FINAL REPORT

For the Florida Department of Transportation

PB99-134009

Influence of Soil Suction and Environmental Condition on the Drying Rate for Some Problematic Soils Phase II Study

Research Report No. FL/DOT/RMC/0702 (2)-9192

State Job No.: 99700-7606-119

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FSU Project No.: 6120-518-39

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16. Abstract

There have been problems on pavement construction claimed by contractors in the State of Florida that the pavement soils hold excessive water and are difficult to dry and compact. This study presents recent research on the effects of the soil suction and the environmental conditions on the soil drying rate. A series of soil suction tests using thermocouple psychrometer method and the drying rate tests using the environmental chamber were conducted in this study. A review of soil suction theory was also conducted. The results of the experimental program show that both suction and relative humidity have direct effect on the soil drying rate. Drying rate decreases with an increase inn soil suction for each soil. As compared to the suction, relative humidity has more significant influence on the soil drying rate. For the A-2-4 soil, which contains percent of fines greater than 20%, the drying rate is low due to the higher suction.

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METRIC CONVERSIONS

inches = 25.4 millimeters

feet = 0.305 meters

square inches = 645.1 millimeters squared

square feet = 0.093 meters squared

cubic feet = 0.028 meters cubed

pounds = 0.454 kilograms

poundforce = 4.45 newtons

poundforce per square inch = 6.89 kilopascals

pound per cubic inch = 16.02 kilograms per meters cubed

DISCLAIMER

"The opinions, findings and conclusions expressed in this publication are those of the authors and not necessarily those of the Department of Transportation or the U.S. Department of Transportation. This publication is prepared in cooperation with the State of Florida Department of Transportation and the U.S. Department of Transportation."

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CHAPTER 1

INTRODUCTION

1.1 Problem Statement

Highway contractors in the State of Florida occasionally encounter soils, which are troublesome or problematic during construction. Common problems include excessive expansion, difficulty in compaction, and slowness in drying. The Florida Department of Transportation (FDOT) has attempted to avoid such problems by limiting the type of soils, which can be used in highway embankment.

According to the FDOT Design Standards (FDOT, 1992), three types of soils, based on the AASHTO Classification System, are selected for embankment use, namely, A-1, A-3, and A-2-4. A-1 soils consist of stone fragment, gravel and sand. A-3 soils are mostly fine sand. Both of these soils are generally rated as excellent to good for roadbed use. However, A-2-4 soils have a maximum of 35% passing No. 200 sieve and a maximum Plasticity Index (PI) of 10. Some types of A-2-4 soils may contain a certain percentage of clay. The clay soils retain excess moisture easily and can cause problems of expansion and slow drying. Therefore, FDOT tries to establish identification methods for screening out those problematic soils before construction.

The FDOT had chosen six potentially problematic soils around the State of Florida to examine their properties. A series of laboratory tests were performed to evaluate the engineering properties of six soils during Phase I study (McDonald, 1995). The laboratory tests consisted of Atterberg limits, grain-size analysis, compaction test, bearing ratio, expansion index, permeability, x-ray diffraction and scanning electron microscope (SEM). The results of the tests showed no significant indication of expansion or swelling and all soils were classified as "Very Low" and "Inactive" in regards to expansion potential. It was found that without the presence of Montmorillonite clay, the soils can also experience the same problem and therefore should not be used as an indicator.

Apparently the previous study could not identify the causes of these problematic soils. It was recommended to study the problem through the approach of environmental effect (i.e., temperature and humidity) and the influence of soil suction on the drying rate.

1.2 Scope of Study

The objective of this study was to find the effects of the soil suction and the environmental condition on the soil drying rate. The goal was to establish a guideline or specification to limit the A-2-4 soils for embankment use through the findings of the test results. Two types of laboratory tests were conducted to correlate the suction and the drying rate of a soil. First, a series of soil suction tests were conducted by using the thermocouple psychrometer method. Second, the soils were subjected to a range of temperature and humidity levels in an environmental chamber to investigate the effect on the drying rate. The soils used in this study were the same as those for the previous (Phase I) study, which were selected by the FDOT in conjunction with the researchers. The test results would allow further correlation of drying rate with suction.

1.3 Report Organization

This report summarizes the laboratory experimental program of suction and drying rate measurements to evaluate the effects of the soil suction and the environmental condition on the drying rate of the soil. This report is the second phase sequential to the previous (Phase I) study (McDonald, 1995).

The problem statement, background, and the objective of this study are presented in Chapter 1. A literature review of soil suction is presented in detail in Chapter 2. The previous (Phase I) work, which evaluated the engineering properties of six troublesome soils, is reviewed in Chapter 3. Two types of experimental program for evaluating the effects of the soil suction and the environmental condition on the soil drying rate are described in Chapter 4. The soil suction test results are presented and analyzed in Chapter 5. The drying rate test results are presented and analyzed in Chapter 6. Correlation and analysis of suction and drying rate experimental results are presented in Chapter 7. The conclusions along with the recommendations are stated in Chapter 8. Some test results from Phase I are included in Appendix A. The raw data and individual test results are summarized in the sequence of the calibration, suction, and drying rate tests in Appendices B, C, and D, respectively.

CHAPTER 2

LITERATURE REVIEW

2.1 Soil Suction Concept

2.1.1 Water in Soil

Two forms of moisture can occur in soil. One is the adsorbed water surrounding the grains in the form of a viscous film. Moisture attracted by a soil particle and accumulated either at its surface or even in its interior is termed " adsorbed moisture", though in the latter case the term "disrobed" would be more correct. The other form of moisture is free water, filling partially or completely, the voids between the grains. Ground water is termed "free" or "gravitational" because the action of gravity is prevailing in this case, whereas in other kinds of moisture the action of gravity is negligible in comparison with that of molecular forces and surface tension. They can be further classified into four catalogues as described in the following:

Combined water is the water held in chemical combination. It will not evaporate and can only be driven off by heating the soil.

Hygroscopic water is the water attracted from the air by soil particles, as common salt attracts water. It is held as a thin film around grains of soil and the finer the texture, the more the surface area to hold hygroscopic water. However, on exposure to variations of temperature and pressure, some evaporates, and may condense on another part of the soil.

Capillary water is the water attracted by particles from the level of a liquid and held by internal attraction against gravity. This water moves from areas of higher tension to lower tension, which may be upward, downward, or sideward. The water discussed in this study falls into this category.

Gravitational water is the water that drains away from a soil through large pores and cracks. Gravitational water is termed "free" or "gravitational" because the action of gravity is prevailing in this case, whereas in other kinds of moisture the action of gravity is negligible in comparison with that of molecular forces and surface tension.

Figures 2.1 and 2.2 systematically illustrate the water classification.

2.1.2 Establishment of Soil Suction Theory

Two approaches of analysis of soil water have been developed:

(1) The static equilibrium method, also known as the capillary rise method, based on the principles of static equilibrium in capillary tubes.

(2) The energy method, also known as the fluid potential method, based on the water potential of the soil.

Surface tension. In a mass of water, forces of attraction exist between the molecules. Below the surface forces tend to balance out resulting in a constant free molecular movement. The molecular attraction between molecules at the surface of the liquid differs from those in the interior of the mass of the liquid. At the surface, the reduced attraction between the liquid and air resulting in increased attractions along the surface of the liquid. These molecular forces pull and hold the water molecules together in a permanent state of tension so that the surface of the water permanently attempts to contract into a minimum area; hence, a drop of water is spherical. The effects of the surface tension can be easily understood by imagining that the surface of water is covered by a thin molecular membrane that is capable of carrying tensile stress. Such a surface cannot possibly exist but the idea is a useful concept to explain surface tension phenomena. Surface tension increases as temperature decreases.

Capillary rise. The earliest approach to the analysis of water retained between soil particles is based on the model representing the soil pores as a system of capillary tubes. A capillary tube is a glass tube of fine diameter. When such a tube is placed into a basin of water, the water inside the tube will be lifted up to a maximum height, h_c, above the surface of the water in the basin and come to equilibrium. In capillary water consideration it is customary to take the free water surface as a datum of zero pressure. So as in soils, we consider pressure above and below atmospheric pressure and simplify readings by taking the value of the atmospheric pressure, P_a, as equal to 0. As shown in Figure 2.3, the forces acting at the top of the water column can be derived from their vertical equilibrium as in equation 2.1:

$$2\pi rT\cos(\alpha) + \pi r^2 u = 0 \qquad (2.1)$$

Where

T = surface tension

α = contact angle

u = suction caused by surface tension

r = Radius of glass tube

From which

$$u = \frac{-2T\cos(\alpha)}{r} \tag{2.2}$$

The height of rise can be obtained by substituting $-\gamma_w h_c$ for u,

$$h_c = \frac{2T\cos(\alpha)}{\gamma_w r} \tag{2.3}$$

Both u and h_c depend on the value of r. They increase as r decreases. For water in a glass tube, $\alpha = 0$, $\gamma_w = 1$ g/cm^3 and T = 0.074 g/cm at 20°C.

$$h_{cmax} = \frac{0.296}{r} \tag{2.4}$$

In soils, there are no regular capillary tubes as such. The channels connecting the voids between soil particles are irregular in shape, size, and distribution. Therefore using the capillary tube model to simulate water in soils is unrealistic.

Energy concept. Due to the limitations of the static equilibrium method, previous researchers tried to explain the soil-water problem by using the potential energy concept. The introduction of the energy concept in soil mechanics dates back to 1907 when E. Buckingham formulated the capillary potential as the work per unit volume of water required pulling water away from soil. In classical studies, the soil water was described in terms of the "forms" of water, such as "gravitational water", "capillary water" and "hygroscopic water". Hillel [1971] argued that soil-water potential should replace the arbitrary categorization of these "forms" of water. Water differs from time to time and place to place not in form, but in its potential energy condition. In unsaturated soil, water is constrained by the capillary and absorptive forces. The water within the soil will exhibit suction of tension, which is at a pressure of less than one atmosphere. This kind of energy condition is generally called the soil tension or soil suction.

The theoretical relationship between water potential and relative humidity is given by Kelvin's equation, as follows:

$$\Psi = (RT / V_w) \log_e e/eo \qquad (2.5)$$

Where:

Ψ = water potential [Pa]

R = universal gas constant [8.3143 J mol $^{-1}$ K $^{-1}$]

e/e_o = relative humidity expressed as a fraction

T = absolute Temperature [K]

V_w = molar volume of water [$1.8*10^5 m^3\ mol^{-1}$]

Soil suction is a measure of the affinity of the soil for water, and is determined from the relative humidity at which there is no movement of water into or out of the soil. Soil suction can vary with season and depth. It is important to have knowledge of the soil suction both at the time of construction and long-term equilibrium has been achieved.

2.1.3 Historical Review of Energy Concept

In 1907, Buckingham first introduced the energy concept to describe the stress state of the soil water. He considered that the soil exerts an attraction sufficient to hold water against the action of gravity, and that this attraction decreases as the amount of water held by the soil increases. He proposed the term "capillary potential," ψ, to describe this attraction. $\psi(\theta)$ has been defined as the work required to pull a unit mass of water away from the large mass of soil whose water content is θ. He introduced the equation as follows:

$$\psi = f(x) \tag{2.6}$$

Where x is the height above water surface in a column of soil standing in water at equilibrium.

Before that time, only "water content" had been used to express the state of water in soil. But if the water contents of two soils are equal, the state of water in soil need not be the same. The concept of capillary potential enabled scientists to compare, with the same scale, the state of water in various moist soils quantitatively.

The concept of capillary potential proposed by Buckingham is in the basis of assuming that the water in soil is in contact with a free water surface. But in most cases, water in soil is subjected to certain pressure. It is not always realistic to measure the value of capillary potential of such water with Buckingham's concept.

Gardner et al [1922] solved the problem by proposing an equation that shows the relationship between the pressure of water in soil and its capillary potential as follows:

$$\psi = \int \frac{dp}{\rho} \tag{2.7}$$

Where

ρ = density of water in soil

P = pressure of water in soil relative to atmospheric pressure

In the general case, ρ is a function of pressure; however, assuming that water is incompressible, ψ becomes equal to P/ρ. The introduction of this relationship between ψ and ρ led to the development of apparatus for measuring capillary potential of water in soil which was not in contact with a free water surface. Tensiometer and suction plate methods were developed on the basis of the above equation. Gardner also pointed out the sign of the $f(x)$ in equation 2.6 should be negative.

The existence of solutes in soil solution can not be ignored in the studies of soil water potential. Various concepts were proposed in the decade after 1935 in an attempt to satisfy this demand. They included pF by Schofield [1935], water potential by Veihmeyer & Edlefsen [1937], osmotic potential and pressure potential by Day [1947], and soil moisture stress, the sum of water suction and osmotic pressure, by Wadleigh & Ayers [1945]. They are all expressions of total potential of water in soil relative to free water at the same temperature.

The concept of pF was introduced by Schofield [1935]. It is defined as the logarithm of the tension (expressed in cm. of water) under which the water is held in the soil.

Schofield has shown that this tension is equal to the decrease in the free energy of the water in the soil relative to a free water surface at the same temperature. It is therefore equal to the work that must be done to remove one gram of water from the soil.

In 1943, Edlefsen and Anderson published a highly valuable report entitled " Thermodynamics of Soil Moisture". It was the first systematic study of thermodynamics of water in soil, and it emphasized the importance of the use of chemical potential which is the water potential in soil.

2.1.4 Definition of Soil Suction

Precise definitions of total potential and its various component potentials were provided by a committee of The International Soil Science Society (ISSS) in 1963 and slightly modified in 1976. The total potential (ψ_t) of a soil can be divided into three components:

$$\psi_t = \psi_p + \psi_g + \psi_o \qquad (2.8)$$

Where:

ψ_t = total potential

ψ_p = pressure potential

ψ_g = gravitational potential

ψ_o = osmotic potential

The pressure potential, ψ_p, is defined as "the amount of useful work that must be done per unit quantity of pure water to transfer reversibly and isothermally to the soil water an infinitesimal quantity of water from a pool at standard atmospheric pressure that contains a solution identical in composition to the soil water and is at the elevation of the point under consideration" [Marshall, 1996]. Similar definitions have been given for gravitational potential, ψ_g, and osmotic potential, ψ_o, which refer to the effect of elevation and the effect of solutes on the energy status of soil water. The sum of gravitational and pressure potential is called hydraulic potential, ψ_h. For pressure potential, ISSS has further defined it as follows:

(1) The positive hydraulic pressure that exists below a water table.

(2) The potential difference experienced by soil that is under a gas pressure different from that of water in the reference state.

(3) The negative pressure or suction experienced by soil water as a result of its affinity for the soil matrix.

Most researchers agree on the third equivalent definition for matric potential which is a subcomponent of pressure potential and is defined as the value of ψ_p when there is no difference between the pressure of air or gas in the soil and the gas pressure on the water in the reference state.

Matric potential can have only a zero or negative value, the magnitude of which increases as water is held more and tightly in the soil. Matric or soil water suction or tension refers the same property but takes the opposite sign (to matric potential)

The sum of matric and osmotic potential is referred to as the water potential ψ_w and is directly related to the relative humidity of vapor in equilibrium with the liquid phase in soils and in plants. ψ_w is an important measure of plant water status and is also important in saline soils, where the osmotic potential of the soil solution is of sufficient magnitude to influence plant water uptake.

The definition for water potential in terms of suction is summarized as follows and illustrated in Figure 2.4.

Total suction (τ). The negative gage pressure, relative to the external gas pressure on the soil water, to which a pool of pure water must be subjected in order to be in equilibrium through a semipermeable (permeable to water molecule only) membrane with the soil water. It is the sum of the matric suction and osmotic suction.

Osmotic (solute) suction (τ_s). The negative gage pressure to which a pool of pure water must be subjected in order to be in equilibrium through a semipermeable membrane with a pool containing a solution identical in composition with the soil water. The value of osmotic suction depends on the concentration of soluble salts in the soil water. It is also termed *solute suction* or *solute potential* and is independent of water content and surcharge pressure.

Matric (soil water) suction (τ_m). The negative gage pressure, relative to the external gas pressure on the soil water, to which a solution identical in composition with the soil water must be subjected in order to be in equilibrium through a porous permeable wall with the soil water. It is also termed *matric potential* or *capillary potential* and is both water content and surcharge pressure dependent.

Matric potential refers to the tenacity with which water is held by the soil matrix and, in the absence of high concentrations of solutes, is the major factor that determines the availability of water to plants in soil science.

Krahn and Fredlund [1972] carried out tests to find the relationship between total, matric and osmotic suction. The results showed that the difference between total suction and matric suction decreases with increasing water content as anticipated since the concentration of salts in the pore water increases with decreasing water content.

2.1.5 Units of Soil Suction

Potentials can be defined as energy per unit mass and therefore they have units of joules per kilogram (J/Kg) in the SI system. It is also possible to define potentials as energy per unit volume or per unit weight. Thus, since the dimensions of energy per unit volume are identical to those of pressure, the appropriate SI unit of pressure is the pascal. Similarly, the dimensions of energy per unit weight are identical to those of length, so the appropriate SI unit is the meter. The terminology that is often used to describe potential energy per unit weight is "pressure head". The parameters, γ and g, are used to convert potentials from one system of dimensions to another as in the following equation:

$$\psi\ [J\ kg^{-1}] = \gamma\psi\ [Pa] = \frac{\psi}{g}\ [m] \qquad (2.9)$$

Where

γ= density of water

g = acceleration due to gravity

A logarithmic pF scale for expressing matric potential proposed by Schofield is also in use, where

$$pF = \log_{10}(\text{negative pressure head, in cm}) \quad (2.10)$$

The complete conversion relationship is shown in Table 2.1.

2.1.6 Soil-Water Characteristic Curve

Mathematical models. The soil-water characteristic curve for a soil is defined as the relationship between water content and suction of the soil. It can be used to estimate various parameters used to describe unsaturated soil behavior such as volume change, shear strength, and flow. Several mathematical models have been studied to characterize the soil-water characteristic curve. Each equation has its own limitation and only applies to some particular soils. The latest model proposed by Fredlund and Xing in 1994 provides not only a theoretical basis for most of the empirical equations but also proposes a new, more general description of the soil-water characteristic curve. The water-characteristic model proposed by Fredlund and Xing [1993] is shown in Equation 2.11.

$$\theta = \theta_s \left[\frac{1}{\ln\left[e + \left(\frac{\psi}{a} \right)^n \right]} \right]^m \tag{2.11}$$

Where

θ_s = saturation moisture content

e = constant 2.718

a = parameter related to air entry value of suction head, ψ_{aev}, and dimensional consistent

n,m = independent model parameters

ψ = Matric suction

For loam, a = 0.834m, θ_s = 0.43, n = 9.9, and m = 0.44. For Yolo light clay, a = 2.7m, θ_s = 0.375, n = 2.05, and m = 0.36

Hysteresis is introduced into the soil moisture due to the geometric effects and variations in the wetting contact angle, which is referred to as the ink bottle and raindrop effect. Two types of water-characteristic curves formed due to the hysteresis effect. A typical desorption and adsorption characteristic curve for a silty soil is shown in Figure 2.5 [Fredlund, 1993]. The relationship between desorption and adsorption is highly hysteretic. The curve covers the entire suction range from 0 to 10^6 kPa. Most soil-water characteristic curves apply in soil science in which volumetric water content, θ, is most commonly used. In geotechnical engineering gravimetric water content, w, is most commonly used. The degree of saturation S is another common measure to be used in the mathematical model.

2.1.7 Factors Affecting Soil Suction

Many factors affect the soil suction value. From a view of the entire environmental circumstance, rainfall, vegetation and ground water play big roles in the variation of soil suction. Nevertheless, the micro mechanism behaviors of the soil-water interaction are the major factors affecting the soil suction value.

Climate. It has been recognized that, in the absence of a shallow water table, soil suction at depth in a profile is generally controlled by the regional climate. Nearer to the exposed ground surface, moisture can be lost and gained rapidly enough to be affected by seasonal weather and other transient influences. At extreme climatic conditions, soil suction could fall to equal only the solute suction during sustained wet weather, or rise beyond the wilting point of trees during a hot dry period. The depth over which these variations persist depends on the severity and duration of the particular influence, and on the nature of the soil itself.

Research into the relationship between soil suction and climate has predominantly used the Thornthwaite Index to quantify the latter. Russam & coleman [1961], Aitchison & Richards [1965] studied the correlation between equilibrium suction and climate.

Ground water table. A Shallow water table may present low soil suction due to the short clearance. The clearance of high water in the State of Florida has been studied [Davidson, 1986]. A minimum height, the clearance, between a groundwater level and a particular elevation within the pavement system has been specified for different type of pavement in Florida.

Vegetation. Vegetation on the ground surface has the ability to apply a tension to the pore-water of up to 1-2 Mpa through the evapotranspiration process.

Temperature. Campbell & Gardner [1971] indicated that change in soil water potential with temperature becomes greater as soils become drier. When water potential falls below about -20 bars, temperature effects may become significant, especially in fine textured soils. Also, a decrease in temperature increase the surface tension and thus increases the soil suction (decreases soil water potential). In fall and winter, cooling of soil tends to draw more moisture into soil subgrades under pavement, whereas summer heating reduces soil affinity of water, the decrease in surface tension T being about 1% per 5°C.

Bulk density. The studies from Campbell & Gardner [1971] also showed, in most cases, that negligible differences will arise from the use of disturbed field samples with altered bulk density rather than undisturbed field soil. Little change was noted except on a clay subsoil sample. Most test results indicate that the variation of matric suction with dry density appears to be of a secondary interest.

Dissolved salts. An increase in the amount of dissolved salts in the soil water slightly increases its surface tension and lowers the capillary potential of the soil. Theoretically, coastal areas or the regions where the soil has high alkaline content should attract more capillary water than similar subgrades do in fresh water areas. In fact, the effect of dissolved salts is relatively minor because of the insignificant evidence.

Moisture content. A decrease in moisture content results in an increase in surface tension and therefore increases soil suction. This is due to the influence on the radii of curvature of the water-wedge surfaces.

Grain size. With the same water content, the fine-grained soils, which have more contact areas, will have less water collected at each of the contact points, and thereby increase the curvature on the air-water interface. The increases of curvature on the air-water interface results in an increase in soil suction.

State of packing of soil. During the process of compressing the soil, the curvature of the air-water interface gradually decreases and the matric potential increases from a negative value to zero. That is why "undisturbed" soil is preferred when the soil suction test is undertaken.

Angle of contact. An increase in the angle of contact will tend to decrease the curvature of the air-water interface and thereby increase the capillary potential of the soil at given water content. A soil treated with oil has less attraction to water than the one in which the particles are completely wetted.

Clay Mineralogy. This is the strongest factor that influences the matric potential. Clay particles adsorb and are surrounded by a diffuse double layer of ions and water molecules. In the last drying stage, the adsorbed water is held by a potential of thousands of bars. Therefore, the higher the active clay content, the lower (the more negative) the matric potential.

Permeability. When a soil is not saturated, the pore size effect contributes little to the permeability. The suction gradient results in the flow of water along particle surfaces and through the finer pores. An increase in soil suction decreases the hydraulic permeability and will increase the time required to obtain static equilibrium.

2.1.8 Values of in-situ soil suction

Henderson [1991] summarized measurements of maximum (dry) and minimum (wet) near-surface suction, and depth to the limit of seasonal influence, extracted from the data collected from a literature review. Apparently, there were no consistent patterns. The extreme dry values may have been affected by unreported or unobserved vegetation, and the wet limit may include values reflecting a shallow water table or a local water surplus. The range of values for each parameter argues in favor of obtaining site-specific suction data. Also it is not wise to rely on one measurement for a particular area.

2.2 Methods for Soil Suction Measurement

There are several ways to classify the methods of measuring soil suction. According to Smith [1991], with different measurement principles involved, the measuring methods can be categorized into five groups. They are High air entry disk method, Porous material method, Psychrometer method, Filter paper method, and squeezing technique. Some methods can only measure matric suction if the measurements are made through the liquid phase. Field and laboratory methods for measuring matric suction are based on the same principles, only the apparatus and procedure are designed for different test environmental conditions. Many of these instruments are available in versions that may be attached to a data logger or some kind of continuous recording device.

There are several problems with many of the techniques due to lack of range, length of time required to reach equilibrium, and their ability to measure only matric suction. Usually, no single method can be used to cover the entire range of moisture tension. Thus, researchers may use more than one measurement method to cover the suction range according to their test purpose and test results. However, evaluating soil suction using the thermocouple psychrometer is one of the most simple and accurate methods, which provides a valuable tool in determining the water potential of solutions, tissues and soils. Table 2.2 modified from Smith [1991] compares the above methods in detail.

2.2.1 High Air Entry Disk

Direct measurement of soil matric suction is operated based on the use of high air entry disk. A high air entry disk has small pores of relatively uniform size. The disk acts as a membrane between air and water. The difference between the air pressure above the contractile skin and the water below the contractile skin is defined as matric suction. The maximum matric suction that can be maintained across the surface of the disk is called its air entry value, $(u_a - u_w)_d$. It is the function of surface tension, T_s, and radius of curvature, R_s, as illustrated in Kelvin's equation:

$$(u_a - u_w)_d = \frac{2T_s}{R_s} \tag{2.12}$$

Where

$(u_a - u_w)_d$ = air entry value of the high air entry disk

T_s = surface tension of the contractile skin or the air-water interface

R_s = radius of the curvature of the contractile skin or the radius of the maximum pore size

The ability of the high air entry disk to withstand a difference between air and water pressures makes the disk suitable for the direct measurement of negative pore-water pressures in an unsaturated soil. More details were described by Fredlund [1995]. Two common devices are used for the direct measurement of matric suction: tensiometer and axis-translation apparatus.

Tensiometer method. For measuring matric and hydraulic potential under wet conditions, there is no substitute for the accuracy of tensiometer, especially as they function equally well below the water table. Two limitations are presented here: trapped-air and response time. Several measuring systems for a tensiometer are available to overcome the problems as pressure transducers and hydraulic selector switches are employed.

Axis-translation technique. Hilf [1956] proposed a technique to measure the negative pore-water pressures that can be performed on either undisturbed or compacted specimens. The major device included a soil chamber with a measuring probe, which was made of a needle with a saturated high air entry ceramic tip. The difference between the air pressure in the chamber and the measured negative water pressure at equilibrium was taken to be the matric suction of the soil, $(u_a - u_w)$. Several types of pressure plate apparatus utilizing the axis-translation technique were studied by Olson and Langfelder [1965].

2.2.2 Porous Material Method

The indirect measurement of soil matric suction can be made using a standard porous block as a measuring sensor. Sensors of this type consist of a porous material whose water content varies with matric potential in a reproducible manner. A physical property of the material that varies with water content is measured and related to the matric potential using a calibration curve. Wide range of porous materials has been examined for their soil-water characteristic relationship in order to select the most appropriate material for making the sensor. These materials include nylon, fiberglass, gypsum plaster, clay ceramics, sintered glass, and metal. The porous block sensors must be brought into equilibrium. At equilibrium, the matric suction in the porous block and the soil are equal. The measurement is made utilizing the electrical or thermal properties of the porous block.

Electrical conductivity sensors. A standard matrix is equilibrated with the soil solution. The measurement is made when the matric potential of the standard matrix in the sensor equals the potential of the soil solution. The matric potential of the sensor is inferred from a measurement of electrical resistance of the sensor and a previously determined relationship between the electrical resistance and the water potential of the matrix. The standard matrix can be any material that desaturated over the water potential range of interest to the investigator. Materials in common use are gypsum, nylon, and fiberglass. The electrical resistance of the sensor will be determined primarily by the water content of the sensor.

Thermal conductivity sensors. A standard matrix is equilibrated with the soil solution. The measurement is made when the matric potential of the standard matrix in the sensor equals the potential of the soil solution. At equilibrium, the water content of the standard matrix is determined by measuring the heat dissipation characteristics of the matrix. The standard matrix is typically a porous ceramic but other porous materials have been used. Heat dissipation is determined by applying a heat pulse to a heater within the ceramic and monitoring the temperature at the center of the ceramic before and after heating. The temperature difference is a function of the thermal diffusivity, and therefore of the water content of the ceramic. Because the thermal conductivity of the surrounding soil may differ substantially from that of the reference matrix, it is important that the reference matrix should be large enough to contain the entire heat pulse over the period of measurement

2.2.3 Psychrometer Method

In 1951, Spanner began the development of an instrument to measure relative humidity in equilibrium with a plant or soil sample within the narrow range between 0.99 and 1.00. Afterward the major developments were focused on improving the accuracy and reliability of measurements, as well as simplifying psychrometer construction and measurement techniques. This method can measure soil total suction because the processing is made through the vapor phase.

Thermocouple psychrometer method. Thermocouple psychrometers sense the relative humidity of vapor in equilibrium with the liquid phase in the soil. The method is best suited to measurements in the range of potentials covered by the thermocouple psychrometer, which is generally -0.1 to -7.0 MPa. Because psychrometers cover an important range of potentials, for which there is a lack of accurate measurement techniques and they are capable of high accuracy, in theory. They have sometimes been used as a standard method against which to compare other methods. This is still too low for testing soils sampled at the end of a drying cycle in the semi-arid and arid areas. The response time depends on the cover of the psychrometer and the magnitude of total suction being measured. It varies from a few hours at several thousand kilopascals suction to about two weeks at 100 kPa suction [Richards, 1974]. The operating principle is explained thoroughly in chapter 4.

Transistor psychrometer method. Improvements in performance have been made and the latest instrument can measure a much wider range of soil suctions in a shorter time. With good laboratory temperature control and the current operating procedures, the transistor psychrometer is capable of measuring the total suction of a soil in the range of pF3.0 to pF5.0 with an accuracy of about ±0.02pF above pF3.5 and only 1 hour needed to reach equilibrium. It has now been established that the transistor psychrometer is an accurate device for the measurement of the total water potential of soils. Work on the instrument is continuing with tests now being carried out on a more portable 8-channel model. It is believed that this will be suitable for field laboratory applications where high accuracy below about pF3.75 is not required.

2.2.4 Filter Paper Method

The Filter Paper Method was adopted by Mcqueen and Miller in 1968 from a technique proposed by Gardner in 1937 and the range is from less than 0.1 tsf to more than 1000 tsf. It is less complicated and more economical than the thermocouple psychrometer method. Small changes in weight may create large errors. The material of the filter paper and calibration solution has big effect on the measurement. A gravimetric scale accurate to 0.001g is required. It is also a time consuming test. Monitoring of the filter paper weight over a period of at least a week may be required to ensure that the equilibrium has been reached and great care must be taken to ensure no moisture loss occurs prior to weighing. This method can measure both matric and total suction and has been widely adopted in the past few years.

In this method, filter paper is used as a sensor and will be at equilibrium with soil water, either through the vapor phase or through liquid and vapor combined phase flow. The soil water potential is determined by measuring the water content of the filter paper and using a moisture release curve to determine the water potential of the paper. When the paper is placed in contact with the water in the soil and the exchange is through the liquid phase flow, then the equilibrium water content of the filter paper corresponds to the matric suction of the soil. On the other hand, the equilibrium water content of the filter paper corresponds to the total suction of the soil if the paper is not in contact with the soil and the exchange is entirely in the vapor phase. Therefore, the same calibration curve is used for both the matric and total suction measurement.

2.2.5 Squeezing Technique

The osmotic suction can be indirectly estimated by measuring the electrical conductivity of the soil. Pure water has low electrical conductivity in comparison to pore water, which contains dissolved salts. The electrical conductivity of the pore-water from the soil can be used to indicate the total concentration of dissolved salts, which is related to the osmotic suction of the soil.

2.3 Application of Soil Suction

2.3.1 Estimation of Volume Change

Clay soil exhibits high strength and low compressibility in most natural conditions. When the moisture content of the soil increases, the volume of the soil mass increases. The driving force behind this volume change is the soil moisture retention force or soil suction. Because of its greater sensitivity to volume change in comparison to moisture content, soil suction has been shown to be a more sensitive and accurate indicator of potential swell, as well as a more reliable parameter for estimating volume change. As the moisture content increases, the soil suction decreases and the soil swell. Various researchers involved in characterization of expansive soils have developed heave prediction methods that involve different interpretations or uses of the soil suction data [Snethen, 1970; Johnson, 1974; Thompson, 1995].

2.3.2 Determination of Coefficient of Permeability

For an unsaturated soil, the coefficient of permeability is primarily determined by the pore-size distribution of the soil and can be predicted from the soil-water characteristic curve. Knowledge of the pore-water pressure or hydraulic head is the major interest in solving the problems involving unsaturated soils. The coefficient of permeability, k, of an unsaturated soil is not constant and depends on the volumetric water content, θ, which, in turn, depends on the soil suction, ψ. There are two approaches in obtaining the permeability function of an unsaturated soil, namely empirical equations and statistical models. Several mathematical models governing the relationship between the coefficient of permeability and matric suction have been proposed and are summarized in Table 2.3.

2.3.3 Influence on Shear Strength

In engineering studies, soil tension is acting as a negative pore pressure, which is very important in affecting problems such as bearing capacity, lateral earth pressures, and the slope stability are related to the shear strength of a soil. The strength state variables generally used for an unsaturated soil are the net normal stress $(\sigma - u_a)$, and the matric suction $(u_a - u_w)$. In this case, the in situ matric suction can increase or decrease in response to the change in the climate conditions such as evaporation and precipitation. As a result, the undrained shear strength will also change. The change can be expressed as follows:

$$\Delta C_u = \Delta(u_a - u_w) \tan \phi^b \tag{2.13}$$

Where

ΔC_u = change in undrained shear strength due to matric suction change

$\Delta(u_a - u_w)$ = change in matric suction due to drying and wetting

ϕ^b = friction angle respect to change of suction

The application of the shear strength equation to different types of geotechnical problems is well presented in Soil Mechanics for Unsaturated Soils by Fredlund [1993].

2.3.4 Relation with Evaporation of Soil Moisture

Previous works describing evaporation most apply to hydrology and soil science. In response to the need to develop a clear rational for geotechnical applications, predictive techniques have been studied to evaluate evaporation from soil surface. The analysis showed that increased evaporative fluxes during the summer months decreased the thickness of the tension-saturated zone above the water table resulting in the increased potential for desaturation of the tailing surface. Figure 2.6 [Holmes, 1961] shows that the actual evaporation rate (AE) from soil surfaces relative to the potential evaporation rate (PE) is a function of water availability, soil texture, and drying rate. No single variable or soil property appears to control the evaporation rate from the soils.

A simple approach for prediction of evaporation from soil surface was presented by Fredlund [1997] and the actual evaporation rates for different types of soils were measured and compared. It was found that a relationship between the actual evaporation rate and total suction does exist when the soil sample is thin. When the observation applies to a thick soil sample, a theoretical approach that includes the influence of flow processes below the soil surface would be required.

Many variables contribute to the variation of soil drying rate, such as water content, temperature, humidity, and soil texture.

An equation shown in Equation 2.14 governs the evaporation from a water surface.

$$E = f(u)(e_s - e_a) \qquad (2.14)$$

Where

E = rate of evaporation (mm/day)

f(u) = transmission function

e_s = saturation vapor pressure at the temperature of the water surface

e_a = vapor pressure of the air in the atmosphere above the water surface

Table 2.1 : Soil Suction Conversion Table

pF	Equivalent Suction							
	cm (H_2O)	mm (Hg)	kPa (kN/m^3)	bar	erg/cm^3	ton/ft^2	lb/in^2	atm
0	$1*10^0$	$(7.35)10^{-1}$	$(9.8)10^{-2}$	$(9.8)10^{-4}$	$(9.8)10^2$	$(1.0245)10^{-3}$	$(1.42)10^{-2}$	$(9.676)10^{-4}$
1	$1*10^1$	$(7.35)10^0$	$(9.8)10^{-1}$	$(9.8)10^{-3}$	$(9.8)10^3$	$(1.0245)10^{-2}$	$(1.42)10^{-1}$	$(9.676)10^{-3}$
2	$1*10^2$	$(7.35)10^1$	$(9.8)10^0$	$(9.8)10^{-2}$	$(9.8)10^4$	$(1.0245)10^{-1}$	$(1.42)10^{-0}$	$(9.676)10^{-2}$
3	$1*10^3$	$(7.35)10^2$	$(9.8)10^1$	$(9.8)10^{-1}$	$(9.8)10^5$	$(1.0245)10^0$	$(1.42)10^1$	$(9.676)10^{-1}$
4	$1*10^4$	$(7.35)10^3$	$(9.8)10^2$	$(9.8)10^0$	$(9.8)10^6$	$(1.0245)10^1$	$(1.42)10^2$	$(9.676)10^0$
5	$1*10^5$	$(7.35)10^4$	$(9.8)10^3$	$(9.8)10^1$	$(9.8)10^7$	$(1.0245)10^2$	$(1.42)10^3$	$(9.676)10^1$
6	$1*10^6$	$(7.35)10^5$	$(9.8)10^4$	$(9.8)10^2$	$(9.8)10^8$	$(1.0245)10^3$	$(1.42)10^4$	$(9.676)10^2$

Table 2.2 : Summary of methods for measuring soil suction

Method	Place	Type	Range	Accuracy	Commercial equipment
Tensiometers	Lab. & Field	y_m	0 to -85 kPa	0.25 kPa	Bourdon gauge Portable Bourdon gauge Mercury manometer Puncture tensiometer Portable electric readout
Axis-Translation	Lab. & Field	ψ_m	0 to 1500 kPa		
Electrical resistance sensors Fiberglass Gypsum	Field	ψ_m	 -0.1 to -100 kPa -50 to -1.5 Mpa	 Low, depends on calibration, salinity, and temperature correction	 Fiberglass sensor Gypsum sensor meter
Heat dissipation sensors	Field	ψ_m	0 to -1 Mpa	0 to -100+- 10 kPa 0 to -300+- 20 kPa 0 to -600+- 100 kPa	
Psychrometers Richards Spanner	Lab & Field	ψ_w	 0 to -300 Mpa 0 to -7 Mpa	 Laboratory, 4 kPa Field, 50 kPa	 Laboratory sample changer Psychrometer Soil psychrometer nanovoltmeter thermometer Dew-point microvoltmeter
Filter Paper	Lab	ψ_m/ ψ_w	-1 kPa to -100 Mpa	~+-30% at -10 kPa	Paper
Pore Fluid Squeezer		ψ_s	entire range		

Table 2.3 : Relation between water coefficient of permeability and matric suction

Equations	Symbols	Source
$k_w = k_s$ for $(u_a - u_w) \leq (u_a - u_w)_b$ $k_w = k_s \{\frac{(u_a - u_w)_b}{(u_a - u_w)}\}^{\eta}$ for $(u_a - u_w) > (u_a - u_w)_b$	η = empircial constant $\eta = 2+3l$	Brooks & Corey (1964)
$k_w = \frac{k_s}{1 + \{\frac{(u_a - u_w)}{(u_a - u_w)_b}\}^{n'}}$	n' = constant	Arbhabhirama & Kridakorn (1968)
$k_w = \frac{k_s}{1 + a\{\frac{(u_a - u_w)}{\rho_w g}\}^{n}}$	a, n = constant	Gardner (1958)

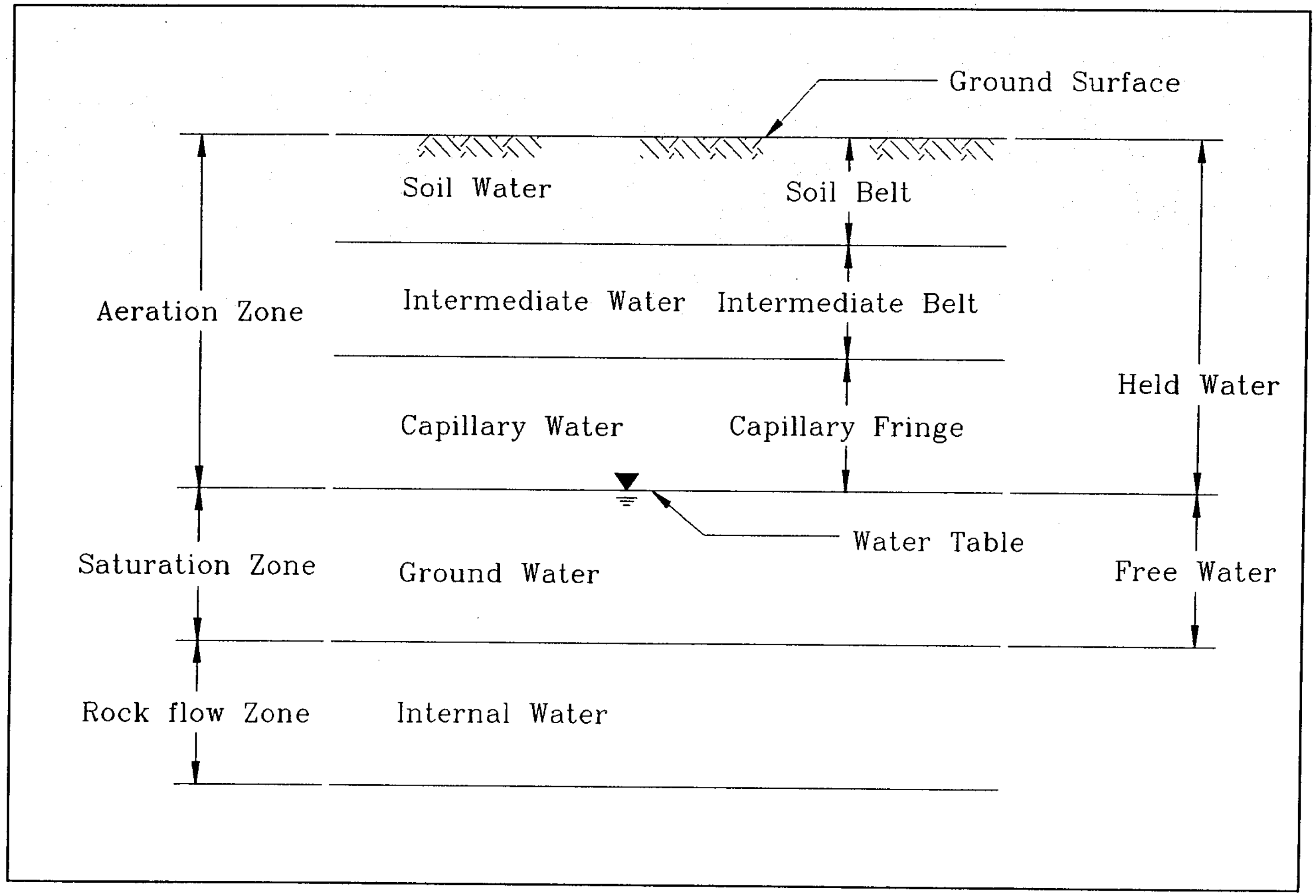

Figure 2.1 : Types of subsurface water

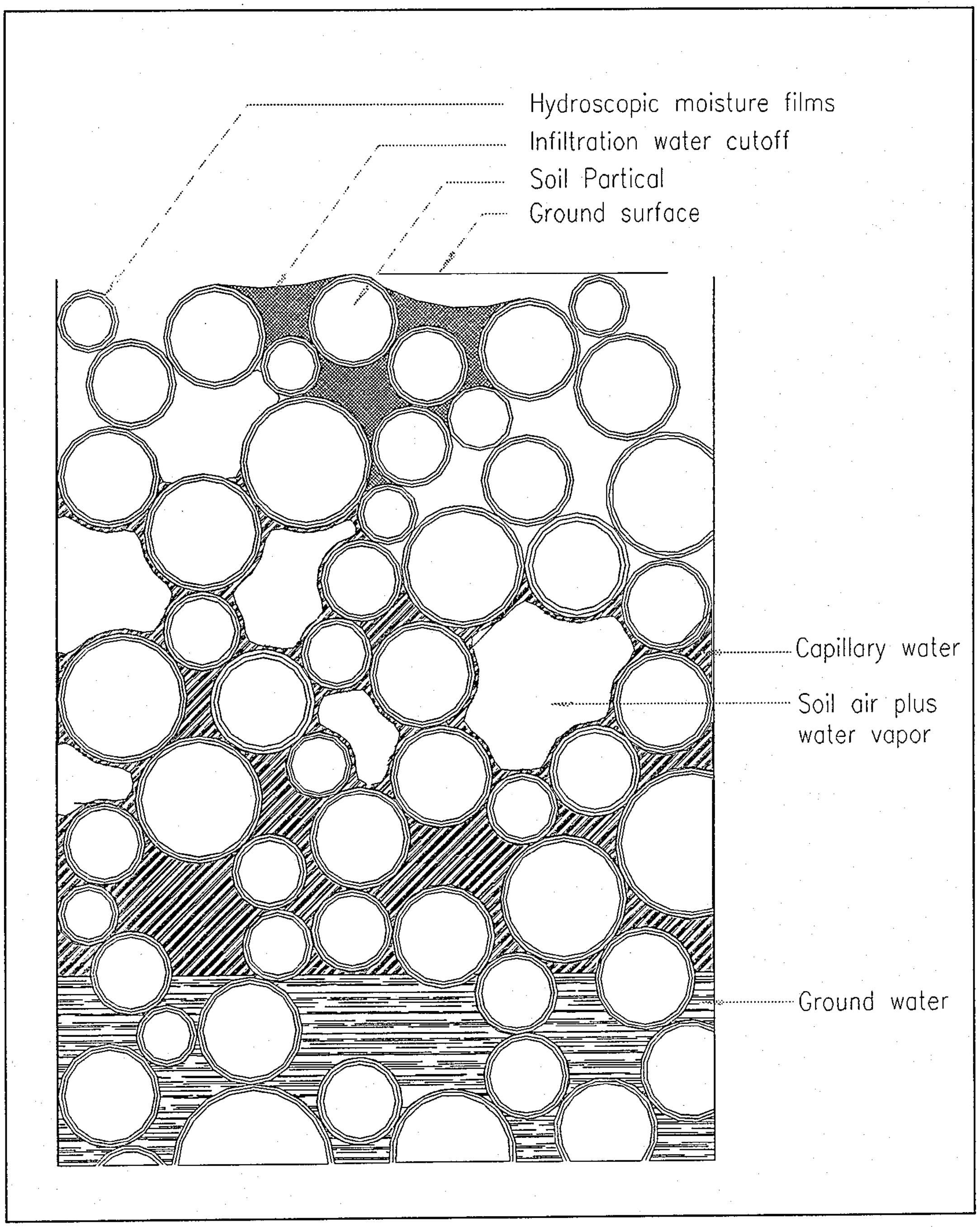

Figure 2.2 : Conventional illustration of soil-water distribution

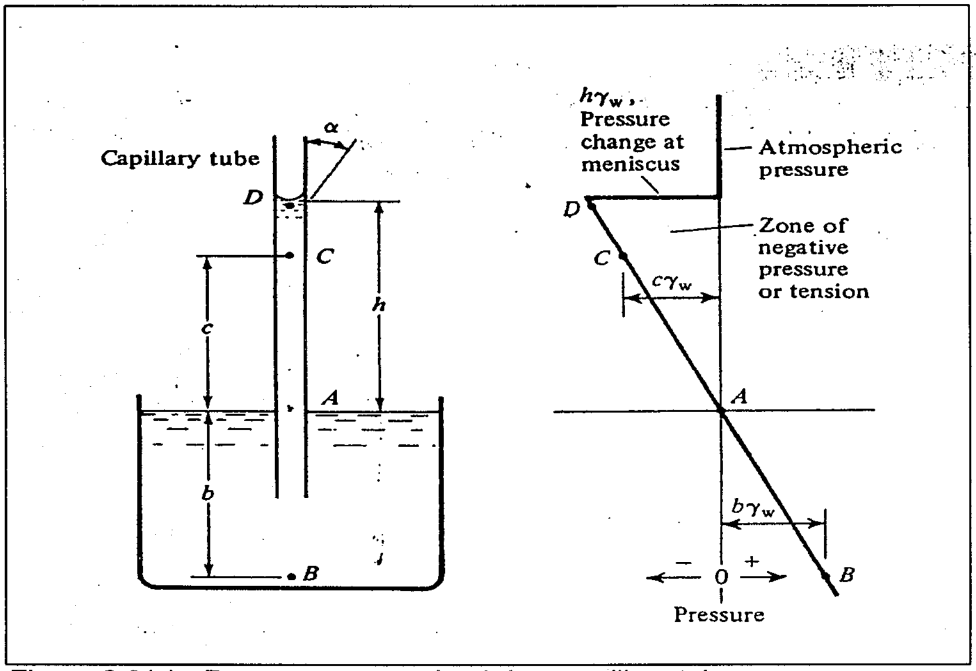

Figure 2.3(a) : Pressure versus depth in a capillary tube

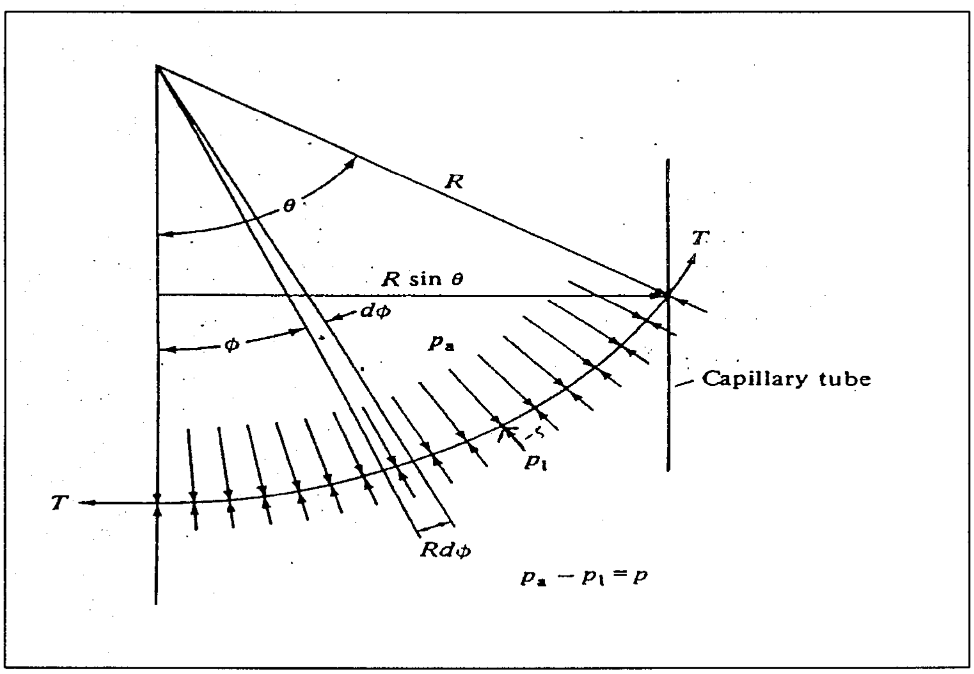

Figure 2.3(b) : Cross section of capillary meniscus

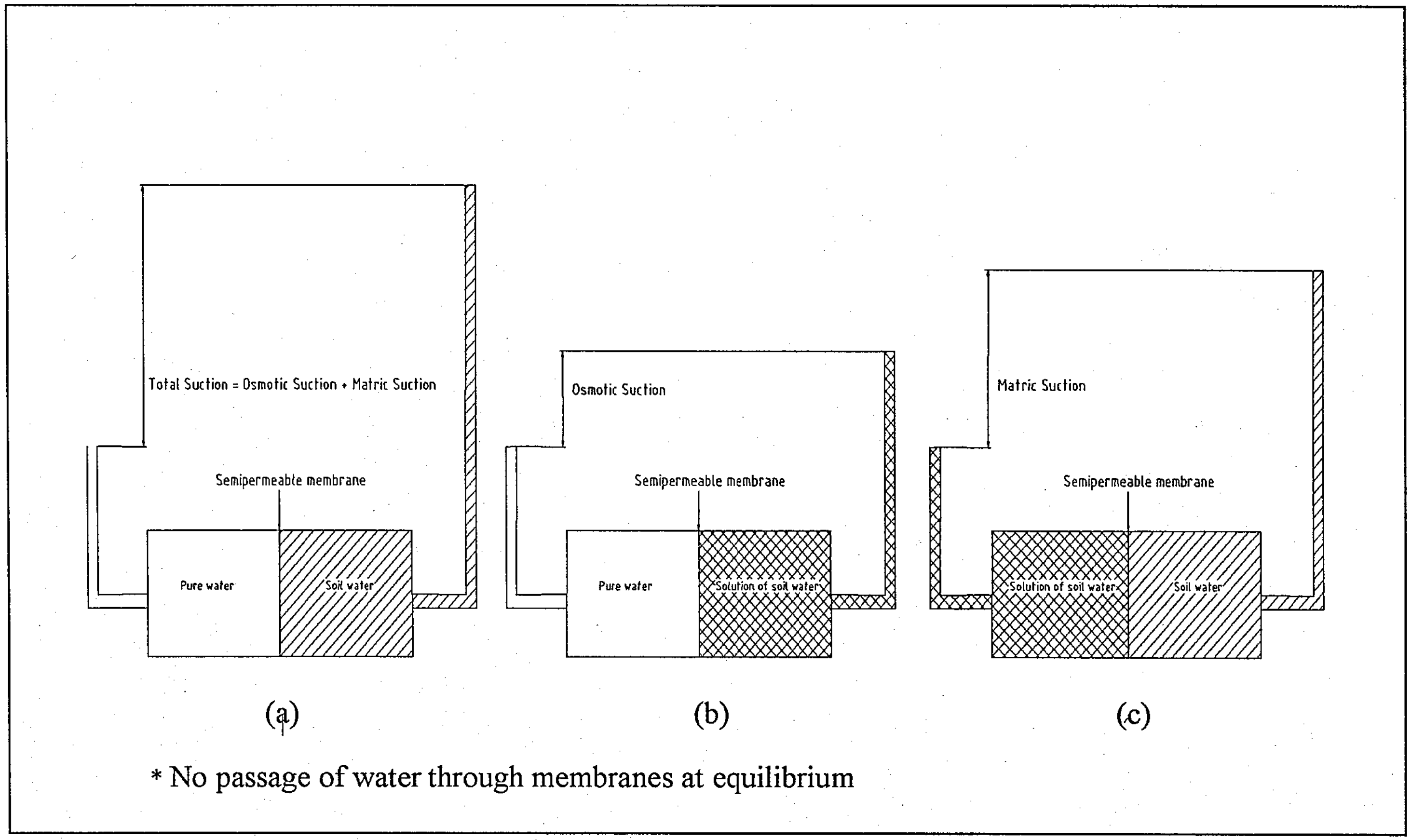

Figure 2.4 : Illustration of the definition of suction

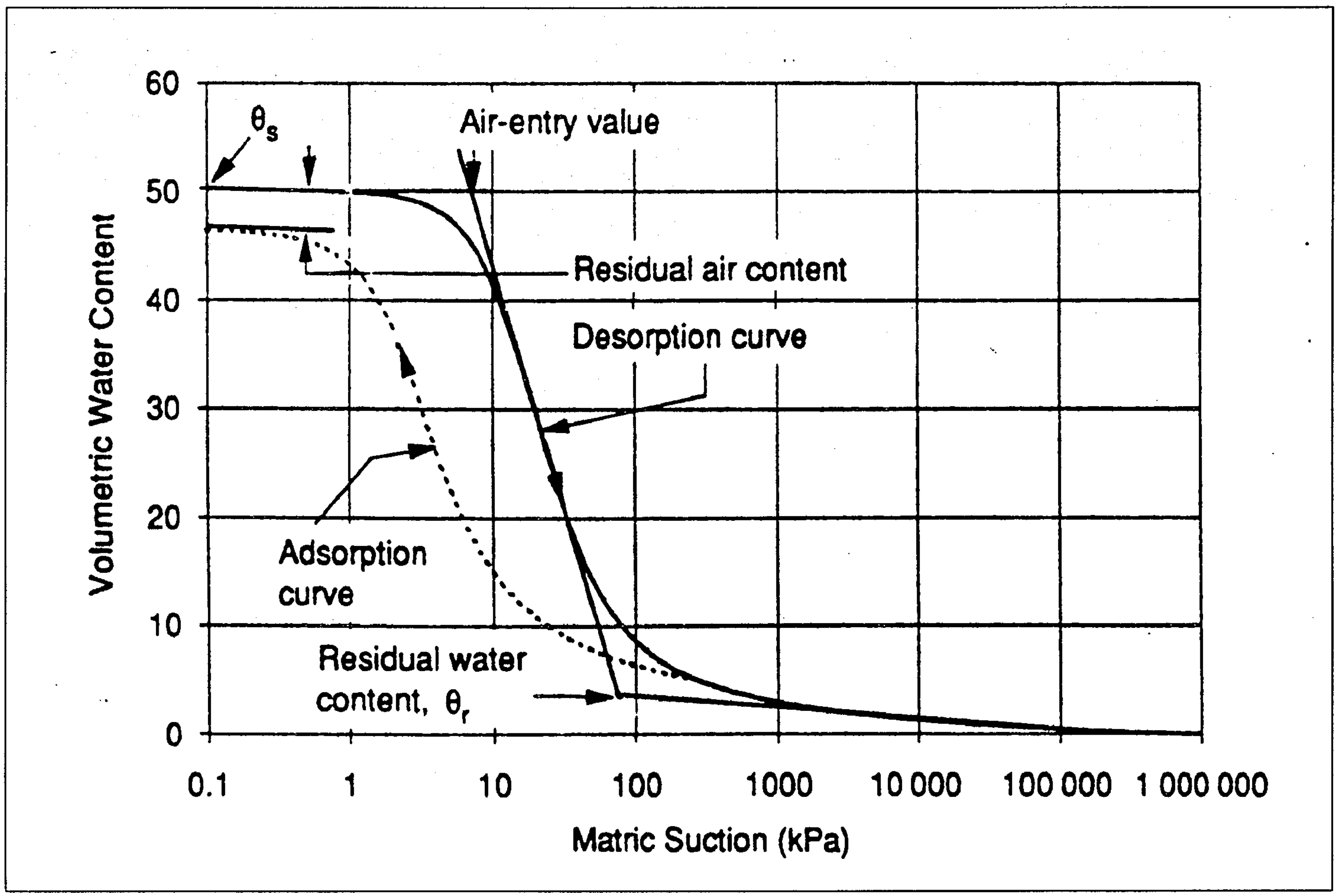

Figure 2.5 : A typical desorption and adsorption characteristic curve for a silty soil

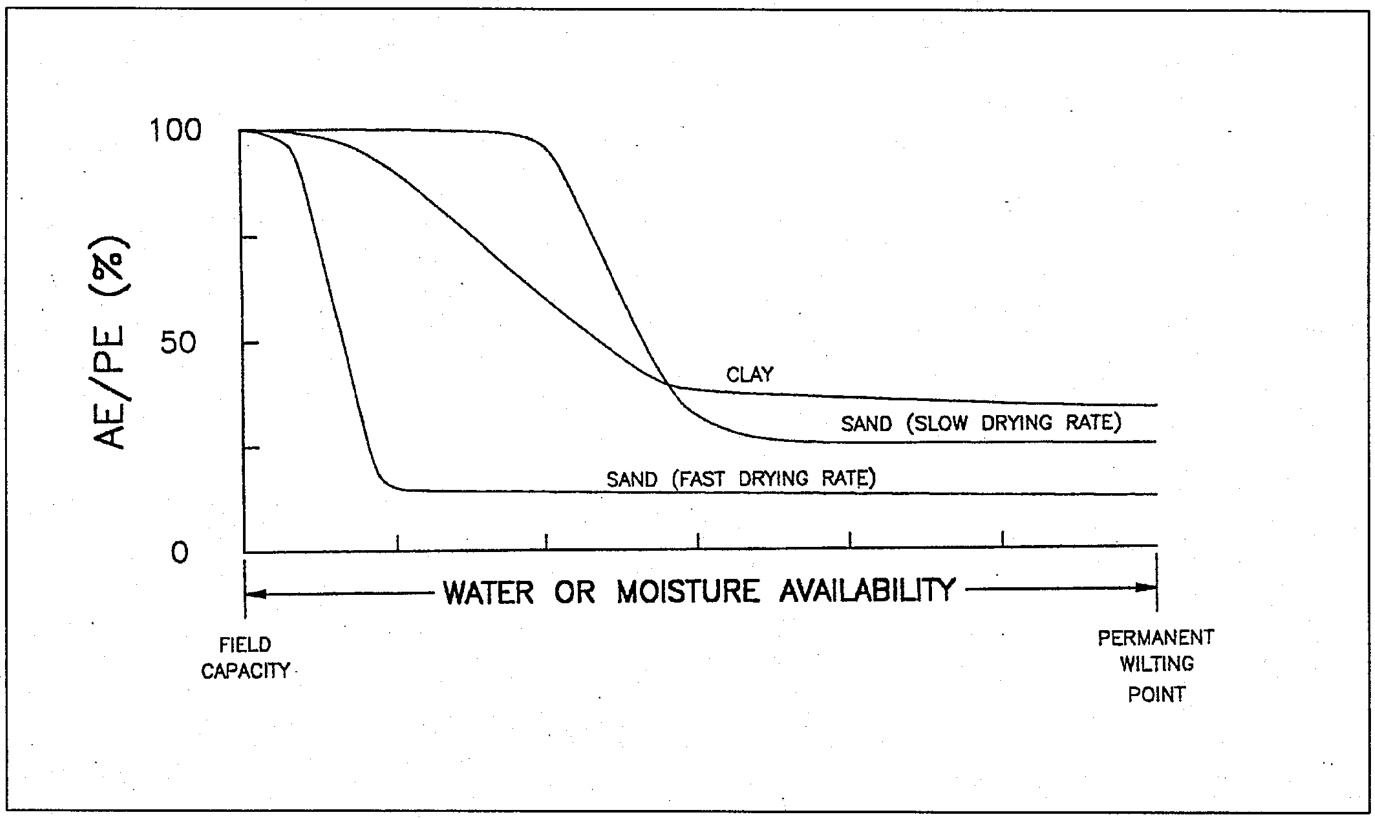

Figure 2.6 : Typical drying curve for sand and clay

CHAPTER 3

REVIEW OF PHASE I STUDY

3.1 Phase I Experimental Program

The problem that soils are difficult to dry and compact was revealed during highway construction in the State of Florida. For this reason, a Phase I evaluation of engineering properties of problematic soils in highway construction was performed (McDonald, 1995). Prior to accepting soils from districts 2, 3, and 5, two soils from each of 6 districts were first examined to determine if they were suitable for the evaluation project. A site location map is shown in Figure 3.1. Table 3.1 lists the basic properties of the selected soils. In order to provide a method to identify the problematic soils, McDonald conducted tests concerning the properties of the problematic soils selected by FDOT. These tests included Moisture Content, Atterberg Limits, Grain-Size Analysis, Compaction Test, Bearing Ratio, Expansion Index, Permeability, X-Ray Diffraction, and Scanning Electron Microscope (SEM). A detailed description of each test was illustrated [McDonald, 1995] and is briefly reviewed in the following. The test results of soil properties for six troublesome soils are summarized in Table 3.2.

