A STUDY OF AN INFRARED OVEN FOR DRYING SOIL SAMPLES

By

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PREFACE

This thesis concerns the use of infrared energy as a quick method of drying soil s ples.

The construction of th infrared oven, the collection of the data and the analyzing and evaluating of the data could not have been completed without the help received from members of the staff of the Agricultural Engineering Department, the Statistics Depart-ent, and the Soils Department of Oklahoma A & M College, Stillwater, Oklahoma.

The author wishes to especially express his appreciation for the time, facilities and consideration given by E. W. Schroeder, Professor and head, Department of Agricultural Engineering, Oklahoma A & M College for directing the graduate studies of the author.

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INTRODUCTION

Among the many factors that are necessary in order to intelligently practice irrigation, is a knowledge of the correct time of application of irrigation water which in itself requires a knowledge of the amount of moisture present in a soil at any particular time. Several methods have been tried but only one seems to give consistent results. That method is collecting samples of the soil, drying them, and determining the amount of water present in the soil samples on a dry weight basis.

With the increasing number of acres coming under irrigation, the proper use of water is becoming more and more important. Irrigation water should be applied to the land only when needed yet before the crops begin to show any signs of water deficiency. On some hot dry summer days, it is possible that the water loss due to evaporation from both the plant and the soil could reduce soil moisture content from a relatively high point to or near the wilting point within 24 hours. Day to day tests are often necessary to accurately determine the soil moisture content. Knowledge of the correct amount of soil moisture present, almost instantaneously, in the soil is very essential to those "intelligently" practicing irrigation. It would really be an advantage if the percent of soil moisture could be determined in one hour rather than the 24 hours required with a conventional oven.

Engineers building roads, dams or any earth structures where compaction to a certain degree is desired, control the percent of soil moisture in the fill material to obtain near optimum compaction. These engineers need a method that will permit determining the soil moisture almost immediately. The infrared soil oven will fulfill this need.

Much work has been done in trying to shorten the time required to determine the percent of moisture of a soil. But nearly all the reported studies were made on the possibilities of eliminating the drying time rather than to shorten it.

Recent tests with an experimental infrared oven (15) tend to show that the infrared oven can possibly fulfill the ever increasing desire for a method that is relatively simple, fast, and accurate in driving off the moisture. With the normal soil drying procedure, at least 24 hours is required to determine the moisture content of a particular soil. However, with the infrared oven, soil samples can be collected and the moisture percent can be determined within one hour.

With the infrared oven (Figure 1) it is possible to dry sixteen of the standard sixteen ounce cans in one hour or as many as 128 in 8 hours, which makes it adaptable to both small and large scale use. The standard oven used in this study (Figure 2), which was a large laboratory size, has a capacity of about 60 of the same size cans. When based on a 24 hour period of time, the infrared oven has about two times the capacity of the large standard oven used in this study.

Previous tests by Mack (15) tended to indicate that when soil samples were dried with the infrared oven, either some of the water of crystallization was evaporated, or the organic matter of the soil was oxidized, or both occured. The infrared oven dried the soil drier than the conventional oven.

Millar and Turk (18) indicate that plants try to adjust their daily intake of water from the soil and their daily loss through transpiration, and evaporation to the amount of water available to them. In other words they use more water when the land is at maximum field capacity than when the moisture content is just below field capacity.

Weir (21) shows that after the soil is at field capacity, with any further drying out of the soil the plants' process of drawing up water through the roots to replace that lost through evaporation, and transpiration, becomes increasingly more difficult. This difficulty will increase until the water movement into the root system is negative, causing wilting. Briggs (4) showed that even though the forces that tend to draw the water into the roots and forces that tend to hold it onto the soil particles are in equilibrium, some damage may be done to the plants. This indicates that the moisture level should be kept above this point.

OBJECTIVE

The general objective of this study is to compare an infrared soils oven with a conventional soils oven. To accomplish this general objective a statistically designed experiment was set up so that the following specific objectives could be obtained;

1. Compare the moisture removed by the infrared soils oven after time exposures of 30, 60, and 90 minutes, with that removed by the standard oven in 24 hours.
2. Compare the organic matter content of soil samples dried in the infrared oven with an exposure time of 30, 60, and 90 minutes and in the standard soils oven for 24 hours, with the organic matter content of soil samples which were air dried.
3. Compare the loss in organic matter with the percent of moisture removed by the infrared oven minus the percent of moisture removed by the standard oven.
4. Compare the amount of organic matter oxidized with the original organic matter content of the soil.

BASIC CONCEPTS

A few of the basic concepts used in this thesis are reviewed here:

SOIL WATER is of three general types, (a) gravational water is the water that flows downward by gravity or through the zone of aeration and is equal to about 40% to 60% of the pore space, (b) capillary water is that water held against the forces of gravity in the zone of aeration, and (c) hygroscopic water is the water that is deposited as extremely thin films on soil particles when the particles are exposed to water vapor. The latter is not available as plant water because it is held so tightly that it can be completely driven off only with heat.

FIELD MOISTURE CAPACITY (maximum field capacity) is the maximum amount of water that can be held against the forces of gravity under ordinary field conditions.

WILTING COEFFICIENT refers to the maximum moisture contents of the soil at which the plants permanently wilt because of insufficient available water. Briggs states that the wilting coefficient for any one soil is about the same for most any plant.

AVAILABLE WATER HOLDING CAPACITY of the soil refers to amount of H_2O soil can hold between field moisture capacity, and the wilting coefficient. Wilting of plants occur when the rate of transpiration exceeds the ability of the soil to supply water. Weir (20) shows that in the process of absorption a plant continously exerts a strong pulling force on the water surrounding its entire root system. He also shows that the adhesive force of the dry soil for the film water may become as high as 25,000 atmospheres. This force would be much greater than the absorptive forces of the roots of most plants which is near 15 atmospheres. In such a case, the dry soil would tend to pull out of the plant any or all of the water therein, thus causing wilting and eventually the complete loss of the plant. It is indicated that this pull on the plant water is increased somewhat proportional with any decrease in the moisture of the soil surrounding the root system.

Water is held in the soil by one or all of the three methods; (a) absorbtive forces which hold water films around soil particles, (b) capillary forces which accounts for water in pore spaces and interstices in soil crumbs, and (c) absorptive force created by organic matter and colloidal materials in soils.

THE PROCEDURE OF DETERMING THE PER CENT OF SOIL MOISTURE is to weigh a sample of soil, dry it in an oven at constant temperature of about 105 degrees Centigrade until it ceases to loose any more weight (this will usually take about 24 hours) and then reweigh it. The difference of these two weights of the sample is the weight of the moisture removed from the soil. The equation may be written as;

$$\text{percent of soil moisture (dry weight basis)} = \frac{100(X-Y)}{Y}$$

where X is the net weight of sample before putting in oven

where Y is the net weight of sample after 24 hrs. in the oven

THEORY OF INFRARED RAYS

Anderson (2) shows that infrared rays are the rays of the electro-magnetic spectrum with wave lengths of 8×10^3 to 4.2×10^6 Angstroms or 8×10^{-5} to 4.2×10^{-3} C. M. These rays are on the long side adjoining the visible light rays of the electro-magnetic spectrum. Between 9,000 angstroms and 30,000 angstroms the infrared heat lamp is most efficient. These infrared rays have many of the characteristics of the visible light rays plus some important additional characteristics.

Some of these additional characteristics are what make infrared energy desirable as a source of heat for a soils oven. The most important of these are: (a) the penetrating ability of these rays, which is high even in soils; (b) the ability of the rays to pass through clean glass or dust free air without heating the glass or the air; and (c) the fact that the rate of energy transfer from the infrared lamp to the soil is constant. The rate of temperature change throughout an infrared heating process would also be constant except for the cooling effects of the radiant and convective heat transfer away from the object being heated. With the conventional oven, the rate of energy transfer and the rate of temperature change of the object being heated is a function of the difference in the temperatures of the object being heated and the source of heat. The rising convetion currents do not obstruct the infrared rays, they only cool off the object after it has absorbed the rays of energy. Some other advantages of infrared heating are, (a) it is instantaneous and (b) the rays can be reflected nearly the same as light rays.

Anderson and Nicholas (1) report that temperatures as high as 1230 degrees Fahrenheit were recorded within a few minutes after one 300 watt infrared heat lamp was exposed to litter at a distance of one inch.

REVIEW OF LITERATURE

DETERMINING SOIL MOISTURE. With the standard soil drying procedure, it is necessary to get the sample hot enough to vaporize the soil water but not so hot that the soil molecules will be broken down. Water vaporizes at about 100 degrees Centigrade whereas some of the soil molecules are likely to be broken down if the temperature exceeds 110 degrees Centigrade. Therefore, a temperature of about 105 degrees Centigrade is used for drying soil samples. At this temperature it will take from two to eight hours for the entire soil sample to reach the temperature of the oven or the temperature of evaporation. Another ten to twenty hours are needed to completely vaporize all of the soil moisture in the sample.

Various attempts have been made to reduce the time and labor of sampling, weighing, drying and reweighing the soil when determining the soil moisture contents. Some of the methods of determining the percent of moisture mentioned by Baver (3), Frevert (10), and Goodman (11) are the use of various electrical resistors, tensiometers, and other methods of measuring and/or calculating the heat evolved or the chemical change when certain chemicals are added to the soil sample. Yet, with each of these methods, there are so many variables to be considered that it is difficult to predict exactly the results under the various conditions normally encountered with the numerous soils.

Goodman approached the problem of shortening the drying time and his report showed some very interesting results with the use of the infrared lamp. Although his apparatus could only dry one sample at a time, he indicated that soil samples could be dried in less than 45 minutes with the use of infrared rays. However, he made no report on the effects of the depth of the soil to be dried or the temperature of the soil samples while drying.

Mack reported that when soil samples were dried by over exposing to infrared rays and were then immediately transferred into the standard soils oven, they would gain weight even though the standard soils oven was at the operating temperature when the soil samples were inserted and remained at that temperature until the samples were removed.

Weir says that there are two essential differences between clays and sand. They are: (a) clays originates through chemical action in rock weathering; (b) clays constitute the colloidal materials in soils. Baver shows the chemical anaylysis of clay soils usually show $SiO_2Al_2O_3$ and H_2O in some form of a hydroxyl. It is believed that the infrared rays may drive off some of the hydroxyl water of these hydroxides.

Mack reported that the depth of soil samples in the cans has some effect on the length of drying time for some soils. He, noted that the infrared rays would dry the soils samples drier than the standard soils oven. He made no investigation as to the effect that the exposure to infrared rays had on the organic matter contents of the soil samples.

QUANTITY AND DISTRIBUTION OF ORGANIC MATTER IN SOILS. Millar and Turk say that organic matter makes up a very small fraction of the total weight of mineral soils. The quantity of organic matter ranges from a fraction of 1 percent for very poor soils to about 12 percent for prairie soils. Sand and sandy loam (lighter soils) are usually lower in organic matter than clays and clay loam (heavier soils).

