepare seedbeds by providing favorable conditions for seed germination and plant growth is the oldest practice of arable agriculture. It reached a relatively high level of development centuries ago. Progress was made by laborious methods of trial and error and traditions of correct practice were empirically developed. During the past century the union of practice and science has been slowly strengthened.

The evolution of tillage implements and machinery is one of the most striking features in the growth of the science of farming.

Great advances have been made in the perfection of tillage tools. Even so, tillage operations remain the most costly of all the various operations of crop production. Thirty per cent of the total power used in agriculture in the United States goes into tillage. Bayer (3) estimates that over half of this power is used in the basic operations of plowing and listing. Miller, Turk and Foth (10) estimate that about one-third of all draft power used on farms is expended in plowing.

Tillage is the greatest power consuming operation on the farm. Therefore, it deserves much consideration from the point of view of economy. Many studies have been undertaken to determine ways and means of reducing the power requirement of tillage machines.

Soil Friction and Tillage

Kummer and Nichols (9) have found that friction between the soil and metal surface has a great influence upon the life and draft of tillage tools. The intensity of this friction governs largely the wearing and scouring properties of the implement. High friction constitutes a waste in power and causes excessive wear of the tillage implement.

Scouring of moldboard plows in sticky soils is one of the most difficult problems facing the plow designers. Bacon (2) found that the moldboards made of plaster of paris and those covered with hog hides proved more successful in the plastic soils of Texas than any other type of moldboard made of steel, iron, glass, brass and

aluminum. According to him, the Texas observations must be regarded as conclusive evidence that the shape of the moldboard is not the only factor to be considered, but the material of the moldboard often contributes more to its successful operation than the shape. Kummer (8) verified these observations and found them to coincide with his own results. These results show that there exists a need for a material which has a lower coefficient of friction for use in tillage implements, not only from the point of view of saving power, but also for better scouring properties. The agricultural engineer, therefore, has to turn his attention to new engineering materials which, when used in the construction of agricultural implements, help to reduce the power requirements and scour satisfactorily. Decay, rust, and corrosion are active all the year round particularly due to the fumes produced in the barns even when the implements are stored inside. Corrosion of metal due to moisture, salt and acids is very common in farm machinery when not adequately protected from the weather. Rust and corrosion are the common cause of scouring troubles and are the chief enemies of agricultural machinery and implements and reduce, very greatly, their useful life and service. Hence, the new engineering material should also be resistant to corrosion and rust.

The agricultural engineer has to look for an engineering material with the usual properties of strength, durability, low coefficient of friction, and, in addition, the properties of scouring and resistance to rust, and corrosion. Fortunately, tetrafluoroethylene resins commercially known as "Teflon" possess these pro-

parties, and it appears that these resins can be used to improve the performance of agricultural machinery and implements.

Statement of the Problem

The problem was to investigate the friction characteristics of "Teflon" and agricultural soils. This study was undertaken with a view to find out whether the friction between "Teflon" and soil was less than the friction between metal and soil.

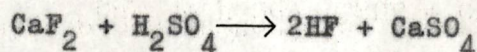
"Teflon" Tetrafluoroethylene Resins

Teflon is the registered trade mark of the du Pont de Nemours and Co. Inc., Wilmington 98, Delaware, for its fluorocarbon resins. The first of these resins was discovered in 1938 (18) as a result of the research on "Freon" series of refrigerants, which are chemical compounds consisting of fluorine, carbon and usually chlorine. The semiplant production of Teflon was started in 1941. The commercial production of these resins was first started in 1950, at Parkersburg, West Virginia. As a result of continued research a number of these resins have been developed.

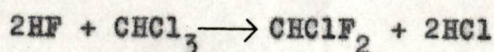
The du Pont Company supplies Teflon as a series of powders and aqueous dispersions. These resins are converted into tape,

sheets, rods, tubes, coated fibres, coated wire, wire enamels, molded parts etc. by a number of manufacturers. The Teflon molding powder is obtained from fluorspar (calcium fluoride), sulfuric acid and chloroform, as a result of chemical reactions between them. The chemical reactions take place in the following four stages (18).

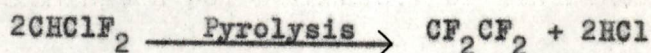
1. The calcium fluoride, CaF_2 , and sulfuric acid, H_2SO_4 , react with each other to give hydrogen fluoride, HF, and calcium sulphate, CaSO_4 .



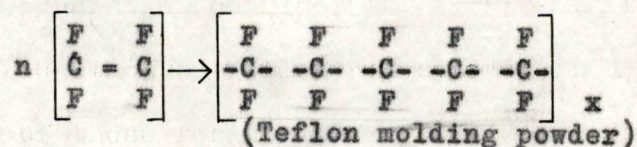
2. The hydrogen fluoride, HF, reacts with chloroform, CHCl_3 , to give chlorodifluoromethane, CHClF_2 , and hydrochloric acid, HCl.



3. The chlorodifluoromethane, CHClF_2 , is converted into gaseous tetrafluoroethylene monomer, CF_2CF_2 , and hydrochloric acid, by pyrolysis.



4. The tetrafluoroethylene monomer, CF_2CF_2 , is polymerized under high pressure and temperature to give Teflon molding powder



Properties of Teflon

"Teflon" has unique properties which make it suitable for adaptation in agricultural use. It has exceptional thermal stability and is suitable for continuous service at 500°F . It also maintains good properties at extremely low temperatures of -450°F .

The most outstanding properties of Teflon for its use as an engineering material for agricultural use are:

1. Frictional property. Teflon has an extremely low coefficient of friction. The coefficient of friction against polished steel is found to be as low as 0.04. The coefficient of friction is independent of the temperature between the limits of 77° F and 572° F.

2. Non-adhesive property. Owing to their low coefficient of friction, few materials tend to stick to the surfaces of these resins. Scouring abilities of agricultural implements can therefore be improved by using Teflon.

3. No water absorption. The water absorption of these resins by the A.S.T.M. test is found to be less than 0.01 per cent.

4. Weathering property. Teflon is not affected by outdoor weathering or by moisture. Tests conducted in Florida have shown that these resins have remained completely unchanged even though they were exposed for over ten years.

5. Mechanical properties. These resins are relatively flexible and tough. They retain their flexibility and toughness over a wide range of temperatures.

6. Chemical properties. These resins have practically universal chemical inertness. They are also relatively impermeable to many chemicals.

7. Electrical properties. These resins have exceptional electrical properties which remain unchanged at temperatures up to 480° F.

8. Non-flammable property. The tetrafluoroethylene resins are non-flammable.

Certain mechanical properties of Teflon are improved by the use of additives. The resistance to deformation under load is increased by a factor of ten, resistance to wear by five hundred times, stiffness by a factor of four to five, compressive strength by a factor of three to four and hardness by 10 per cent. The modified compositions of Teflon still retain their low coefficient of friction. Types of additives that are generally suitable include metallic copper and bronzes, glass fibre, graphite, coke flour, molybdenum disulfide, clay, talc, silica, asbestos, and calcium fluoride powder.

The physical properties of compounded Teflon depend on the additive, the amount of additive, uniformity of the blend, and molding, and annealing techniques. The most striking advantage of modified Teflon over uncompounded Teflon is its resistance to wear.

Uses of Teflon

Electrical application. Teflon is extensively used in the electrical industry, particularly in insulation for use at high frequencies and high temperatures. Specific fields of application include motors, generators, and transformers of all types; and aircraft, automotive, communications, electronics, locomotive and marine equipment.

Chemical applications. In many instances in the chemical industry Teflon has been found to be the only material which gives the desired performance. These resins are used as gaskets, valve

components, pump components, and pipes and tubings, where the equipment is required to handle corrosive liquids.

Mechanical applications. Due to their low coefficient of friction, these resins are used in mechanical parts, primarily as bearing surfaces. In the textile twisting machines Teflon is used to eliminate lubricants which contaminate the goods.

Non-adhesive application. Teflon is used where sticky materials are required to be handled owing to its unique non-adhesive property. These resins are used in a variety of applications in food processing equipment especially in machinery used in the preparation and handling of candy; in the rubber and plastic industries, to prevent sticking to molds and platens; and in industries in which glue is handled extensively.

Agricultural application. At present Teflon is not being used to any great extent in agriculture. But investigations are being made at different places on the use of Teflon in agriculture.

Friction

Friction is a force, which opposes relative motion between two surfaces, which are in contact with each other. A force is required to cause a plane surface to slide over another plane surface, against which it is pressed. The force of friction acts at the surfaces of contact tangential to the surfaces and is always in the direction opposite to the direction of motion. As the force applied to cause motion increases, the force of friction

also increases up to a particular limit. The relative motion between the two surfaces begins when the maximum force of friction is just overcome. This maximum force of friction is called the limiting friction. In the manufacture of machines, great care is taken to reduce friction as much as possible, but friction is not always undesirable. It is often necessary and beneficial. But for friction, it would not be possible to drive machinery by belts and clutches.

Causes of Friction

There are two main causes of friction. One - the unevenness of the surfaces and two - adhesion and cohesion between the particles of matter. Even though the surfaces of many objects may appear smooth to the naked eye, they will show numerous tiny mountains and valleys, when examined under a microscope. When the surfaces are in contact with each other, these tiny mountains and valleys interlock and tend to prevent the relative motion between the surfaces. The small particles of matter have attraction for each other. This force of attraction is known as cohesion and adhesion. Adhesion and cohesion form the part of the frictional resistance, opposing the sliding of one surface over another.

Static Friction

When two bodies are in contact with each other and a force parallel to the surfaces of contact is applied to one of the bodies, and the force is less than a certain amount, motion will

not take place, the frictional resistance being equal to the force. As the force is increased to a certain value, the resistance will fail to increase, and sliding will take place. This maximum resistance is called the maximum static friction.

Kinetic Friction

To keep one body sliding on another at a constant speed, a certain force, parallel to the surface of contact, is required. The opposing resistance offered by the surfaces is called kinetic friction.

Coefficient of Friction

The coefficient of friction is defined as the ratio between the limiting force of friction and the normal force between the surfaces of contact.

If μ = coefficient of friction,

F = limiting force of friction,

and N = normal force between the surfaces,

$$\text{then } \mu = \frac{F}{N}$$

The angle made by the resultant of the frictional force and the normal force with the normal force, is called the angle of friction. As the friction increases, the angle of friction also increases and is maximum, when the friction is maximum. The coefficient of friction is equal to the tangent of the angle of friction.

$$\mu = \tan \phi, \phi \text{ being the angle of friction}$$

Laws of Friction

The following laws of friction were the results of experiments conducted by Coulomb. These laws were later confirmed by Morin (17) and hold good for dry surfaces.

1. Limiting force of static and kinetic friction is proportional to the normal pressure, i.e. the coefficient of friction is independent of the normal pressure.

2. The coefficient of friction is independent of the area of the surfaces of contact.

3. The coefficient of kinetic friction is less than that for static friction and for low speeds is independent of the relative velocity of the surfaces.

4. Friction is only slightly affected by ordinary temperature changes.

The laws of friction for lubricated surfaces differ greatly from the laws for dry surfaces. When a film of lubricant exists between the surfaces, the friction is practically independent of the nature of the surfaces. It is also independent of the normal pressure. The temperature greatly affects the friction of lubricated surfaces.

Review of Previous Work Done

Tillage Tool Surfaces and Shapes

Trullinger (21) reported in 1925 that tillage is one of the greatest, if not the greatest, power consuming agricultural operation. According to him even in those days much study was undertaken to determine ways and means of reducing the power requirements of tillage machines during the production of desired tillage results. This study resulted in the special shaping of tillage tool surfaces, for various purposes, and established the broad general fact, that different soils require different tools and shapes, to produce the desired tillage results.

Soil and Metal Friction

Nichols (12) started his classic investigations in soil and metal friction in 1923. He published many useful results, which are extensively used and quoted in many text books on tillage and soils, and by research workers in the field of the dynamic properties of the soil. In his study on "The Sliding of Metal over Soil" (13), his object was to determine the friction between soil and metals and the underlying variables affecting it. In this study his primary equipment was a piece of flat metal of chilled plow iron of area 24.52 square inches, pulled by a spring balance. Three points were located to determine the angle of friction by increasing the weights of the slider to double and triple its weight of 1500 grams. The soils used were made up of mixtures of

clean, rough grained white quartz sand and very finely divided clay of great plasticity; 98.6 per cent of which, passed through a one hundred mesh sieve and the balance going through an eighty-mesh sieve. These mixtures varied from pure sand to pure clay and the intervening mixtures contained 25, 50 and 75 per cent of clay; the remaining portion being sand. These soils were air dried and water was added to them in various amounts by means of a steam jet over an atomizer, to determine the effect of moisture on the coefficient of friction. The moisture percentages used by him were, air dry, 0.5, 2, 4, 6, 8, 10, 12 and 15. He found that in the case of air dried sand, the coefficient of friction varied with the speed. The values for the coefficient of friction were 0.400 for a speed of 1760 millimeters per minute, 0.500 for a speed of 4600 millimeters per minute and 0.533 for a speed of 5600 millimeters per minute. He found this to be true for all soils in which the bearing power was not sufficient to hold the weight of the slider. He also found that friction was not independent of the area of contact, and it varied directly as the weight per square inch.

Nichols found that the coefficient of friction varied also with the nature of the surfaces. He got a value of 0.185 for the coefficient of friction for highly polished chilled steel and a value of 0.388 for the same material with a smooth but unpolished surface.

From the studies made Nichols laid down the following fundamental laws for sliding friction between a metal surface and the

soil. These laws were grouped separately under four phases of the moisture in the soil.

A. Friction Phase. In this phase the soil was dry and the bearing power of the soil was less than the pressure. The laws of sliding friction in this phase were:

- (a) The coefficient of friction varied with the speed
- (b) It was proportional to the pressure per unit area, and
- (c) It varied with the smoothness and materials of the surface.

B. Friction Phase. In this phase the soil had some moisture but not enough to adhere to the metal surface. The bearing power was greater than the pressure per unit area. The laws of sliding friction for this phase were:

- (a) The magnitude of the friction was proportional to the total pressure between the two surfaces
- (b) The coefficient of friction depended upon the roughness and materials of surfaces
- (c) It was independent of the area of contact, and
- (d) It was independent of the speed of sliding.

C. Stiction Phase. In this phase the soil had so much moisture that it adhered to the sliding surface. The laws of sliding friction for this phase were:

- (a) The coefficient of friction varied with the speed
- (b) It varied with the area of contact

- (c) It varied with the pressure per unit area
- (d) It varied with the surface tension of the film moisture,
i.e.

- (1) It varied with the amount of colloidal
matter present
- (2) It varied with the amount of water present
- (3) It varied with the temperature and viscosity
of soil solution, and

- (e) It varied with the surface and kind of metal.

D. Sliction Phase. In this phase there was enough moisture present in the soil to give a lubricating effect. The laws of sliding friction for this phase were:

- (a) The coefficient of friction varied with the pressure
per unit area
- (b) It varied with the speed
- (c) It varied with the amount of moisture and viscosity
present, and
- (d) It varied with the nature of the surface and the kind
of material of the surface.

According to Nichols, the coefficient of sliding friction was a dynamic and constantly varying factor rather than a fixed quantity; and in any soil, it was affected by moisture content and particle size.

Nichols published another paper (12) in 1931 on his study of soil and metal friction. This paper contained the summary of his

findings of soil and metal friction studies which were started by him in 1923. He used a series of synthetic soils varying widely in their physical properties. Moisture was applied by the condensation method. The metals used by him were various samples of chilled iron and a group of plow steels. The values for the coefficient of friction were obtained from carefully cleaned and polished metals. The soils used were uniformly moistened and uncemented, varying little in temperature (mean 80° F) and free from roots and parts of undecayed vegetable matter, pebbles or other materials.

Nichols divided the frictional resistance into four phases which depended upon the pressure of the metal surface and the structure and content of the soil. The graphical representation of the relationship between frictional values and moisture content was given by him as reproduced in figure 1.

The four phases of frictional resistance mentioned in his earlier paper published in 1925 (13) were given new names as shown below.

<u>Earlier name.</u>	<u>New name.</u>
A. Friction Phase	A. (Compression) Phase
B. Friction Phase	B. (Friction) Phase
C. Stiction Phase	C. (Adhesion) Phase
D. Slicktion Phase	D. (Lubrication) Phase

The laws of friction in both cases remained the same. The new names have been widely accepted and quoted in many text books.

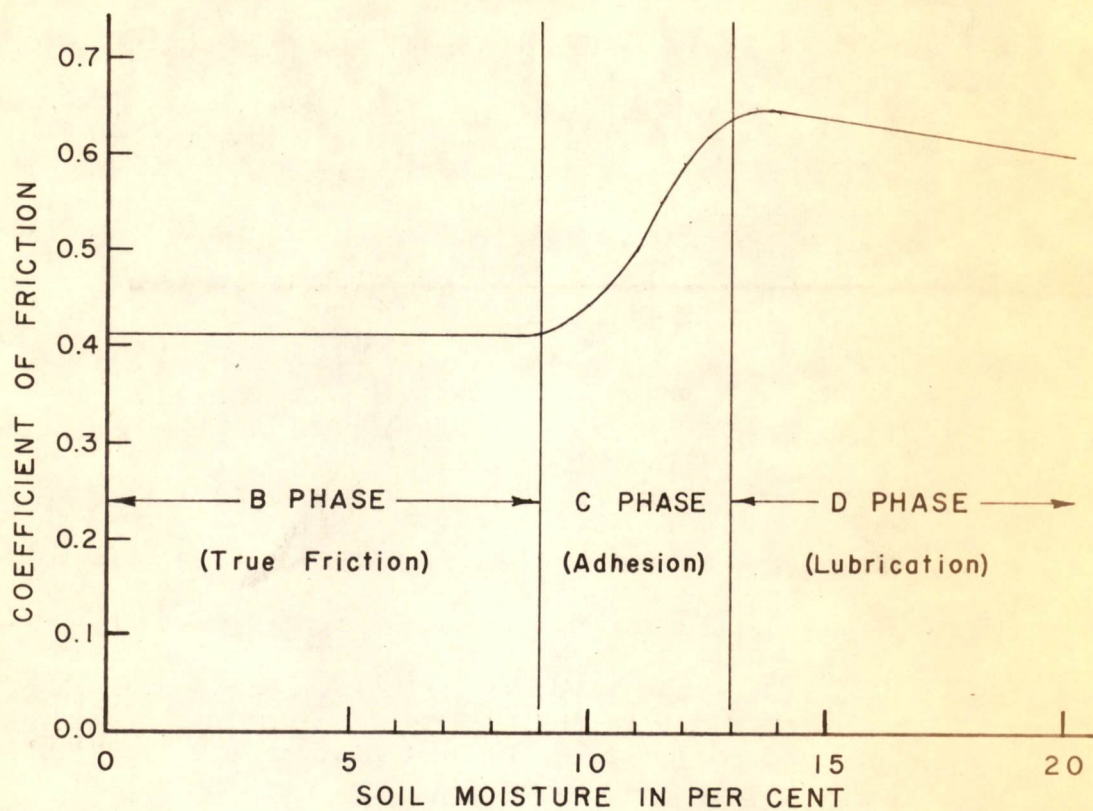


Figure 1. Characteristic curve showing the effect of moisture on soil/metal friction. (from Nichols (12).)

Nichols found that the bearing power and moisture content were important factors in the classification of friction phases. These factors depend largely upon the colloidal content in the soil which determined their reactions. The moisture content and the structure of a soil determined its resistance to compression and this factor, according to Nichols, determined the A and B phases. He also found that the moisture content was directly responsible for the C and D phases. He concluded that the moisture content at which these phases occurred depended upon the amount of colloidal clay and the proportion of adsorbed moisture to film moisture. Also, temperature and salts in the soil solution affected the force exerted by moisture films and so entered into frictional values.

For the A compression phase, Nichols found the following relationship between the coefficient of friction, μ' , and the speed, S, in feed per minute:

$$\mu' = 0.010S + 0.33$$

This formula was derived from experiments with dry sand which was practically free from colloidal clay.

For the B (Friction) phase Nichols found that with non-plastic soils the coefficient of friction varied directly with the colloidal content. He expressed the relation between the coefficient of friction, μ' , and the colloidal content, C, as,

$$\mu' = 0.0076C + 28$$

For the C (Adhesion) phase, he found that the moisture

film adhering to the metal surface increased the frictional force rapidly. He derived the following formulas expressing the relationship between the moisture content, M , and colloidal content, C , of the soil,

$$M = 0.2C + 10$$

when maximum adhesion for a nickel slider on non-plastic soil occurred.

$$M = 0.13C + 4.77$$

when adhesion first became evident.

Nichols also found that the moisture content of maximum adhesion was approximately that of the upper plastic limit. The maximum rise of the coefficient of friction varied directly with the plasticity number. He expressed the value for the coefficient of friction in plastic soils by the formula,

$$\mu' = 0.06P_n + 0.42$$

where μ' = coefficient of sliding friction, and

P_n = Plasticity number.

He also expressed the following relationship between the coefficient of friction, μ' , the colloidal content of the soil, C , and the hardness of the metal, H , as determined by the Brinell test, for soil friction values in the B phase.

$$\mu' = 0.24 + 0.005C - 0.0001H$$

Nichols found from his investigations that the values of μ' for the plastic soils tested were in the neighborhood of the values obtained for the Cecil clay containing 32 per cent of colloid. He concluded that when a sufficient amount of colloidal material

was present to cover the coarser particles, the soil friction (B phase) did not materially change with the increase in the colloidal content. He also studied the effect of polish on the coefficient of friction and found that in the case of sand, polish had no effect on friction whereas in the case of other soils, high polish showed a reduced coefficient of friction.

Payne (14) defined soil/metal friction as the tangential force produced at the interface, when soil slides over another material. In his investigations to find the soil/metal friction, Payne regarded the variables, such as moisture content, as changes in the quality of one of the surfaces. In order to avoid the bearing capacity of the soil from entering into the values for the coefficient of friction, he arranged his apparatus so that the soil/metal interface lay in the vertical plane. The apparatus used by Payne consisted of a wedge shaped vertical tine (apex leading) suspended on the tool bar of a tractor. The whole of one side of the tine formed a sensitive plate, on which the forces in two mutually perpendicular directions were measured with the help of strain gages. The normal load was increased by rotating the whole tine about its vertical axis. A correction was applied to the results when it was found that the movement between the soil and the slider was at an inclination of more than 10° to the horizontal. The speeds used were those found commonly in cultivation varying from 0.34 to 4.54 miles per hour. Four nominal speeds in four random blocks were selected and the true speed for each run

was measured by timing the tractor between marking posts. Payne found that the relationship between normal and tangential forces was linear when plotted, and was independent of speed. He used seven different kinds of soils.

Payne found that the frictional properties of soil may be represented by the equation

$$S' = C_{\alpha} + \sigma \tan \mathcal{S}$$

where S' = maximum tangential stress at interface,

C_{α} = tangential adhesion,

σ = externally applied normal stress on interface,

$\mathcal{S}$ = angle of soil/metal friction.

Soil and Aluminum Friction

Bockhop (4) conducted tests to find soil/aluminum friction. He used in his tests four different soils and an aluminum slider of eight inches by six inches, with an area of contact of forty-eight square inches, and a calibrated spring balance to measure frictional resistance. The soils were contained in boxes three feet wide and twelve feet long, made of aluminum and lined with galvanized sheet. He mixed his soil with a hoe, shovel and rake to obtain uniform moisture distribution. A sprinkling can was used for varying the moisture content of the soils. He packed the soil by hand giving it a "sheep's-foot" effect with the fingers and rolling it smooth twice to compact the surface. He used different loads on the slider to find the coefficient of

friction between aluminum and soil. As a result of his investigation Bockhop found that Nichols' equation $\mu' = 0.24 - 0.005C - 0.0001H$ did not hold good for aluminum. He concluded that the values of the constants are dependent upon the type of material.

Agricultural Material and Teflon Friction

Reddy (15) made a study of the friction characteristics of agricultural materials such as hay and grass ensilage on Teflon. As a result of his investigation, Reddy found that the values of the coefficient of friction were 32 per cent less than those obtained for a conventional metal like steel.

Teflon and Steel Friction

Shooter and Thomas (5) were the first to recognize the low friction of Teflon in 1949. For a piece of fabricated tetrafluoroethylene fluorocarbon resin sliding on steel they reported a coefficient of friction of 0.04, when the sliding speeds were from 0.02 to two feet per minute; the loads were from two to nine pounds; and the temperatures were from 68° F to 392° F.

Teflon Covered Moldboard Plow

The Pineapple Research Institute in Hawaii (1) conducted research with a surfacing of Teflon, over a moldboard plow to improve the scouring properties of the moldboard plow. It was found that the plowing time was reduced to half and the tractors operated in third gear instead of second.

According to the experiments conducted at Hawaii by Tribble

(20), it appears that Teflon holds out a great future in the manufacture of moldboard plows for use in plastic soils. The Hawaiian soils contain 85 per cent of clay and are moderately to highly plastic. Their plastic index ranges from ten to twenty, with common values of sixteen to eighteen. These soils stick to standard moldboards and shares.

Tribble reported that Teflon, as a moldboard cover, was used for preliminary trials on a fourteen inch general purpose bottom, to improve the scouring of the moldboard. The soils were plowed at various depths, speeds and moisture levels and it was found that there were no scouring difficulties; and there was no mechanical damage done to the Teflon sheet, even though large boulders of basalt were present in these soils, which were expected to cause mechanical damage. The experiment was repeated with a thirty-two inch moldboard. For eighteen inches depth of plowing, at a speed of 3.5 miles per hour, the draft was found to be 6500 pounds, as against an estimated draft of 7200 pounds, at a unit draft of 12.5 pounds per square inch. Different compounded Teflon products showed that they endured plowing from 200 to 400 acres. Under Hawaiian conditions the Teflon covered moldboard plow had reduced land preparation costs.

CHAPTER II

MATERIALS AND METHODS

The materials immediately necessary for conducting the present investigation were Teflon and soils of different textures.

Teflon

The Teflon covered disk used by Reddy (15) for his study of the friction characteristics of Teflon and agricultural material was readily available, and was used in conducting the tests.

The disk was forty-eight inches in diameter and had a cover of Teflon sheet of 1/16 inch in thickness. The Teflon sheet was glued to 3/4 inch thick plywood with the adhesive Garlick No. 201 recommended by the manufacturers of Teflon. This adhesive consisted of two parts, A and B. Part B was heated to 125° F before mixing it with an equal volume of part A. The mixture was stirred until it had a creamy appearance and was applied to the cementable surface of Teflon and also to the plywood surface. The sheet was then laid over the plywood surface and loaded over with bricks to provide equal pressure over the entire surface of the disk. The disk was left in this condition for a period of fourteen to sixteen hours for curing. The edges were then cut and made smooth.

Soils

It was considered necessary to conduct the tests with different kinds of soils containing different proportions of colloidal

clay.

In all, five samples of soil were collected; four of these being from the Agricultural Experiment Station at Jackson in West Tennessee and one sample from Memphis, across the Mississippi river in Arkansas. The soils from Jackson, Tennessee, were a loamy sand, a Hyman fine sandy loam, a Lintonia silty loam and a Dexter silty clay loam. The loamy sand was designated as an Independence-Huckabee loamy sand, although this designation was not yet official. The soil from Memphis was a Sharkey clay.

CHAPTER III

INSTRUMENTATION

The procedure followed for determining the friction characteristics of Teflon and soil was essentially the same as followed by Richter (16) and Reddy (15).

A Teflon covered disk forty-eight inches in diameter was fixed on a vertical arbor of one inch diameter. The arbor was supported in bearings in a square iron frame made of angle irons and carried a sheave of $7 \frac{1}{8}$ inches in diameter, at the bottom. This sheave was connected to the pulley on the spindle of a tapping machine through sheaves on a jack shaft, fitted in the iron frame.

The soil was packed in cylindrical cans with both ends open. The following sizes of cans were used in the tests:

Serial Number	Diameter of can in inches	Length of can in inches	Cross sectional area of can in square inches
1	2.50	4.75	4.90
2	3.00	4.62	7.06
3	3.25	4.37	8.35
4	3.88	6.25	10.40

A hook was soldered on each can. The can filled with the soil was placed on the Teflon disk. A string was carried from the hook on the can to a sensitive scale called a detectogram, manufactured by Detecto Scales Incorporated, Chicago, Illinois. The force of friction was measured on the detectogram when the disk

rotated.

Details of the Apparatus

The apparatus used in the investigation consisted of the following:

- (1) An iron frame with a vertical arbor fixed in the center of the frame, and a jack shaft fixed to one side.
- (2) A plywood disk with a Teflon surface.
- (3) Arrangement of belts and pulleys for driving the Teflon disk.
- (4) Scale for the measurement of the frictional force
- (5) Device for varying the moisture content of the soil.

The iron frame. The iron frame, four feet square and two feet by eight inches in height, was sturdily built with angle iron. A vertical arbor was fixed in bearings in the center of the frame and a jack shaft was fixed vertically on one side of the frame in bearings, for easy rotation. The arbor had an iron plate, $7/16$ inch thick and 12 inches in diameter, rigidly fixed at the upper end and carried a sheave of $7 \frac{1}{8}$ inches in diameter at the bottom. The jack shaft had a sheave of $1 \frac{1}{2}$ inches in diameter at the bottom and two pulleys, one of $8 \frac{1}{2}$ inches in diameter and the other of $1 \frac{1}{2}$ inches in diameter, fixed at the upper end, one below the other.

The Teflon disk. The Teflon covered disk of forty-eight inches in diameter, was fixed rigidly to the iron plate on the upper end of the arbor by means of nuts and bolts so that the disk

rotated along with the arbor.

Arrangement of the drive. The source of power for driving the Teflon disk was an electrically driven tapping machine made by Bakewell Manufacturing Company, Los Angeles, California. The vertical driving spindle of the tapping machine carried in the front, two sheaves of $1\frac{1}{2}$ and $8\frac{1}{2}$ inches in diameter at the lower end, and a cone pulley of four stages at the upper end. The tapping machine had another cone pulley of four stages at the rear end. These two cone pulleys were connected to each other by means of a V-belt, which could be shifted on to any pair of pulleys on the two cones, for changing the speed as desired.

The sheaves at the lower end of the spindle, in the front of the tapping machine, were connected to the sheaves at the upper end of the jack shaft by a second V-belt. A third V-belt connected the sheave on the lower end of the jack shaft and the pulley on the lower end of the arbor. The arrangement of the drive is shown schematically in figure 2.

Measurement of the force of friction. A sensitive detectogram scale, which could accurately measure a force up to one hundredth of a pound was used for measuring the force of friction. The detectogram scale was tested and corrected for accuracy before it was used in the tests.