3.1.1 Natural Moisture Content

To ensure that a constant moisture content level was maintained during the storage time, a moisture content check was performed. The procedure and calculation followed the Standard Method ASTM D 2216. The soils were put in metal tins and dried in a drying oven at 110°C (230°F) for 24 hours. Three samples from different depths within the container were obtained for the test. Test results showed that the moisture was well controlled inside the storage container. The results of the test could also be used as an indication of the in-situ moisture content of the soil. The values from the district 5 soils were probably less than the in-situ values because they were shipped in soil bags during a dry period in the summer. The moisture content of each soil is presented in Table 3.3.

3.1.2 Atterberg Limits

The Attergberg limits refer to the Liquid Limit (LL), Plastic Limit (PL), Shrinkage Limit (SL), and Plasticity Index (PI). These properties were used in the classification of the soil and gave an indication of their engineering properties. The LL, PL, and PI were determined for the soils in the test program. The procedure followed the Standard ASTM D 423 for determining the LL, and the Standard ASTM D 424 for PL and PI. The LL, PL, and PI for each soil are listed in Table 3.4

3.1.3 Grain size Analysis

A combination of ASTM D 421 Standard Method (Sieve Analysis) for particle sizes larger than 0.075 mm (.003 in) and ASTM D 1140 Standard Method (Hydrometer Analysis) for particles smaller than 0.075mm were used to analyze soil grain size. The hydrometer analysis is useful in identifying the percentage of clay in each soil in this study. The percentage of passing versus the grain size for each soil was plotted in Figures A.1 through A.6. From the graphs, the corresponding percentage of gravel, sand, and clay for each soil was determined and is shown in Table 3.5. The soil classification using the AASHTO and Unified systems is presented in Table 3.6.

3.1.4 Compaction Test

A modified compaction test was performed on all soils. In this test, determination of the dry unit weight of the soil was done for each compacted sample and then plotted against the water content as included in Appendix from Figures A.7 to A.12. Figure 3.2 compares the dry density-water content for six soils. Maximum dry density for each soil was determined at optimum moisture content from the peak of the regression curve. The results from the compaction test for the maximum dry density are consistent with normal values obtained for clayey sand and silty sand soils. The procedures followed Standard ASTM D 1557. Table 3.7 lists the values for each of the soils at optimum conditions.

3.1.5 Bearing Ratio

In this test, the Limerock Bearing Ratio (LBR) method is used to measure the bearing capacity of a soil. The LBR test is a modification of the California Bearing Ratio (CBR) test. Three main modifications were employed to best present the soils encountered in Florida. They were eliminating the swell test, using a two-day soaking period instead of four-day, and changing the strength standard to that of typical crushed Florida limerock, which is 5.5 Mpa (800 psi). Minimum LBR values of soils have been set by the FDOT for use in pavement construction. The LBR value can be obtained from the following equation. The results of limerock bearing ratio values for 2-day soaking and 4-day soaking are shown in Table 3.8(a) and Table 3.8(b) respectively.

$$LBR\ (\%) = \frac{Corrected\text{-}Unit\text{-}Load(\frac{lb}{in^2})}{800(\frac{lb}{in^2})} * 100 \qquad (3.1)$$

3.1.6 Expansion Index

The expansion index is used to classify soils according to their potential for expansion, which is considered to be a basic property of the soil. The soil was first compacted to a degree of saturation (S_{meas}) of 50%±1 and then allowed to swell against a surcharge pressure. An empirical equation recommended in the Standard Test Method was used to eliminate the difficulty of achieving the degree of saturation of 50%±1. Equation 3.2 shows the recommended relationship. A value of 50 or higher of the soil indicates that the potential problems in pavement design would become significant. Test results were presented in Table 3.9 and showed that the potential expansion of each soil is "very low".

$$EI_{50} = EI_{meas} - (50 - S_{meas}) * (\frac{65 + EI_{meas}}{220 - S_{meas}}) \qquad (3.2)$$

3.1.7 X-ray Diffraction and Scanning Electron Microscope

For identifying the fine-grained soil minerals and the study of their crystal structure, X-ray diffraction is the most widely used method. The principle of this method is based on Bragg's law as shown in the following equation:

$$\nu\lambda = 2d \sin\theta \tag{3.3}$$

A Phillips Automatic Powder Diffractometer Model APD 35-20 was used to produce the X-ray diffractometer charts for the samples. The results of the analysis are shown in Table 3.10.

Another method, scanning electron microscope, can directly reveal particles and particle arrangements since it can resolve distances to less than 100 $\mathring{A}$. An Environmental Scanning Electron Microscope (ESEM) Model E-3 by ElectroScan Corporation was used to take the pictures. Some pictures show that a normal sieve analysis may not give an accurate size distribution due to the attractive forces, which hold the particles together. Either a mechanical breaking of the soil or a wet sieve is required when using this test program to separate the clay and the silt particles from the sands.

3.1.8 Permeability

Permeability is the property of a porous material, which permits the passage, or seepage of fluids through its interconnecting voids. Two methods were available to tackle the difficulty of the saturation. The Florida Method FM 5-513 was used when possible. If the soil was difficult to saturate completely, then ASTM Standard D 5084 was adopted and the coefficient of permeability was found using a Flexible Wall Permeameter (FWP). The FWP is best used when the coefficient of permeability is less than $1x10^{-3}$ cm/sec ($3.28x10^{-5}$ ft/sec). Permeability results are listed in Table 3.11.

3.2 Summary of Test Results

The primary complaint about the soils from the contractors was that they were hard to compact and slow in drying. From the moisture content test, it was found that the in-situ water content was greater than the optimum water content for most soils. All soils have a good distribution of particle sizes for the sand range. This allows for the tight packing of the particles during compaction. A low value of permeability conformed to the tight packing. Also the presence of montmorillonite or similar type clay in the soil could be a factor in the low permeability values. From the expansion index test results, all of the soils were classified as very low for expansion potential and were inactive. The summary of the test results is presented in Table 3.2. The low permeability and high in-situ moisture content may contribute to the slow drying and compacting problems during construction.

The motivation for evaluating the effect of soil suction and environmental conditions for the six problematic soils is based on the results of a previous evaluation (Ping & McDonald, 1996). Since no significant evidence directly related to those properties for the drying problem existed, a further study of the effect of soil suction and the environmental conditions was recommended to evaluate the problematic soils.

Table 3.1 : Soil locations and basic properties

District	Location	AASHTO Class	Description	Color
2	**Clay County** SR 100 and C-21B	A-2-6	Clayey Sand	Orange
2	**Madison County** SR 14	A-2-4	Silty Sand	Brown
3	**Jackson County** US 231, Alford City	A-2-4	Silty Sand	Brown
3	**Jackson County** US 231, Jacobs Road	A-2-4	Silty Sand	Reddish Brown
5	**Brevard County** SR 520	A-2-4	Silty Sand	Black
5	**Marion County** U.S. I-75	A-2-4	Silty Sand	Dark Brown

Table 3.2 : Summary of Previous Experimental Program Results

Soil Properties	District 2		District 3		District 5		Test Method
	Clay County	Madsion County	Alford City	Jacobs Road	Brevard County	Marion County	
Soil Color	Orange	Light Brown	Light Brown	Radish Brown	Black	Orange	
Visual Desciption	Clayey Sand	Silty Sand	Silty Sand	Silty Sand	Silty Sand	Clayey Sand	
AASHTO Classification	A-2-6	A-2-4	A-2-4	A-2-4	A-2-4	A-2-4	
Unified Classification	SC	SM	SM	SM	SM	SC	
Moisture Contents, %	11.91	12.99	13.66	13.05	2.22	8.72	ASTM D 2216
Liquid Limit	27	18	NP	15	19	23	ASTM D 423
Plastic LImit	14	NP	NP	NP	NP	14	ASTM D 424
Plastic Index	13	NP	NP	NP	NP	9	ASTM D 424
Passing 40 Sieve, %	89.5	91	71.9	78.3	89.3	78.2	
Passing 200 Sieve, %	27.5	25.1	17.6	20	16.8	19.9	ASTM D 421 & 1140
Clay, %	24	12	4	8	10	12	ASTM D 2221
Maximum Dry Density, KN/m	20.5	20.6	20.4	20.5	19.8	20.4	ASTM D 2222
Optimum Moisture Content, %	9.1	8.5	7.6	7.9	9.25	9.3	ASTM D 2223
LBR (2 Day Soaking)	30,31	85,89	88,100	63,78	91,94	88,90	ASTM D 2224
LBR (4 Day Soaking)	48,51	88,89	96,108	77,78	93,94	83,94	ASTM D 2225
Permeability, cm/sec	$6x10^{-5}-1x10^{-6}$	$x10^{-6}-3x10^{-7}$	$2-5x10^{-6}$	$2-9.5x10-^{5}$	$2-8x10-^{5}$	$3x10^{-5}-2x10^{-6}$	ASTM D 2226
Expansion Index	2	1	0	0	0	1	ASTM D 2227

Table 3.3 : Moisture content results

District	Location	Test 1	Test 2	Test 3	Test 4	Average
2	Clay County	11.96	12.16	11.81	11.71	11.91
2	Madison County	12.9	12.72	12.73	13.61	12.99
3	Alford City	13.88	12.89	14.2	-	13.66
3	Jacobs Road	13.17	12.68	13.32	-	13.05
5	Brevard County	2.22	2.17	2.22	2.26	2.22
5	Marion County	8.71	8.9	8.77	8.49	8.72

Table 3.4 : Atterberg limits results

District	Location	LL	PL	PI
2	Clay County	11.96	12.16	11.81
2	Madison County	12.9	12.72	12.73
3	Alford City	13.88	12.89	14.2
3	Jacobs Road	13.17	12.68	13.32
5	Brevard County	2.22	2.17	2.22
5	Marion County	8.71	8.9	8.77

Table 3.5 : Percentage of major soil constituents

District	Location	Gravel, %	Sand, %	Silt, %	Clay, %
2	Clay County	0	72.5	3.5	24
2	Madison County	1.4	73.5	13.1	12
3	Alford City	2	80.4	13.6	4
3	Jacobs Roads	1.8	78.2	12	8
5	Brevard County	2.4	80.8	6.8	10
5	Marion County	1.3	78.8	7.9	12

Table 3.6 : Soil classification by AASHTO and Unified system

District	Location	Passing No.40	Passing No.200	LL, %	PI, %	AASHTO	Unified
2	Clay County	89.50	27.50	27	13	A-2-6	SC
2	Madison County	91.00	25.10	18	NP	A-2-4	SM
3	Alford City	71.90	17.60	NP	NP	A-2-4	SM
3	Jacobs Road	78.30	20.00	15	NP	A-2-4	SM
5	Brevard County	89.30	16.80	19	NP	A-2-4	SM
5	Marion County	78.20	19.90	23	9	A-2-4	SC

Table 3.7 : Results from the modified proctor compaction test

District	Location	Max Dry r, kN/m^3	Optimum W_c, %
2	Clay County	20.5	9.1
2	Madison County	20.6	8.5
3	Alford City	20.4	7.6
3	Jacobs Road	20.5	7.9
5	Brevard County	19.8	9.25
5	Marion County	20.4	9.3

TABLE 3.8(a) : Limerock bearing ratio values for 2-day soaking

District	Location	Wc,(%)	ρdry,kN/m^3	LBR	Swell,%
2	Clay County	9.06 9.10	19.4 19.3	30 31	0.41 0.13
2	Madison County	8.50 8.50	20.1 20.4	85 89	0.02 0.02
3	Alford City	7.75 7.75	20.0 20.3	88 100	0.00 0.02
3	Jacobs Road	7.93 7.93	20.2 20.2	63 78	0.07 0.13
5	Brevard County	9.25 9.25	19.5 19.4	91 94	0.00 0.04
5	Marion County	9.27 9.27	20.1 20.1	90 88	0.11 0.02

TABLE 3.8(b) : Limerock bearing ratio values for 4-day soaking

District	Location	Wc,(%)	ρdry,kN/m^3	LBR	Swell,%
2	Clay County	9.39 9.39	19.9 19.9	51 44	0.15 0.41
2	Madison County	8.50 8.50	20.0 20.1	88 89	0.90 0.00
3	Alford City	7.76 7.76	20.0 20.2	96 108	0.16 0.11
3	Jacobs Road	7.93 7.93	20.2 20.2	77 78	0.42 0.29
5	Brevard County	9.25 9.25	19.4 19.4	94 93	0.07 0.07
5	Marion County	9.27 9.27	20.2 20.2	94 83	0.04 0.00

TABLE 3.9 : Expansion index values from experimental program

District	Location	Test			Average	Potential Expansion
		1	2	3		
2	Clay County	5	2	0	2	Very Low
2	Madison County	0	3	0	1	Very Low
3	Alford City	0	0	0	0	Very Low
3	Jacobs Roads	0	0	0	0	Very Low
5	Brevard County	0	0	0	0	Very Low
5	Marion County	4	0	1	1	Very Low

0-20:Very Low; 21-50:Low; 51-90:Medium; 91-130:High; >130:Very High

TABLE 3.10 : X-ray diffraction results

District	Location	Minerals Present
2	Clay County	Kaolinite
2	Madison County	Kaolinite, minor quartz, trace chlorite
3	Alford City	Kaolinite, minor quartz, trace chlorite
3	Jacobs Road	Kaolinite, trace quartz
5	Brevard County	Kaolinite, Smectite, Illite, minor quartz
5	Marion County	Kaolinite

Table 3.11 : Permeability results from experimental program

District	Location	Dry Density kN/m3	Water Content %	Permeability (cm/sec): Compaction Permeameter (Soiltest)	Permeability (cm/sec): Flexible Wall Permeameter, Confining Pressure: 69 kPa	138 kPa	Average
2	Clay County	19.3 18.5	9.8 9		1.85E-06 5.74E-05	1.23E-06 5.65E-05	1.54E-06 5.70E-05
2	Madison County	19.6 19.7 19.6	9.8 9.6 9.8		4.11E-07 1.20E-06 3.13E-06	2.03E-07 5.65E-07 2.05E-06	3.07E-07 8.83E-07 2.59E-06
3	Alford City	19.3 19.9 19.7	7.1 7.2 7.3	4.93E-06 4.23E-06 2.32E-06			
3	Jacobs Road	19.6 19.4 19.3	8.6 7.6 7.3		2.79E-05 6.10E-05 1.10E-04	1.84E-05 5.54E-05 7.73E-05	2.32E-05 5.82E-05 9.37E-05
5	Brevard County	18.6 18.7	10.2 10.1		9.38E-05 3.63E-05	5.36E-05 1.92E-05	7.37E-05 2.78E-05
5	Marion County	19.5 19.1	9.6 9.6		3.98E-06 2.49E-05	1.29E-06 2.13E-05	2.64E-06 2.13E-05

Table 3.12 : Activity values for soils in experimental study

District	Location	Activity	Classification
2	Clay County	0.54	Inactive
2	Madison County	0	Inactive
3	Alford City	0	Inactive
3	Jacobs Road	0	Inactive
5	Brevard County	0	Inactive
5	Marion County	0.67	Inactive

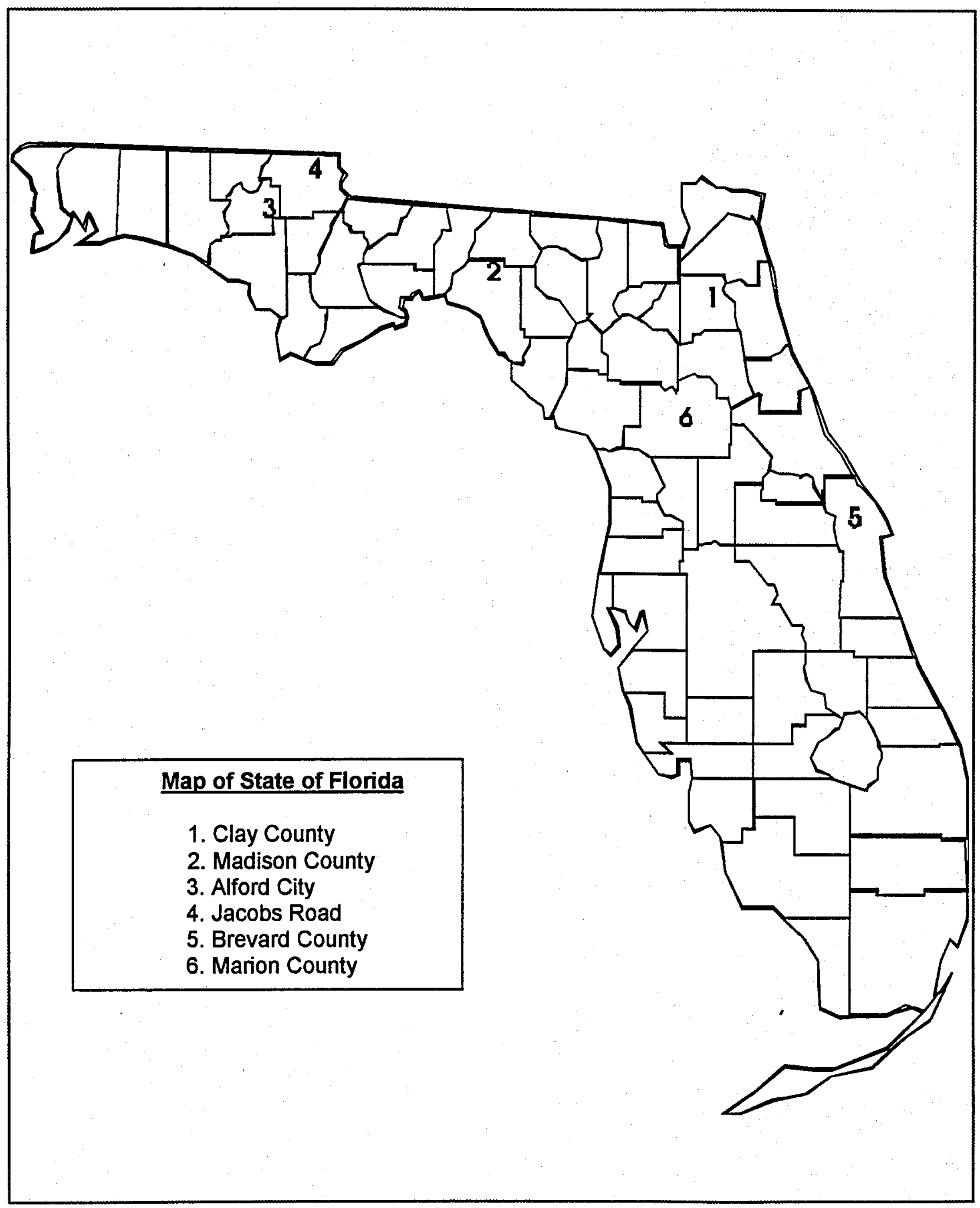

Figure 3.1: Site Location Map

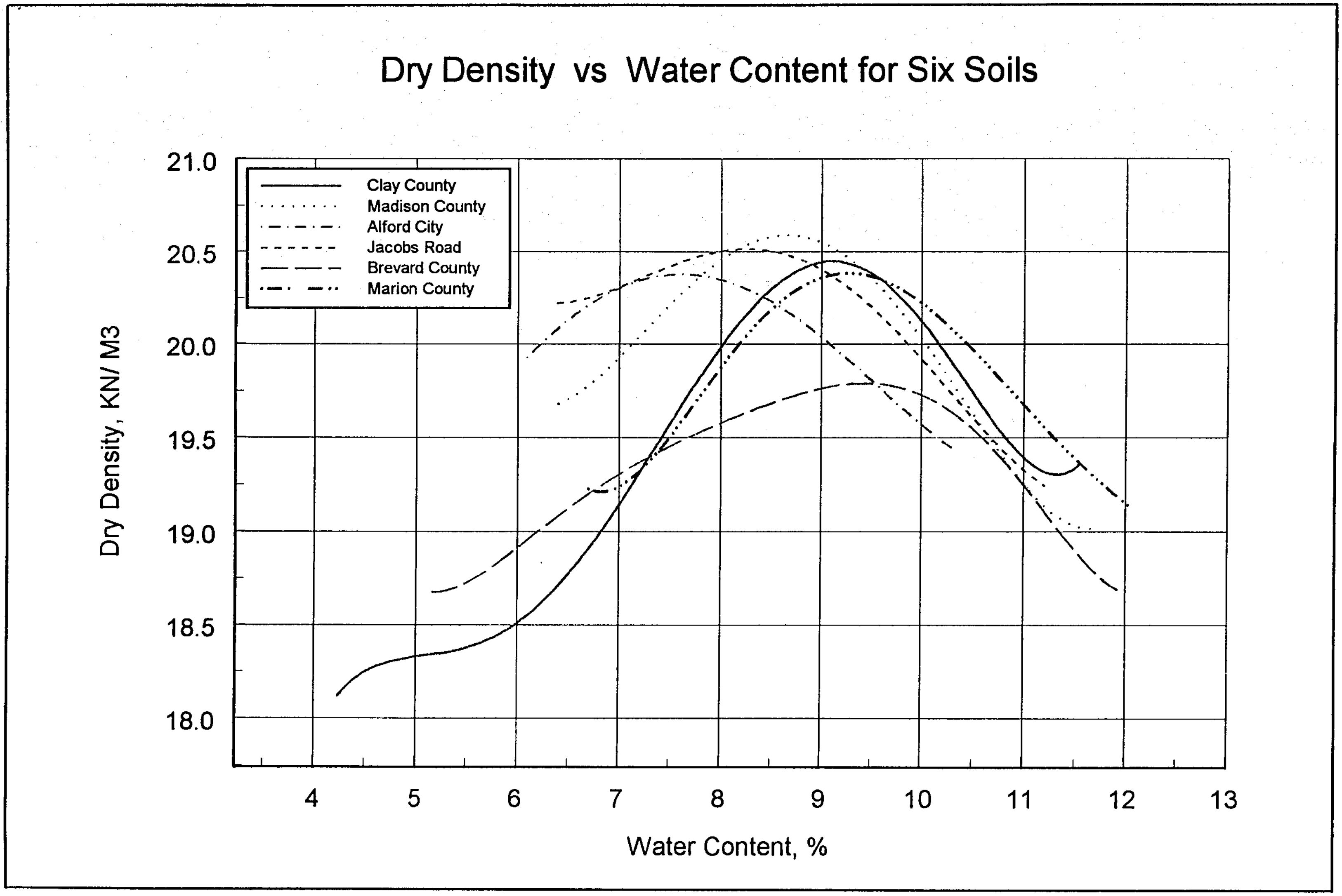

Figure 3.2 : Dry density at different water contents for six soils

CHAPTER 4

LABORATORY EXPERIMENTAL PROGRAM

4.1 General

The purposes of the experimental program were to correlate drying rate with soil suction as well as environmental effects such as temperature and humidity, and to further investigate the relationship between the drying rate and the percent of fines. The laboratory testing program involved two types of test: the soil suction test and the drying rate test. The soil suction test was chosen from AASHTO Designation T273-86 to determine the soil suction values at different water content for six troublesome soils. The soil drying rate test was generated by using an environmental chamber (incubator) in which a variety of temperature and humidity were used to simulate the environmental condition in Florida.

The soils selected for this study were the same as those used for Phase I tests [McDonald, 1996]. The basic soil properties were summarized in Chapter 3 in detail.

4.2 Soil Suction Test

Basically, the soil suction test procedure followed AASHTO DESIGNATION T 273-86 [1993], which is the standard method of testing for measuring soil suction, except that the soil samples were remolded. This test method covers the procedure for determining total suction force using thermocouple psychrometers of the Spanner [1951] type.

Two series of suction tests were performed. Series A was done in normal laboratory room temperature and humidity, and series B was performed inside an incubator, which provides desired constant temperature and relative humidity. The soil suction test program is summarized in Table 4.1.

4.2.1 Suction Measurement Devices

The test devices consisted of three major parts: monitor system, sensor system, and sample chamber system. Each system has its own designation for this test.

Monitor system. A WESCOR HR-33T Dew Point Microvoltmeter shown in Figure 4.1 was used to monitor and record the output data. The HR-33T Dew Point Microvoltmeter is a self-contained electronic system that has been specifically designed for measuring water potential with thermocouple transducers. It contains sophisticated sensing and control circuitry that automatically maintains the temperature of the thermocouple junction at the dew point temperature when operating in the dew point mode. The HR-33T permits water potential to be determined with a variety of sensors in either the dew point (hygrometric) or the wet bulb (psychrometric) mode. The same sensors are used for both modes but the electronic control and measuring apparatus operate differently. The operation principle for both modes is illustrated in Figure 4.2. According to the work by Brisco [1984], one advantage of the dew point mode is that it provides a continuous output rather than a falling plateau. Since the time of reading is not critical, the dew point mode was chosen to obtain accurate measurement in this program.

Sensor system. Thermocouple psychrometer was used as a sensor for this test. Klute [1986] thoroughly illustrated the use of the psychrometer for both laboratory and in-situ. Two major types of thermocouple psychrometers were most often used. One was developed by Richards and Ogata in 1958 and the other was developed by Spanner in 1951. Nine thermocouple psychrometers of the Spanner type with a known cooling coefficient (Π_V) produced by Wescor, Inc.

(Model PST-55-15-SF) were used for the tests. A typical psychrometer consists of a sensing thermocouple junction, a chromel-constantan thermocouple, and two reference junctions of copper-constantan and copper-chromel. A construction schematic view of the psychrometer is shown in Figure 4.3.

Wescor peltier cooled psychrometers are available with either stainless steel screen shields or porous ceramic shields. A PST-55-15-SF psychrometer is specified as a psychrometer that is covered with a Dutch weave stainless thermocouple shield and has 1.5 meters lead length. SF is the SUREFAST connector with which the connection process can be accomplished by pushing the cable connector into the receptacle until it is firmly in place.

Two important principles underlie the usefulness of thermocouple psychrometers: The Seebeck Effect and the Peltier Effect. The electrical principles of these two effects are briefly described in the following. More details about the electrical behavior of the psychrometer may be found elsewhere [Brisco, 1984].

1. The Seebeck Effect is the phenomenon that permits a thermocouple to be used for temperature measurement. A thermocouple is formed when two different metals

are joined together. If both ends of the wire are joined to form a closed loop, electrical current will flow through the wires whenever the junctions are at different temperatures. The magnitude of the produced voltage is dependent upon the temperature difference between the junctions.

2. The Peltier Effect is the phenomenon, which allows a thermocouple junction to be cooled by passing an electrical current through the junction. When current flows across the junction of two dissimilar metals, heat will be either absorbed or liberated at the junction. If the current flows in the same direction as the current produced by the Seebeck Effect at the hot junction, heat is absorbed. If the current flows in the opposite direction, heat is liberated.

In order to have accurate measurement, protecting psychrometers from contamination is most important. If contaminations are presented at the junction, the rate of evaporation will be changed, thereby the output is reduced, and satisfactory precision cannot be obtained.

Sample chamber system. The sample chamber assembled with metal cans and polystyrene box is shown in Figure 4.4

and 4.5. Each one-pint paint container was sealed with a No. 13 rubber stopper and placed in a 12-in. X 12-in. X 15-in. polystyrene box, which can accommodate nine one-pint paint containers. A thermocouple psychrometer was inserted into each container, with the calibration solution or soil specimen inside, and well sealed. The sample chamber was placed inside an environmental chamber for series B suction tests.

4.2.2 Calibration of Psychrometers

Nine PST-55-15-SF thermocouple psychrometers were calibrated with the assistance of salt solution which causes a vapor pressure lowering of relative humidity in the atmosphere that can be converted to suction using Kelvin's equation (Equation 3.5). Sodium chloride (NaCl) was chosen as the salt in the calibration solutions because the relative humidity of these solutions is independent of temperature in the normal range of operating temperature. Four calibration standard concentrations were used to adequately define the calibration lines. They were 290, 500, 1000, and 1800 osmolality, respectively. Table 4.2 specifies the gram formula weight of NaCl per 1000 grams of distilled water (the molality M) for some levels of relative humidity in equilibrium with the solutions. The time to reach equilibrium depends on the concentration of salt solution. According to Snethen [1970], the equilibrium voltage outputs from the psychrometers can be obtained within the metal pint container in 48 hours or less with 0.05M solutions and 12 hours or less with 2.0M solutions.

The calibration of psychrometers was accomplished using the device illustrated in Section 4.1 except that the soil specimen was substituted by filter paper with 3ml known water potential of sodium chloride solutions in it. Sufficient time was allowed for the vapor equilibrium to occur within each container. The calibration of psychrometers followed the procedure illustrated in AASHTO DESIGNATION T 273-86 [1993]. Eight(8) amps of cooling current was applied for 30 seconds. The output of the psychrometer was approximately 0.75 microvolts per bar in the dewpoint mode. After the temperature and the microvolt output were obtained, a straight line representing the best fit of the data points was determined for each psychrometer. The calibration line of each psychrometer can be expressed by the following equation:

$$\tau^{\circ} = a\ \mathbf{E}_{25} - b \qquad (4.1)$$

Where

τ° = total soil suction, Kpa

a, b = calibration constants

$\mathbf{E}_{25}$ = psychrometric microvoltmeter reading corrected to 25°C, μV

The slope of the calibration line will always be positive and the y-intercept should be equal to or less than zero. The calibration line is valid for the useful life of the thermocouple psychrometer. However, under normal use, an annual check of the calibration at least one point will assure that the equipment is operating properly. For this study, the psychrometers were calibrated twice within one year to adjust the soil suction test results.

4.2.3 Sample Preparation

The soils used in this study were from different locations around the State of Florida, i.e., Clay County, Madison County, Jackson County, Brevard County, and Marion County. Classification indices for these soils are shown in Table 3.6. Five soils were classified as A-2-4 soil, according to the AASHTO Classification System, except one soil from Clay County, which was classified as A-2-6 soil.

The soils were compacted in a mold, which has a diameter of 4-inch and a height of 8-inch, at optimum water content for Series A tests and at optimum water content plus 4% for Series B tests. The compaction energy was achieved by using a 10-lb hammer dropped from a height of 457 mm (18 in) with eight equal layers for 25 blows per layer. The compacted soils were cut into nine 1.5in. x 1.5in. x 1.5in cubes immediately after removal from the mold. The maximum dry density and optimum water content were recorded.

4.2.4 Test Procedure

According to the suggested data record form from the AASHTO Standard Test, the procedure can be divided into three parts. They are Suction test, Weight-Volume Relation test, and Water Content test. Each test is described in the following:

Soil suction. The nine 1.5-in. X 1.5-in x 1.5-in-cube soil samples described in Section 4.2.3 were placed in individual metal containers (one-pint paint cans with interiors coated with wax to prevent corrosion). Of nine specimens, two were tested at their optimum water content and sealed with rubber stoppers right after cutting. These two specimens represented the optimum water content of the soils. The remainder were either wetted with varying amounts of distilled water or dried at room temperature for varying lengths of time. Three of the remaining specimens were dried at room temperature for 1, 2, and 4 hours. The dried specimens were sealed after their drying times. The remaining four specimens were wetted with 0.5, 1, 2, and 4 ml distilled water respectively, and sealed in the sample containers immediately after adding water. The purpose of the wetting and drying process is to establish a range of water contents over which the soil suction can be measured. All of the nine specimens were weighed before the containers were sealed.

Nine thermocouple psychrometers were first fed through the center of the polystyrene box together and then each of them was fed through the hole in the center of rubber stopper. Both the holes on the cover of the polystyrene box and the rubber stopper were sealed with sealant to ensure that the system was airtight and the thermocouple psychrometers were extended approximately one inch beyond the bottom of the stoppers.

The specimens were allowed to come to equilibrium in the sealed containers. The temperature equilibrium was obtained in a few hours after placing the cover on the thermal container. Equilibrium of the relative humidity of the air measured by the psychrometers is usually obtained within 48 to 72 hours, according to the AASHTO Standard Method. It was found that the time to reach the relative humidity equilibrium varied widely for different samples. It was ranged from three days to ten days depending on the suction values of the soils.

Each psychrometer was connected to the HR-33T microvoltmeter (Figure 4.6) and the output electromotive forces (emfs) for each psychrometer were recorded. The cooling coefficient, Πv, of each psychrometer at 25°C was measured at manufactory preliminarily. And the cooling coefficient at the temperatures other than 25°C was calibrated using the following equation:

$$\Pi v(\text{at } T^{\circ}C) = \Pi v(\text{at } 25^{\circ}C) - (25-T) \times 0.7 \qquad (4.2)$$

Where

T = measured temperature before applying cooling current

The operation of the HR-33T dew point microvoltmeter followed the manual provided by Wescor Inc [1988]. The magnitude of the peak output emf is directly related to the relative humidity of the medium. The temperature output of the thermocouple psychromreter was recorded in °C and the output of emf in microvolts. 30 seconds of cooling current was applied for the test which was identical to that used to determine the calibration line.

Weight-volume relations. Since the soil specimens might experience volume change during the soil suction test, determining the specific volume of each specimen after the soil suction test becomes more complicated. Most of the researchers use the volume displacement method to measure the volume of the specimen, which has an irregular shape, by submerging it into water.

The wet weight of the specimens was measured immediately after removal from the metal containers. Before putting the soil into water, the soil was wrapped with pure wax to prevent water coming into contact with the soil and then the weight of the soil with wax on it was determined. The temperature of the water was recorded. The temperature of the melted wax needed to be well controlled to make the wrapping work easier. The weight of the soil with the wax in water was measured by submerging the object, which was hung under the scale, into water to determine the bulk densities.

Figure 4.7 illustrates the schematic view of the measuring system for the weight-volume relation test.

Water content. Following the soil suction and weight-volume relation measurements, the actual moisture content was then determined. The wax was taken off from the soil sample carefully so that no water was allowed to flow into the soil specimen. The wet specimens were weighed immediately after the wax was taken off and dried in a microwave for 12 minutes until the water inside the soil was completely gone.

4.2.5 Data Reduction and Interpretation

Soil suction. The recorded psychrometer voltage outputs, $E\tau$, can be converted to the equivalent outputs at the calibration temperature, E_{25}, using the following equation:

$$E_{25} = \frac{E\tau}{0.325 + 0.027T} \qquad (4.3)$$

The soil suction, τ, of each individual specimen was determined using the psychrometer calibration equation obtained from the calibration test. Nine calculated suction values (ordinate, log scale) versus the corresponding water contents (abscissa) were plotted on a semi-log plot to establish the relationship of log soil suction and water content, which is linear and can be expressed using the following equation:

$$\log \tau = A - Bw \qquad (4.4)$$

Where

τ = Soil suction, kPa

A = y-intercept

B = slope

W = water content, percent

The data points between soil suction values of 200 kPa (2 tsf) and 2000 kPa (20 tsf) were recommended by AASHTO Standard to establish the τ-ω relationship if some variation occured at the upper or lower end of the curve because the limits of the measurement range were approached. The recommendation was too conservative according to the literature, which stated that the measurement of a psychrometer could range from 100 kPa to 8000 kPa.

Weight-volume relations. The volume of wet soil plus wax can be found by determining the apparent loss of weight when the body is wholly immersed in the water of known specific gravity, which is the weight of wet soil plus wax minus the weight of wet soil plus wax in water over the density of water at the recorded temperature. The volume of the wax can be obtained by the weight of wax over its specific gravity, which is 0.55. The equations for specific volume test are as follows:

$$V_{wet\ soil\ +wax} = \frac{(W_{wetsoil+wax}) - (W_{wetsoil+wax})_{inwater}}{d_{water}} \qquad (4.5)$$

$$V_{wax} = \frac{W_{wax}}{0.55} \qquad (4.6)$$

$$V_{wet\ soil} = V_{wet\ soil\ +wax} - V_{wax} \qquad (4.7)$$

$$\gamma_{dry} = \frac{W_{drysoil}}{V_{wetsoil}} \qquad (4.8)$$

$$Specific\ Volume = \frac{1}{\gamma_{dry}} \qquad (4.9)$$

The specific volume can be used to determine the compressibility of a soil (α).

Water content. The actual water content in percentage is the difference in weight between the wet soil and the dry soil over the dry soil weight. The water contents determined in the final stage were compared to those prepared in the beginning of the test.

4.3 Soil Drying Rate Test

The purpose of this experiment was to investigate the environmental influence on the soil drying rate. The drying rate of a soil is defined as the amount of water loss (gram) within one unit of time (hour) in this study. An environmental chamber (incubator) was used to simulate the temperature and humidity conditions in Florida. Two groups of experiments were conducted. In the Group I tests, the samples were compacted at their optimum water content and the drying path was starting from the optimum water content. Four levels of temperature were selected from 0° to 40° (0°C, 10°C, 25°C, and 40°C) to cover the variation in temperature, to which the soil surface was subjected. Three levels of relative humidity (55%, 75%, and 95%) were chosen to represent the dry, normal, and wet weather through a year in the State of Florida. In the Group II tests, the soils were compacted at their optimum water content plus 4.0 percent. Two levels of temperature (10°C and 25°C) and two levels of relative humidity (75% and 95%) were used. The soil drying rate test program is tabulated in Table 4.3.

4.3.1 Equipment

In order to simulate the variations of temperature and humidity in the State of Florida, a Reach-In Incubator, Model 3911, manufactured by Forma Scientific, Inc. was used as an environmental chamber in the drying rate test. The incubator has 11 cubic feet capacity and wide temperature ranges, heated or refrigerated. Its temperature range is from 0°C to 60°C (±0.3 °C at temperature range from 25°C to 35°C) and the humidity range is above ambient to 95% ±5%. A controller of Watlow 982 Dual LED PID type microprocessor allows researchers to program the machine. A schematic view of the machine is shown in Figure 4.8.

4.3.2 Sample Preparation

The soils used for the drying rate test were the same as those used in the soil suction test. They were compacted using the modified Proctor compaction method at optimum water content for Group I tests. The maximum dry density and the optimum water content were recorded. For Group II tests, soils were compacted at the water content of optimum plus 4.0 percent. The corresponding dry density for each soil was also recorded. The specimen size was 4-inch in diameter and 5-inch in height. The specimens were weighed before being placed in the environmental chamber.

4.3.3 Test Procedure

Six troublesome soils were compacted using the 4-in mold modified Proctor method with optimum conditions. As mentioned above, for the Group I tests, the samples were dried at their optimum water content until the drying rate (water loss per hour) was less than 0.05. For the Group II tests, soils were dried from optimum water content plus 4.0 percent to optimum water content minus 4.0 percent. The drying time depends on the range of the water content, and the temperature and humidity selected for each test. Usually it took about 7 to 10 days for the Group I tests and 4 to 7 days for the Group II tests. The drying rate versus time as well as water content was compared among the six problematic soils.

Initially, the proposed tests consisted of 12 sets (the combination of 4 levels of temperature and 3 levels of humidity). Due to the limitation of the incubator, only seven sets out of the twelve combinations were achieved for the Group I test and 4 sets for the Group II test. For each test, the temperature and humidity were set at the desired level and allowed to reach equilibrium. The soil samples were then placed into the incubator immediately after removal from the compaction molds. The initial weight of each sample was recorded along with the time when sample was weighed. The measuring interval was increased as the water content decreased. Temperature and humidity at each measurement were also recorded to control the designated environmental condition.

Once the measurements of a set of temperature and humidity were done, the above steps were repeated for the remaining sets of temperature and humidity.

4.3.4 Data Reduction and Interpretation

The drying rate of each soil at different time can be obtained by dividing the difference in the weight by the elapsed time between two consecutive measurements and the sample surface area. The drying rate decreases as the elapsed time increases. The relation between the drying rate and the elapsed time is shown in the following equation:

$$\text{drying rate [gram/hr/ft}^2\text{]} = \frac{W_n - W_{n-1}}{(t_n - t_{n-1})A} \qquad (4.10)$$

where,

W_n = the weight of the n^{th} measurement, gram

W_{n-1} = the weight of the $n-1^{th}$ measurement, gram

t_n = the elapsed time of the n^{th} measurement, hour

t_{n-1}=the elapsed time of the $n-1^{th}$ measurement, hour

A = sample surface area exposed to air, ft^2

The average drying rate is the total water loss divided by the total elapsed time and the surface area. The equation can be written as the following:

$$\text{average drying rate (gram/hr/ft}^2\text{)} = \frac{W_n - W_1}{(t_n - t_1)A} \qquad (4.11)$$

where,

W_n= the weight of the n^{th} measurement, gram

W_1= the weight of the initial measurements, gram

t_n= the elapsed time of the n^{th} measurement, hour

t_1= the elapsed time of the initial measurement, hour

A = sample surface area exposed to air, ft^2

The effect of temperature and humidity on the drying rate was analyzed. The relation between water content and drying rate was also determined to correlate the soil suction with the drying rate of the soil.

Table 4.1 : Summary of Soil Suction Test Program

Soil Location	Series A		Series B	
	Moisture content %	Dry density kN/m^3	Moisture content %	Dry density kN/m^3
Clay County	18.7	9.27	19.5	9.1
Madison County	19.1	9	19.1	8.6
Alford City	19.4	7.6	19.4	7.6
Jacobs Road	19.08	7.8	19.9	7.8
Brevard County	18.9	9.3	18.9	9.3
Marion County	19.4	9.3	19.4	9.3
Environmental condition	Lab temperature and humidity		Temperature : 25°C Humidity : 75%	
Callibration	Series A		Series B	

Table 4.2 : Concentration of Sodium Chloride for Certain Levels of Relative Humidity

Osmolality (mM/kg)	NaCl / 100 grams solution (gram)	Molality (M)	Relative Humidity (%)	Suction at 25 °C (kPa)
290	0.9094	0.15704	99.47	725
500	1.571	0.55014	99.09	1250
1000	3.115	0.27283	98.19	2500
1800	5.463	0.98878	96.77	4500

Table 4.3 Summary of drying rate tests at different temperature and humidity

	Group I			Group II	
Temperature	Humidity			Humidity	
oC	55%	75%	95%	75%	95%
0	-	-	X	-	-
10	-	X	X	X	X
25	X	X	X	X	X
40	X	-	-	-	-
Compaction condition	Optimum water content			Optimum water content plus 4 percent	

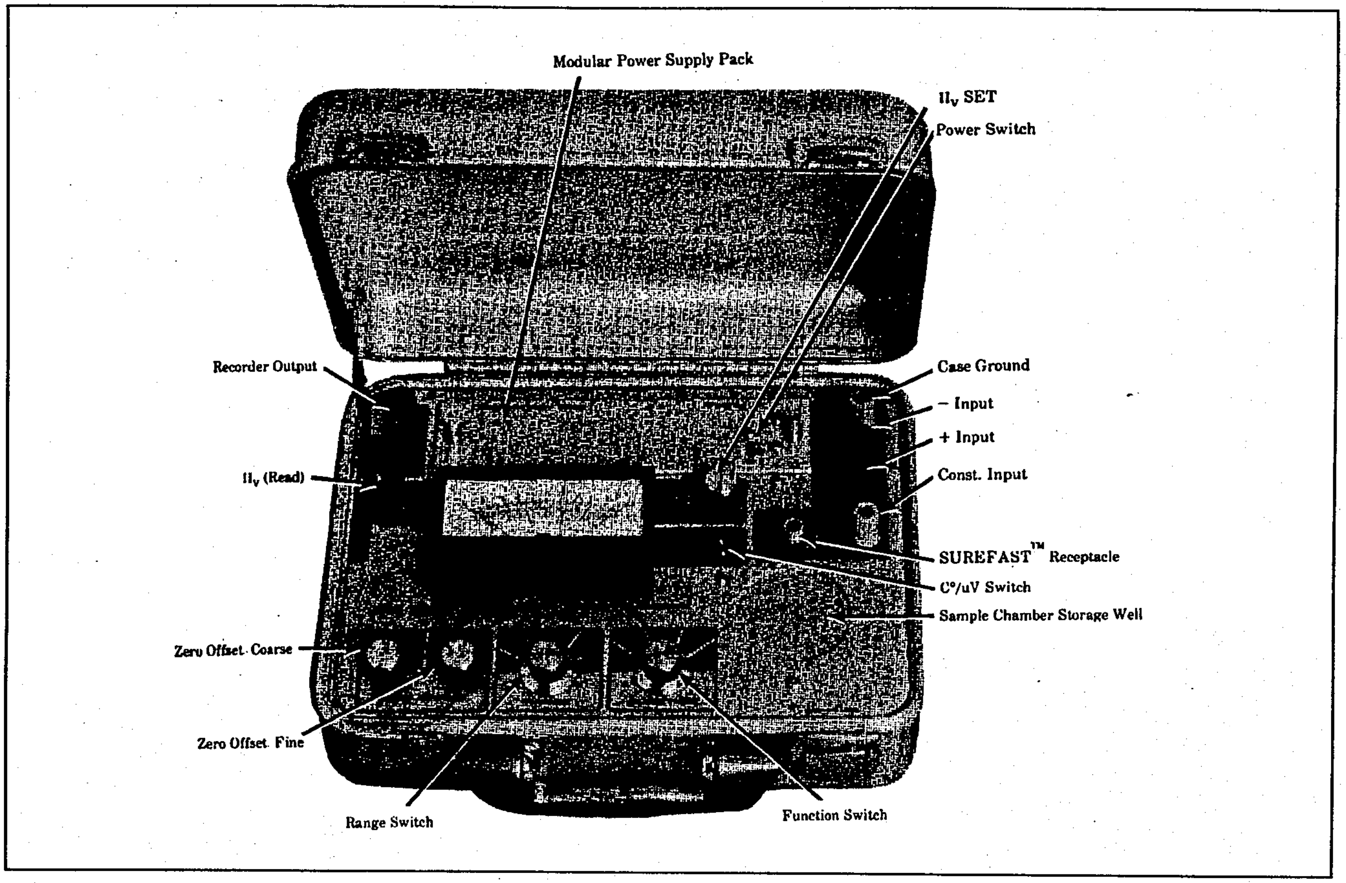

Figure 4.1 : WESCOR HR-33T Dew Point Microvoltmeter

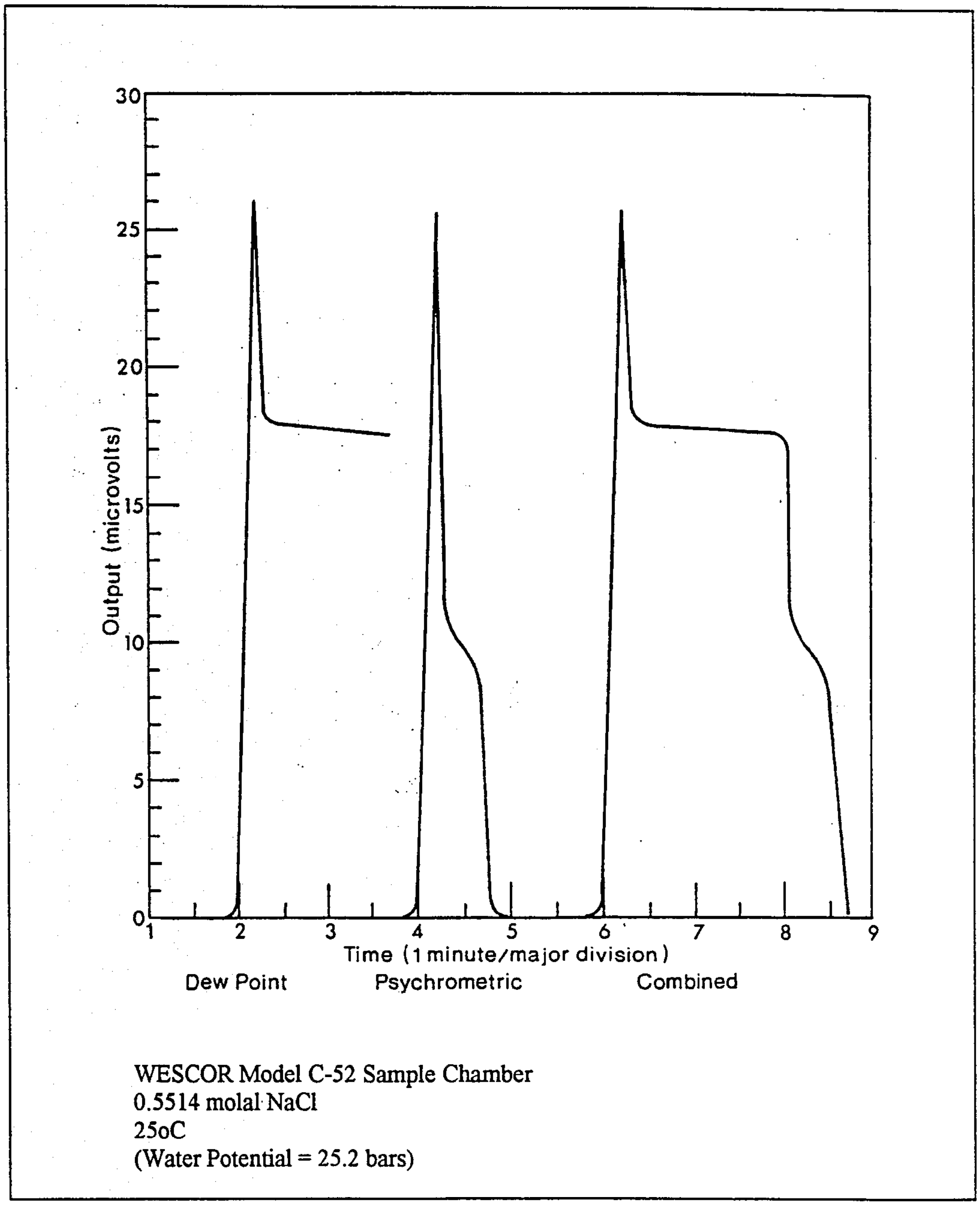

Figure 4.2 : Operational principle for both modes of Psychrometers

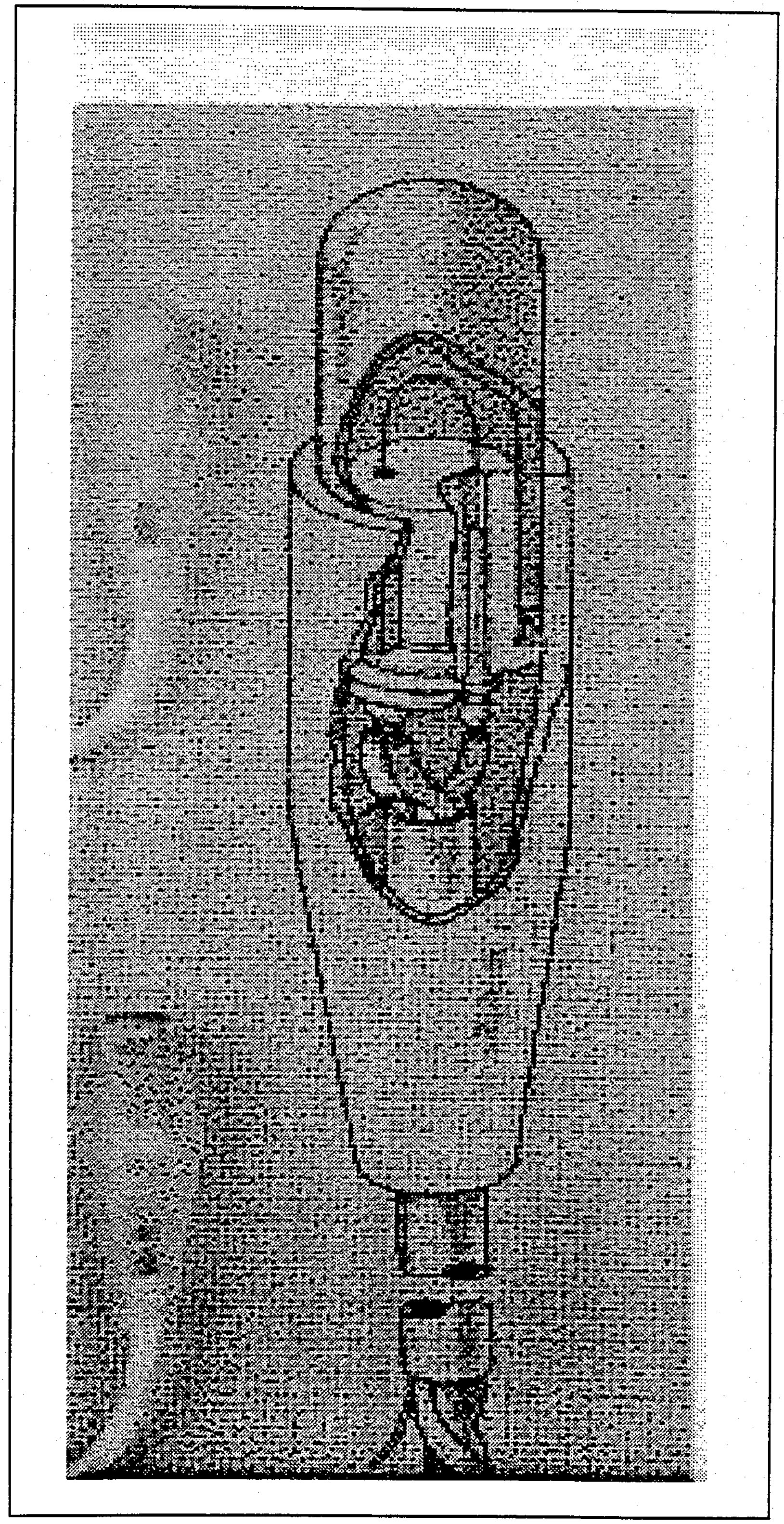

Figure 4.3: Construction schematic view of Psychrometer

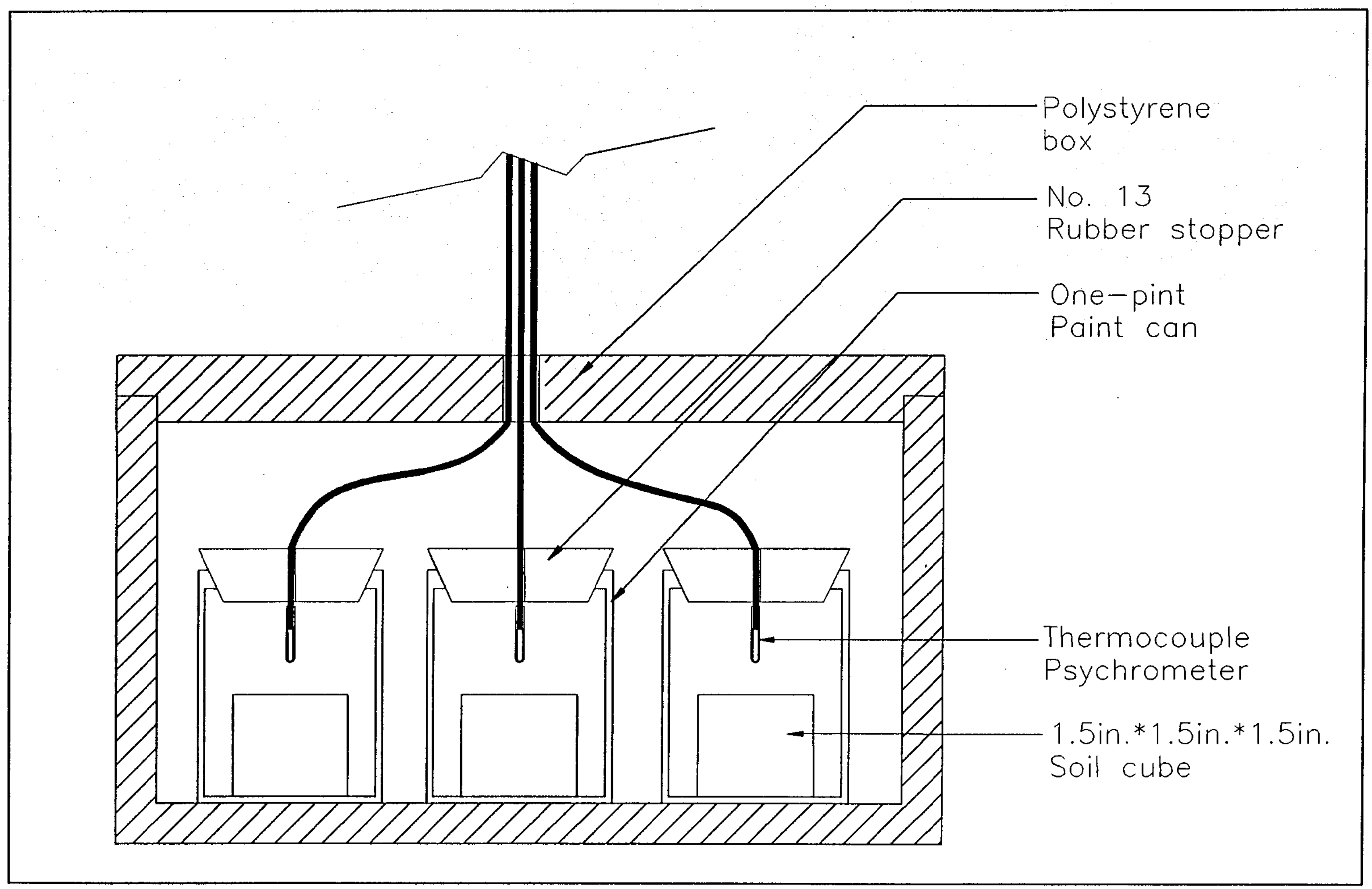

Figure 4.4: Section view of sample chamber assembly

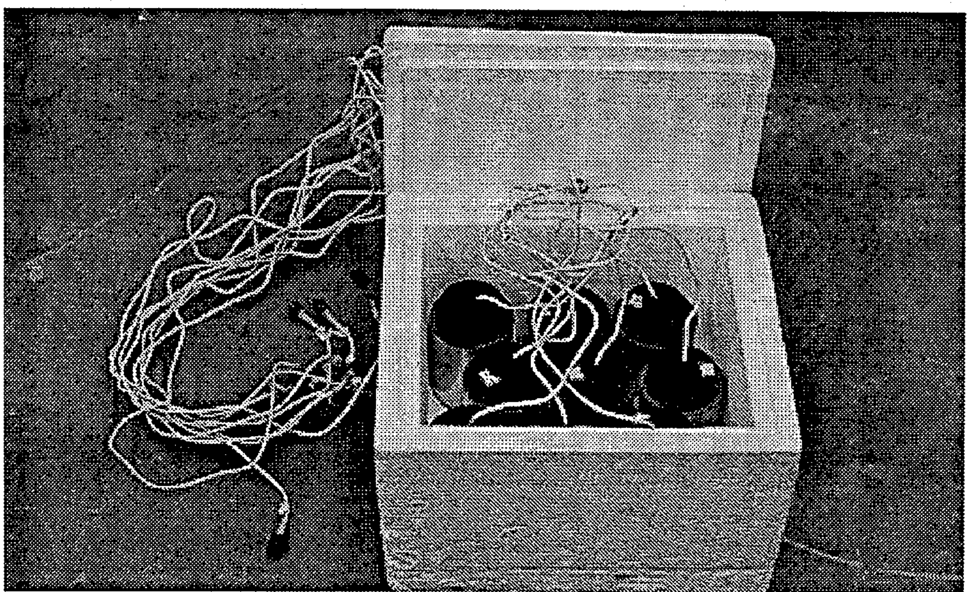

Figure 4.5 : Sample chamber system for soil suction test

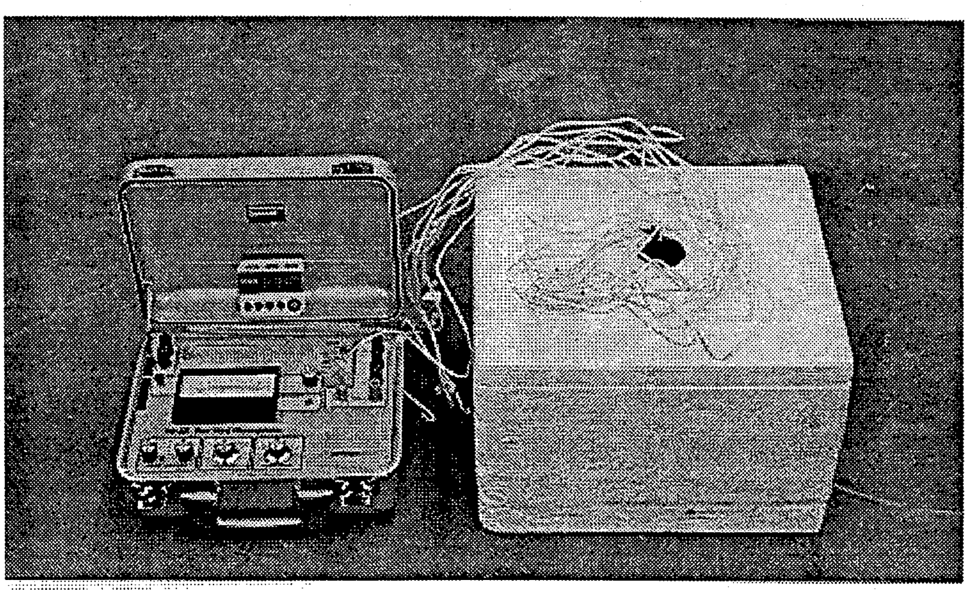

Figure 4.6 : Soil suction test apparatus assembly

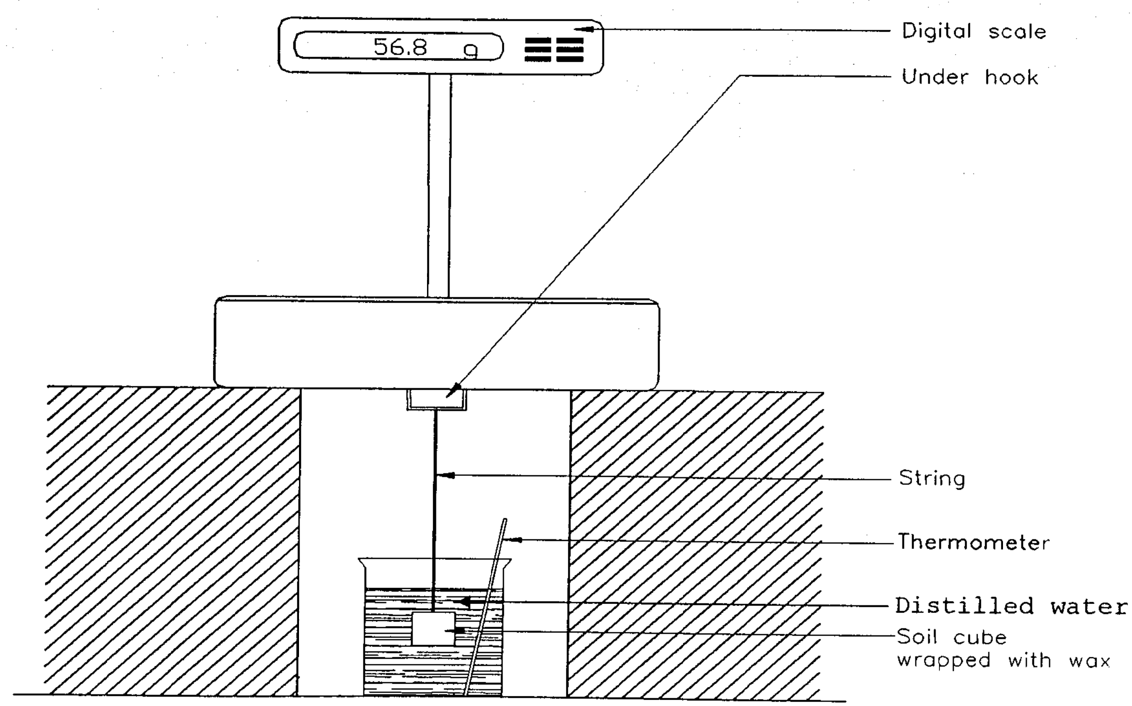

Figure 4.7 : Schematic view of measuring system for Weight-Volume relation test

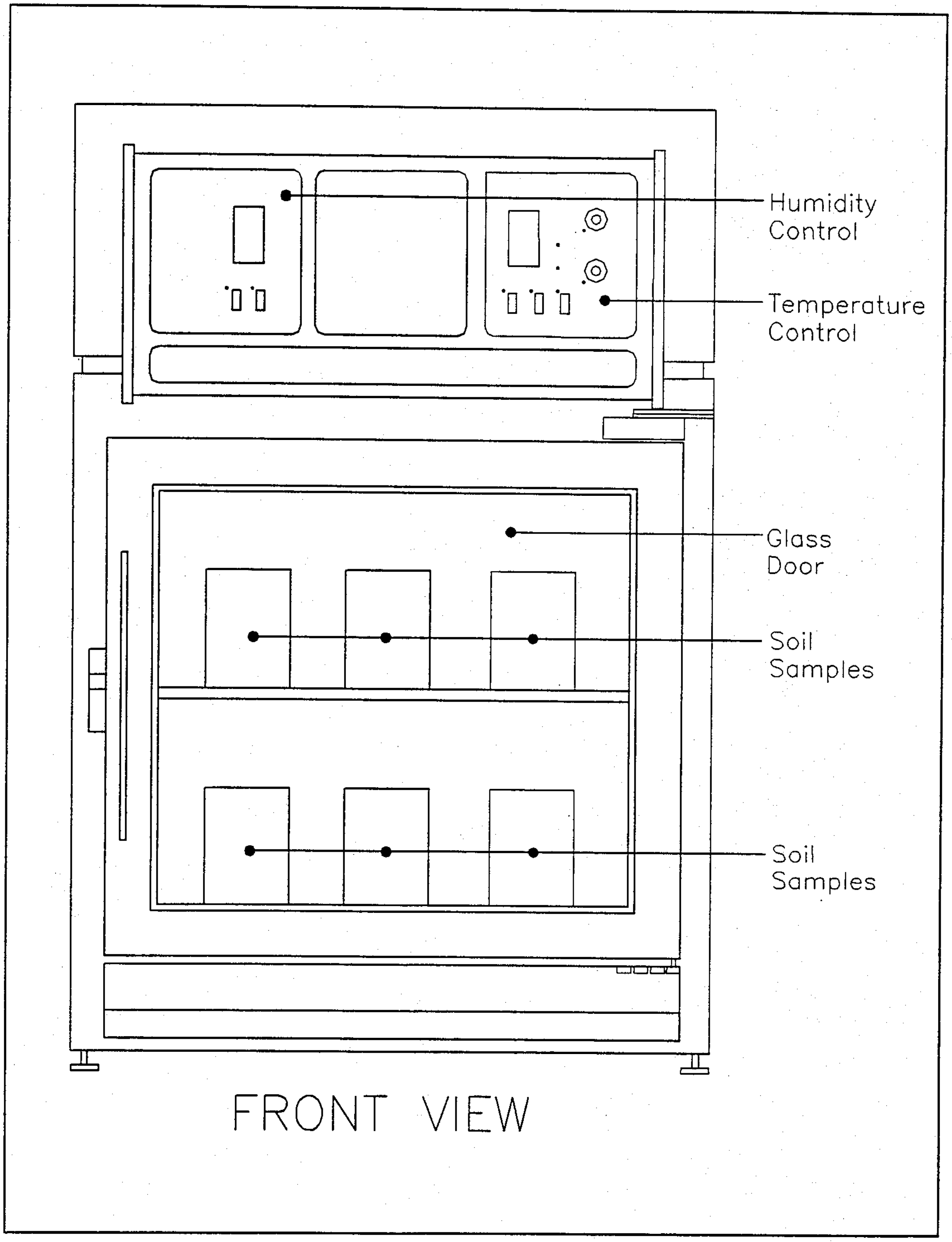

Figure 4.8 : Schematic view of Reach-in Incubator, Model 3911

CHAPTER 5

PRESENTATION AND ANALYSIS OF SOIL SUCTION TEST RESULTS

5.1 General

This chapter presents the soil suction test results from the experimental program described in Chapter 4. Calibration results of nine psychrometers are also presented. The soil suction test results are analyzed to investigate the suction values at different water content and to further correlate with other parameters such as the percent of fines, degree of saturation, and permeability. Factors affecting the suction test results are also discussed in this chapter

5.2 Results of Psychrometer Calibration

Four different concentrations of sodium chloride were used to establish the calibration lines of nine psychrometers, i.e., 290, 500, 1000, and 1800 Osmolality, respectively. Each psychrometer was calibrated using two pieces of filter papers (5.5 cm in diameter) saturated with 3 ml NaCl solution. Microvolt outputs, which are related to the humidity conditions inside the cans, were recorded at least 3 times a day after temperature equilibrium (deviations within ±0.5 microvolts).