QUICK DRYING OVENS. Recently the infrared oven has become increasingly more useful throughout industry as a drier. They are used for drying water, paints, many solvents on machinery, woodwork, fabric, paper and earth products. Some large hotels in N. Y. use infrared ovens for cooking meals.

Egeler (7) listed six advantages of the infrared oven. They may be summed up as:

1. Immediate heat
2. Efficient use of energy
3. Adaptability to various uses
4. Higher quality of products
5. Efficient space saver
6. More simple equipment, installation, and maintenance

He also states that for greater oven efficiency, the oven should have double walled insulating enclosures with the inside wall polished. The ovens he referred to were being used for dehydrating.

Anwyl (2) states that studies made in the clay-brick industry have shown that if lamination of air is prevented, air movement around the clay products being dried will speed the drying and shorten the time required in the oven. These studies had no references to an oven heated by infrared lamps.

Broughton, and Gillman (7) state that with a new fiberglass superheater, probably heated by infrared rays, a maximum temperature of 700 degrees Fahrenheit can be obtained with a wide range of either voltage. phase, or frequency in an oven with two open ends. A small volume of low pressure, clean air was continually passed through this oven which was used primarily for drying fabrics. These authors state that with this oven, the oven temperature was virtually independent of the external conditions as in contrast to the effects of the external conditions of the normal oven with a door when the door is opened momentarily.

The Electiral World (8) reports that a Detroit tractor manufacturer, uses a controlled electric infrared oven with a continuous volume of high velocity air passing through it to heat various tractor parts to the temperature of the boiling point of water within twenty seconds. This oven had both ends open.

Mertz (17) reports "perfect" results from a versatile infrared oven. The oven is made in three banks of 12 heater units per bank. The shape of the oven can be changed as needed. The drying cycle can also be changed and each bank has individual temperature control. No reference was made here of the air flow.

Factory Management and Maintenance (9) reports that Edwin L. Weigand Co., has placed on market radiant heating panels that may be "stacked like buildings blocks" and are electrically connected by jumpers. The temperature of the oven can be varied from 0 to 700 degrees Fahrenheit. The heating elements and reflectors are removable and the shape is variable.

DESIGN AND CONSTRUCTION OF THE INFRARED OVEN

In order to accommodate 16 standard sixteen ounce soil sample cans, the square infrared oven shelf and floor was made 18 in. on a side. The walls and bottom of the oven were all made of three-sixteenth inches asbestos sheets. The top of the oven was made of 3/4 inch plywood panel.

Six 250 watt lamps were placed in the top of the oven. Five were spaced 72 degrees apart centered on the circumference of a 12 inch diameter circle. The sixth lamp was placed at the center of the 12 inch circle (Figure 3). Two sheets of the three-sixteenth inch asbestos, each covered with a sheet of aluminum foil served as reflectors for the top (Figure 4). One of the reflectors was located at the base of the lamps and the other one was about 3 1/2 inches lower. Both reflectors were supported by the lamps. The top was independently supported by three legs that rested on and were fastened to a board on which the oven would stand (Figures 4 & 5). The top then could be moved up and down on the legs. This arrangement of the top was used to adjust the height of the lamps above the shelf of the oven. The most uniformly high temperature, found in a previous study by Mack, was obtained by locating the lamps about 12 inches above the shelf on which samples were placed. The shelf was made of hardware cloth with small loops to raise it about 1 inch above the bottom of the oven. The oven door was hinged at the bottom and was made of sheet metal covered on the inside with a sheet of asbestos and a sheet of aluminum foil. Six 3/4 inch holes were drilled through the floor to permit adequate oven ventilation.

The center infrared lamp in the top (Figure 3) was connected directly to the main switch on the oven. The other five lamps were

Figure 1--Experimental model infrared oven with nine standard 16 ounce soil sample cans

Figure 2--The Standard Soils oven, used in this study, with the standard 16 ounce soil sample cans inserted

Figure 3--The oven top, underside showing the arrangement of the six lamps

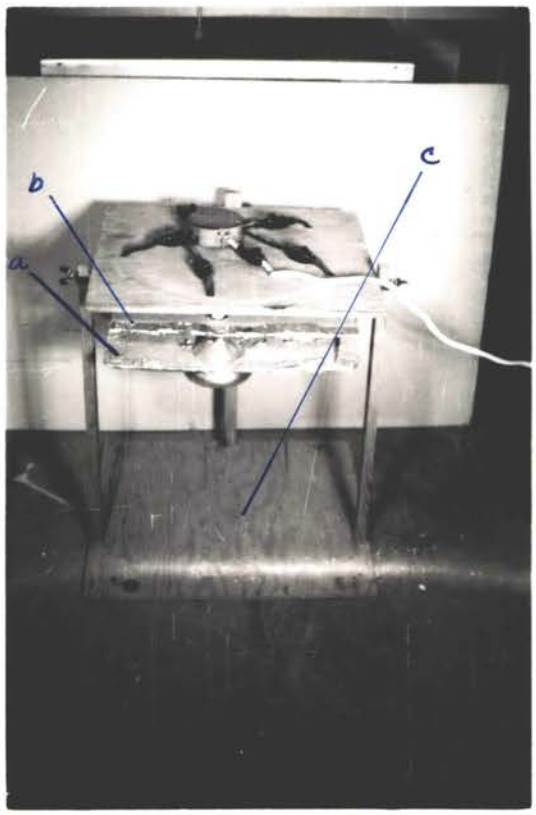

Figure 4--The oven top fastened to the three legs.
a-lower reflector; b-upper reflector;
c-base panel

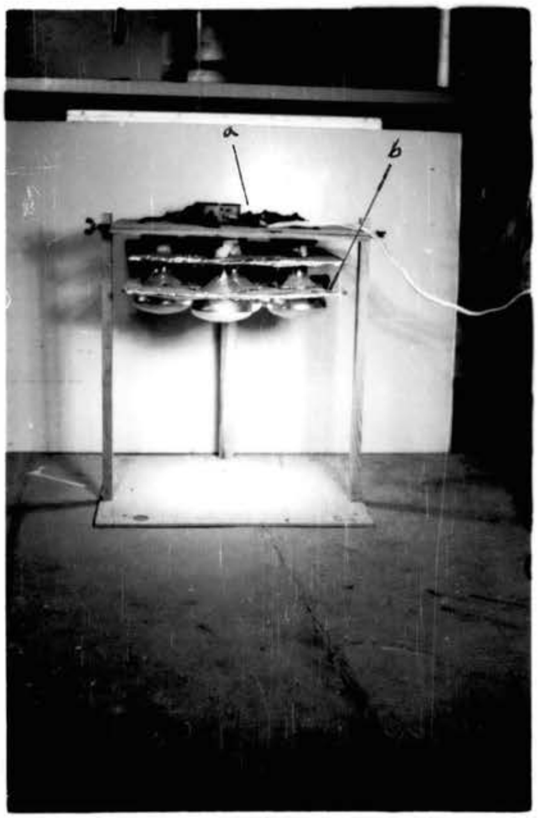

Figure 5--The oven top, legs and base panel.
a-main switch; b-lower reflector

individually controlled. The sixth switch was used as the main switch to control all current to the oven. The six lamps were mounted in porcelin sockets which were fastened to the top, which was a plywood panel, (3/4" x 22" x 22") (Figure 4). The two reflectors at the top of the oven kept the excess heat from the electrical sockets and plywood top.

METHOD OF OBTAINING DATA

This study was made on six different soils. Soil number 1 was a sand. Soil number 2 was a loam. Soil number 3 was a clay loam. Soil number 4 was a loam. Soil number 5 was a clay. Soil number 6 was a sand. Soil number 3 was a mixture of three soils, number 1, 4, and 5. Soil number 4 was obtained in Jackson County, Oklahoma. The other four soils, 1, 2, 5 and 6 were obtained at various locations in Payne County, Oklahoma.

Before being used, all soils were run through a no. 10 sieve to remove any foreign matter and insure uniformity. A total of thirty triplicate tests were used for this study, five triplicate tests being run on each soil type, each test at a different moisture level. Water was added to the soil to obtain the different moisture levels. No exact measurements were made of the water when it was added.

The following procedure was used for each of the thirty tests, twelve of the standard 16 ounce soil sample cans with their respective lids were weighed on balances (Figure 6) and filled with 100.00 grams of moisture laden soil that had been run through the soil splitter. Nine of these cans and lids were inserted into the infrared oven (Figure 1) and exposed to the infrared rays. The remaining three cans and lids were inserted into the standard oven. Before inserting the sample cans in either oven, the lids were removed and placed under their respective cans. After thirty minutes of exposure, without turning off the infrared lamps, three samples were randomly taken from the infrared oven. Each was then covered with its lid, and allowed to cool to a temperature low enough to permit handling, and then reweighed. After sixty minutes of exposure, another three samples were randomly taken from the infrared, covered, and reweighed after they too had cooled. After ninety minutes of exposure to the infrared lamps the remaining three samples were taken from the infrared oven, covered, and reweighed in the same manner. After twenty-four hours, the three samples in the standard soils oven were taken from the oven covered, cooled and weighed in the same manner as those from the infrared oven.

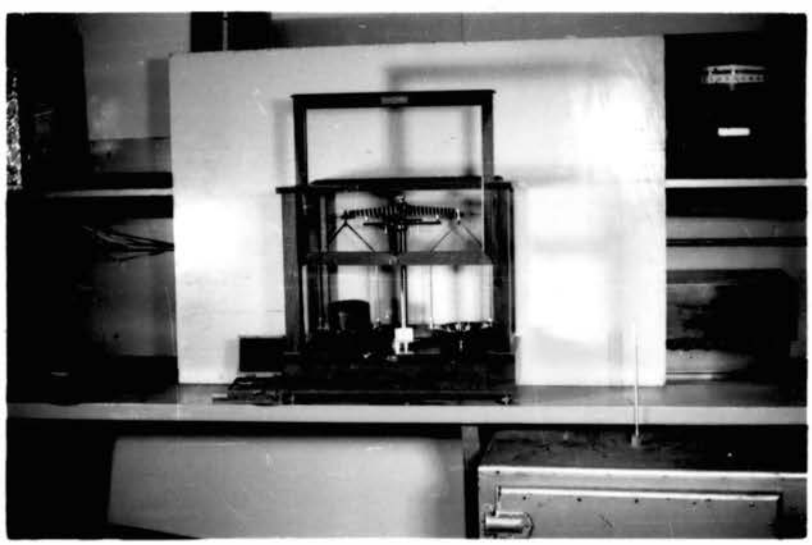

Figure 6--Balance used in this study

ANALYSIS OF DATA

MOISTURE

MOISTURE REMOVED. The percent of moisture removed (table I through VI) was computed on the assumption that, after a certain time in the oven, the entire loss in weight of the soil samples was due to the evaporation of soil moisture. The discussion of the organic matter content may tend to indicate otherwise.