A string was connected to the hook, soldered on the lower most position of the open ended cylindrical can, and was carried under a pulley to the detectogram. The soil was packed inside

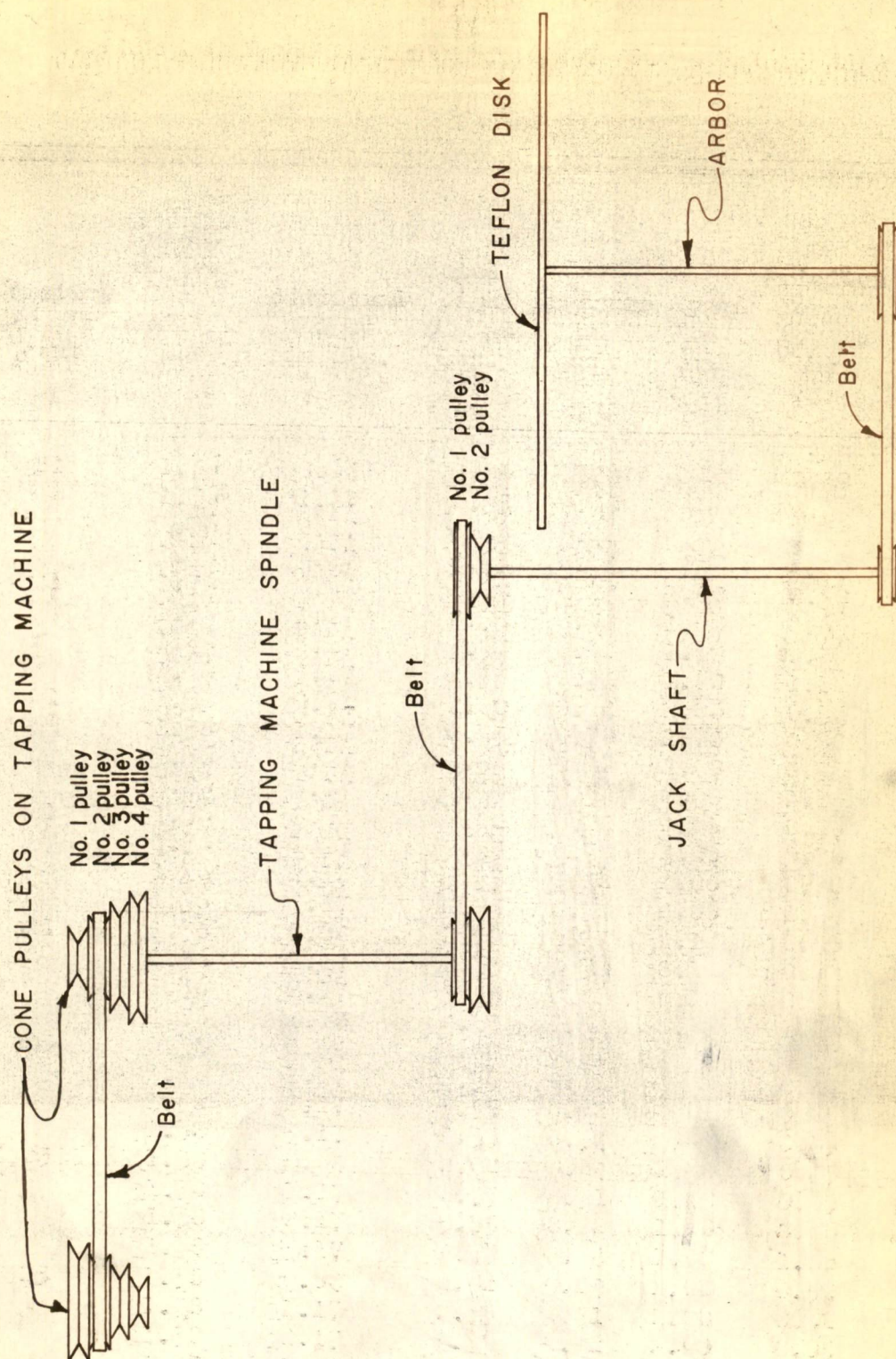


Figure 2. Schematic diagram showing the arrangement of drive (not to scale).

the open ended cylindrical can. When the Teflon disk rotated, the force of friction between the soil and Teflon was registered on the detectogram scale.

The detectogram scale and the Teflon disk were arranged on either side of the tapping machine, so that the detectogram faced the test can held on the Teflon disk. With this arrangement, it was convenient to attend to all the parts of the equipment and to read the detectogram by standing in the center. This arrangement of the apparatus is shown in figure 3.

Moisture content of soil. In order to determine how friction was affected by different moisture contents, soils with varying moisture contents were used. Since the moisture content in the soil is expressed as a percentage of the dry weight of the soil, the soil was dried in an electric oven at a temperature of 105°C. The soil was left in the oven at this temperature for several days to make sure that it dried completely. One pound of this dry soil was accurately weighed in a closed sample can and was used in the experiment.

Moisture was added to the soil by spreading the soil on a sheet of paper and spraying the soil with water. The water was applied in the form of a mist with a small hand operated sprayer.



Figure 3. Measurement of the force of friction between soil and Teflon.

CHAPTER IV

PROCEDURE

The procedure used in finding the friction characteristics of Teflon with soil consisted of the following:

1. Calibration of the apparatus for speed.
2. Preparing the soil samples.
3. Measuring the force of friction between soil and Teflon for different pressures, moisture and clay contents, and areas of contact.
4. Mechanical analysis of the soil samples.

Calibration of the Apparatus for Speed

It was possible to obtain several speeds for the Teflon disk by the manipulation of the belts on different pulleys of the tapping machine and the jack shaft, and by putting the tapping machine under direct gear and back gear positions. With the help of an electric revolution counter and a stop watch, the speed of the Teflon disk at eighteen inches radius from the center of the disk was determined. It was decided to operate the disk under low speeds, since many of the tillage implements work at these speeds.

For calibrating speed, the time taken for a known number of revolutions of the Teflon disk was noted. The speed of the Teflon disk at eighteen inches radius was calculated from these observations. The results obtained are given in table I under Appendix A.

Preparing the Soil Samples for Test

The soil samples were first run through a No. 4 sieve and all big lumps, pieces of stone and roots and other dead remains of the plants were separated. The finer particles of organic matter and humus were not separated. The sieved samples were kept in tin cans for drying in an electric oven. The temperature was maintained at 105° C for several days, to make sure that the soils were completely dry. One pound of the soil was accurately weighed on the detectogram scale, in a sample can covered with a lid, so as to prevent adsorption of the moisture while weighing. The weighed soil was then spread on a sheet of paper and sprayed lightly. The equipment used for adding moisture to the soil is illustrated in figure 4. After every spraying, the soil was turned over by lifting the ends of the corner of the paper. The soil was weighed at frequent intervals to see if it had attained the desired percentage of moisture. When the soil was mixed with the desired percentage of moisture, it was poured into the test can, with an open end of the can being kept on the Teflon disk. The soil was compacted by pressing with the fingers after it was poured inside the can and covered with a thin metal disk, so as to ensure that the moisture was not lost by evaporation during the test. The ends of the can were slightly raised from the surface of the Teflon disk, so that the metal in the can did not

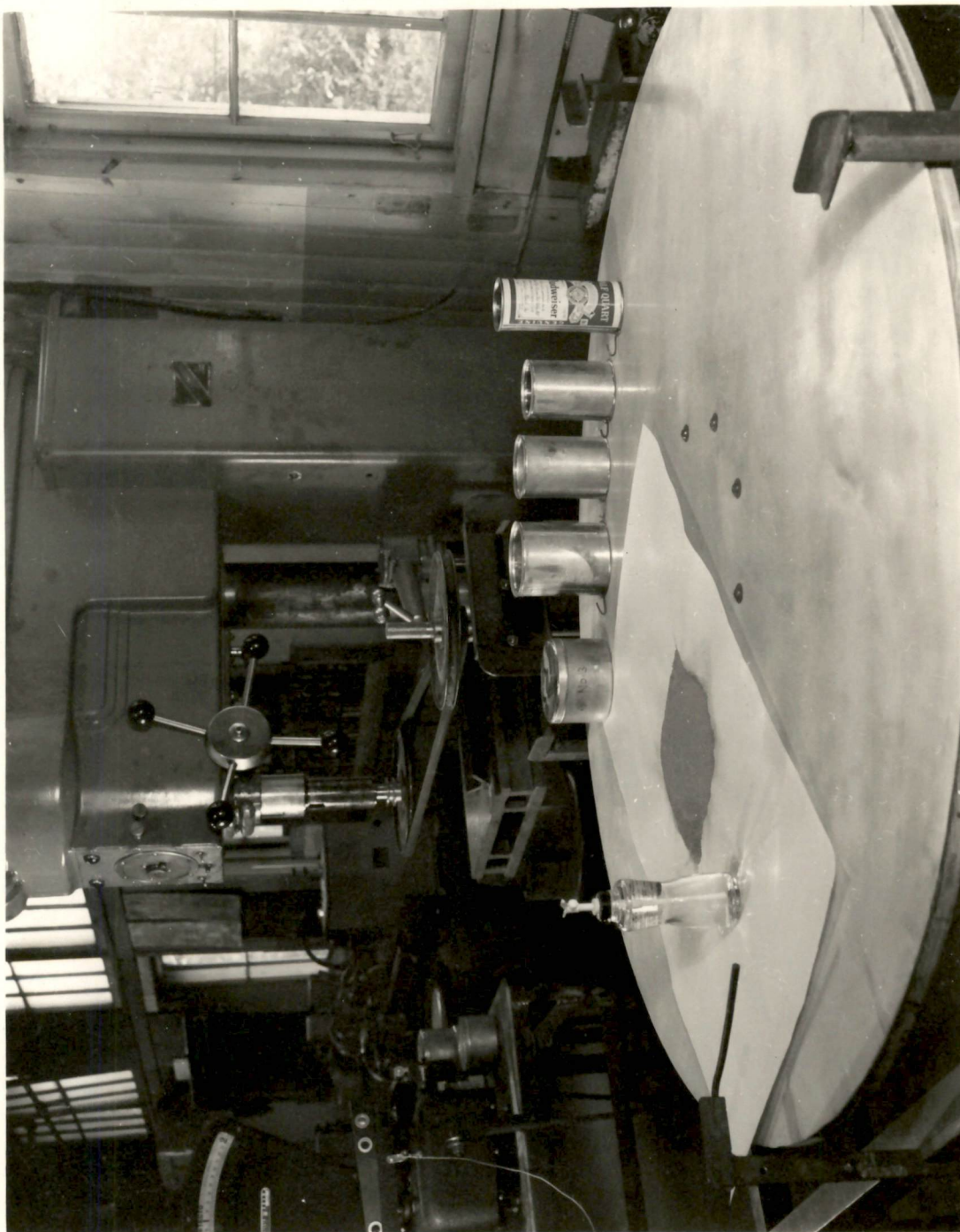


Figure 4. Equipment used for adding moisture to the soil.

interfere with the results.

In all, five different kinds of soils were used in the test. In each case, the percentage of moisture was increased in stages, until a film of water appeared on the Teflon disk. In order to determine the percentage of moisture, the dry weight of the soil was taken as the basis. The following formula was used for finding the percentage of moisture in the soil:

$$\frac{(\text{Weight of wet soil} - \text{Weight of dry soil}) \times 100}{\text{Weight of dry soil}}$$

= Moisture in per cent

Measurement of the Frictional Force

In some cases considerable difficulty was experienced in noting the readings as the needle of the detectogram scale moved over wide ranges. In all such cases, the average between the maximum and minimum readings was noted as the force of friction.

For each soil and each moisture content, four different pressures and four different speeds were tried. The pressure on the soil was increased by placing weights on the metal cover over the soil, in order to study the effect of pressure on friction. The speeds selected were 1, 2, 4.06 and 8.12 miles per hour. These speeds were obtained by manipulating the position of the V-belt on the cone pulleys of the tapping machine.

The readings for static friction were obtained by moving the Teflon disk very gently by hand, the rest of the arrangement remaining the same as for kinetic friction.

The readings obtained for the static and kinetic friction are given in tables II to VI under Appendix B.

In the case of two samples of soils, with 7.3 and 22.4 per cent clay, frictional force was also measured for four different cans of varying diameters, to find if the area of contact had any effect on the frictional force. These observations are recorded in table VII under Appendix B. In all cases the tests were conducted under room temperatures varying from 74° F to 86° F.

Mechanical Analysis of the Soil Samples Used in the Test

All the five samples of soil used in the tests, were subjected to mechanical analysis to find their colloidal content. The mechanical analysis of the soils used in the tests was done by the pipette method described by Bayer (3). Two replications of the samples of soils were taken for the analysis. About ten grams of each sample was weighed very accurately in an analytical balance and was placed in a beaker. The sample was then mixed with ten millilitres of water and heated slowly for several hours. Hydrogen peroxide was added at intervals to oxidize all the organic matter in the soil. After complete oxidation of the organic matter water was added to the soil sample and the whole mixture was transferred over a Whatman No. 42 filter paper fixed on a Buchner funnel. The soil held on the filter paper was leached with 400 millilitres of 0.1N hydrochloric acid. The excess of the hydrochloric acid was washed with fifty millilitres of water and 150 millilitres of ethyl alcohol. The Buchner funnel, along with

the filter paper, was heated for several hours in an electric oven at 105° C for drying the soil. The soil was then transferred very carefully from the filter paper to a 500 millilitre flask. Two hundred millilitres of water and six to fourteen millilitres of sodium hydroxide were added to the flask. The mixture was stirred well by shaking the flask periodically for forty-eight hours. At the end of forty-eight hours, the mixture was transferred to a one thousand millilitre graduate. The mixture was then diluted to one litre by adding water. The whole mixture was stirred well and allowed to stand for seven hours and forty-seven minutes. At the end of the period, twenty-five millilitres of the aliquot at ten centimeters depth was drawn out through a pipette by using an aspirator bottle. The aliquot was transferred to a beaker which was weighed previously and was dried in the oven at 105° C for several hours. The beaker was then weighed after the aliquot had evaporated completely and the clay content of the sample was calculated from the following formula:

$$\frac{(\text{Weight of beaker + clay} - \text{Weight of beaker}) 4000}{\text{Dry weight of soil sample}} \\ = \text{per cent of clay less than 0.002 millimetre}$$

The results obtained in the two replications were very close and the average between the two was taken as the percentage of clay for each sample. The average percentages of clay were found to be 5.7, 7.3, 9.6, 22.4, and 41.2, the first four being for the samples obtained from Jackson and the last one for the sample obtained from Memphis. The equipment used is shown in figure 5.

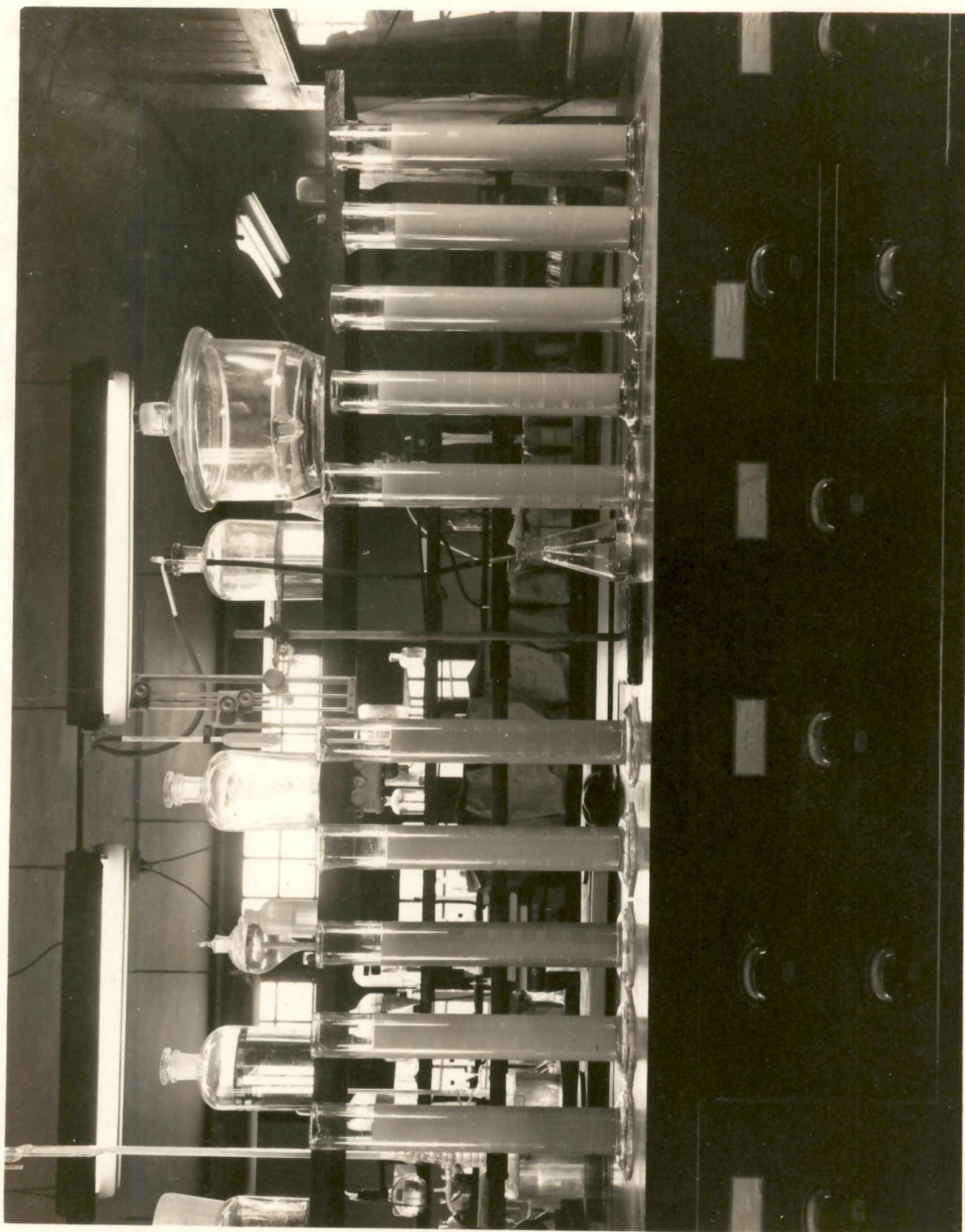


Figure 5. Equipment used for the mechanical analysis of the soils.

CHAPTER V

RESULTS AND DISCUSSION

The friction characteristics of Teflon with soil were investigated for the following soils:

1. Soil with 5.7 per cent of clay.
2. Soil with 7.3 per cent of clay.
3. Soil with 9.6 per cent of clay.
4. Soil with 22.4 per cent of clay.
5. Soil with 41.2 per cent of clay.

Soil with 5.7 per cent of Clay

It was not possible to work with a completely dry soil as the soil particles were drawn out of the test can when the Teflon disk was rotated. The lowest amount of moisture with which the test could be conducted in the case of this soil was 2 per cent, but even then the readings could be taken only for low speeds of one and two miles per hour. The moisture content for this sample was increased in stages of 2 per cent up to a maximum of 10 per cent.

For each moisture content, four different pressures, and four different speeds for each pressure, were used to find the force of friction. The values obtained for the force of friction, both static and kinetic, are given in table II under Appendix B. The coefficient of friction in each case was calculated and is also included in the table.

Figures 6 to 9 indicate the behaviour of the coefficient

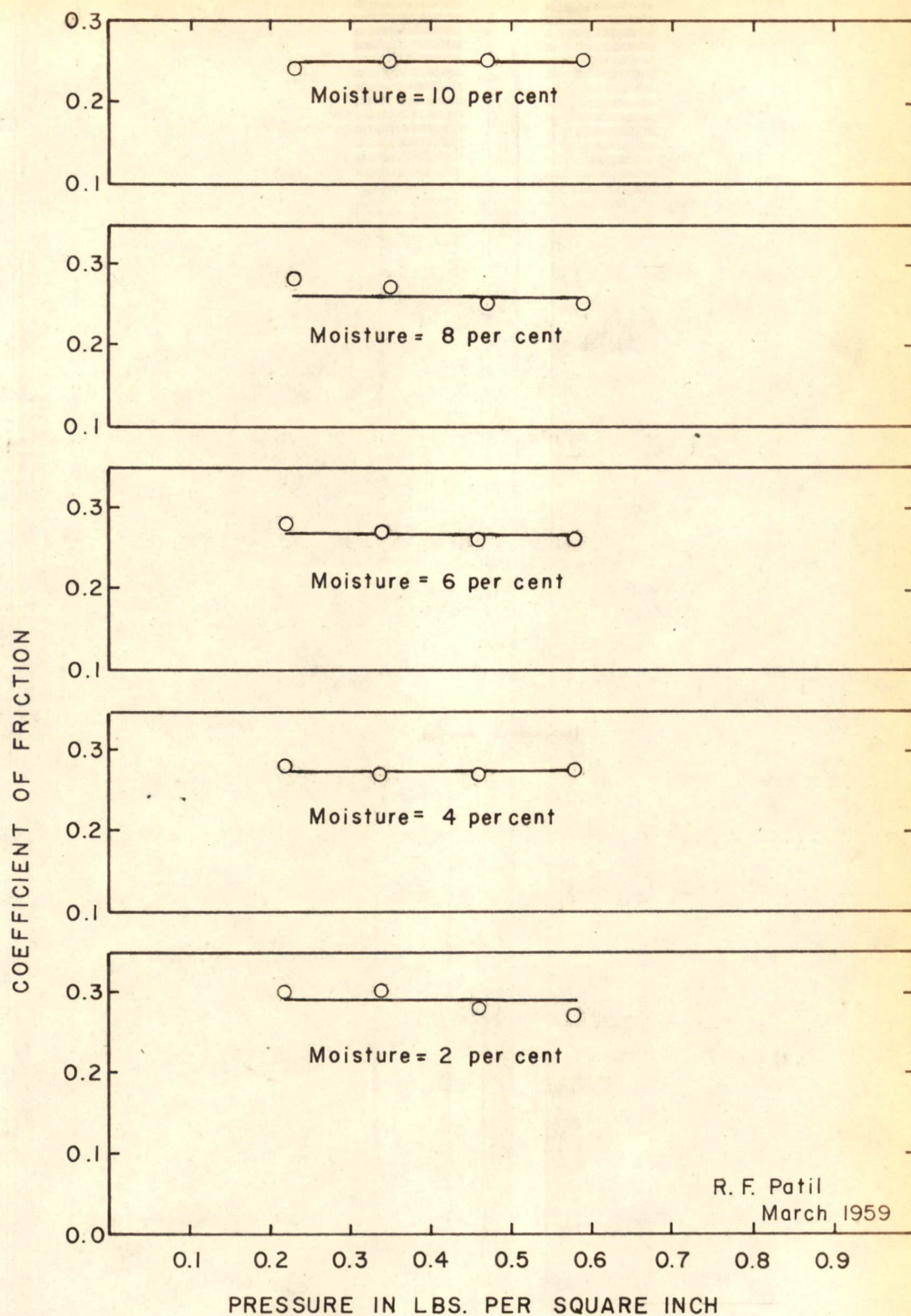


Figure 6. Coefficient of friction vs. pressure at one mph for 5.7 per cent clay soil.

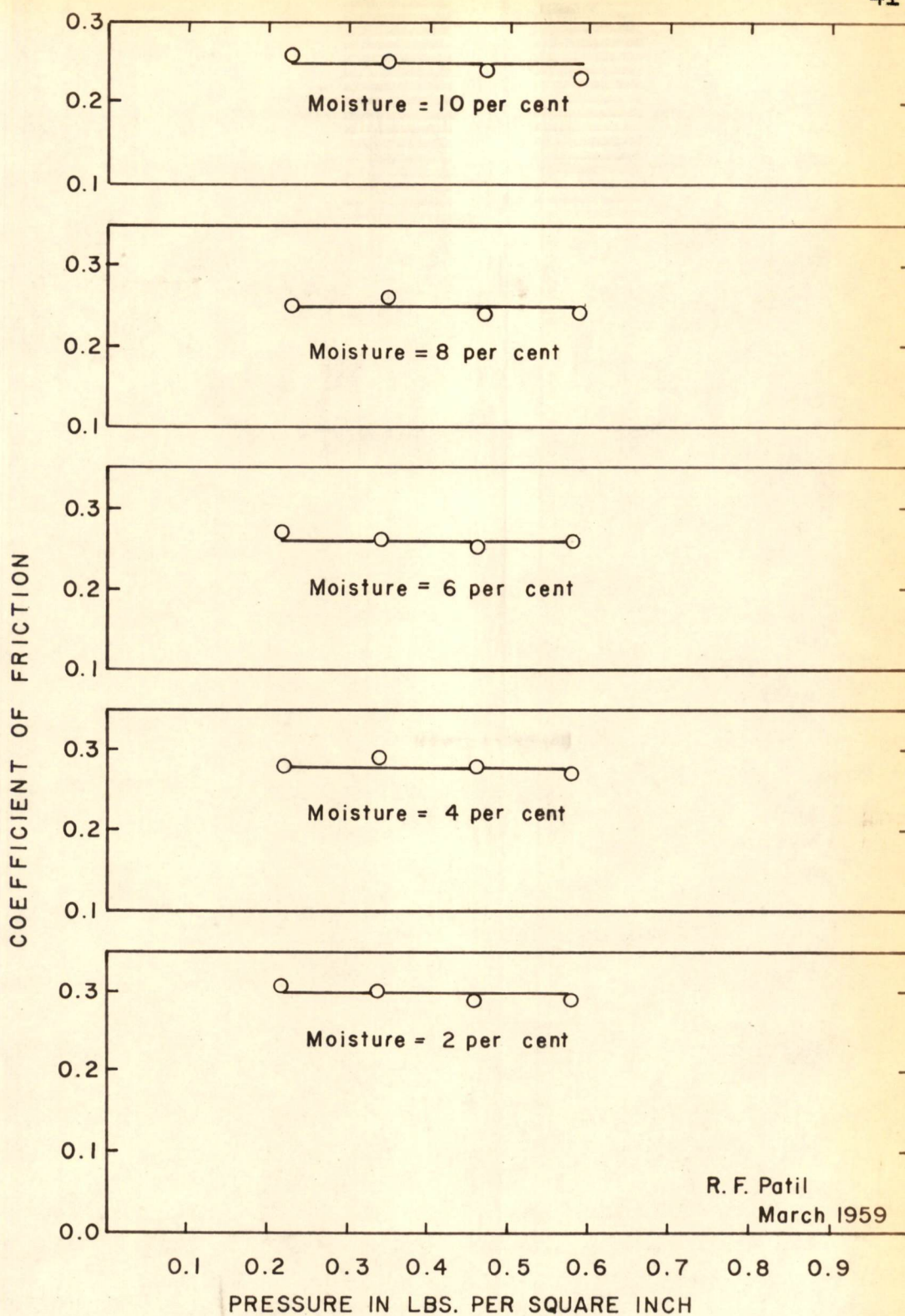


Figure 7. Coefficient of friction vs. pressure at two mph for 5.7 per cent clay soil.

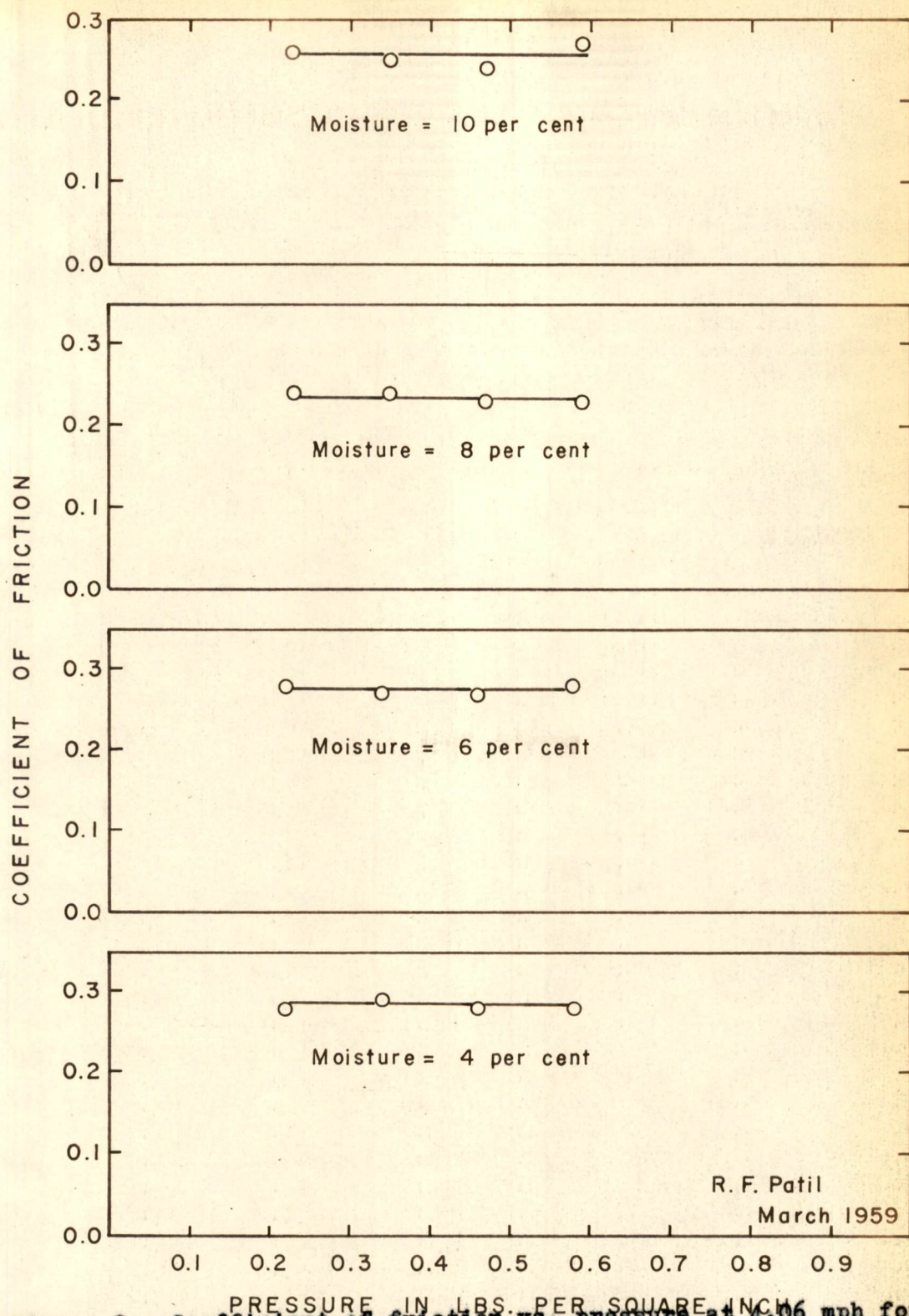


Figure 8. Coefficient of friction vs. pressure at 4.06 mph for 5.7 per cent clay soil.