Many factors contribute to the variation of the equilibrium time. The more concentrated the solution, the less time it takes to reach equilibrium. A change in psychrometer reading can occur as a result of changes in psychrometer sensitivity with temperature [Rawlins, 1966]. Thus, psychrometer calibrations are necessary for each temperature at which soil-water potential is measured if greater accuracy is required.

Since the soil suction test program had been conducted for longer than one year, the psychrometers were calibrated twice in order to meet the required measurement conditions for suction tests. Calibration A, which was performed in normal laboratory room temperature, was synchronized with the series A suction tests. Calibration B was performed inside an incubator where the series B suction tests were also performed. It was found that the time needed to reach equilibrium for Calibration B (4 to 7 days) was shorter than that for Calibration A, which was about 10 to 15 days.

There exists a relationship between water potential and the concentration of a solution as shown in Equation 5.1. For a 100 Osmolality Sodium Chloride, its water potential is -2.5 bar. The water potentials for 290, 500, 1000, and 1800 Osmolality can be calculated using the following equation:

$$WaterPotential[bar] = -2.5 * \frac{concentration[osmolality]}{100} \tag{5.1}$$

From the test results, it is apparent that the #7 psychrometer has the highest E_{25} value among the nine psychrometers. Microvolt outputs at measured temperatures were adjusted to the equivalent microvolts at 25°C (E_{25}). The average E_{25} values from the last three E_{25}s of each psychrometer for four different concentrations are shown in Tables B.1(a) through B.1(b). The data were used to build the calibration lines of nine psychrometers. The calibration lines of each psychrometer for Calibration A and B are shown in Figures B.1 through B.9. The equations obtained from the calibration lines are listed in Tables B.2(a) and B.2(b). All of the equations have the y-intercept less than zero, and a positive slope of the calibration line.

5.3 Presentation of Soil Suction Test Results

The final three microvolts readings for each test at temperature 25°C (E_{25}) were averaged and utilized to obtain the suction values at different water content. Two different suction units, kilopascal (kPa) and tons per square foot (tsf) were used in analysis. The test results, which include soil suction, water content, and specific volume, are illustrated in Tables 5.1(a) and 5.1(b) for the soil from Clay County. The relationship between soil suction and water content is illustrated in Figure 5.1 for the soil from Clay County. The complete detailed test results of each soil are presented in Appendix C. The soil suction test results for six soils (Series A and Series B) are summarized in Tables 5.2(a) and 5.2(b). Only the results from Series B test are utilized for further analysis.

5.4 Analysis of Soil Suction Test Results

The primary objective of the soil suction test program in this study was to investigate the suction value at different water content and further correlate it with other soil parameters such as the percent of fines, degree of saturation, permeability, and drying rate. As shown in Table 5.2, the suction values ranged from 0 kPa to 4000 kPa, which are relatively small as compared to the entire range of suction from 0 kPa to 10^6 kPa [Fredlund, 1995]. For silty sands, the magnitudes of suction values from this study are reasonable.

5.4.1 Effect of Moisture Content

The suction test results shown in Table 5.2(b) indicate that while most of the soils possess low suction values (less than 665 kPa) when the soils are air-dried up to four hours from optimum water content, the soils from Clay County and Madison County have relatively high suction values (2262.95 kPa for Clay County soil and 3697.94 kPa for Madison County soil). Most of the data fell into the range of 100 kPa to 1000 kPa. The data from Series B tests were analyzed using exponential regression model and plotted in Figure 5.2 for all six soils. Figure 5.3 is a modification from Figure 5.2 by changing Y-axis from linear to logarithm scale so that the change of soil suction at lower values can be observed more clearly. The difference in soil suction among six soils at the wet side of optimum is relatively small as compared to those at the dry side.

It is shown in Figure 5.2 that the soil suction increases with a decrease in water content, and it increases sharply for dry soils with very little decrease in water content. The slope of the regression line for Clay County soil is the highest among the six soils while the one for Alford City has the lowest slope. This indicates that the suction value of Clay County soil is highly sensitive to the change of moisture. The suction-water content ($\tau-\omega$) relationships for the wet side of optimum behave differently from those for the dry side.

The suction values at optimum moisture content (OMC) are compared as shown in Figure 5.4. It shows that Madison County soil has the highest suction value at OMC. The suction values for the moisture range from optimum minus 4 to optimum plus 4 percent for the six soils are summarized in Table 5.3. The suction values at different water content for the six soils are presented in Table 5.4. The results show that Alford City soil has the lowest suction value among the six soils (168kPa to 405kPa). As shown in Figure 5.3, the regression lines for Clay County and Madison County soils have much higher slopes than those for the other soils. This may be a good indicator to explain the difference in behavior for these two soils.

5.4.2 Effect of Percent Fines

For soils with substantial clay fraction (greater than 15%), the interactions of the clay minerals with the pore fluid are expected to dominate the measured soil suction. The study by Acar (1992) demonstrated that the total suction in soil specimens compacted at their optimum water content may be estimated by a knowledge of the plasticity index of the soil. It can vary up to 20 times the atmospheric pressure only by the changes in the composition of the clay fraction. Similar to the swelling potential of fine-grained soils, the fine fraction and activity of the soil mixture define the total suction at optimum water content. Swelling potential is directly related to the total suction in soil by a factor dependent upon the activity of the soil mixture.

The suction values are plotted versus the percent of clay content as well as the percent of passing #200 sieve fines for the six soils at different water content in Figures 5.5 and 5.6, respectively. It is shown that the suction values vary significantly with water content when the percent of clay content is greater than 10, and the percent of passing #200 sieve fines is greater than 20. The suction values can be limited within 100 to 3000 kPa with the percent of fines (-#200 sieve) less than 20.

5.4.3 Effect of Permeability

The suction value and the permeability at specific water content (at which the permeability was measured) for the six soils are summarized in Table 5.5. Figure 5.7 shows no significant evidence of any correlation between the soil suction and permeability for these soils. It may be due to the narrow range of suction values (from 100kPa to 500kPa). A wide range of suction values and the permeability values at unsaturated condition should be obtained in order to correlate suction and permeability of unsaturated soils.

5.4.4 Effect of Degree of Saturation

The effect of saturation on soil suction has often been of fundamental concern in groundwater flow. Soil suction has been demonstrated to increase from 100 kPa to 10 MPa by a decrease in the degree of saturation from 100% to 20% [Olson and Daniel, 1981]. Figures 5.8 and 5.9 illustrate the effect of degree of saturation on the soil suction value. There is basically no significant change in suction values when the degree of saturation falls into the range of 95% to 70%. However, the suction values of Clay County and Madison County soils increase significantly by a decrease in the degree of saturation below 70%.

5.5 Presentation of Specific volume test results

Most clay soils increase in volume as the soil moisture content increases. Another way to state the generalization of clay soils is that soil volume decreases as soil suction increases and vise versa. Volume change for sand soils is not as significant as for clay soils. The results from the weight-volume tests are presented in Table 5.2 as with the suction test results. The values of the specific volume for each soil remain at the same level (within the range of 0.04 to 0.07) regardless of the water content. These values are extremely low as compared with those from high volume change soils.

5.6 Discussion on Factors Affecting Test Results

Many factors contributed to the deviation of the test results. The most significant one was the temperature fluctuation. The laboratory room temperature was not well controlled, and varied with the ambient temperature when the Series A was conducted. The fluctuation of temperature resulted in unstable microvolts outputs and a longer equilibrium time. Therefore, the lower R^2 values for the Series A tests were obtained as a result. the situation was improved for the series B by using the environmental chamber for a better control of the temperature. Rawlins and Dalton [1967] pointed out that as air is heated, its water-holding capacity increases. This causes a decrease in relative humidity unless sufficient water enters the air during heating to compensate. In a sealed chamber where water vapor can neither enter nor leave, the error in water potential resulting from changes in temperature of the chamber would be very small. The error will be also less as the sample area increases relative to the chamber wall area, and will be the least for the ideal psychrometer where the junction is completely surrounded by the sample and heat flow to and from the junction is restricted to conduction through air.

The concentration of the calibration solution for psychrometers is very important and it needs to be made accurately. The more concentrated the solution, the more accurate the calibration will result. When measuring extremely low soil suction, a more soluble calibrating solute than NaCl or KCl is needed.

The water distribution of each specimen is also a factor of test error. A wider range of water content is needed to cover the wet and dry conditions when high accuracy is required. The regression model needs more data points to achieve a higher confidence level. As shown in Tables 5.2(a) and 5.2(b), most regression curves have R^2 values between 0.7 and 0.9.

Table 5.1(a) : Summary of soil suction, water content, and specific volume test results for Clay County Soil

Series A   Dry density: 18.7 KN/m^3 Water content : 9.27%

A. Soil Suction Test										
Psychrometer No.		9B	8	7	4	5B	6	3	2	1
Sample container No.		63	63	62	60	61	61	58	55	54
Water content Increment (0, +, -)		4hr	2hr	1hr	0.5ml	N	N	1ml	2ml	4ml
E_{25}, Microvolts*		29.85	13.87	5.39	3.10	2.90	2.83	2.83	3.40	3.66
Soil Suction, Tons/ft2 (π)		37.83	16.21	4.55	2.75	2.65	2.69	2.71	2.57	3.35
Soil Suction, kPa (π)		3619.63	1551.21	435.20	263.09	254.03	257.25	258.90	245.53	320.58
B. Water Content										
Weight in Grams	Tare Plus Wet Soil	332.5	350.45	368.3	376.5	376.8	372.3	371.5	381.7	385.9
	Tare Plus Dry Soil	326.2	342	357.8	364.59	364.7	360.29	359.2	368	369.9
	Water (W_w)	6.3	8.45	10.5	11.91	11.92	12.01	12.3	13.7	16
	Tare	237.1	237.1	237.1	237.1	237.1	237.1	237.1	237.1	237.1
	Dry Soil (W_s)	89.1	104.9	120.7	127.49	127.6	123.2	122.1	130.9	132.8
Water Content (%)		7.07%	8.06%	8.70%	9.34%	9.34%	9.75%	10.07%	10.47%	12.05%
C. Specific Volume										
Test Temperature of Water (°C)		33°C	33°C	33°C	33°C	33°C	33°C	33°C	33°C	33°C
Weight in Grams	Wet Soil and Wax	135.6	148.2	160.5	166.7	164	168.7	151.5	165.1	172.4
	Wet Soil (W)	132.1	142.5	143.4	147.6	146.3	155.1	147.4	148	151.4
	Wax	3.5	5.7	17.1	19.1	17.7	13.6	4.1	17.1	21
	Wet Soil and Wax in Water	34.4	39.5	38.5	42	38	39	39	39	41
	Dry Soil (W_s)	123.38	131.88	131.92	134.99	133.80	141.32	133.91	133.98	135.12
Volume in CC	Wet soil and Wax	101.2	108.7	122	124.7	126	129.7	112.5	126.1	131.4
	Wax	6.36	10.36	31.09	34.73	32.18	24.73	7.45	31.09	38.18
	Wet Soil (V)	94.84	98.34	90.91	89.97	93.82	104.97	105.05	95.01	93.22
Density KN/m^3	Wet Density (γ_m) = (W/V)*9.8	13.65	14.20	15.46	16.08	15.28	14.48	13.75	15.27	15.92
	Dry Density (γ_d) = (W_s/V)*9.8	12.75	13.14	14.22	14.70	13.98	13.19	12.49	13.82	14.21
Specific Volume (V_γ) =1/ρ_d		0.078	0.076	0.070	0.068	0.072	0.076	0.080	0.072	0.070

* E_{25} was calculated by averaging the last three readings from soil suction test results

Table 5.1(b) : Summary of soil suction, water content, and specific volume test results for Clay County soil

Series B   Dry density: 19.5 KN/m^3 Water content :9.1%

A. Soil Suction Test										
Psychrometer No.		1	2	3	4	5B	6	7	8	9B
Sample container No.		54	55	58	60	61	61	62	63	63
Water content Increment (0, +, -)		4hr	2hr	1hr	N	N	0.5ml	1ml	2ml	4ml
E25, Microvolts*		18.87	16.62	11.03	8.03	6.81	3.70	2.79	2.75	2.77
Soil Suction, Tons/ft2 (π)		23.65	19.39	13.61	9.30	7.57	3.78	1.19	1.14	1.13
Soil Suction, kPa (π)		2262.95	1855.44	1302.47	890.26	724.32	362.07	114.06	108.95	108.17
B. Water Content										
Weight in Grams	Tare Plus Wet Soil	271.9	268	258.8	249.4	248.1	257.7	271.7	246.5	253.3
	Tare Plus Dry Soil	262.2	257.9	249.1	240.3	238.9	247.7	259.8	235.8	240.6
	Water (W_w)	9.7	10.1	9.7	9.1	9.2	10	11.9	10.7	12.7
	Tare	134.2	134.2	134.2	134.2	134.2	134.2	134.2	134.1	134.1
	Dry Soil (W_s)	128	123.7	114.9	106.1	104.7	113.5	125.6	101.7	106.5
Water Content (%)		7.58%	8.16%	8.44%	8.58%	8.79%	8.81%	9.47%	10.52%	11.92%
C. Specific Volume										
Test Temperature of Water (°C)		33°C	33°C	33°C	33°C	33°C	33°C	33°C	33°C	33°C
Weight in Grams	Wet Soil and Wax	162.4	153.4	142.57	132.65	131.4	137.53	154.35	126.65	135.6
	Wet Soil (W)	138.97	142.88	125.5	115.89	114.5	124.5	138.19	112.9	119.25
	Wax	23.43	10.52	17.07	16.76	16.9	13.03	16.16	13.75	16.35
	Wet Soil and Wax in Water	45.1	55.4	44.29	39.31	39.78	44.5	51.77	38.7	40.12
	Dry Soil (W_s)	129.18	132.09	115.73	106.74	105.25	114.42	126.23	102.15	106.54
Volume in CC	Wet soil and Wax	117.3	98	98.28	93.34	91.62	93.03	102.58	87.95	95.48
	Wax	42.60	19.13	31.04	30.47	30.73	23.69	29.38	25.00	29.73
	Wet Soil (V)	74.70	78.87	67.24	62.87	60.89	69.34	73.20	62.95	65.75
Density KN/m^3	Wet Density (γ_m) = (W/V)*9.8	18.23	17.75	18.29	18.07	18.43	17.60	18.50	17.58	17.77
	Dry Density (γ_d) = (W_s/V)*9.8	16.95	16.41	16.87	16.64	16.94	16.17	16.90	15.90	15.88
Specific Volume (V_γ) =1/ρ_d		0.059	0.061	0.059	0.060	0.059	0.062	0.059	0.063	0.063

* E_{25} was calculated by averaging the last three readings from soil suction test results

Table 5.2(a) : Summary of soil suction test results for six soils (Series A)

Psychrometer Number		1	2	3	4	5B	6	7	8	9B	
Cooling Coefficient		54	55	58	60	61	61	62	63	63	
Water status		4hr*	2hr	1hr	N**	N	0.5ml***	1ml	2ml	4ml	R^2
Clay County	water content	12.05%	10.47%	10.07%	9.34%	9.34%	9.75%	8.70%	8.06%	7.07%	0.5849
	suction (kPa)	320.58	245.53	258.90	263.09	254.03	257.25	435.20	1551.21	3619.63	
	specific volume	0.070	0.072	0.080	0.068	0.072	0.076	0.070	0.076	0.078	
Madison County	water content	11.54%	10.28%	9.66%	9.27%	8.89%	8.95%	8.18%	7.67%	6.49%	0.7418
	suction (kPa)	229.94	273.54	308.50	325.94	329.21	326.21	572.21	599.21	3211.14	
	specific volume	0.066	0.069	0.068	0.069	0.065	0.068	0.067	0.069	0.066	
Alford City	water content	4.41%	5.97%	6.74%	7.46%	7.41%	7.50%	7.91%	8.55%	10.20%	0.7535
	suction (kPa)	380.59	314.94	280.52	306.32	315.38	315.10	258.10	286.69	237.57	
	specific volume	0.056	0.057	0.056	0.053	0.054	0.058	0.057	0.055	0.056	
Jacobs Road	water content	4.00%	5.41%	6.11%	7.07%	7.10%	7.73%	7.94%	9.60%	11.30%	0.6172
	suction (kPa)	460.15	191.62	354.78	110.69	258.70	229.53	196.66	148.38	2.85	
	specific volume	0.066	0.064	0.065	0.062	0.064	0.064	0.066	0.067	0.065	
Brevard County	water content	6.17%	6.97%	7.75%	9.05%	9.03%	9.55%	10.13%	10.57%	12.00%	0.7028
	suction (kPa)	586.14	400.17	444.61	259.27	213.13	251.22	214.26	46.69	102.71	
	specific volume	0.058	0.058	0.060	0.055	0.057	0.059	0.057	0.057	0.056	
Marion County	water content	5.78%	7.57%	8.33%	8.92%	9.06%	9.25%	9.43%	11.18%	12.15%	0.8653
	suction (kPa)	647.73	425.33	435.30	424.86	343.47	325.94	205.79	141.37	148.48	
	specific volume	0.054	0.057	0.055	0.054	0.057	0.058	0.056	0.058	0.056	

* 4hr indicates that soil had been air-dried for 4 hours after removal from compaction mold.

** N represents natural condition which is at its optimum water content.

*** 0.5 ml means that the soil was wetted by adding 0.5 ml distilled water after removal from compaction mold.

Table 5.2(b) : Summary of soil suction test results for six soils (Series B)

Soil	Psychrometer Number	1	2	3	4	5B	6	7	8	9B	
	Cooling Coefficient	54	55	58	60	61	61	62	63	63	
	Water status	4hr*	2hr	1hr	N**	N	0.5ml***	1ml	2ml	4ml	R^2
Clay County	water content	7.58%	8.16%	8.44%	8.58%	8.79%	8.81%	9.47%	10.52%	11.92%	0.7569
	suction (kPa)	2262.95	1855.44	1302.47	890.26	724.32	362.07	114.06	108.95	108.17	
	specific volume	0.059	0.061	0.059	0.060	0.059	0.062	0.059	0.063	0.063	
Madison County	water content	5.60%	7.13%	7.69%	8.12%	8.40%	8.77%	9.14%	9.78%	11.27%	0.7907
	suction (kPa)	3697.94	755.02	410.90	420.70	556.84	347.18	187.45	242.43	192.57	
	specific volume	0.065	0.071	0.068	0.070	0.062	0.069	0.073	0.067	0.069	
Alford City	water content	4.32%	5.82%	7.06%	7.52%	7.40%	7.75%	8.06%	8.24%	10.40%	0.8339
	suction (kPa)	413.00	316.21	258.66	269.91	276.01	232.31	223.26	241.26	218.27	
	specific volume	0.056	0.058	0.058	0.056	0.054	0.058	0.057	0.059	0.056	
Jacobs Road	water content	5.30%	6.39%	6.94%	7.50%	7.38%	8.10%	8.37%	9.24%	10.71%	0.7357
	suction (kPa)	663.14	422.42	358.40	353.38	369.03	261.03	280.55	247.15	271.59	
	specific volume	0.059	0.060	0.058	0.061	0.061	0.061	0.061	0.063	0.061	
Brevard County	water content	6.59%	7.71%	8.29%	8.93%	8.81%	9.29%	9.83%	10.72%	11.71%	0.7727
	suction (kPa)	633.82	507.88	451.57	464.07	493.45	375.90	432.17	428.18	338.43	
	specific volume	0.058	0.059	0.060	0.055	0.057	0.059	0.057	0.057	0.056	
Marion County	water content	6.31%	7.60%	8.36%	9.20%	9.20%	9.34%	9.78%	10.59%	11.99%	0.9023
	suction (kPa)	632.21	445.62	417.45	360.96	369.03	259.72	236.39	212.84	189.13	
	specific volume	0.056	0.058	0.055	0.054	0.058	0.058	0.056	0.057	0.056	

* 4hr indicates that soil had been air-dried for 4 hours after removal from compaction mold.

** N represents natural condition which is at its optimum water content.

*** 0.5 ml means that the soil was wetted by adding 0.5 ml distilled water after removal from compaction mold.

Table 5.3 : Soil suction values at different water content for six soils (Series B)

Soils	Calibration Equations	Soil suction value at different levels of water content, τ [kPa]								
		Water content , ω [%]								
		OMC-4%	OMC-3%	OMC-2%	OMC-1%	OMC	OMC+1%	OMC+2%	OMC+3%	OMC+4%
Clay County	τ = 8.228E5*EXP(-0.8117ω)	13106	5820	2585	1148	510	226	101	45	20
Madison County	τ = 3.181E4*EXP(-0.5039ω)	3294	1990	1203	727	439	265	160	97	58
Alford City	τ = 600.9*EXP(-0.1097ω)	405	363	325	291	261	234	210	188	168
Jacobs Road	τ = 1250*EXP(-0.1668ω)	652	552	467	395	335	283	240	203	172
Brevard County	τ = 1149*EXP(-0.1026ω)	670	605	546	493	445	401	362	327	295
Marion County	τ = 2622*EXP(-0.2287ω)	780	621	494	393	313	249	198	157	125

Notes : τ = soil suction in kPa
ω = water content

Table 5.4 : Soil suction values at different water content for six soils (Series B)

Soils	Calibration Equations	Soil suction value at different water content, τ [kPa]							
		Water content , ω [%]							
		0	2.5	5	7.5	OMC	10	12.5	15
Clay County	τ = 8.228E5*EXP(-0.8117ω)	822800	108144	14214	1868	510 $(9.1)^{+}$	246	32	4
Madison County	τ = 3.181E4*EXP(-0.5039ω)	31810	9025	2561	727	439 $(8.5)^{+}$	206	58	17
Alford City	τ = 600.9*EXP(-0.1097ω)	601	457	347	264	261 $(7.6)^{+}$	201	153	116
Jacobs Road	τ = 1250*EXP(-0.1668ω)	1250	824	543	358	335 $(7.9)^{+}$	236	155	102
Brevard County	τ = 1149*EXP(-0.1026ω)	1149	889	688	532	445 $(9.25)^{+}$	412	319	247
Marion County	τ = 2622*EXP(-0.2287ω)	2622	1480	836	472	313 $(9.3)^{+}$	266	150	85

Note : τ = soil suction in kPa

ω = water content

+ the value represents the actual water content @ OMC

Table 5.5 : Summary of permmeability and suction values for six soils

District	Location	Water content [%]	Average permeability [x10^{-6} cm/sec]	Suction [kPa]
2	Clay County	9.40	29.3	400
2	Madison County	9.73	1.3	236
3	Alford City	7.20	3.8	273
3	Jacobs Road	7.83	58.4	339
5	Brevard County	10.15	50.8	406
5	Marion County	9.60	12.9	292

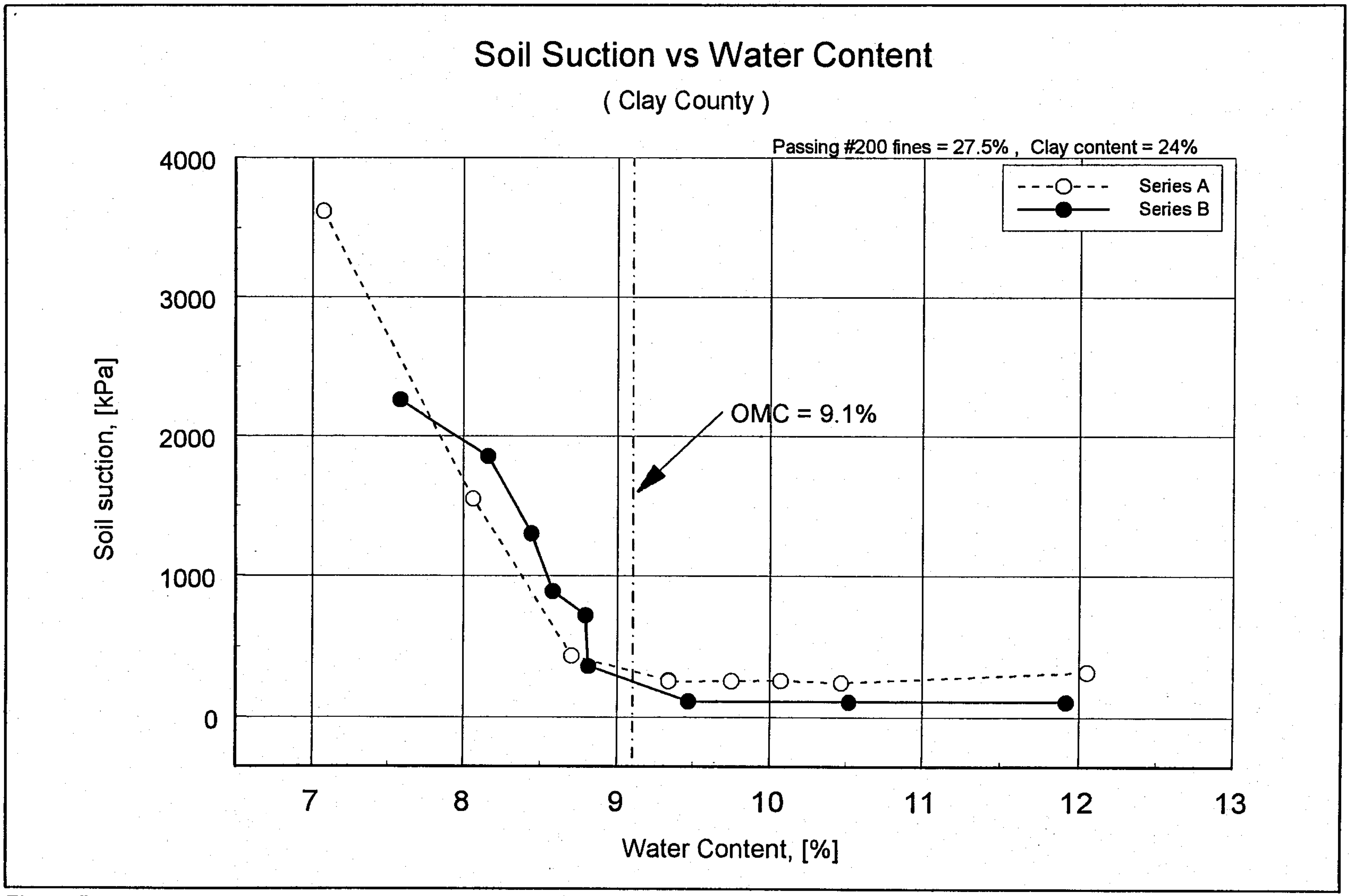

Figure 5.1 : Comparison of suction values from Series A and Series B for Clay County soil

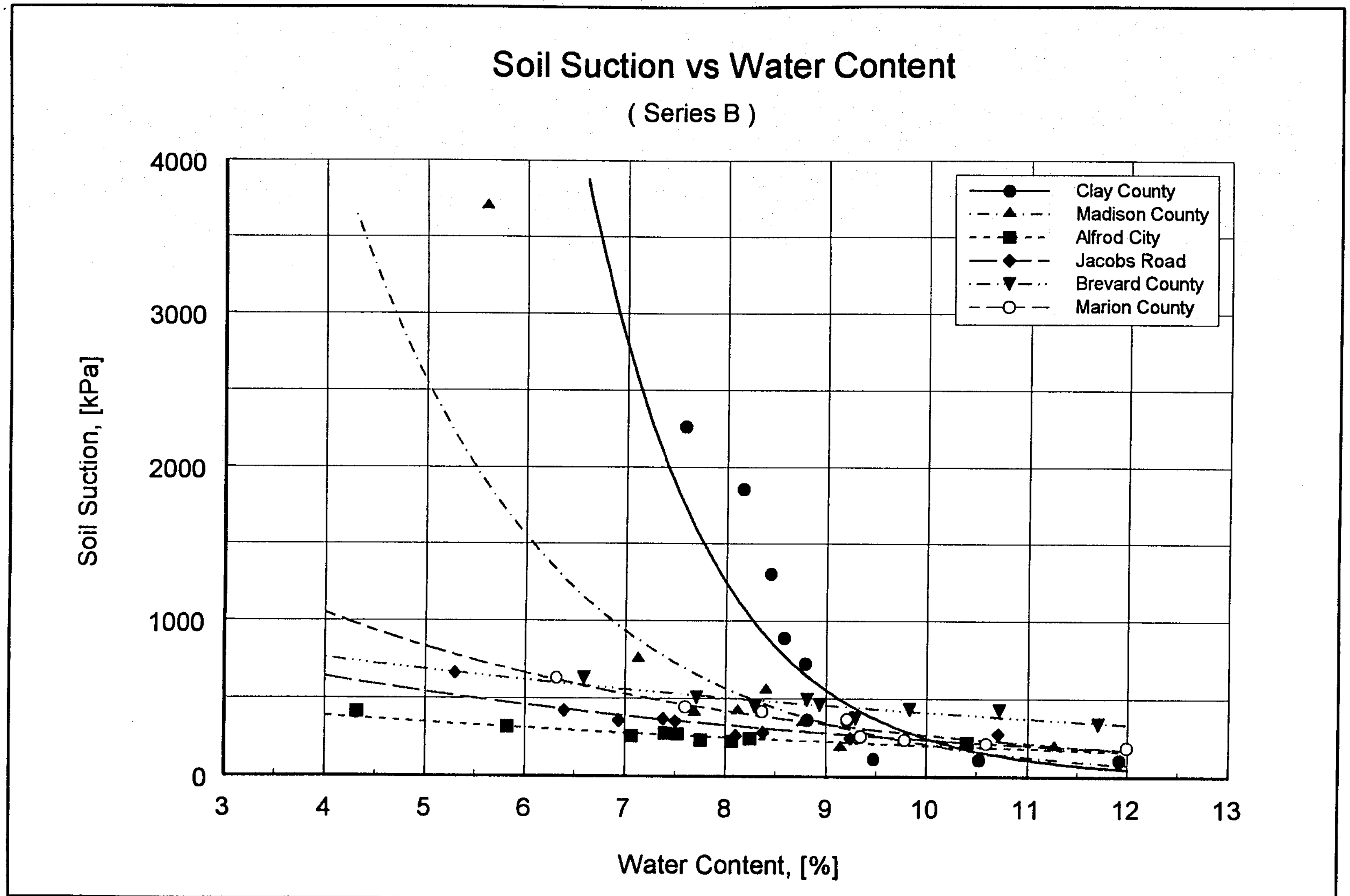

Figure 5.2 : Soil suction values at different water content for six soils (Series B)

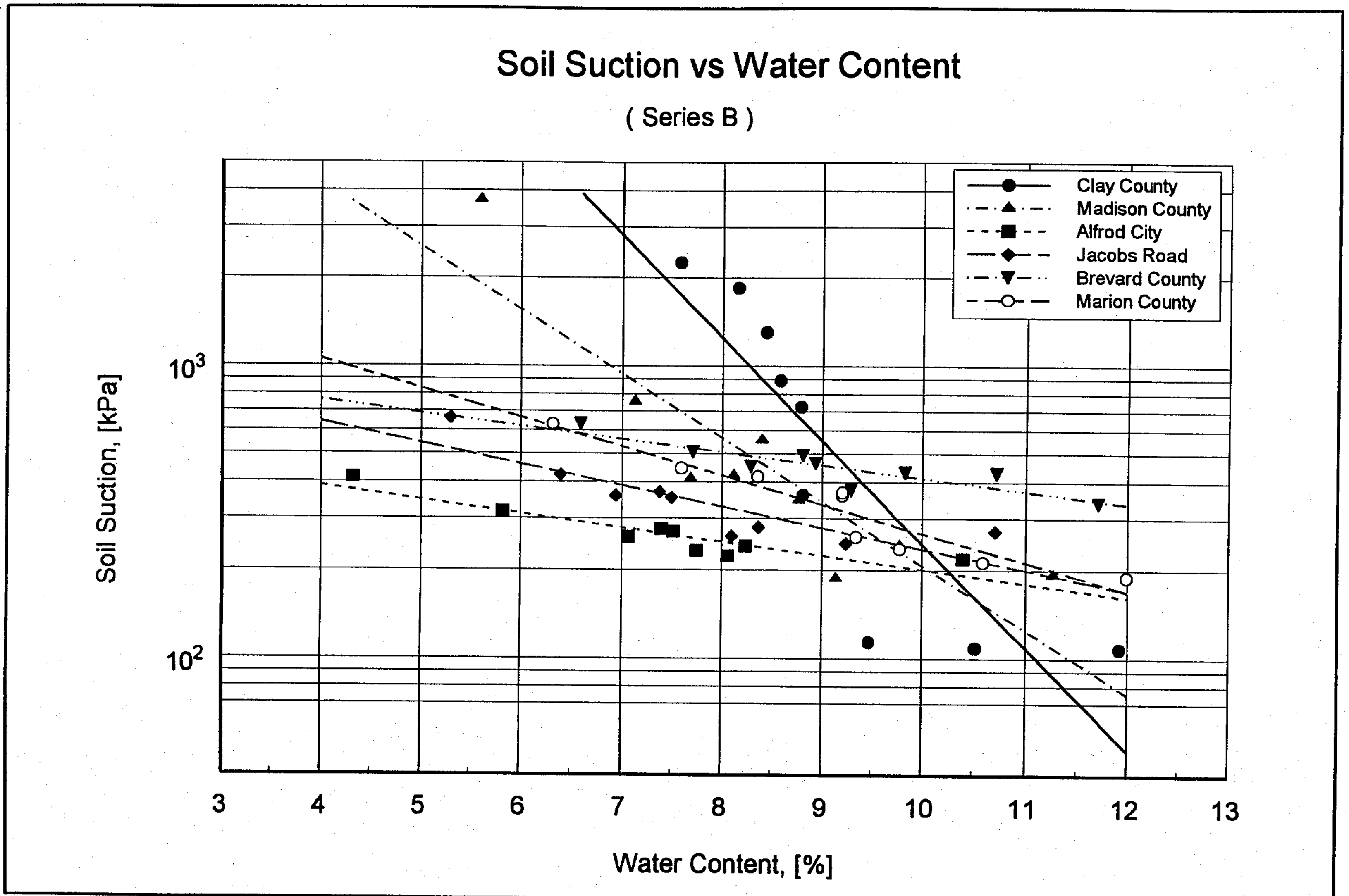

Figure 5.3 : Soil suction values at different water content for six soils (Series B, Semi-log scale)

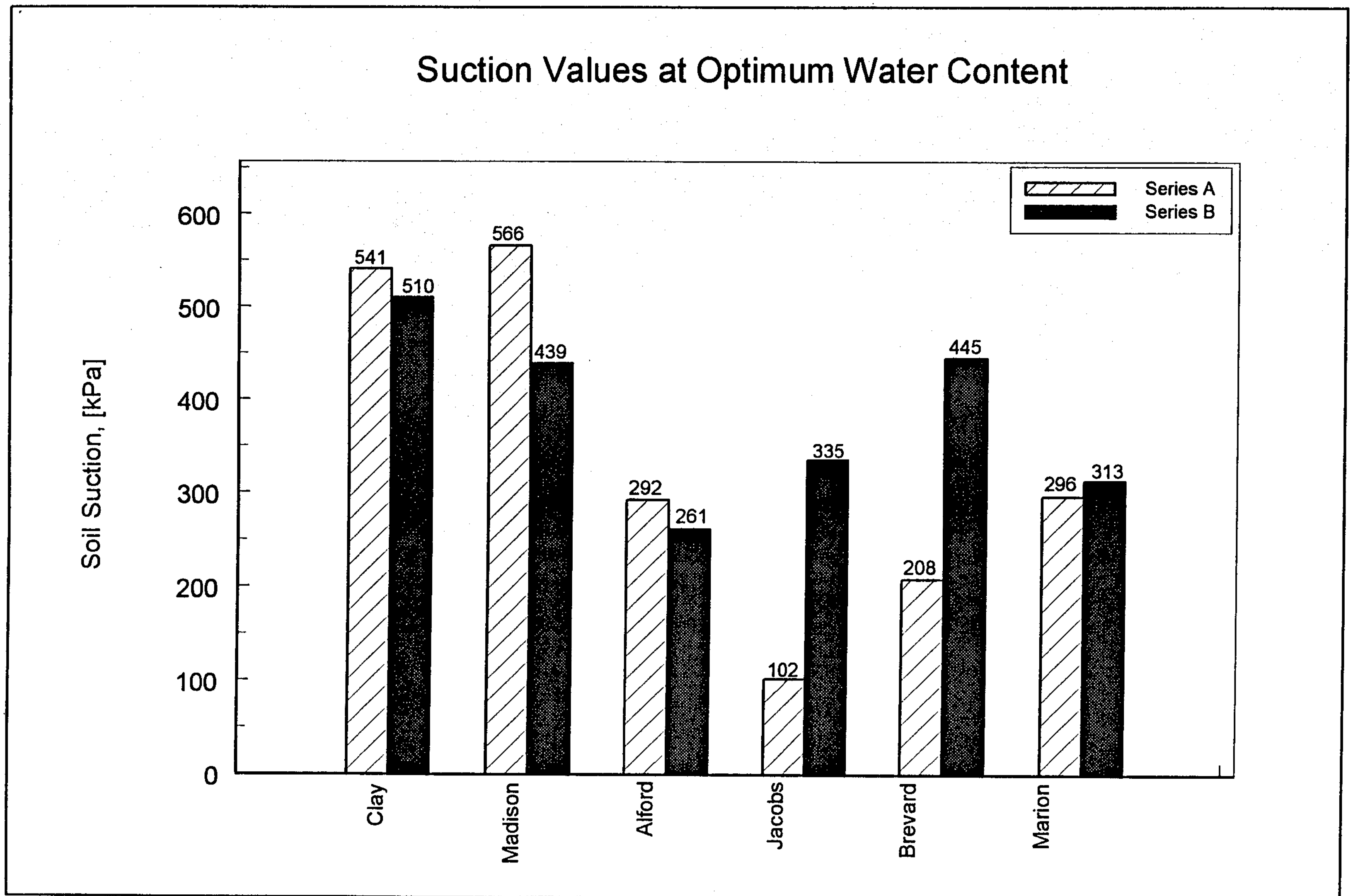

Figure 5.4 : Comparison of suction values at optimum water content from Series A and Series B for six soils

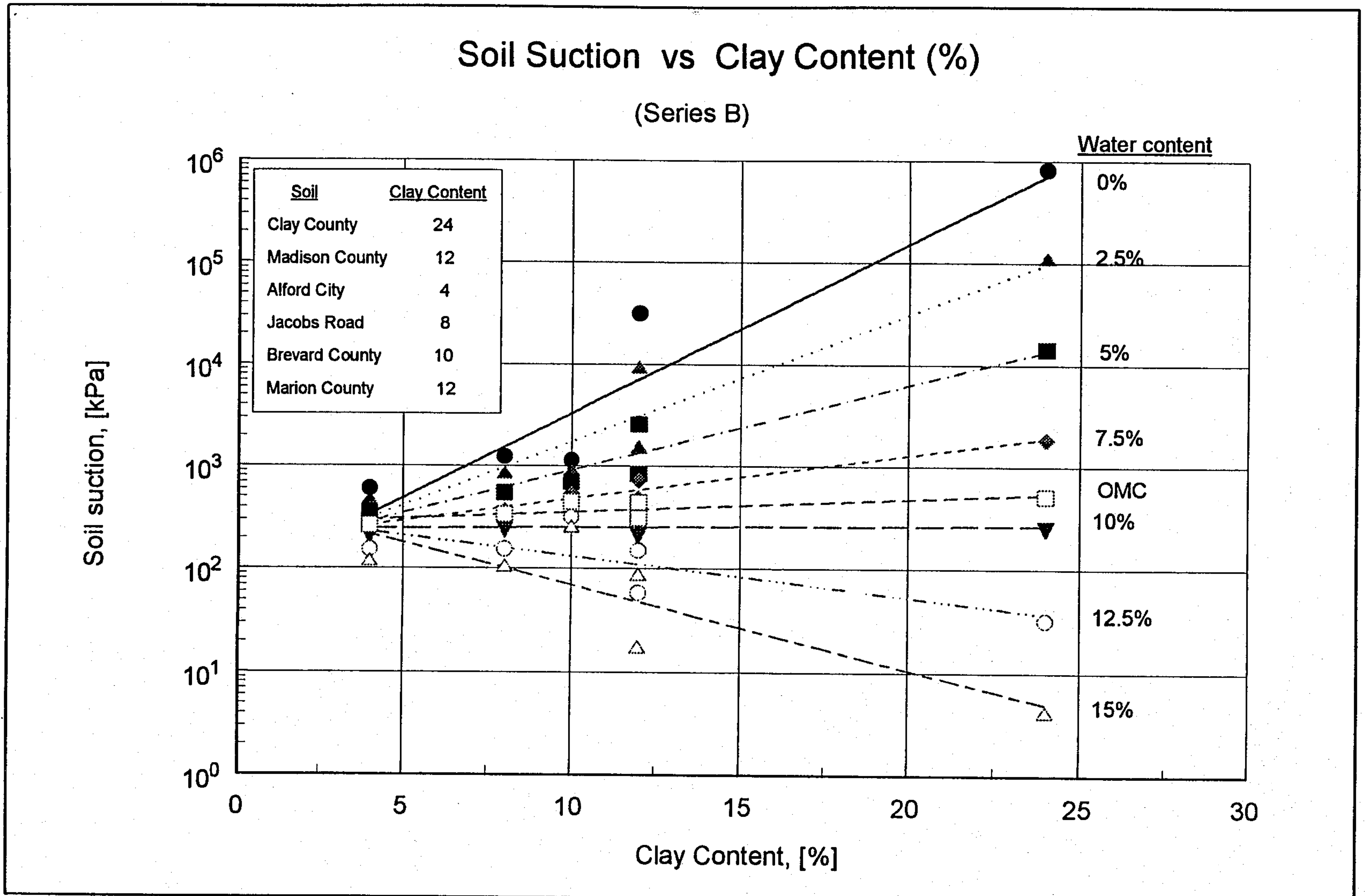

Figure 5.5 : Relationship between soil suction and percent of clay content for different water content (Series B)

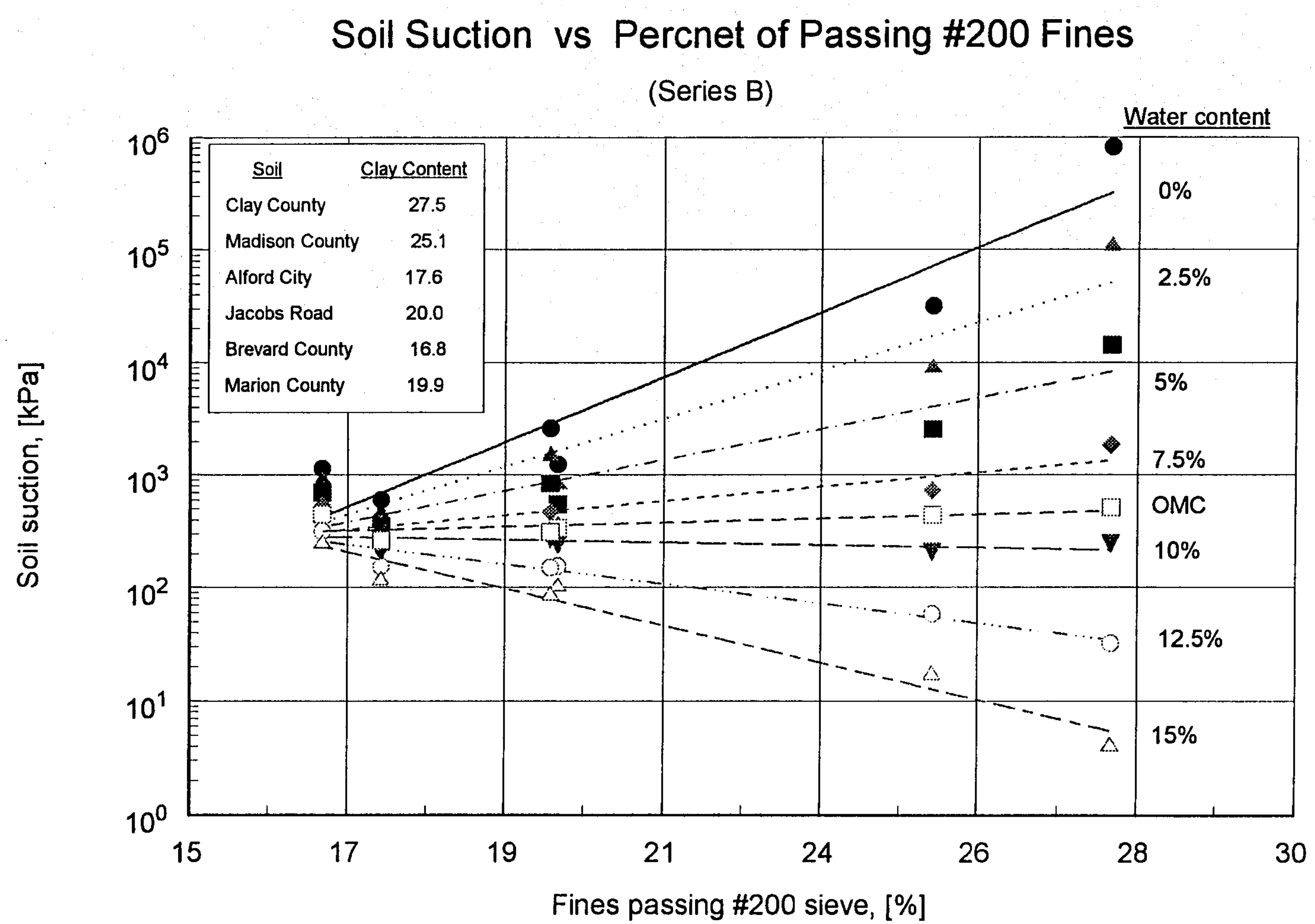

Figure 5.6 : Relationship between soil suction and percent of passing #200 fines for different water content (Series B)

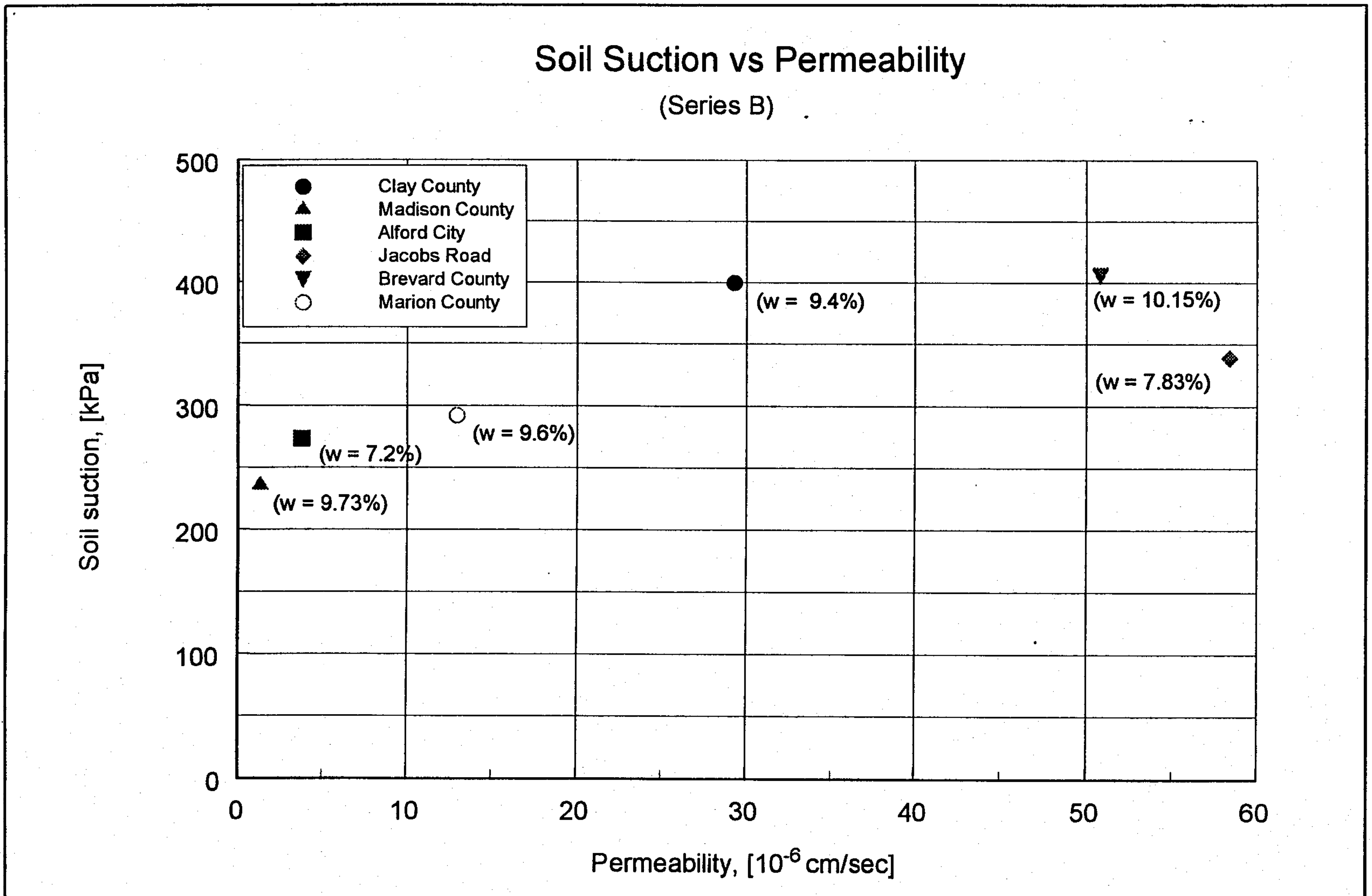

Figure 5.7 : Relationship between soil suction and permeability for six soils (Series B)

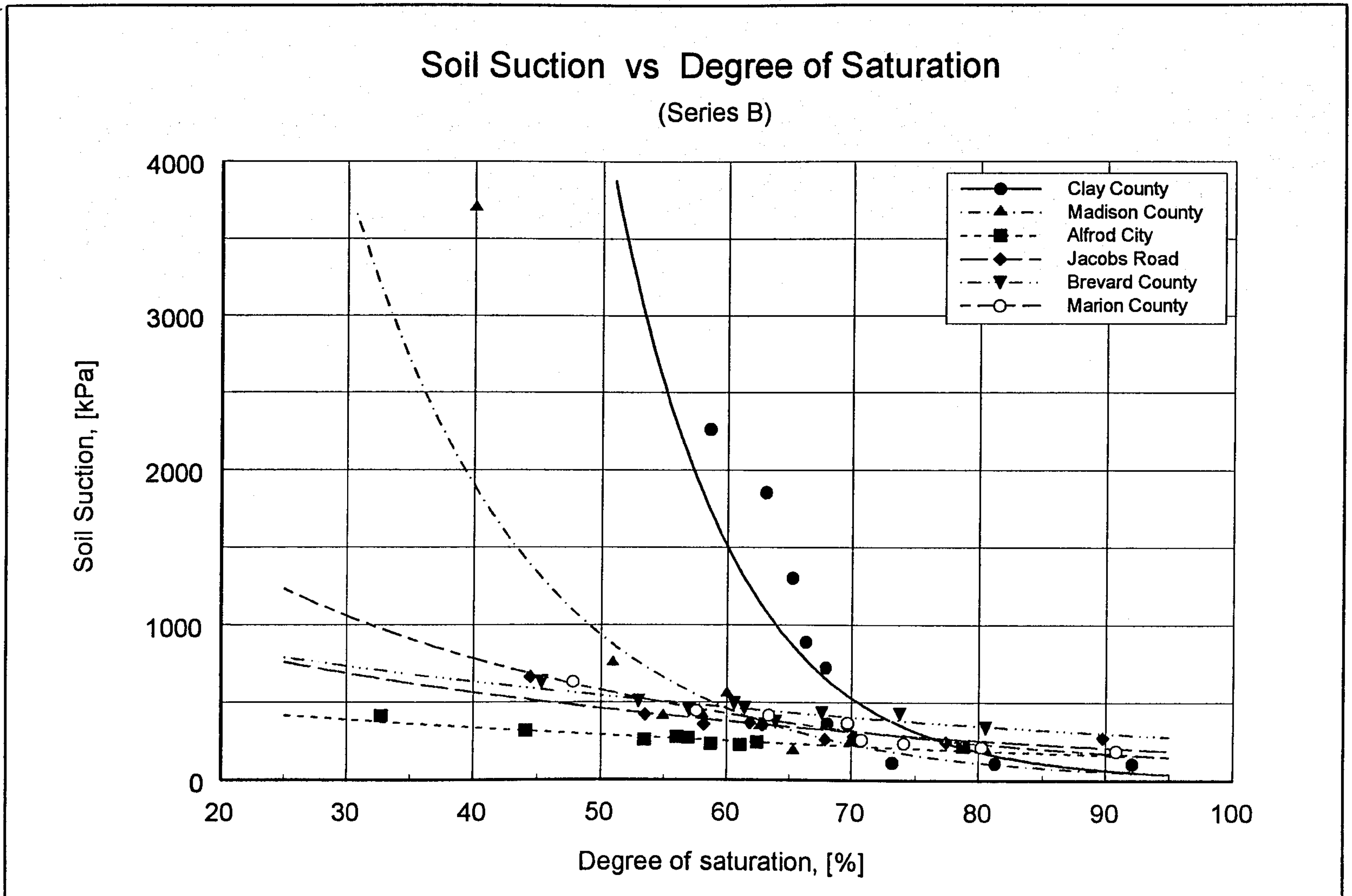

Figure 5.8 : Soil suction values at different degree of saturation for six soils (Series B)

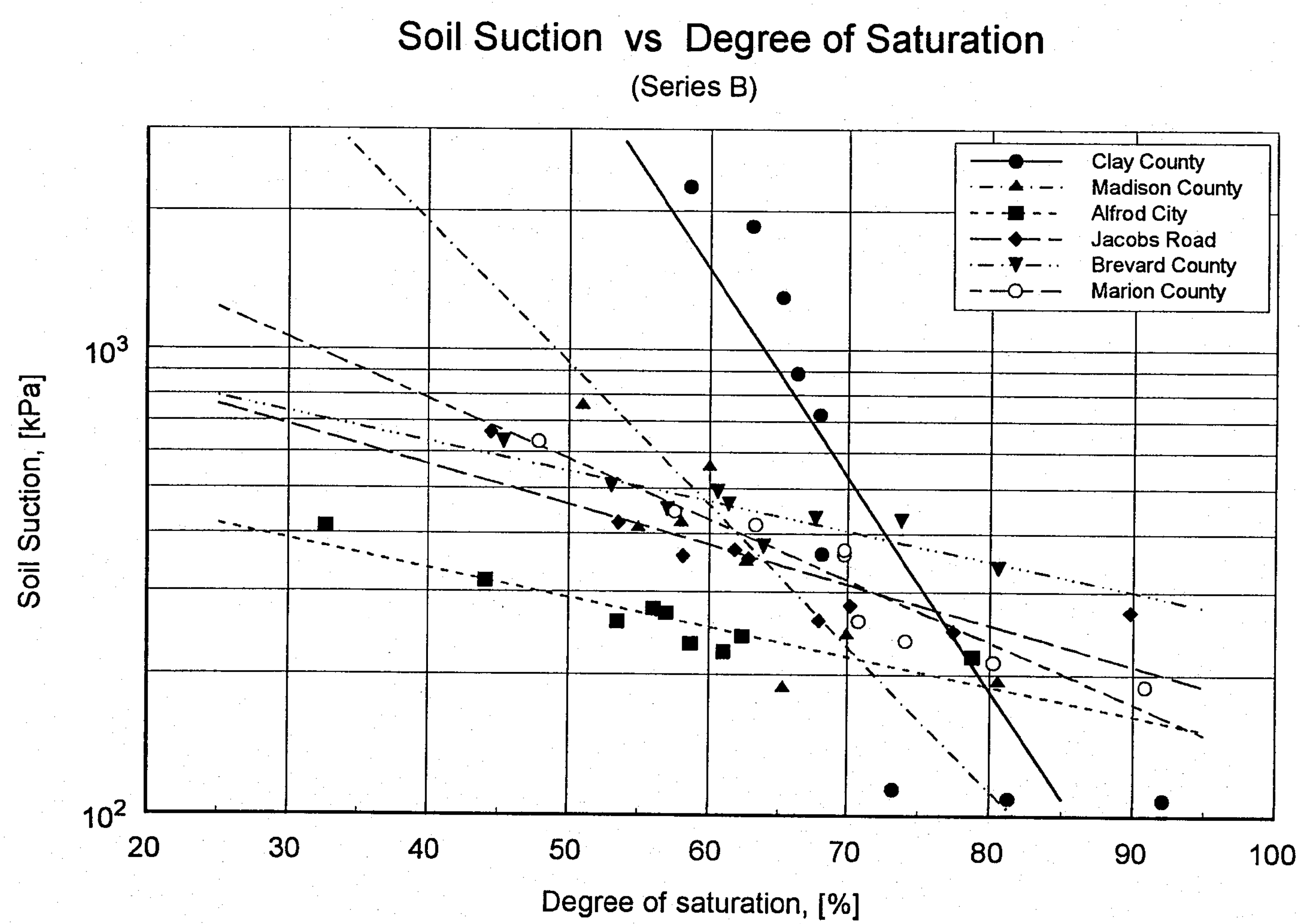

Figure 5.9 : Soil suction values at different degree of saturation for six soils (Series B, Semi-log scale)

CHAPTER 6

PRESENTATION AND ANALYSIS OF DRYING RATE TEST RESULTS

6.1 General

The soils were tested to investigate the drying rate under different environmental conditions. During the drying rate test, soil weight was measured approximately every 4 hours in the first 24 hours, and then the measuring interval was gradually increased to avoid the measurement error due to the smaller amount of water loss and the accuracy of the measuring scale. The temperature and humidity inside the incubator were recorded at the time when the weight of the soil was measured. The measured soil weight data were further converted to the loss in water for each time interval. The accumulated water loss was calculated as well as the water content for each measurement. Finally the soil drying rates were determined from the measurements. The drying rate test results are presented and analyzed in this chapter.