ANALYSIS OF VARIANCE. Table I shows the percent of moisture removed from soil no. 1, type, sand, after 30, 60, and 90 minutes exposure in the infrared oven and that removed by the standard oven after 24 hours. From this data table VII was computed. In table VII ("F" value for sand type soil), the high calculated "F" value for the method shows that there is a highly significant difference in the amount of moisture removed by the four treatments. With further investigation, this table shows a highly significant difference when the infrared oven is compared with the standard oven. This is indicated by the fact that the calculated value of "F" is very high when compared with tabulated "F" value at eigher 1% or 5% level. This tends to indicate that one of the ovens is drying the soil samples drier than the other. When the time treatments of the infrared oven are compared, the 30 minute treatment against the average of the 60 and 90 minutes treatments, a highly significant difference is indicated by the high value of the calculated "F". When the 60 minutes treatment is compared with the 90 minutes treatment, we get a relative low valued calculated "F". This shows that there is not a significant difference between the two treatments. That is, the 60 minute treatment will dry this soil just as dry as the

TABLE I

SOIL NO 1 SOIL TYPE sand *

The percent of soil moisture removed by the infrared oven with 30, 60, and 90 minutes of exposure and by the standard oven after 24 hours.

Moisture Level	Per Cent of Moisture Removed d. w. b. — Time in Oven — Infrared oven (minutes) 30	60	90	Standard Oven 24 hours
1	2.8	2.9	2.9	2.2
	2.9	3.0	3.1	2.2
	3.2	3.1	3.1	2.2
2	10.9	11.4	11.1	10.2
	11.0	11.4	11.5	10.3
	11.1	11.8	11.6	10.5
3	11.7	11.9	11.9	11.0
	11.9	12.1	12.0	11.2
	12.1	12.4	12.5	11.8
4	14.4	15.0	14.0	13.8
	14.7	15.0	15.0	13.9
	14.7	15.0	15.2	13.9
5	23.2	24.0	24.6	23.0
	23.6	24.3	24.8	23.5
	24.3	25.6	24.9	24.7

*per cent of sand 87
per cent of silt 7.5
per cent of clay 5.5

TABLE II

SOIL NO 2 SOIL TYPE loam *

The percent of soil moisture removed by the infrared oven with 30, 60, and 90 minutes of exposure and by the standard oven after 24 hours.

Moisture Level	Per Cent of Moisture Removed d. w. b.			
	Time in Oven			
	Infrared oven (minutes) 30	60	90	Standard Oven 24 hours
1	11.4	12.8	13.0	9.6
	11.6	13.0	13.2	9.9
	11.9	13.1	13.2	9.9
2	14.4	15.2	15.4	12.3
	14.7	15.6	15.5	12.3
	14.9	15.7	15.5	12.4
3	17.1	18.0	18.4	15.3
	18.1	18.7	19.4	16.0
	18.4	19.1	19.4	16.2
4	23.5	24.6	24.6	21.6
	23.7	25.7	24.7	21.9
	24.0	26.0	26.1	22.5
5	27.2	29.4	27.7	26.3
	27.5	29.6	29.3	26.7
	29.0	29.6	30.5	27.4

*per cent of sand 59
per cent of silt 31
per cent of clay 10

TABLE III

SOIL NO 3 SOIL TYPE clay loam *

The percent of soil moisture removed by the infrared oven with 30, 60, and 90 minutes of exposure and by the standard oven after 24 hours.

Moisture Level	Per Cent of Moisture Removed d. w. b. — Time in Oven — Infrared oven (minutes) 30	60	90	Standard Oven 24 hours
1	9.9	10.0	9.9	8.3
	10.0	10.3	10.3	8.4
	10.1	10.3	10.5	8.4
2	13.8	14.3	14.5	12.5
	13.9	14.5	14.6	12.5
	14.1	14.5	14.6	12.5
3	15.0	14.9	15.1	13.5
	15.1	15.5	15.6	13.9
	15.5	15.5	16.0	14.3
4	18.0	18.3	17.9	16.1
	18.7	18.3	18.4	16.4
	18.8	18.3	18.6	16.7
5	22.1	23.6	23.7	21.2
	22.1	23.8	23.9	21.6
	23.3	24.6	24.5	21.8

* per cent of sand 44
per cent of silt 32
per cent of clay 24

TABLE IV

SOIL NO 4 SOIL TYPE loam *

The percent of soil moisture removed by the infrared oven with 30, 60, and 90 minutes of exposure and by the standard oven after 24 hours.

Moisture Level	Per Cent of Moisture Removed d. w. b. — Time in Oven — Infrared oven (minutes) 30	60	90	Standard Oven 24 hours
	17.2	18.2	18.2	15.8
1	17.5	18.4	18.6	16.2
	17.7	18.6	20.0	16.8
	18.6	19.5	18.8	17.0
2	18.9	19.7	18.8	17.6
	19.2	21.3	19.6	17.9
	21.3	21.6	21.8	19.4
3	21.4	21.8	22.1	19.5
	21.5	22.0	22.2	19.6
	21.9	26.2	26.3	23.6
4	23.7	26.3	26.5	24.0
	24.8	26.4	26.5	24.0
	22.3	27.7	27.5	24.1
5	26.3	27.7	27.7	25.2
	27.1	27.7	28.3	25.2

*per cent of sand 43
per cent of silt 38
per cent of clay 19

TABLE V

SOIL NO 5 SOIL TYPE clay *

The percent of soil moisture removed by the infrared oven with 30, 60, and 90 minutes of exposure and by the standard oven after 24 hours.

Moisture Level	Per Cent of Moisture Removed			
	Time in Oven			
	Infrared oven (minutes)			Standard Oven
	30	60	90	24 hours
	22.6	22.8	22.6	22.4
1.	23.2	23.7	23.1	21.3
	23.3	24.1	24.8	23.0
	24.7	28.3	28.5	26.8
2.	24.8	28.5	28.6	26.8
	26.8	28.8	29.1	27.1
	26.1	28.8	29.1	26.7
3.	26.1	29.2	29.4	27.6
	27.1	29.4	29.4	28.4
	28.0	29.4	28.9	27.5
4.	28.5	30.1	30.1	28.0
	29.3	31.4	30.9	28.5
	24.7	29.6	30.1	28.0
5.	26.0	30.0	30.1	28.1
	26.2	30.3	30.2	28.4

*per cent of sand 32
percent of silt 36
percent of clay 32

TABLE VI

SOIL NO 6 SOIL TYPE sand *

The percent of soil moisture removed by the infrared oven with 30, 60, and 90 minutes of exposure and by the standard oven after 24 hours.

Moisture Level	Per Cent of Moisture Removed d. w. b.			
	Time in Oven			
	Infrared oven (minutes) 30	60	90	Standard Oven 24 hours
	13.4	13.3	14.5	12.8
1	13.8	13.9	15.1	13.1
	14.2	14.0	15.6	13.6
	14.1	14.4	14.9	13.2
2	14.2	14.6	15.0	14.0
	14.2	14.6	15.4	14.2
	17.3	18.0	17.8	14.6
3	17.7	18.1	17.9	17.0
	17.7	18.4	18.0	17.1
	19.4	20.9	20.8	19.7
4	20.1	21.1	20.9	20.1
	20.3	21.1	21.5	20.3
	20.4	20.6	20.4	19.7
5	20.7	21.0	20.7	20.3
	21.3	21.3	20.9	20.7

*per cent of sand 87
per cent of silt 7
per cent of clay 5

TABLE VII

SOIL NO 1 SOIL TYPE Sand

Computation of "F", test of significance of difference between block moisture level, method of treatment and interaction of the moisture level and treatment.

Variate	df	ss	ms	F-Value Calculated	F-Value 5%	F-Value 1%
Total	59	2860.510				
Block Moisture	4	2844.460	711.110			
Method	3	9.120	3.040	22.100**	2.84	4.31
Stand V_s I R	1	7.480	7.480	54.200**	4.08	7.31
30 V_s $\frac{60/90}{2}$	1	1.616	1.616	11.820**	4.08	7.31
60 V_s 90	1	0.016	0.016	0.116	4.08	7.31
Moisture X Method	12	1.390	0.116	0.840	2.00	2.66
Error	40	5.540	0.138			

90 minutes treatment. Therefore, this big difference, indicated in the comparison of the 30 minute treatment versus the average of 60 and 90 minute treatment must occur between 30 and 60 minutes. This means that somewhere between 30 and 60 minutes, the soil samples are completely dry.

The data in table VIII, ("F" value for loam type soil), computed from table II, shows a highly significant difference when the four treatments were compared with each other. Still further analysis showed that there was a highly significant difference in the results obtained from the infrared oven and the standard oven. The orthognal breakdown of the treatment in the infrared oven showed that there was a highly significant difference between the 30 minutes treatment and the average of the 60 and 90 minutes treatment. However, no significance was noted when the 60 minute treatment was compared with the 90 minute treatment nor was there interaction. It is here indicated that, with a loam soil, the infrared oven will dry it somewhere between 30 and 60 minutes.

Table IX, ("F" value for clay loam), was computed from table III. It shows a highly significant difference between the methods of treatment. There was also a highly significant difference between the treatment of the infrared oven and the standard oven. A highly significant difference was also noted when the 30 minutes treatment was compared to the average of the 60 and 90 minutes treatment. When the 60 minutes treatment was compared with the 90 minutes treatment, there was no significant difference in the amount of moisture removed by either treatment. With clay loam type soil, the interaction appeared to be significant. Yet, it is possible that this may be due intirely, or partially, to the fact that the significance between the 30 minutes treatment and the average of the 60 and 90 minutes treatment was so high, as indicated by the extremely high calculated "F" value.

TABLE VIII

SOIL NO 2 SOIL TYPE Loam

Computation of "F", test of significance of difference between block mositure level, method of treatment and interaction of the moisture level and treatment.

Variate	df	ss	ms	F - Value Calculated	5%	1%
Total	59	2333.022				
Block Moisture	4	2219.432	554.850	1335.000		
Method	3	93.390	31.130	** 75.000	2.84	4.31
Stand V_s I R	1	78.010	78.010	** 188.000	4.08	7.31
30 V $\frac{60 + 90}{2}$	1	15.370	15.370	** 37.000	4.08	7.31
60 V_s 90	1	0.001	0.001	0.003	4.08	7.31
Moisture X Method	12	2.51	0.200	0.482	2.00	2.66
Error	40	16.69	0.417			

TABLE IX

SOIL NO 3 SOIL TYPE Clay loam

Computation of "F", test of significance of difference between block moisture level, method of treatment and interaction of the moisture level and treatment.