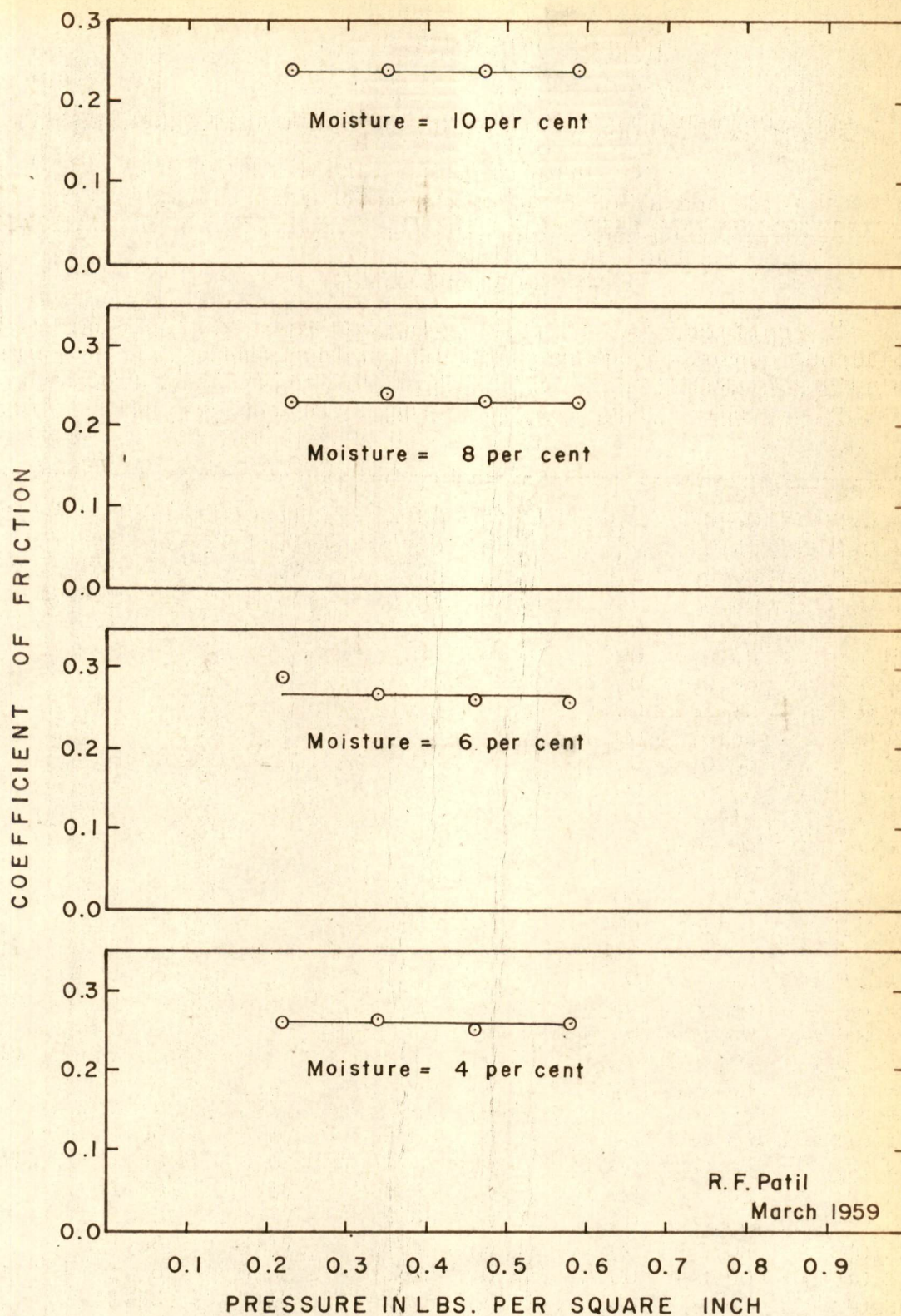


Figure 9. Coefficient of friction vs. pressure at 8.12 mph for 5.7 per cent clay soil.

of friction against pressure for different speeds and moisture contents. From these curves it is seen that the pressure had practically no effect on the coefficient of friction. Figure 10 shows the curves for the coefficient of friction against moisture for different speeds, under a pressure of 0.4 pound per square inch. These curves indicate that the coefficient of friction decreased as the moisture content increased, the lubrication phase being reached. Figure 11 shows the behaviour of the coefficient of friction against speed, under a pressure of 0.4 pound per square inch for different moisture contents. These curves indicate that speed had no effect on the coefficient of friction.

The following conclusions can be drawn for this soil:

1. The coefficient of friction was independent of pressure.
2. The coefficient of friction decreased as the moisture content increased.
3. The coefficient of friction was independent of speed.

Soil with 7.3 per cent Clay

The lowest amount of moisture with which the soil could be worked was 4 per cent. The moisture was increased by stages of 2 per cent to a maximum of 14 per cent, beyond which it was not possible to work.

For every stage of moisture content, four different pressures were used. For every pressure, four different speeds were used. The values obtained for the force of friction for different moistures, pressures and speeds are given in table III under Appendix B.

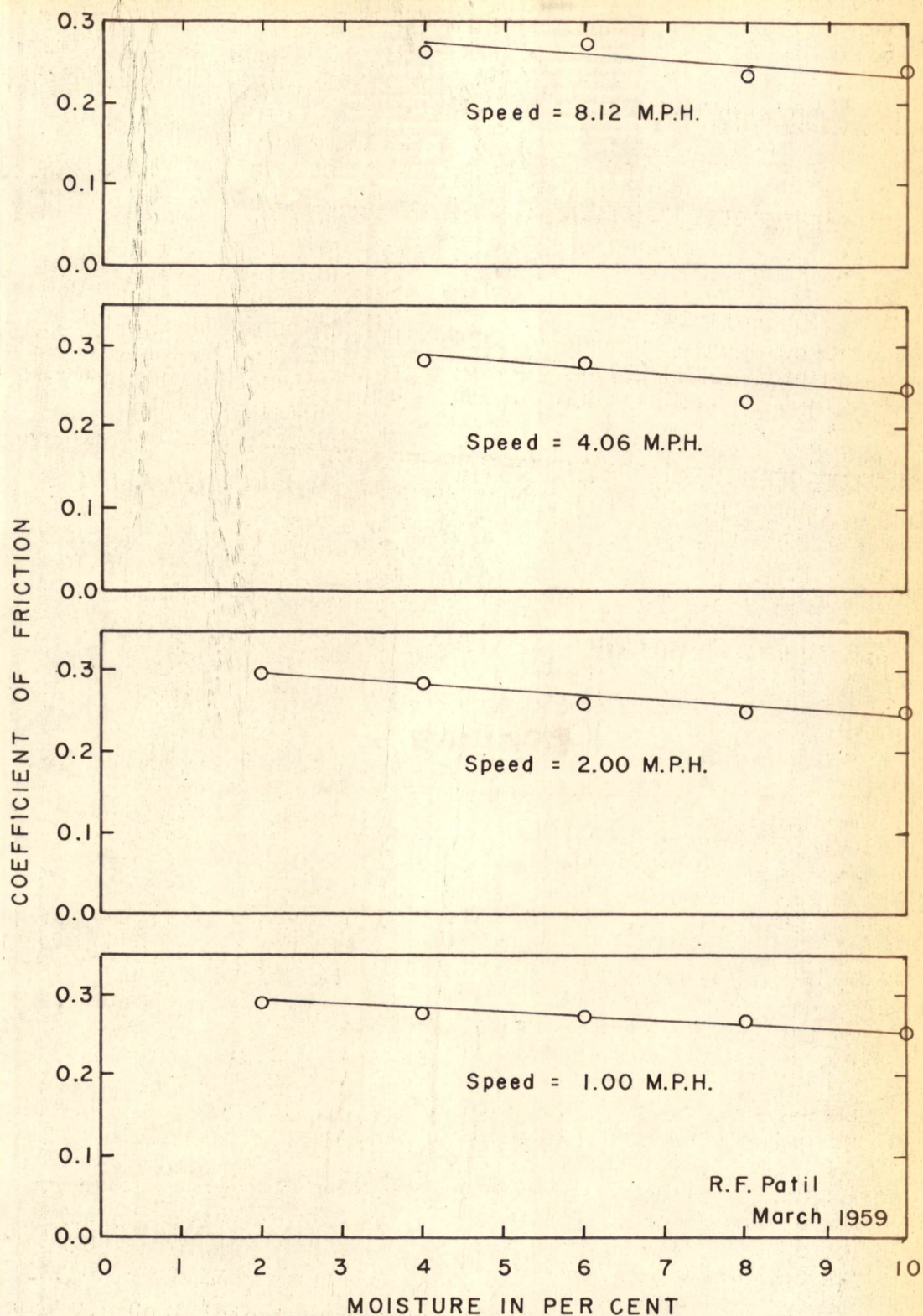


Figure 10. Coefficient of friction vs. moisture at 0.4 psi for

5.7 per cent clay soil.

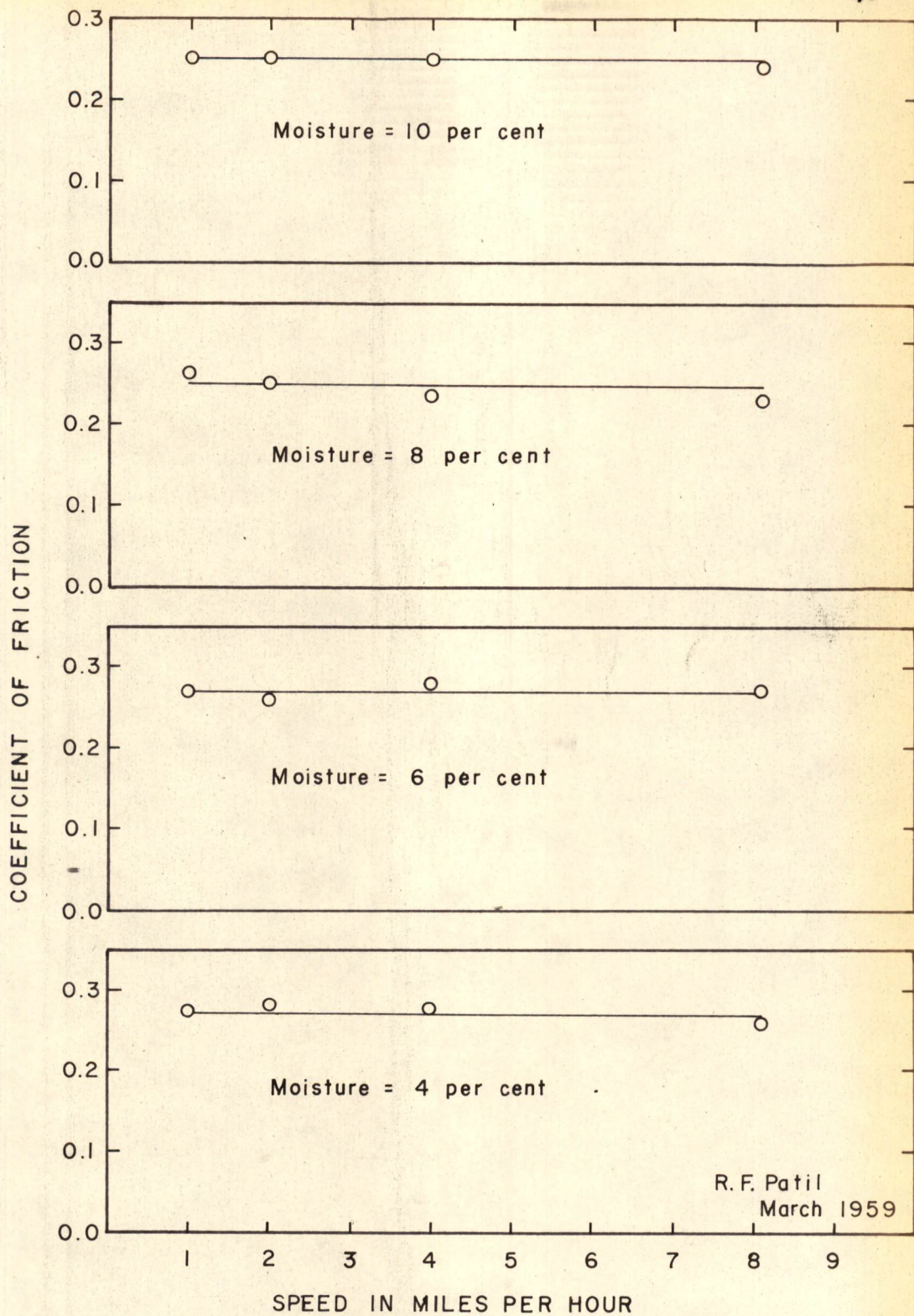


Figure 11. Coefficient of friction vs. speed at 0.4 psi for 5.7 per cent clay soil.

The values for the coefficient of friction for this soil have been plotted in figures 12 to 17. The examination of the curves in figures 12 to 15 shows that the pressure had no effect on the coefficient of friction, except at higher moisture contents. It is noticed that the coefficient of friction decreased with increase in pressure, for higher percentages of moisture. This may be due to the moisture being squeezed out under greater pressures, producing a lubrication effect on the Teflon surface.

Figure 16 shows that the coefficient of friction decreased for all speeds, as the amount of moisture increased up to 10 per cent. Thereafter the coefficient of friction increased with moisture. It therefore seems that the friction for the moisture contents from 4 to 10 per cent was in the 'B' phase as determined by Nichols (12). Thereafter the friction appears to be in the 'C' phase. It is also noticed that the increase in the friction in the 'C' phase, with increase in moisture content, is much sharper at higher speeds.

Figure 17 indicates that speed had no effect on the coefficient of friction at lower moisture contents. It is seen that the coefficient of friction increased with speed at 14 per cent moisture. At this moisture content, it was noticed that the water holding capacity of the soil was exceeded. The smaller particles of the soil formed a thin paste with the excess of moisture. This paste appeared in the form of a thin film on the Teflon disk. The values of friction for this moisture percentage cannot therefore be regard-

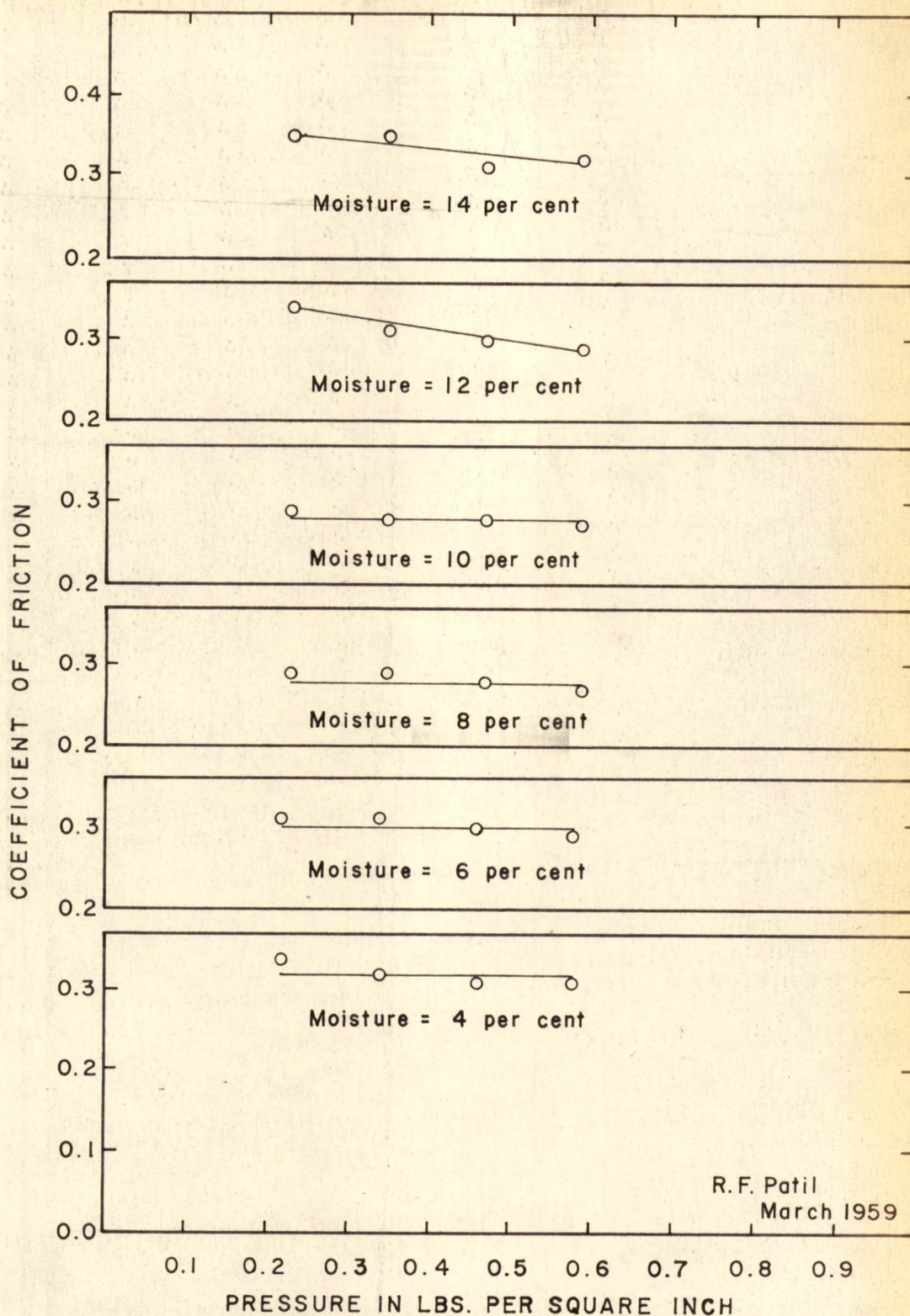


Figure 12. Coefficient of friction vs. pressure at one mph

for 7.3 per cent clay soil.

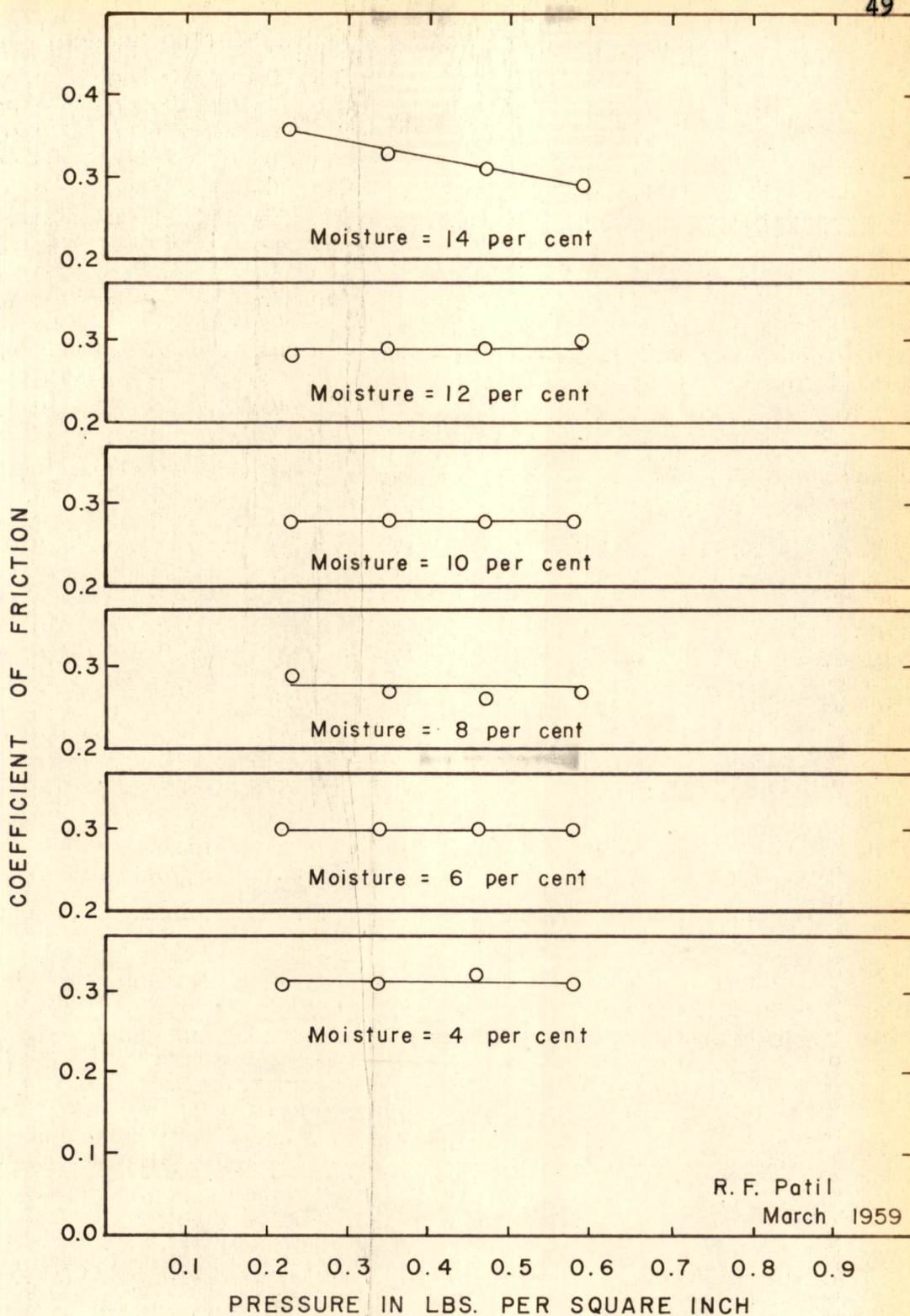


Figure 13. Coefficient of friction vs. pressure at two mph for 7.3 per cent clay soil.

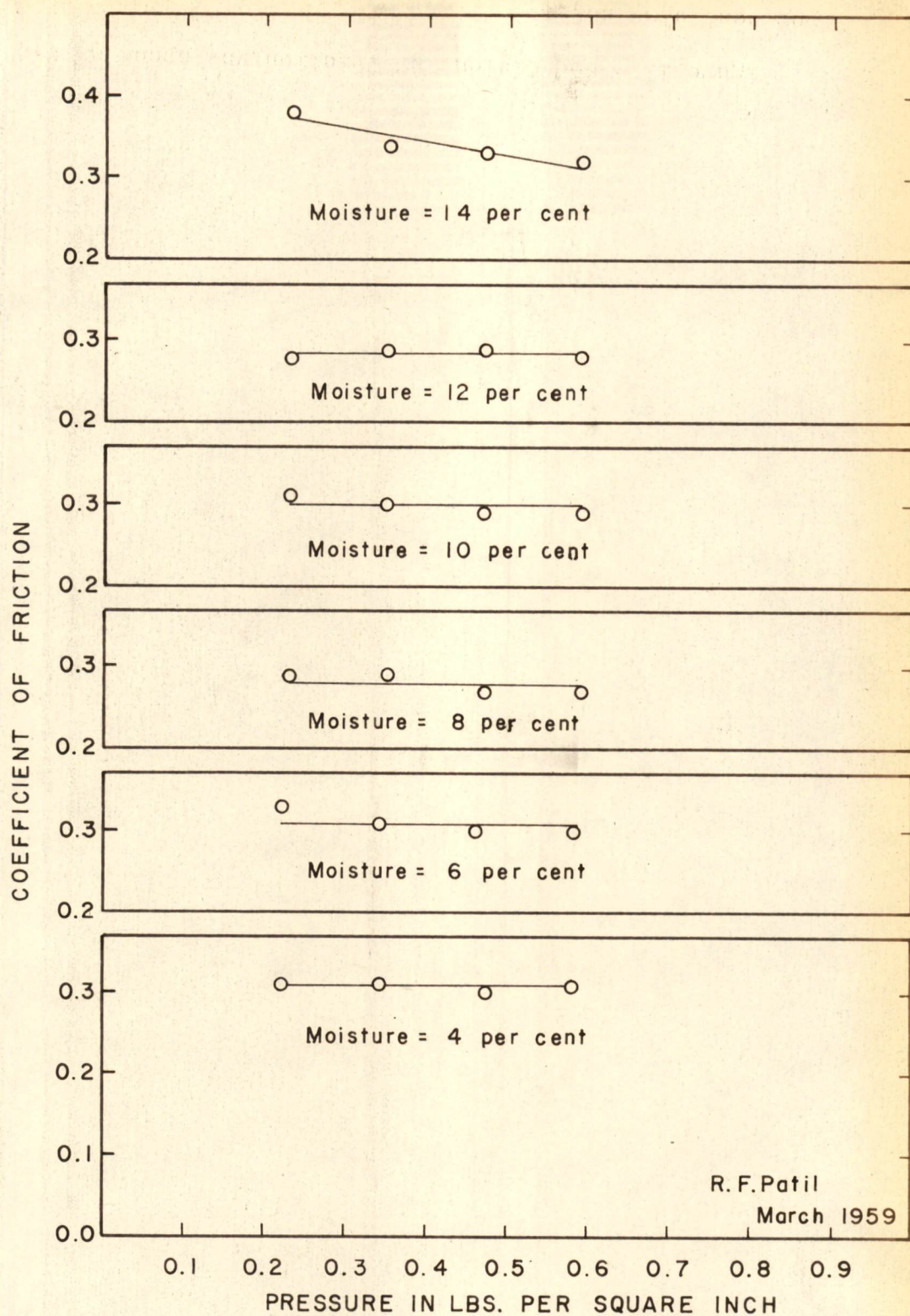


Figure 14. Coefficient of friction vs. pressure at 4.06 mph for 7.3 per cent clay soil.

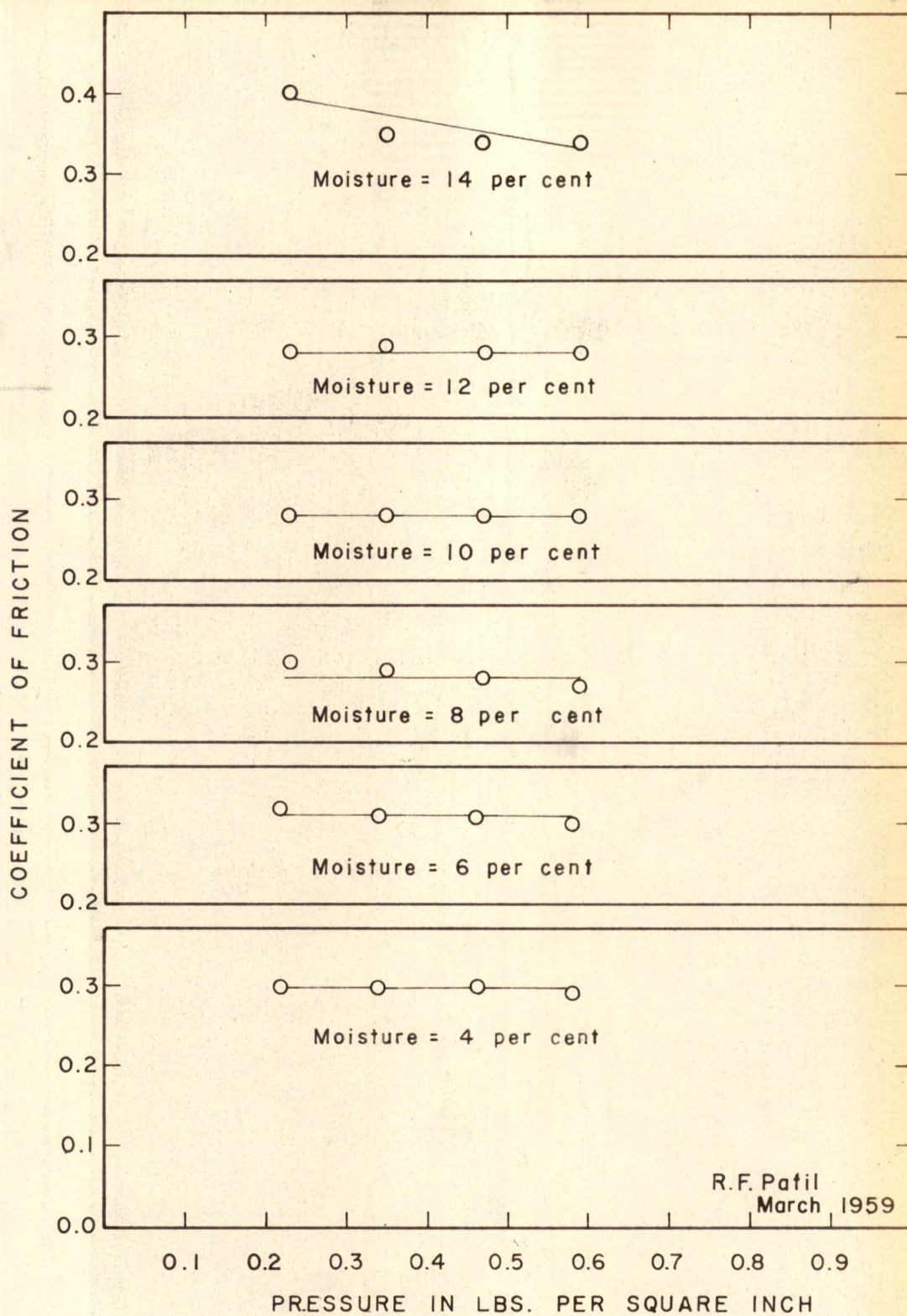


Figure 15. Coefficient of friction vs. pressure at 8.12 mph for 7.3 per cent clay soil.

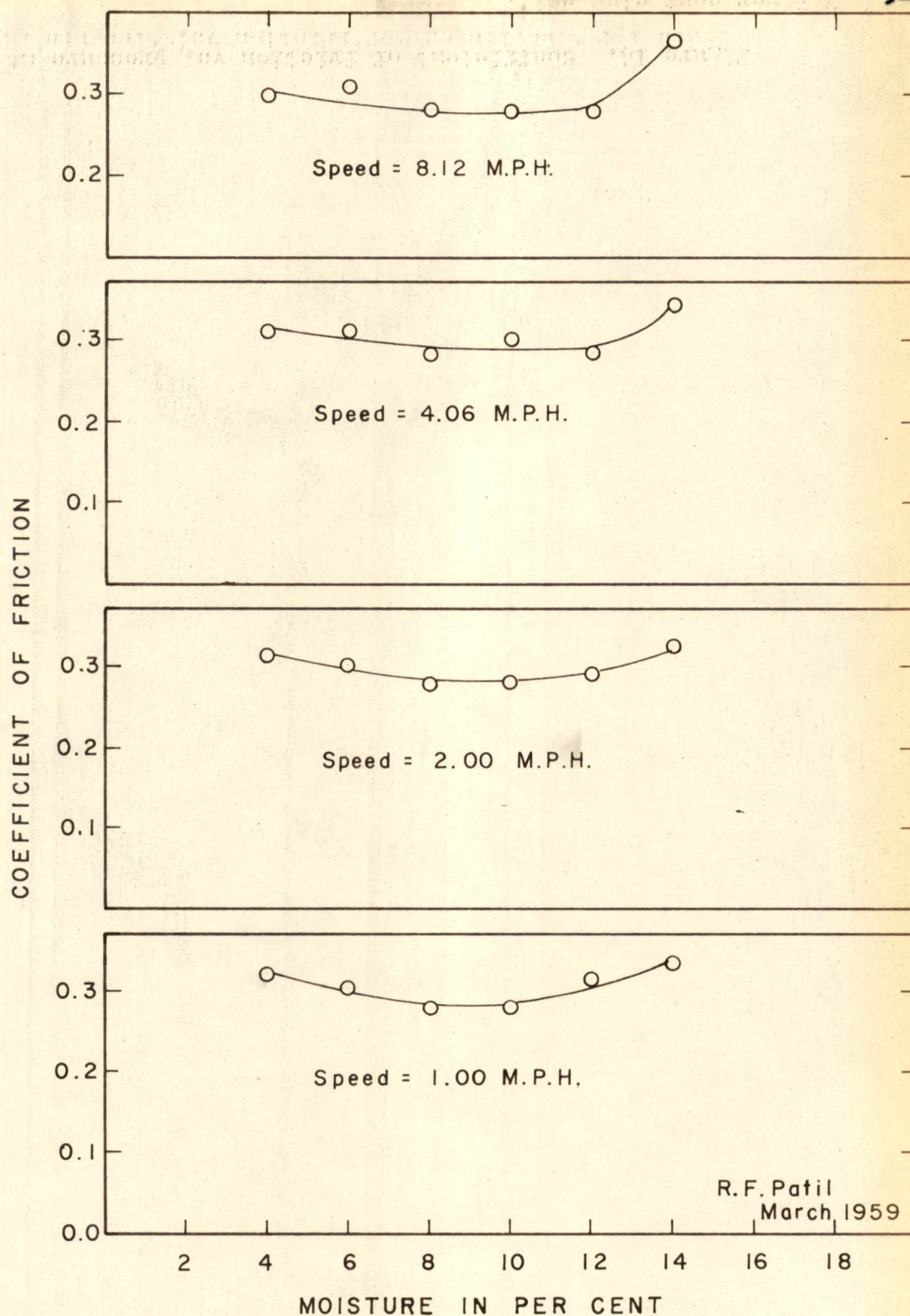


Figure 16. Coefficient of friction vs. moisture at 0.4 psi for 7.3 per cent clay soil.