6.2 Presentation of Soil Drying Rate Test Results

Two groups of test results from the drying rate experiment are presented in this section. The soil drying rate basically follows the logarithmic trend of decreasing drying rate versus the elapsed time.

6.2.1 Group I test results

For Group I tests, the soil samples were dried from optimum water content to the desired water content. The measured soil weight data are summarized in Table 6.1. The recorded weight and time interval are further developed in terms of water loss, water content, and drying rate as shown in Tables 6.2(a) through 6.2(f) for the six soils, respectively. The drying characteristics of the six soils under the condition of 25°C temperature and 75% relative humidity are presented in Table 6.3 for further analysis. Table 6.4 summarizes the accumulated water loss within 200 hours for the six soils under different conditions. Detailed data concerning the Group I test results are presented in Appendix D.

The accumulated water loss versus elapsed time for the six soils are illustrated in Figure 6.1. The changes of water content with the elapsed time are shown in Figure

6.2. The changes of drying rate with the corresponding water content are shown in Figure 6.3. Tables and figures for the complete group I test results are presented in Appendix D in detail.

6.2.2 Group II test results

For Group II tests, the soil samples were dried from a wet condition in which the water content was at optimum water content plus 4 percent. The water evaporation characteristics of the Group II tests were different from the optimum water content to the dry side. The soil drying data (Group II) are summarized in Table 6.5. The recorded weight and time interval are further developed in terms of water loss, water content, and drying rate as shown in Tables 6.6(a) through 6.6(f) for the six soils, respectively. The drying characteristics of the six soils under the condition of 25°C temperature and 75% relative humidity are presented in Table 6.7 for further analysis. The accumulated water loss within the first 24, 48, 72, 90, and 200 hours for the six soils under various conditions are summarized in Table 6.8(a), (b), (c), (d), and (e), respectively. The Group II test results are presented in Appendix E in detail.

The accumulated water loss versus elapsed time for the six soils is shown in Figure 6.4. The changes of water content with the elapsed time are shown in Figure 6.5. The changes of drying rate with the corresponding water content are illustrated in Figure 6.6. Tables and figures for the complete Group II test results at various levels of temperature and relative humidity are presented in Appendix E in detail.

6.3 Analysis of Soil Drying Rate Test Results

The factors affecting the soil drying rate, such as drying time, water content, temperature and relative humidity, percent of clay content and percent of passing #200 sieve, are discussed in this section. The water content for the Group I test covers the range from optimum water content down to almost dry condition, while the range of water content is from optimum water content plus 4 percent to optimum water content minus 4 percent for the Group II test.

6.3.1 Effect of water content

As shown in Figure 6.1, for Group I tests, the water evaporates quickly at the beginning for all six soils, and then the rate of water loss levels off after drying for several days. It is also shown that the drying rate for the Clay County soil continues to dry even at the end of the drying period. As shown in Figure 6.2, the water content of the soils decreases rapidly at the beginning and the Marion County soil ceases to dry at a relatively higher water content (slightly over 3 percent) after a few days of drying. The water content of the soils other than the Marion County retains within the range of 2 percent to 1 percent. The drying rate versus water content is shown in Figure 6.3 and the Alford City soil has the highest drying rate whereas the Marion County soil has the lowest drying rate for the range of water content less than 8 percent.

As shown in Figures 6.4 and 6.5, the rate of water loss and the corresponding water content level for Group II tests have similar trend as found in Figures 6.1 and 6.2. However, as shown in Figure 6.6, the relationship between the drying rate and water content is different from that in Figure 6.3 when the soil water content is higher than the optimum water content (8-9 percent). The Clay County soil has the lowest drying rate at a water content higher than 8 percent, and the Marion County soil has the lowest drying rate at a water content lower than 7 percent. Similarly as for the Group I test, the Alfrod City soil has the highest drying rate overall for the Group II test.

The evaporation rate data are summarized in Table 6.4 for the Group I test results at different environmental conditions. It is shown in Table 6.4 that the Clay County soil lost the highest amount of water while the Marion County soil evaporated the least amount of water within a certain period of time. Apparently, the Marion County soil has the lowest average drying rate while the Clay County soil appears to have the highest average drying rate. Figure 6.7 shows the comparison of the average drying rate within first 200 hours for the Group I test at temperature 25°C and 75% relative humidity. The drying rate for both Group I and Group II tests in a 90-hour period of elapsed time are compared in Figure 6.8.

The drying rates for Group I and Group II tests for each soil type are different at the identical water content under either the dry or wet condition. The drying rates at optimum water content for the two groups are compared in Figure 6.9 at temperature 25°C and 75% relative humidity. As shown in Figure 6.9, the average drying rate from the Group II test is lower than that from the Group I test for the same moisture condition. This is probably due to the difference in moisture distribution at the surface of the tested specimen. For instance, at optimum water content, the surface of the cylindrical soil from the Group II test was drier than that from the Group I test, which was still saturated with water immediately after compaction.

6.3.2 Effect of temperature and relative humidity

The influence of temperature and relative humidity on the drying rate are demonstrated in Figures 6.10, 6.11, and 6.12 for the Clay County soil from the Group I tests. It is shown that the drying curves at 95% relative humidity are very different from those at 55% and 75% relative humidities. When the relative humidity is either 55% or 75%, the accumulated water loss increases rapidly with time at the early stage, and it increases with an increase in temperature. Thus, large differences in water evaporation are found at the early drying stage in a couple of days. When the relative humidity is up to 95%, the accumulated water loss is not much influenced by the temperature, and it increases slowly with time. The drying curves for the Group II tests are shown in Figures 6.13, 6.14, and 6.15 for the Clay County soil, and the trend is similar with the Group I test results.

Considering the effect of the relative humidity as illustrated in Figures 6.16 and 6.17 for the Group I and Group II tests, respectively, it is apparent that the relative humidity has much stronger effect on the soil drying rate than the temperature. It also indicates that extremely humid weather condition reduces the evaporation of soil water significantly regardless of the temperature. Another observation is that the difference in the accumulated water loss due to the effect of relative humidity becomes more significant when the temperature is higher. It indicates that, in the severe humid environment, higher temperature tends to prevent water from evaporating.

The objective of the Group II drying rate tests is to compare the drying time from the wet side of optimum water content to optimum water content for the six soils. The drying time data are summarized in Table 6.9(a), (b), (c), and (d) at different environmental conditions. The comparison of the drying time needed to dry from optimum water content plus 4, 3, 2, and 1 percent to optimum water content for the six soils at different environmental conditions are illustrated in Figures 6.18, 6.19, 6.20, and 6.21, respectively. It is shown that at 75% relative humidity, the Marion County soil is taken the shortest time to reach the optimum water content, while the Clay County soil is taken the longest time. When the relative humidity is up to 95%, the Alford City soil is taken the shortest time to reach the optimum water content. The difference in drying time between 10°C and 25°C at 75% relative humidity is greater than that at 95% relative humidity. The effect of temperature becomes insignificant when the relative humidity is greater than about 90%.

6.3.3 Effect of percent of clay content and passing #200 fines

The effect of the percent of clay content on the drying time is presented in Figure 6.22. Basically, the drying time increases gradually with an increase in the percent of clay content. At temperature 25°C, the drying time at 95% relative humidity is about 4 times higher than that at 75% relative humidity for the same percent of clay content. The trend for the soils to dry from optimum water content plus 4 percent to optimum water content versus the percent of fines is shown in Figures 6.23. Although the data are scattered, the drying time increases with an increase in the percent of passing #200 fines.

6.4 Discussion on Factors Affecting Drying Rate Test Result

There were two minor problems observed when the drying rate tests were performed. The relative locations of the soil samples inside the environmental chamber were different when the six samples were placed and tested simultaneously. This resulted in different airflow impact inside the chamber to which the six soil samples were subjected. The other problem was that the digital weighing scale was only significant to one decimal point. This could cause an error in reading when the weight loss was less than 0.1 gram. The data points at the drier conditions (water content less than 2%) should be taken with caution for possible measurement errors.

There is also a practical limitation in using the Reach-In Incubator (Model 3911). The chamber cannot be operated with extremely high relative humidity and high temperature or with low relative humidity and low temperature. Therefore, the drying rates of the soils at the extreme environmental conditions (e.g., very humid with high temperature) are not included in this study.

Table 6.1 : Measured soil weight (Group I) at temperature 25°C & humidity 75%

Date	Time	Weight (g)		
		Marion (19.9,9.3%)	Clay (19.9,9.15%)	Madison (19.9,8.5%)
20-Mar	14:25	2094.7		
	16:36	2085.5		
	18:50	2074.9		
	21:10	2065.7		
	23:40	2056.9		
21-Mar	1:00	2052.3		
	7:10	2034.8		
	9:40	2029.4		
	12:00	2025.0		
	14:26	2021.4		
	16:28	2018.9		
	22:28	2011.7		
22-Mar	1:18	2009.2		
	2:18	2008.3		
	8:18	2004.2		
	11:35	2002.2		
	14:23	2000.9		
	17:06	1999.6		
	22:12	1997.6		
23-Mar	7:50	1994.4		
	11:25	1993.6		
	19:50	1991.6		
24-Mar	8:56	1987.0		
	10:44	1986.8	2054.8	
	13:48	1986.6	2040.7	
	20:05	1986.0	2014.4	
	23:43	1985.5	2000.5	
25-Mar	11:35	1984.7	1964.1	
	13:15	1984.4	1960.8	
	14:20			2082.6
	21:34	1983.9	1949.2	2050.2
26-Mar	9:05	1983.1	1938.9	2013.1
	11:15	1982.9	1937.3	2008.4
	13:15	1982.8	1936.1	2004.9
	17:30	1982.6	1933.5	1999.1
	19:20	1982.4	1932.4	1997.2
	23:08	1982.2	1930.4	1993.6
27-Mar	9:23	1981.7	1925.9	1987.2
	11:40	1981.6	1925.2	1986.0
	13:45	1981.5	1924.5	1985.0
	16:24	1981.3	1923.4	1983.8
	19:55	1981.2	1922.5	1982.3

Date	Time	Weight (g)		
		Alford (19.9,7.6%)	Jacobs (20.2,7.9%)	Brevard (18.8,9.25%)
9-Apr	13:00			1972.8
	13:20		2097.0	
	17:25		2077.7	1952.7
	17:40	2055.9		
10-Apr	9:30	1989.1	2026.4	1908.7
	11:45	1982.0	2021.7	1904.8
	13:51	1976.3	2017.4	1901.2
	22:40	1962.7	2006.1	1889.7
11-Apr	9:20	1955.4	1999.2	1879.8
	13:35	1953.3	1997.0	1876.5
	16:30	1952.0	1995.7	1874.7
	22:30	1950.2	1993.8	1871.4
12-Apr	10:20	1945.6	1990.2	1865.1
	16:45	1945.6	1988.9	1862.7
	22:15	1943.9	1987.4	1860.5
13-Apr	13:50	1941.4	1984.7	1856.1
	15:57	1940.8	1984.3	1855.5
	17:45	1940.6	1984.0	1855.1
14-Apr	9:50	1938.8	1982.0	1851.9
	12:20	1938.4	1981.6	1851.2
	19:25	1937.7	1980.9	1850.3
15-Apr	9:10	1936.5	1979.7	1848.6
	11:20	1936.3	1979.3	1848.2
	13:16	1936.0	1979.2	1848.1
	16:43	1935.7	1979.0	1847.7
	20:20	1935.5	1978.6	1847.4
	22:16	1935.3	1978.3	1847.2
16-Apr	9:15	1934.6	1977.5	1846.4
	12:45	1934.4	1977.3	1846.1
	16:45	1934.2	1977.1	1845.9
17-Apr	0:10	1933.7	1976.5	1845.3
	9:10	1933.3	1976.1	1844.8
	15:32	1933.0	1975.8	1844.5
18-Apr	9:35	1932.4	1974.8	1844.0
	17:00	1932.0	1974.6	1843.6
19-Apr	16:33	1931.1	1973.1	1842.9
20-Apr	10:15	1930.7	1972.9	1842.7

Table 6.1 : Measured soil weight (Group I) at temperature 25°C & humidity 75% (Cont'd)

Date	Time	Weight (g)			Date	Time	Weight (g)		
		Marion (19.9,9.3%)	Clay (19.9,9.15%)	Madison (19.9,8.5%)			Alford (19.9,7.6%)	Jacobs (20.2,7.9%)	Brevard (18.8,9.25%)
	22:54	1980.9	1921.6	1981.1					
28-Mar	9:35	1980.4	1918.8	1977.8					
	13:20	1980.1	1918.0	1976.8					
	16:33	1980.1	1917.6	1975.9					
	19:50	1979.9	1916.6	1975.3					
	22:55	1979.7	1916.1	1974.4					
29-Mar	10:46	1979.1	1913.9	1972.2					
	13:27	1979.0	1913.4	1971.6					
	16:45	1978.9	1913.0	1971.0					
	19:56	1978.8	1912.3	1970.6					
	23:00	1978.8	1912.0	1970.2					
30-Mar	10:36	1978.1	1910.3	1968.2					
	13:47	1978.1	1910.0	1967.8					
	17:00	1977.9	1909.5	1967.3					
31-Mar	10:40	1977.3	1907.6	1965.5					
	17:05	1977.1	1907.4	1964.7					
1-Apr	11:03	1976.7	1905.8	1963.1					
	20:55	1976.4	1905.0	1962.5					
2-Apr	0:45	1975.9	1904.0	1960.9					
	10:20	1975.4	1902.9	1959.7					
	20:33	1975.4	1902.5	1959.2					
3-Apr	8:40		1900.8	1956.9					

Table 6.2(a) : Drying rate test results for Clay County soil (Group I)

Dry density : 19.9 KN/m^3 Water content : 9.15%

Time	Weight	Temperature	Humidity	Time	Cum. Time	Water loss	Cum.Water	Water Con.	Avg. Drying Rate	Drying Rate
	(gram)	(°C)	(%)	(hour)	(hour)	(gram)	loss(gram)	(%)	(gram/hr/ft^2)	(gram/hr/ft^2)
3241044	2054.8	25.0	75	0.00	0.00	0	0	9.15	10.27	10.27
3241348	2040.7	25.0	75	3.07	3.07	14.1	14.1	8.40	9.44	9.44
3242005	2014.4	25.0	75	6.28	9.35	26.3	40.4	7.00	8.87	8.60
3242343	2000.5	25.0	75	3.63	12.98	13.9	54.3	6.27	8.59	7.86
3251135	1964.1	25.0	75	11.87	24.85	36.4	90.7	4.33	7.49	6.30
3251315	1960.8	25.0	75	1.67	26.52	3.3	94.0	4.16	7.28	4.06
3252134	1949.2	25.0	74	8.32	34.83	11.6	105.6	3.54	6.22	2.86
3260905	1938.9	25.0	75	11.52	46.35	10.3	115.9	2.99	5.13	1.84
3261115	1937.3	25.0	75	2.17	48.52	1.6	117.5	2.91	4.97	1.52
3261315	1936.1	25.0	75	2.00	50.52	1.2	118.7	2.84	4.82	1.23
3261730	1933.5	25.0	75	4.25	54.77	2.5	121.2	2.71	4.54	1.21
3261920	1932.4	25.0	75	1.83	56.60	1.1	122.3	2.65	4.44	1.23
3262308	1930.4	25.0	75	3.80	60.40	2.0	124.3	2.55	4.23	1.08
3270923	1925.9	25.0	75	10.25	70.65	4.5	128.8	2.31	3.74	0.90
3271140	1925.2	25.0	75	2.28	72.93	0.7	129.5	2.27	3.65	0.63
3271345	1924.5	25.0	75	2.08	75.02	0.7	130.2	2.23	3.56	0.69
3271624	1923.4	25.0	75	2.65	77.67	1.1	131.3	2.18	3.47	0.85
3271955	1922.5	25.0	75	3.52	81.18	0.9	132.2	2.13	3.34	0.53
3272254	1921.6	25.0	75	2.98	84.17	0.9	133.1	2.08	3.25	0.62
3280935	1918.8	25.0	75	10.68	94.85	2.8	135.9	1.93	2.94	0.54
3281320	1918.0	25.0	75	3.75	98.60	0.8	136.7	1.89	2.85	0.44
3281633	1917.6	25.0	75	3.22	101.82	0.4	137.1	1.87	2.76	0.26
3281750	1916.6	25.0	75	3.28	105.10	1.0	138.1	1.81	2.70	0.63
3282255	1916.1	25.0	75	3.08	108.18	0.5	138.6	1.79	2.63	0.33
3291046	1913.9	25.0	75	11.85	120.03	2.2	140.8	1.67	2.41	0.38
3291327	1913.4	25.0	75	2.68	122.72	0.5	141.3	1.64	2.36	0.38
3291645	1913.0	25.0	75	3.30	126.02	0.4	141.7	1.62	2.31	0.25
3291956	1912.3	25.0	75	3.18	129.20	0.7	142.4	1.59	2.26	0.45
3292300	1912.0	25.0	75	3.07	132.27	0.3	142.7	1.57	2.22	0.20
3301036	1910.3	25.0	75	11.60	143.87	1.7	144.4	1.48	2.06	0.30
3301347	1910.0	25.0	75	3.18	147.05	0.3	144.7	1.46	2.02	0.19
3301700	1909.5	25.0	75	3.22	150.27	0.5	145.2	1.44	1.98	0.32
3311040	1907.6	25.0	75	17.67	167.93	1.9	147.1	1.34	1.80	0.22
3311705	1907.4	25.0	75	6.42	174.35	0.2	147.3	1.33	1.73	0.06
4011103	1905.8	25.0	75	17.97	192.32	1.6	148.9	1.24	1.59	0.18
4012055	1905.0	25.0	75	9.87	202.18	0.8	149.7	1.20	1.52	0.17
4020045	1904.0	25.0	75	3.83	206.01	1.0	150.7	1.14	1.50	0.54
4021020	1902.9	25.0	75	9.58	215.59	1.1	151.8	1.09	1.45	0.24
4022033	1902.5	25.0	75	10.22	225.81	0.4	152.2	1.07	1.38	0.08
4030840	1900.8	25.0	75	12.12	237.93	1.7	153.9	0.97	1.33	0.29

Table 6.2(b) : Drying rate test resuls for Madison County soil (Group I)

Dry density : 19.9 KN/m^3 Water content : 8.5%

Time	Weight (gram)	Temperature (°C)	Humidity (%)	Time (hour)	Cum. Time (hour)	Water loss (gram)	Cum.Water loss(gram)	Water Con. (%)	Avg. Drying Rate (gram/hr/ft^2)	Drying Rate (gram/hr/ft^2)
3251420	2082.6	25.0	75	0.00	0.00	0	0	8.50	10.27	10.27
3252134	2050.2	25.0	74	7.23	7.23	32.4	32.4	6.81	9.20	9.20
3260905	2013.1	25.0	75	11.52	18.75	37.1	69.5	4.88	7.61	6.61
3261115	2008.4	25.0	75	2.17	20.92	4.7	74.2	4.63	7.28	4.45
3261315	2004.9	25.0	75	2.00	22.92	3.5	77.7	4.45	6.96	3.59
3261730	1999.1	25.0	75	4.25	27.17	5.8	83.5	4.15	6.31	2.80
3261920	1997.2	25.0	75	1.83	29.00	1.9	85.4	4.05	6.05	2.13
3262308	1993.6	25.0	75	3.80	32.80	3.6	89.0	3.86	5.57	1.95
3270923	1987.2	25.0	75	10.25	43.05	6.4	95.4	3.53	4.55	1.28
3271140	1986.0	25.0	75	2.28	45.33	1.2	96.6	3.47	4.38	1.08
3271345	1985.0	25.0	75	2.08	47.42	1.0	97.6	3.42	4.23	0.99
3271624	1983.8	25.0	75	2.65	50.07	1.2	98.8	3.35	4.05	0.93
3271955	1982.3	25.0	75	3.52	53.58	1.5	100.3	3.27	3.84	0.88
3272254	1981.1	25.0	75	2.98	56.57	1.2	101.5	3.21	3.68	0.83
3280935	1977.8	25.0	75	10.68	67.25	3.3	104.8	3.04	3.20	0.63
3281320	1976.8	25.0	75	3.75	71.00	1.0	105.8	2.99	3.06	0.55
3281633	1975.9	25.0	75	3.22	74.22	0.9	106.7	2.94	2.95	0.57
3281750	1975.3	25.0	75	3.28	77.50	0.6	107.3	2.91	2.84	0.38
3282255	1974.4	25.0	75	3.08	80.58	0.9	108.2	2.86	2.76	0.60
3291046	1972.2	25.0	75	11.85	92.43	2.2	110.4	2.75	2.45	0.38
3291327	1971.6	25.0	75	2.68	95.12	0.6	111.0	2.72	2.40	0.46
3291645	1971.0	25.0	75	3.30	98.42	0.6	111.6	2.69	2.33	0.37
3291956	1970.6	25.0	75	3.18	101.60	0.4	112.0	2.66	2.26	0.26
3292300	1970.2	25.0	75	3.07	104.67	0.4	112.4	2.64	2.21	0.27
3301036	1968.2	25.0	75	11.60	116.27	2.0	114.4	2.54	2.02	0.35
3301347	1967.8	25.0	75	3.18	119.45	0.4	114.8	2.52	1.97	0.26
3301700	1967.3	25.0	75	3.22	122.67	0.5	115.3	2.49	1.93	0.32
3311040	1965.5	25.0	75	17.67	140.33	1.8	117.1	2.40	1.71	0.21
3311705	1964.7	25.0	75	6.42	146.75	0.8	117.9	2.36	1.65	0.26
4011103	1963.1	25.0	75	17.97	164.72	1.6	119.5	2.27	1.49	0.18
4012055	1962.5	25.0	75	9.87	174.58	0.6	120.1	2.24	1.41	0.12
4020045	1960.9	25.0	75	3.83	178.41	1.6	121.7	2.16	1.40	0.86
4021020	1959.7	25.0	75	9.58	187.99	1.2	122.9	2.10	1.34	0.26
4022033	1959.2	25.0	75	10.22	198.21	0.5	123.4	2.07	1.28	0.10
4030840	1956.9	25.0	75	12.12	210.33	2.3	125.7	1.95	1.23	0.39

Table 6.2(c) : Drying rate test results for Jacobs Road soil (Group I)

Dry density : 20.2 KN/m^3 Water content : 7.90%

Time	Weight	Temperature	Humidity	Time	Cum. Time	Water loss	Cum.Water	Water Con.	Avg. Drying Rate	Drying Rate
	(gram)	(°C)	(%)	(hour)	(hour)	(gram)	loss(gram)	(%)	(gram/hr/ft^2)	(gram/hr/ft^2)
4091320	2097.0	25.0	75	0.00	0.00	0.00	0	7.90	10.27	10.27
4091725	2077.7	25.0	75	4.08	4.08	19.3	19.3	6.91	9.71	9.71
4100930	2026.4	25.0	75	13.08	17.17	51.3	70.6	4.27	8.45	8.05
4101145	2021.7	25.0	75	2.25	19.42	4.7	75.3	4.03	7.96	4.29
4101351	2017.4	25.0	75	2.10	21.52	4.3	79.6	3.80	7.60	4.20
4102240	2006.1	25.0	75	8.82	30.33	11.3	90.9	3.22	6.15	2.63
4110920	1999.2	25.0	75	10.67	41.00	6.9	97.8	2.87	4.90	1.33
4111335	1997.0	25.0	75	4.25	45.25	2.2	100.0	2.75	4.54	1.06
4111630	1995.7	25.0	75	2.92	48.17	1.3	101.3	2.69	4.32	0.92
4112230	1993.8	25.0	75	6.00	54.17	1.9	103.2	2.59	3.91	0.65
4121020	1990.2	25.0	75	11.83	66.00	3.6	106.8	2.40	3.32	0.62
4121635	1988.9	25.0	75	6.25	72.25	1.3	108.1	2.34	3.07	0.43
4122215	1987.4	25.0	75	5.67	77.92	1.5	109.6	2.26	2.89	0.54
4131350	1984.7	25.0	75	14.58	92.50	2.7	112.3	2.12	2.49	0.38
4131557	1984.3	25.0	75	2.12	94.62	0.4	112.7	2.10	2.45	0.39
4131745	1984.0	25.0	75	1.80	96.42	0.3	113.0	2.09	2.41	0.34
4140950	1982.0	25.0	75	16.08	112.50	2.0	115.0	1.98	2.10	0.26
4141220	1981.6	25.0	75	2.50	115.00	0.4	115.4	1.96	2.06	0.33
4141925	1980.9	25.0	75	7.08	122.08	0.7	116.1	1.93	1.95	0.20
4150910	1979.7	25.0	75	13.75	135.83	1.2	117.3	1.86	1.77	0.18
4151120	1979.3	25.0	75	2.17	138.00	0.4	117.7	1.84	1.75	0.38
4151316	1979.2	25.0	75	1.93	139.93	0.1	117.8	1.84	1.73	0.11
4151643	1979.0	25.0	75	2.45	142.38	0.2	118.0	1.83	1.70	0.17
4152020	1978.6	25.0	75	3.62	146.00	0.4	118.4	1.81	1.67	0.23
4152216	1978.3	25.0	75	1.93	147.93	0.3	118.7	1.79	1.65	0.32
4160915	1977.5	25.0	75	10.98	158.92	0.8	119.5	1.75	1.54	0.15
4161245	1977.3	25.0	75	3.50	162.42	0.2	119.7	1.74	1.51	0.12
4161625	1977.1	25.0	75	3.67	166.08	0.2	119.9	1.73	1.48	0.11
4170010	1976.5	25.0	75	5.75	171.83	0.6	120.5	1.70	1.44	0.21
4170910	1976.1	25.0	75	9.00	180.83	0.4	120.9	1.68	1.37	0.09
4171532	1975.8	25.0	75	6.37	187.20	0.3	121.2	1.66	1.33	0.10
4180935	1974.8	25.0	75	18.05	205.25	1.0	122.2	1.61	1.22	0.11
4181700	1974.6	25.0	75	7.42	212.67	0.2	122.4	1.60	1.18	0.06
4201633	1973.1	25.0	75	23.45	236.12	1.5	123.9	1.52	1.08	0.13
4211015	1972.9	25.0	75	17.70	253.82	0.2	124.1	1.51	1.00	0.02

Table 6.2(d) : Drying rate test results for Alford City soil (Group I)

Dry density : 19.9 KN/m^3 Water content : 7.60%

Time	Weight	Temperature	Humidity	Time	Cum. Time	Water loss	Cum.Water	Water Con.	Avg. Drying Rate	Drying Rate
	(gram)	(°C)	(%)	(hour)	(hour)	(gram)	loss(gram)	(%)	(gram/hr/ft^2)	(gram/hr/ft^2)
4091740	2055.9	25.0	75	0.00	0.00	0.00	0	7.60	12.32	12.32
4100930	1989.1	25.0	75	13.83	13.83	66.8	66.8	4.10	9.92	9.92
4101145	1982.0	25.0	75	2.25	16.08	7.1	73.9	3.73	9.44	6.48
4101351	1976.3	25.0	75	2.10	18.18	5.7	79.6	3.43	8.99	5.57
4102240	1962.7	25.0	75	8.82	27.00	13.6	93.2	2.72	7.09	3.17
4110920	1955.4	25.0	75	10.67	37.67	7.3	100.5	2.34	5.48	1.41
4111335	1953.3	25.0	75	4.25	41.92	2.1	102.6	2.23	5.03	1.01
4111630	1952.0	25.0	75	2.92	44.83	1.3	103.9	2.16	4.76	0.92
4112230	1950.2	25.0	75	6.00	50.83	1.8	105.7	2.07	4.27	0.62
4121020	1945.6	25.0	75	11.83	62.67	4.6	110.3	1.83	3.61	0.80
4121635	1945.6	25.0	75	6.25	68.92	0.0	110.3	1.83	3.29	0.00
4122215	1943.9	25.0	75	5.67	74.58	1.7	112.0	1.74	3.08	0.62
4131350	1941.4	25.0	75	14.58	89.17	2.5	114.5	1.61	2.64	0.35
4131557	1940.8	25.0	75	2.12	91.28	0.6	115.1	1.58	2.59	0.58
4131745	1940.6	25.0	75	1.80	93.08	0.2	115.3	1.57	2.54	0.23
4140950	1938.8	25.0	75	16.08	109.17	1.8	117.1	1.47	2.20	0.23
4141220	1938.4	25.0	75	2.50	111.67	0.4	117.5	1.45	2.16	0.33
4141925	1937.7	25.0	75	7.08	118.75	0.7	118.2	1.41	2.04	0.20
4150910	1936.5	25.0	75	13.75	132.50	1.2	119.4	1.35	1.85	0.18
4151120	1936.3	25.0	75	2.17	134.67	0.2	119.6	1.34	1.82	0.19
4151316	1936.0	25.0	75	1.93	136.60	0.3	119.9	1.32	1.80	0.32
4151643	1935.7	25.0	75	2.45	139.05	0.3	120.2	1.31	1.78	0.25
4152020	1935.5	25.0	75	3.62	142.67	0.2	120.4	1.30	1.73	0.11
4152216	1935.3	25.0	75	1.93	144.60	0.2	120.6	1.29	1.71	0.21
4160915	1934.6	25.0	75	10.98	155.58	0.7	121.3	1.25	1.60	0.13
4161245	1934.4	25.0	75	3.50	159.08	0.2	121.5	1.24	1.57	0.12
4161625	1934.2	25.0	75	3.67	162.75	0.2	121.7	1.23	1.54	0.11
4170010	1933.7	25.0	75	5.75	168.50	0.5	122.2	1.20	1.49	0.18
4170910	1933.3	25.0	75	9.00	177.50	0.4	122.6	1.18	1.42	0.09
4171532	1933.0	25.0	75	6.37	183.87	0.3	122.9	1.17	1.37	0.10
4180935	1932.4	25.0	75	18.05	201.92	0.6	123.5	1.14	1.26	0.07
4181700	1932.0	25.0	75	7.42	209.33	0.4	123.9	1.12	1.22	0.11
4191633	1931.1	25.0	75	23.45	232.78	0.9	124.8	1.07	1.10	0.08
4201015	1930.7	25.0	75	17.70	250.48	0.4	125.2	1.05	1.03	0.05

Table 6.2(e) : Drying rate test results for Marion County soil (Group I)

Dry density : 19.9 KN/m^3 Water content : 9.30%

Time	Weight	Temperature	Humidity	Time	Cum. Time	Water loss	Cum.Water	Water Con.	Avg. Drying Rate	Drying Rate
	(gram)	(°C)	(%)	(hour)	(hour)	(gram)	loss(gram)	(%)	(gram/hr/ft^2)	(gram/hr/ft^2)
3201425	2094.7	25.0	75	0.00	0.00	0.0	0.0	9.30	9.03	9.03
3201636	2085.5	25.0	90	2.18	2.18	9.2	9.2	8.82	8.65	8.65
3201850	2074.9	25.0	75	2.23	4.42	10.6	19.8	8.27	9.21	9.75
3202110	2065.7	25.1	77	2.33	6.75	9.2	29.0	7.79	8.82	8.10
3202340	2056.9	25.0	76	2.50	9.25	8.8	37.8	7.33	8.39	7.23
3210100	2052.3	25.0	76	1.33	10.58	4.6	42.4	7.09	8.23	7.09
3210710	2034.8	25.0	74	6.17	16.75	17.5	59.9	6.17	7.34	5.83
3210940	2029.4	25.0	75	2.50	19.25	5.4	65.3	5.89	6.97	4.44
3211200	2025.0	25.0	75	2.33	21.58	4.4	69.7	5.66	6.63	3.87
3211426	2021.4	25.0	77	2.43	24.02	3.6	73.3	5.48	6.27	3.04
3211628	2018.9	25.1	77	2.03	26.05	2.5	75.8	5.34	5.98	2.53
3212228	2011.7	25.0	75	6.00	32.05	7.2	83.0	4.97	5.32	2.46
3220118	2009.2	25.0	75	2.83	34.88	2.5	85.5	4.84	5.03	1.81
3220218	2008.3	25.0	75	1.00	35.88	0.9	86.4	4.79	4.94	1.85
3220818	2004.2	25.0	75	6.00	41.88	4.1	90.5	4.58	4.44	1.40
3221135	2002.2	25.0	75	3.28	45.16	2.0	92.5	4.47	4.21	1.25
3221423	2000.9	25.0	75	2.80	47.96	1.3	93.8	4.41	4.02	0.95
3221706	1999.6	25.0	75	2.72	50.68	1.3	95.1	4.34	3.85	0.98
3222212	1997.6	25.0	75	5.10	55.78	2.0	97.1	4.23	3.57	0.81
3230750	1994.4	25.0	75	9.63	65.41	3.2	100.3	4.07	3.15	0.68
3231125	1993.6	25.0	75	3.58	69.00	0.8	101.1	4.02	3.01	0.46
3231950	1991.6	25.0	75	8.42	77.41	2.0	103.1	3.92	2.73	0.49
3240856	1987.0	24.9	73	13.07	90.48	4.6	107.7	3.68	2.44	0.72
3241044	1986.8	25.0	75	1.80	92.28	0.2	107.9	3.67	2.40	0.23
3241348	1986.6	25.0	75	3.07	95.35	0.2	108.1	3.66	2.33	0.13
3242005	1986.0	25.0	75	6.28	101.63	0.6	108.7	3.63	2.20	0.20
3242343	1985.5	25.0	75	3.63	105.26	0.5	109.2	3.60	2.13	0.28
3251135	1984.7	25.0	75	11.87	117.13	0.8	110.0	3.56	1.93	0.14
3251315	1984.4	25.0	75	1.67	118.80	0.3	110.3	3.54	1.91	0.37
3252134	1983.9	25.0	74	8.32	127.12	0.5	110.8	3.52	1.79	0.12
3260905	1983.1	25.0	75	11.52	138.63	0.8	111.6	3.48	1.65	0.14
3261115	1982.9	25.0	75	2.17	140.80	0.2	111.8	3.47	1.63	0.19
3261315	1982.8	25.0	75	2.00	142.80	0.1	111.9	3.46	1.61	0.10

Table 6.2(e) : Drying rate test results for Marion County Soil (Group I) (Cont'd)

Dry density : 19.9 KN/m^3 Water content : 9.30%

Time	Weight	Temperature	Humidity	Time	Cum. Time	Water loss	Cum.Water	Water Con.	Avg. Drying Rate	Drying Rate
	(gram)	(°C)	(%)	(hour)	(hour)	(gram)	loss(gram)	(%)	(gram/hr/ft^2)	(gram/hr/ft^2)
3261730	1982.6	25.0	75	4.25	147.05	0.2	112.1	3.45	1.57	0.10
3261920	1982.4	25.0	75	1.83	148.88	0.2	112.3	3.44	1.55	0.22
3262308	1982.2	25.0	75	3.80	152.68	0.2	112.5	3.43	1.51	0.11
3270923	1981.7	25.0	75	10.25	162.93	0.5	113.0	3.40	1.42	0.10
3271140	1981.6	25.0	75	2.28	165.22	0.1	113.1	3.40	1.41	0.09
3271345	1981.5	25.0	75	2.08	167.30	0.1	113.2	3.39	1.39	0.10
3271624	1981.3	25.0	75	2.65	169.95	0.2	113.4	3.38	1.37	0.15
3271955	1981.2	25.0	75	3.52	173.47	0.1	113.5	3.38	1.34	0.06
3272254	1980.9	25.0	75	2.98	176.45	0.3	113.8	3.36	1.32	0.21
3280935	1980.4	25.0	75	10.68	187.13	0.5	114.3	3.34	1.25	0.10
3281320	1980.1	25.0	75	3.75	190.88	0.3	114.6	3.32	1.23	0.16
3281633	1980.1	25.0	75	3.22	194.10	0.0	114.6	3.32	1.21	0.00
3281750	1979.9	25.0	75	3.28	197.38	0.2	114.8	3.31	1.19	0.13
3282255	1979.7	25.0	75	3.08	200.46	0.2	115.0	3.30	1.18	0.13
3291046	1979.1	25.0	75	11.85	212.31	0.6	115.6	3.27	1.12	0.10
3291327	1979.0	25.0	75	2.68	215.00	0.1	115.7	3.26	1.11	0.08
3291645	1978.9	25.0	75	3.30	218.30	0.1	115.8	3.26	1.09	0.06
3291956	1978.8	25.0	75	3.18	221.48	0.1	115.9	3.25	1.07	0.06
3292300	1978.8	25.0	75	3.07	224.55	0.0	115.9	3.25	1.06	0.00
3301036	1978.1	25.0	75	11.60	236.15	0.7	116.6	3.22	1.01	0.12
3301347	1978.1	25.0	75	3.18	239.33	0.0	116.6	3.22	1.00	0.00
3301700	1977.9	25.0	75	3.22	242.55	0.2	116.8	3.21	0.99	0.13
3311040	1977.3	25.0	75	17.67	260.21	0.6	117.4	3.17	0.93	0.07
3311705	1977.1	25.0	75	6.42	266.63	0.2	117.6	3.16	0.91	0.06
4011103	1976.7	25.0	75	17.97	284.60	0.4	118.0	3.14	0.85	0.05
4012055	1976.4	25.0	75	9.87	294.47	0.3	118.3	3.13	0.82	0.06
4020045	1975.9	25.0	75	3.83	298.30	0.5	118.8	3.10	0.82	0.27
4021020	1975.4	25.0	75	9.58	307.88	0.5	119.3	3.07	0.80	0.11
4022033	1975.4	25.0	75	10.22	318.09	0.0	119.3	3.07	0.77	0.00

Table 6.2(f) : Drying rate test results for Brevard County soil (Group I)

Dry density : 18.8 KN/m^3 Water content : 9.25%

Time	Weight (gram)	Temperature (°C)	Humidity (%)	Time (hour)	Cum. Time (hour)	Water loss (gram)	Cum.Water loss(gram)	Water Con. (%)	Avg. Drying Rate ($gram/hr/ft^2$)	Drying Rate ($gram/hr/ft^2$)
4091300	1972.8	25.0	75	0.00	0.00	0.00	0	9.25	10.27	10.27
4091725	1952.7	25.0	75	4.42	4.42	20.1	20.1	8.14	9.34	9.34
4100930	1908.7	25.0	75	13.08	17.50	44.0	64.1	5.70	7.52	6.91
4101145	1904.8	25.0	75	2.25	19.75	3.9	68.0	5.48	7.07	3.56
4101351	1901.2	25.0	75	2.10	21.85	3.6	71.6	5.28	6.73	3.52
4102240	1889.7	25.0	75	8.82	30.67	11.5	83.1	4.65	5.56	2.68
4110920	1879.8	25.0	75	10.67	41.33	9.9	93.0	4.10	4.62	1.91
4111335	1876.5	25.0	75	4.25	45.58	3.3	96.3	3.92	4.34	1.59
4111630	1874.7	25.0	75	2.92	48.50	1.8	98.1	3.82	4.15	1.27
4112230	1871.4	25.0	75	6.00	54.50	3.3	101.4	3.63	3.82	1.13
4121020	1865.1	25.0	75	11.83	66.33	6.3	107.7	3.29	3.33	1.09
4121635	1862.7	25.0	75	6.25	72.58	2.4	110.1	3.15	3.11	0.79
4122215	1860.5	25.0	75	5.67	78.25	2.2	112.3	3.03	2.95	0.80
4131350	1856.1	25.0	75	14.58	92.83	4.4	116.7	2.79	2.58	0.62
4131557	1855.5	25.0	75	2.12	94.95	0.6	117.3	2.75	2.54	0.58
4131745	1855.1	25.0	75	1.80	96.75	0.4	117.7	2.73	2.50	0.46
4140950	1851.9	25.0	75	16.08	112.83	3.2	120.9	2.55	2.20	0.41
4141220	1851.2	25.0	75	2.50	115.33	0.7	121.6	2.52	2.16	0.57
4141925	1850.3	25.0	75	7.08	122.42	0.9	122.5	2.47	2.05	0.26
4150910	1848.6	25.0	75	13.75	136.17	1.7	124.2	2.37	1.87	0.25
4151120	1848.20	25.0	75	2.17	138.33	0.4	124.6	2.35	1.85	0.38
4151316	1848.1	25.0	75	1.93	140.27	0.1	124.7	2.34	1.83	0.11
4151643	1847.7	25.0	75	2.45	142.72	0.4	125.1	2.32	1.80	0.34
4152020	1847.4	25.0	75	3.62	146.33	0.3	125.4	2.31	1.76	0.17
4152216	1847.2	25.0	75	1.93	148.27	0.2	125.6	2.29	1.74	0.21
4160915	1846.4	25.0	75	10.98	159.25	0.8	126.4	2.25	1.63	0.15
4161245	1846.1	25.0	75	3.50	162.75	0.3	126.7	2.23	1.60	0.18
4161625	1845.9	25.0	75	3.67	166.42	0.2	126.9	2.22	1.57	0.11
4170010	1845.3	25.0	75	5.75	172.17	0.6	127.5	2.19	1.52	0.21
4170910	1844.8	25.0	75	9.00	181.17	0.5	128.0	2.16	1.45	0.11
4171532	1844.5	25.0	75	6.37	187.53	0.3	128.3	2.14	1.40	0.10
4180935	1844.0	25.0	75	18.05	205.58	0.5	128.8	2.12	1.29	0.06
4181700	1843.6	25.0	75	7.42	213.00	0.4	129.2	2.10	1.25	0.11
4201633	1842.9	25.0	75	23.45	236.45	0.7	129.9	2.06	1.13	0.06

Table 6.3 : Summary of soil drying rate (Group I) test results

(Temperature : 25^{O}C, Relative Humidity : 75%)

Sample Surface Area = 0.487 ft^2

	Clay	Madison	Jacobs	Alford	Marion	Brevard
Dry density [KN/m3]	19.9	19.9	20.2	19.9	19.9	18.8
Initial water content [%]	9.15	8.50	7.90	7.60	9.30	9.25
Initial water weight [gram]	172.30	163.15	153.53	145.21	178.23	167.03
Total elapsed time [hour]	257.93	230.33	253.82	250.48	340.10	236.45
Total water loss [gram]	153.90	125.70	124.10	125.20	119.30	129.90
Average drying rate , [gram per hour per ft^2]						
Within first 90 hours	3.08	2.51	2.56	2.62	2.45	2.65
Within first 200 hours	1.54	1.26	1.25	1.27	1.18	1.31
Drying rate, [gram per hour per ft^2]						
@ water content = 2%	0.58	0.27	0.27	0.67	-	-
@ water content = 4%	3.75	2.08	4.98	8.65	0.47	2.05
@ water content = 6%	7.65	8.12	9.14	11.22	4.99	7.21
@ water content = 8%	9.20	9.95	-	-	8.82	9.20
@ optimum water content	10.27	10.27	10.27	12.32	9.04	10.27

Table 6.4(a): Water evaporation within 90 hours for six soils (Group I)

Soil	% Clay	% - #200	Weight of evaporated water within 90 hour at different conditions, [gram]						
			0°C	10°C		25°C			40°C
	(%)	(%)	95% R.H.	75% R.H.	95% R.H.	55% R.H.	75% R.H.	95% R.H.	55% R.H.
Clay County	24	27.5	90.7	120.3	82.8	139.1	134.7	80.6	151.3
Madison County	12	25.1	77.0	113.6	88.6	119.0	110.0	72.1	138.6
Jacobs Road	8	20	69.7	105.6	88.5	109.1	111.8	91.4	125.5
Alford City	4	17.6	85.5	106.0	91.5	122.6	114.7	97.0	126.9
Marion County	12	19.9	64.0	93.3	66.6	116.9	107.5	72.2	126.5
Brevard County	10	16.8	58.6	102.0	72.3	124.5	115.9	95.1	141.0

Table 6.4(b): Water evaporation within 200 hours for six soils (Group I)

Soil	% Clay	% - #200	Weight of evaporated water within 200 hour at different conditions, [gram]						
			0°C	10°C		25°C			40°C
	(%)	(%)	95% R.H.	75% R.H.	95% R.H.	55% R.H.	75% R.H.	95% R.H.	55% R.H.
Clay County	24	27.5	119.6	138.3	114.2	153.3	149.6	112.0	160.0
Madison County	12	25.1	92.5	127.0	103.8	130.9	123.7	77.6	147.3
Jacobs Road	8	20	96.1	117.9	109.8	118.7	121.9	105.1	131.5
Alford City	4	17.6	110.5	116.5	106.5	131.8	123.4	110.8	131.5
Marion County	12	19.9	82.1	104.5	77.9	128.5	115.0	79.4	133.6
Brevard County	10	16.8	91.1	120.9	93.8	138.6	128.7	118.5	147.1

Table 6.5 : Measured soil weight (GroupII) at temperature 25°C & humidity 75%

Date	Time	Temp. °C	Humidity %	Soil Weight [gram]					
				Clay	Madison	Jacobs	Alford	Marion	Brevard
				(18.5,13.3%)	(19,11.7%)	(19,12%)	(19,11.7%)	(18.3,13.2%)	(18.1,12.9%)
26-Mar	10:25	25.0	75	2013.3					
	10:50	25.0	75		2041.3				
	11:02	25.0	75	2010.3	2039.6				
	11:30	25.0	75	2008.1	2037.2				
	11:51	25.0	75			2044.8			
	12:05	25.0	75	2006.0	2034.7	2043.3			
	12:38	25.0	75					1999.4	
	13:00	25.0	75	2002.4	2030.9	2039.3	2046.8	1996.6	
	15:00	25.0	75	1994.7	2022.4	2030.5	2035.1	1985.0	
	15:40	25.0	75						1967.9
	17:40	25.0	75	1984.7	2012.0	2019.1	2021.4	1970.5	1957.2
27-Mar	9:35	25.0	75	1926.4	1951.3	1952.3	1942.6	1895.5	1887.0
	12:35	25.0	75	1915.8	1940.9	1940.8	1929.4	1884.8	1875.6
	17:00	25.0	75	1901.0	1927.1	1925.9	1911.7	1871.7	1860.5
28-Mar	0:50	25.0	75	1876.7	1908.4	1903.6	1890.7	1855.2	1840.0
	9:50	25.0	75	1855.5	1895.2	1886.2	1879.7	1843.4	1823.4
	22:35	25.0	75	1838.8	1885.6	1873.0	1871.3	1833.8	1808.2
29-Mar	8:20	25.0	75	1830.8	1881.0	1867.3	1867.4	1829.1	1800.2
	20:15	25.0	75	1824.1	1876.8	1862.9	1864.0	1825.7	1793.2
30-Mar	10:00	25.0	75	1818.3	1873.3	1859.2	1860.8	1822.4	1787.3
Total elapsed time [hr]				95.59	95.17	94.16	93.01	93.37	90.34
Dry Soil weight [gram]				1777.2	1828.3	1825.7	1832.3	1766.9	1742.6
Initial Water Content				13.28%	11.65%	12.00%	11.71%	13.16%	12.93%
Dry Unit Weight [KN/m^3]				18.45	18.98	18.96	19.02	18.34	18.09

Table 6.6(a) : Drying rate test results for Clay County soil (Group II)

Dry density : 18.45 KN/m^3 Water content : 13.28%

Time	Weight (gram)	Temperature (°C)	Humidity (%)	Time (hour)	Cum. Tme (hour)	Water loss (gram)	Cum.Water loss(gram)	Water Con. (%)	Avg. Drying Rate ($gram/hr/ft^2$)	Drying Rate ($gram/hr/ft^2$)
3261025	2013.3	25.0	75	0.00	0.00	0.00	0	13.28	10.27	10.27
3261102	2010.3	25.0	75	0.62	0.62	3.0	3.0	13.12	9.98	9.98
3261130	2008.1	25.0	75	0.47	1.08	2.2	5.2	12.99	9.85	9.67
3261205	2006.0	25.0	75	0.58	1.67	2.1	7.3	12.87	8.99	7.40
3261300	2002.4	25.0	75	0.92	2.58	3.6	10.9	12.67	8.66	8.06
3261500	1994.7	25.0	75	2.00	4.58	7.7	18.6	12.24	8.33	7.91
3261740	1984.7	25.0	75	2.67	7.25	10.0	28.6	11.68	8.10	7.70
3270025	1960.0	25.0	75	6.75	14.00	24.7	53.3	10.29	7.82	7.51
3270935	1926.4	25.0	75	9.17	23.17	33.6	86.9	8.40	7.70	7.53
3271235	1915.8	25.0	75	3.00	26.17	10.6	97.5	7.80	7.65	7.26
3271700	1901.0	25.0	75	4.42	30.59	14.8	112.3	6.97	7.54	6.88
3280050	1876.7	25.0	75	7.83	38.42	24.3	136.6	5.60	7.30	6.37
3280950	1855.5	25.0	75	9.00	47.42	21.2	157.8	4.41	6.83	4.84
3282235	1838.8	25.0	75	12.75	60.17	16.7	174.5	3.47	5.96	2.69
3290820	1830.8	25.0	75	9.75	69.92	8.0	182.5	3.02	5.36	1.68
3282015	1824.1	25.0	75	11.92	81.84	6.7	189.2	2.64	4.75	1.15
3301000	1818.3	25.0	75	13.75	95.59	5.8	195.0	2.31	4.19	0.87

Table 6.6(b) : Drying rate test resuls for Madison County soil (Group II)

Dry density : 18.98 KN/m^3 Water content : 11.65%

Time	Weight	Temperature	Humidity	Time	Cum. Tme	Water loss	Cum.Water	Water Con.	Avg. Drying Rate	Drying Rate
	(gram)	(°C)	(%)	(hour)	(hour)	(gram)	loss(gram)	(%)	(gram/hr/ft^2)	(gram/hr/ft^2)
3261050	2041.3	25.0	75	0.00	0.00	0.0	0.0	11.65	18.48	18.48
3261102	2039.6	25.0	75	0.20	0.20	1.7	1.7	11.56	17.45	17.45
3261130	2037.2	25.0	75	0.47	0.67	2.4	4.1	11.43	12.62	10.55
3261205	2034.7	25.0	75	0.58	1.25	2.5	6.6	11.29	10.84	8.81
3261300	2030.9	25.0	75	0.92	2.17	3.8	10.4	11.08	9.85	8.51
3261500	2022.4	25.0	75	2.00	4.17	8.5	18.9	10.62	9.31	8.73
3261740	2012.0	25.0	75	2.67	6.83	10.4	29.3	10.05	8.80	8.01
3270150	1978.0	25.0	75	8.17	15.00	34.0	63.3	8.19	8.66	8.55
3270935	1951.3	25.0	75	7.75	22.75	26.7	90.0	6.73	8.12	7.07
3271235	1940.9	25.0	75	3.00	25.75	10.4	100.4	6.16	8.00	7.12
3271700	1927.1	25.0	75	4.42	30.17	13.8	114.2	5.40	7.77	6.42
3280050	1908.4	25.0	75	7.83	38.00	18.7	132.9	4.38	7.18	4.90
3280950	1895.2	25.0	75	9.00	47.00	13.2	146.1	3.66	6.38	3.01
3282235	1885.6	25.0	75	12.75	59.75	9.6	155.7	3.13	5.35	1.55
3290820	1881.0	25.0	75	9.75	69.50	4.6	160.3	2.88	4.74	0.97
3282015	1876.8	25.0	75	11.92	81.42	4.2	164.5	2.65	4.15	0.72
3301000	1873.3	25.0	75	13.75	95.17	3.5	168.0	2.46	3.62	0.52

Table 6.6(c) : Drying rate test results for Jacobs Road soil (Group II)

Dry density : 18.96 KN/m^3 Water content : 12.0%

Time	Weight	Temperature	Humidity	Time	Cum. Tme	Water loss	Cum.Water	Water Con.	Avg. Drying Rate	Drying Rate
	(gram)	(°C)	(%)	(hour)	(hour)	(gram)	loss(gram)	(%)	(gram/hr/ft^2)	(gram/hr/ft^2)
3261151	2044.8	25.0	75	0.00	0.00	0.0	0.0	12.00	14.37	14.37
3261205	2043.3	25.0	75	0.23	0.23	1.5	1.5	11.92	13.22	13.22
3261300	2039.3	25.0	75	0.92	1.15	4.0	5.5	11.70	9.82	8.96
3261500	2030.5	25.0	75	2.00	3.15	8.8	14.3	11.22	9.32	9.03
3261740	2019.1	25.0	75	2.67	5.82	11.4	25.7	10.59	9.07	8.78
3270151	1983.0	25.0	75	8.18	14.00	36.1	61.8	8.62	9.06	9.06
3270935	1952.3	25.0	75	7.74	21.74	30.7	92.5	6.93	8.74	8.14
3271235	1940.8	25.0	75	3.00	24.74	11.5	104.0	6.30	8.63	7.87
3271700	1925.9	25.0	75	4.42	29.16	14.9	118.9	5.49	8.37	6.93
3280050	1903.6	25.0	75	7.83	36.99	22.3	141.2	4.27	7.84	5.85
3280950	1886.2	25.0	75	9.00	45.99	17.4	158.6	3.31	7.08	3.97
3282235	1873.0	25.0	75	12.75	58.74	13.2	171.8	2.59	6.01	2.13
3290820	1867.3	25.0	75	9.75	68.49	5.7	177.5	2.28	5.32	1.20
3282015	1862.9	25.0	75	11.92	80.41	4.4	181.9	2.04	4.65	0.76
3301000	1859.2	25.0	75	13.75	94.16	3.7	185.6	1.83	4.05	0.55

Table 6.6(d) : Drying rate test results for Alford City soil (Group II)

Dry density : 19.02 KN/m^3 Water content :11.71%

Time	Weight	Temperature	Humidity	Time	Cum. Tme	Water loss	Cum.Water	Water Con.	Avg. Drying Rate	Drying Rate
	(gram)	(°C)	(%)	(hour)	(hour)	(gram)	loss(gram)	(%)	(gram/hr/ft^2)	(gram/hr/ft^2)
3261300	2046.8	25.0	75	0.00	0.00	0.0	0.0	11.71	14.37	14.37
3261500	2035.1	25.0	75	2.00	2.00	11.7	11.7	11.07	12.01	12.01
3261740	2021.4	25.0	75	2.67	4.67	13.7	25.4	10.32	11.18	10.55
3262300	1992.5	25.0	75	5.33	10.00	28.9	54.3	8.74	11.15	11.13
3270935	1942.6	25.0	75	10.59	20.59	49.9	104.2	6.02	10.39	9.68
3271235	1929.4	25.0	75	3.00	23.59	13.2	117.4	5.30	10.22	9.03
3271700	1911.7	25.0	75	4.42	28.01	17.7	135.1	4.33	9.91	8.23
3280050	1890.7	25.0	75	7.83	35.84	21.0	156.1	3.19	8.94	5.51
3280950	1879.7	25.0	75	9.00	44.84	11.0	167.1	2.59	7.65	2.51
3282235	1871.3	25.0	75	12.75	57.59	8.4	175.5	2.13	6.26	1.35
3290820	1867.4	25.0	75	9.75	67.34	3.9	179.4	1.92	5.47	0.82
3282015	1864.0	25.0	75	11.92	79.26	3.4	182.8	1.73	4.74	0.59
3301000	1860.8	25.0	75	13.75	93.01	3.2	186.0	1.56	4.11	0.48

Table 6.6(e) : Drying rate test results for Marion County soil (Group II)