Variate	df	ss	ms	F - Value Calculated	5%	1%
Total	59	1223.400				
Block Moisture	4	1176.580	294.140	2675.00		
Method	3	38.550	12.850	116.80**	2.84	4.31
Stand V_s IR	1	36.180	36.180	323.50**	4.08	7.31
30 V_s $\frac{60 + 90}{2}$	1	2.300	2.300	20.90**	4.08	7.31
60 V_s 90	1	0.065	0.065	0.59	4.08	7.31
Moisture X Method	12	3.850	0.320	2.90**	2.00	2.66
Error	40	4.420	0.110			

Table X, ("F" value for loam), was computed from the data in table IV. In this table, the method of treatment was highly significant. The comparison of the standard oven and the infrared oven appeared to be highly significant. The comparison of the 30 minutes treatment and the average of the 60 and 90 minutes treatment showed to be highly significant, but the comparison of the 60 minutes treatment with the 90 minutes treatment appeared to be not significant. This indicated that the soil samples were not completely dry at 30 minutes but they were about as dry at 60 minutes as they were at 90 minutes. This test also showed that for loam type soil, interaction was not significant.

Table XI, ("F" value for clay type soil), was computed from table V. In this test, the calculated "F" values showed that the method of treatment was highly significant. Within the method, the comparison of the infrared oven and the standard oven appeared to be highly significant. The comparison of the 30 minute treatment with the average of the 60 and 90 minute treatments in the infrared oven showed that there was a highly significant difference in the amount of moisture removed by the two treatments. However, when the 60 minutes treatment was compared with the 90 minutes treatment, there was no significant difference. This indicates that for clay type soil, more than 30 minutes are needed to dry out a sample, yet at 60 minutes, it is as dry as it is at 90 minutes. These tests on clay type soil showed that the interaction was significant. Yet, again we notice that the calculated "F" value for comparison of the treatments of the infrared oven and the standard oven was very high. It is believed that the calculated "F" value for these treatments had affected the value of the "F" that was calculated for the interaction.

TABLE X

SOIL NO 4 SOIL TYPE loam

Computation of "F", test of significance of difference between block moisture level, method of treatment and interaction of the moisture level and treatment.

Variate	df	ss	ms	F - Value Calculated	F - Value 5%	F - Value 1%
Total	59	782.370				
Block Moisture	4	678.020	169.500	278.000		
Method	3	67.480	22.490	36.950**	2.84	4.31
Stand V_s I R	1	42.730	42.730	70.000**	4.08	7.31
$\frac{30\ V_s\ 60/90}{2}$	1	24.750	24.750	40.600**	4.08	7.31
60 V_s 90	1	0.001	0.001	0.0016	4.08	7.31
Moisture X Method	12	12.370	1.030	1.74	2.00	2.66
Error	40	24.500	0.610			

TABLE XI

SOIL NO 5 SOIL TYPE Clay

Computation of "F", test of significance of difference between block moisture level, method of treatment and interaction of the moisture level and treatment.

Variate	df	ss	ms	F - Value Calculated	5%	1%
Total	59	392.470				
Block Moisture	4	282.690	70.670			
Method	3	70.970	23.660	52.700**	2.84	4.31
Stand V_s I R	1	9.293	9.293	20.610**	4.08	7.31
30 V_s $\frac{60+90}{2}$	1	61.669	61.669	137.100**	4.08	7.31
60 V_s 90	1	0.008	0.008	0.017	4.08	7.31
Moisture X Method	12	20.790	1.730	3.85**	2.00	2.66
Error	40	18.020	0.450			

Table XII, ("F" value for sand), was computed from table VI. This table follows the general pattern of the other tables (VII through XI) in that the method of treatment is highly significant, the comparison of the infrared oven with the standard oven is highly significant, the comparison of the 30 minutes treatment with the average of the 60 and 90 minutes treatments are highly significant, and the comparison of the 60 minutes treatment with the 90 minutes is not significant to the amount of moisture removed. But table XII like table IX and XI differ from tables VII, VIII and X in that the interaction shows to be significant. Also like tables IX and XI, table XII shows high calculated "F" values for either one or both the comparison of the standard oven with the infrared oven or the comparison of the 30 minutes treatment with the average of the 60 and 90 minutes treatment.

Table VII through XII, each for a different soil type, are all consistent in showing that; (a) the infrared oven dries the soil samples drier than the standard oven; and (b) that the drying time in the infrared oven is somewhere between 30 and 60 minutes. The soil types are not consistent in showing the significance of the interaction. Three showed interaction to be insignificant whereas three indicated that there is reason to suspect that interaction is significant in determining the amount of moisture removed.

REGRESSION STUDY. In figures (7 through 12) the average of the percent of moisture removed from three samples by the infrared oven in 30, 60, and 90 minutes was plotted against that removed by the conventional oven after 24 hours. A regression study tends to indicate that there is a close similiarity between the conventional oven and the 60 and 90 minutes treatments. In five out of six graphs, both the 60 and the 90 minutes curves are nearly parallel to and tend to average out about 1.90 percent drier than the conventional oven. Figure 11 shows

TABLE XII

SOIL NO 2 SOIL TYPE Sand

Computation of "F", test of significance of difference between block moisture level, method of treatment and interaction of the moisture level and treatment.

Variate	df	ss	ms	F - Value		
				Calculated	5%	1%
Total	59	523.110				
Block Moisture	4	494.940	123.73			
Method	3	13.520	4.506	20.30**	2.84	4.31
Stand V_s I R	1	9.846	9.846	44.350**	4.08	7.31
30 V_s $\frac{60/90}{2}$	1	3.173	3.173	14.29**	4.08	7.31
60 V_s 90	1	0.526	0.526	2.370	4.08	7.31
Moisture X Method	12	5.770	0.481	2.17*	2.00	2.66
Error	40	8.880	0.222			