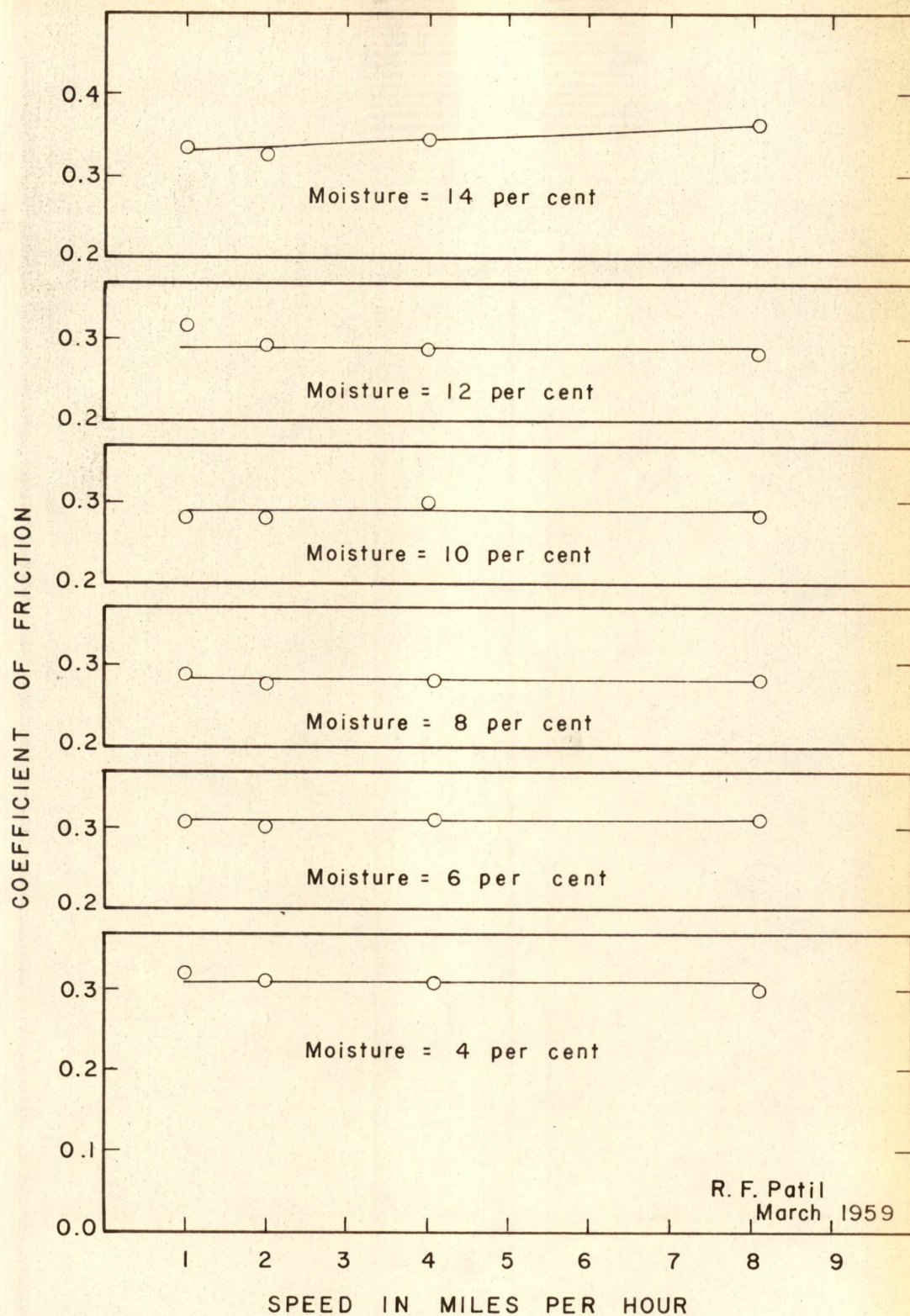


Figure 17. Coefficient of friction vs. speed at 0.4 psi for 7.3 per cent clay soil.

ed as truly representing the friction between Teflon and soil. The friction was more between soil and soil. This explains the higher values of friction at higher speeds.

The following conclusions can be drawn for this soil:

1. The coefficient of friction was independent of pressure at lower moisture contents. But at higher moisture contents, the coefficient of friction decreased with increase in the pressure.
2. The coefficient of friction decreased as moisture increased up to a particular limit, whereas at higher moisture content, it increased as the moisture increased.
3. The coefficient of friction was independent of speed for lower moisture contents, but it increased with the speed at higher moisture contents.

Soil with 9.6 per cent Clay

The lowest amount of moisture with which this soil could be worked was 4 per cent. Even then, the readings could be taken only for lower speeds of one and two miles per hour. No readings could be taken for higher speeds, as the particles of soil were flowing out of the can at these speeds. The moisture was increased to a maximum of 16 per cent in stages of 4 per cent. It was not possible to take readings for higher moisture contents, as the soil paste started flowing out of the can at these moisture contents.

For every stage of moisture content four different pressures were used; and for each pressure four different speeds were used.

The values obtained for the force and coefficient of friction for different moisture contents, pressures and speeds are given in table IV under Appendix B. The values for the coefficient of friction are plotted in figures 18 to 23. The examination of the figures from 18 to 21 shows that the coefficient of friction was independent of pressure at all speeds. Figure 22 shows that the coefficient of friction was independent of moisture up to 12 per cent. The trend of the curves shows that the friction entered the 'C' phase thereafter, the friction increasing with moisture. Figure 23 indicates that the coefficient of friction was independent of speed.

The following conclusions can be drawn for this soil:

1. The coefficient of friction was independent of pressure.
2. The coefficient of friction varied with the moisture only at higher percentages of moisture, being independent of moisture at lower percentages.
3. The coefficient of friction was independent of the speed.

Soil with 22.4 per cent of Clay

The lowest moisture content with which this soil could be worked was 10 per cent. The moisture was increased in stages of 2 per cent to a maximum of 22 per cent. For each stage of moisture content four different pressures were used; and for each pressure four different speeds were used. The observations made during this test are given in table V under Appendix B.

The values for the coefficient of friction are plotted in

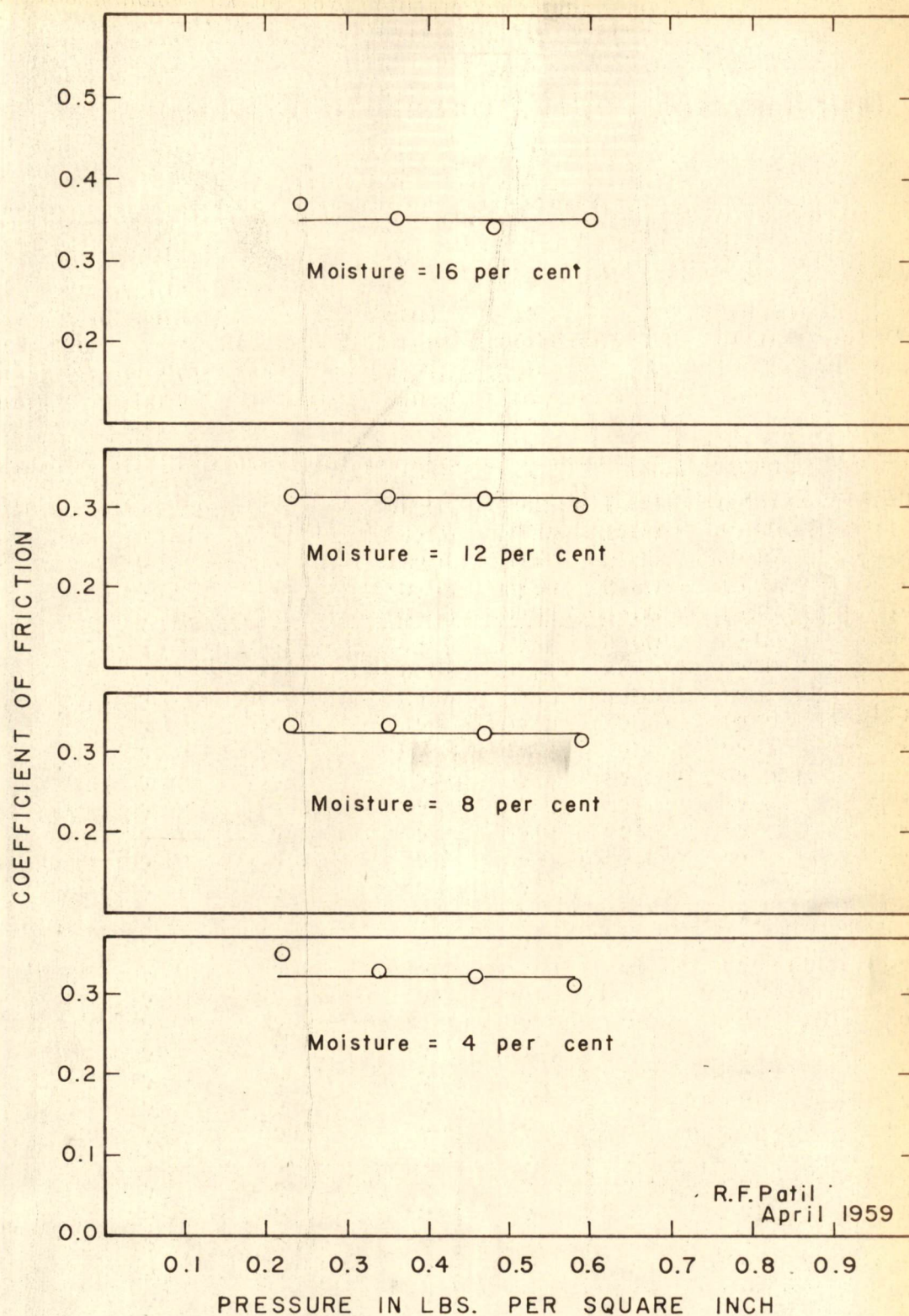


Figure 18. Coefficient of friction vs. pressure at one mph for 9.6 per cent clay soil.

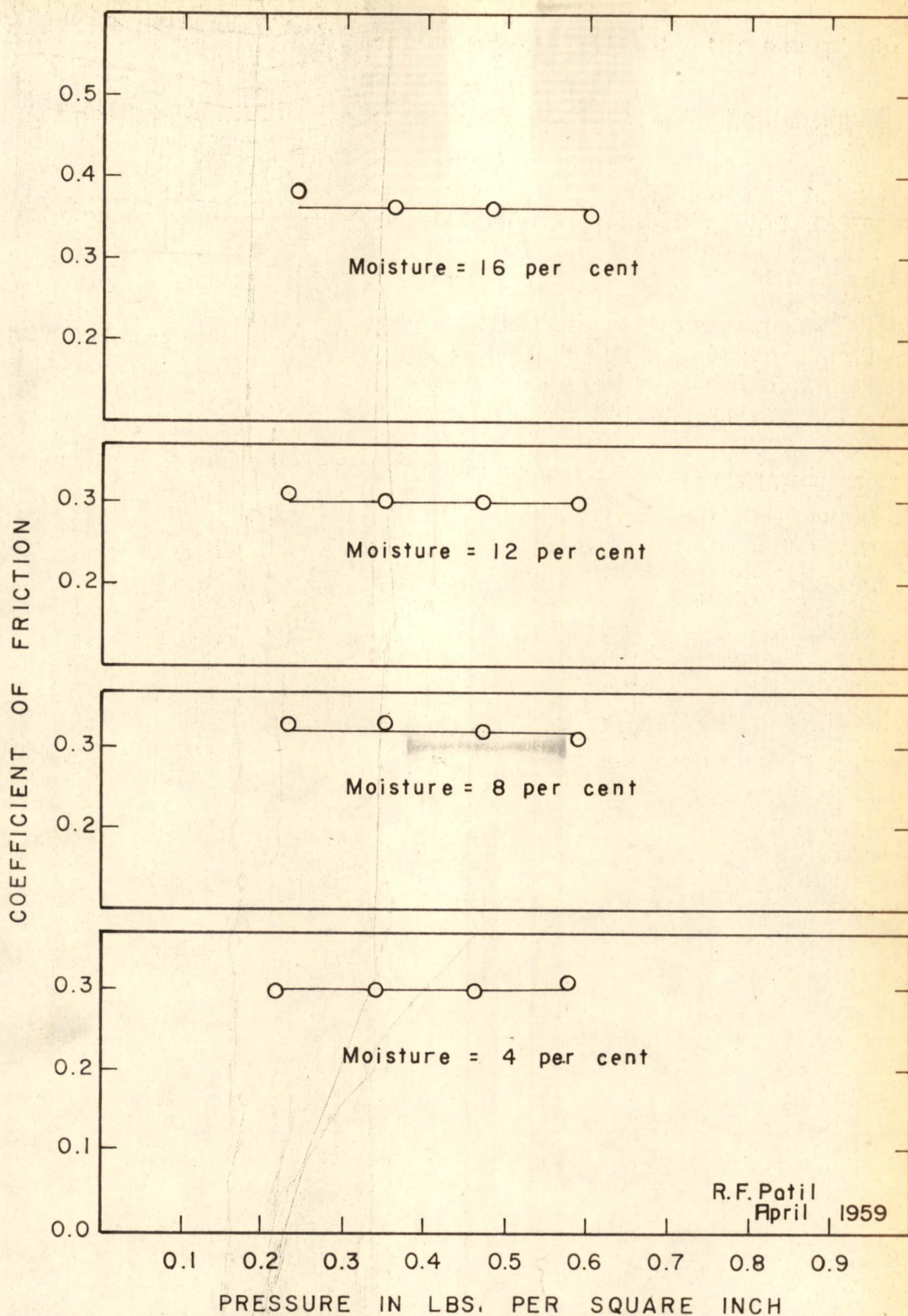
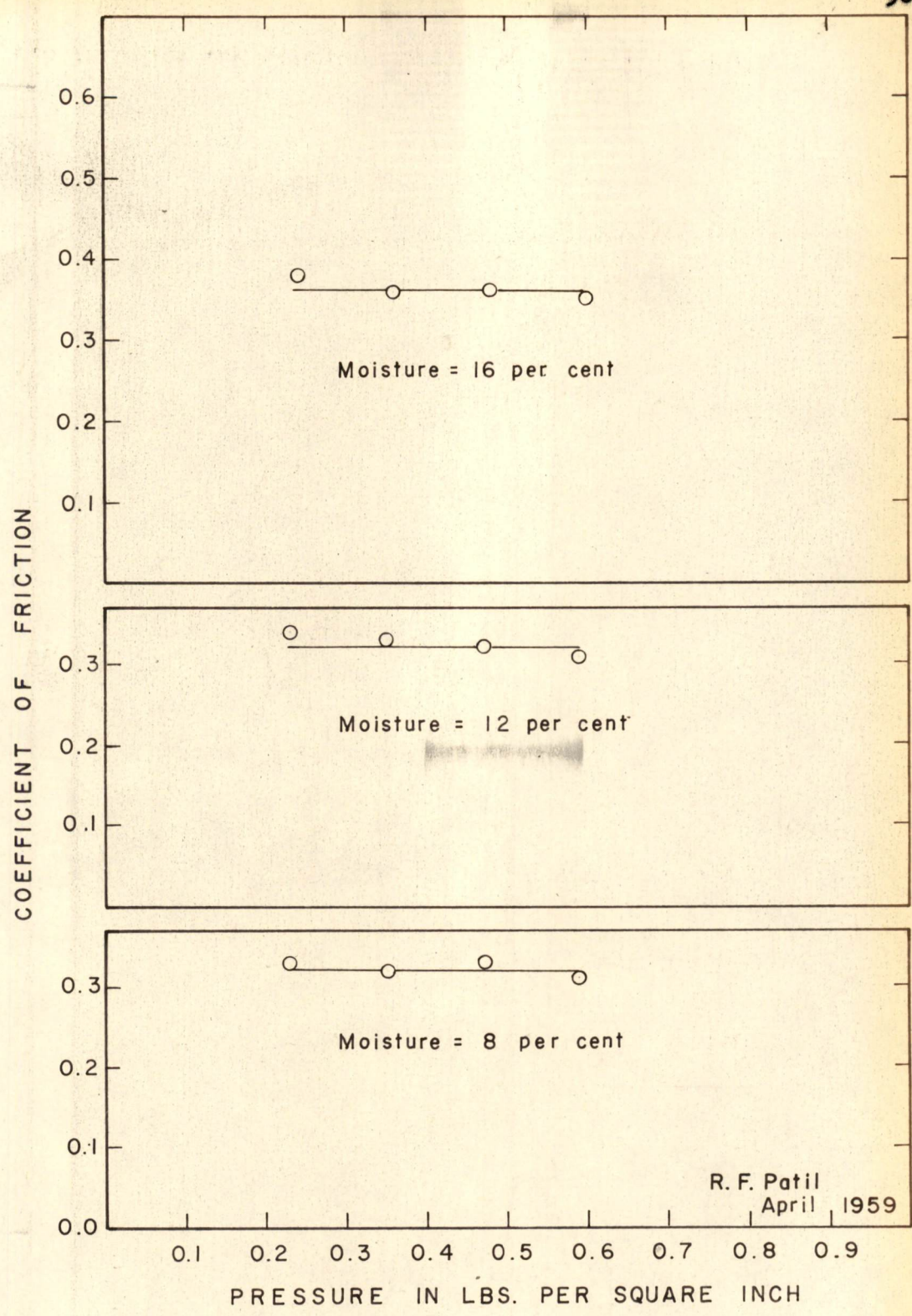


Figure 19. Coefficient of friction vs. pressure at two mph for 9.6 per cent clay soil.



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Figure 20. Coefficient of friction vs. pressure at 4.06 mph for 9.6 per cent clay soil.

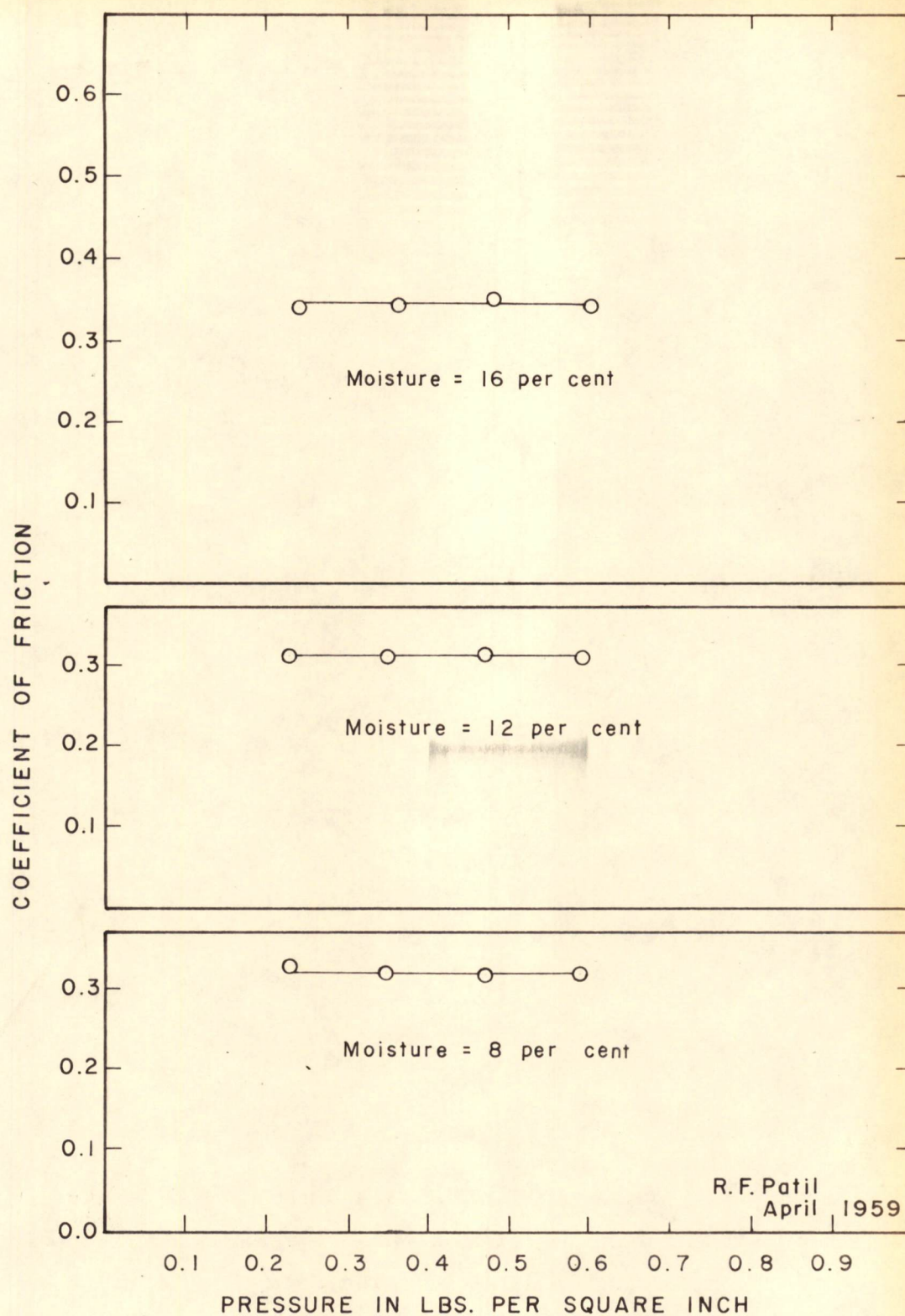


Figure 21. Coefficient of friction vs. pressure at 8.12 mph for 9.6 per cent clay soil.

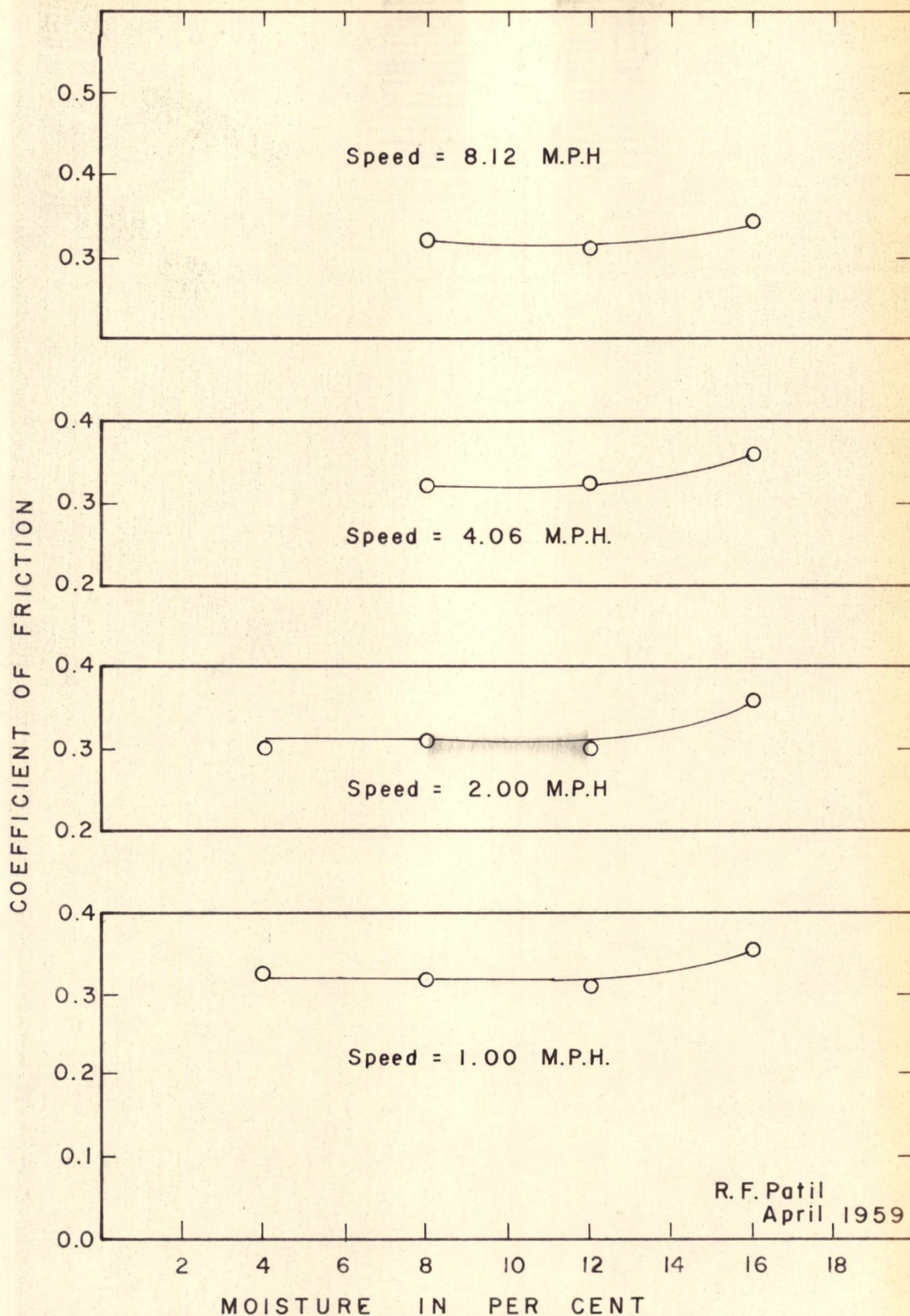


Figure 22. Coefficient of friction vs. moisture at 0.4 psi for 9.6 per cent clay soil.

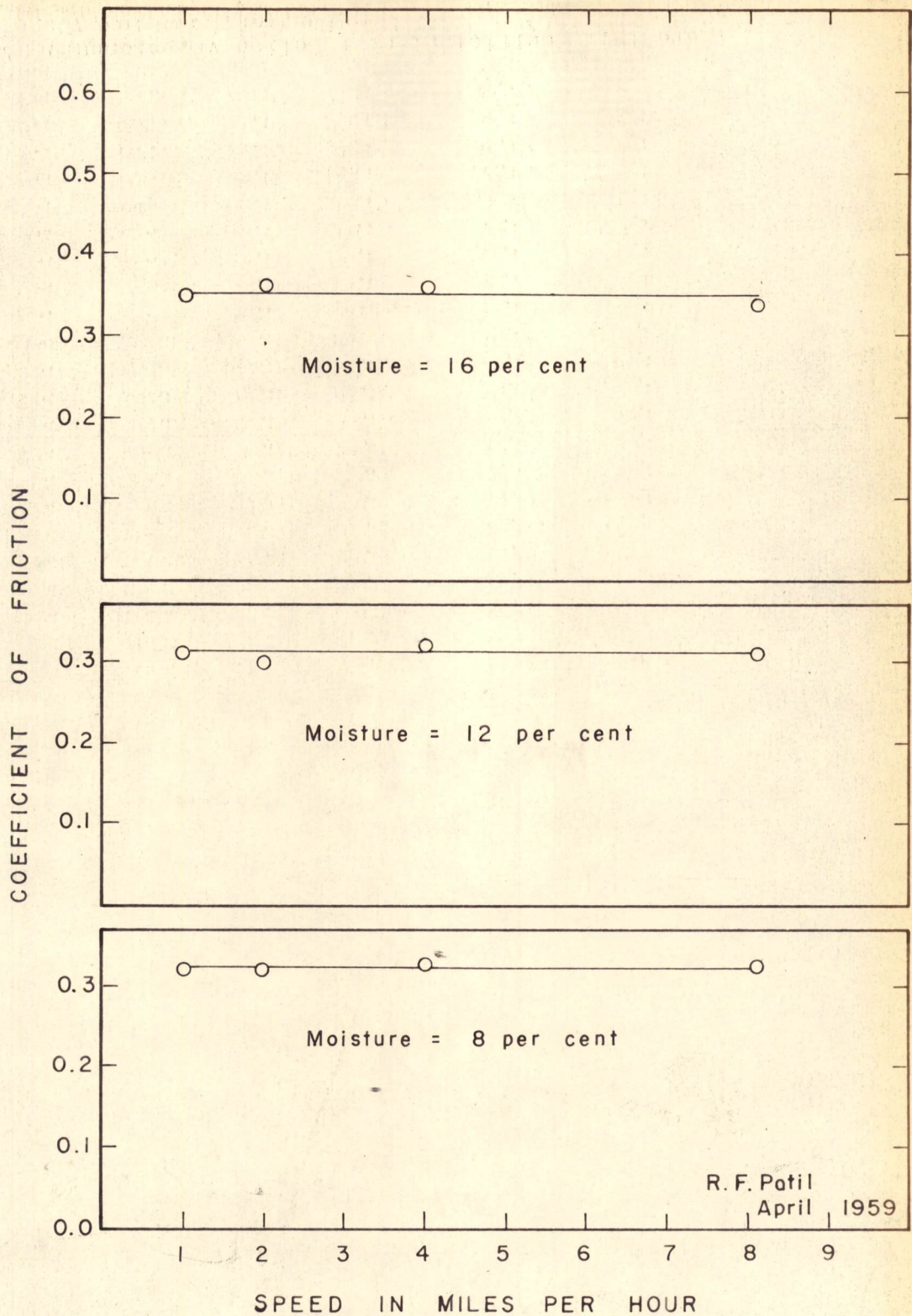


Figure 23. Coefficient of friction vs. speed at 0.4 psi for 9.6 per cent clay soil.

figures 24 to 29. The behaviour of the coefficient of friction against pressure is indicated in figures 24 to 27. It is seen that at speeds of one and two miles per hour, the coefficient of friction was independent of pressure for 10 per cent moisture. For all other moisture contents except 22 per cent the coefficient of friction decreased as the pressure increased. At 22 per cent moisture, the coefficient of friction first increased with pressure and then dropped again. At this moisture it was noticed that at slow speeds a thin film of the soil paste was formed on the Teflon surface at places and the figures obtained cannot be said to be truly representing the frictional force between soil and Teflon but rather soil against soil.

At a speed of 4.06 miles per hour, the coefficient of friction decreased as pressure increased for all moisture contents; whereas, for the speed of 8.12 miles per hour, the coefficient of friction was found to be independent of pressure up to 14 per cent of moisture. Thereafter the coefficient of friction decreased as pressure increased.

Figure 28 shows that the coefficient of friction increased with the moisture, the increase being more sharp at lower speeds. The high content of clay seems to be responsible for this kind of behaviour. As the moisture increased, the soil became more plastic in nature and resulted in greater adhesion to the Teflon surface.

Figure 29 shows that the coefficient of friction was independent of speed for lower moisture contents up to 14 per cent.