Dry density : 18.34 KN/m^3 Water content : 13.16%

Time	Weight	Temperature	Humidity	Time	Cum. Tme	Water loss	Cum.Water	Water Con.	Avg. Drying Rate	Drying Rate
	(gram)	(°C)	(%)	(hour)	(hour)	(gram)	loss(gram)	(%)	(gram/hr/ft^2)	(gram/hr/ft^2)
3261238	1999.4	25.0	75	0.00	0.00	0.0	0.0	13.16	16.43	16.43
3261300	1996.6	25.0	75	0.37	0.37	2.8	2.8	13.00	15.67	15.67
3261500	1985.0	25.0	75	2.00	2.37	11.6	14.4	12.34	12.49	11.91
3261740	1970.5	25.0	75	2.67	5.03	14.5	28.9	11.52	11.79	11.16
3270138	1927.0	25.0	75	7.97	13.00	43.5	72.4	9.06	11.44	11.21
3270935	1895.5	25.0	75	7.95	20.95	31.5	103.9	7.28	10.18	8.14
3271235	1884.8	25.0	75	3.00	23.95	10.7	114.6	6.67	9.83	7.32
3271700	1871.7	25.0	75	4.42	28.37	13.1	127.7	5.93	9.24	6.09
3280050	1855.2	25.0	75	7.83	36.20	16.5	144.2	5.00	8.18	4.33
3280950	1843.4	25.0	75	9.00	45.20	11.8	156.0	4.33	7.09	2.69
3282235	1833.8	25.0	75	12.75	57.95	9.6	165.6	3.79	5.87	1.55
3290820	1829.1	25.0	75	9.75	67.70	4.7	170.3	3.52	5.17	0.99
3282015	1825.7	25.0	75	11.92	79.62	3.4	173.7	3.33	4.48	0.59
3301000	1822.4	25.0	75	13.75	93.37	3.3	177.0	3.14	3.89	0.49

Table 6.6(f) : Drying rate test results for Brevard County soil (Group II)

Dry density : 18.09 KN/m^3 Water content : 12.93%

Time	Weight (gram)	Temperature (°C)	Humidity (%)	Time (hour)	Cum. Tme (hour)	Water loss (gram)	Cum.Water loss(gram)	Water Con. (%)	Avg. Drying Rate (gram/hr/ft^2)	Drying Rate (gram/hr/ft^2)
3161540	1967.9	25.0	75	0.00	0.00	0.0	0.0	12.93	11.91	11.91
3261740	1957.2	25.0	75	2.00	2.00	10.7	10.7	12.31	10.99	10.99
3270140	1918.0	25.0	75	8.00	10.00	39.2	49.9	10.07	10.25	10.06
3270935	1887.0	25.0	75	7.92	17.92	31.0	80.9	8.29	9.27	8.04
3271235	1875.6	25.0	75	3.00	20.92	11.4	92.3	7.63	9.06	7.80
3271700	1860.5	25.0	75	4.42	25.34	15.1	107.4	6.77	8.70	7.02
3280050	1840.0	25.0	75	7.83	33.17	20.5	127.9	5.59	7.92	5.37
3280950	1823.4	25.0	75	9.00	42.17	16.6	144.5	4.64	7.04	3.79
3282235	1808.2	25.0	75	12.75	54.92	15.2	159.7	3.76	5.97	2.45
3290820	1800.2	25.0	75	9.75	64.67	8.0	167.7	3.31	5.32	1.68
3282015	1793.2	25.0	75	11.92	76.59	7.0	174.7	2.90	4.68	1.21
3301000	1787.3	25.0	75	13.75	90.34	5.9	180.6	2.57	4.11	0.88

Table 6.7 : Summary of soil drying rate Group II test results

(Temperature : 25^{O}C, Relative Humidity : 75%)

Sample Surface Area =0.487 ft^2

	Clay	Madison	Jacobs	Alford	Marion	Brevard
Dry density [KN/m^3]	18.5	19.0	19.0	19.0	18.3	18.1
Initial water content [%]	13.30	11.70	12.00	11.70	13.20	12.90
Initial water weight [gram]	236.10	213.00	219.10	214.50	232.50	225.30
Total elapsed time [hr]	95.6	95.2	94.2	93.0	93.4	90.3
Total water loss [gram]	195.0	168.0	185.6	186.0	177.0	180.6
Average drying rate , [gram per hour per ft^2]						
Within first 90 hours	4.43	3.74	4.18	4.18	3.99	3.99
Within first 200 hours	-	-	-	-	-	-
Drying rate, [gram per hour per ft^2]						
@ water content = 2%	-	-	0.75	1.02	-	-
@ water content = 4%	4.00	4.00	5.30	7.44	1.99	2.82
@ water content = 6%	6.50	7.00	7.60	9.53	6.20	5.94
@ water content = 8%	7.30	8.40	8.36	10.74	9.30	7.93
@ water content = 10%	7.52	8.00	8.86	10.67	11.20	9.98
@ water content = 12%	7.80	-	14.37	10.52	11.60	10.86
@ water content = optimum water content	7.53	8.30	8.67	10.60	11.20	9.13

Table 6.8 (a) : Water evaporation within 24 hours for six soils (Group II)

Soil	% Clay (%)	% - #200 (%)	Weight of evaporated water within 24 hours at different conditions, [gram]			
			10°C		25°C	
			75% RH	95% RH	75% RH	95% RH
Clay County	24	27.5	72.8	34.0	89.8	27.7
Madison County	12	25.1	73.7	33.4	94.3	28.8
Jacobs Road	8	20	76.0	32.0	101.2	25.7
Alford City	4	17.6	89.6	37.8	119.0	31.8
Marion County	12	19.9	90.6	34.7	114.8	29.1
Brevard County	10	16.8	108.0	31.4	102.8	26.3

Table 6.8 (b) : Water evaporation within 48 hours for six soils (Group II)

Soil	% Clay (%)	% - #200 (%)	Weight of evaporated water within 48 hours at different conditions, [gram]			
			10°C		25°C	
			75% RH	95% RH	75% RH	95% RH
Clay County	24	27.5	131.0	59.1	159.1	49.2
Madison County	12	25.1	129.7	59.5	146.9	54.8
Jacobs Road	8	20	131.8	55.9	160.7	46.0
Alford City	4	17.6	149.1	68.2	169.2	58.1
Marion County	12	19.9	137.8	60.6	158.1	51.8
Brevard County	10	16.8	125.0	54.9	151.5	46.3

Table 6.8 (c) : Water evaporation within 72 hours for six soils (Group II)

Soil	% Clay	% - #200	Weight of evaporated water within 72 hours at different conditions, [gram]			
			10°C		25°C	
	(%)	(%)	75% RH	95% RH	75% RH	95% RH
Clay County	24	27.5	163.5	81.6	183.7	73.0
Madison County	12	25.1	156.3	84.5	161.2	77.6
Jacobs Road	8	20	161.8	79.1	178.8	70.7
Alford City	4	17.6	166.7	98.0	180.7	90.5
Marion County	12	19.9	157.4	84.6	171.5	79.0
Brevard County	10	16.8	150.2	77.6	172.0	70.6

Table 6.8 (d) : Water evaporation within 90 hours for six soils (Group II)

Soil	% Clay	% - #200	Weight of evaporated water within 90 hours at different conditions, [gram]			
			10°C		25°C	
	(%)	(%)	75% RH	95% RH	75% RH	95% RH
Clay County	24	27.5	175.6	97.8	192.6	88.6
Madison County	12	25.1	164.1	102.4	166.7	95.3
Jacobs Road	8	20	171.1	96.1	184.5	87.7
Alford City	4	17.6	171.8	119.6	185.3	112.5
Marion County	12	19.9	164.6	101.7	176.2	96.1
Brevard County	10	16.8	161.0	94.4	180.5	87.3

Table 6.8 (e) : Water evaporation within 200 hours for six soils (Group II)

Soil	% Clay (%)	% - #200 (%)	Weight of evaporated water within 200 hours at different conditions, [gram]			
			10°C		25°C	
			75% RH	95% RH	75% RH	95% RH
Clay County	24	27.5	-	163.1	-	143.3
Madison County	12	25.1	-	144.9	-	141.7
Jacobs Road	8	20	-	156.0	-	152.2
Alford City	4	17.6	-	165.4	-	181.8
Marion County	12	19.9	-	142.7	-	139.1
Brevard County	10	16.8	-	154.2	-	162.5

Table 6.9(a) : Time needed for soils to dry from OMC+4% to OMC

Soil	Percentage of Clay	Percentage of passing #200	Time to reach OMC, [hour] @ Environmental Condition			
			10°C,75%	10°C,95%	25°C,75%	25°C,95%
Clay County	24	27.5	22.75	59.57	19.07	72.59
Madison County	12	25.1	21.97	54.21	15.46	66.39
Jacobs Road	8	20	22.34	61.76	16.98	74.57
Alford City	4	17.6	18.09	46.4	14.11	58.3
Marion County	12	19.9	16.17	51.75	12.55	63.81
Brevard County	10	16.8	19.14	57.03	14.68	73.07

Table 6.9(b) : Time needed for soils to dry from OMC+3% to OMC

Soil	Percentage of Clay	Percentage of passing #200	Time to reach OMC, [hour] @ Environmental Condition			
			10°C,75%	10°C,95%	25°C,75%	25°C,95%
Clay County	24	27.5	19.73	51.07	14.51	56.41
Madison County	12	25.1	19.57	46.8	13.23	52.13
Jacobs Road	8	20	19.16	54.72	12.79	57.23
Alford City	4	17.6	15.95	42.74	10.78	43.89
Marion County	12	19.9	14.61	47.62	9.72	50.98
Brevard County	10	16.8	16.44	50.01	11.4	55.67

Table 6.9(c) : Time needed for soils to dry from OMC+2% to OMC

Soil	Percentage of Clay	Percentage of passing #200	Time to reach OMC, [hour] @ Environmental Condition			
			10°C,75%	10°C,95%	25°C,75%	25°C,95%
Clay County	24	27.5	13.35	35.1	9.7	36.54
Madison County	12	25.1	13.37	33.5	8.92	35.09
Jacobs Road	8	20	12.97	28.45	8.61	37.03
Alford City	4	17.6	10.76	28.91	7.34	27.25
Marion County	12	19.9	10.04	32.69	6.47	35.04
Brevard County	10	16.8	11.76	36.02	7.84	36.57

Table 6.9(d) : Time needed for soils to dry from OMC+1% to OMC

Soil	Percentage of Clay	Percentage of passing #200	Time to reach OMC, [hour] @ Environmental Condition			
			10°C,75%	10°C,95%	25°C,75%	25°C,95%
Clay County	24	27.5	6.74	18.11	4.85	18.79
Madison County	12	25.1	6.73	17.02	4.39	15.83
Jacobs Road	8	20	6.60	18.92	4.47	17.98
Alford City	4	17.6	5.38	14.51	3.89	13.3
Marion County	12	19.9	5.02	16.76	3.24	15.78
Brevard County	10	16.8	5.93	18.3	4.29	17.01

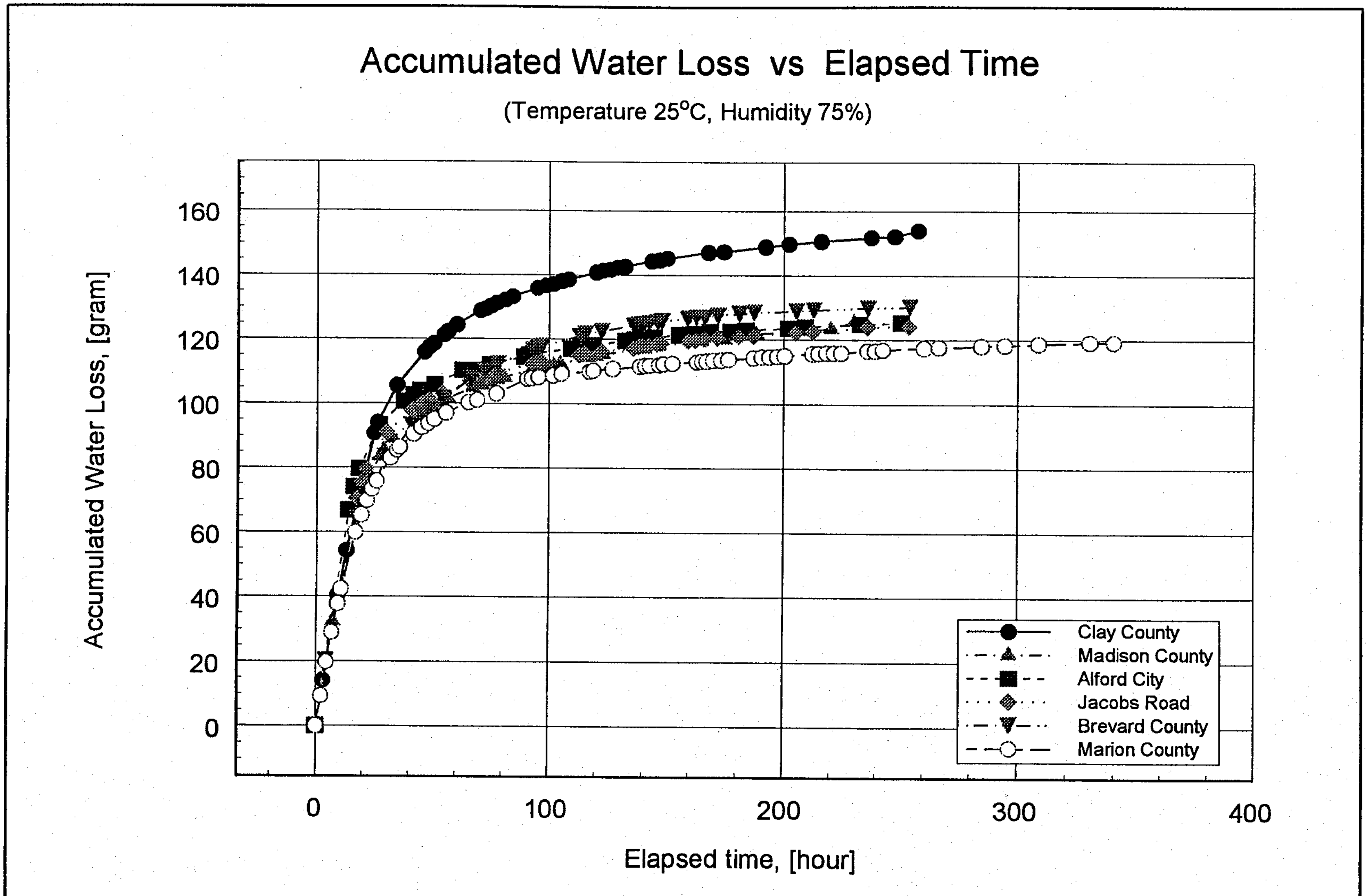

Figure 6.1 : Water loss versus elapsed time at temperature 25°C and 75% relative humidity for six soils (Group I)

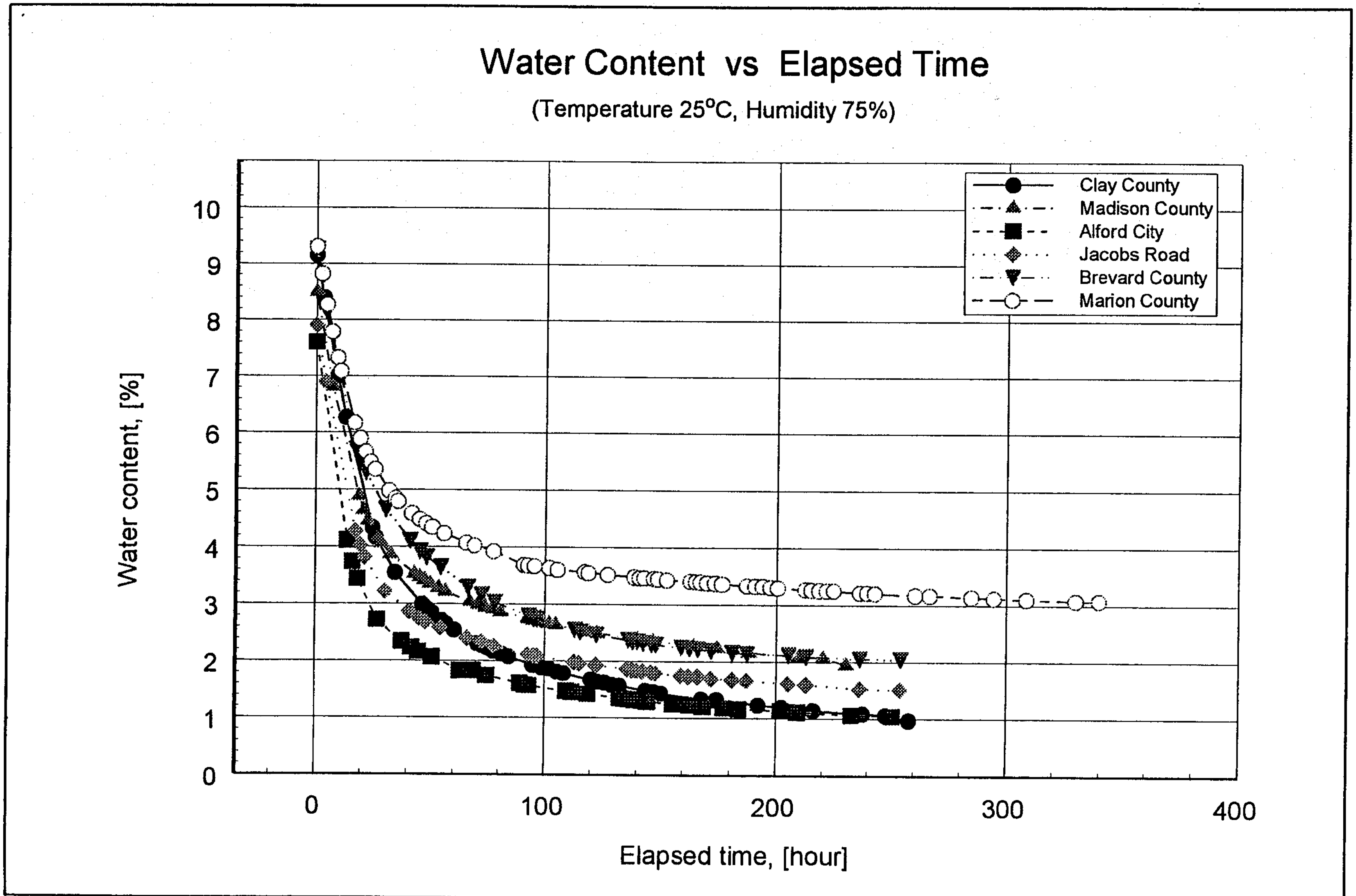

Figure 6.2 : Water content versus elapsed time at temperature 25°C and relative humidity 75% for six soils (Group I)

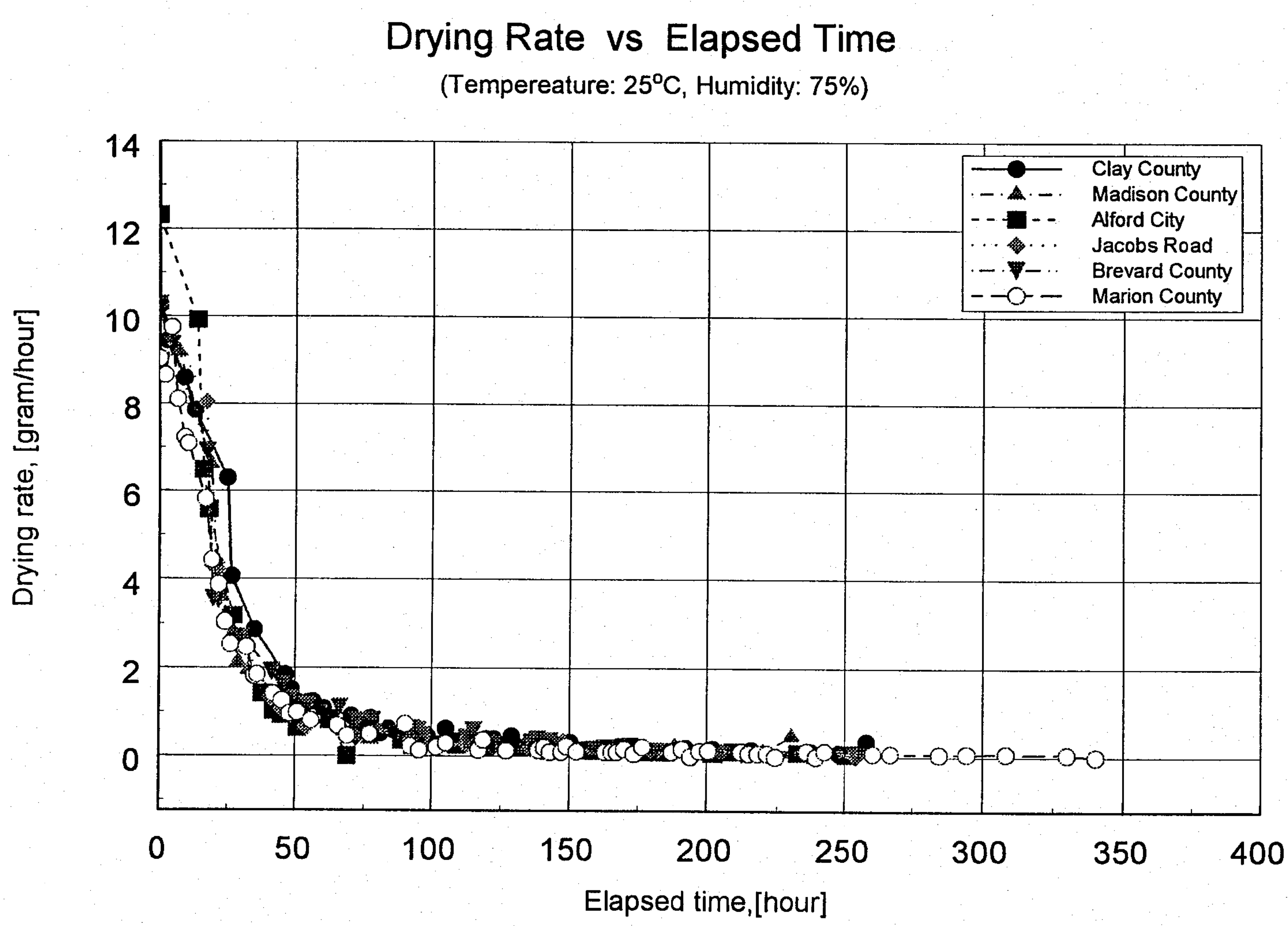

Figure 6.3 : Drying rate vs elapsed time for six soils at temperature 25^{o}C and 75% relative humidity (Group I)

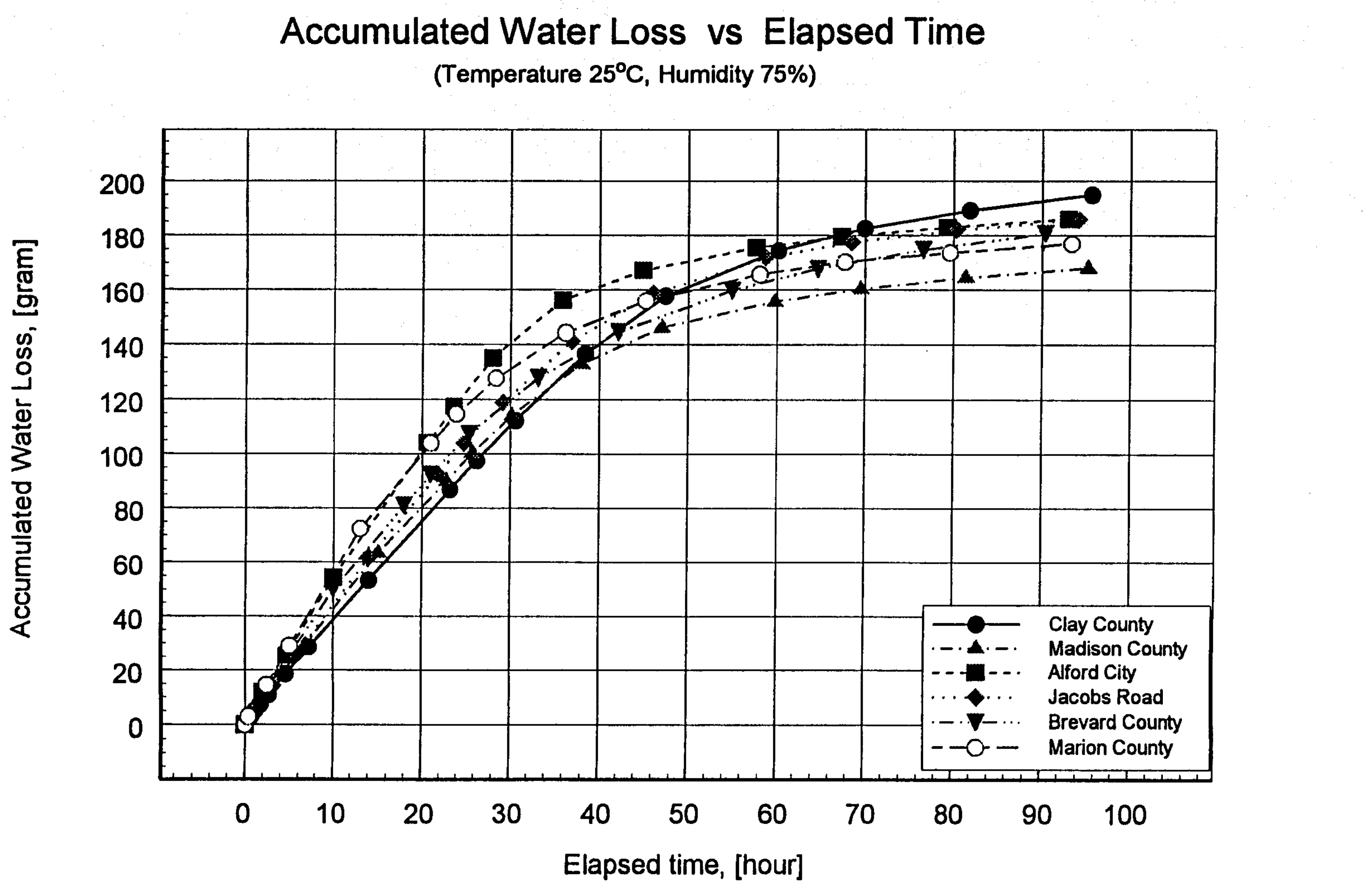

Figure 6.4: Water loss vs elapsed time at temperature 25°C and 75% relative humidity for six soils (Group II)

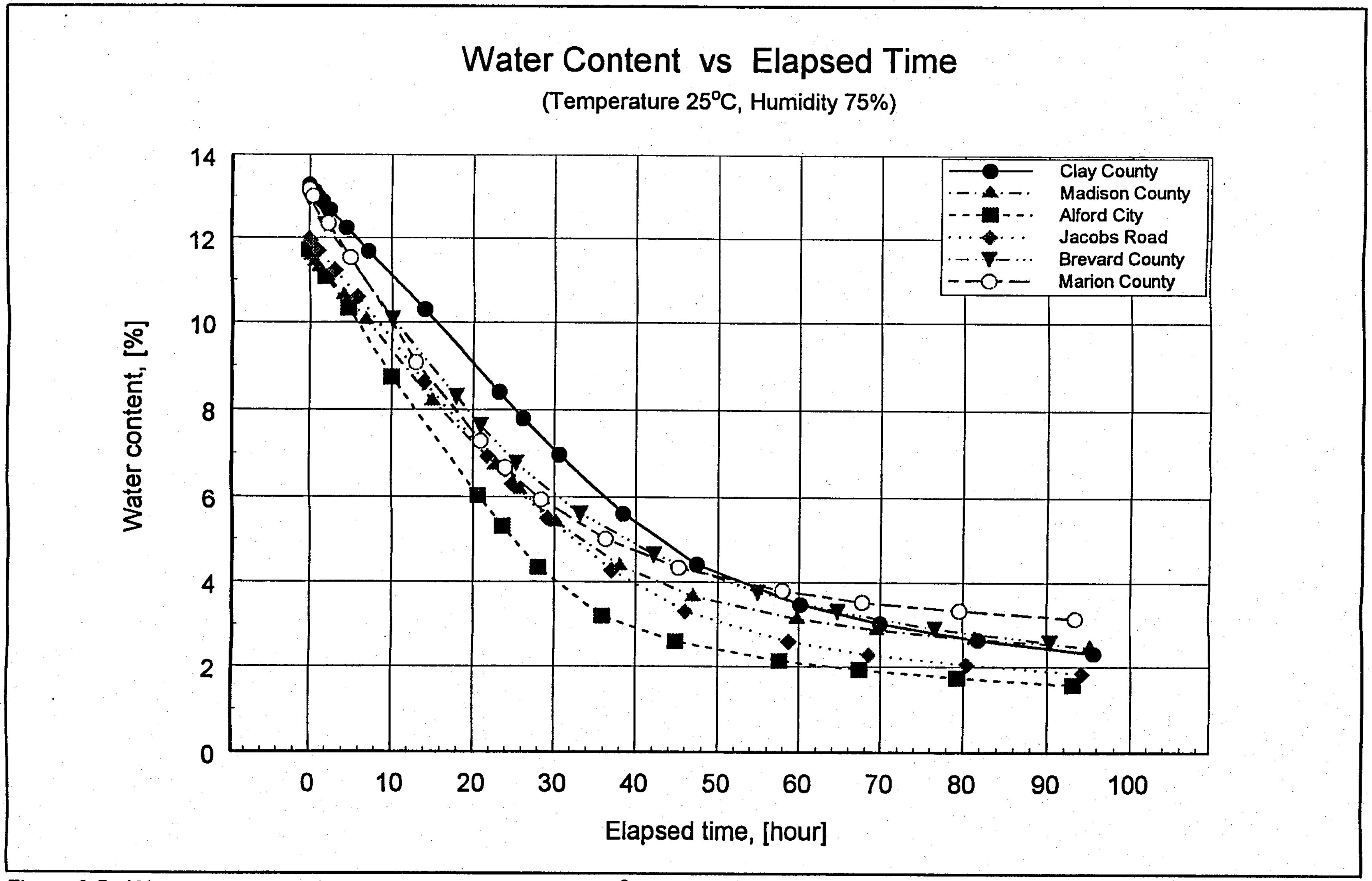

Figure 6.5 : Water content vs elapsed time at temperature 25°C and relative humidity 75% for six soils (Group II)

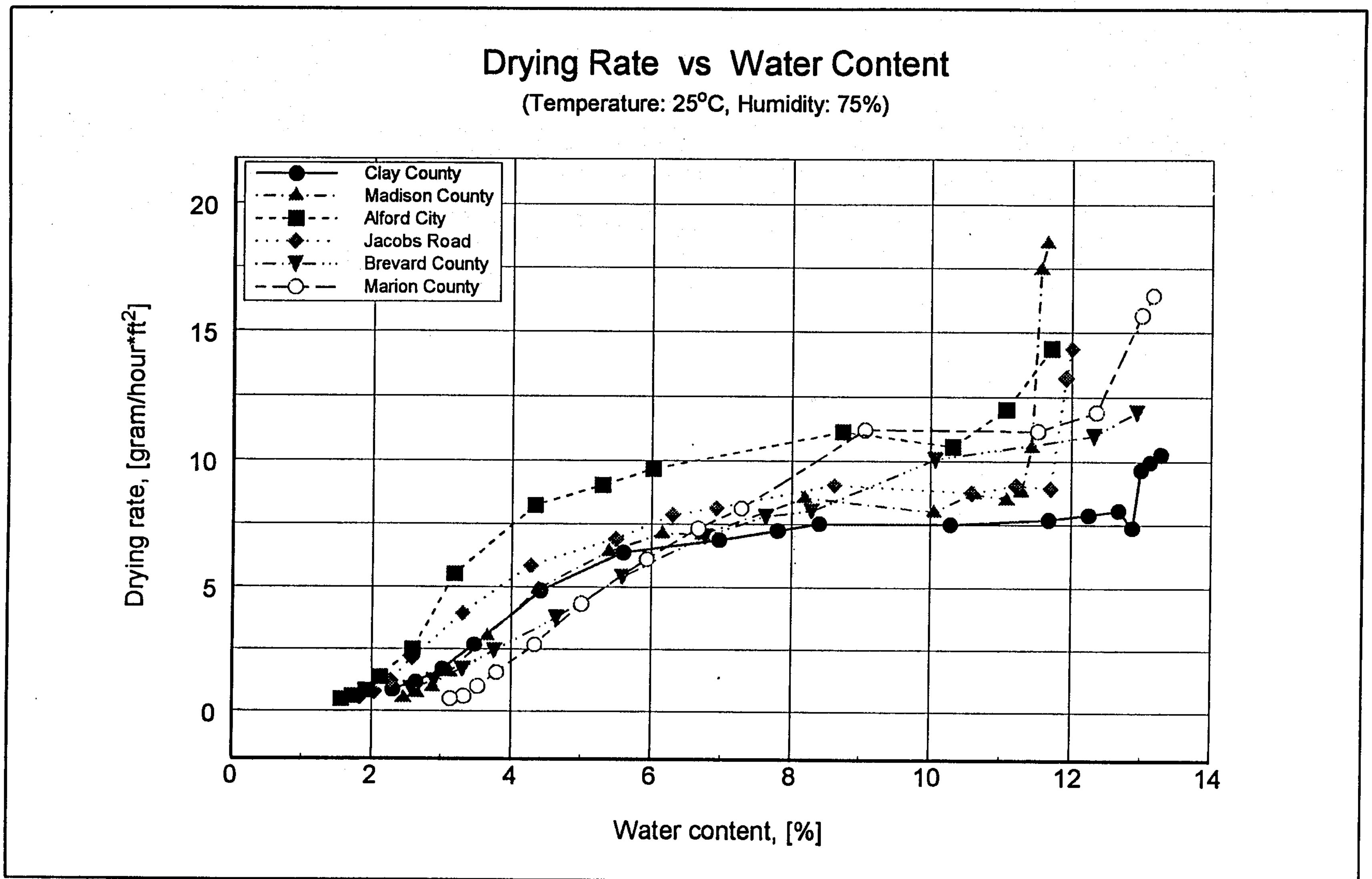

Figure 6.6 : Drying rate vs water content for six soils at temperature 25°C and 75% relative humidity (Group II)

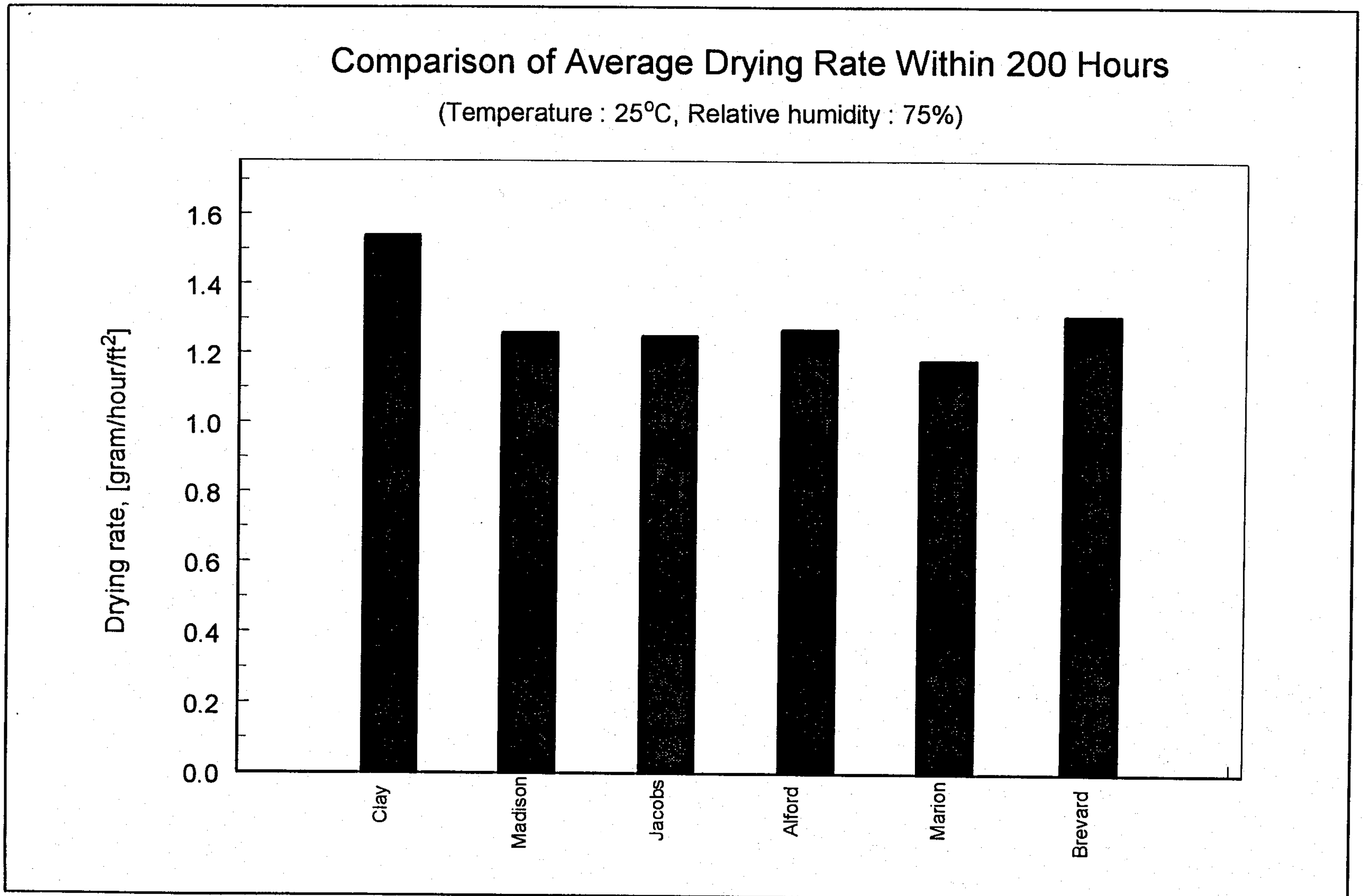

Figure 6.7 : Comparison of average drying rate for six soils within 200 hours (Group I)

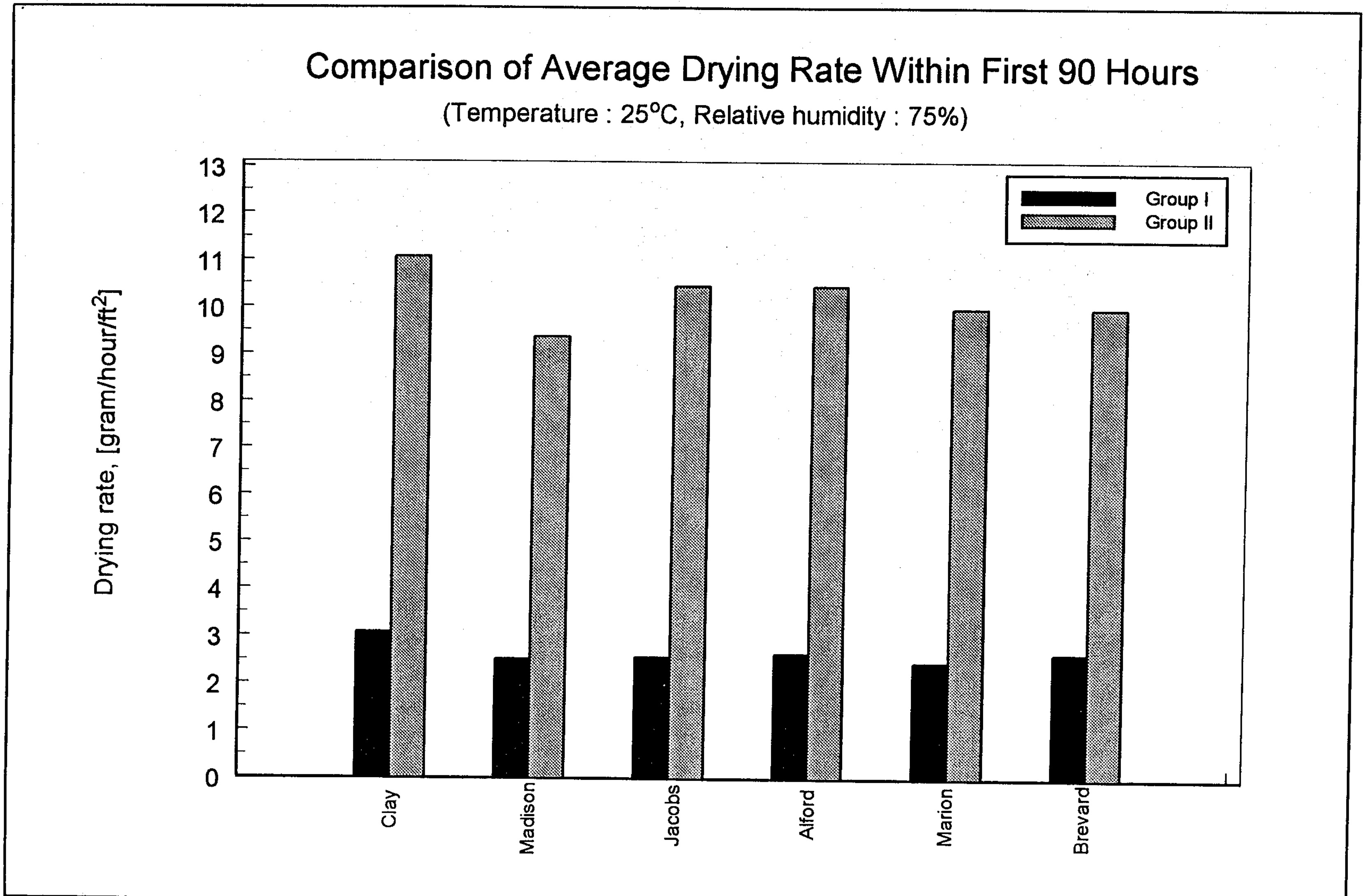

Figure 6.8 : Comparison of average drying rate for Group I and Group II tests within first 90 hours

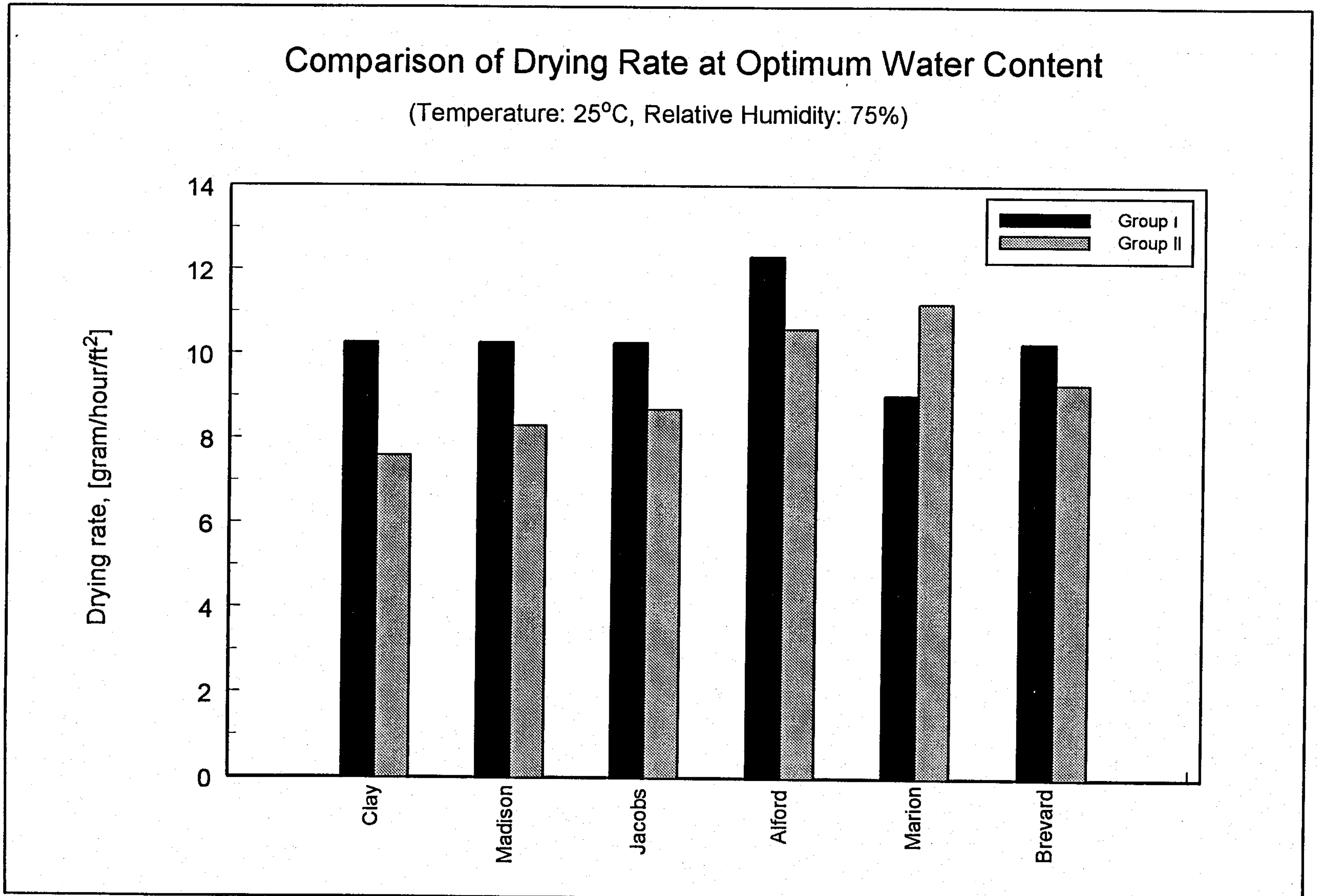

Figure 6.9 : Comparison of drying rate at optimum water content for Group I and Group II tests

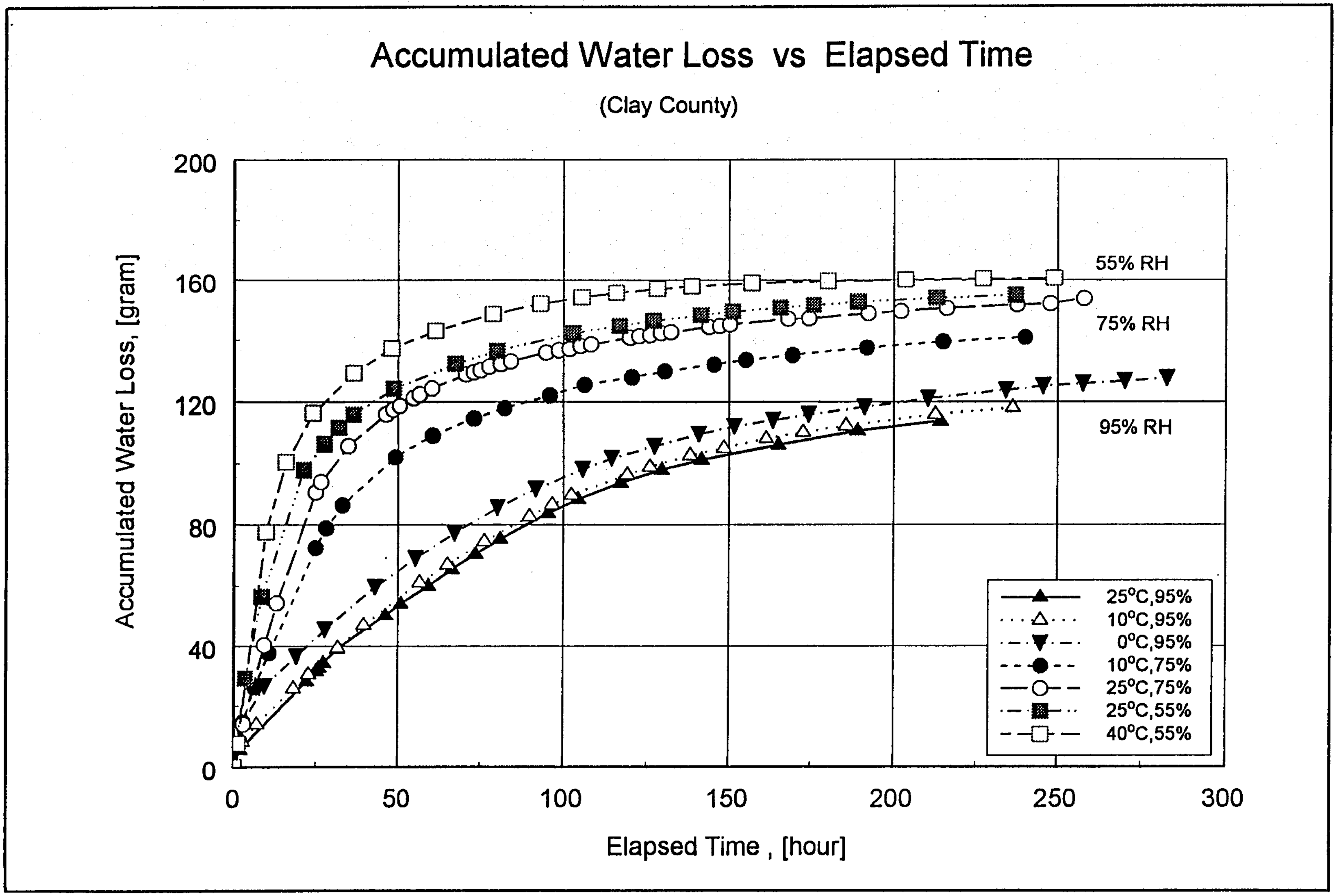

Figure 6.10 : Comparison of water loss at different temperature and relative humidity for Clay County soil (Group I)

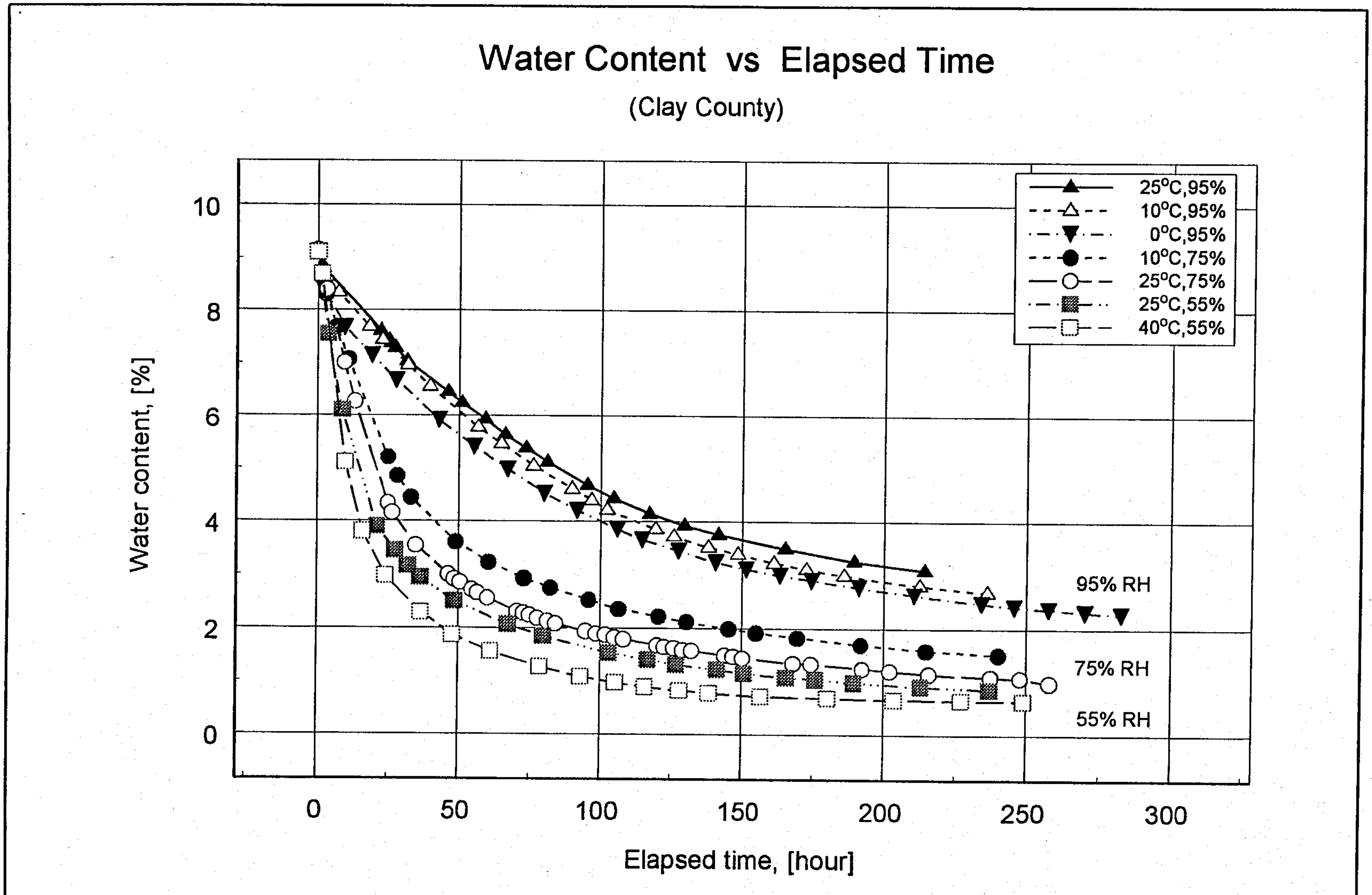

Figure 6.11 : Comparison of the change of water content at different temperature and relative humidity for Clay County soil (Group I)

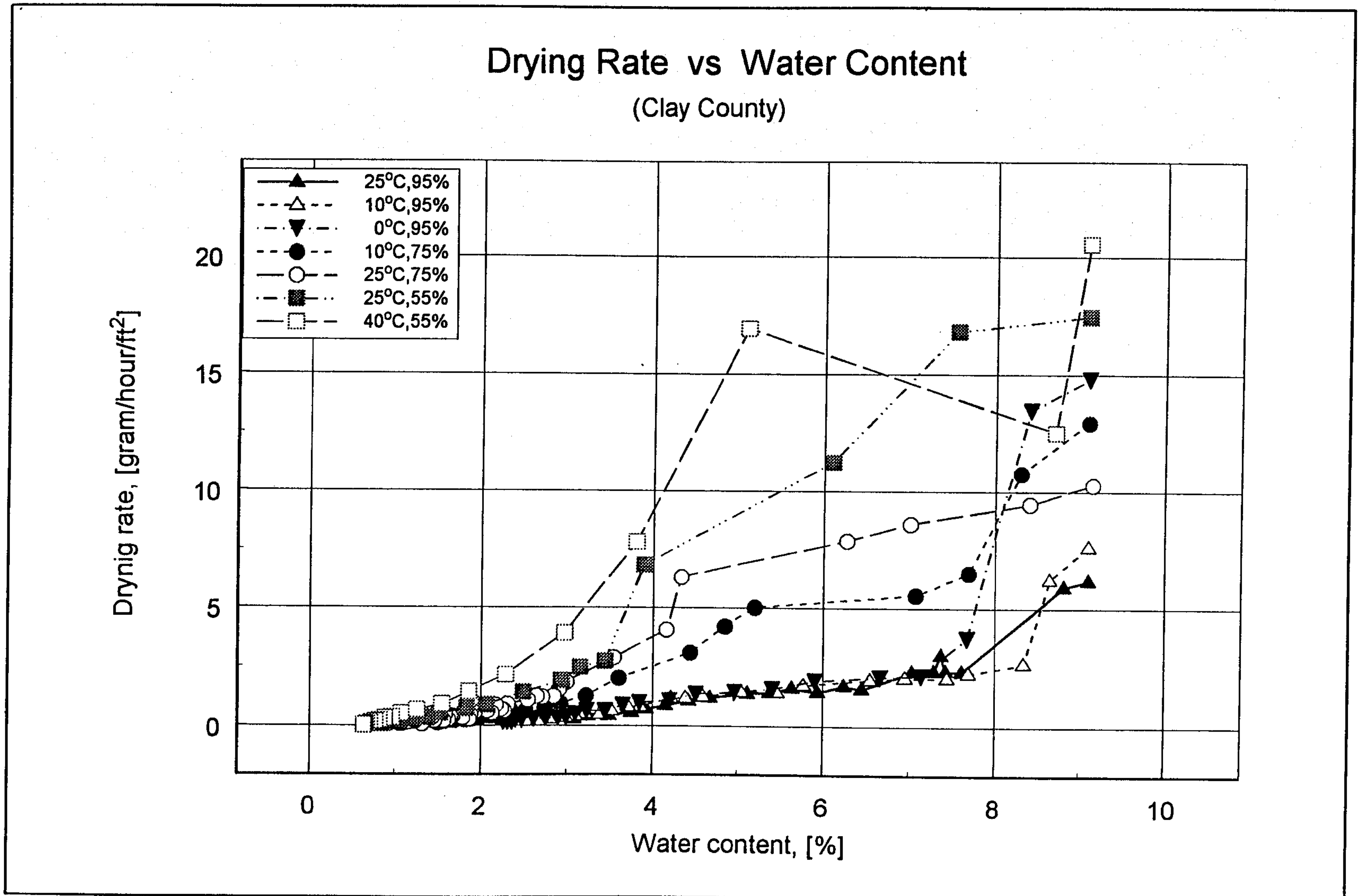

Figure 6.12 : Comparison of drying rate at different temperature and relative humidity for Clay County soil (Group I)

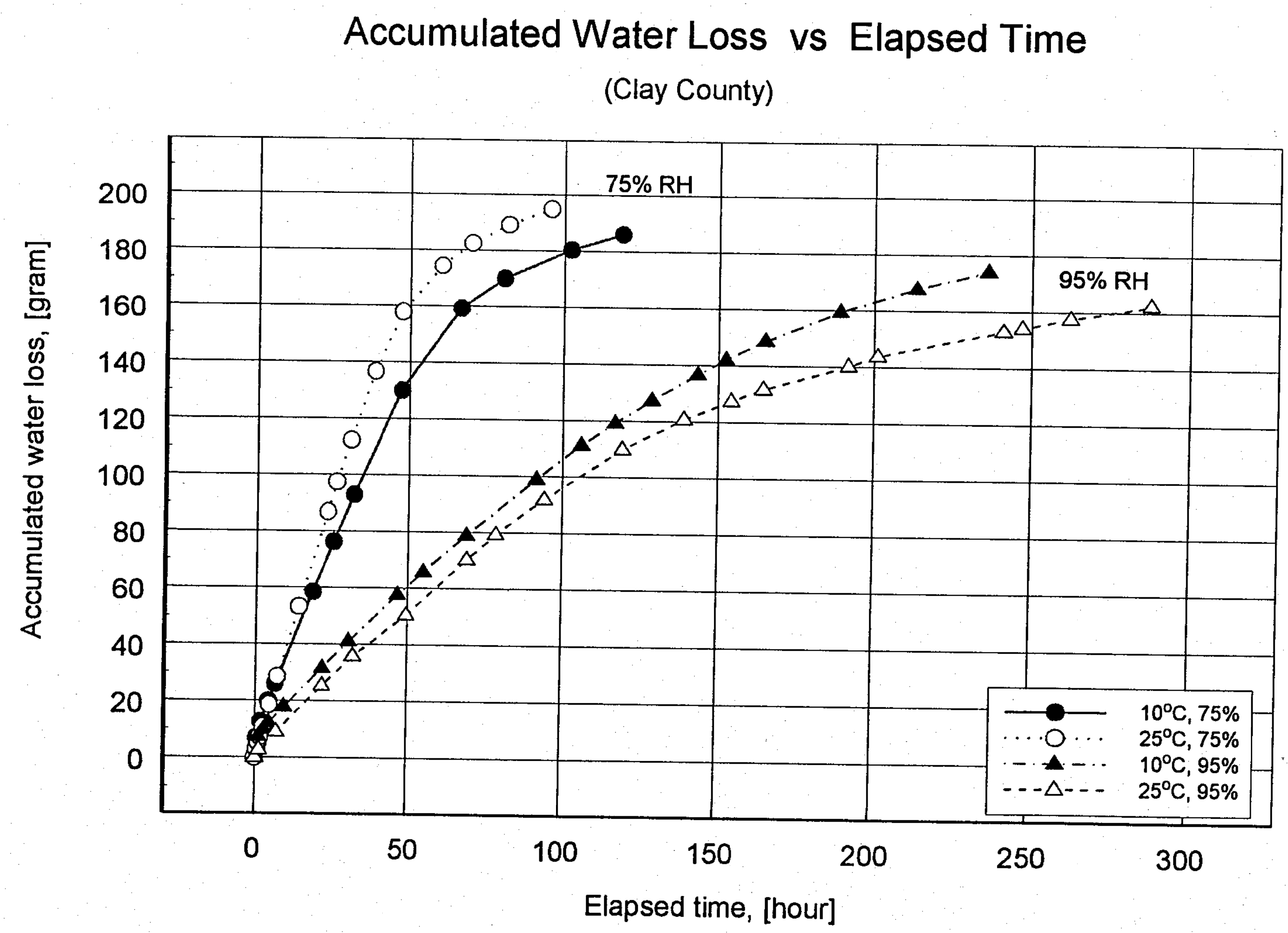

Figure 6.13 : Comparison of water loss at different temperature and relative humidity for Clay County soil(Group II)