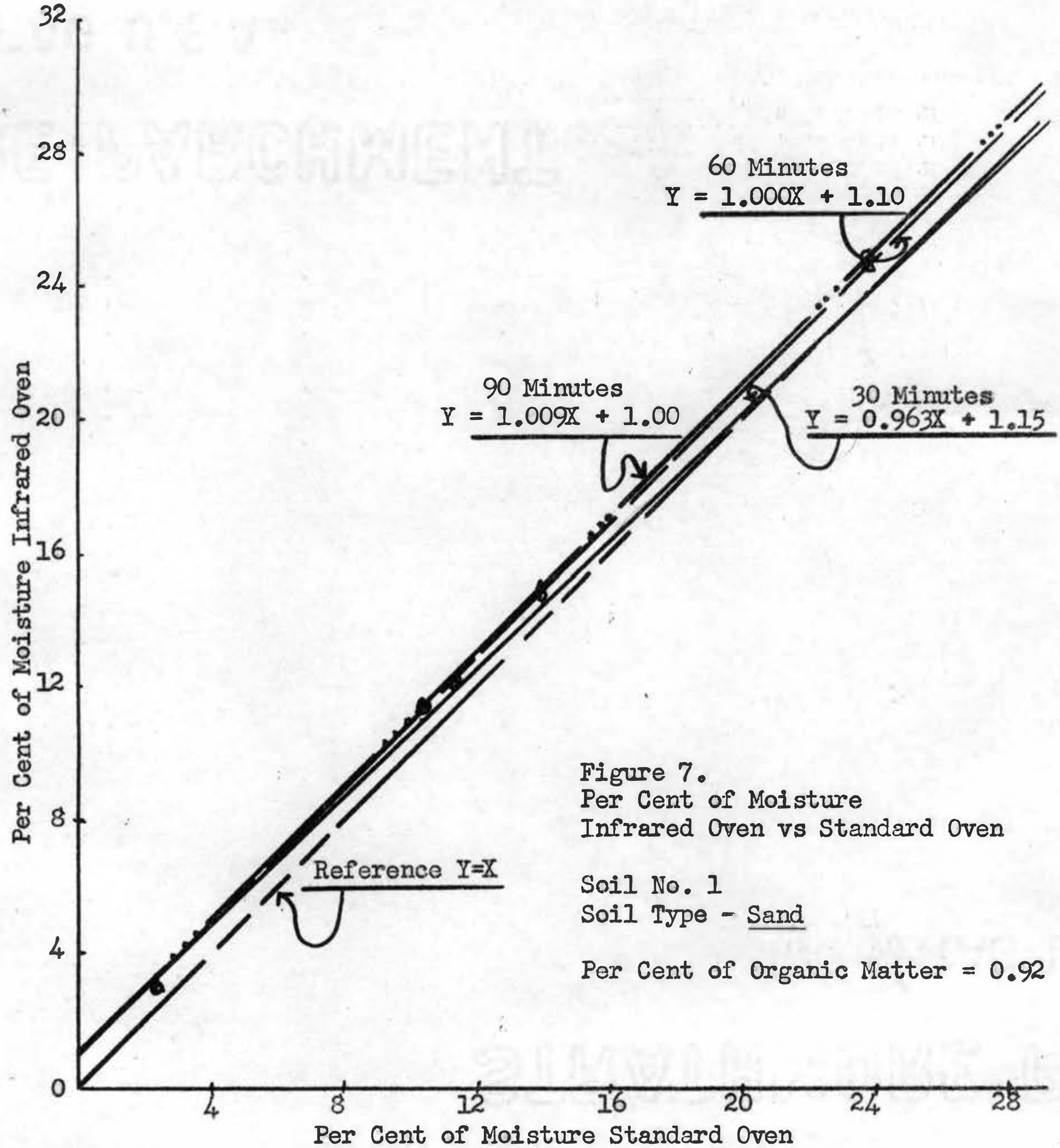

Figure 7.
Per Cent of Moisture
Infrared Oven vs Standard Oven

Soil No. 1
Soil Type - Sand

Per Cent of Organic Matter = 0.92

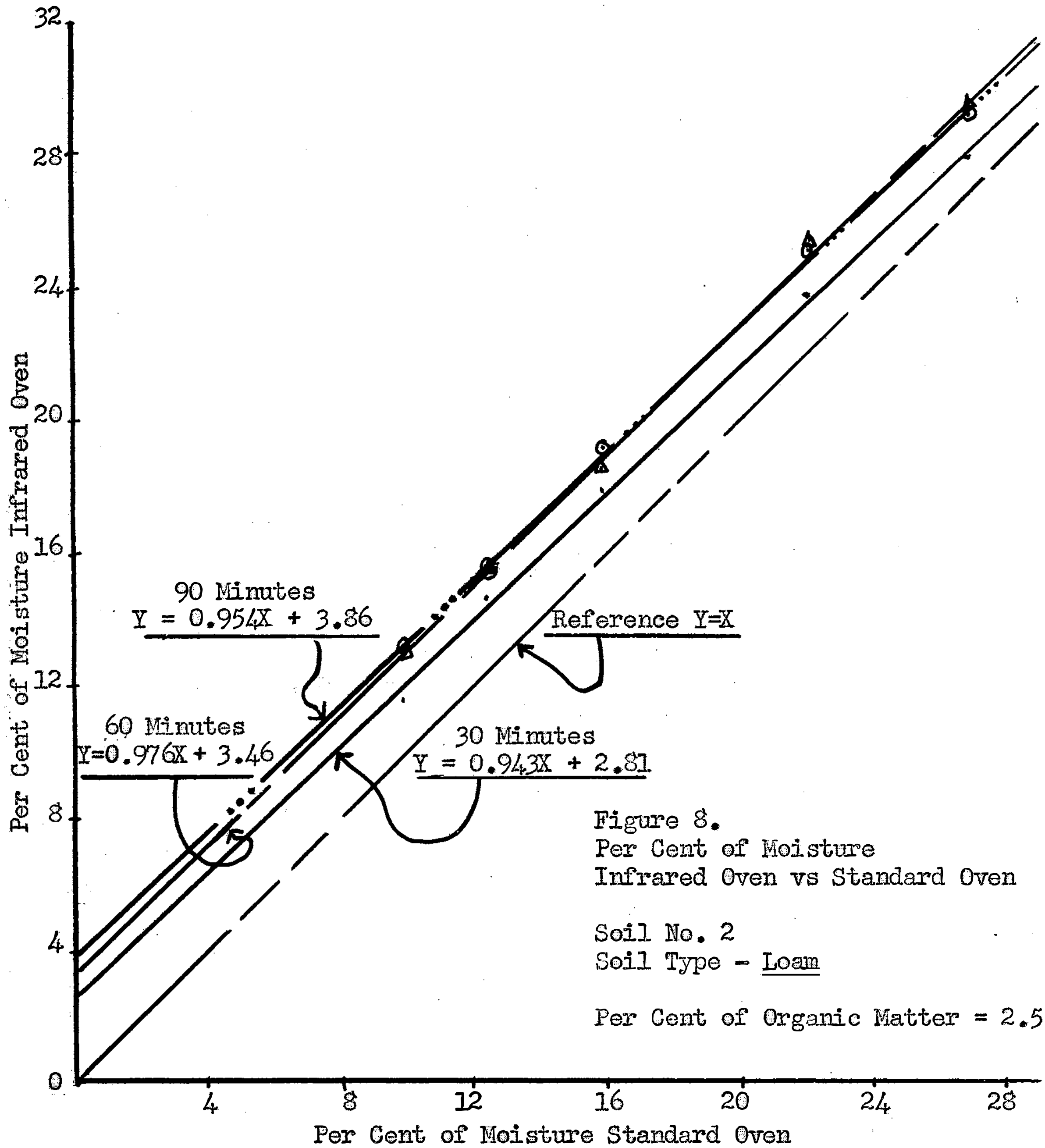

Figure 8.
Per Cent of Moisture
Infrared Oven vs Standard Oven

Soil No. 2
Soil Type - Loam

Per Cent of Organic Matter = 2.55

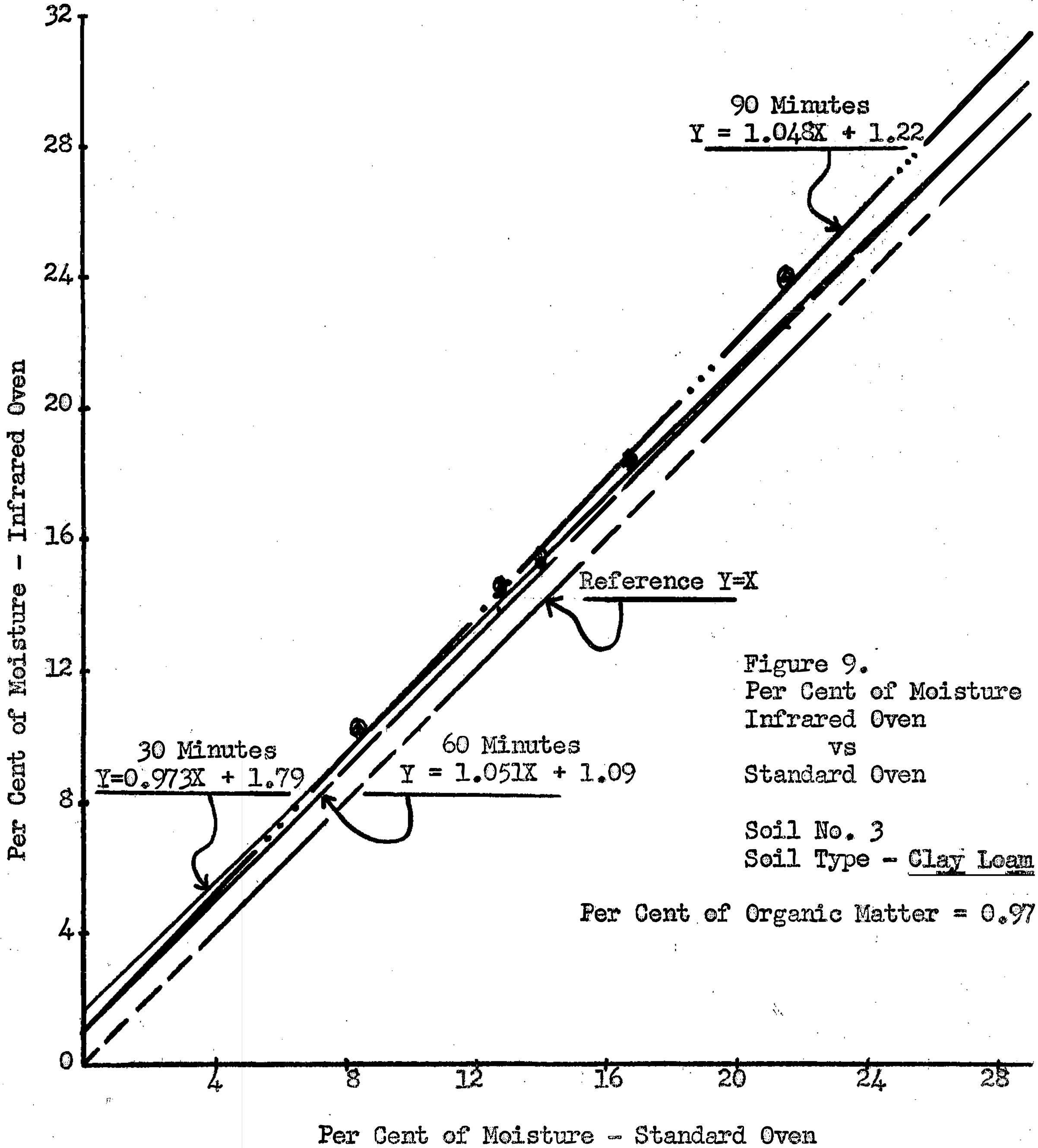

Figure 9.
Per Cent of Moisture
Infrared Oven
vs
Standard Oven

Soil No. 3
Soil Type - Clay Loam

Per Cent of Organic Matter = 0.97

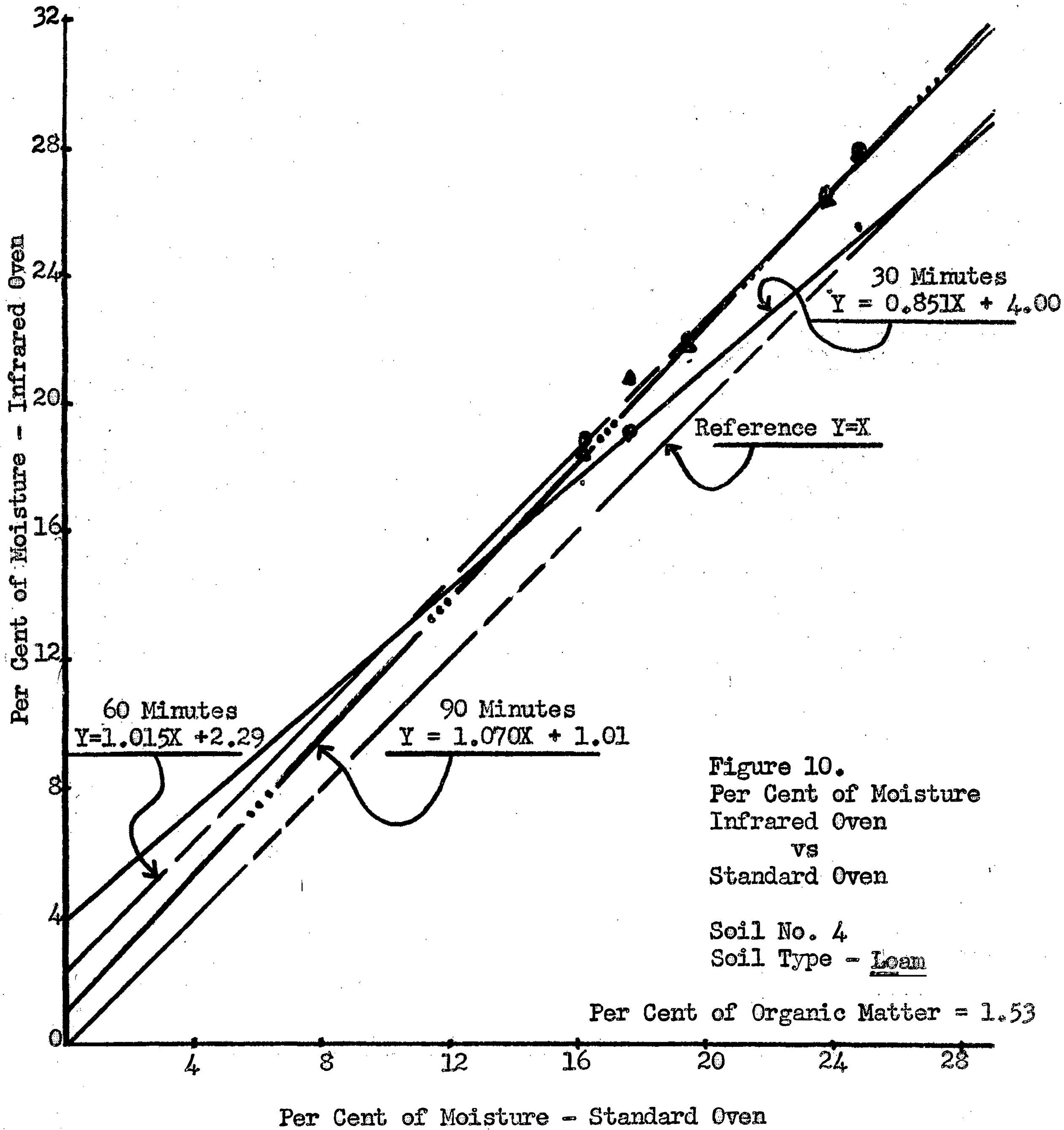

Figure 10.
Per Cent of Moisture
Infrared Oven
vs
Standard Oven

Soil No. 4
Soil Type - Loam

Per Cent of Organic Matter = 1.53

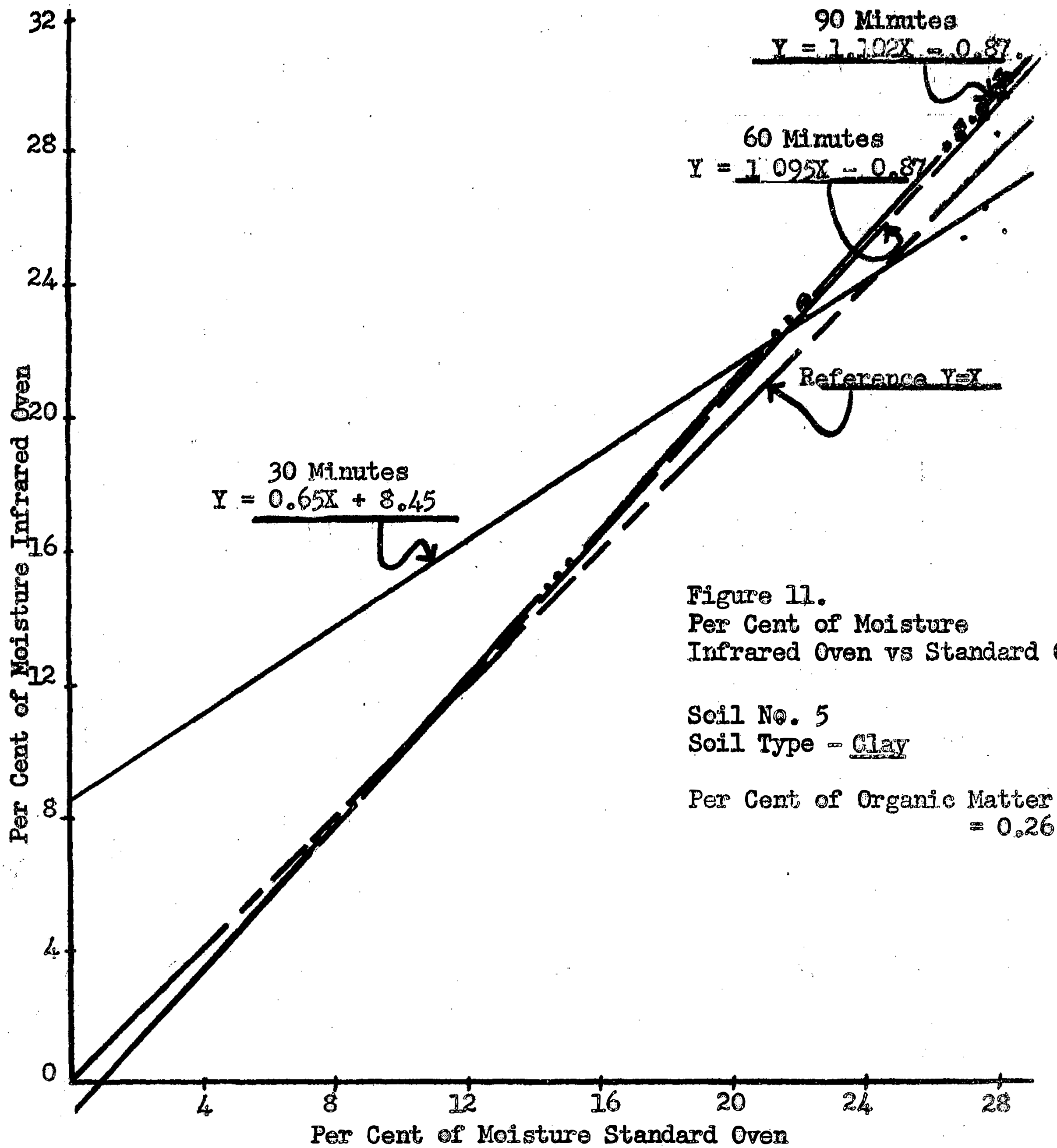

Figure 11.
Per Cent of Moisture
Infrared Oven vs Standard Oven

Soil No. 5
Soil Type - Clay

Per Cent of Organic Matter = 0.26

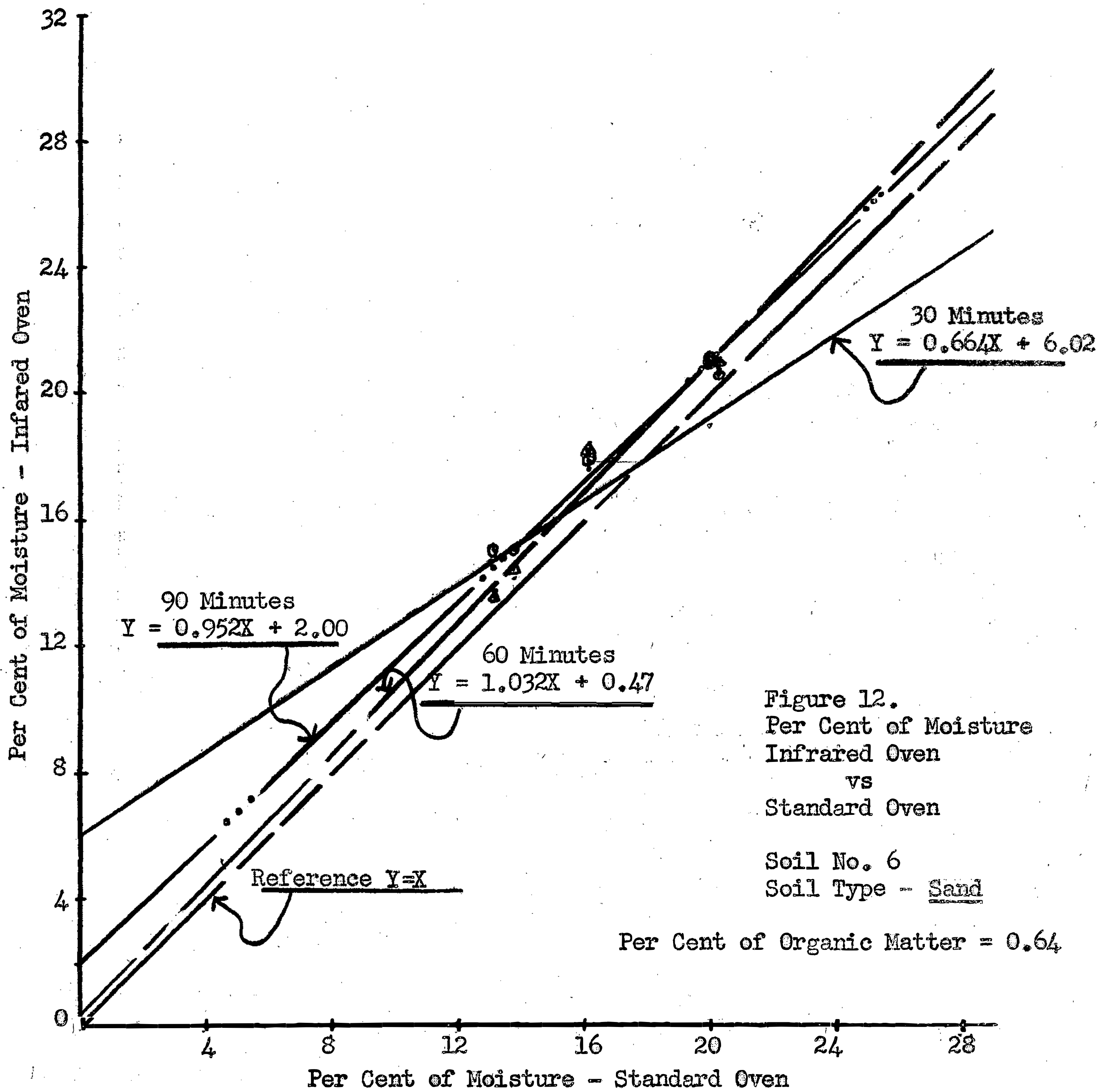

Figure 12.
Per Cent of Moisture
Infrared Oven
vs
Standard Oven

Soil No. 6
Soil Type - Sand

Per Cent of Organic Matter = 0.64

differences in several aspects; (a) both the 60 and 90 minutes cross the reference line at about the same place and (b) the 30 minutes treatment has a much greater slope than the others, increasing the horizontal angle made with the reference line. This would indicate that for clay type soil with a moisture content higher than 24 percent, the 30 minutes drying time will not get all the water out. Figure 12 has some of the characteristics of figure 11 in that the 30 minute curve forms a relatively large angle with the reference line. In all cases the slope of the 30 minute curve is less than that of the reference line. Likewise, in all cases the slopes of both the 60 and 90 minute curves are almost as great or are greater than that of the reference curve. In these regression studies, only soil type clay showed any tendencies of the ordinate to be negative with a positive abscissa. No tests were run on the clay soil at low moisture per cents. All were above 22 percent.

ORGANIC MATTER

One test for each of the six soil types, near the middle of the moisture levels, was designated as a spot-check test and one sample from each of these "spot-check" tests were analyzed after they came out of the oven to determine their organic matter content. These analyses were compared with a sample of the same soil that had not been exposed to either oven. The data of these analyses are contained in table XIII and plotted in graph, (Figure 13). This graph shows that both the 60 and 90 minutes treatments tend to reduce the organic matter content of all soils.

Figure 13 tends to show that some of the difference in the amount of moisture removed by the 60 minutes treatment in the infrared oven and the moisture removed by the 24 hour treatment in the standard soil

TABLE XIII

Percent of organic matter after 30, 60, and 90 minutes in the infrared oven and after 24 hours in the standard oven.