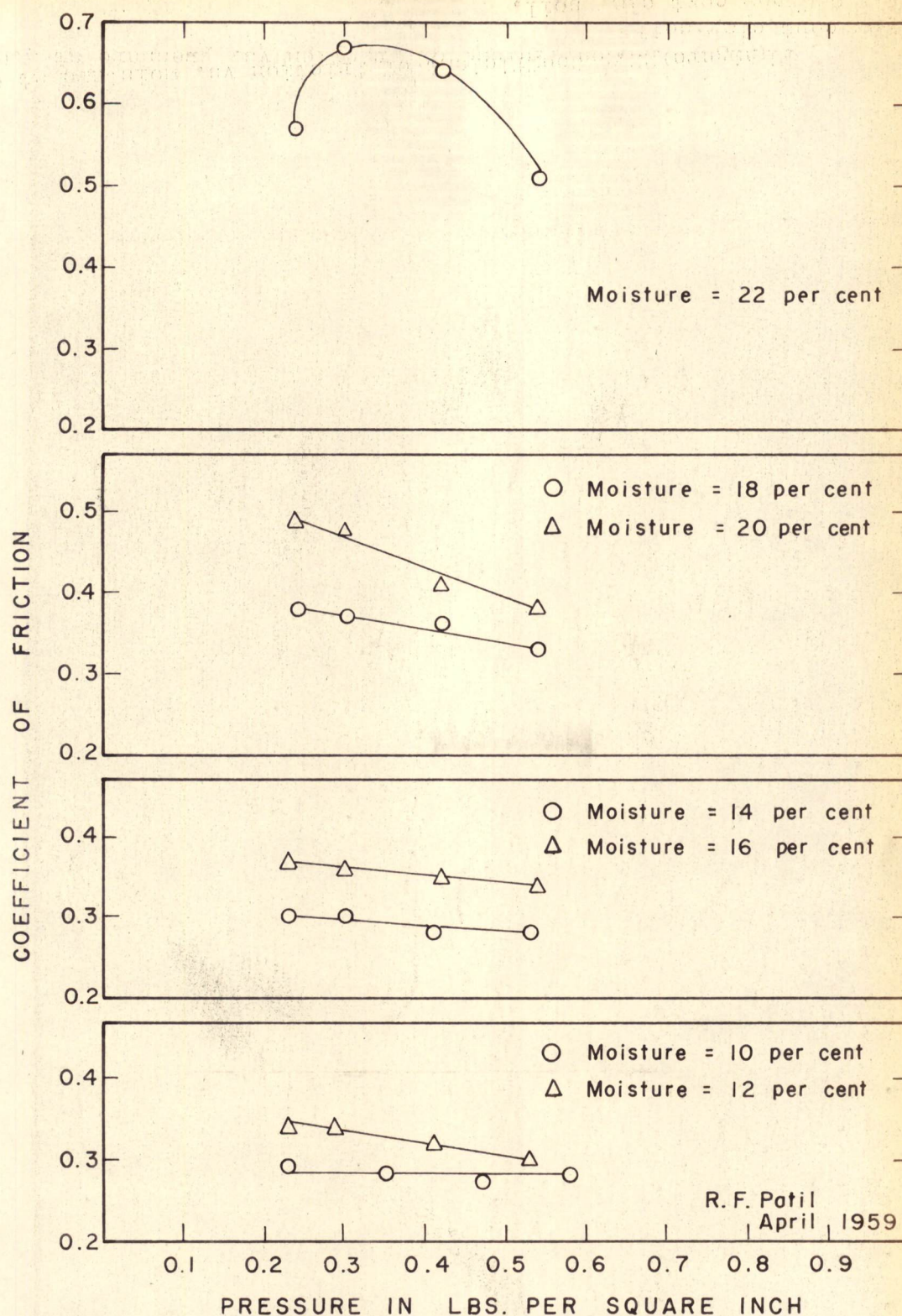


Figure 24. Coefficient of friction vs. pressure at one mph for

22.4 per cent clay soil.

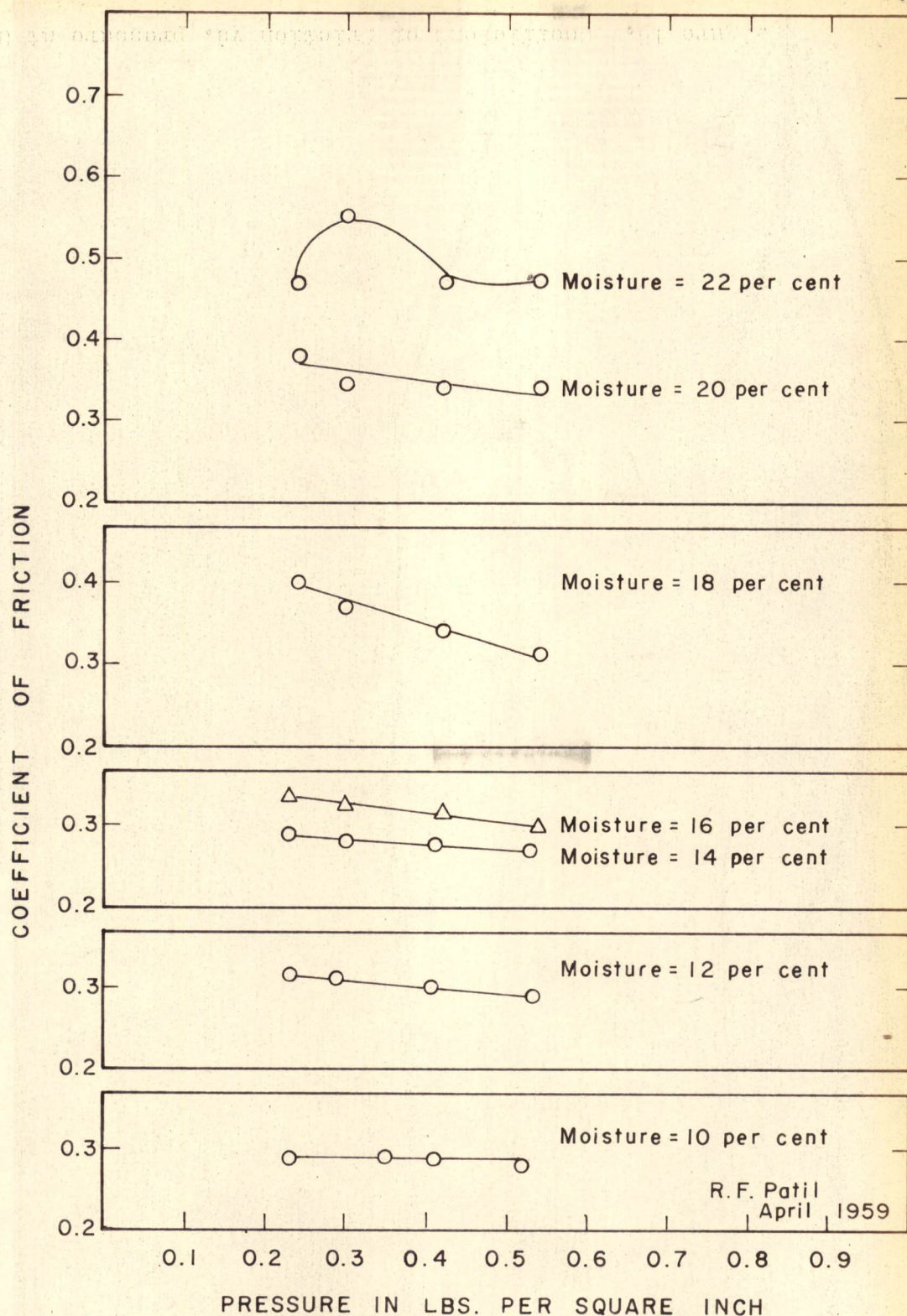


Figure 25. Coefficient of friction vs. pressure at two mph for 22.4 per cent clay soil.

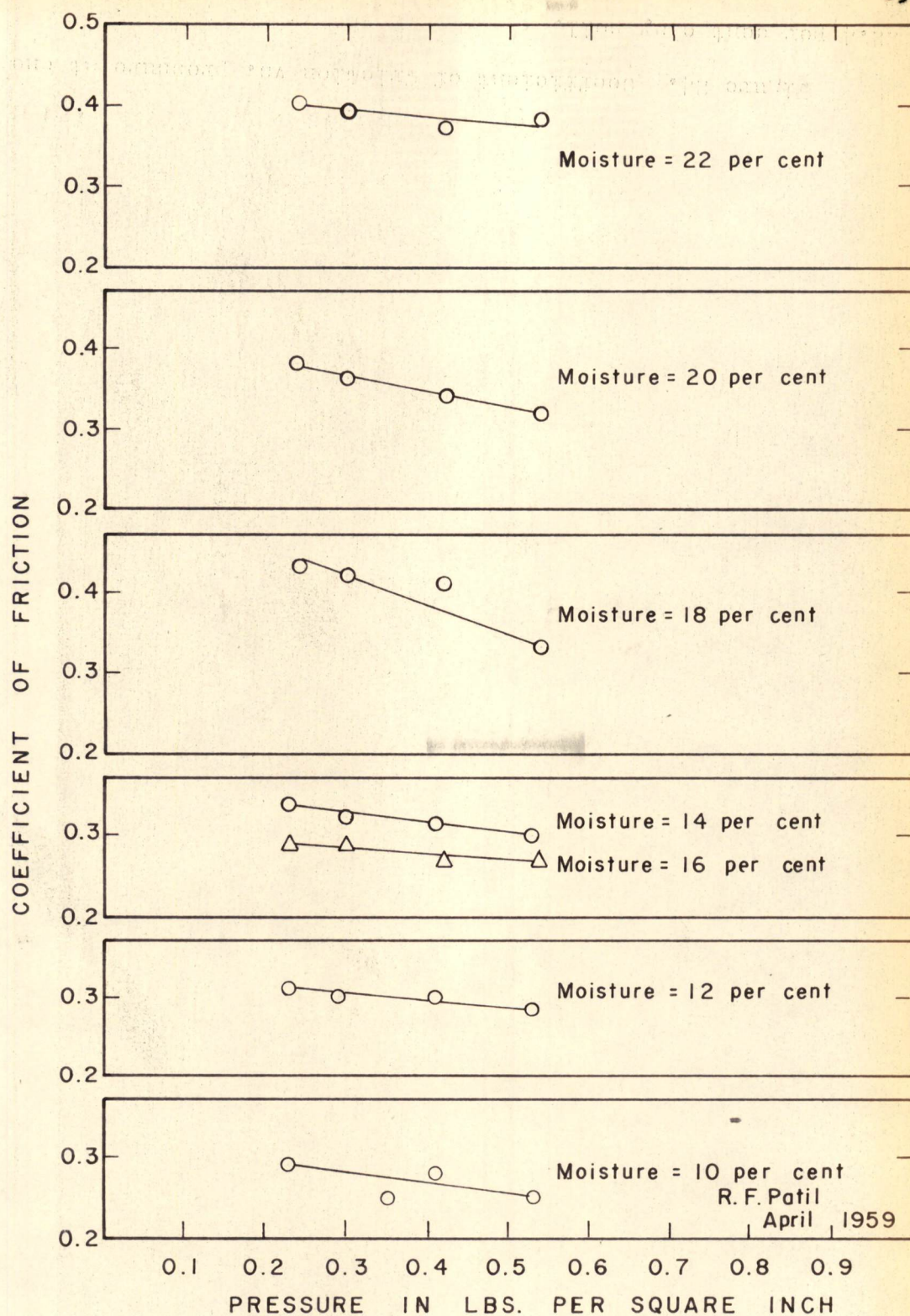


Figure 26. Coefficient of friction vs. pressure at 4.06 mph for 22.4 per cent clay soil.

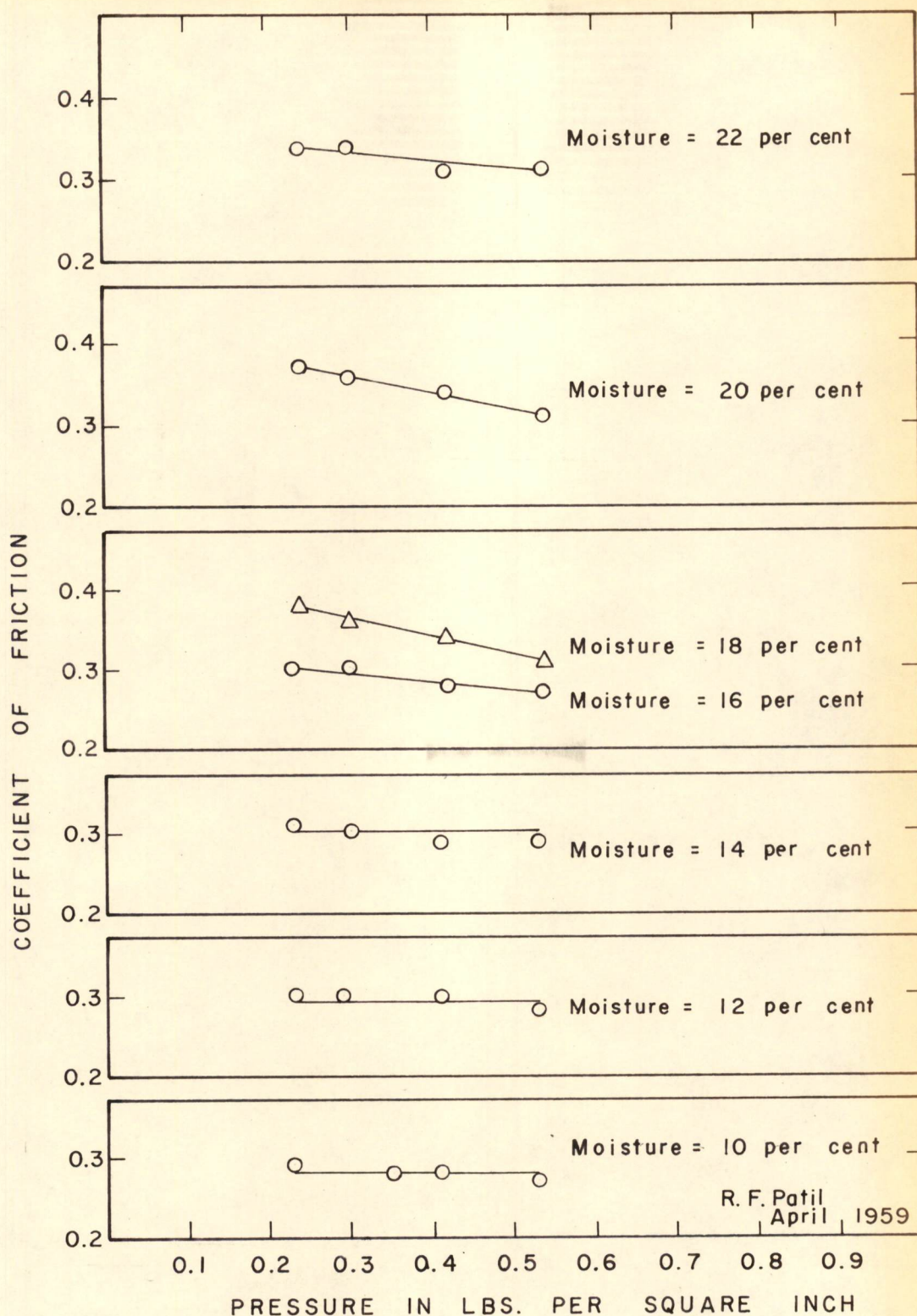
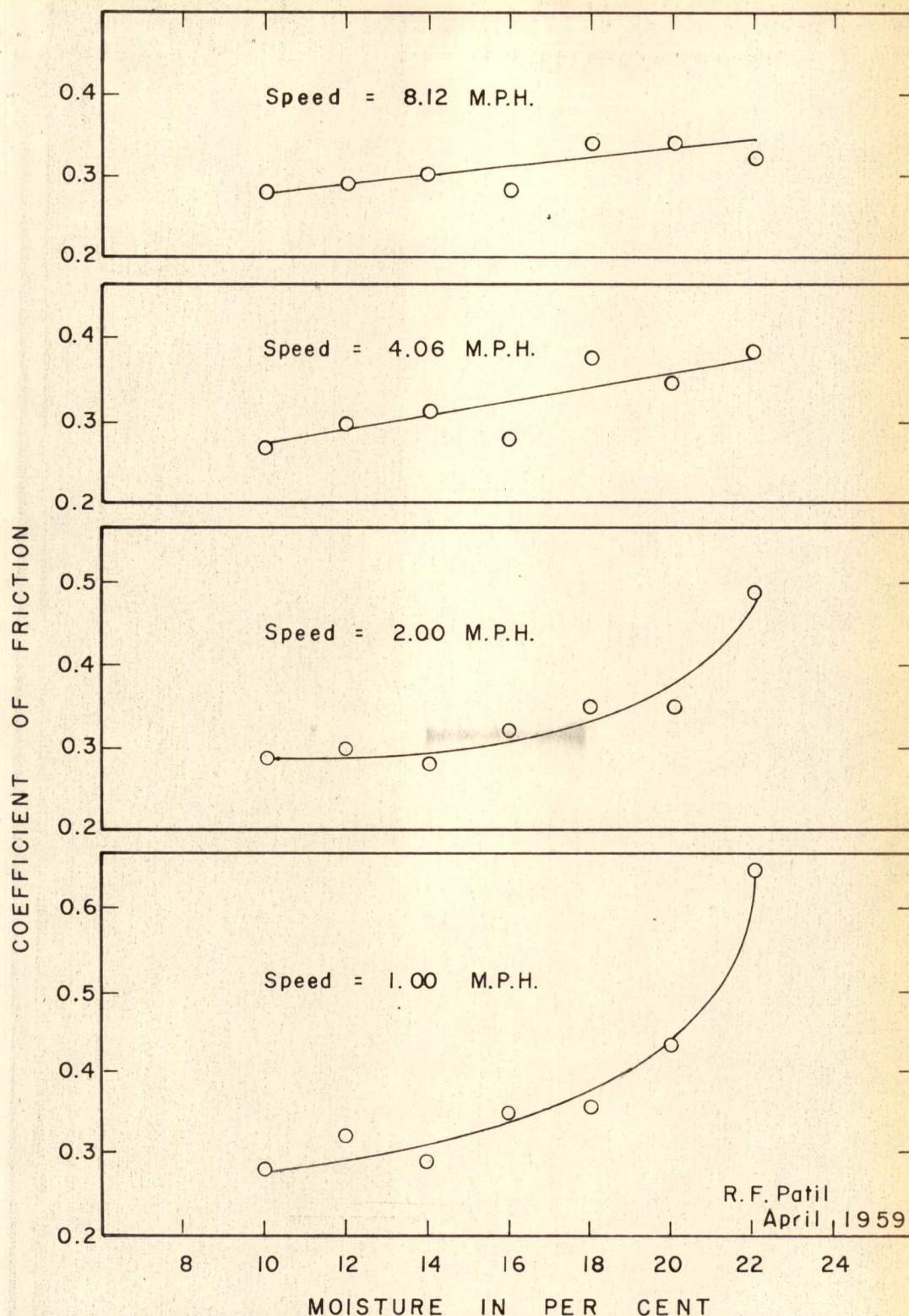


Figure 27. Coefficient of friction vs. pressure at 8.12 mph for 22.4 per cent clay soil.



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Figure 28. Coefficient of friction vs. moisture at 0.4 psi for 22.4 per cent clay soil.

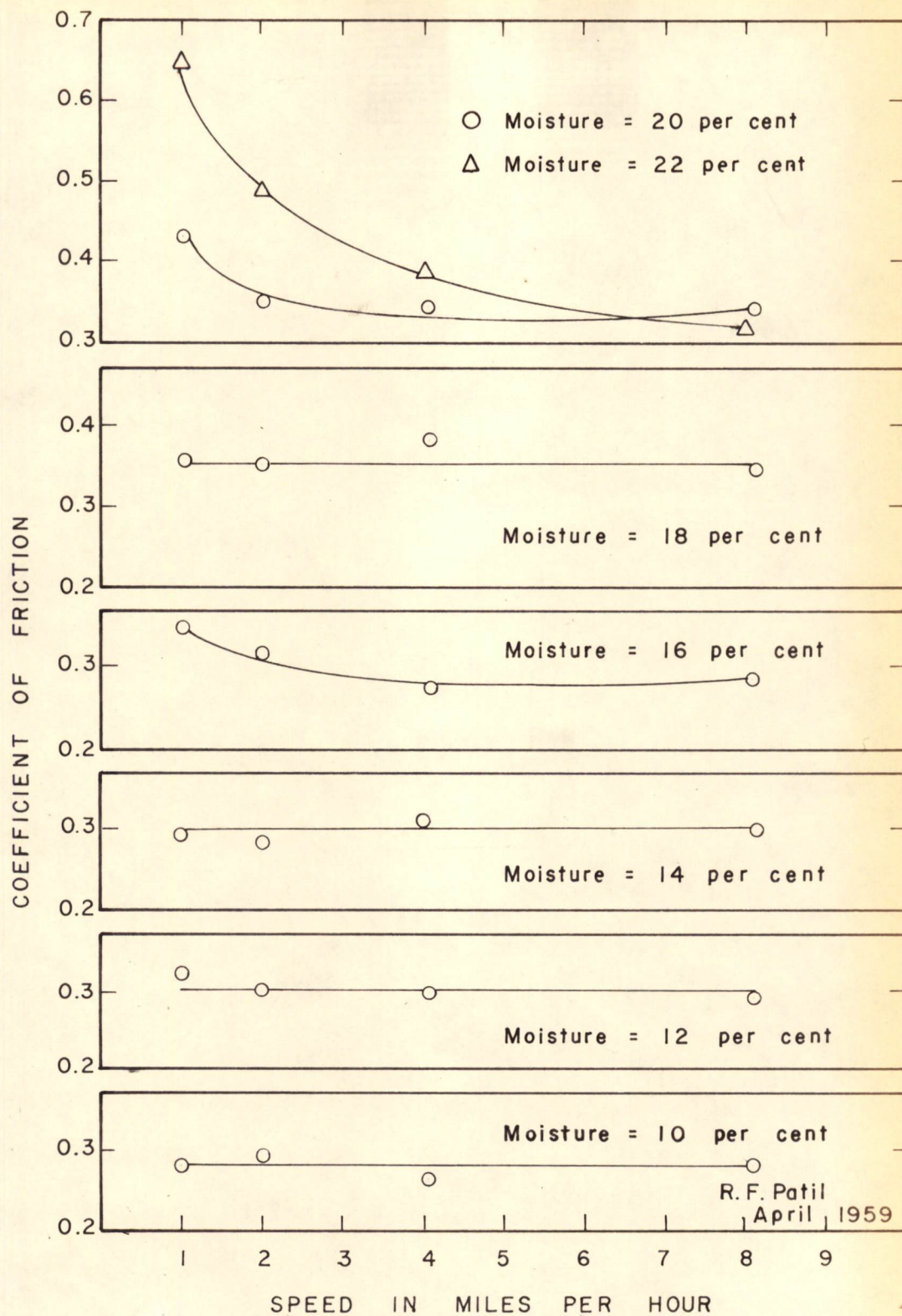


Figure 29.C coefficient of friction vs. speed at 0.4 psi for 22.4 per cent clay soil.

As the moisture increased, the coefficient of friction decreased as the speed increased, the decrease being more sharp as the speed increased from one to 4.06 miles per hour. At 18 per cent moisture, however, the coefficient of friction showed a tendency of remaining independent of the speed.

The following conclusions can be drawn for this soil:

1. The coefficient of friction generally decreased as the pressure increased particularly at higher moisture contents.
2. The coefficient of friction increased as the moisture content increased, the increase being more sharp for lower speeds and higher moisture contents.
3. The coefficient of friction was independent of speed for lower moisture contents, but at higher moisture contents it decreased with increase in the speed.

Soil with 41.2 per cent of Clay

This soil remained considerably dry even when moisture was added up to 15 per cent. The lowest amount of moisture with which the test could be conducted was 15 per cent. It was generally found that as the clay content in the soil increased, the amount of moisture which was necessary to add to the soil also increased, before it could be used in the test. This is because the particles of clay are smaller in size and more numerous in number than the particles of silt and sand and therefore have greater specific surface which has to be covered with the film of moisture. According to Bayer (3), a given weight or volume of two micron clay has

fifty times more surface than the same quantity of very fine sand and has ten times more surface than the weight of silt. The moisture in the sample was increased in stages of 2 per cent up to a maximum of 32 per cent. The test could not be carried out at higher percentages of moisture as the soil paste started flowing out of the can.

For each stage of moisture content, four different pressures and for each pressure, four different speeds were tried. The readings obtained in the test are recorded in table VI under Appendix B. The values for the coefficient of friction are plotted against pressure, moisture and speed in figures 30 to 35. The curves in figures 30 to 33 indicate that at lower moisture content, the coefficient of friction was independent of pressure for all speeds, except in the case of 8.12 miles per hour. In all other cases, as the moisture increased, the coefficient of friction generally decreased with increase in the pressure. In the case of 23, 25 and 27 per cent moisture, at a speed of one mile per hour, the coefficient of friction had a tendency to increase with the pressure, but it dropped off again as the pressure increased more. This is indicated in figure 30.

Figure 34 represents the behaviour of the coefficient of friction against moisture. For the moisture contents from 15 per cent to 25 per cent, it is found that the coefficient of friction was either independent of moisture or decreased very slightly with increase in the moisture content. This seemed to be in the

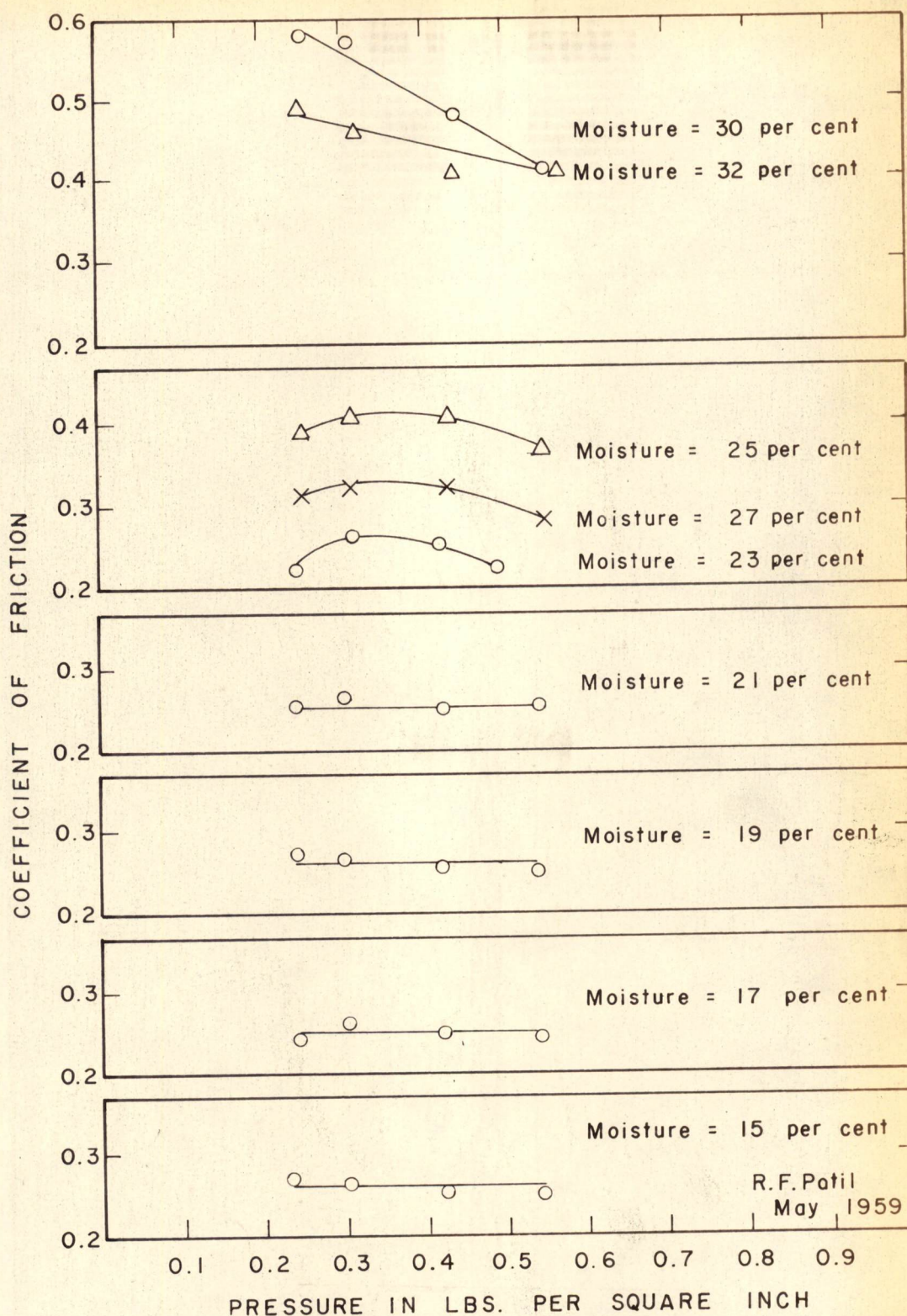


Figure 30. Coefficient of friction vs. pressure at one mph for 41.2 per cent clay soil.

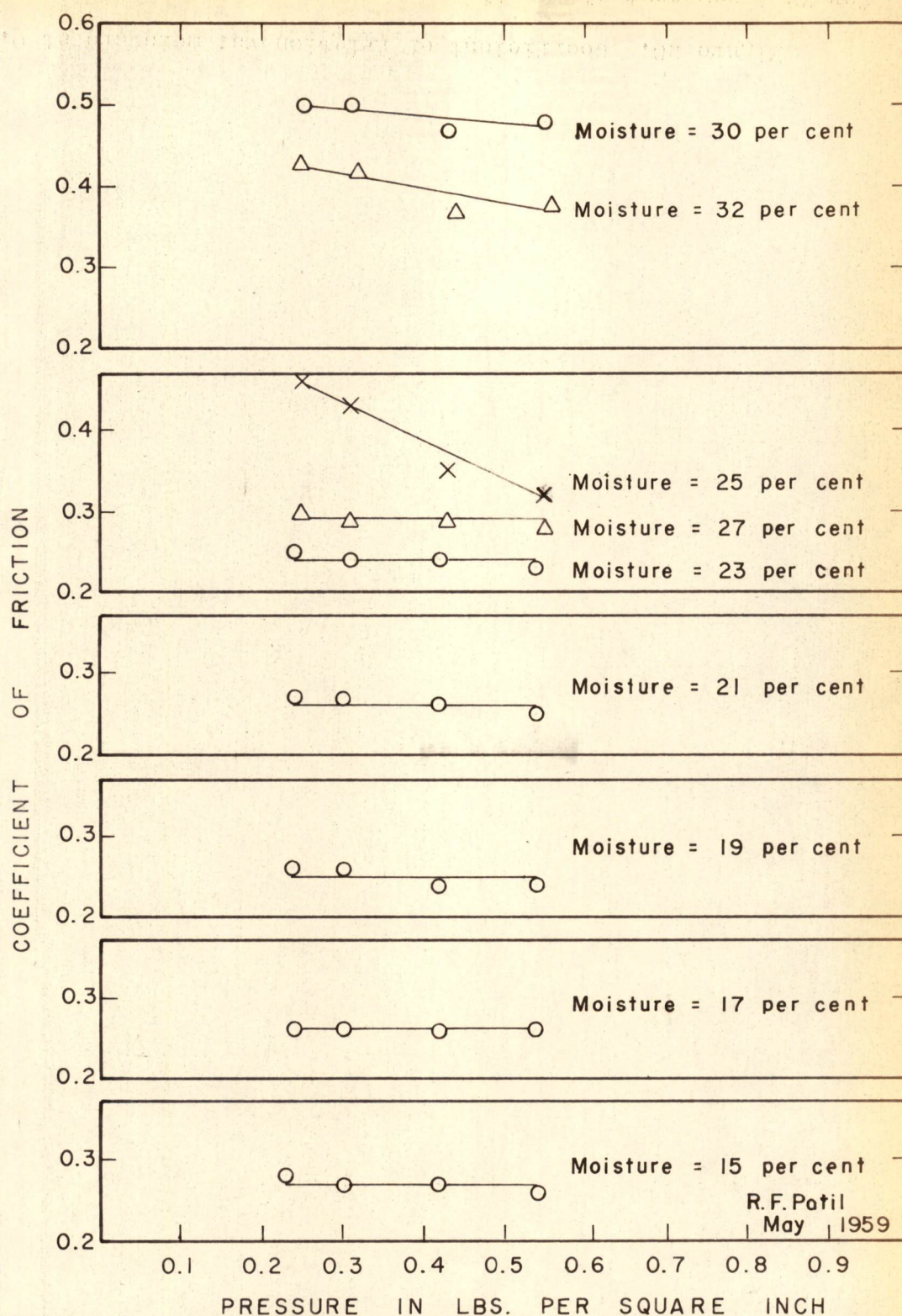


Figure 31. Coefficient of friction vs. pressure at two mph for

41.2 per cent clay soil.