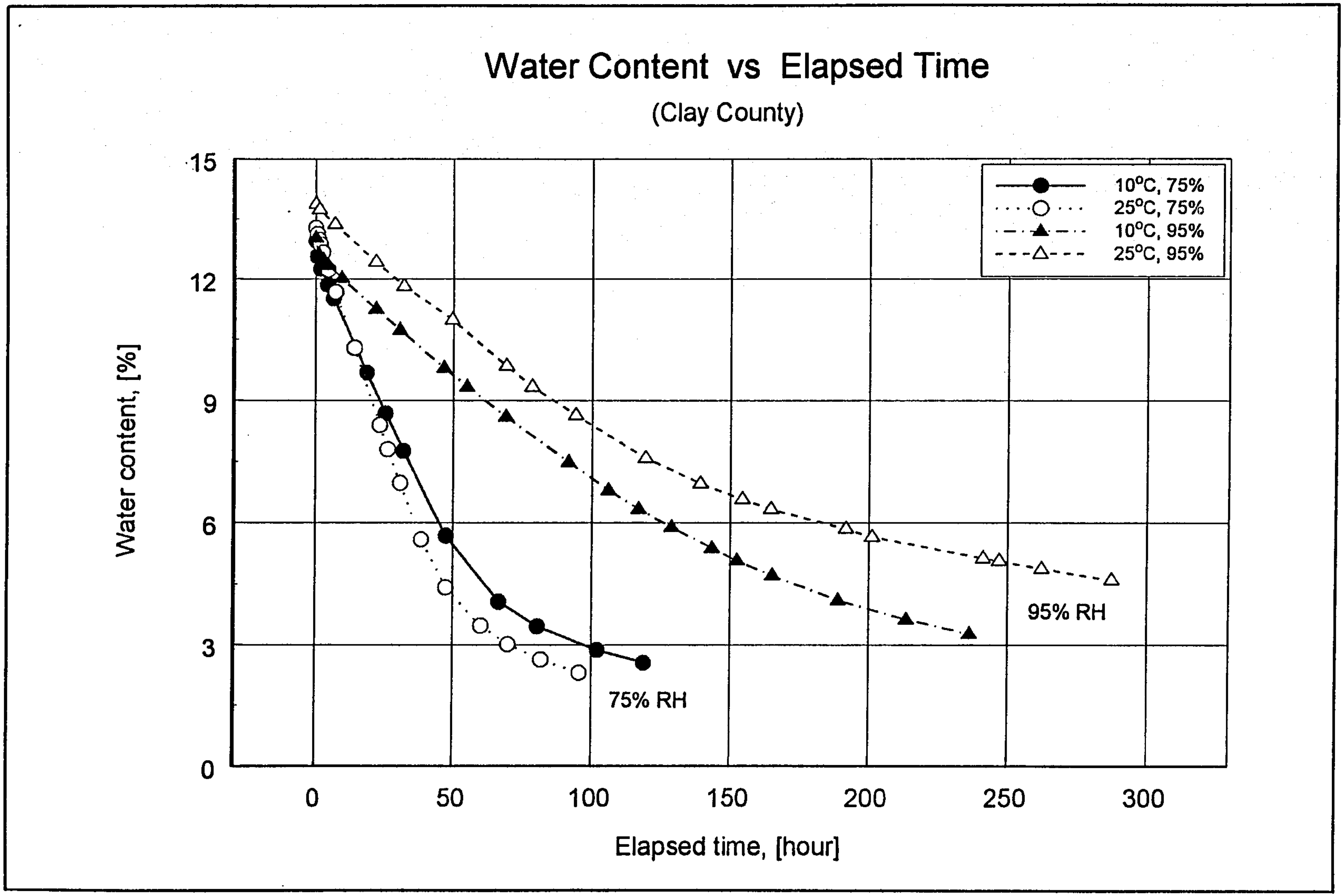

Figure 6.14 : Comparison of the change of water content at different temperature and relative humidity for Clay County soil (Group II)

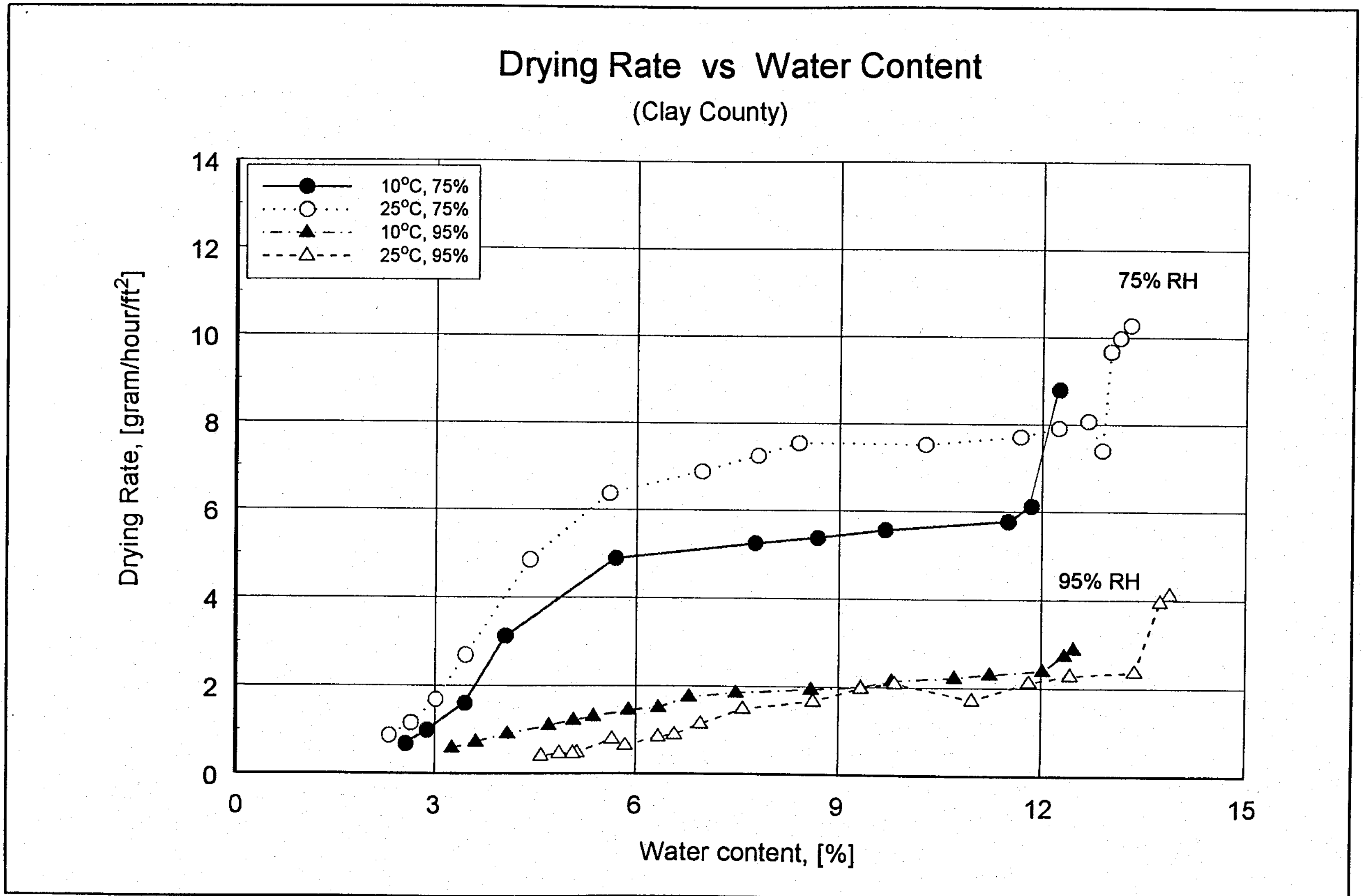

Figure 6.15 : Comparison of drying rate at different temperature and relative humidity for Clay County soil (Group II)

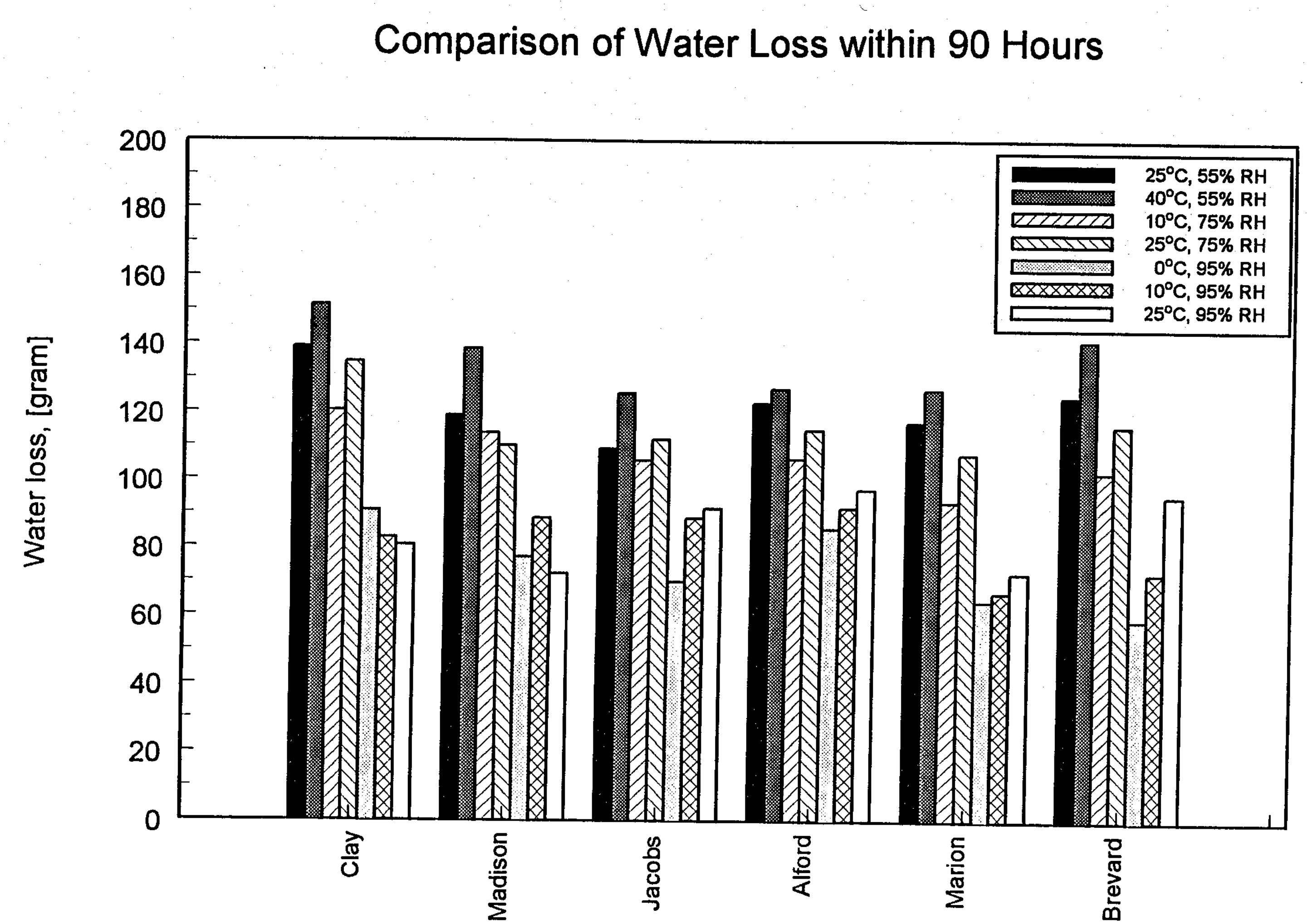

Figure 6.16(a) : Comparison of water loss within 90 hours at different environmental conditions for six soils (Group I)

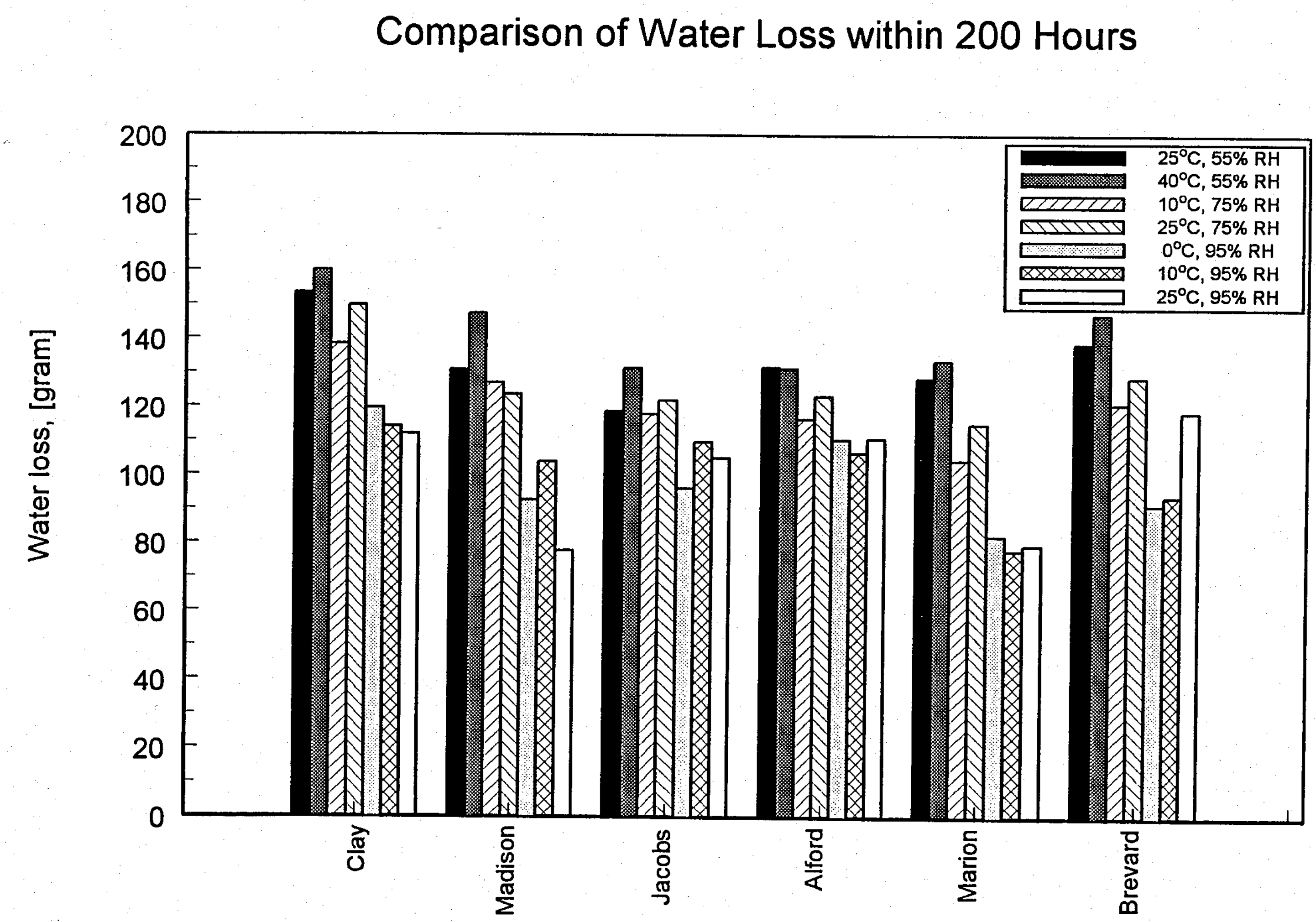

Figure 6.16(b) : Comparison of water loss within 200 hours at different environmental conditions for six soils (Group I)

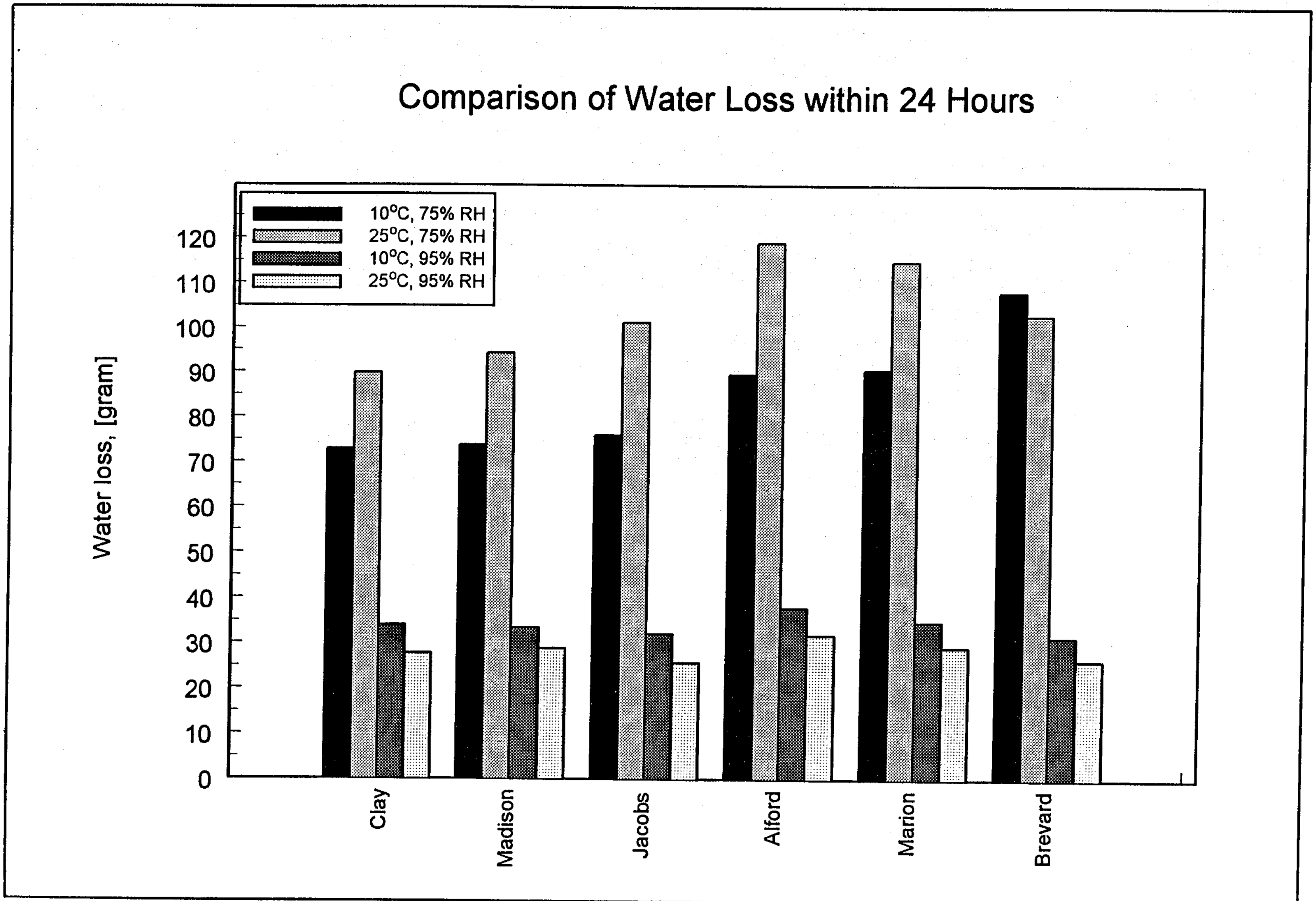

Figure 6.17(a) : Comparison of water loss within 24 hours at different environmental conditions for six soils (Group II)

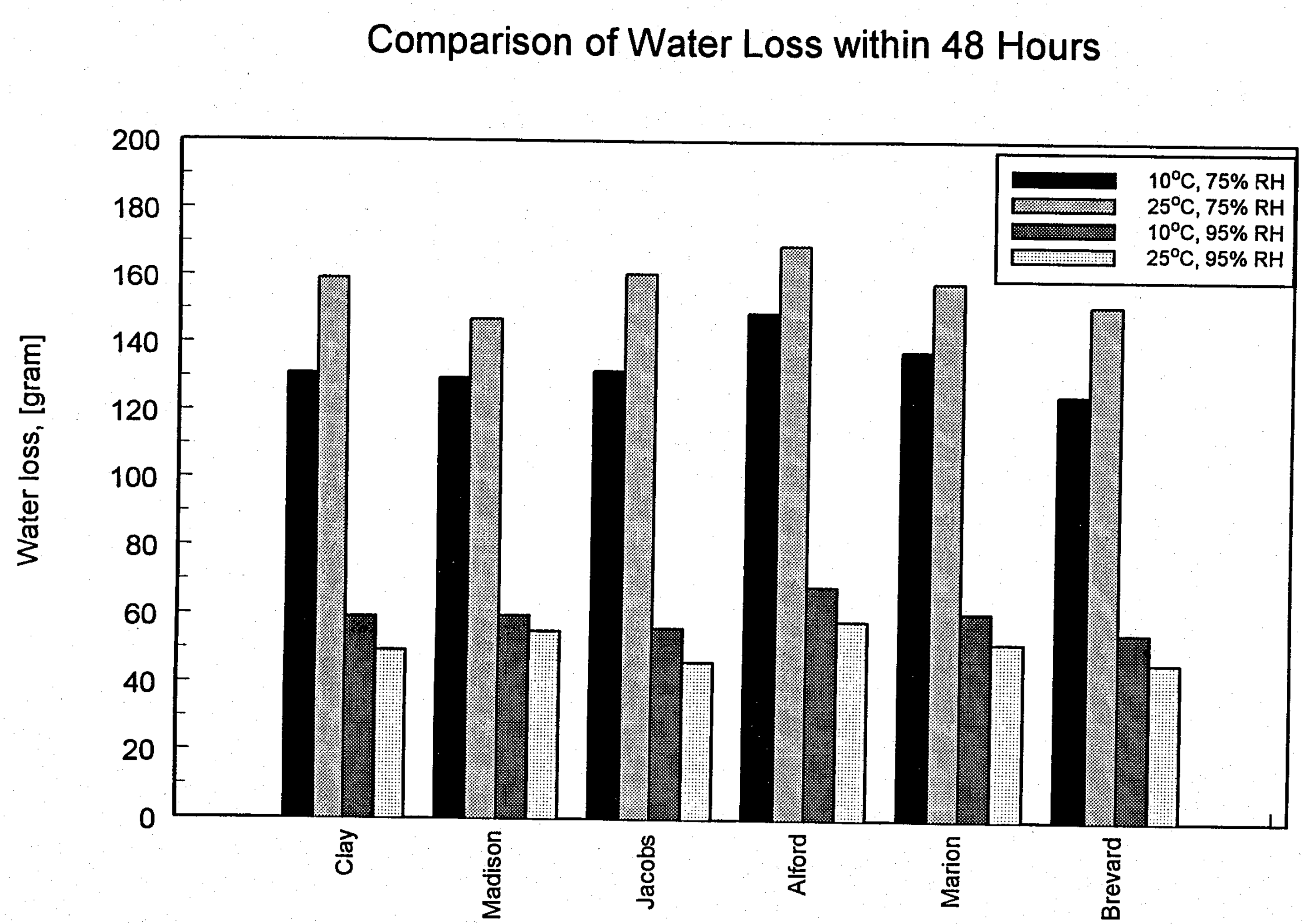

Figure 6.17(b) : Comparison of water loss within 48 hours at different environmental conditions for six soils (Group II)

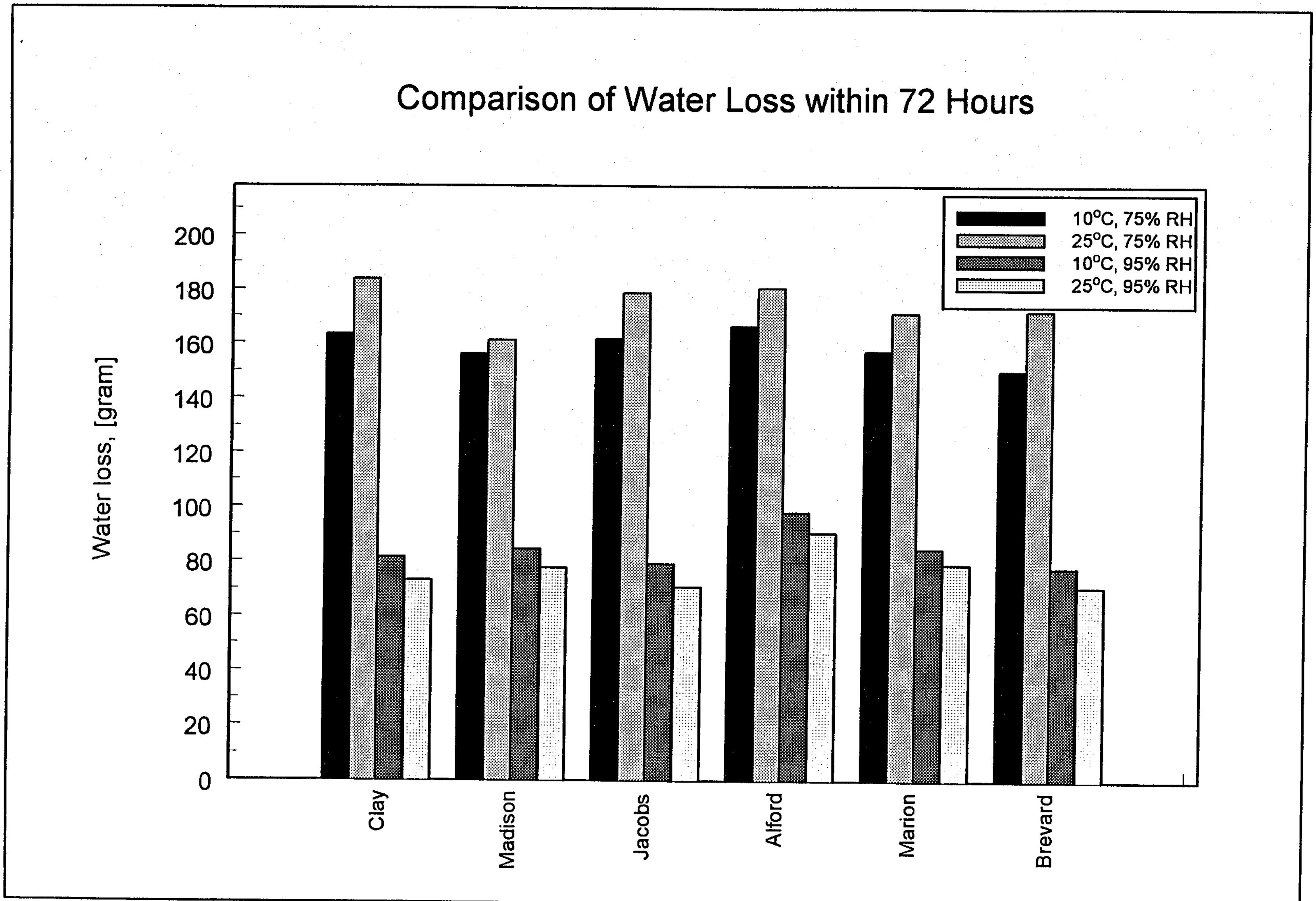

Figure 6.17(c) : Comparison of water loss within 72 hours at different environmental conditions for six soils (Group II)

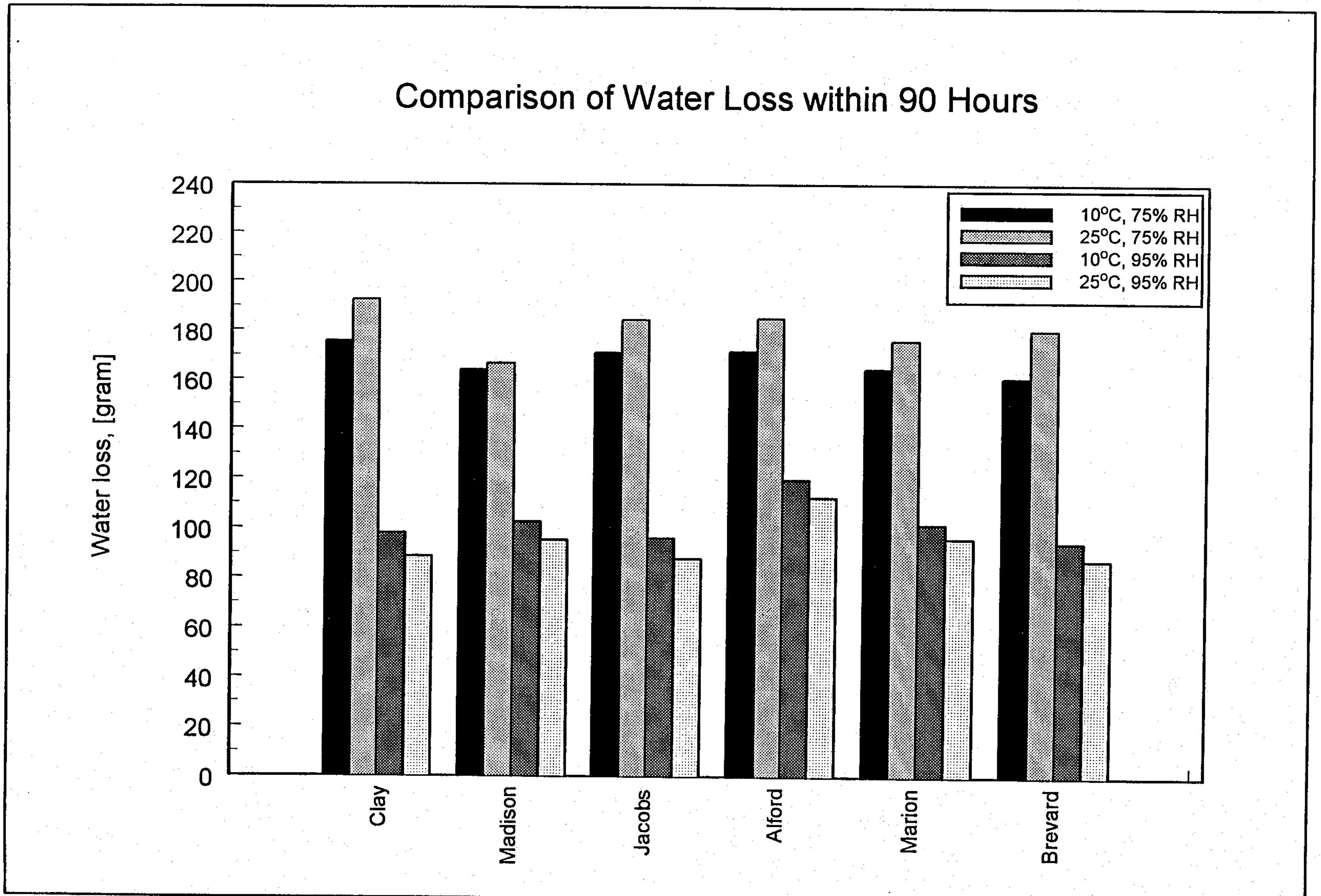

Figure 6.17(d) : Comparison of water loss within 90 hours at different environmental conditions for six soils (Group II)

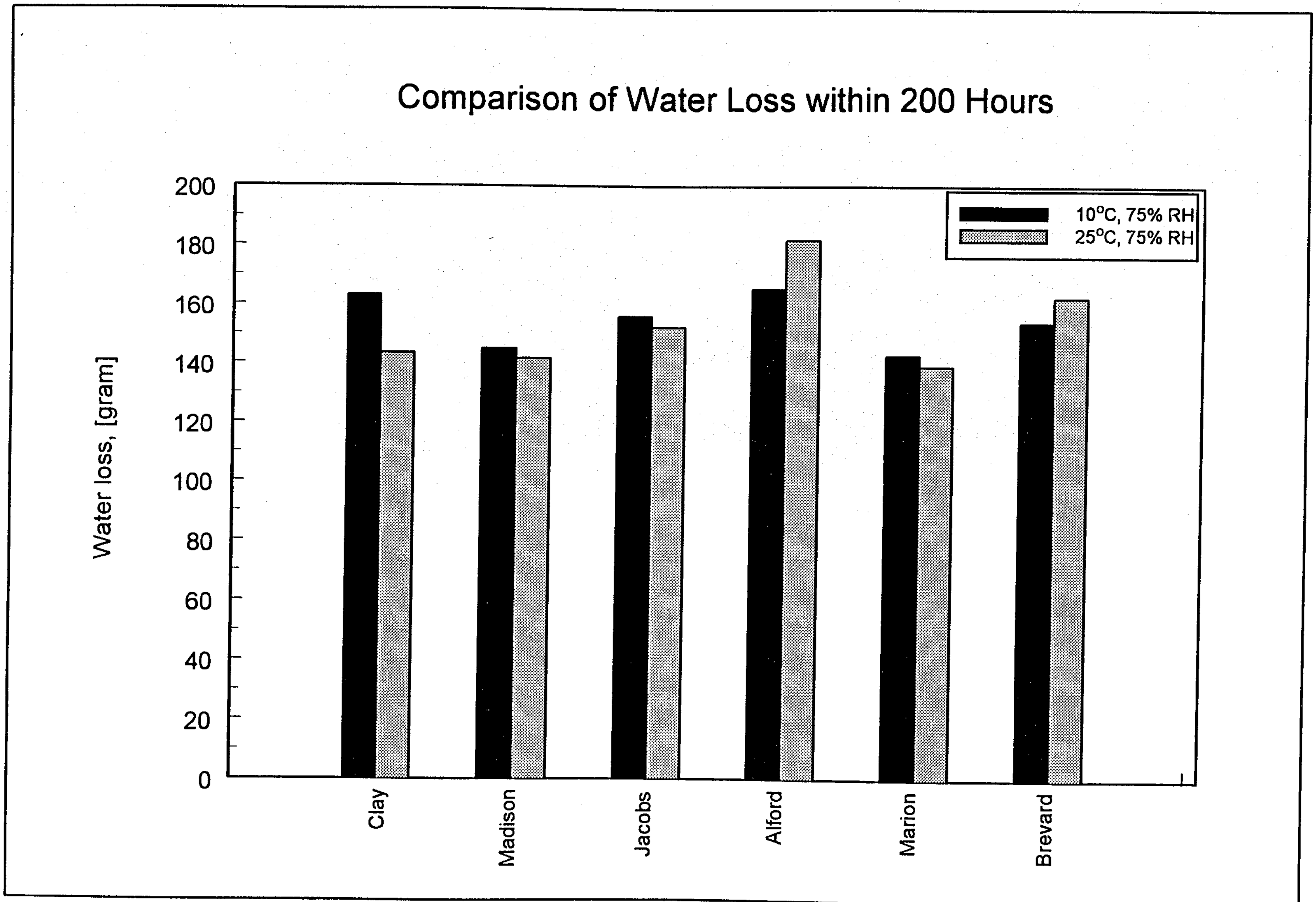

Figure 6.17(e) : Comparison of water loss within 200 hours at different environmental conditions for six soils (Group II)

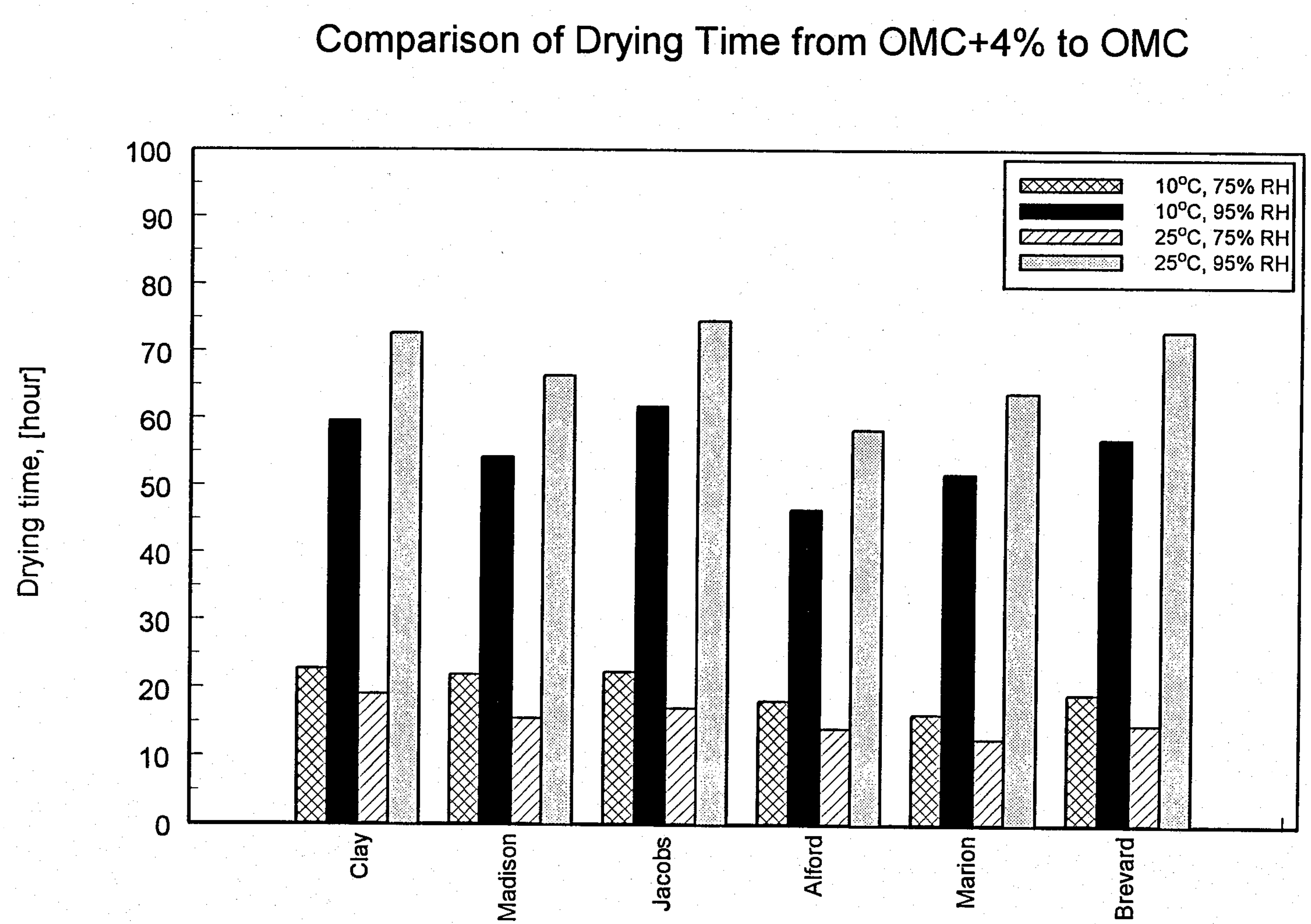

Figure 6.18 : Comparison of drying time from OMC+4% to OMC at different environmental conditions for six soils (Group II)

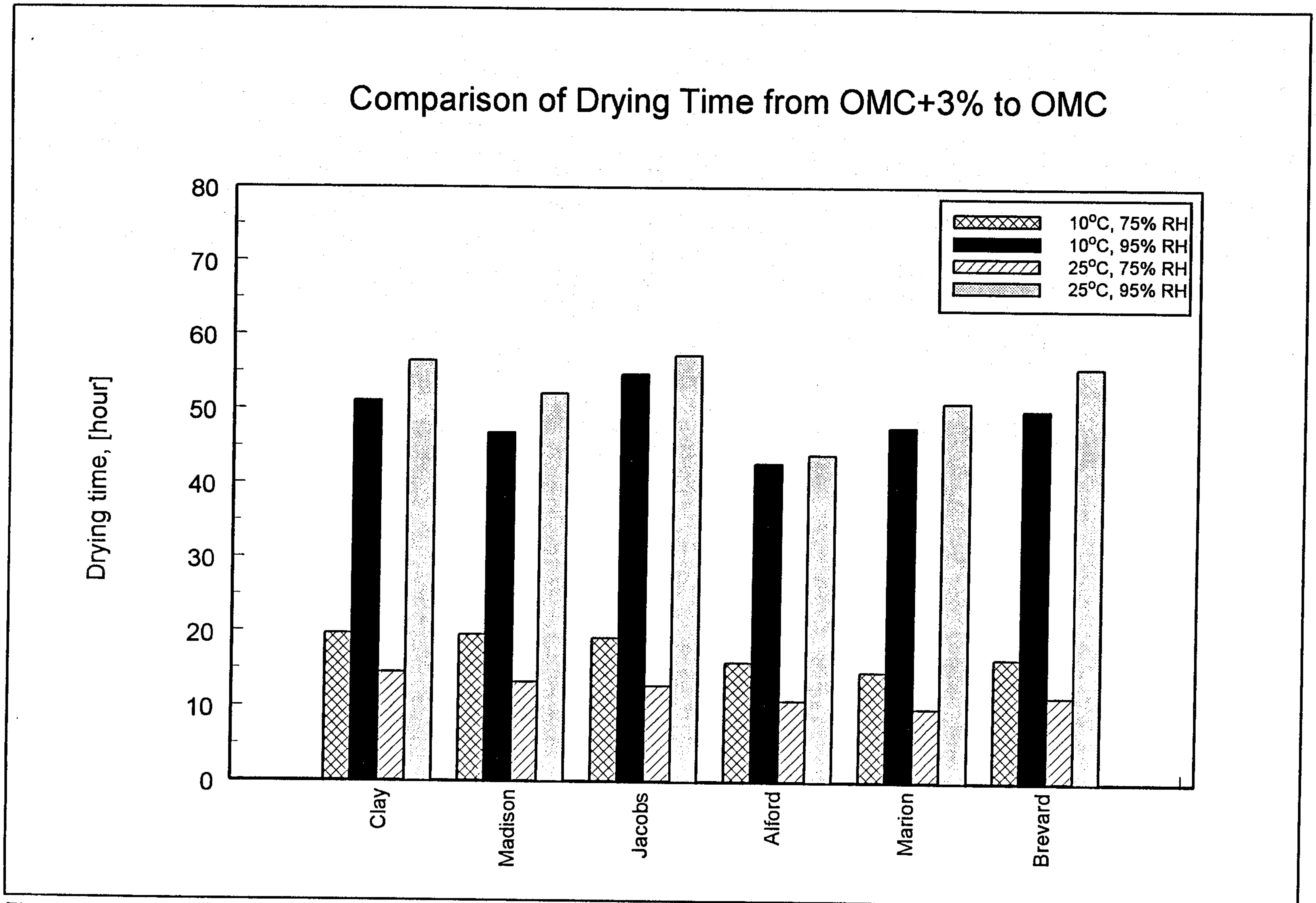

Figure 6.19 : Comparison of drying time from OMC+3% to OMC at different environmental conditions for six soils (Group II)

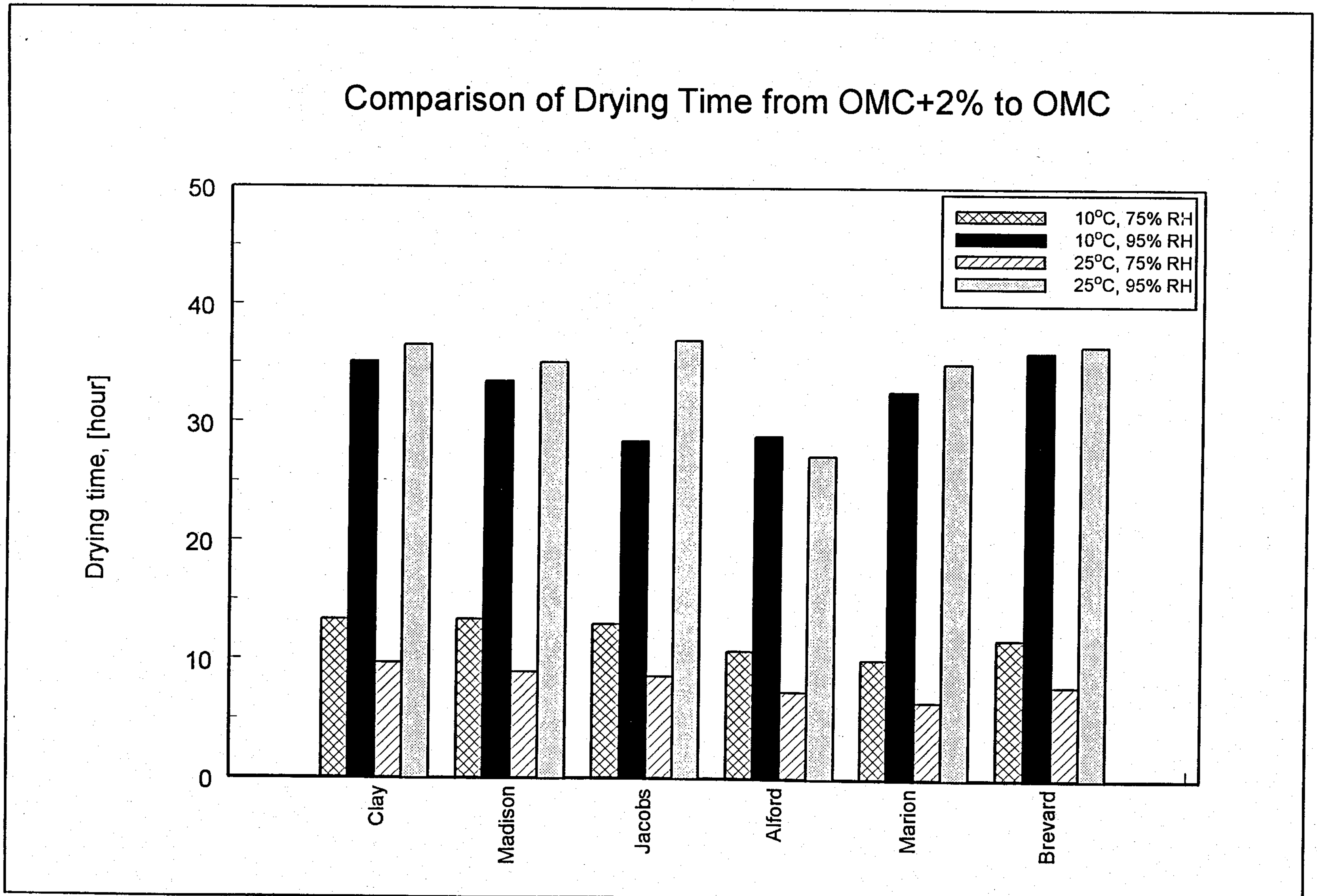

Figure 6.20 : Comparison of drying time from OMC+2% to OMC at different environmental conditions for six soils (Group II)

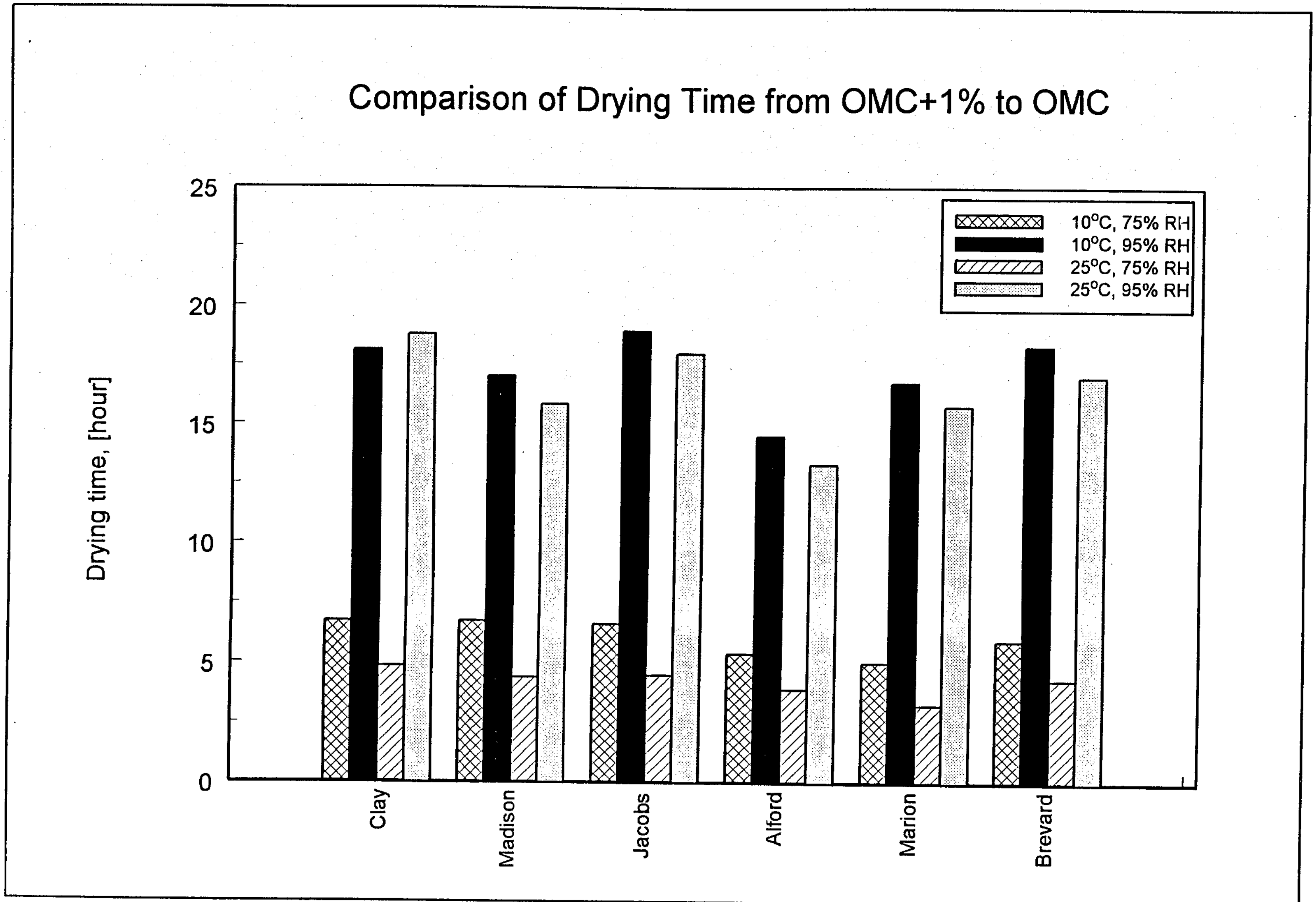

Figure 6.21 : Comparison of drying time from OMC+1% to OMC at different environmental conditions for six soils (Group II)

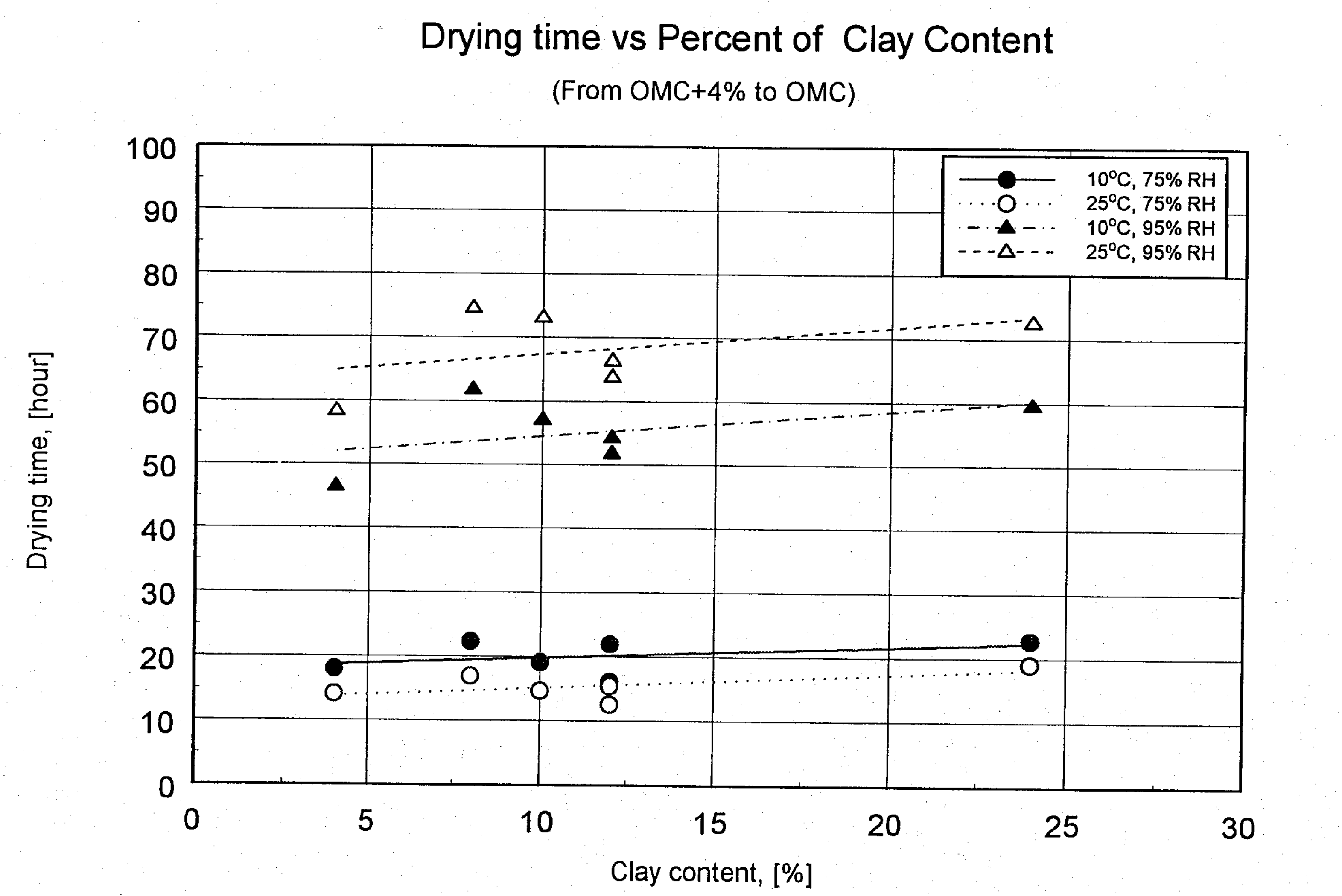

Figure 6.22 : Comparison of drying time for different percent of clay content from OMC+4% to OMC (Group II)

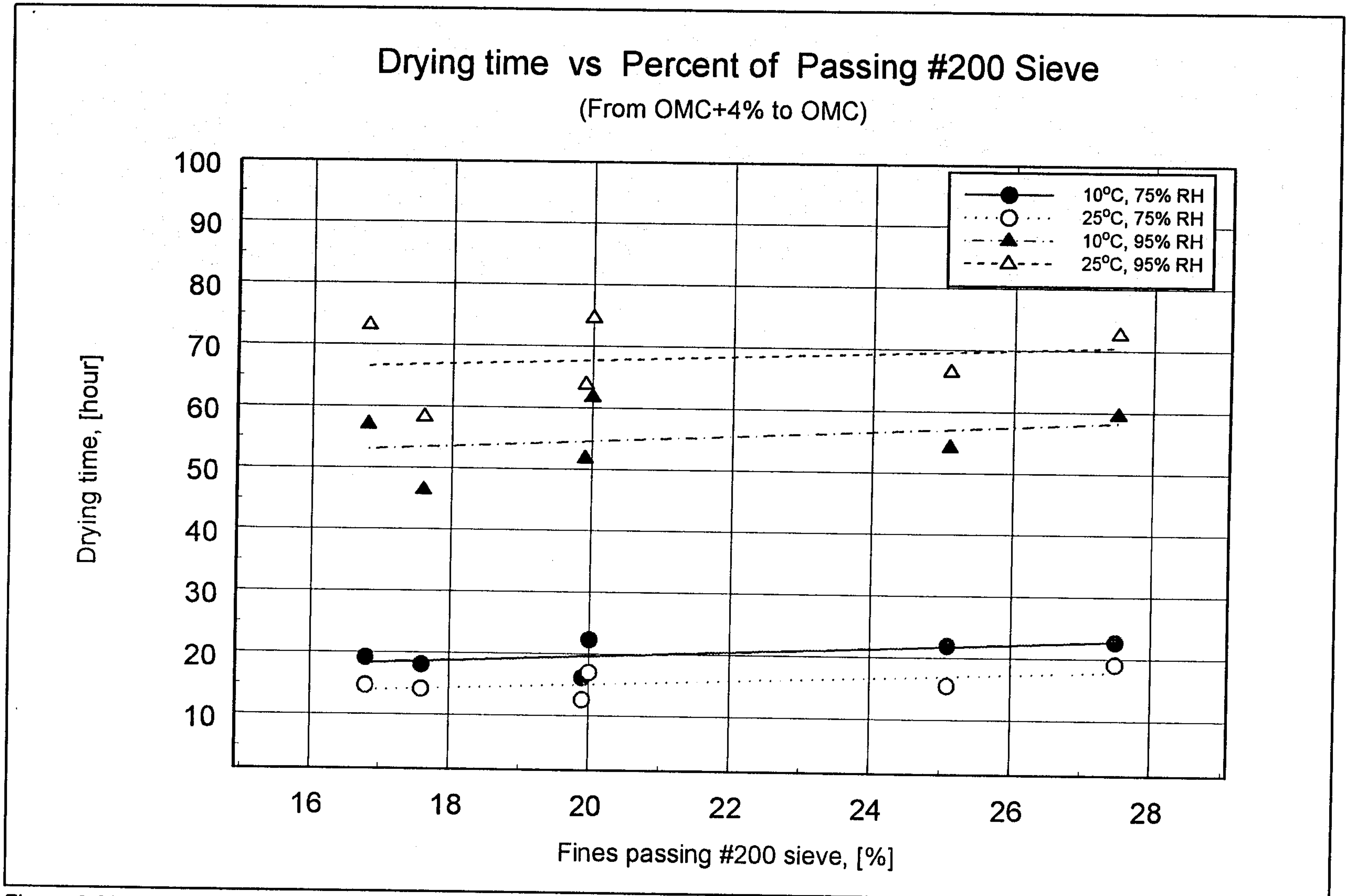

Figure 6.23 : Comparison of drying time for different percent of passing #200 sieve from OMC+4% to OMC (Group II)

CHAPTER 7

CORRELATION AND ANALYSIS OF SUCTION AND DRYING RATE EXPERIMENTAL RESULTS

7.1 Correlation of Suction and Drying Rate Test Results

Soil suction is a basic soil property that represents the ability of a soil to retain water. Correlation relationship exists between drying rate and soil suction. The suction and drying rate test results are further analyzed in this chapter. Detailed plots concerning the correlation of soil suction and drying rate results are presented in Appendix F.

7.1.1 Soil suction versus drying time

Since the test results from the soil suction Series B are more reliable than those from Series A, the data from the drying rate test are used to correlate with the data from the Series B suction test. Figures 7.1 through 7.5 provide the changes of soil suction value with time for the six soils at temperature 25°C with various relative humidity during the drying period. It is shown in the figures that the soils from Clay County and Madison County have higher suction values compared to the other four soils. The drying curves shown in Figures 7.1 and 7.2 indicate that there is no significant influence on the soil suction values when the environmental relative humidity changes from 55% to 75%. As shown in Figure 7.3, the drying curves under 95% relative humidity increase very slowly with time, which is in constrast to the sharp increase on soil suction in the beginning of the drying period under lower relative humidity (55% and 75%). With the same amount of elapsed time, the suction values for Clay County and Madison County soils under 95% relative humidity condition are much lower than those under 55% and 75% relative humidity conditions. Similiar trends apply to the drying rate Group II tests, which are illustrated in Figures 7.4 and 7.5.

7.1.2 Drying rate versus drying time

Figures 7.6 through 7.10 demonstrate the drying rate versus elapsed drying time. The drying rate is the highest under 55% relative humidity condition and is the lowest under 95% relative humidity condition at the beginning of the drying cycles. It is shown in Figure 7.9 that, when the soil water condition of the drying cycle is below the optimum water content, the difference in the drying rate is not significant for the six soils. However, when the soil water condition is above the optimum water content, the soils from Clay County and Madison County have lower drying rates than the other soils.

7.1.3 Drying rate versus soil suction

Summaries of drying rate and soil suction at temperature 25°C are presented in Tables 7.1 and 7.2. The drying rates are plotted as a function of soil suction as shown in Figures 7.11 through 7.15. Each type of soil has its own drying rate-suction characteristics. It is shown that the drying rate decreases with an increase in soil suction. It appears that the soils from Alford City, Jacobs Road, Brevard County, and Marion County have drying rates higher than those from Clay County and Madison County. In terms of percent of fines, it appears that a soil, which has percent of fines higher than 20%, may have a lower drying rate under high humidity and would be more difficult to handle during construction.

7.2 Discussion on Theoretical Relationship Between Suction and Relative Humidity

A theoretical relationship between the relative humidity (actual vapor pressure divided by saturation vapor pressure in the unsaturated soil voids) and total suction based on the Kelvin's equation (Equation 2.5) is shown in Figure 7.16. It indicates that relative humidity is an exponential function of total suction. The decline in relative humidity with increasing suction is initially small and a substantial decrease in the relative humidity occurs only after the suction value 1000kPa. Theoretically, the relationship occurs independent of water content when all the variables are well controlled.

As shown in Figure 7.16, a suction value at 7000kPa has a corresponding relative humidity 95% (in unsaturated soil voids). A soil with the suction value higher than 7000kPa will result in a relative humidity lower than 95% and this means no more water will evaporate from the soil when a soil is subjected to an environmental condition at 95% relative humidity. For instance, the soils from Clay and Madison County, which contain percent of fines greater than 20%, possess suction value higher than 7000 kPa will cause the soil to stop drying.