Soil No.	Control	30 Minutes Infrared	60 Minutes Infrared	90 Minutes Infrared	Standard Oven
1	0.92	0.64	0.40	0.40	0.87
2	2.55	2.08	0.63	0.59	2.53
3	0.97	0.73	0.45	0.38	0.78
4	1.53	1.20	0.73	0.49	1.44
5	0.26	0.21	0.17	0.17	0.24
6	0.64	0.28	0.26	0.21	0.61

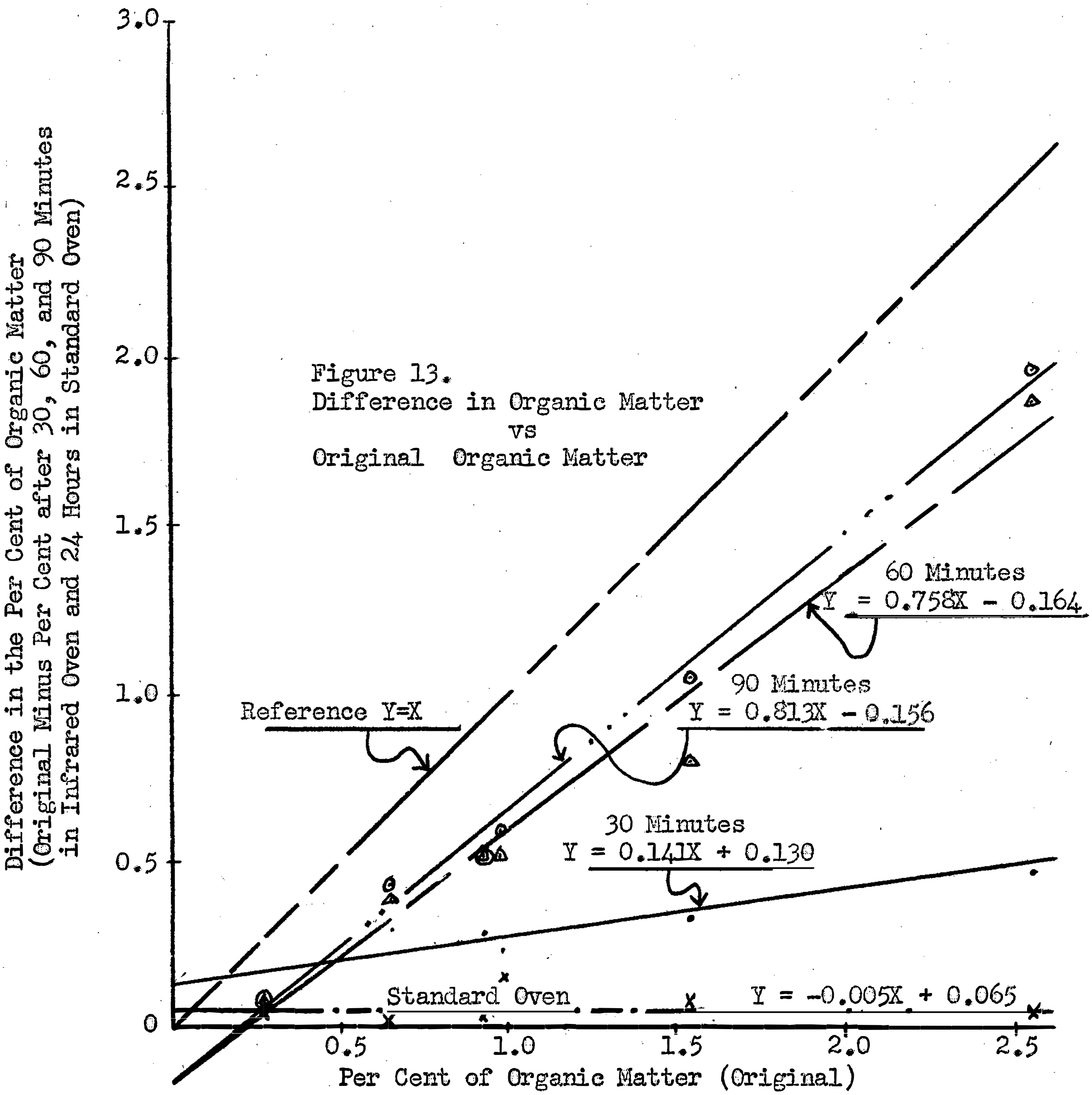

Figure 13.
Difference in Organic Matter
vs
Original Organic Matter

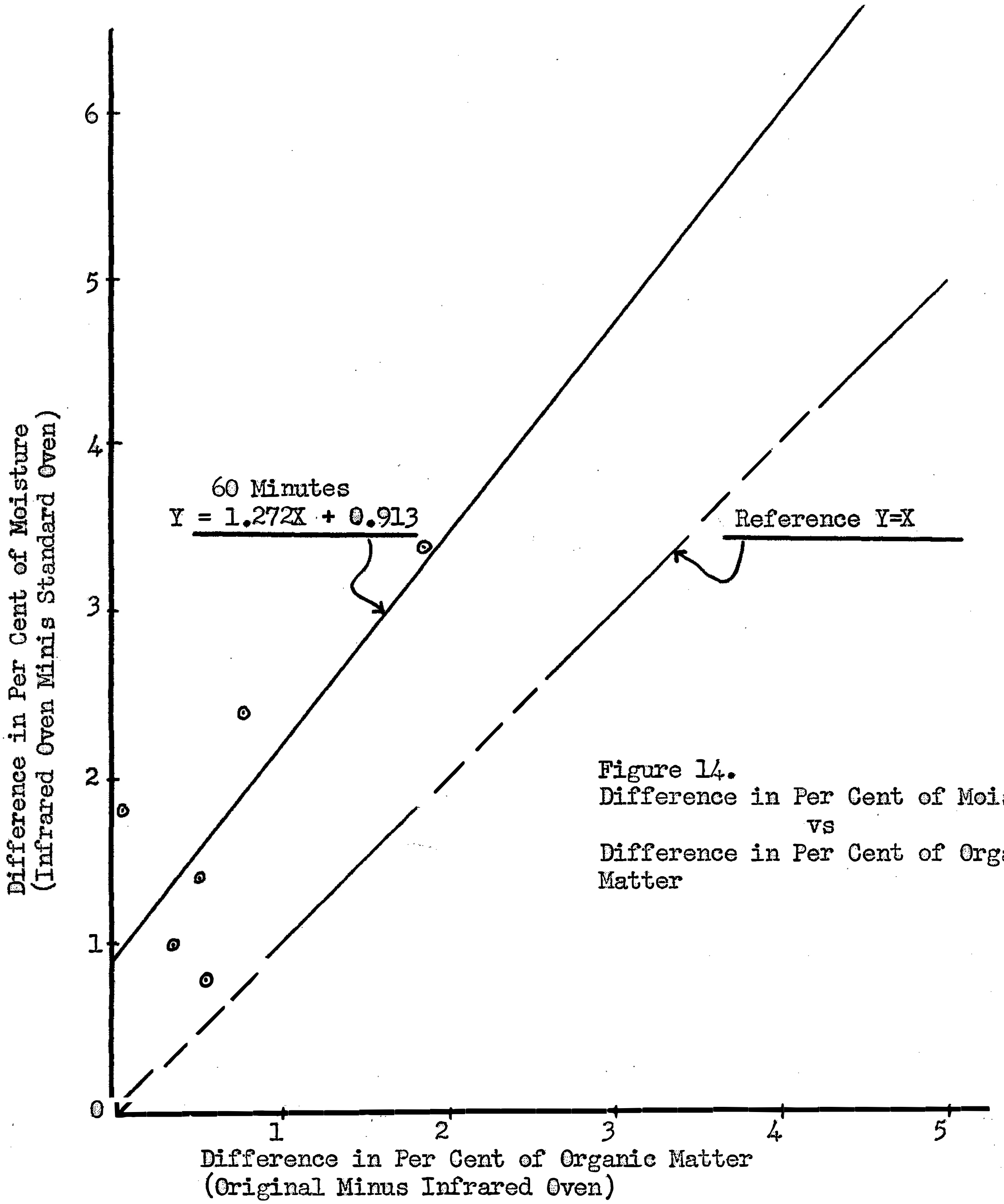

Figure 14.
Difference in Per Cent of Moisture
vs
Difference in Per Cent of Organic Matter

oven was probably due to reduction of the organic matter content. Figure 14 and 15 more clearly shows that the loss in organic matter is responsible for the increase in the amount of moisture removed by the infrared oven over the standard oven. The 60 minute treatment curves were used in these graphs because it had been shown that there was no significant difference in the amount of moisture removed by the 60 minutes treatment and the 90 minutes treatment. Also, the 30 minutes treatment had not completely dried three of the six soil samples.

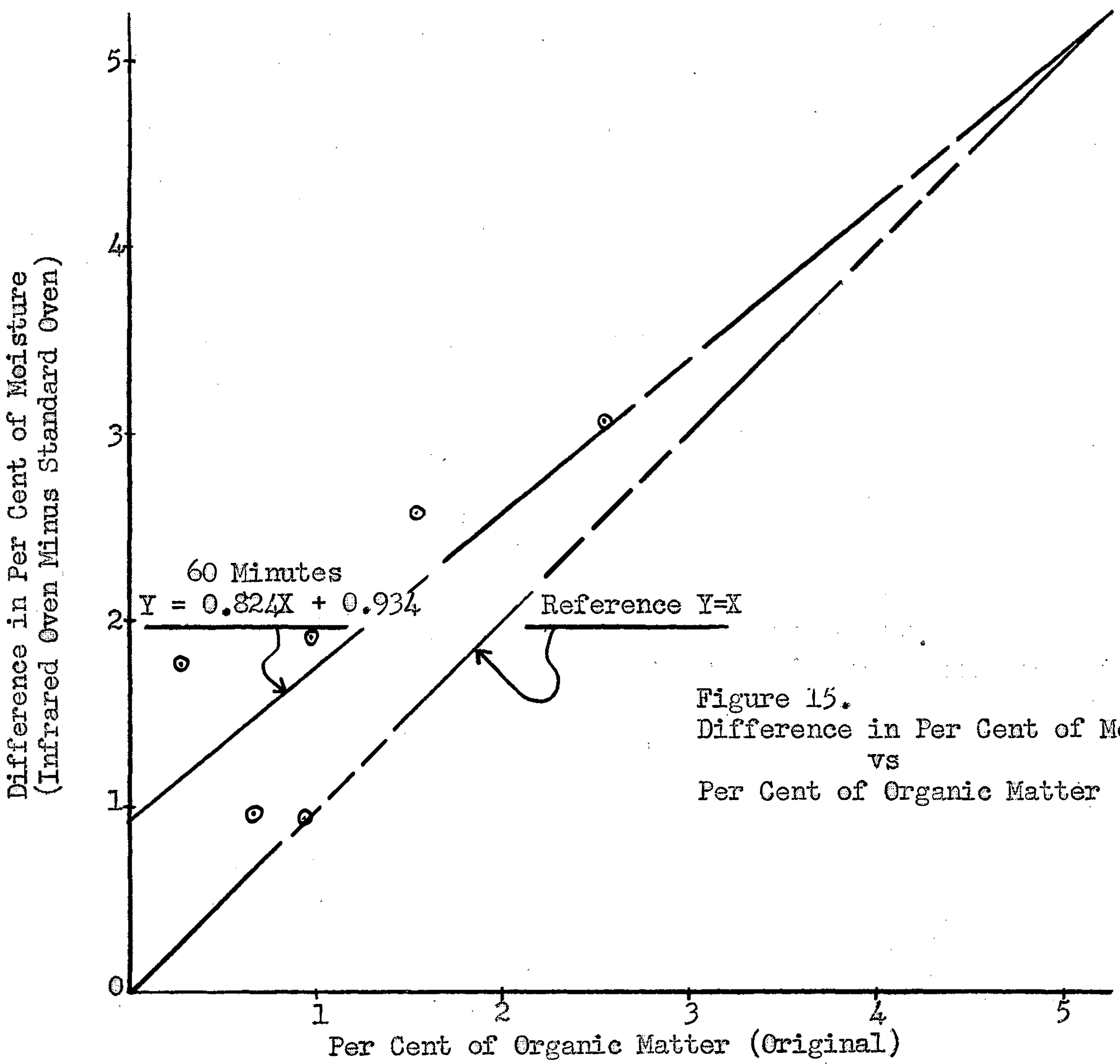

Figure 15.
Difference in Per Cent of Moisture
vs
Per Cent of Organic Matter

RESULTS

Tables I through VI were designed to show the percent of moisture removed by the standard oven in 24 hours and the infrared oven for 30, 60 and 90 minutes of treatment. In the analyses, it was first assumed that all of the loss in weight of a soil sample after exposing it in either oven was due entirely to evaporated moisture. It was noted on that basis that the infrared oven would get more moisture out of a soil sample than the standard oven. Figure 18 shows that the infrared oven removed an average of about 1.90 percent more moisture than the standard oven. The ratio of the percent of moisture removed by the standard oven to the percent of moisture removed by the infrared oven is $P_s = \frac{P_{ir} - 1.60}{1.0182}$

where P_s = percent of moisture removed by standard oven

where P_{ir} = percent of moisture removed by infrared oven

The standard deviation from the regression was 0.798 percent of soil moisture.