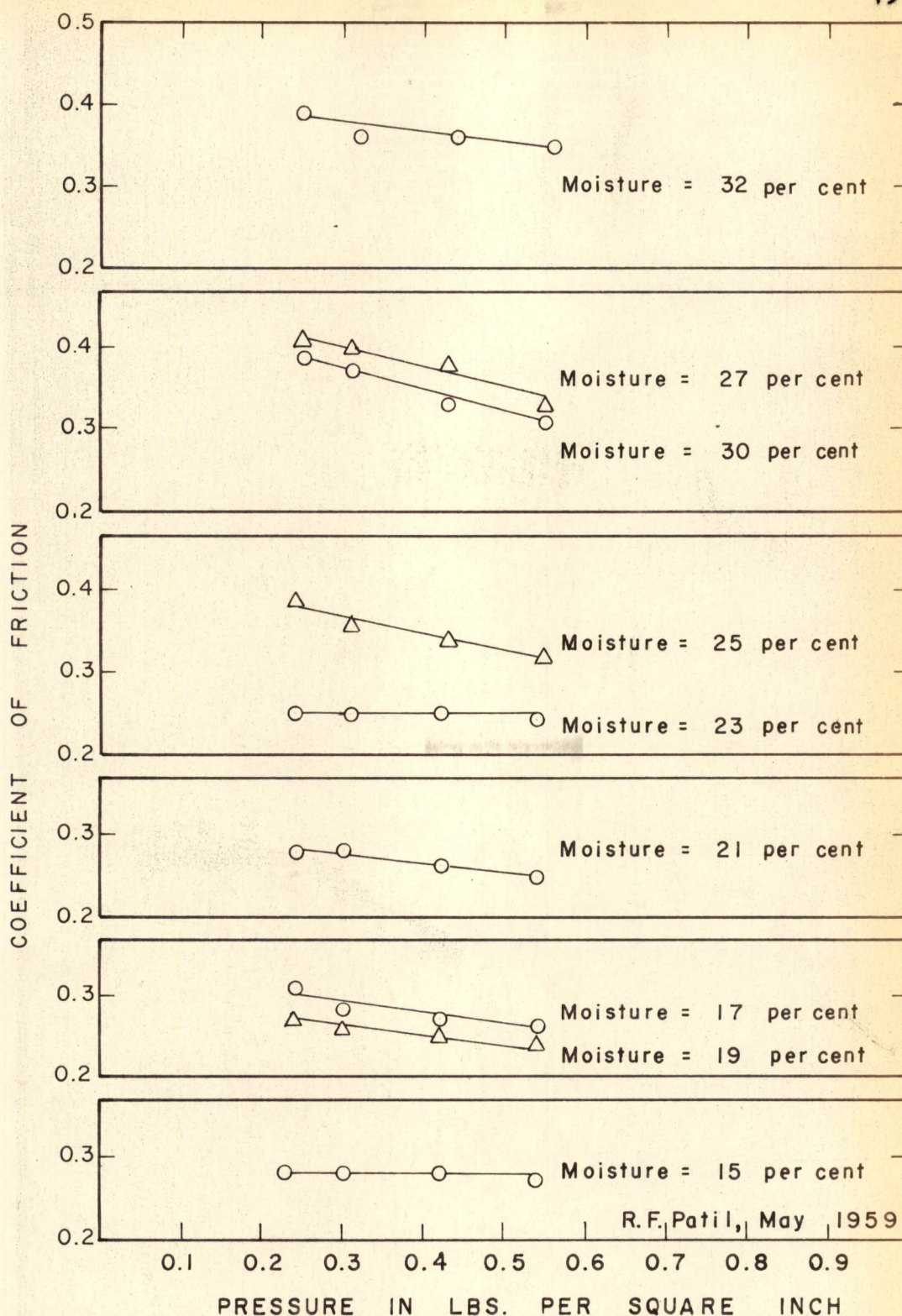


Figure 32. Coefficient of friction vs. pressure at 4.06 for 41.2 per cent clay soil.

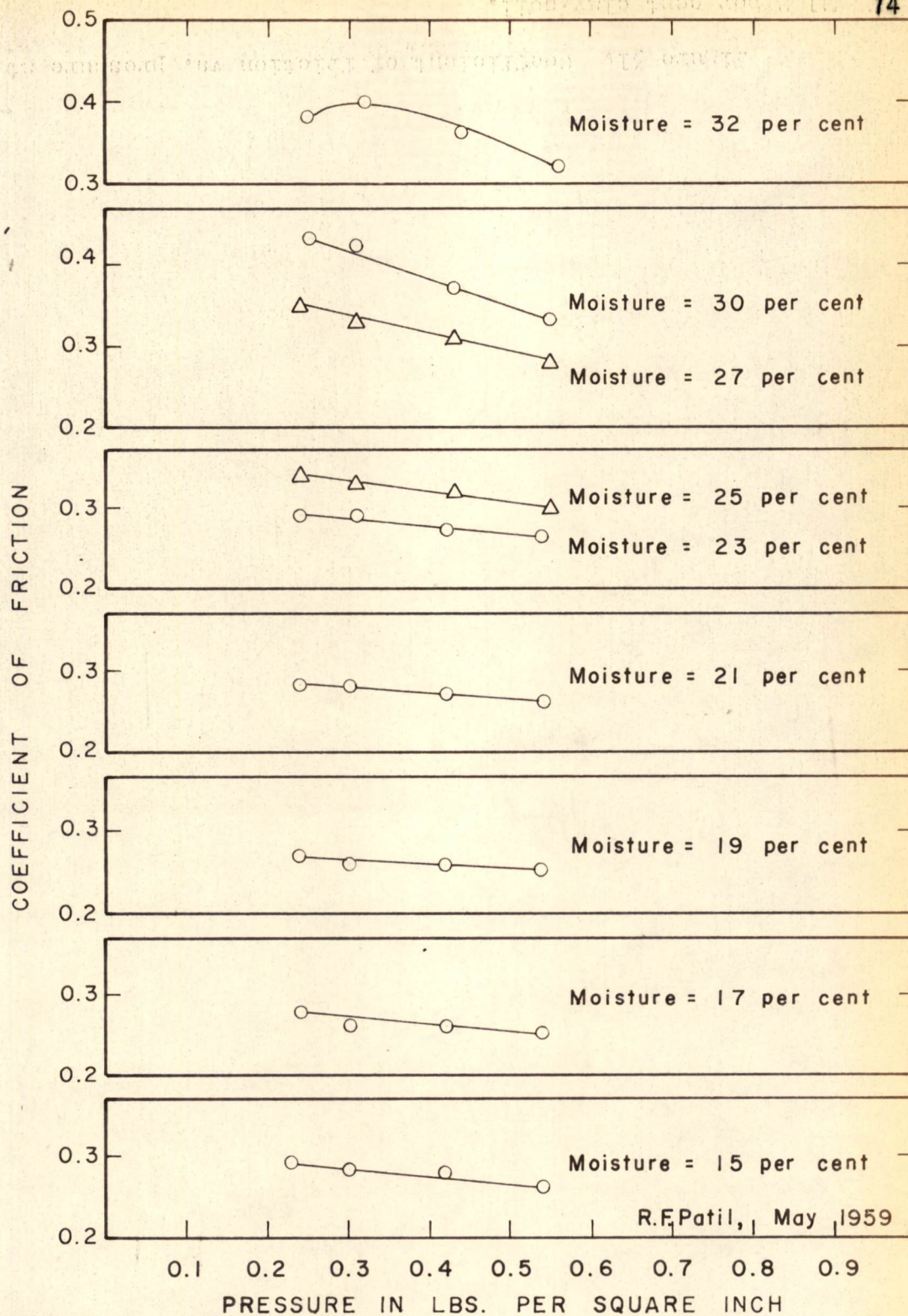


Figure 33. Coefficient of friction vs. pressure at 8.12 mph for 41.2 per cent clay soil.

'B' phase. Thereafter the behaviour of the coefficient of friction is not uniform. The coefficient of friction generally showed a tendency to increase with increase in moisture content, having entered the 'C' phase, even though the curves are not quite uniform. At higher speeds, however, the curves appear to smoothen, indicating that the increase in the coefficient of friction with increase in the moisture content is tending to be uniform at higher speeds.

Figure 35 shows that the coefficient of friction is independent of speed for lower moisture contents. But for higher moisture contents, the coefficient of friction is noticed to be decreasing as the speed increased. At higher moisture contents the adhesion between the soil and Teflon appeared to be greater at lower speeds than for higher speeds. This greater adhesion seems to be responsible for greater coefficient of friction at lower speeds.

The following conclusions can be drawn for this soil:

1. The coefficient of friction is independent of pressure for low speeds and low moisture contents; but for high speeds and high moisture contents, the coefficient of friction decreased generally as the pressure increased.

2. The coefficient of friction was either independent or decreased very slightly, as the moisture content increased for lower percentages of moisture; but it increased generally with increase in moisture content for higher percentages of moisture.

3. The coefficient of friction was independent of speed for lower moisture contents; but for higher moisture contents

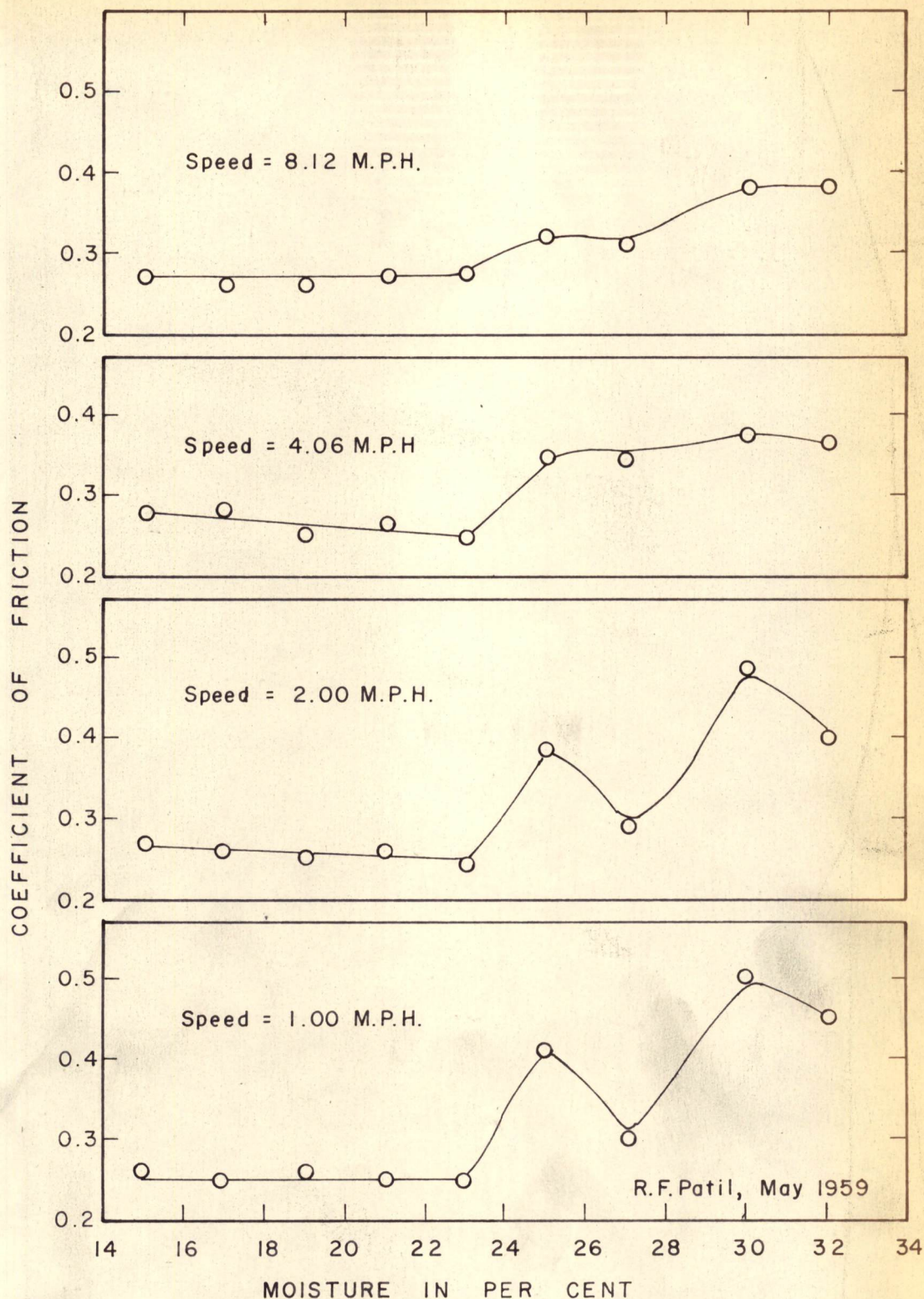


Figure 34. Coefficient of friction vs. moisture at 0.4 psi for 41.2 per cent clay soil.

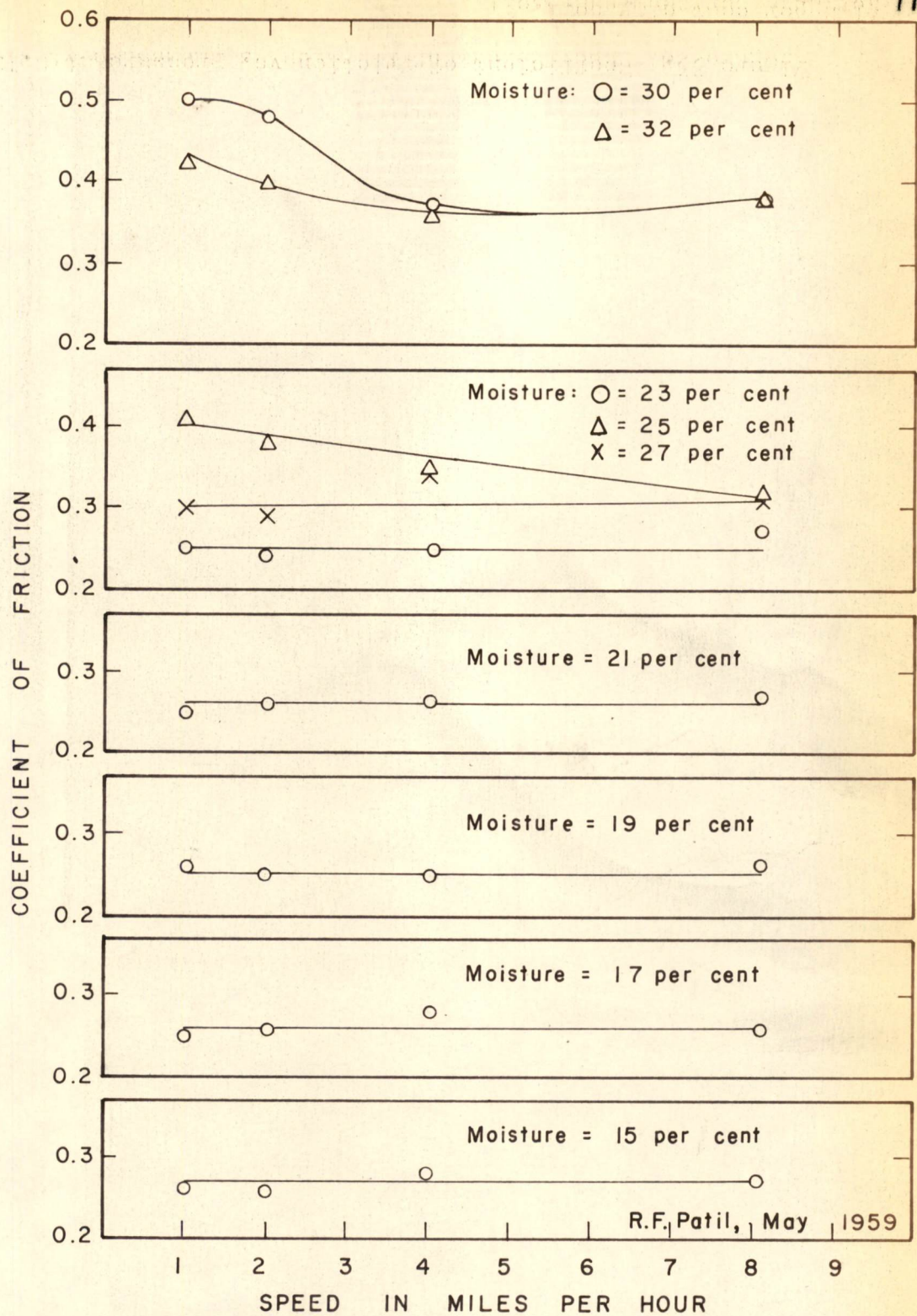


Figure 35. Coefficient of friction vs. speed at 0.4 psi for 41.2 per cent clay soil.

it generally decreased with increase in speed.

Test on Area of Contact

Some tests were also carried out to find whether the area of contact had any effect on friction. For this purpose four different cans of the sizes 2.50, 3.00, 3.25 and 3.88 inches in diameter were used. The tests were made with the soils containing 7.3 and 22.4 per cent clay. In the case of each soil two different moisture were taken. For each moisture, two different speeds were used. The total pressure was kept the same. The observations made are given in table VII under Appendix B.

Figure 36 shows the behaviour of the coefficient of friction for different areas of contact. It will be seen from the curves that the area of contact had some influence on the coefficient of friction. The coefficient of friction generally increased as the area of contact increased. In the case of 7.3 per cent clay soil, however, it is noticed that the increase in the coefficient of friction existed only when the area was increased from 4.90 square inches to 7.06 square inches. Thereafter the coefficient of friction remained practically independent of the area. The increase in the coefficient of friction as the area of contact increased is more pronounced for 22.4 per cent clay.

Clay Content of Soil and Teflon/Soil Friction

From the results obtained for different types of soils containing different percentages of clay, an attempt was made to study

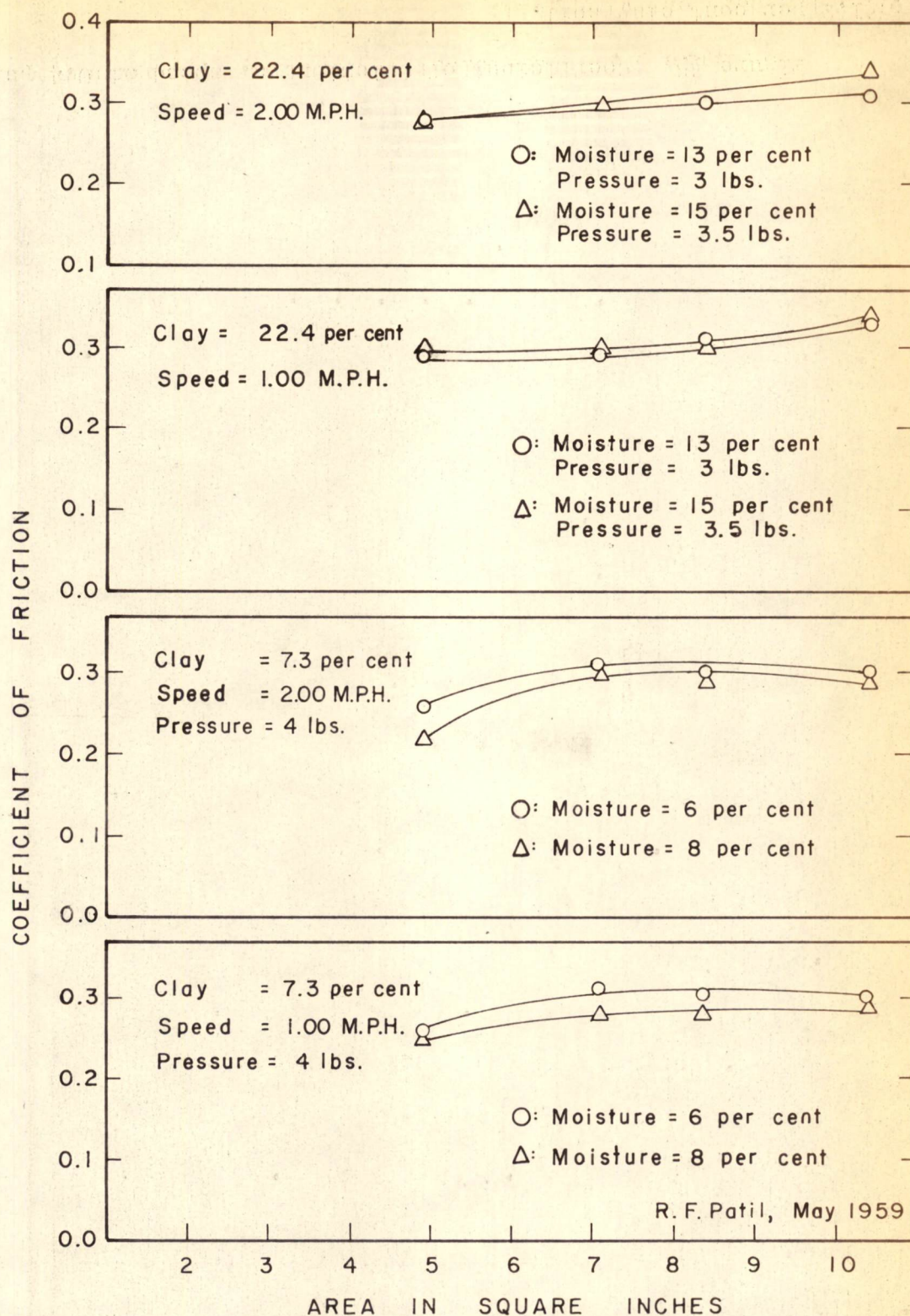


Figure 36. Coefficient of friction vs. area of contact.

how the clay content in the soil affected friction. Figure 37 shows the effect of clay on the coefficient of friction. The curves in this figure have been drawn for the same speed, the same area of contact, the same pressure and the same moisture content. The ranges of moisture content used for the different clays were not identical. In some cases the figures for this analysis were obtained by extrapolating the curves already drawn for those soils under given conditions.

It will be seen from the curves in figure 37 that the clay in the soil had an influence on the coefficient of friction. As the clay content increased the coefficient of friction was found to increase up to 10 per cent of clay. Thereafter the coefficient of friction was found to decrease as the clay content increased. This can be explained by the fact that while the soils with lower clay content had reached the 'C' phase, the soils with higher percentages of clay still remained in the 'B' phase for the same moisture content.

Nichols (12) found that with non-plastic soils, the coefficient of friction varied directly with the colloidal content. His observations were found to agree in the present tests with the non-plastic soils, with 5.7, 7.3 and 9.6 per cent of clay.

The following were the average values of the coefficient of friction for the different soils used in the present tests:

Clay per cent	<u>Average Values of the Coefficient of Friction</u>	
	Static	Kinetic
5.7	0.24	0.26

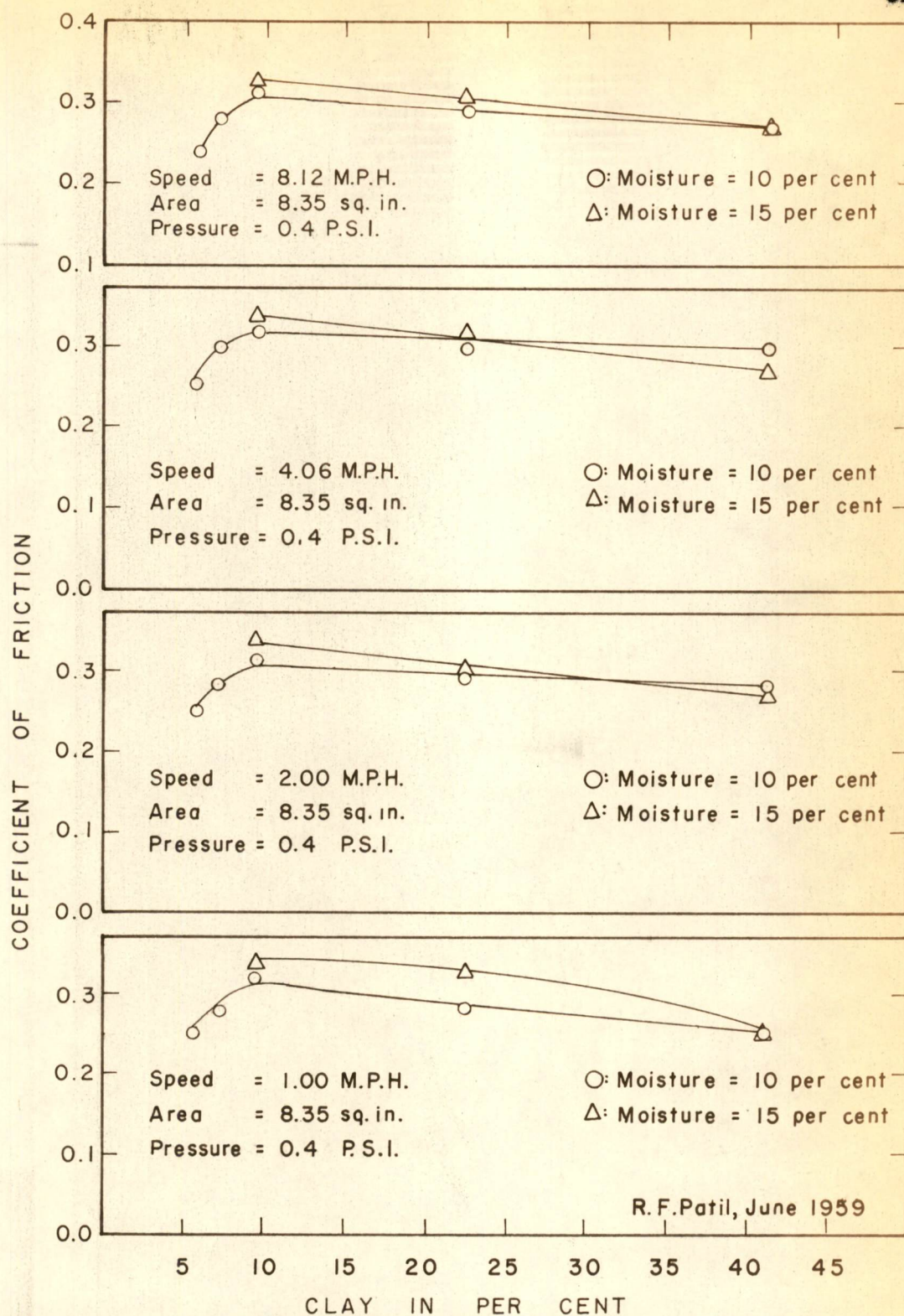


Figure 37. Coefficient of friction vs. clay content.

Clay per cent	<u>Average Values of the Coefficient of Friction</u>	
	Static	Kinetic
7.3	0.25	0.30
9.6	0.28	0.33
22.4	0.28	0.34
41.2	0.19	0.31

From the above values for the coefficient of friction it is seen that the static coefficient of friction was always less than the kinetic coefficient of friction. This behaviour of Teflon agreed with its property mentioned by the E.I. du Pont de Nemours and Company (6, and 7).

Since the static friction is less than the kinetic friction in the case of soils, it can be safely assumed that the power required to start the soil movement against the ground engaging surface of an implement covered with Teflon would be less than the power required to continue relative motion.

The following values were found by Nichols (10) for the coefficient of friction of metal against soils with different percentages of colloidal content:

Clay Content in per cent	Coefficient of Friction
0	0.26
8	0.36
16	0.40
24	0.47
32	0.51

These values were for the 'B' phase friction whereas the average values for Teflon found in the present tests included the values for the 'C' phase also, which were higher than for 'B' phase. Comparing the figures obtained for Teflon in the present tests with those obtained by Nichols given above, it will be found that the coefficient of friction for Teflon is generally much less than the coefficient of friction for metal.

Figure 38 shows two curves for the coefficient of friction against clay, one for soil/metal friction drawn from the figures obtained by Nichols, and the other for soil/Teflon friction drawn from the figures obtained in the present tests. The curve for soil/metal friction shows that there was continuous increase in the coefficient of friction, as the percentage of clay increased. But the curve for soil/Teflon friction shows that the coefficient of friction increased with the percentage of clay only for smaller values. For higher percentages of clay the coefficient of friction shows a tendency to decrease as the clay content increased. This perhaps explains why plastic soils with high percentage of clay do not stick to the Teflon covered moldboard plow.

The curves also indicate that the coefficient of friction for soil/Teflon friction is less than the coefficient of friction for soil/metal friction. The minimum difference happens to be at about 10 per cent of clay, the coefficient of friction for soil/Teflon friction being less than soil/metal friction by 0.03. For the higher clay percentages this difference goes on increasing up to 0.18 for 32 per cent of clay.

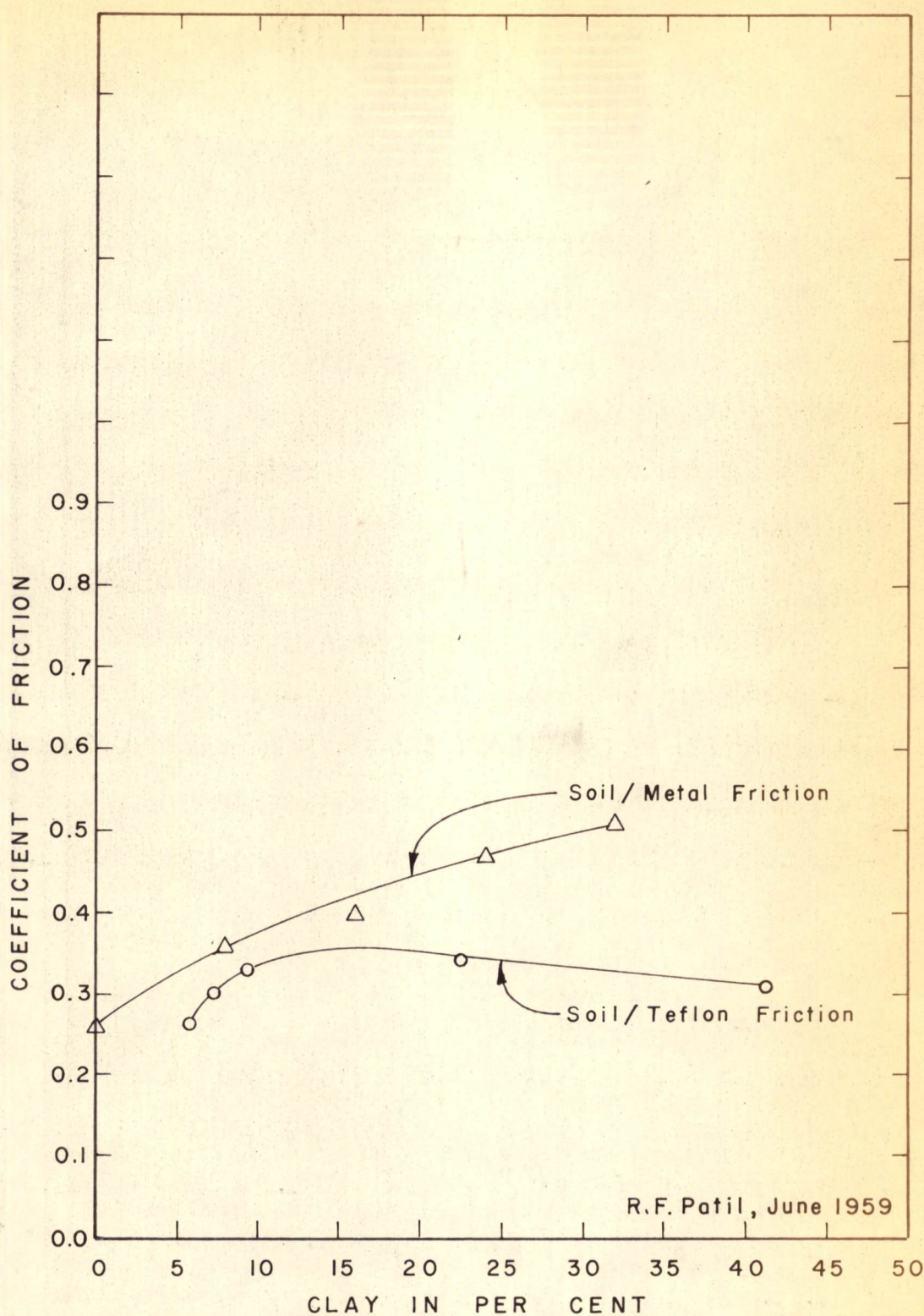


Figure 38. Coefficient of friction for soil/metal and soil/Teflon.