It is difficult to compare all the controlling variables since each soil type has a different initial water content and the volume of water available for evaporation. The analysis for a soil sample other than a thin layer requires a theoretical approach that includes the influence of the flow process below the soil surface.

Table 7.1(a) : Summary of soil suction and drying rate at OMC

Soils	Percent of Clay	Percent of Passing #200	Water content	Suction	Drying rate (Group II)	
					@75%R.H.	@95%R.H.
	%	%	%	kPa	gram/hour/ft^2	
Clay	24	27.5	9.1	510	7.5	1.8
Madison	12	25.1	8.5	439	8.5	2.3
Jacobs	8	20	7.9	335	8.8	2.0
Alford	4	17.6	7.6	261	10.6	2.8
Marion	12	19.9	9.3	313	11.3	2.3
Brevard	10	16.8	9.25	445	9.2	2.2

Table 7.1(b) : Summary of soil suction and drying rate at OMC plus 1%

Soils	Percent of Clay	Percent of Passing #200	Water content	Suction	Drying rate (Group II)	
					@75%R.H.	@95%R.H.
	%	%	%	kPa	gram/hour/ft^2	
Clay	24	27.5	10.1	226	7.5	2.0
Madison	12	25.1	9.5	265	8.1	1.9
Jacobs	8	20	8.9	283	9.1	1.9
Alford	4	17.6	8.6	234	11.3	2.5
Marion	12	19.9	10.3	249	11.3	1.8
Brevard	10	16.8	10.25	401	10.3	1.8

Table 7.1(c) : Summary of soil suction and drying rate at OMC plus 2%

Soils	Percent of Clay	Percent of Passing #200	Water content	Suction	Drying rate (Group II)	
					@75%R.H.	@95%R.H.
	%	%	%	kPa	gram/hour/ft^2	
Clay	24	27.5	11.1	101	7.8	1.8
Madison	12	25.1	10.5	160	8.8	2.1
Jacobs	8	20	9.9	240	8.8	1.8
Alford	4	17.6	9.6	210	11.2	2.2
Marion	12	19.9	11.3	198	11.3	2.3
Brevard	10	16.8	11.25	362	10.6	1.8

Table 7.1(d) : Summary of soil suction and drying rate at OMC plus 3%

Soils	Percent of Clay	Percent of Passing #200	Water content	Suction	Drying rate (Group II)	
					@75%R.H.	@95%R.H.
	%	%	%	kPa	gram/hour/ft^2	
Clay	24	27.5	12.1	45	11.5	2.1
Madison	12	25.1	11.5	97	12.5	2.6
Jacobs	8	20	10.9	203	8.8	2.1
Alford	4	17.6	10.6	188	11.2	2.6
Marion	12	19.9	12.3	157	12.0	3.0
Brevard	10	16.8	12.25	327	11.1	2.2

Table 7.1(e) : Summary of soil suction and drying rate at OMC plus 4%

Soils	Percent of Clay	Percent of Passing #200	Water content	Suction	Drying rate (Group II)	
					@75%R.H.	@95%R.H.
	%	%	%	kPa	gram/hour/ft^2	
Clay	24	27.5	13.1	20	10.0	2.4
Madison	12	25.1	12.5	58	-	3.5
Jacobs	8	20	11.9	172	13.1	2.8
Alford	4	17.6	11.6	168	12.2	2.9
Marion	12	19.9	13.3	125	16.5	-
Brevard	10	16.8	13.25	295	-	4.0

Table 7.2(a) : Summary of soil suction and drying rate at 25°C

(Water content = 8%)

Soils	Percent of Clay	Percent of Passing #200	Suction	Drying rate (Group II)	
				@75%R.H.	@95%R.H.
	%	%	kPa	gram/hour/ft^2	
Clay	24	27.5	1245	7.4	1.6
Madison	12	25.1	565	8.5	2.3
Jacobs	8	20	329	8.8	1.9
Alford	4	17.6	250	10.9	2.8
Marion	12	19.9	421	9.3	2.0
Brevard	10	16.8	506	7.9	1.8

Table 7.2(b) : Summary of soil suction and drying rate at 25°C

(Water content = 9%)

Soils	Percent of Clay	Percent of Passing #200	Suction	Drying rate (Group II)	
				@75%R.H.	@95%R.H.
	%	%	kPa	gram/hour/ft^2	
Clay	24	27.5	553	7.5	1.8
Madison	12	25.1	341	8.4	2.2
Jacobs	8	20	279	8.9	1.9
Alford	4	17.6	224	11.2	2.4
Marion	12	19.9	335	11.3	2.4
Brevard	10	16.8	456	8.9	2.1

Table 7.2(c) : Summary of soil suction and drying rate at 25°C

(Water content = 10%)

Soils	Percent of Clay	Percent of Passing #200	Suction	Drying rate (Group II)	
				@75%R.H.	@95%R.H.
	%	%	kPa	gram/hour/ft^2	
Clay	24	27.5	246	7.5	2.0
Madison	12	25.1	206	7.9	1.9
Jacobs	8	20	236	8.8	1.9
Alford	4	17.6	201	10.8	2.4
Marion	12	19.9	266	11.3	1.9
Brevard	10	16.8	412	10.0	2.0

Table 7.2(d) : Summary of soil suction and drying rate at 25°C

(Water content = 11%)

Soils	Percent of Clay	Percent of Passing #200	Suction	Drying rate (Group II)	
				@75%R.H.	@95%R.H.
	%	%	kPa	gram/hour/ft^2	
Clay	24	27.5	109	7.5	1.7
Madison	12	25.1	125	8.8	2.3
Jacobs	8	20	200	8.8	2.1
Alford	4	17.6	180	11.7	2.6
Marion	12	19.9	212	11.3	2.4
Brevard	10	16.8	372	10.5	1.7

Table 7.2(e) : Summary of soil suction and drying rate at 25°C

(Water content = 12%)

Soils	Percent of Clay	Percent of Passing #200	Suction	Drying rate (Group II)	
				@75%R.H.	@95%R.H.
	%	%	kPa	gram/hour/ft^2	
Clay	24	27.5	48	7.9	2.2
Madison	12	25.1	75	-	3.1
Jacobs	8	20	169	14.5	2.8
Alford	4	17.6	161	15.0	3.1
Marion	12	19.9	169	11.6	2.6
Brevard	10	16.8	335	11.0	2.1

Table 7.2(f) : Summary of soil suction and drying rate at 25°C

(Water content = 13%)

Soils	Percent of Clay	Percent of Passing #200	Suction	Drying rate (Group II)	
				@75%R.H.	@95%R.H.
	%	%	kPa	gram/hour/ft^2	
Clay	24	27.5	22	7.5	2.3
Madison	12	25.1	45	-	3.8
Jacobs	8	20	143	-	3.3
Alford	4	17.6	144	-	3.5
Marion	12	19.9	134	15.0	3.5
Brevard	10	16.8	303	12.0	2.3

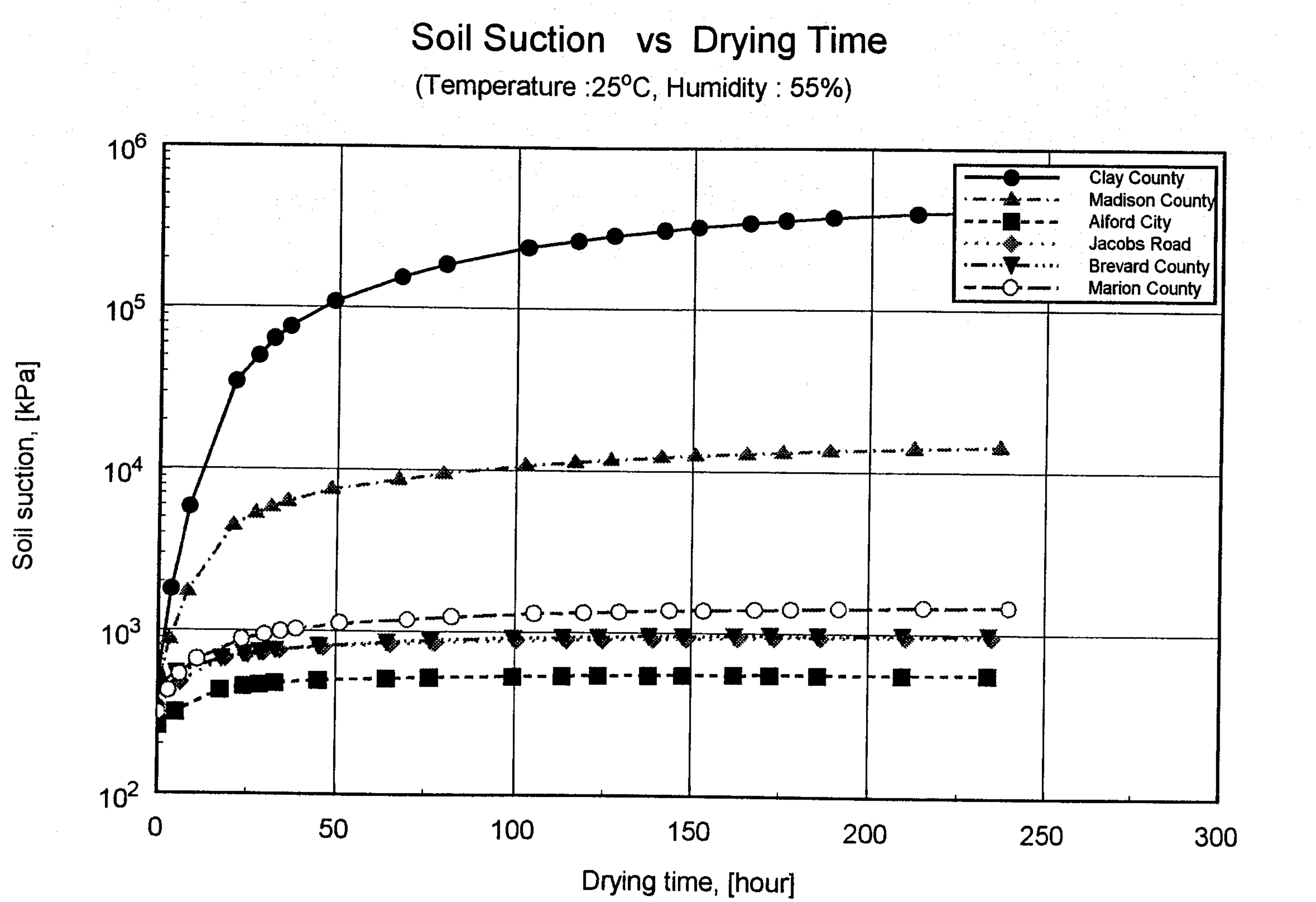

Figure 7.1 : Soil suction versus drying time for six soils at temperature 25°C and 55% relative humidity (Group I)

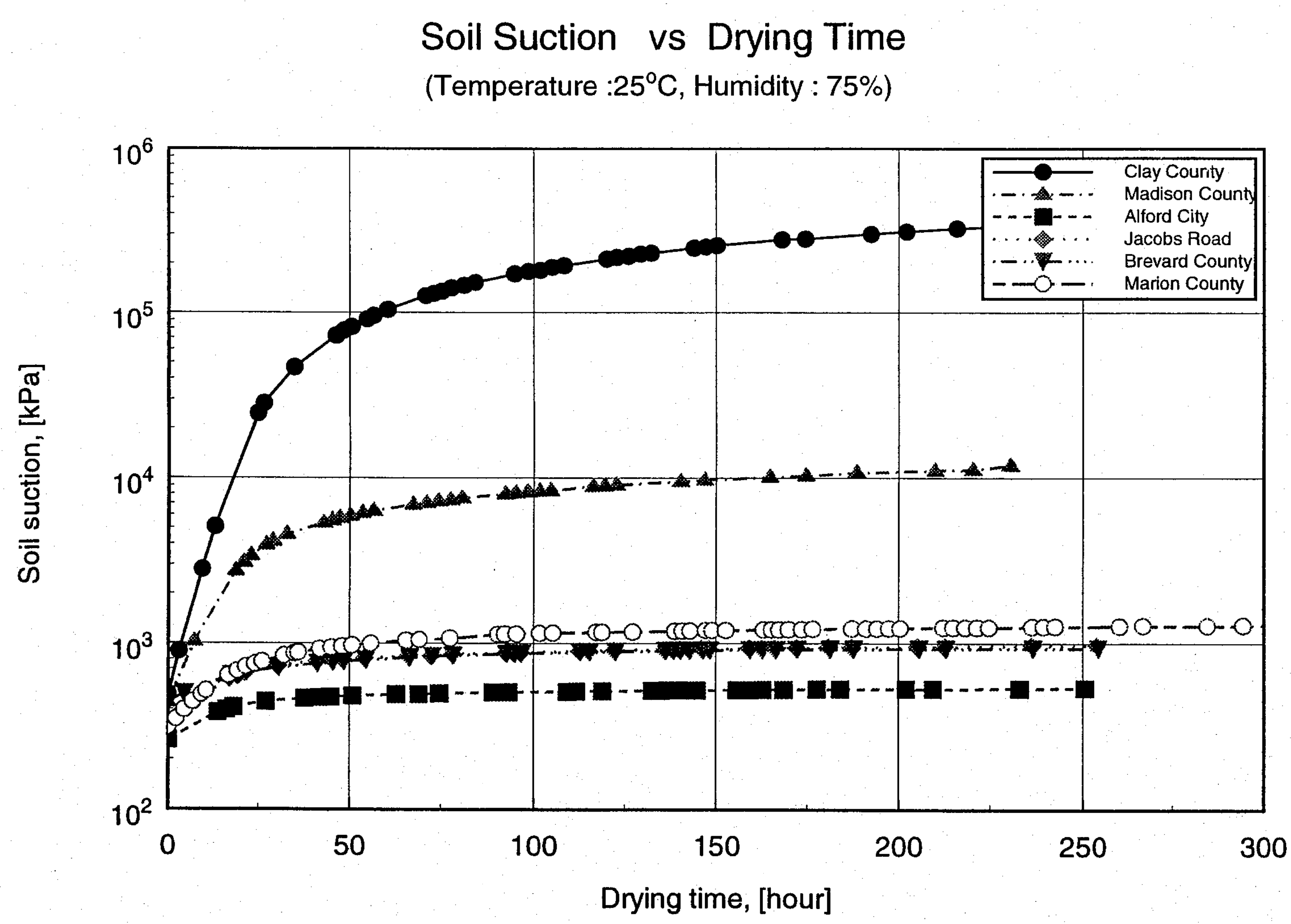

Figure 7.2 : Soil suction versus drying time for six soils at temperature 25°C and 75% relative humidity (Group I)

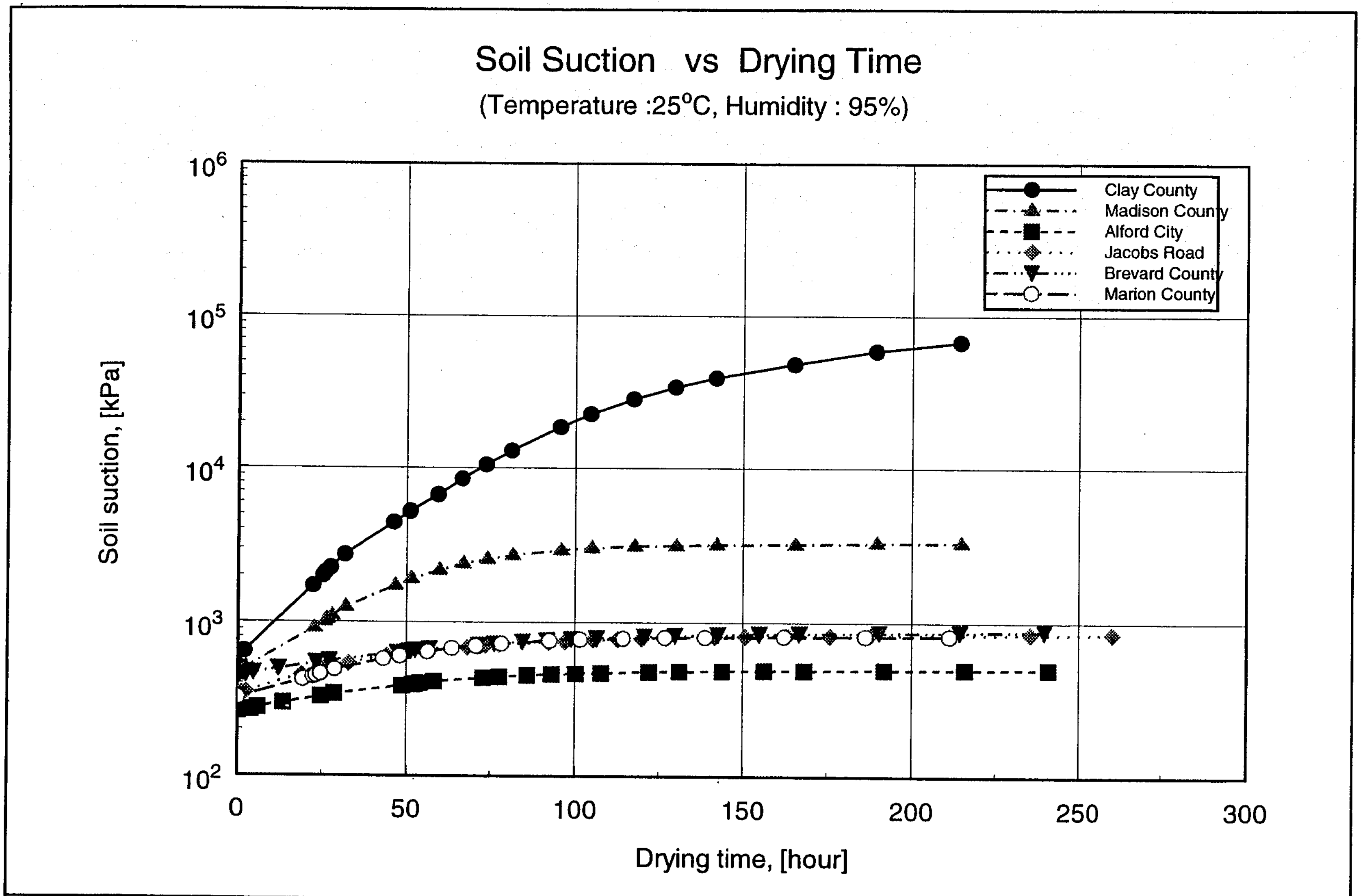

Figure 7.3 : Soil suction versus drying time for six soils at temperature 25°C and 95% relative humidity (Group I)

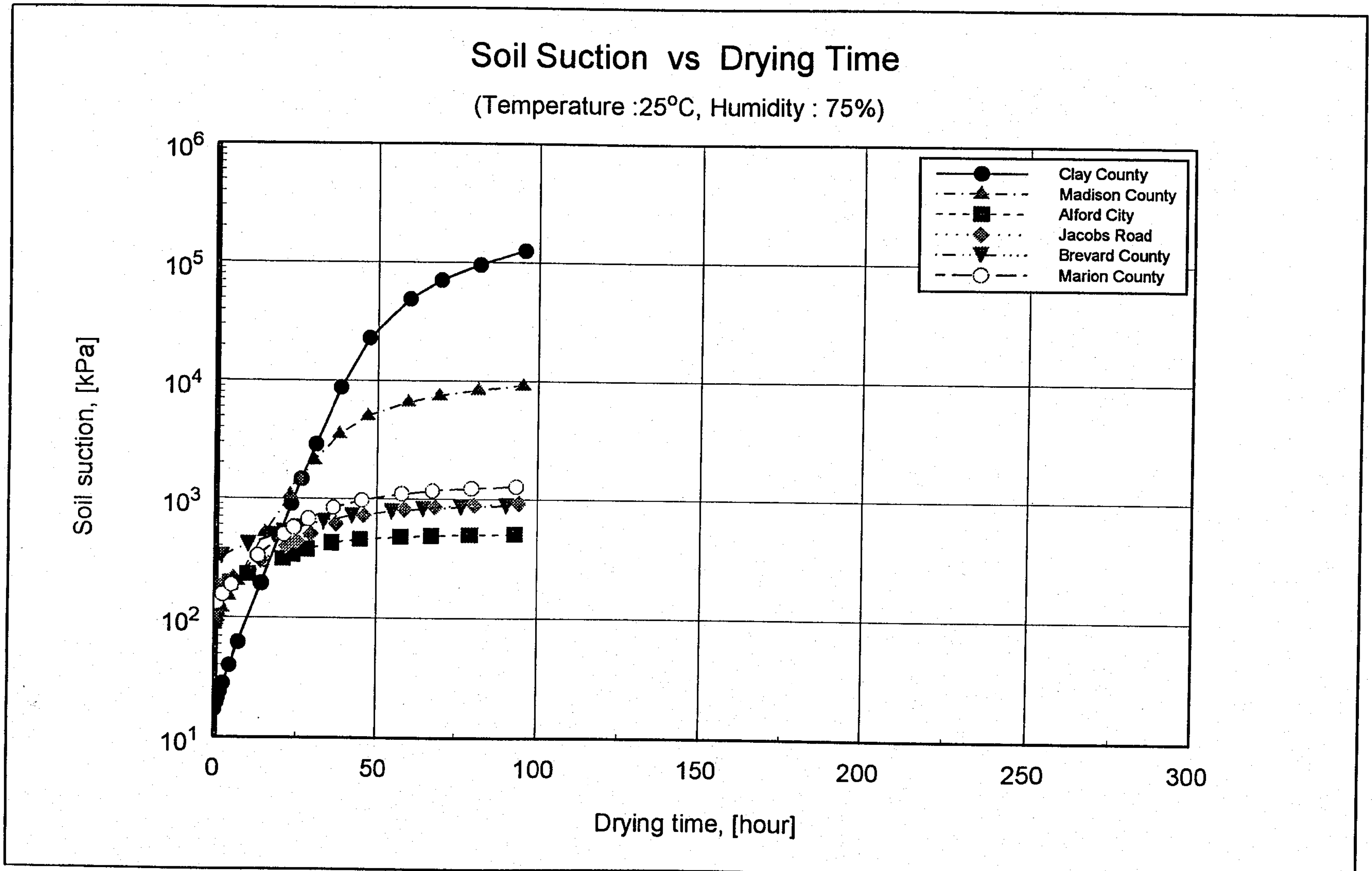

Figure 7.4 : Soil suction versus drying time for six soils at temperature 25°C and 75% relative humidity (Group II)

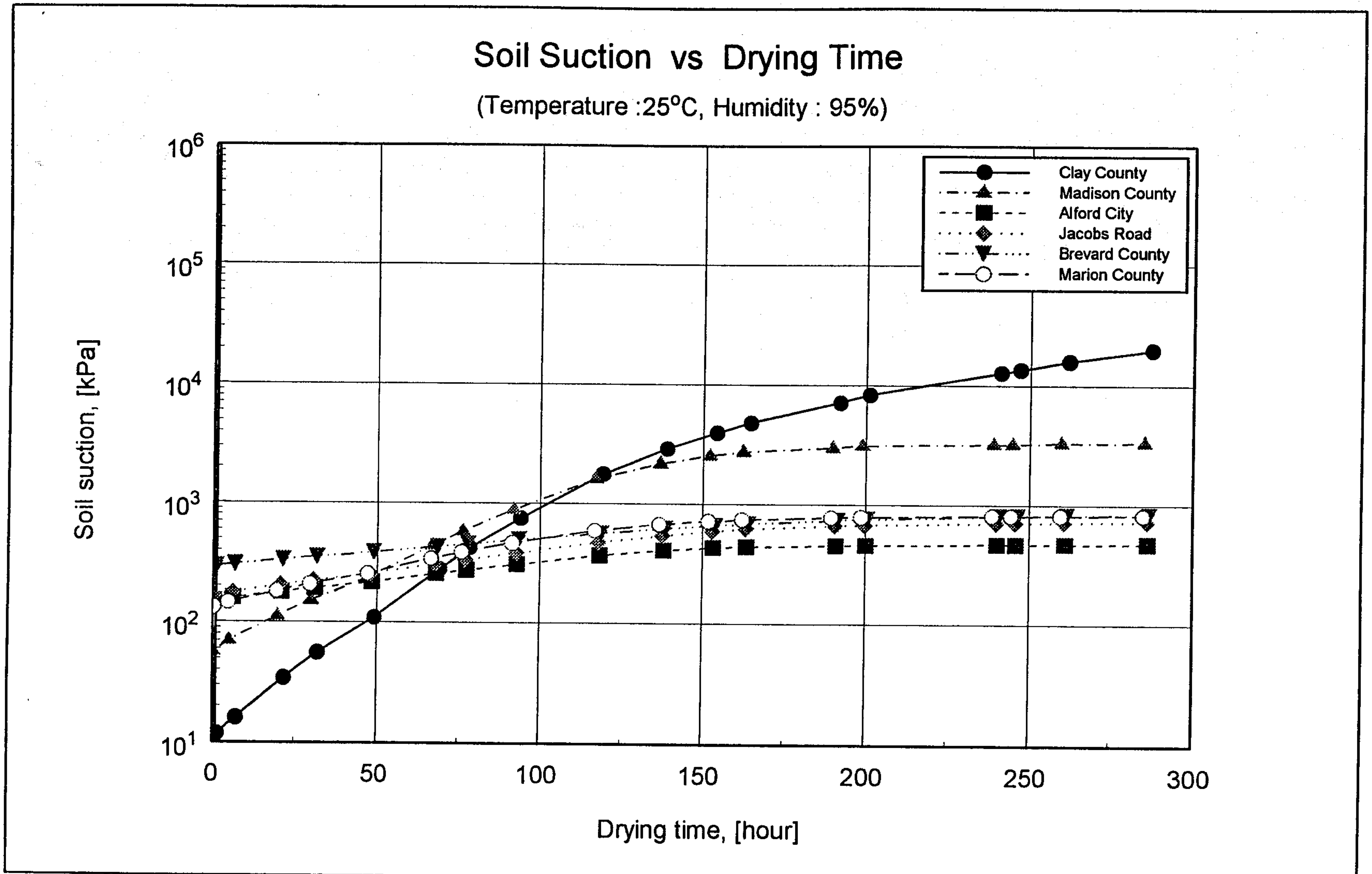

Figure 7.5 : Soil suction versus drying time for six soils at temperature 25°C and 95% relative humidity (Group II)

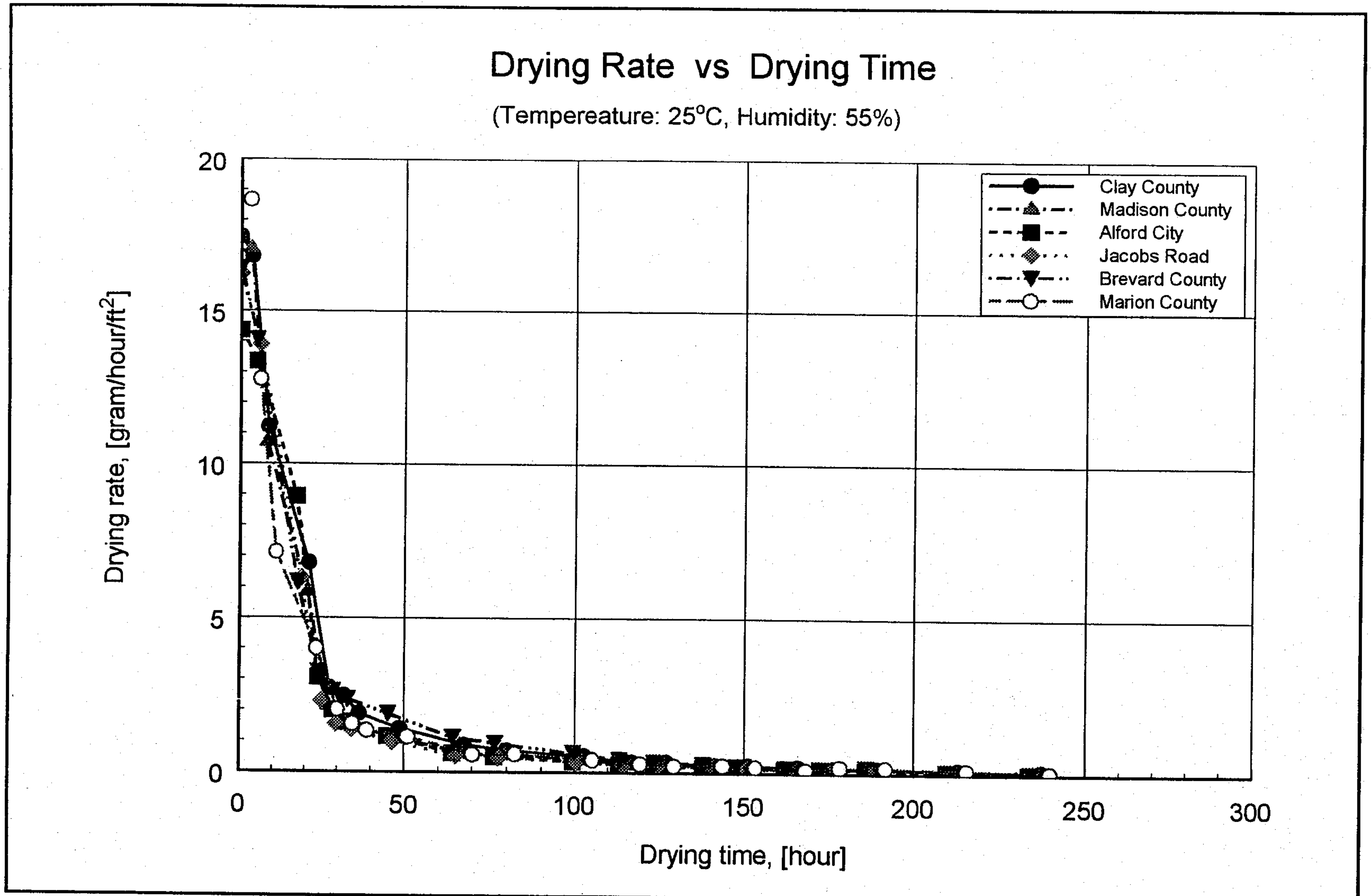

Figure 7.6 : Drying rate vs drying time for six soils at temperature 25°C and 55% relative humidity (Group I)

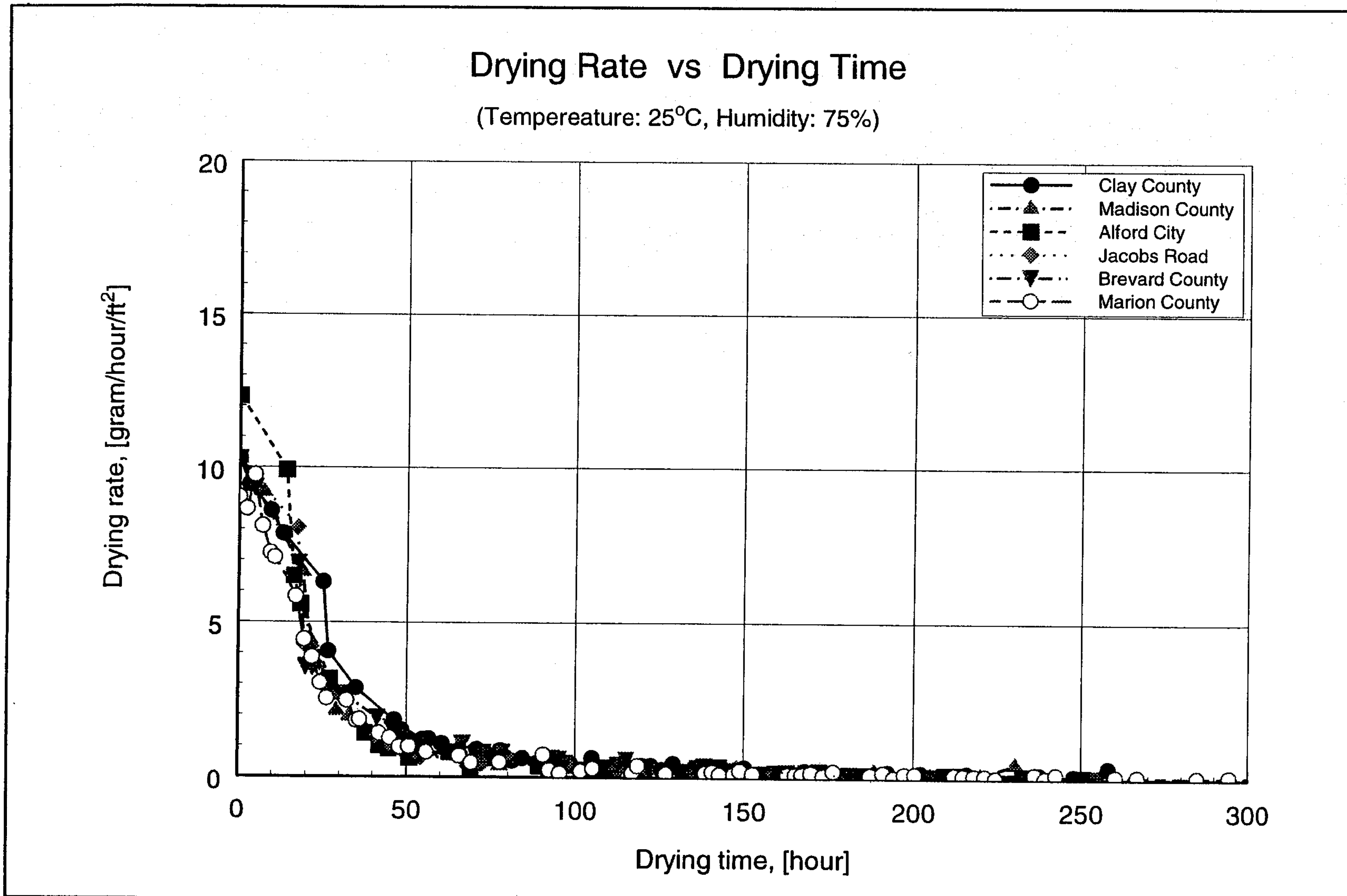

Figure 7.7 : Drying rate vs drying time for six soils at temperature 25°C and 75% relative humidity (Group I)

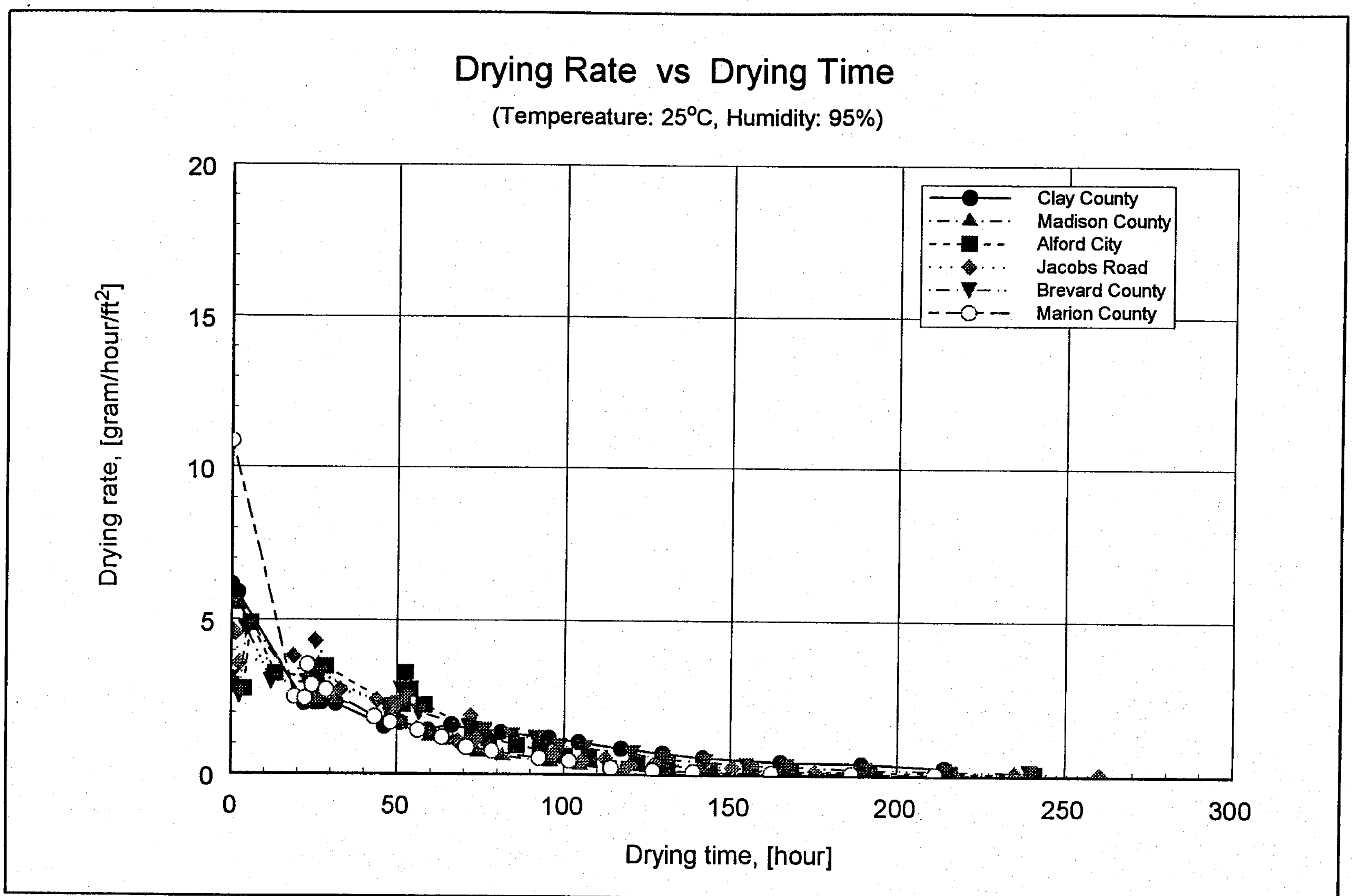

Figure 7.8 : Drying rate vs drying time for six soils at temperature 25°C and 95% relative humidity (Group I)

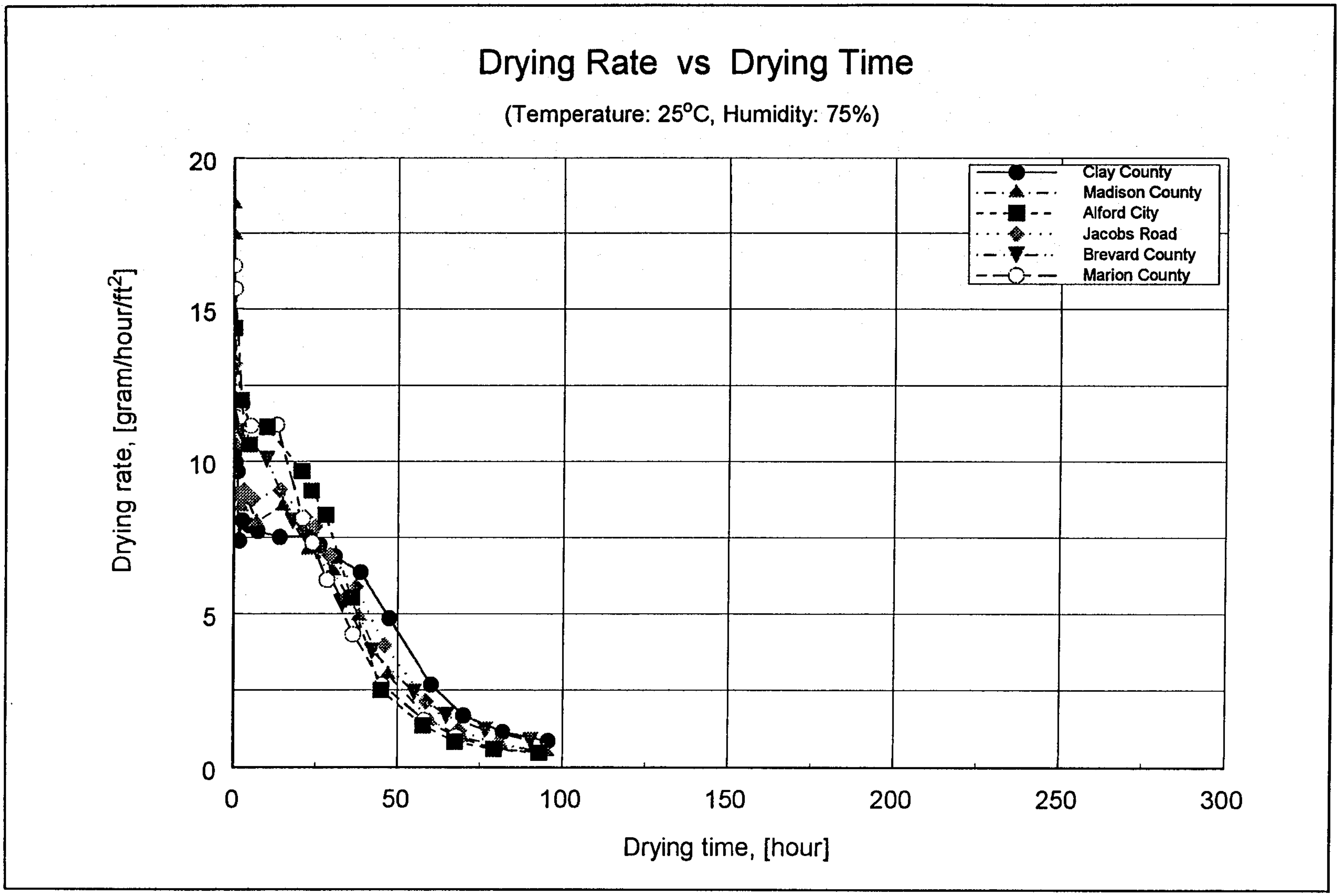

Figure 7.9 : Drying rate vs drying time for six soils at temperature 25°C and 75% relative humidity (Group II)

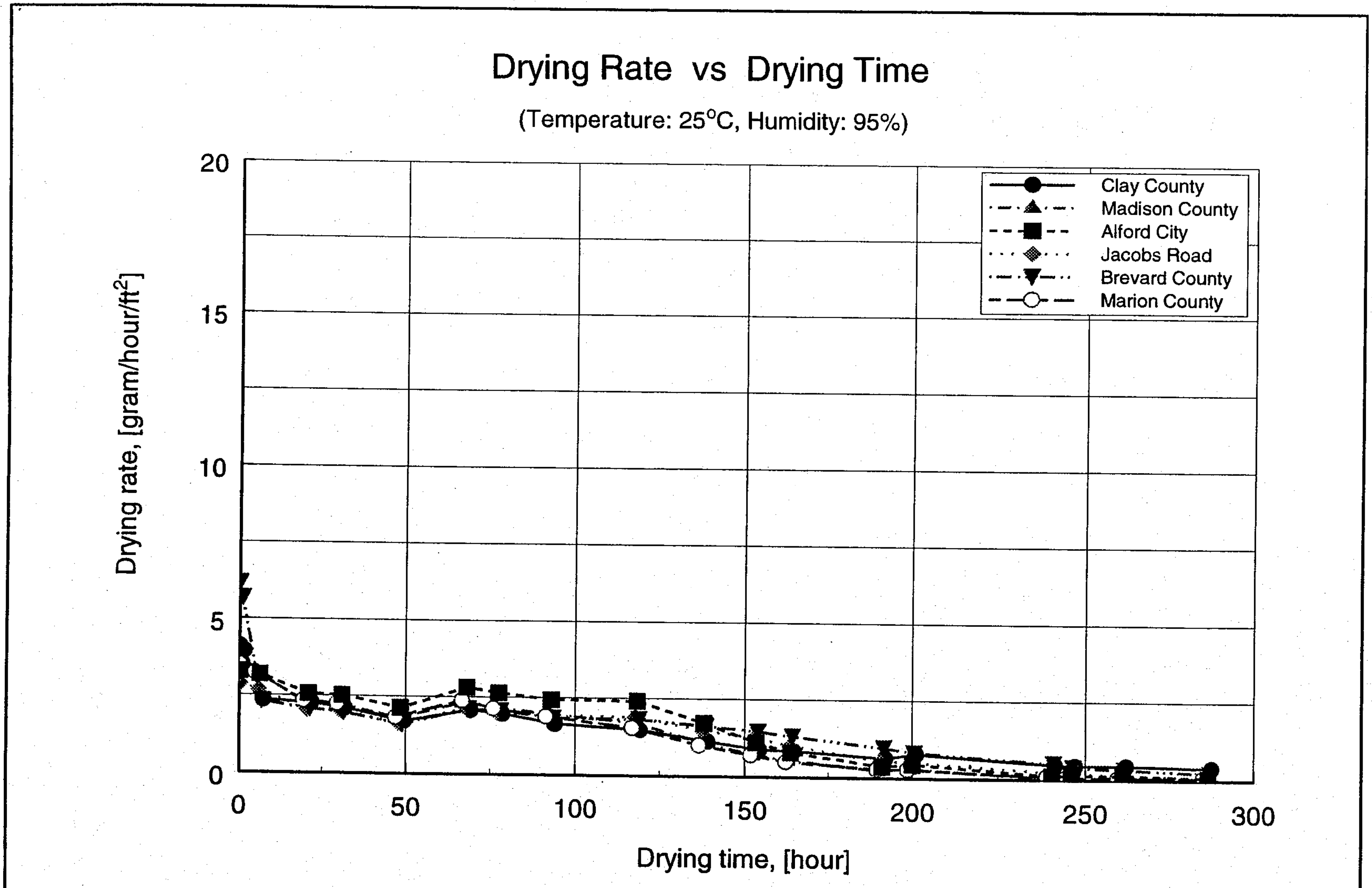

Figure 7.10 : Drying rate vs drying time for six soils at temperature 25°C and 95% relative humidity (Group II)

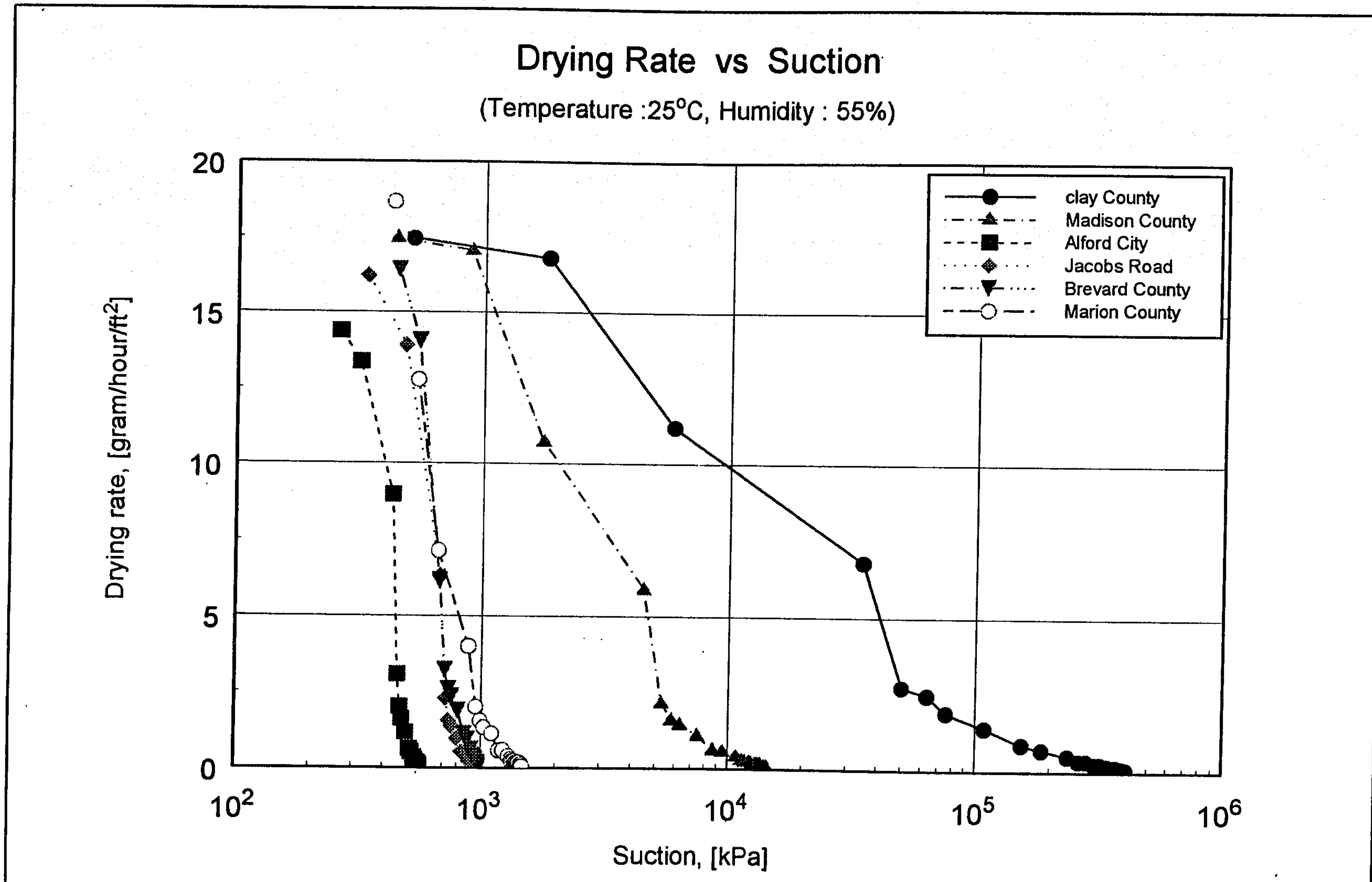

Figure 7.11 : Drying rate versus soil suction for six soils at temperature 25°C and 55% relative humidity (Group I)

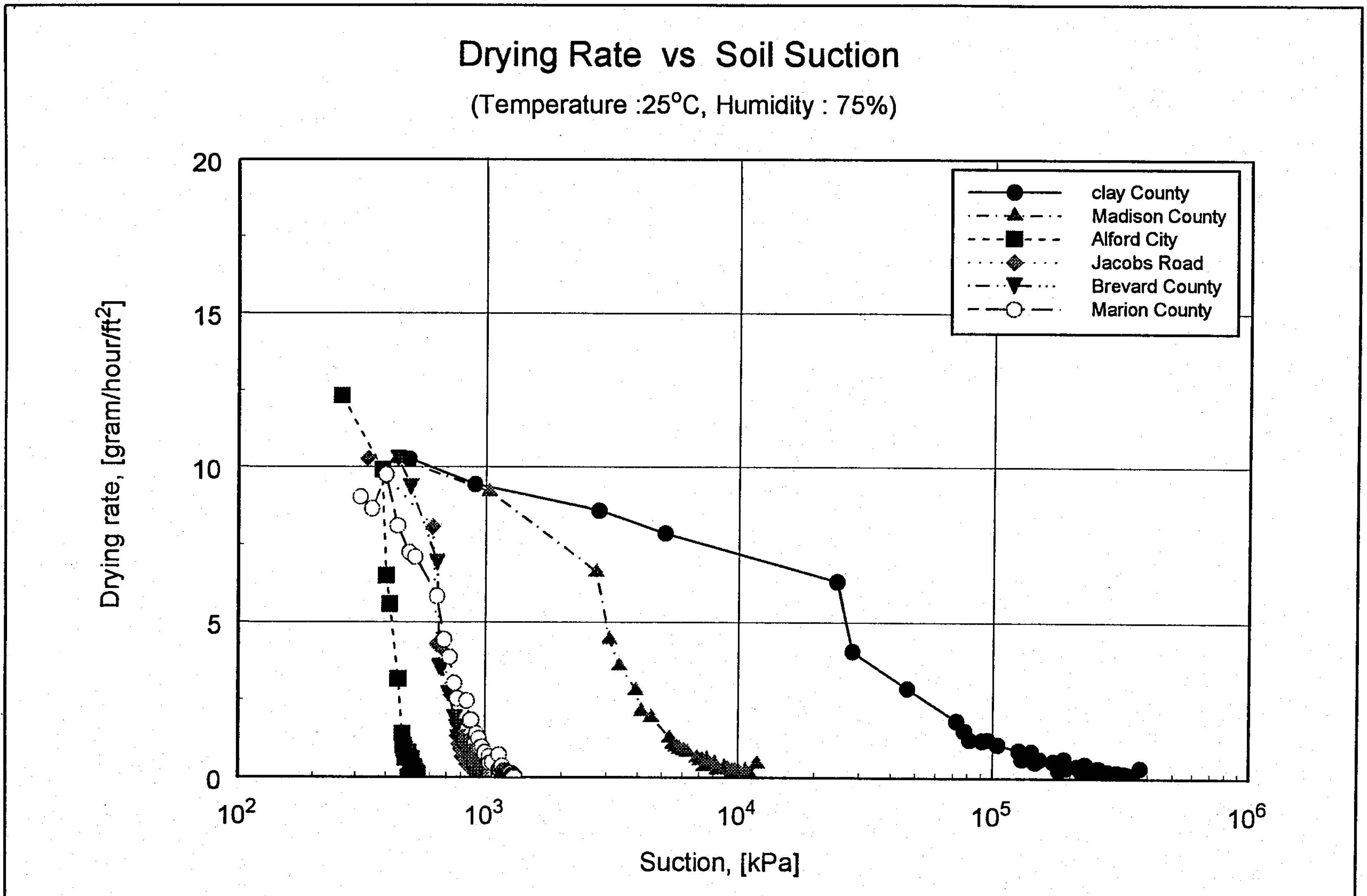

Figure 7.12 : Drying rate versus soil suction for six soils at temperature 25°C and 75% relative humidity (Group I)

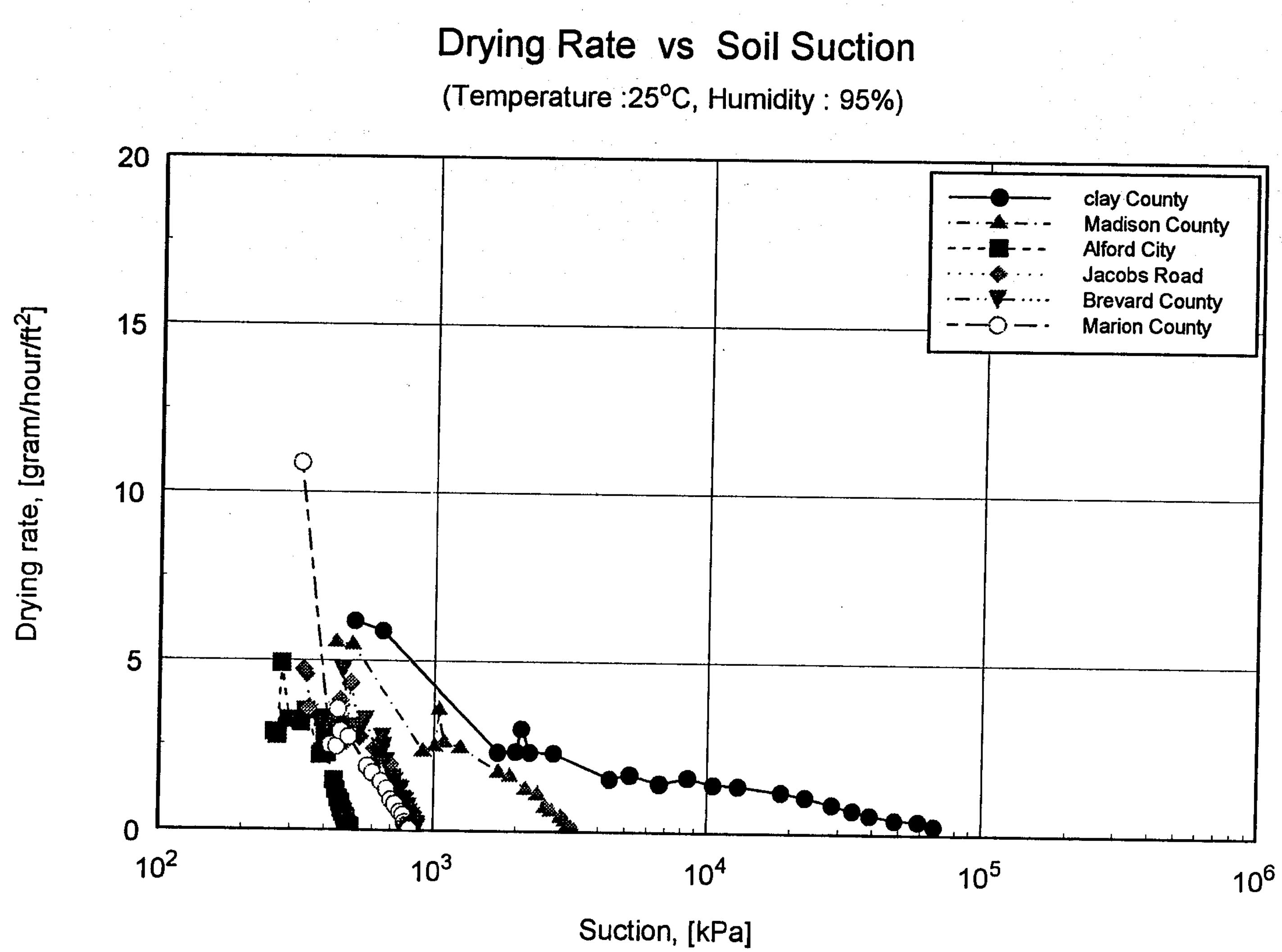

Figure 7.13 : Drying rate versus soil suction for six soils at temperature 25°C and 95% relative humidity (Group I)

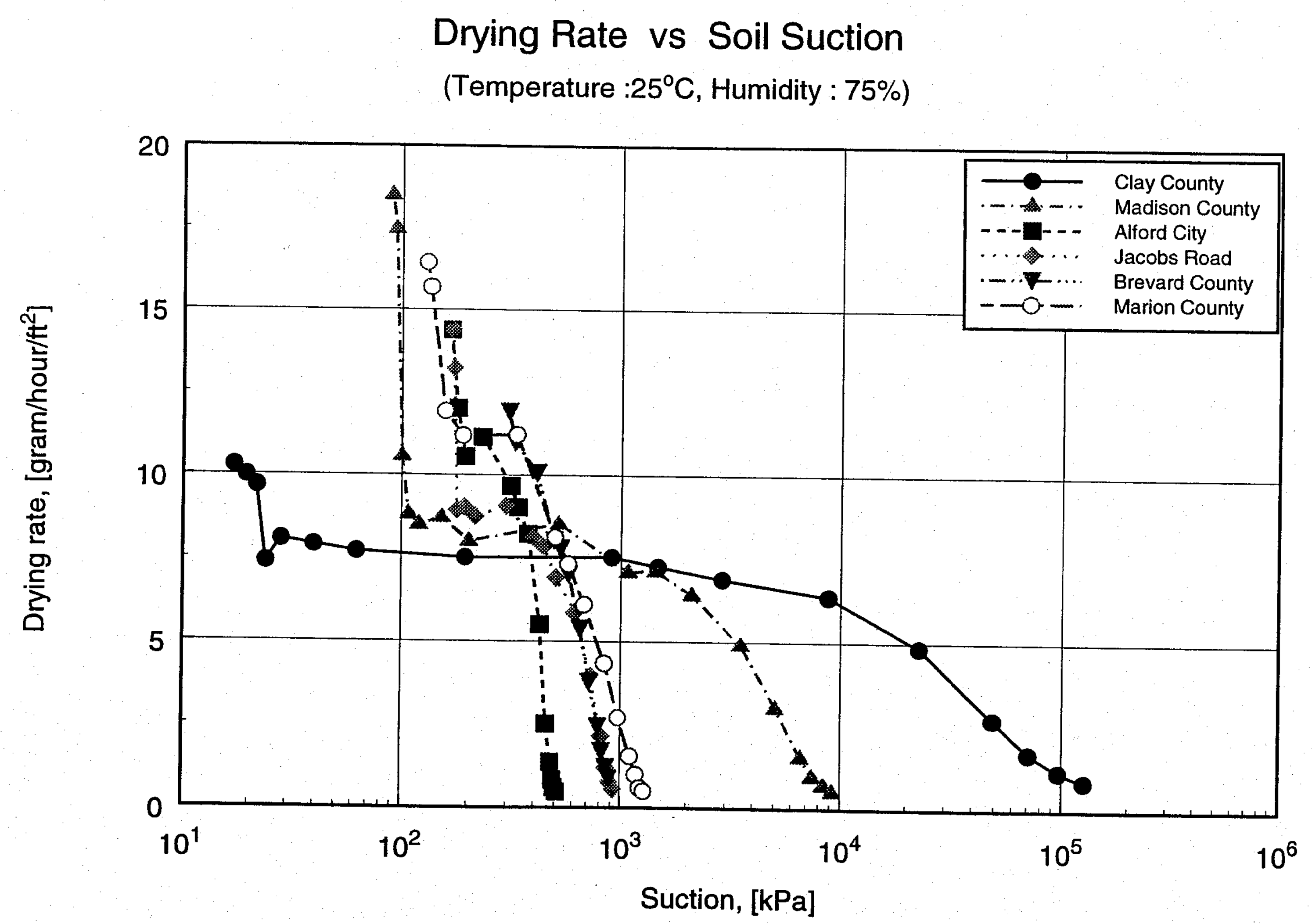

Figure 7.14 : Drying rate versus soil suction for six soils at temperature 25°C and 75% relative humidity (Group II)

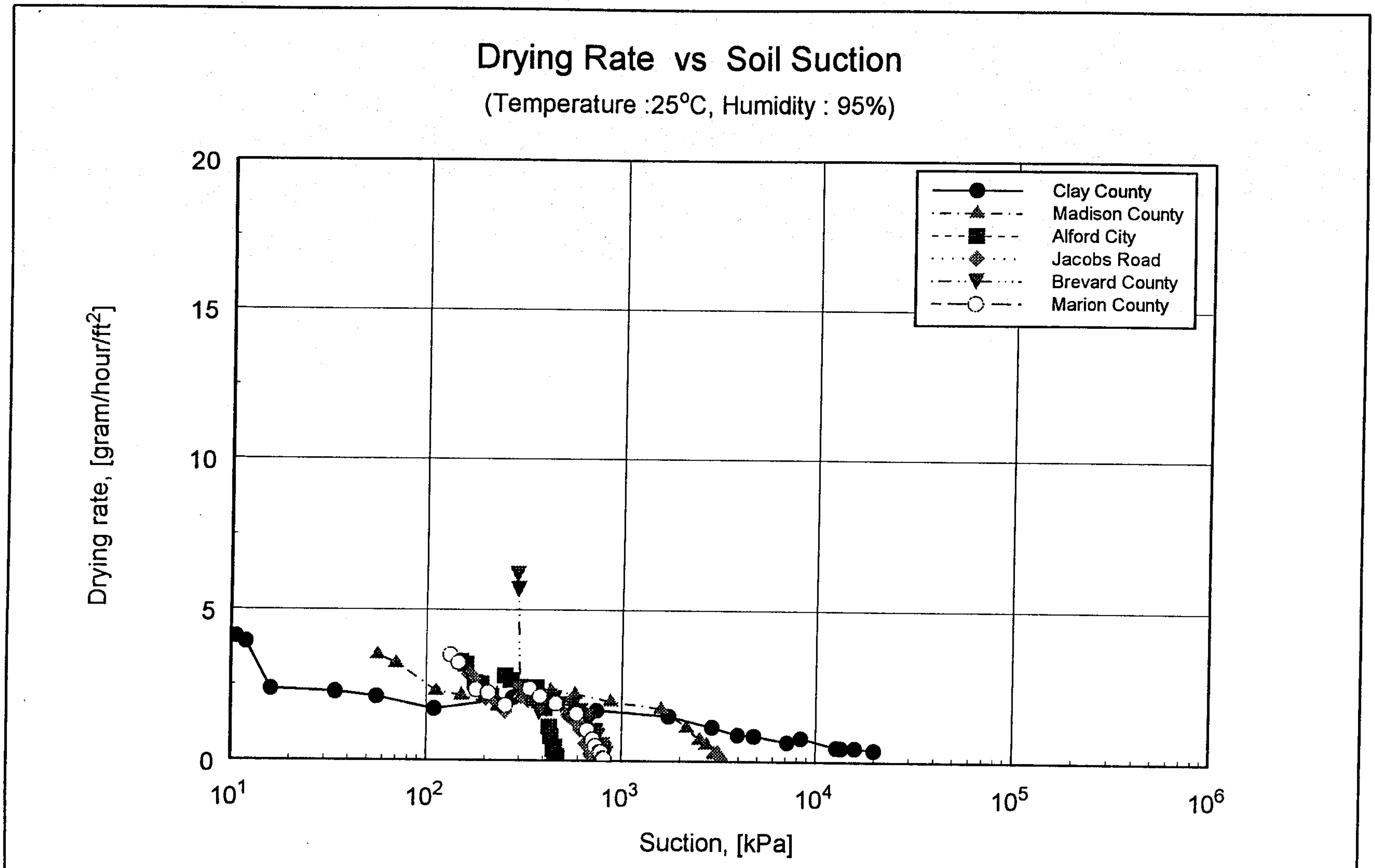

Figure 7.15 : Drying rate versus soil suction for six soils at temperature 25°C and 95% relative humidity (Group II)

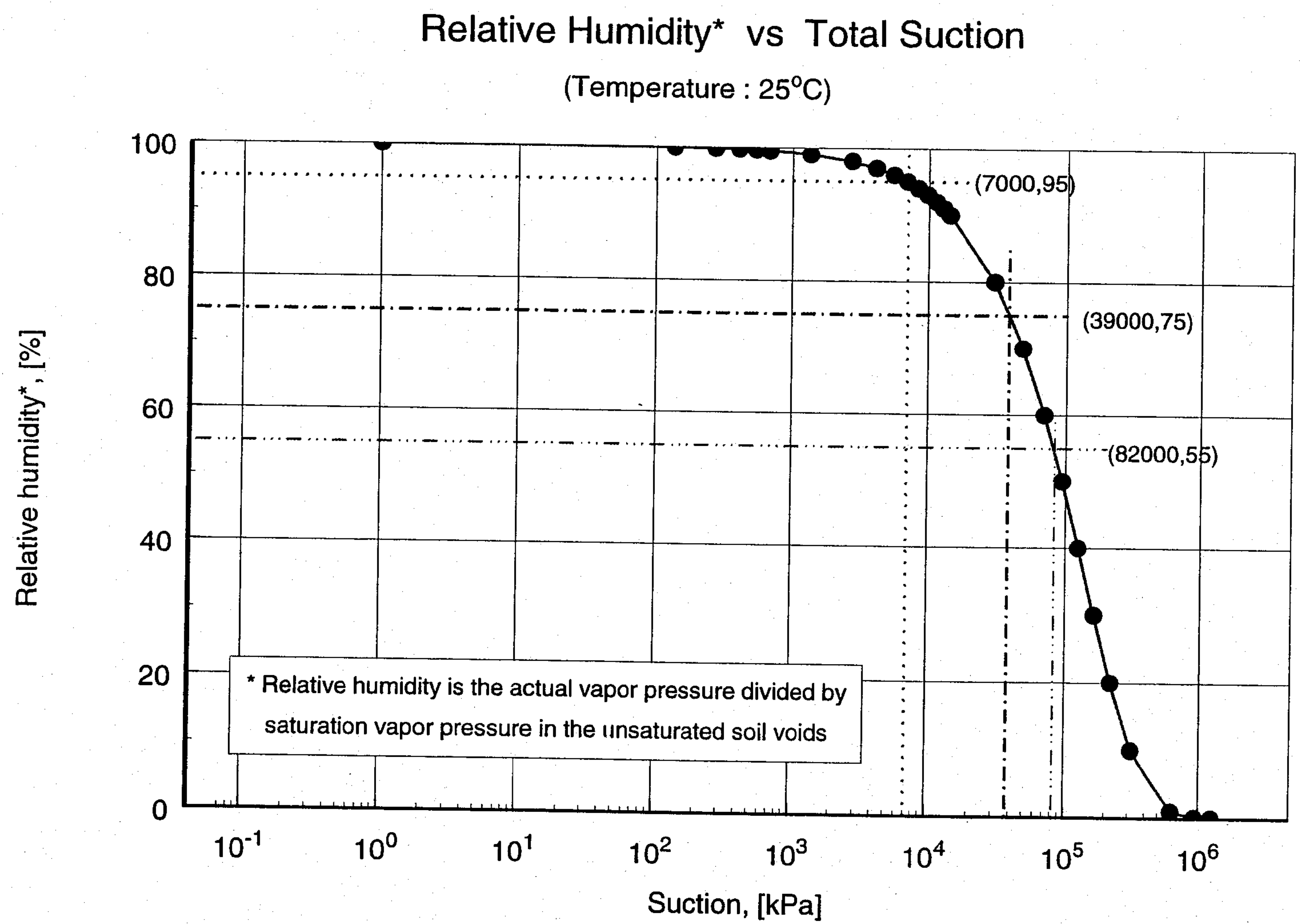

Figure 7.16 : Theoretical relationship between relative humidity in unsaturated soil voids and total suction at temperature 25°C

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

The soils used for this study were classified as low in plasticity and permeability, non-swelling and non-active and were tested with a range of water content below and above the optimum water content. The conclusions are drawn based on the analysis and findings of the soil suction and drying rate test results.