Analysis of the organic matter contents of samples run through both ovens showed that there is probably some oxidization of any soil samples that are normally run through either oven. The time of exposure in the infrared oven appeared to have a decided effect on the amount of organic matter oxidized, especially as the original organic matter content increased.

When the reduction in soil moisture was compared with the reduction in organic matter, the values of 30 minutes treatment were not to meaningful in that three of the values were negative. Yet, all curves had a similar appearance. The 60 and 90 minutes curve show the same general trend all along. As the original organic matter contents increased, there was a greater difference in the amount of soil moisture removed by the two ovens (Figure 13 and 14). The infrared oven appears to remove more moisture from soils than the standard oven when actually this loss in weight is not due entirely to loss in moisture but is due partially to the loss in organic matter. After 90 minutes in the infrared oven there was an average of about 62.0 percent of the original organic matter removed from all soils. After 60 minutes in the infrared oven there was an average of about 56.0 percent of the original organic matter removed from the soil samples. After 30 minutes in the infrared oven there was an average of 25.0 percent of the original organic matter removed from the soils samples. Whereas after 24 hours the standard oven removed an average of about 7.0 percent of the original organic matter.

Figures 16 and 17 indicate that there is no significant correlation between the difference in moisture (infrared oven with 60 minutes exposure minus the conventional oven) and the original moisture percent or with the percent of clay in the sample.

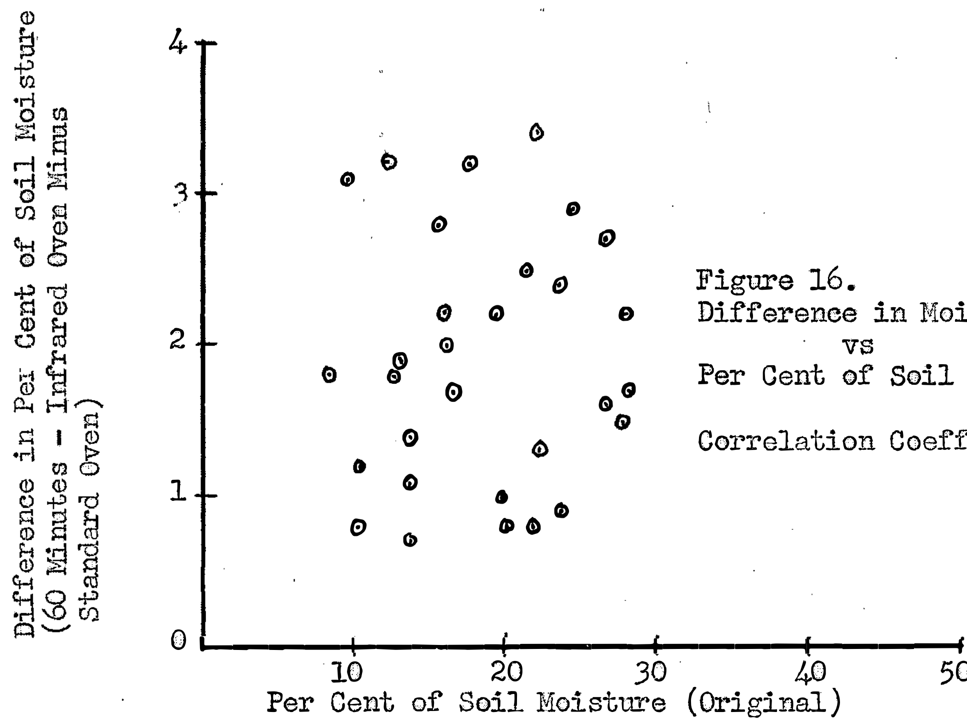

Figure 16.
Difference in Moisture
vs
Per Cent of Soil Moisture

Correlation Coefficient = 0.200

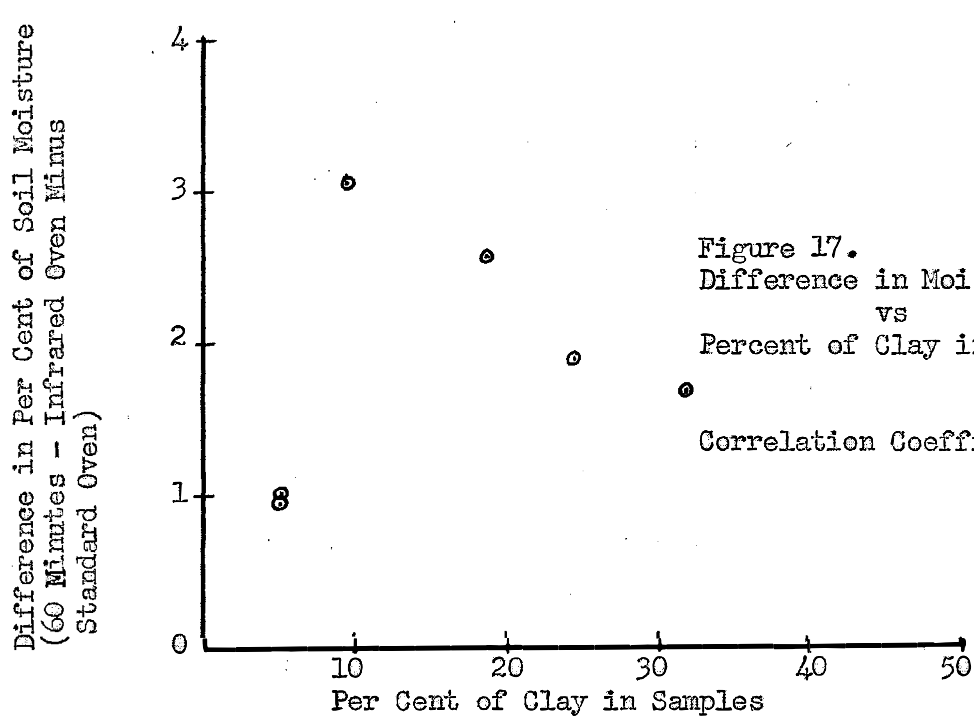

Figure 17.
Difference in Moisture
vs
Percent of Clay in Samples

Correlation Coefficient = 0.248

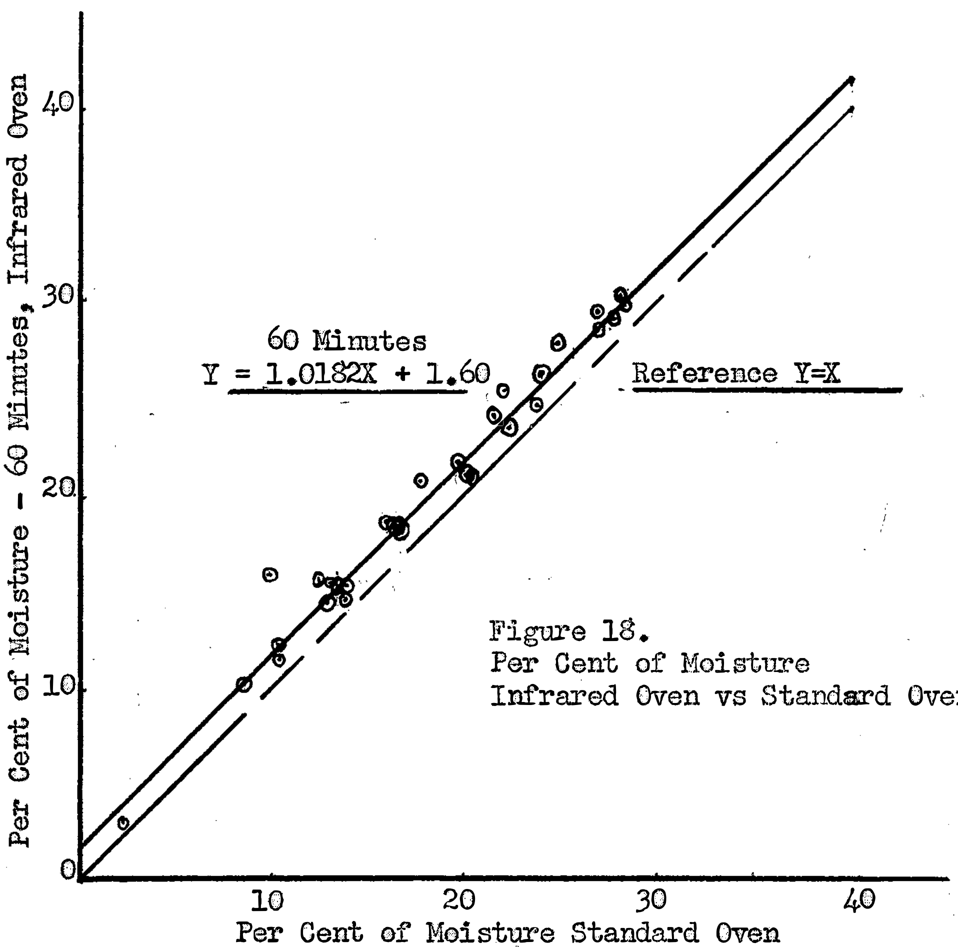

Figure 18.
Per Cent of Moisture
Infrared Oven vs Standard Oven

CONCLUSIONS

1. The infrared oven will dry soils faster than the conventional oven with some sacrifice of accuracy.

2. All soils were as dry in 60 minutes as they were in 90 minutes. Sixty minutes was the shortest time tested in which all samples were completely dry.

3. Sixty minutes of exposure in the infrared oven removed an average of 56 percent of the original organic matter.

4. The increase in the amount of moisture removed from the samples can not all be accounted for as oxidized organic matter.

5. There is no significant correlation between the difference in moisture (infrared oven with 60 minutes exposure minus the conventional oven) and the original moisture percent or with the percent of clay in the sample.

6. The correction to be applied to the infrared oven with 60 minutes of exposure, based on these tests,

$$P_s = \frac{P_{ir} - 1.60}{1.0182}$$

where P_s = moisture removed by standard oven

where P_{ir} = moisture removed by infrared oven

7. The standard deviation from regression was 0.798 percent of soil moisture.

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