CHAPTER VI

CONCLUSIONS

Effect of Pressure on Friction

It was found, in general, that the coefficient of friction was either independent of the unit pressure or decreased as the pressure increased. For soils with 5.7 and 9.6 per cent clay content the results indicate that pressure and coefficient of friction are independent of each other. For soils with 7.3, 22.4, and 41.2 per cent of clay the results indicate that the coefficient of friction decreased as the pressure increased; although at low moisture content, it can be assumed they are independent. The decrease in the value of the coefficient of friction for higher pressures appears to be due to the lubrication effect produced, as a result of a part of the moisture being squeezed out under these high pressures.

Effect of Moisture on Friction

In the case of the soil with 5.7 per cent of clay, the coefficient of friction decreased as the moisture content increased. This is because the soil being more sandy in nature, the moisture readily percolated and produced a lubrication effect on the Teflon surface. For the soil with 7.3 per cent of clay, the coefficient of friction first decreased as the moisture content increased up to a particular limit and thereafter, it increased as the moisture content increased. This is due to the friction being in the 'B'

phase for the lower contents of moisture and entering the 'C' phase for higher moisture contents.

For the soil with 9.6 per cent of clay, the coefficient of friction was found to be independent of moisture content, for lower percentages of moisture. For higher percentages of moisture, the coefficient of friction increased as the moisture content increased. This indicates that the friction was in the 'B' phase for lower moisture contents and entered the 'C' phase for higher moisture contents.

In the case of the soil with 22.4 per cent of clay, the coefficient of friction was found to increase as the moisture content increased. This soil was worked with moisture contents of 10 per cent and above. It therefore seems that the friction, in the case of this soil, entered the 'C' phase at once, owing to the high moisture content.

For the soil with 41.2 per cent of clay, the coefficient of friction was either independent or decreased slightly, as the moisture content increased up to 25 per cent moisture. For higher moisture contents, the coefficient of friction generally increased as the moisture content increased. This behaviour also shows that the friction was in the 'B' phase for lower moisture contents and entered the 'C' phase for higher moisture contents.

Effect of Speed on Friction

It was generally found that in the case of all soils, for lower moisture contents, the coefficient of friction was inde-

pendent of the speed. It varied with speed for higher moisture contents in the case of soils with 7.3, 22.4, and 41.2 per cent of clay.

Effect of Area of Contact on Friction

It was found that the area of contact had some effect on the coefficient of friction. The coefficient of friction generally increased directly with the area of contact even though slightly.

Effect of Soil Clay Content on Friction

For all clay contents, the static friction was found to be less than the kinetic friction. The kinetic friction increased as the clay content increased from 5.7 per cent of clay to approximately 10 percent and thereafter it decreased slightly as the clay content increased up to 41.2 per cent of clay. The coefficient of friction for soil/Teflon friction was found to be less by 0.03 than the coefficient of friction for soil/metal friction, when the clay content was 10 per cent. The difference between the two coefficients increased as the clay content increased from 10 per cent to 32 per cent. The coefficient of friction for soil/Teflon friction was less by 0.18 when the clay was 32 per cent. As the friction of Teflon against soil is less than the friction of metal against soil, it can be assumed that the power required for working the implements covered with Teflon will be less as compared with the implements made of metal.

It therefore appears that Teflon can be used with advantage in agricultural implements such as moldboard plows, disk

plows and disk harrows to reduce the power requirement for primary and secondary tillage. The only drawback in the wide use of Teflon in tillage machinery is its present high cost; however cheaper varieties of Teflon can be adapted for use in agricultural machinery; such as Kelon - C, manufactured from the scraps of Teflon, which costs less and has greater wear resistance than uncompounded Teflon.

CHAPTER VII

RECOMMENDATIONS AND SUGGESTIONS FOR FUTURE STUDY

Owing to the property of low coefficient of friction, it seems that Teflon can be used in the construction of tillage tools not only for improving their scouring but also for reducing their power requirements. Tests have been conducted at Hawaii (1,20) primarily to study the scouring properties of the Teflon covered moldboard plows, while working in plastic soils. It appears that no definite studies have been made with regard to the reduction in the power requirements of the tillage tools covered with Teflon. It is therefore recommended that field studies should be undertaken with some of the tillage tools covered with Teflon, to find how much power can be reduced by using Teflon covered tillage tools as compared with metal tools.

Since the compounded Teflon has better properties than uncompounded Teflon, it is suggested that the field tests should include studies to find which additive is most suitable for working with soils and also to find whether the compounded Teflon is cheaper and more lasting than other varieties.

Teflon is available in the form of tape, sheets, rods, tubes, coated fibres, coated wire, wire enamels, molded parts etc. Studies should therefore be conducted to find which form of Teflon is more convenient and economical to use. Whether, for instance, painting of metal surfaces is more convenient and economical than to cover the metal surfaces with Teflon tape or sheeting or molded parts to fit the surfaces of metal parts of tillage tools.

CHAPTER VIII

SUMMARY

The bulk of the energy absorbed in tillage is used in soil/ implement friction and tillage implements are materially affected by soil friction. If the tillage operations on the farms have to be more economical, power must be reduced. If the power has to be reduced without affecting the quality of tillage, soil/implement friction which absorbs the bulk of the energy should be reduced. In order to reduce soil/implement friction, the surface of the implement should be of such material that it has a lower coefficient of friction than the conventional metals like steel.

"Teflon", tetrafluoroethylene resins, developed by E.I. du Pont de Nemours and Company, Wilmington, Delaware, are found to possess the lowest coefficient of friction of all known solids. These resins are also found to have non-adhesive properties and are not affected by moisture. They are chemically inert and corrosion resistant. These resins can therefore be used with advantage in the construction of tillage tools to reduce power and hence to reduce the cost on tillage.

The present study was made to find the friction characteristics of Teflon against soil. Five different soils containing 5.7, 7.3, 9.6, 22.4 and 41.2 per cent of clay were used in the tests. The soils were worked with different percentages of moisture. For each stage of moisture content, four different pressures; and

for each pressure, four different speeds were used.

The method employed in conducting the tests was the same as used by Richter (16) and Reddy (15). A Teflon covered disk, forty-eight inches in diameter, was made to rotate at different speeds, by an electrically powered tapping machine, through a series of V-belts and pulleys. Open ended cylindrical cans were used to hold the soil. The soil was packed in these cans and kept on the Teflon disk, taking care to see that the edges of the can did not come in contact with the Teflon surface. A string was carried to a sensitive detectogram scale from a hook on the lowermost position of the can. When the Teflon disk rotated, the soil can was held stationary by the string and the force of friction was read from the detectogram scale.

Generally the coefficient of friction remained independent of pressure for lower clay contents and lower moisture contents; but it decreased with increase in pressure for higher clay contents, when the moisture increased. For lower moisture contents, the coefficient of friction was either independent of moisture or decreased as moisture increased; for higher moisture contents, it increased as the moisture content increased. When the moisture contents were low, the coefficient of friction remained independent of the speed but it varied with the speed for higher moisture contents. The coefficient of friction generally increased as the area of contact increased and varied with the clay content of the soil.

As a result of the test it was found that the static coefficient of friction was less than the kinetic coefficient of friction. It was also found that the coefficient of friction of Teflon against soil was less than the coefficient of friction of metal against soil. There is, therefore, a possibility of reducing the power required to work agricultural machinery such as tillage tools, by providing the working parts with a cover of Teflon.

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APPENDIX A

TABLE I

OBSERVATIONS FOR DETERMINING THE SPEED OF TEFLON DISK AT
18 INCHES RADIUS

DATE OF TEST: January 28, 1959

POSITION OF GEAR ON TAPPING MACHINE: Back

Cone Pulley on Tapping Machine	Pulley on Jack Shaft	Motor Speed	Number of Revolutions	Time Taken		Revolutions per Minute	Speed at 18" Radius	
				Min.	Sec.		ft./ min.	mph
No. 1	No. 1	Low	5	1	14	4.06	38.2	0.43
No. 1	No. 1	High	10	1	14	8.12	76.4	0.87
No. 1	No. 2	Low	100	1	44	57.7	543.0	6.17
No. 1	No. 2	High	100	-	52	115.4	1086.0	12.34
No. 2	No. 1	Low	5	1	52	2.68	25.25	0.29
No. 2	No. 1	High	10	1	52	5.36	50.50	0.57
No. 2	No. 2	Low	50	1	19	38.0	357.5	4.06
No. 2	No. 2	High	100	1	19	76.0	715.0	8.12
No. 3	No. 1	Low	5	4	55	1.018	9.58	0.11
No. 3	No. 1	High	10	4	55	2.036	19.16	0.22
No. 3	No. 2	Low	10	-	41	14.65	138.0	1.57
No. 3	No. 2	High	20	-	41	29.3	276.0	3.14
No. 4	No. 1	Low	5	7	48	0.64	6.04	0.07
No. 4	No. 1	High	10	7	48	1.28	12.08	0.14
No. 4	No. 2	Low	10	1	04	9.23	87.0	1.00
No. 4	No. 2	High	20	1	04	18.46	174.0	2.00

APPENDIX B

TABLE II

READINGS FOR TESTS ON TEFLON AGAINST 5.7 PER CENT CLAY SOIL

DATE OF TEST: March 17, 1959
 SIZE OF CAN USED: Diameter 3.25 inches
 Height 4.5 inches
 Area 8.35 Sq. inches
 TEMPERATURE: 76° F

Moisture in per cent	Weight of Test Can & Soil in lbs.	Additional Weight in lbs.	Total Weight (R) in lbs.	Pressure in psi.	Speed in mph.	Friction Force (F) in lbs.	Coefficient of Friction F/R
2	1.17	0.66	1.83	0.22	-	0.48	0.26
	1.17	1.66	2.83	0.34	-	0.68	0.24
	1.17	2.66	3.83	0.46	-	0.88	0.23
	1.17	3.66	4.83	0.58	-	1.02	0.21
2	1.17	0.66	1.83	0.22	1.00	0.54	0.30
	1.17	1.66	2.83	0.34	1.00	0.86	0.30
	1.17	2.66	3.83	0.46	1.00	1.06	0.28
	1.17	3.66	4.83	0.58	1.00	1.32	0.27
2	1.17	0.66	1.83	0.22	2.00	0.56	0.31
	1.17	1.66	2.83	0.34	2.00	0.84	0.30
	1.17	2.66	3.83	0.46	2.00	1.12	0.29
	1.17	3.66	4.83	0.58	2.00	1.38	0.29
4	1.19	0.66	1.85	0.22	-	0.46	0.25
	1.19	1.66	2.85	0.34	-	0.67	0.24
	1.19	2.66	3.85	0.46	-	0.92	0.24
	1.19	3.66	4.85	0.58	-	1.10	0.23
4	1.19	0.66	1.85	0.22	1.00	0.52	0.28
	1.19	1.66	2.85	0.34	1.00	0.78	0.27
	1.19	2.66	3.85	0.46	1.00	1.05	0.27
	1.19	3.66	4.85	0.58	1.00	1.34	0.28
4	1.19	0.66	1.85	0.22	2.00	0.52	0.28
	1.19	1.66	2.85	0.34	2.00	0.82	0.29
	1.19	2.66	3.85	0.46	2.00	1.10	0.28
	1.19	3.66	4.85	0.58	2.00	1.32	0.27
4	1.19	0.66	1.85	0.22	4.06	0.52	0.28
	1.19	1.66	2.85	0.34	4.06	0.82	0.29

TABLE II (continued)

READINGS FOR TESTS ON TEFLON AGAINST 5.7 PER CENT CLAY SOIL

Moisture in per cent	Weight of Test Can & Soil in lbs.	Additional Weight in lbs.	Total Weight (R) in lbs.	Pressure in psi.	Speed in mph.	Friction Force (F) in lbs.	Coefficient of Friction F/R
4	1.19	2.66	3.85	0.46	4.06	1.08	0.28
	1.19	3.66	4.85	0.58	4.06	1.34	0.28
4	1.19	0.66	1.85	0.22	8.12	0.48	0.26
	1.19	1.66	2.85	0.34	8.12	0.74	0.26
	1.19	2.66	3.85	0.46	8.12	0.98	0.25
	1.19	3.66	4.85	0.58	8.12	1.26	0.26
6	1.21	0.66	1.87	0.22	-	0.52	0.28
	1.21	1.66	2.87	0.34	-	0.68	0.24
	1.21	2.66	3.87	0.46	-	0.94	0.24
	1.21	3.66	4.87	0.58	-	1.08	0.22
6	1.21	0.66	1.87	0.22	1.00	0.52	0.28
	1.21	1.66	2.87	0.34	1.00	0.78	0.27
	1.21	2.66	3.87	0.46	1.00	1.02	0.26
	1.21	3.66	4.87	0.58	1.00	1.26	0.26
6	1.21	0.66	1.87	0.22	2.00	0.50	0.27
	1.21	1.66	2.87	0.34	2.00	0.76	0.26
	1.21	2.66	3.87	0.46	2.00	0.98	0.25
	1.21	3.66	4.87	0.58	2.00	1.28	0.26
6	1.21	0.66	1.87	0.22	4.06	0.52	0.28
	1.21	1.66	2.87	0.34	4.06	0.78	0.27
	1.21	2.66	3.87	0.46	4.06	1.04	0.27
	1.21	3.66	4.87	0.58	4.06	1.34	0.28
6	1.21	0.66	1.87	0.22	8.12	0.54	0.29
	1.21	1.66	2.87	0.34	8.12	0.78	0.27
	1.21	2.66	3.87	0.46	8.12	1.02	0.26
	1.21	3.66	4.87	0.58	8.12	1.28	0.26
8	1.23	0.66	1.89	0.23	-	0.50	0.26
	1.23	1.66	2.89	0.35	-	0.68	0.24
	1.23	2.66	3.89	0.47	-	0.88	0.23
	1.23	3.66	4.89	0.59	-	1.06	0.22
8	1.23	0.66	1.89	0.23	1.00	0.52	0.28
8	1.23	1.66	2.89	0.35	1.00	0.78	0.27

TABLE II (continued)

READINGS FOR TESTS ON TEFLON AGAINST 5.7 PER CENT CLAY SOIL

Moisture in per cent	Weight of Test Can & Soil in lbs.	Additional Weight in lbs.	Total Weight (R) in lbs.	Pressure in psi.	Speed in mph.	Friction Force (F) in lbs.	Coefficient of Friction F/R
8	1.23	2.66	3.89	0.47	1.00	0.98	0.25
	1.23	3.66	4.89	0.59	1.00	1.22	0.25
8	1.23	0.66	1.89	0.23	2.00	0.48	0.25
	1.23	1.66	2.89	0.35	2.00	0.74	0.26
	1.23	2.66	3.89	0.47	2.00	0.94	0.24
	1.23	3.66	4.89	0.59	2.00	1.18	0.24
8	1.23	0.66	1.89	0.23	4.06	0.46	0.24
	1.23	1.66	2.89	0.35	4.06	0.68	0.24
	1.23	2.66	3.89	0.47	4.06	0.88	0.23
	1.23	3.66	4.89	0.59	4.06	1.14	0.23
8	1.23	0.66	1.89	0.23	8.12	0.44	0.23
	1.23	1.66	2.89	0.35	8.12	0.68	0.24
	1.23	2.66	3.89	0.47	8.12	0.88	0.23
	1.23	3.66	4.89	0.59	8.12	1.12	0.23
10	1.25	0.66	1.91	0.23	-	0.48	0.25
	1.25	1.66	2.91	0.35	-	0.80	0.28
	1.25	2.66	3.91	0.47	-	1.08	0.28
	1.25	3.66	4.91	0.59	-	1.30	0.27
10	1.25	0.66	1.91	0.23	1.00	0.45	0.24
	1.25	1.66	2.91	0.35	1.00	0.74	0.25
	1.25	2.66	3.91	0.47	1.00	0.98	0.25
	1.25	3.66	4.91	0.59	1.00	1.25	0.25
10	1.25	0.66	1.91	0.23	2.00	0.50	0.26
	1.25	1.66	2.91	0.35	2.00	0.74	0.25
	1.25	2.66	3.91	0.47	2.00	0.96	0.24
	1.25	3.66	4.91	0.59	2.00	1.15	0.23
10	1.25	0.66	1.91	0.23	4.06	0.50	0.26
	1.25	1.66	2.91	0.35	4.06	0.72	0.25
	1.25	2.66	3.91	0.47	4.06	0.94	0.24
	1.25	3.66	4.91	0.59	4.06	1.34	0.27
10	1.25	0.66	1.91	0.23	8.12	0.46	0.24
	1.25	1.66	2.91	0.35	8.12	0.70	0.24
	1.25	2.66	3.91	0.47	8.12	0.96	0.24
	1.25	3.66	4.91	0.59	8.12	1.18	0.24

TABLE III

READINGS FOR TESTS ON TEFLON AGAINST 7.3 PER CENT CLAY SOIL

DATE OF TEST: March 25, 1959

SIZE OF CAN USED: Diameter 3.25 inches

Height 4.5 inches

Area 8.35 Sq. inches

TEMPERATURE: 80° F.

Moisture in per cent	Weight of Test Can & Soil in lbs.	Additional Weight in lbs.	Total Weight (R) in lbs.	Pressure in psi.	Speed in mph.	Friction Force (F) in lbs.	Coefficient of Friction F/R
4	1.19	0.66	1.85	0.22	-	0.54	0.29
	1.19	1.66	2.85	0.34	-	0.74	0.26
	1.19	2.66	3.85	0.46	-	0.90	0.23
	1.19	3.66	4.85	0.58	-	1.15	0.24
4	1.19	0.66	1.85	0.22	1.00	0.62	0.34
	1.19	1.66	2.85	0.34	1.00	0.92	0.32
	1.19	2.66	3.85	0.46	1.00	1.18	0.31
	1.19	3.66	4.85	0.58	1.00	1.50	0.31
4	1.19	0.66	1.85	0.22	2.00	0.58	0.31
	1.19	1.66	2.85	0.34	2.00	0.88	0.31
	1.19	2.66	3.85	0.46	2.00	1.24	0.32
	1.19	3.66	4.85	0.58	2.00	1.52	0.31
4	1.19	0.66	1.85	0.22	4.06	0.58	0.31
	1.19	1.66	2.85	0.34	4.06	0.88	0.31
	1.19	2.66	3.85	0.46	4.06	1.14	0.30
	1.19	3.66	4.85	0.58	4.06	1.48	0.31
4	1.19	0.66	1.85	0.22	8.12	0.56	0.30
	1.19	1.66	2.85	0.34	8.12	0.84	0.30
	1.19	2.66	3.85	0.46	8.12	1.14	0.30
	1.19	3.66	4.85	0.58	8.12	1.40	0.29
6	1.21	0.66	1.87	0.22	-	0.50	0.27
	1.21	1.66	2.87	0.34	-	0.68	0.24
	1.21	2.66	3.87	0.46	-	0.88	0.23
	1.21	3.66	4.87	0.58	-	1.07	0.22
6	1.21	0.66	1.87	0.22	1.00	0.58	0.31
	1.21	1.66	2.87	0.34	1.00	0.88	0.31

TABLE III(continued)

READINGS FOR TESTS ON TEFLON AGAINST 7.3 PER CENT CLAY SOIL

Moisture in per cent	Weight of Test Can & Soil in lbs.	Additional Weight in lbs.	Total Weight (R) in lbs.	Pressure in psi.	Speed in mph.	Friction Force (F) in lbs.	Coefficient of Friction F/R
6	1.21	2.66	3.87	0.46	1.00	1.16	0.30
	1.21	3.66	4.87	0.58	1.00	1.43	0.29
6	1.21	0.66	1.87	0.22	2.00	0.57	0.30
	1.21	1.66	2.87	0.34	2.00	0.86	0.30
	1.21	2.66	3.87	0.46	2.00	1.16	0.30
	1.21	3.66	4.87	0.58	2.00	1.44	0.30
6	1.21	0.66	1.87	0.22	4.06	0.62	0.33
	1.21	1.66	2.87	0.34	4.06	0.90	0.31
	1.21	2.66	3.87	0.46	4.06	1.18	0.30
	1.21	3.66	4.87	0.58	4.06	1.45	0.30
6	1.21	0.66	1.87	0.22	8.12	0.60	0.32
	1.21	1.66	2.87	0.34	8.12	0.90	0.31
	1.21	2.66	3.87	0.46	8.12	1.20	0.31
	1.21	3.66	4.87	0.58	8.12	1.48	0.30
8	1.23	0.66	1.89	0.23	-	0.40	0.21
	1.23	1.66	2.89	0.35	-	0.62	0.21
	1.23	2.66	3.89	0.47	-	0.82	0.21
	1.23	3.66	4.89	0.59	-	1.20	0.25
8	1.23	0.66	1.89	0.23	1.00	0.55	0.29
	1.23	1.66	2.89	0.35	1.00	0.83	0.29
	1.23	2.66	3.89	0.47	1.00	1.10	0.28
	1.23	3.66	4.89	0.59	1.00	1.30	0.27
8	1.23	0.66	1.89	0.23	2.00	0.54	0.29
	1.23	1.66	2.89	0.35	2.00	0.78	0.27
	1.23	2.66	3.89	0.47	2.00	1.00	0.26
	1.23	3.66	4.89	0.59	2.00	1.32	0.27
8	1.23	0.66	1.89	0.23	4.06	0.54	0.29
	1.23	1.66	2.89	0.35	4.06	0.84	0.29
	1.23	2.66	3.89	0.47	4.06	1.06	0.27
	1.23	3.66	4.89	0.59	4.06	1.30	0.27
8	1.23	0.66	1.89	0.23	8.12	0.56	0.30
	1.23	1.66	2.89	0.35	8.12	0.84	0.29
	1.23	2.66	3.89	0.47	8.12	1.10	0.28
	1.23	3.66	4.89	0.59	8.12	1.40	0.28

TABLE III (continued)

READINGS FOR TESTS ON TEFLON AGAINST 7.3 PER CENT CLAY SOIL

Moisture in per cent	Weight of Test Can & Soil in lbs.	Additional Weight in lbs.	Total Weight (R) in lbs.	Pressure in psi.	Speed in mph.	Friction Force (F) in lbs.	Coefficient of Friction F/R
8	1.23	3.66	4.89	0.59	8.12	1.34	0.27
10	1.25	0.66	1.91	0.23	-	0.48	0.25
	1.25	1.66	2.91	0.35	-	0.69	0.24
	1.25	2.66	3.91	0.47	-	0.95	0.24
	1.25	3.66	4.91	0.59	-	1.22	0.25
10	1.25	0.66	1.91	0.23	1.00	0.55	0.29
	1.25	1.66	2.91	0.35	1.00	0.82	0.28
	1.25	2.66	3.91	0.47	1.00	1.08	0.28
	1.25	3.66	4.91	0.59	1.00	1.34	0.27
10	1.25	0.66	1.91	0.23	2.00	0.54	0.28
	1.25	1.66	2.91	0.35	2.00	0.82	0.28
	1.25	2.66	3.91	0.47	2.00	1.09	0.28
	1.25	3.66	4.91	0.59	2.00	1.35	0.28
10	1.25	0.66	1.91	0.23	4.06	0.60	0.31
	1.25	1.66	2.91	0.35	4.06	0.88	0.30
	1.25	2.66	3.91	0.47	4.06	1.14	0.29
	1.25	3.66	4.91	0.59	4.06	1.43	0.29
10	1.25	0.66	1.91	0.23	8.12	0.54	0.28
	1.25	1.66	2.91	0.35	8.12	0.82	0.28
	1.25	2.66	3.91	0.47	8.12	1.10	0.28
	1.25	3.66	4.91	0.59	8.12	1.40	0.28
12	1.27	0.66	1.93	0.23	-	0.58	0.30
	1.27	1.66	2.93	0.35	-	0.82	0.28
	1.27	2.66	3.93	0.47	-	1.08	0.28
	1.27	3.66	4.93	0.59	-	1.28	0.26
12	1.27	0.66	1.93	0.23	1.00	0.66	0.34
	1.27	1.66	2.93	0.35	1.00	0.92	0.31
	1.27	2.66	3.93	0.47	1.00	1.18	0.30
	1.27	3.66	4.93	0.59	1.00	1.44	0.29
12	1.27	0.66	1.93	0.23	2.00	0.55	0.28
	1.27	1.66	2.93	0.35	2.00	0.85	0.29
	1.27	2.66	3.93	0.47	2.00	1.15	0.29
	1.27	3.66	4.93	0.59	2.00	1.46	0.30

TABLE III(continued)

READINGS FOR TESTS ON TEFLON AGAINST 7.3 PER CENT CLAY SOIL

Moisture in per cent	Weight of Test Can & Soil in lbs.	Additional Weights in lbs.	Total Weight (R) in lbs.	Pressure in psi.	Speed in mph.	Friction Force (F) in lbs.	Coefficient of Friction F/R
12	1.27	0.66	1.93	0.23	4.06	0.55	0.28
	1.27	1.66	2.93	0.35	4.06	0.86	0.29
	1.27	2.66	3.93	0.47	4.06	1.13	0.29
	1.27	3.66	4.93	0.59	4.06	1.40	0.28
12	1.27	0.66	1.93	0.23	8.12	0.54	0.28
	1.27	1.66	2.93	0.35	8.12	0.84	0.29
	1.27	2.66	3.93	0.47	8.12	1.12	0.28
	1.27	3.66	4.93	0.59	8.12	1.40	0.28
14	1.29	0.66	1.95	0.23	-	0.58	0.30
	1.29	1.66	2.95	0.35	-	0.85	0.29
	1.29	2.66	3.95	0.47	-	1.15	0.29
	1.29	3.66	4.95	0.59	-	1.30	0.26
14	1.29	0.66	1.95	0.23	1.00	0.68	0.35
	1.29	1.66	2.95	0.35	1.00	1.04	0.35
	1.29	2.66	3.95	0.47	1.00	1.22	0.31
	1.29	3.66	4.95	0.59	1.00	1.58	0.32
14	1.29	0.66	1.95	0.23	2.00	0.70	0.36
	1.29	1.66	2.95	0.35	2.00	0.98	0.33
	1.29	2.66	3.95	0.47	2.00	1.24	0.31
	1.29	3.66	4.95	0.59	2.00	1.45	0.29
14	1.29	0.66	1.95	0.23	4.06	0.75	0.38
	1.29	1.66	2.95	0.35	4.06	1.00	0.34
	1.29	2.66	3.95	0.47	4.06	1.30	0.33
	1.29	3.66	4.95	0.59	4.06	1.58	0.32
14	1.29	0.66	1.95	0.23	8.12	0.78	0.40
	1.29	1.66	2.95	0.35	8.12	1.02	0.35
	1.29	2.66	3.95	0.47	8.12	1.35	0.34
	1.29	3.66	4.95	0.59	8.12	1.70	0.34

TABLE IV

READINGS FOR TESTS ON TEFLON AGAINST 9.6 PER CENT CLAY SOIL

DATE OF TEST: April 1, 1959
 SIZE OF CAN USED: Diameter 3.25 inches
 Height 4.5 inches
 Area 8.35 Sq. inches
 TEMPERATURE: 78° F.

Moisture in per cent	Weight of Test Can & Soil in lbs.	Additional Weight in lbs.	Total Weight (R) in lbs.	Pressure in psi.	Speed in mph.	Friction Force (F) in lbs.	Coefficient of Friction F/R
4	1.19	0.66	1.85	0.22	-	0.62	0.34
	1.19	1.66	2.85	0.34	-	0.80	0.28
	1.19	2.66	3.85	0.46	-	1.00	0.26
	1.19	3.66	4.85	0.58	-	1.26	0.26
4	1.19	0.66	1.85	0.22	1.00	0.65	0.35
	1.19	1.66	2.85	0.34	1.00	0.94	0.33
	1.19	2.66	3.85	0.46	1.00	1.22	0.32
	1.19	3.66	4.85	0.58	1.00	1.49	0.31
4	1.19	0.66	1.85	0.22	2.00	0.56	0.30
	1.19	1.66	2.85	0.34	2.00	0.86	0.30
	1.19	2.66	3.85	0.46	2.00	1.16	0.30
	1.19	3.66	4.85	0.58	2.00	1.48	0.31
8	1.23	0.66	1.89	0.23	-	0.52	0.28
	1.23	1.66	2.89	0.35	-	0.80	0.28
	1.23	2.66	3.89	0.47	-	1.04	0.27
	1.23	3.66	4.89	0.59	-	1.32	0.27
8	1.23	0.66	1.89	0.23	1.00	0.62	0.33
	1.23	1.66	2.89	0.35	1.00	0.95	0.33
	1.23	2.66	3.89	0.47	1.00	1.24	0.32
	1.23	3.66	4.89	0.59	1.00	1.52	0.31
8	1.23	0.66	1.89	0.23	2.00	0.63	0.33
	1.23	1.66	2.89	0.35	2.00	0.95	0.33
	1.23	2.66	3.89	0.47	2.00	1.25	0.32
	1.23	3.66	4.89	0.59	2.00	1.50	0.31
8	1.23	0.66	1.89	0.23	4.06	0.62	0.33
	1.23	1.66	2.89	0.35	4.06	0.94	0.32

TABLE IV (continued)

READINGS FOR TESTS ON TEFLON AGAINST 9.6 PER CENT CLAY SOIL

Moisture in per cent	Weight of Test Can & Soil in lbs.	Additional Weight in lbs.	Total Weight (R) in lbs.	Pressure in psi.	Speed in mph.	Friction Force (F) in lbs.	Coefficient of Friction F/R
8	1.23	2.66	3.89	0.47	4.06	1.28	0.33
	1.23	3.66	4.89	0.59	4.06	1.52	0.31
8	1.23	0.66	1.89	0.23	8.12	0.62	0.33
	1.23	1.66	2.89	0.35	8.12	0.94	0.32
	1.23	2.66	3.89	0.47	8.12	1.26	0.32
	1.23	3.66	4.89	0.59	8.12	1.54	0.32
12	1.27	0.66	1.93	0.23	-	0.53	0.27
	1.27	1.66	2.93	0.35	-	0.78	0.27
	1.27	2.66	3.93	0.47	-	1.06	0.27
	1.27	3.66	4.93	0.59	-	1.28	0.26
12	1.27	0.66	1.93	0.23	1.00	0.60	0.31
	1.27	1.66	2.93	0.35	1.00	0.90	0.31
	1.27	2.66	3.93	0.47	1.00	1.20	0.31
	1.27	3.66	4.93	0.59	1.00	1.45	0.30
12	1.27	0.66	1.93	0.23	2.00	0.60	0.31
	1.27	1.66	2.93	0.35	2.00	0.88	0.30
	1.27	2.66	3.93	0.47	2.00	1.18	0.30
	1.27	3.66	4.93	0.59	2.00	1.45	0.30
12	1.27	0.66	1.93	0.23	4.06	0.65	0.34
	1.27	1.66	2.93	0.35	4.06	0.96	0.33
	1.27	2.66	3.93	0.47	4.06	1.24	0.32
	1.27	3.66	4.93	0.59	4.06	1.54	0.31
12	1.27	0.66	1.93	0.23	8.12	0.60	0.31
	1.27	1.66	2.93	0.35	8.12	0.92	0.31
	1.27	2.66	3.93	0.47	8.12	1.22	0.31
	1.27	3.66	4.93	0.59	8.12	1.54	0.31
16	1.31	0.66	1.97	0.24	-	0.56	0.28
	1.31	1.66	2.97	0.36	-	0.84	0.28
	1.31	2.66	3.97	0.48	-	1.15	0.29
	1.31	3.66	4.97	0.60	-	1.41	0.28
16	1.31	0.66	1.97	0.24	1.00	0.72	0.37
	1.31	1.66	2.97	0.36	1.00	1.04	0.35
	1.31	2.66	3.97	0.48	1.00	1.36	0.34
	1.31	3.66	4.97	0.60	1.00	1.74	0.35

TABLE IV (continued)

READINGS FOR TESTS ON TEFLON AGAINST 9.6 PER CENT CLAY SOIL

Moisture in per cent	Weight of Test Can & Soil in lbs.	Additional Weight in lbs.	Total Weight (R) in lbs.	Pressure in psi.	Speed in mph.	Friction Force (F) in lbs.	Coefficient of Friction F/R
16	1.31	0.66	1.97	0.24	2.00	0.74	0.38
	1.31	1.66	2.97	0.36	2.00	1.06	0.36
	1.31	2.66	3.97	0.48	2.00	1.42	0.36
	1.31	3.66	4.97	0.60	2.00	1.75	0.35
16	1.31	0.66	1.97	0.24	4.06	0.74	0.38
	1.31	1.66	2.97	0.36	4.06	1.08	0.36
	1.31	2.66	3.97	0.48	4.06	1.42	0.36
	1.31	3.66	4.97	0.60	4.06	1.75	0.35
16	1.31	0.66	1.97	0.24	8.12	0.67	0.34
	1.31	1.66	2.97	0.36	8.12	1.02	0.34
	1.31	2.66	3.97	0.48	8.12	1.38	0.35
	1.31	3.66	4.97	0.60	8.12	1.70	0.34

TABLE V

READINGS FOR TESTS ON TEFLON AGAINST 22.4 PER CENT CLAY SOIL

DATE OF TEST: April 27, 1959
 SIZE OF CAN USED: Diameter 3.25 inches
 Height 4.5 inches
 Area 8.35 Sq. inches
 TEMPERATURE: 84° F.

Moisture in per cent	Weight of Test Can & Soil in lbs.	Additional Weight in lbs.	Total Weight (R) in lbs.	Pressure in psi.	Speed in mph.	Friction Force (F) in lbs.	Coefficient of Friction F/R
10	1.25	0.64	1.89	0.23	-	0.45	0.24
	1.25	1.64	2.89	0.35	-	0.67	0.23
	1.25	2.64	3.89	0.47	-	0.86	0.22
	1.25	3.64	4.89	0.58	-	1.15	0.24
10	1.25	0.64	1.89	0.23	1.00	0.54	0.29
	1.25	1.64	2.89	0.35	1.00	0.82	0.28
	1.25	2.64	3.89	0.47	1.00	1.06	0.27
	1.25	3.64	4.89	0.58	1.00	1.37	0.28
10	1.25	0.64	1.89	0.23	2.00	0.54	0.29
	1.25	1.64	2.89	0.35	2.00	0.84	0.29
	1.25	2.17	3.42	0.41	2.00	0.98	0.29
	1.25	3.17	4.42	0.53	2.00	1.25	0.28
10	1.25	0.64	1.89	0.23	4.06	0.54	0.29
	1.25	1.64	2.89	0.35	4.06	0.72	0.25
	1.25	2.17	3.42	0.41	4.06	0.94	0.28
	1.25	3.17	4.42	0.53	4.06	1.12	0.25
10	1.25	0.64	1.89	0.23	8.12	0.54	0.29
	1.25	1.17	2.42	0.35	8.12	0.68	0.28
	1.25	2.17	3.42	0.41	8.12	0.94	0.28
	1.25	3.17	4.42	0.53	8.12	1.20	0.27
12	1.27	0.64	1.91	0.23	-	0.53	0.28
	1.27	1.64	2.91	0.35	-	0.75	0.26
	1.27	2.64	3.91	0.47	-	1.00	0.26
	1.27	3.64	4.91	0.59	-	1.28	0.26
12	1.27	0.64	1.91	0.23	1.00	0.64	0.34
	1.27	1.17	2.44	0.29	1.00	0.82	0.34
	1.27	2.17	3.44	0.41	1.00	1.10	0.32
	1.27	3.17	4.44	0.53	1.00	1.33	0.30

TABLE V (continued)

READINGS FOR TESTS ON TEFLON AGAINST 22.4 PER CENT CLAY SOIL

Moisture in per cent	Weight of Test Can & Soil in lbs.	Additional Weight in lbs.	Total Weight (R) in lbs.	Pressure in psi.	Speed in mph.	Friction Force (F) in lbs.	Coefficient of Friction F/R
12	1.27	0.64	1.91	0.23	2.00	0.62	0.32
	1.27	1.17	2.44	0.29	2.00	0.76	0.31
	1.27	2.17	3.44	0.41	2.00	1.05	0.30
	1.27	3.17	4.44	0.53	2.00	1.30	0.29
12	1.27	0.64	1.91	0.23	4.06	0.60	0.31
	1.27	1.17	2.44	0.29	4.06	0.74	0.30
	1.27	2.17	3.44	0.41	4.06	1.02	0.30
	1.27	3.17	4.44	0.53	4.06	1.25	0.28
12	1.27	0.64	1.91	0.23	8.12	0.58	0.30
	1.27	1.17	2.44	0.29	8.12	0.72	0.30
	1.27	2.17	3.44	0.41	8.12	1.02	0.30
	1.27	3.17	4.44	0.53	8.12	1.24	0.28
14	1.29	0.64	1.93	0.23	-	0.52	0.27
	1.29	1.17	2.46	0.30	-	0.65	0.26
	1.29	2.17	3.46	0.41	-	0.88	0.25
	1.29	3.17	4.46	0.53	-	1.11	0.25
14	1.29	0.64	1.93	0.23	1.00	0.58	0.30
	1.29	1.17	2.46	0.30	1.00	0.73	0.30
	1.29	2.17	3.46	0.41	1.00	0.98	0.28
	1.29	3.17	4.46	0.53	1.00	1.25	0.28
14	1.29	0.64	1.93	0.23	2.00	0.56	0.29
	1.29	1.17	2.46	0.30	2.00	0.70	0.28
	1.29	2.17	3.46	0.41	2.00	0.98	0.28
	1.29	3.17	4.46	0.53	2.00	1.20	0.27
14	1.29	0.64	1.93	0.23	4.06	0.65	0.34
	1.29	1.17	2.46	0.30	4.06	0.78	0.32
	1.29	2.17	3.46	0.41	4.06	1.08	0.31
	1.29	3.17	4.46	0.53	4.06	1.34	0.30
14	1.29	0.64	1.93	0.23	8.12	0.60	0.31
	1.29	1.17	2.46	0.30	8.12	0.74	0.30
	1.29	2.17	3.46	0.41	8.12	1.00	0.29
	1.29	3.17	4.46	0.53	8.12	1.28	0.29
16	1.31	0.64	1.95	0.23	-	0.56	0.29

TABLE V (continued)

READINGS FOR TESTS ON TEFLON AGAINST 22.4 PER CENT CLAY SOIL

Moisture in per cent	Weight of Test Can & Soil in lbs.	Additional Weight in lbs.	Total Weight (R) in lbs.	Pressure in psi.	Speed in mph.	Friction Force (F) in lbs.	Coefficient of Friction F/R
16	1.31	1.17	2.48	0.30	-	0.68	0.27
	1.31	2.17	3.48	0.42	-	0.88	0.25
	1.31	3.17	4.48	0.54	-	1.18	0.26
16	1.31	0.64	1.95	0.23	1.00	0.72	0.37
	1.31	1.17	2.48	0.30	1.00	0.90	0.36
	1.31	2.17	3.48	0.42	1.00	1.22	0.35
	1.31	3.17	4.48	0.54	1.00	1.52	0.34
16	1.31	0.64	1.95	0.23	2.00	0.66	0.34
	1.31	1.17	2.48	0.30	2.00	0.82	0.33
	1.31	2.17	3.48	0.42	2.00	1.10	0.32
	1.31	3.17	4.48	0.54	2.00	1.35	0.30
16	1.31	0.64	1.95	0.23	4.06	0.57	0.29
	1.31	1.17	2.48	0.30	4.06	0.72	0.29
	1.31	2.17	3.48	0.42	4.06	0.95	0.27
	1.31	3.17	4.48	0.54	4.06	1.20	0.27
16	1.31	0.64	1.95	0.23	8.12	0.58	0.30
	1.31	1.17	2.48	0.30	8.12	0.74	0.30
	1.31	2.17	3.48	0.42	8.12	0.98	0.28
	1.31	3.17	4.48	0.54	8.12	1.20	0.27
18	1.33	0.64	1.97	0.24	-	0.58	0.29
	1.33	1.17	2.50	0.30	-	0.81	0.32
	1.33	2.17	3.50	0.42	-	1.08	0.31
	1.33	3.17	4.50	0.54	-	1.32	0.29
18	1.33	0.64	1.97	0.24	1.00	0.74	0.38
	1.33	1.17	2.50	0.30	1.00	0.92	0.37
	1.33	2.17	3.50	0.42	1.00	1.25	0.36
	1.33	3.17	4.50	0.54	1.00	1.50	0.33
18	1.33	0.64	1.97	0.24	2.00	0.78	0.40
	1.33	1.17	2.50	0.30	2.00	0.92	0.37
	1.33	2.17	3.50	0.42	2.00	1.20	0.34
	1.33	3.17	4.50	0.54	2.00	1.40	0.31
18	1.33	0.64	1.97	0.24	4.06	0.84	0.43

TABLE V (continued)

READINGS FOR TESTS ON TEFLON AGAINST 22.4 PER CENT CLAY SOIL

Moisture in per cent	Weight of Test Can & Soil in lbs.	Additional Weight in lbs.	Total Weight (R) in lbs.	Pressure in psi.	Speed in mph.	Friction Force (F) in lbs.	Coefficient of Friction F/R
18	1.33	1.17	2.50	0.30	4.06	1.06	0.42
	1.33	2.17	3.50	0.42	4.06	1.42	0.41
	1.33	3.17	4.50	0.54	4.06	1.50	0.33
18	1.33	0.64	1.97	0.24	8.12	0.75	0.38
	1.33	1.17	2.50	0.30	8.12	0.90	0.36
	1.33	2.17	3.50	0.42	8.12	1.20	0.34
	1.33	3.17	4.50	0.54	8.12	1.40	0.31
20	1.35	0.64	1.99	0.24	-	0.74	0.37
	1.35	1.17	2.52	0.30	-	0.95	0.38
	1.35	2.17	3.52	0.42	-	1.22	0.35
	1.35	3.17	4.52	0.54	-	1.40	0.31
20	1.35	0.64	1.99	0.24	1.00	0.98	0.49
	1.35	1.17	2.52	0.30	1.00	1.22	0.48
	1.35	2.17	3.52	0.42	1.00	1.45	0.41
	1.35	3.17	4.52	0.54	1.00	1.70	0.38
20	1.35	0.64	1.99	0.24	2.00	0.76	0.38
	1.35	1.17	2.52	0.30	2.00	0.85	0.34
	1.35	2.17	3.52	0.42	2.00	1.20	0.34
	1.35	3.17	4.52	0.54	2.00	1.54	0.34
20	1.35	0.64	1.99	0.24	4.06	0.76	0.38
	1.35	1.17	2.52	0.30	4.06	0.90	0.36
	1.35	2.17	3.52	0.42	4.06	1.20	0.34
	1.35	3.17	4.52	0.54	4.06	1.45	0.32
20	1.35	0.64	1.99	0.24	8.12	0.74	9.37
	1.35	1.17	2.52	0.30	8.12	0.90	0.36
	1.35	2.17	3.52	0.42	8.12	1.18	0.34
	1.35	3.17	4.52	0.54	8.12	1.40	0.31
22	1.37	0.64	2.01	0.24	-	0.66	0.33
	1.37	1.17	2.54	0.30	-	0.82	0.32
	1.37	2.17	3.54	0.42	-	1.05	0.30
	1.37	3.17	4.54	0.54	-	1.22	0.27
22	1.37	0.64	2.01	0.24	1.00	1.15	0.57
	1.37	1.17	2.54	0.30	1.00	1.70	0.67

TABLE V (continued)

READINGS FOR TESTS ON TEFLON AGAINST 22.4 PER CENT CLAY SOIL

Moisture in per cent	Weight of Test Can & Soil in lbs.	Additional Weight in lbs.	Total Weight (R) in lbs.	Pressure in psi.	Speed in mph.	Friction Force (F) in lbs.	Coefficient of Friction F/R
22	1.37	2.17	3.54	0.42	1.00	2.26	0.64
	1.37	3.17	4.54	0.54	1.00	2.33	0.51
22	1.37	0.64	2.01	0.24	2.00	0.95	0.47
	1.37	1.17	2.54	0.30	2.00	1.40	0.55
	1.37	2.17	3.54	0.42	2.00	1.65	0.47
	1.37	3.17	4.54	0.54	2.00	2.12	0.47
22	1.37	0.64	2.01	0.24	4.06	0.80	0.40
	1.37	1.17	2.54	0.30	4.06	1.00	0.39
	1.37	2.17	3.54	0.42	4.06	1.30	0.37
	1.37	3.17	4.54	0.54	4.06	1.70	0.38
22	1.37	0.64	2.01	0.24	8.12	0.68	0.34
	1.37	1.17	2.54	0.30	8.12	0.85	0.34
	1.37	2.17	3.54	0.42	8.12	1.10	0.31
	1.37	3.17	4.54	0.54	8.12	1.40	0.31

TABLE VI

READINGS FOR TESTS ON TEFLON AGAINST 41.2 PER CENT CLAY SOIL

DATE OF TEST: May 6, 1959

SIZE OF CAN USED: Diameter 3.25 inches

Height 4.5 inches

Area 8.35 Sq. inches

TEMPERATURE: 82° F.

Moisture in per cent	Weight of Test Can & Soil in lbs.	Additional Weight in lbs.	Total Weight (R) in lbs.	Pressure in psi.	Speed in mph.	Friction Force (F) in lbs.	Coefficient of Friction F/R
15	1.30	0.64	1.94	0.23	-	0.35	0.18
	1.30	1.17	2.47	0.30	-	0.43	0.17
	1.30	2.17	3.47	0.42	-	0.55	0.16
	1.30	3.17	4.47	0.54	-	0.67	0.15
15	1.30	0.64	1.94	0.23	1.00	0.52	0.27
	1.30	1.17	2.47	0.30	1.00	0.65	0.26
	1.30	2.17	3.47	0.42	1.00	0.88	0.25
	1.30	3.17	4.47	0.54	1.00	1.10	0.25
15	1.30	0.64	1.94	0.23	2.00	0.54	0.28
	1.30	1.17	2.47	0.30	2.00	0.66	0.27
	1.30	2.17	3.47	0.42	2.00	0.94	0.27
	1.30	3.17	4.47	0.54	2.00	1.15	0.26
15	1.30	0.64	1.94	0.23	4.06	0.55	0.28
	1.30	1.17	2.47	0.30	4.06	0.68	0.28
	1.30	2.17	3.47	0.42	4.06	0.96	0.28
	1.30	3.17	4.47	0.54	4.06	1.20	0.27
15	1.30	0.64	1.94	0.23	8.12	0.56	0.29
	1.30	1.17	2.47	0.30	8.12	0.70	0.28
	1.30	2.17	3.47	0.42	8.12	0.96	0.28
	1.30	3.17	4.47	0.54	8.12	1.18	0.26
17	1.32	0.64	1.96	0.24	-	0.42	0.21
	1.32	1.17	2.49	0.30	-	0.48	0.19
	1.32	2.17	3.49	0.42	-	0.60	0.17
	1.32	3.17	4.49	0.54	-	0.75	0.17
17	1.32	0.64	1.96	0.24	1.00	0.48	0.24
	1.32	1.17	2.49	0.30	1.00	0.64	0.26
	1.32	2.17	3.49	0.42	1.00	0.86	0.25
	1.32	3.17	4.49	0.54	1.00	1.10	0.24

TABLE VI (continued)

READINGS FOR TESTS ON TEFLON AGAINST 41.2 PER CENT CLAY SOIL

Moisture in per cent	Weight of Test Can & Soil in lbs.	Additional Weight in lbs.	Total Weight (R) in lbs.	Pressure in psi.	Speed in mph.	Friction Force (F) in lbs.	Coefficient of Friction F/R
17	1.32	0.64	1.96	0.24	2.00	0.50	0.26
	1.32	1.17	2.49	0.30	2.00	0.64	0.26
	1.32	2.17	3.49	0.42	2.00	0.90	0.26
	1.32	3.17	4.49	0.54	2.00	1.15	0.26
17	1.32	0.64	1.96	0.24	4.06	0.60	0.31
	1.32	1.17	2.49	0.30	4.06	0.70	0.28
	1.32	2.17	3.49	0.42	4.06	0.94	0.27
	1.32	3.17	4.49	0.54	4.06	1.18	0.26
17	1.32	0.64	1.96	0.24	8.12	0.55	0.28
	1.32	1.17	2.49	0.30	8.12	0.66	0.26
	1.32	2.17	3.49	0.42	8.12	0.92	0.26
	1.32	3.17	4.49	0.54	8.12	1.14	0.25
19	1.34	0.64	1.98	0.24	-	0.36	0.18
	1.34	1.17	2.51	0.30	-	0.46	0.18
	1.34	2.17	3.51	0.42	-	0.67	0.19
	1.34	3.17	4.51	0.54	-	0.82	0.18
19	1.34	0.64	1.98	0.24	1.00	0.53	0.27
	1.34	1.17	2.51	0.30	1.00	0.64	0.26
	1.34	2.17	3.51	0.42	1.00	0.88	0.25
	1.34	3.17	4.51	0.54	1.00	1.12	0.25
19	1.34	0.64	1.98	0.24	2.00	0.52	0.26
	1.34	1.17	2.51	0.30	2.00	0.66	0.26
	1.34	2.17	3.51	0.42	2.00	0.86	0.24
	1.34	3.17	4.51	0.54	2.00	1.06	0.24
19	1.34	0.64	1.98	0.24	4.06	0.54	0.27
	1.34	1.17	2.51	0.30	4.06	0.64	0.26
	1.34	2.17	3.51	0.42	4.06	0.87	0.25
	1.34	3.17	4.51	0.54	4.06	1.10	0.24
19	1.34	0.64	1.98	0.24	8.12	0.54	0.27
	1.34	1.17	2.51	0.30	8.12	0.66	0.26
	1.34	2.17	3.51	0.42	8.12	0.90	0.26
	1.34	3.17	4.51	0.54	8.12	1.14	0.25

TABLE VI (continued)

RADINGS FOR TESTS ON TEFLON AGAINST 41.2 PER CENT CLAY SOIL

Moisture in per cent	Weight of Test Can & Soil in lbs.	Additional Weight in lbs.	Total Weight (R) in lbs.	Pressure in psi.	Speed in mph.	Friction Force (F) in lbs.	Coefficient of Friction F/R
21	1.36	0.64	2.00	0.24	-	0.30	0.15
	1.36	1.17	2.53	0.30	-	0.45	0.18
	1.36	2.17	3.53	0.42	-	0.68	0.19
	1.36	3.17	4.53	0.54	-	0.80	0.18
21	1.36	0.64	2.00	0.24	1.00	0.50	0.25
	1.36	1.17	2.53	0.30	1.00	0.65	0.26
	1.36	2.17	3.53	0.42	1.00	0.88	0.25
	1.36	3.17	4.53	0.54	1.00	1.12	0.25
21	1.36	0.64	2.00	0.24	2.00	0.54	0.27
	1.36	1.17	2.53	0.30	2.00	0.68	0.27
	1.36	2.17	3.53	0.42	2.00	0.90	0.26
	1.36	3.17	4.53	0.54	2.00	1.15	0.25
21	1.36	0.64	2.00	0.24	4.06	0.56	0.28
	1.36	1.17	2.53	0.30	4.06	0.70	0.28
	1.36	2.17	3.53	0.42	4.06	0.90	0.26
	1.36	3.17	4.53	0.54	4.06	1.14	0.25
21	1.36	0.64	2.00	0.24	8.12	0.56	0.28
	1.36	1.17	2.53	0.30	8.12	0.72	0.28
	1.36	2.17	3.53	0.42	8.12	0.96	0.27
	1.36	3.17	4.53	0.54	8.12	1.20	0.26
23	1.38	0.64	2.02	0.24	-	0.35	0.17
	1.38	1.17	2.55	0.31	-	0.44	0.17
	1.38	2.17	3.55	0.42	-	0.65	0.18
	1.38	3.17	4.55	0.54	-	0.85	0.19
23	1.38	0.64	2.02	0.24	1.00	0.45	0.22
	1.38	1.17	2.55	0.31	1.00	0.65	0.26
	1.38	2.17	3.55	0.42	1.00	0.88	0.25
	1.38	3.17	4.55	0.54	1.00	1.02	0.22
23	1.38	0.64	2.02	0.24	2.00	0.50	0.25
	1.38	1.17	2.55	0.31	2.00	0.62	0.24
	1.38	2.17	3.55	0.42	2.00	0.85	0.24
	1.38	3.17	4.55	0.54	2.00	1.05	0.23

TABLE VI (continued)

READINGS FOR TESTS ON TEFLON AGAINST 41.2 PER CENT CLAY SOIL

Moisture in per cent	Weight of Test Can & Soil in lbs.	Additional Weight in lbs.	Total Weight (R) in lbs.	Pressure in psi.	Speed in mph.	Friction Force (F) in lbs.	Coefficient of Friction F/R
23	1.38	0.64	2.02	0.24	4.06	0.50	0.25
	1.38	1.17	2.55	0.31	4.06	0.64	0.25
	1.38	2.17	3.55	0.42	4.06	0.88	0.25
	1.38	3.17	4.55	0.54	4.06	1.08	0.24
23	1.38	0.64	2.02	0.24	8.12	0.59	0.29
	1.38	1.17	2.55	0.31	8.12	0.73	0.29
	1.38	2.17	3.55	0.42	8.12	0.96	0.27
	1.38	3.17	4.55	0.54	8.12	1.20	0.26
25	1.40	0.64	2.04	0.24	-	0.33	0.16
	1.40	1.17	2.57	0.31	-	0.48	0.19
	1.40	2.17	3.57	0.43	-	0.58	0.16
	1.40	3.17	4.57	0.55	-	0.85	0.19
25	1.40	0.64	2.04	0.24	1.00	0.80	0.39
	1.40	1.17	2.57	0.31	1.00	1.05	0.41
	1.40	2.17	3.57	0.43	1.00	1.45	0.41
	1.40	3.17	4.57	0.55	1.00	1.70	0.37
25	1.40	0.64	2.04	0.24	2.00	0.95	0.46
	1.40	1.17	2.57	0.31	2.00	1.10	0.43
	1.40	2.17	3.57	0.43	2.00	1.25	0.35
	1.40	3.17	4.57	0.55	2.00	1.45	0.32
25	1.40	0.64	2.04	0.24	4.06	0.80	0.39
	1.40	1.17	2.57	0.31	4.06	0.92	0.36
	1.40	2.17	3.57	0.43	4.06	1.20	0.34
	1.40	3.17	4.57	0.55	4.06	1.48	0.32
25	1.40	0.64	2.04	0.24	8.12	0.70	0.34
	1.40	1.17	2.57	0.31	8.12	0.85	0.33
	1.40	2.17	3.57	0.43	8.12	1.15	0.32
	1.40	3.17	4.57	0.55	8.12	1.38	0.30
27	1.42	0.64	2.06	0.25	-	0.44	0.21
	1.42	1.17	2.59	0.31	-	0.59	0.23
	1.42	2.17	3.59	0.43	-	0.71	0.20
	1.42	3.17	4.59	0.55	-	0.85	0.19

TABLE VI (continued)

READINGS FOR TESTS ON TEFLON AGAINST 41.2 PER CENT CLAY SOIL

Moisture in per cent	Weight of Test Can & Soil in lbs.	Additional Weight in lbs.	Total Weight (R) in lbs.	Pressure in psi.	Speed in mph.	Friction Force (F) in lbs.	Coefficient of Friction F/R
27	1.42	0.64	2.06	0.25	1.00	0.64	0.31
	1.42	1.17	2.59	0.31	1.00	0.84	0.32
	1.42	2.17	3.59	0.43	1.00	1.15	0.32
	1.42	3.17	4.59	0.55	1.00	1.30	0.28
27	1.42	0.64	2.06	0.25	2.00	0.62	0.30
	1.42	1.17	2.59	0.31	2.00	0.75	0.29
	1.42	2.17	3.59	0.43	2.00	1.05	0.29
	1.42	3.17	4.59	0.55	2.00	1.30	0.28
27	1.42	0.64	2.06	0.25	4.06	0.80	0.39
	1.42	1.17	2.59	0.31	4.06	0.95	0.37
	1.42	2.17	3.59	0.43	4.06	1.18	0.33
	1.42	3.17	4.59	0.55	4.06	1.42	0.31
27	1.42	0.64	2.06	0.25	8.12	0.72	0.35
	1.42	1.17	2.59	0.31	8.12	0.86	0.33
	1.42	2.17	3.59	0.43	8.12	1.10	0.31
	1.42	3.17	4.59	0.55	8.12	1.30	0.28
30	1.45	0.64	2.09	0.25	-	0.54	0.26
	1.45	1.17	2.62	0.31	-	0.64	0.24
	1.45	2.17	3.62	0.43	-	0.75	0.21
	1.45	3.17	4.62	0.55	-	0.92	0.20
30	1.45	0.64	2.09	0.25	1.00	1.20	0.58
	1.45	1.17	2.62	0.31	1.00	1.50	0.57
	1.45	2.17	3.62	0.43	1.00	1.75	0.48
	1.45	3.17	4.62	0.55	1.00	1.91	0.41
30	1.45	0.64	2.09	0.25	2.00	1.04	0.50
	1.45	1.17	2.62	0.31	2.00	1.30	0.50
	1.45	2.17	3.62	0.43	2.00	1.71	0.47
	1.45	3.17	4.62	0.55	2.00	2.21	0.48
30	1.45	0.64	2.09	0.25	4.06	0.86	0.41
	1.45	1.17	2.62	0.31	4.06	1.04	0.40
	1.45	2.17	3.62	0.43	4.06	1.39	0.38
	1.45	3.17	4.62	0.55	4.06	1.54	0.33

TABLE VI (continued)

READINGS FOR TESTS ON TEFLON AGAINST 41.2 PER CENT CLAY SOIL

Moisture in per cent	Weight of Test	Additional Weight in lbs.	Total Weight (R) in lbs.	Pressure in psi.	Speed in mph.	Friction	
	Can & Soil in lbs.					Force (F) in lbs.	Coefficient of Friction F/R
30	1.45	0.64	2.09	0.25	8.12	0.89	0.43
	1.45	1.17	2.62	0.31	8.12	1.09	0.42
	1.45	2.17	3.62	0.43	8.12	1.34	0.37
	1.45	3.17	4.62	0.55	8.12	1.52	0.33
32	1.47	0.64	2.11	0.25	-	0.62	0.29
	1.47	1.17	2.64	0.32	-	0.75	0.28
	1.47	2.17	3.64	0.44	-	0.82	0.22
	1.47	3.17	4.64	0.56	-	0.96	0.21
32	1.47	0.64	2.11	0.25	1.00	1.04	0.49
	1.47	1.17	2.64	0.32	1.00	1.20	0.46
	1.47	2.17	3.64	0.44	1.00	1.50	0.41
	1.47	3.17	4.64	0.56	1.00	1.91	0.41
32	1.47	0.64	2.11	0.25	2.00	0.91	0.43
	1.47	1.17	2.64	0.32	2.00	1.11	0.42
	1.47	2.17	3.64	0.44	2.00	1.33	0.37
	1.47	3.17	4.64	0.56	2.00	1.76	0.38
32	1.47	0.64	2.11	0.25	4.06	0.82	0.39
	1.47	1.17	2.64	0.32	4.06	0.96	0.36
	1.47	2.17	3.64	0.44	4.06	1.30	0.36
	1.47	3.17	4.64	0.56	4.06	1.60	0.35
32	1.47	0.64	2.11	0.25	8.12	0.80	0.38
	1.47	1.17	2.64	0.32	8.12	1.05	0.40
	1.47	2.17	3.64	0.44	8.12	1.30	0.36
	1.47	3.17	4.64	0.56	8.12	1.50	0.32

TABLE VII

READINGS FOR TESTS TO DETERMINE THE EFFECT OF AREA OF CONTACT

DATE: May 9, 1959

TEMPERATURE: 79° F.

Clay in per cent	Moisture in per cent	Diameter of Test Can in inches	Area of Contact in Sq. ins.	Total Pressure (R) in lbs.	Speed in mph.	Friction Force (F) in lbs.	Coeffic. of Fric. F/R
7.3	6	2.50	4.90	4.00	1.00	1.05	0.26
		3.00	7.06	4.00	1.00	1.24	0.31
		3.25	8.35	4.00	1.00	1.18	0.30
		3.88	10.40	4.00	1.00	1.20	0.30
7.3	6	2.50	4.90	4.00	2.00	1.03	0.26
		3.00	7.06	4.00	2.00	1.25	0.31
		3.25	8.35	4.00	2.00	1.20	0.30
		3.88	10.40	4.00	2.00	1.20	0.30
7.3	8	2.50	4.90	4.00	1.00	1.00	0.25
		3.00	7.06	4.00	1.00	1.14	0.28
		3.25	8.35	4.00	1.00	1.14	0.28
		3.88	10.40	4.00	1.00	1.15	0.29
7.3	8	2.50	4.90	4.00	2.00	0.90	0.22
		3.00	7.06	4.00	2.00	1.20	0.30
		3.25	8.35	4.00	2.00	1.15	0.29
		3.88	10.40	4.00	2.00	1.15	0.29
22.4	13	2.50	4.90	3.00	1.00	0.88	0.29
		3.00	7.06	3.00	1.00	0.86	0.29
		3.25	8.35	3.00	1.00	0.94	0.31
		3.88	10.40	3.00	1.00	0.98	0.33
22.4	13	2.50	4.90	3.00	2.00	0.84	0.28
		3.00	7.06	3.00	2.00	0.90	0.30
		3.25	8.35	3.00	2.00	0.90	0.30
		3.88	10.40	3.00	2.00	0.93	0.31
22.4	15	2.50	4.90	3.50	1.00	1.04	0.30
		3.00	7.06	3.50	1.00	1.06	0.30
		3.25	8.35	3.50	1.00	1.05	0.30
		3.88	10.40	3.50	1.00	1.18	0.34
22.4	15	2.50	4.90	3.50	2.00	0.98	0.28
		3.00	7.06	3.50	2.00	1.06	0.30
		3.25	8.35	3.50	2.00	1.06	0.30
		3.88	10.40	3.50	2.00	1.20	0.34