8.1.1 Suction Test Program

Based on the test results, the conclusions may be drawn as the following:

1. Most of the soils possess low suction values in the range of 100 kPa to 1000 kPa except that the soils from Clay County and Madison County have relatively higher suction values at drier condition (more than 3000 kPa). These suction values are relatively low as compared to the full range of suction values from 0 kPa to 1000000 kPa for the moisture condition from

full saturation to air-dry condition.

2. The soil suction increases with a decrease in water content and it increases rapidly for some soils with very little decrease in water content. The suction-water content (τ-ω) relationships for the wet side of the optimum water content behave differently from those for the dry side of the optimum. This trend is very significant for the soils from Clay County and Madison County.
3. The suction values vary significantly with water content when the percent of clay content is greater than 10% and the percent of fines passing #200 sieve is greater than 20%. The suction values are generally limited to within 100 to 3000 kPa with the percent of fines (-#200 sieve) less than 20%.
4. No significant evidence of correlation exists between the soil suction and permeability values for the six soils.
5. No significant changes in suction value occur when the degree of saturation is within 95% to 70%. However, the suction values of Clay County and Madison County soils increase significantly with a decrease in the degree of saturation below 70%.
6. The values of the specific volume for the six soils

are within the range of 0.04 to 0.07 regardless of the water content. Those values are very low as compared with those from high volume change soils.

8.1.2 Soil drying rate test program

1. The Clay County soil evaporated the largest amount of water among the six soils within a certain period of time while the Marion County soil evaporated the least amount of water.
2. In general, the drying rate decreases with a decrease in water content. When the soil is dried from the wet side of optimum water content, the rate of decrease in drying is more significant
3. Overall, the Alford City soil had the highest drying rate for the entire range of drying period. The Clay County soil had the lowest drying rate at the water content higher than 8 percent. The Marion County soil ceased to dry at relatively higher water content, which resulted in the lowest drying rate at the water content lower than 7 percent.
4. The influence of the relative humidity on the soil drying rate is much more significant than that of the temperature. When the relative humidity is at 95%, the rate of water evaporation reduces significantly as compared to the rate at either 55%

or 75% relative humidity.

5. The time needed to dry from the wet side of optimum water content to optimum water content for the six soils varied at different levels of relative humidity. Generally, the Clay County soil needs the longest time to reach optimum water content whereas the Marion County soil needs the shortest time at 75% relative humidity. When the relative humidity is high (95%), the Jacobs Road soil takes the longest time to reach optimum water content while the Alford City soil takes the shortest time to reach optimum water content.
6. The drying rate increases with an increase in the percent of -#200 fines or clay content.

8.1.3 Correlation and analysis of suction and drying rate experimental results

1. The difference in the drying rate for the six soils is not significant when the soil water condition is below the optimum water content. When the soil water condition is above the optimum water content, the Clay and Madison County soils have lower drying rates.
2. The drying rate decreases with an increase in soil

suction. The drying rate values for both Group I and Group II tests in terms of soil suction are quite similar when the soil suction value is higher than 400 kPa. When the soil suction is lower than 400 kPa, it appears that the Clay County soil has the lowest drying rate on the basis of the same amount of suction.

3. The soils from Alford City, Jacobs Road, Brevard County, and Marion County have higher drying rates than those from Clay County and Madison County.
4. The A-2-4 soils with high percent of -#200 fines (>20%) may have lower drying rates or higher suction values, which would be more difficult to handle for highway construction in a region with high relative humidity.

8.2 Recommendations

The following recommendations are made based on the observations and discussions in this study

1. Both suction and drying rate tests should be done in a well temperature-controlled laboratory to eliminate the effect of temperature fluctuation and gradient so that a high accuracy may be achieved.
2. For the suction test, alternative test methods should be used to double check the test results.

The filter paper method is recommended for its economical sake.

3. When the suction value is low, the accuracy of the data recording becomes important. A data logger connected to a PC is recommended to allow the automated storage, reduction, and manipulation of the data.

4. In order to fully investigate the relationship between the drying rate and the percent of clay fraction or percent of fines passing #200 sieve, the soils selected for the test program should have an entire range of distribution of the percent of fines up to 35% for A-2-4 soils.

APPENDIX A : PHASE I TEST RESULTS

LIST OF FIGURES

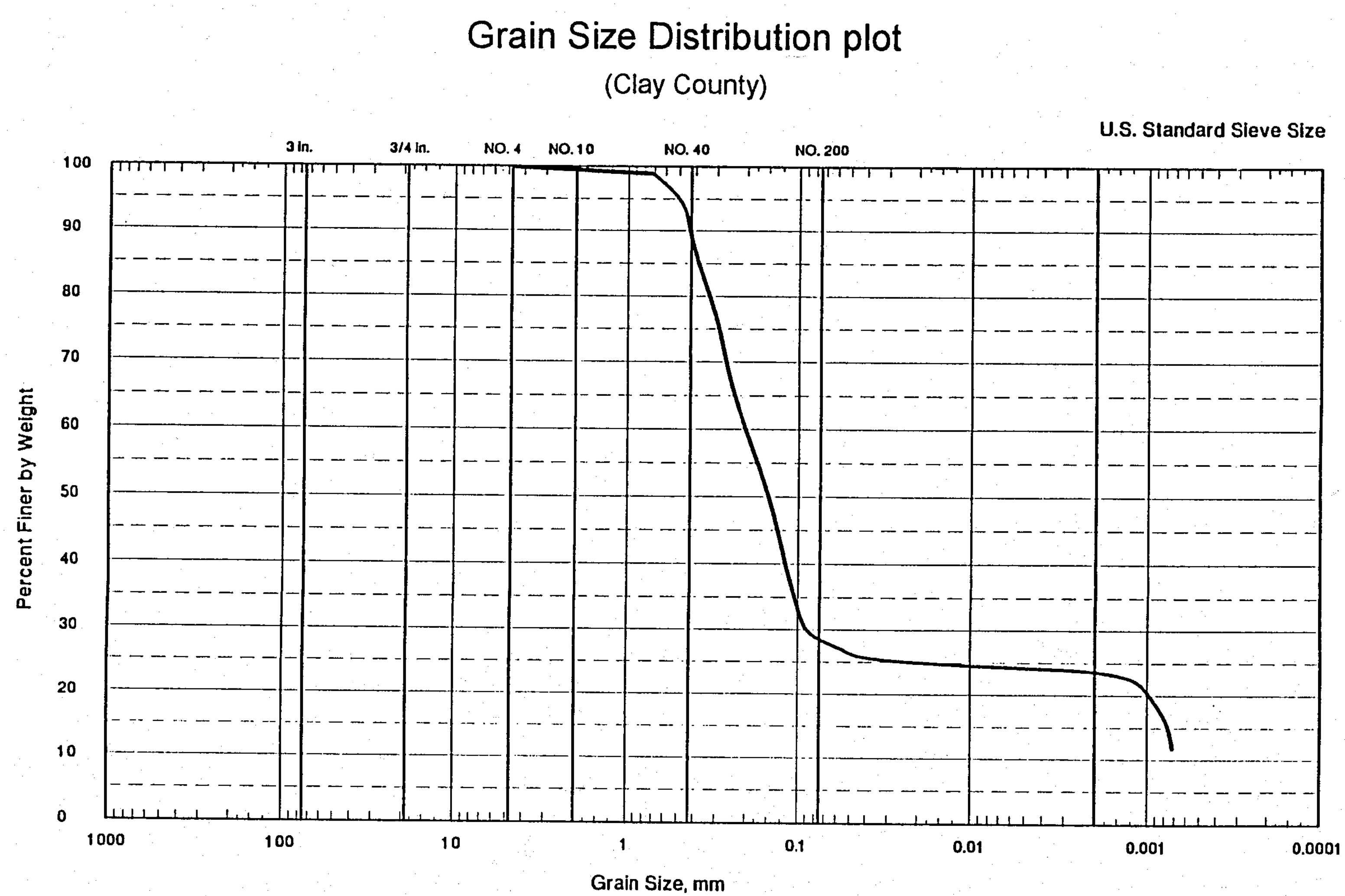

Figure A.1 : Grain size distribution plot for Clay County soil

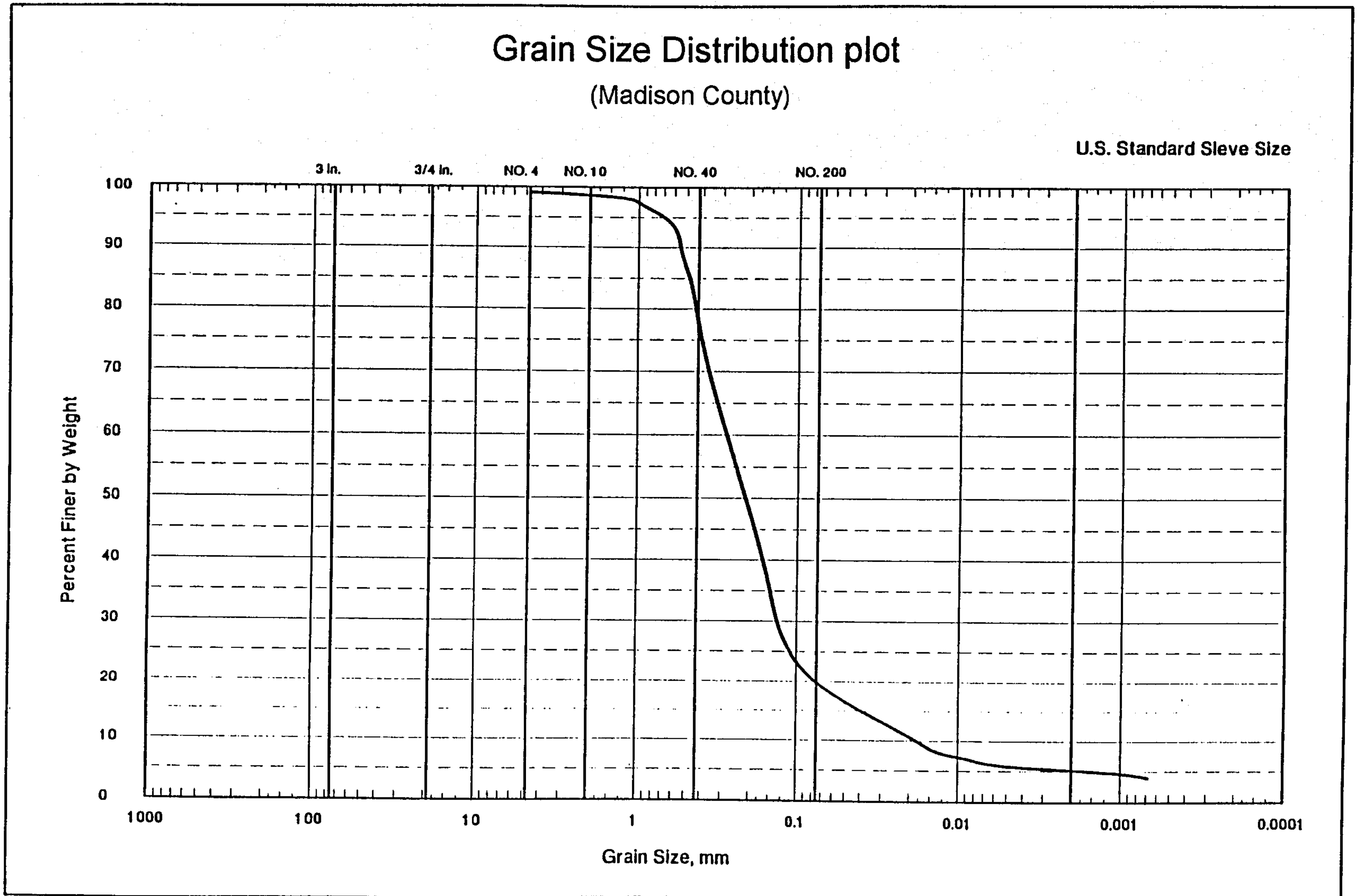

Figure A.2 : Grain size distribution plot for Madison County soil

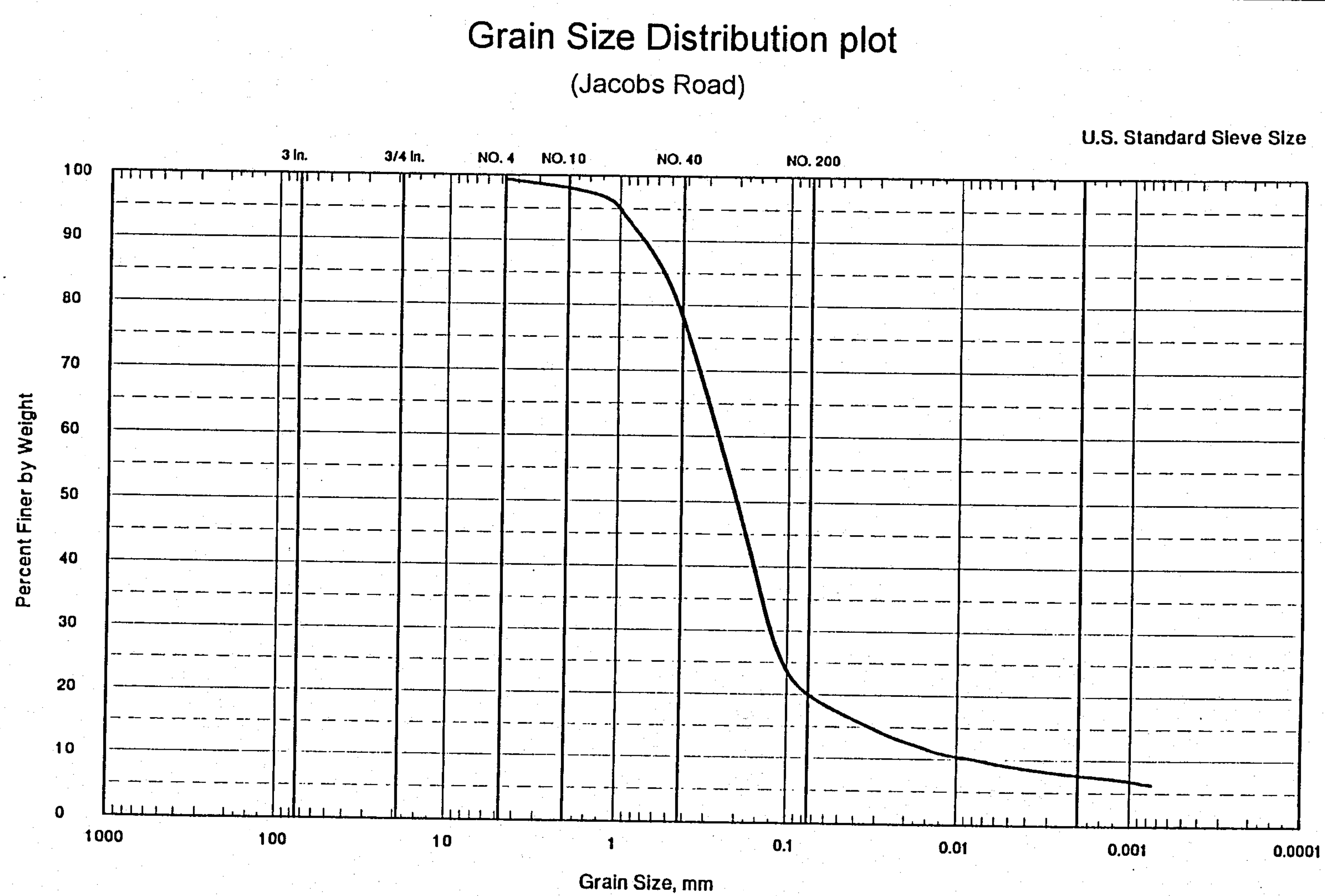

Figure A.3 : Grain size distribution plot for Jacobs Road soil

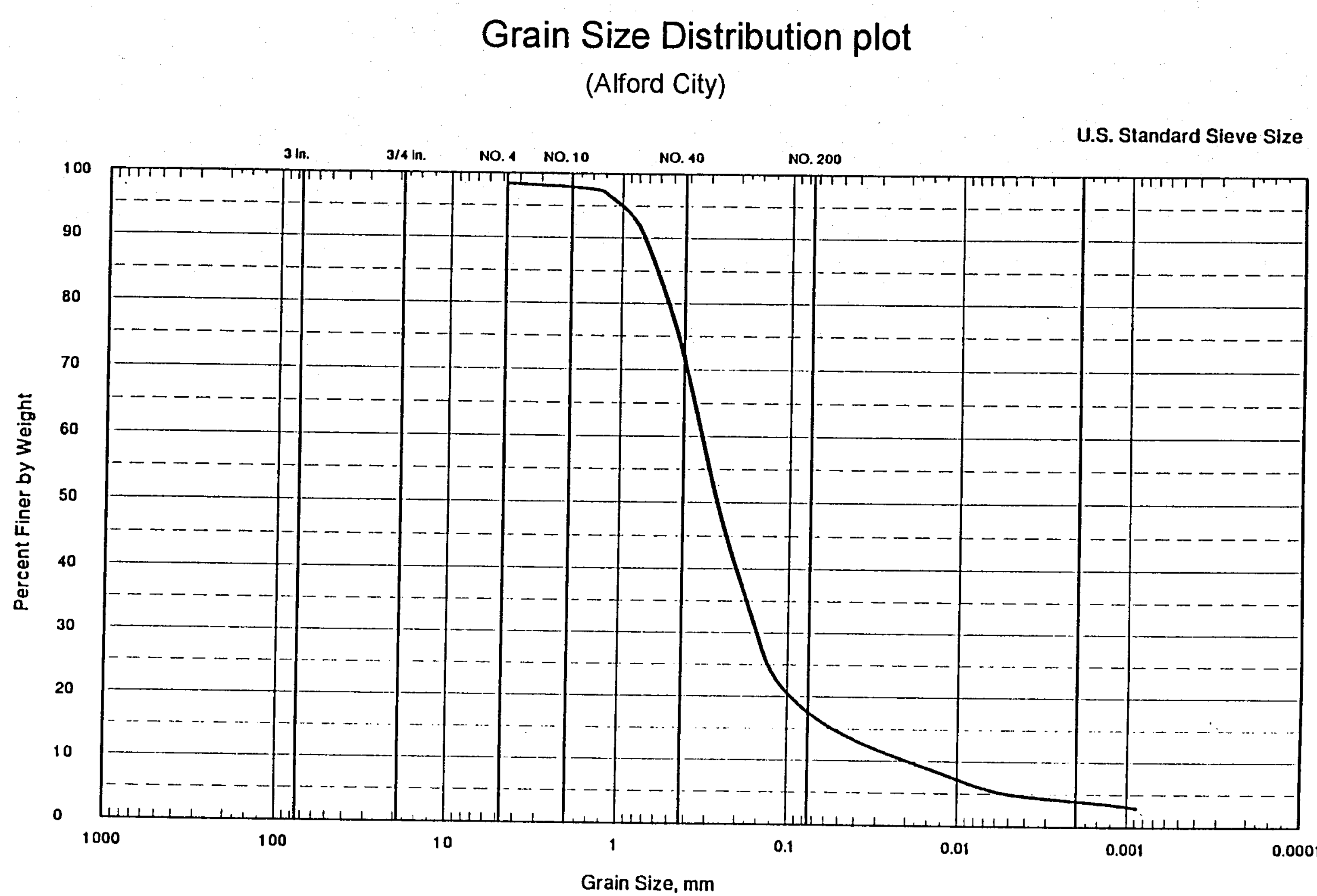

Figure A.4 : Grain size distribution plot for Alford City soil

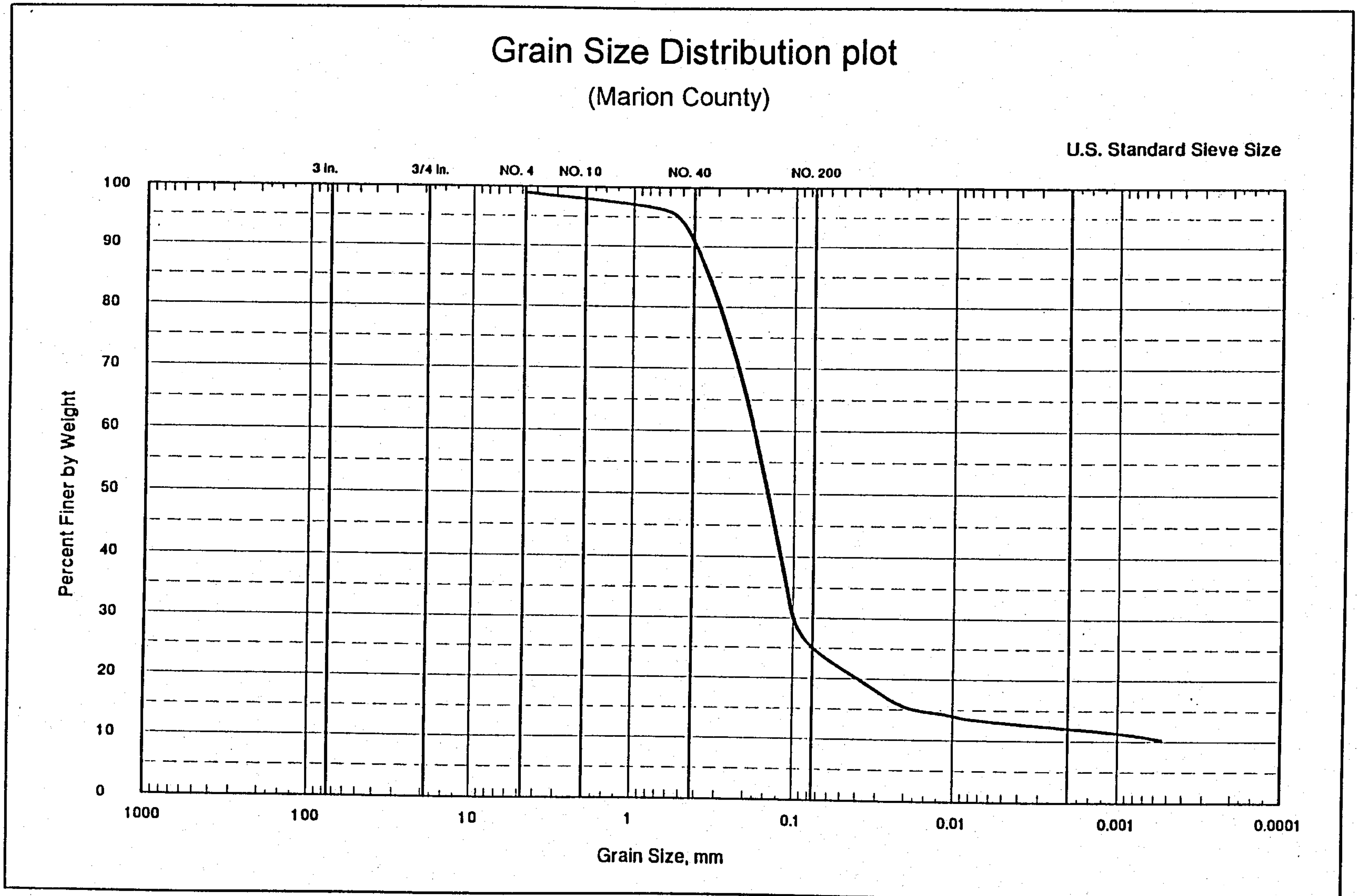

Figure A.5 : Grain size distribution plot for Marion County soil

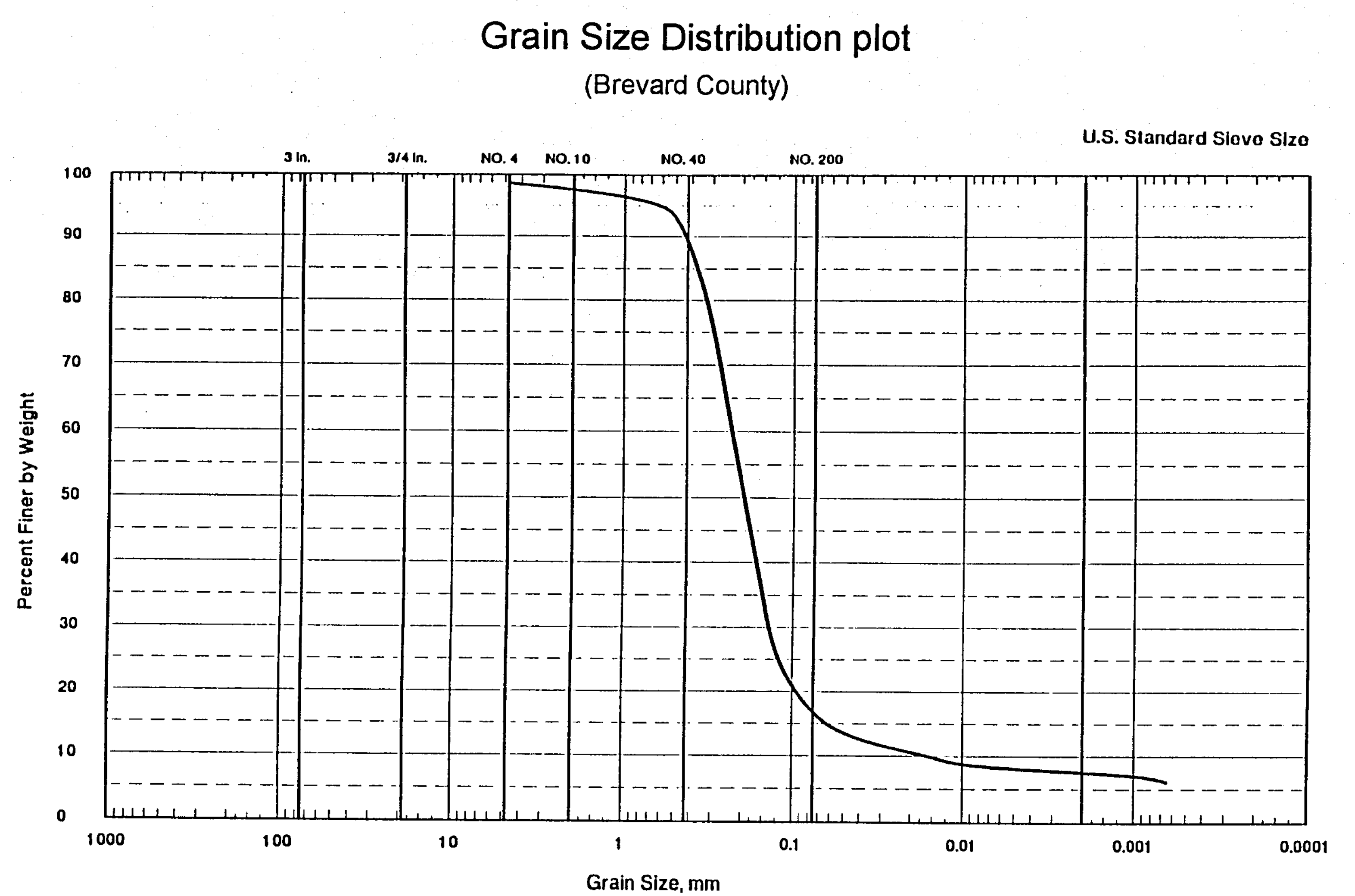

Figure A.6 : Grain size distribution plot for Brevard County soil

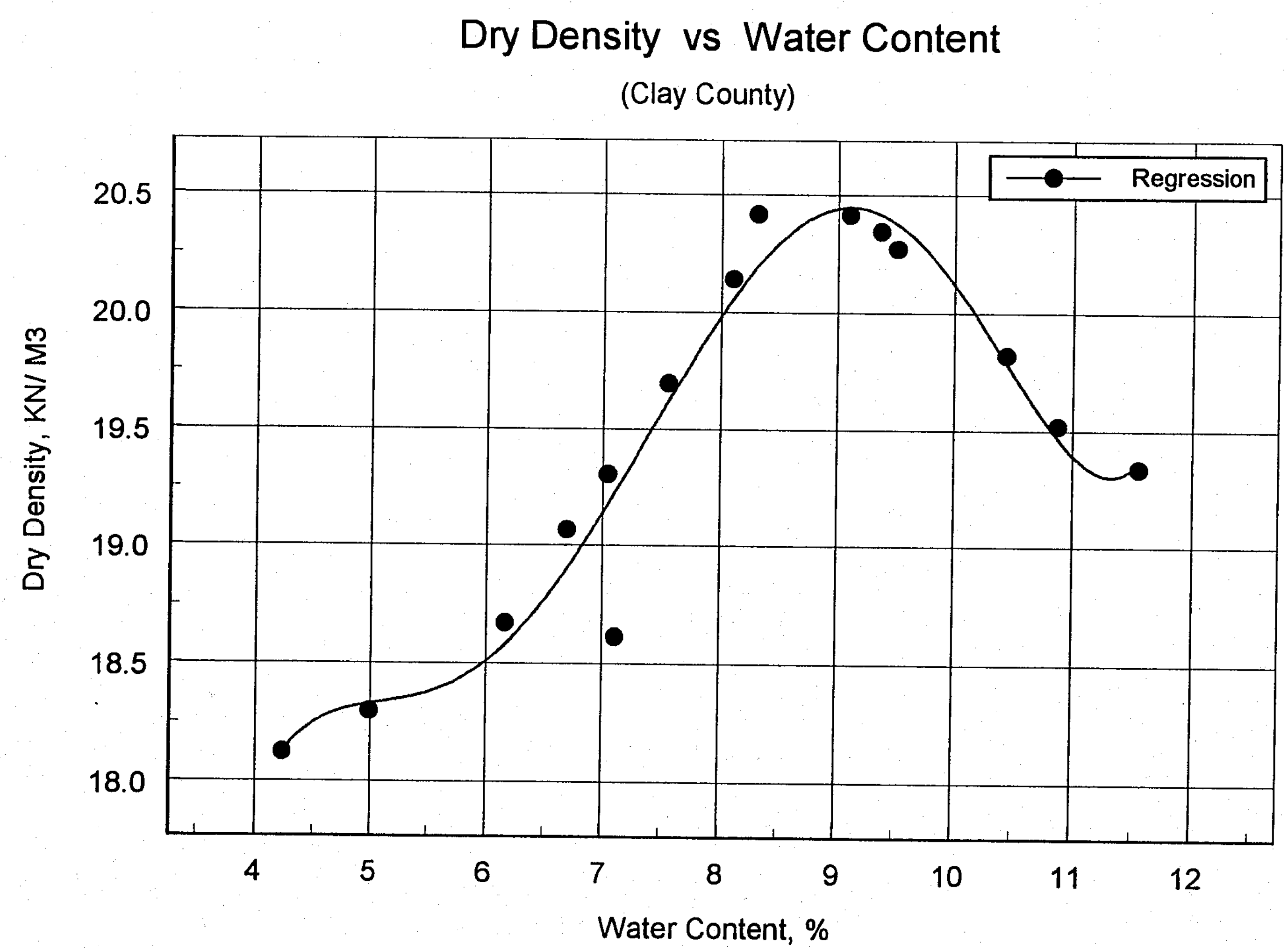

Figure A.7 : Plot of Compaction Test for Clay County

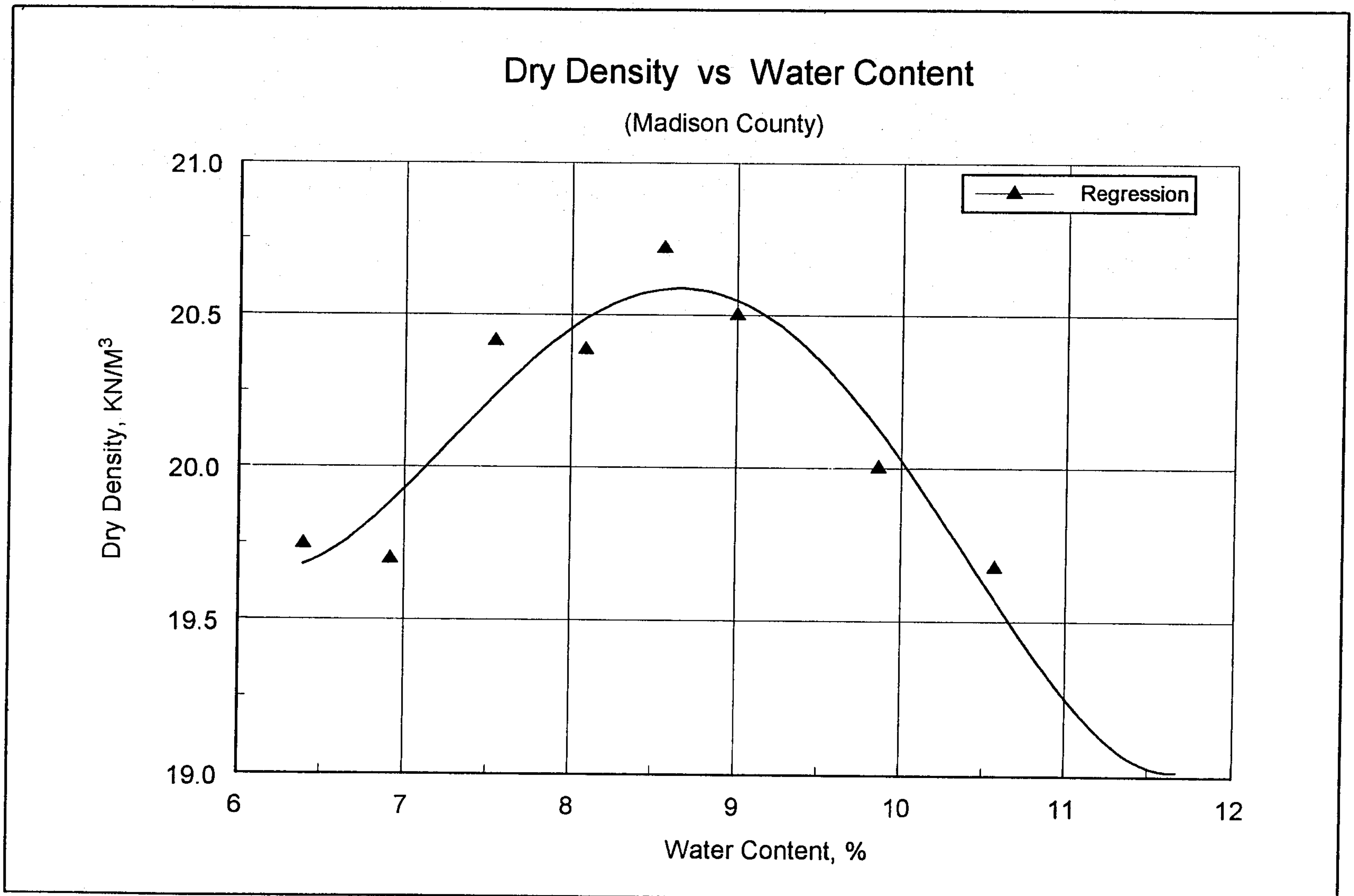

Figure A.8 : Plot of Compaction Test for Madison County

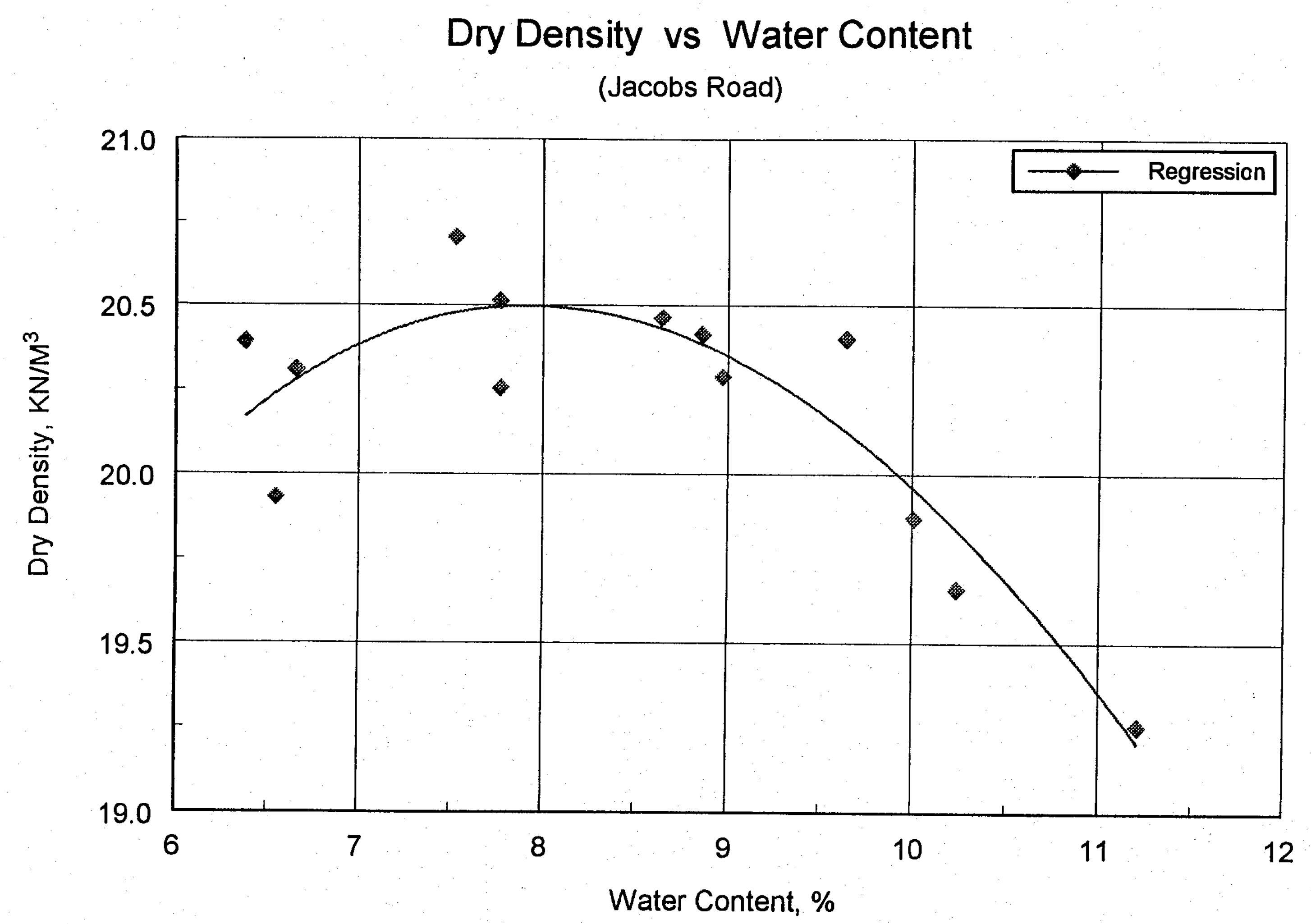

Figure A.9 : Plot of Compaction Test for Jacobs Road

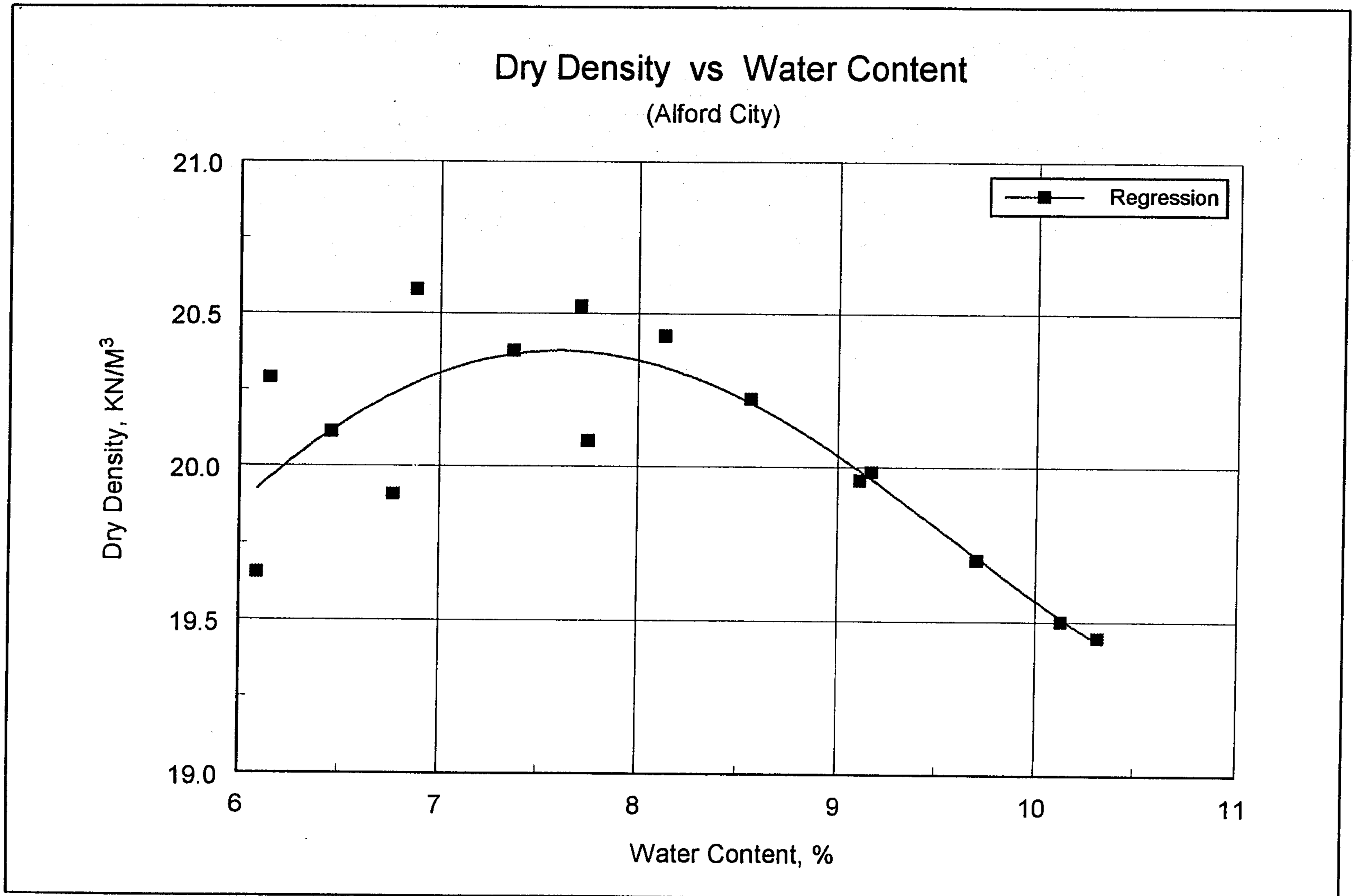

Figure A.10 : Plot of Compaction Test for Alford City

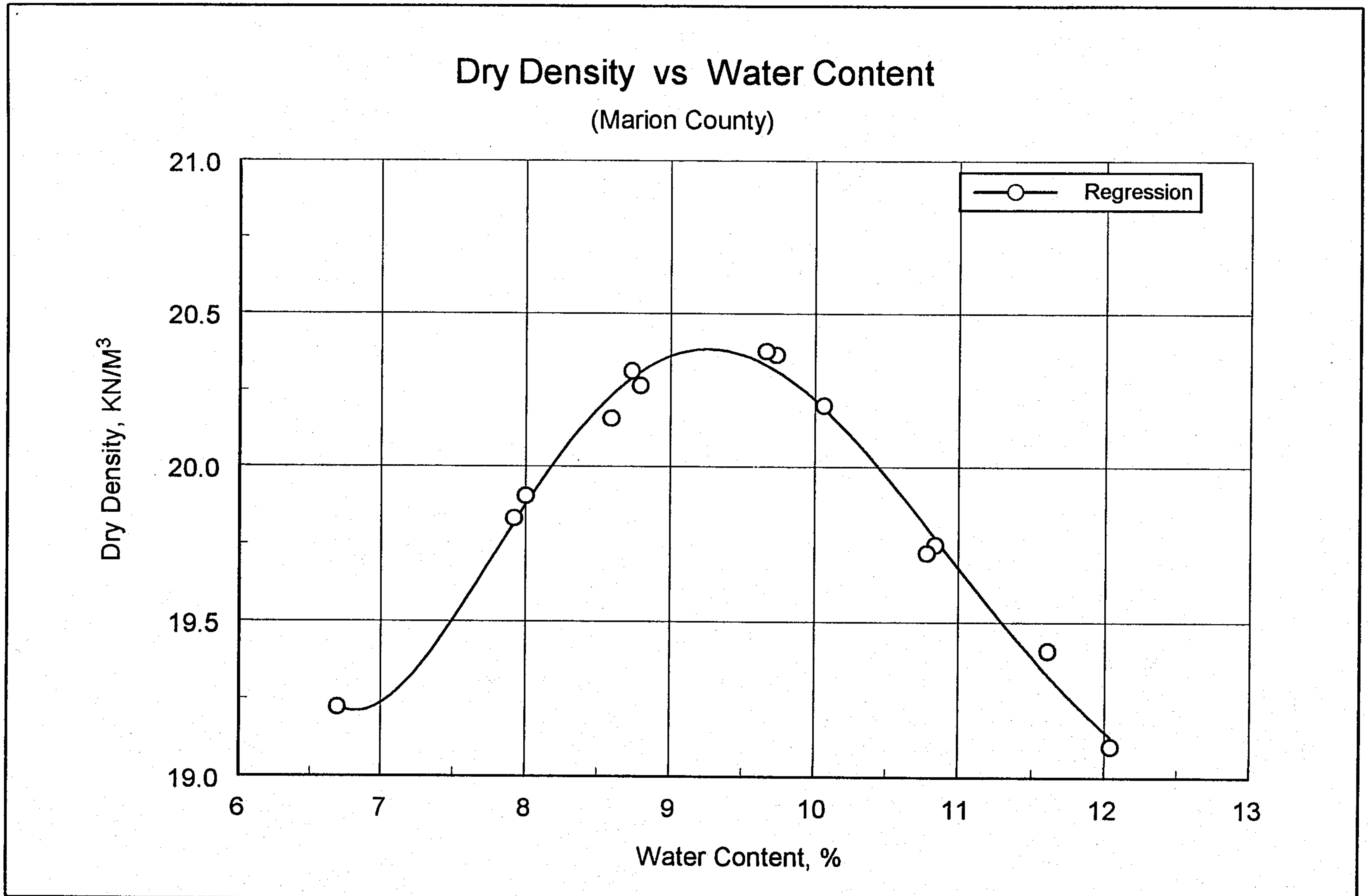

Figure A.11 : Plot of Compaction Test for Marion County

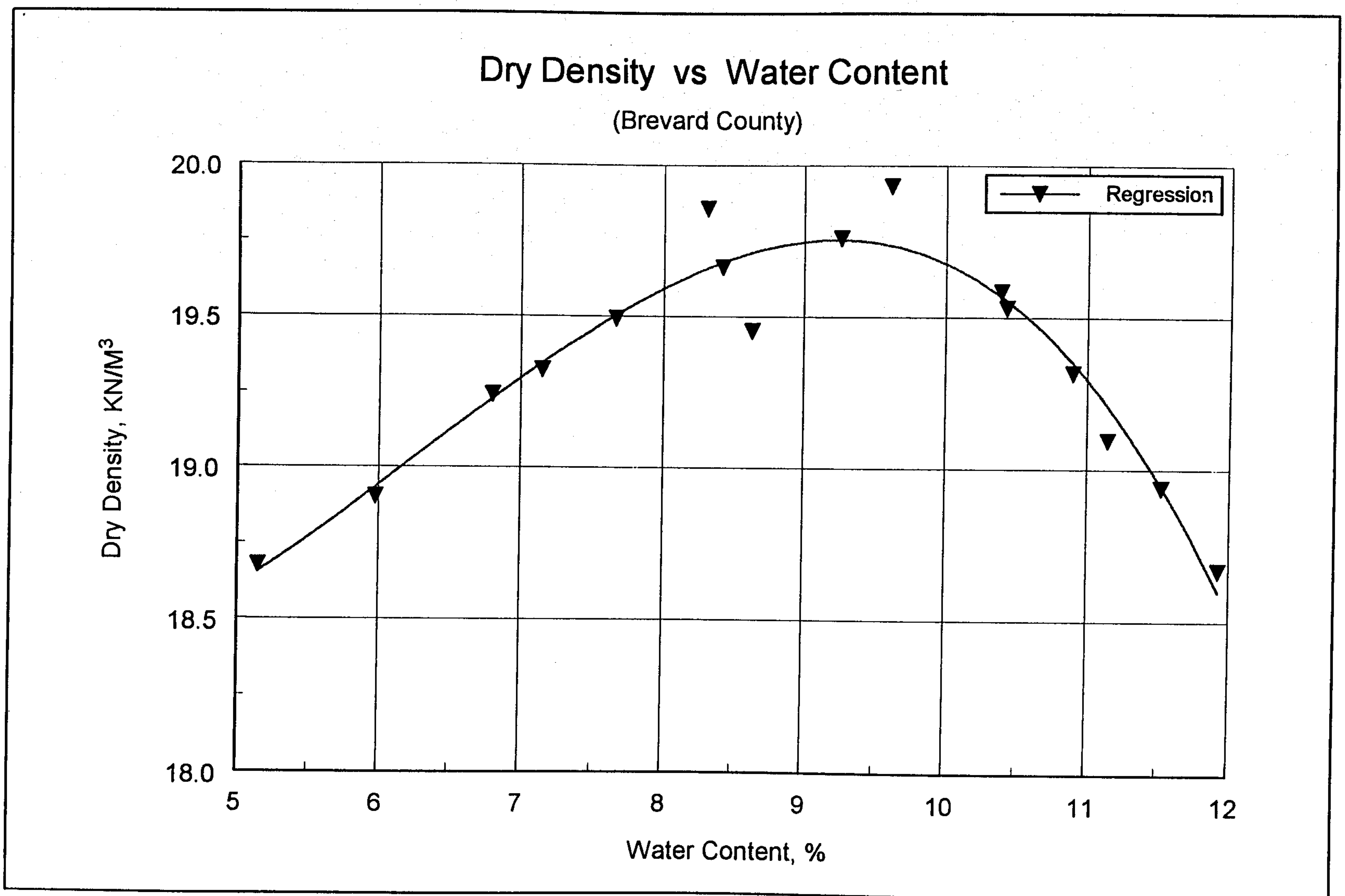

Figure A.12 : Plot of Compaction Test for Brevard County

APPENDIX B: CALIBRATION RESULTS

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Table B.1(a) : Microvolt outputs corresponding to four concentrations for nine psychrometers

(Calibration A)

Osmolality	Psychrometer Number (Microvolt)									Corresponding suction	
	1	2	3	4	5	6	7	8	9	tsf	kPa
290	8.26	8.50	7.29	8.28	7.22	7.15	9.14	8.39	9.17	7.60	727.61
500	9.44	10.36	9.89	9.53	10.59	10.48	10.51	10.59	10.03	13.10	1254.50
1000	20.91	22.18	20.38	20.38	21.98	21.78	22.31	21.34	21.13	26.20	2509.00
1800	36.54	38.47	36.43	36.77	38.24	38.11	38.47	36.77	36.88	47.16	4516.20

Table B.1(b) : Microvolt outputs corresponding to four concentrations for nine psychrometers

(Calibration B)

Osmolality	Psychrometer Number (Microvolt)									Corresponding suction	
	1	2	3	4	5	6	7	8	9	tsf	kPa
290	6.10	7.04	6.81	5.70	5.64	7.63	7.61	6.15	5.52	7.60	727.61
500	12.72	12.87	12.44	12.87	12.87	12.55	15.01	12.87	13.60	13.10	1254.50
1000	20.80	22.09	21.77	22.52	22.52	21.92	24.66	22.52	22.73	26.20	2509.00
1800	35.60	38.62	36.13	38.08	37.75	36.94	40.14	36.02	37.65	47.16	4516.20

Table B.2(a) : Equations of Calibration Lines for Nine Psychrometers
(Calibration A)

Psychrometer No.	Cooling Coefficient	Equation	R^2
1	54	$\tau = 127.67\ E_{25} - 146.69$	0.9916
2	55	$\tau = 121.76\ E_{25} - 168.45$	0.9946
3	58	$\tau = 127.2E_{25} - 101.08$	0.9977
4	60	$\tau = 127.16\ E_{25} - 131.11$	0.9917
5	61	$\tau = 120.29E_{25} - 94.81$	0.9989
6	61	$\tau = 120.52E_{25} - 83.824$	0.9989
7	62	$\tau = 123.43\ E_{25} - 230.09$	0.9924
8	63	$\tau = 129.7\ E_{25} - 247.73$	0.9965
9	63	$\tau = 129.68E_{25} - 251.32$	0.9898

Table B.2(b) : Equations of Calibration Lines for Nine Psychrometers
(Calibration B)

Psychrometer No.	Cooling Coefficient	Equation	R^2
1	54	$\tau = 132.05E_{25} - 231.4$	0.9926
2	55	$\tau = 122.08\ E_{25} - 208.73$	0.9979
3	58	$\tau = 131.23\ E_{25} - 279.38$	0.9965
4	60	$\tau = 119.8\ E_{25} - 119.44$	0.9923
5	61	$\tau = 120.8\ E_{25} - 127.46$	0.9913
6	61	$\tau = 130.54\ E_{25} - 327.71$	0.9991
7	62	$\tau = 119.36\ E_{25} - 356.83$	0.991
8	63	$\tau = 129.21\ E_{25} - 253.61$	0.989
9	63	$\tau = 121.38\ E_{25} - 160.44$	0.9856

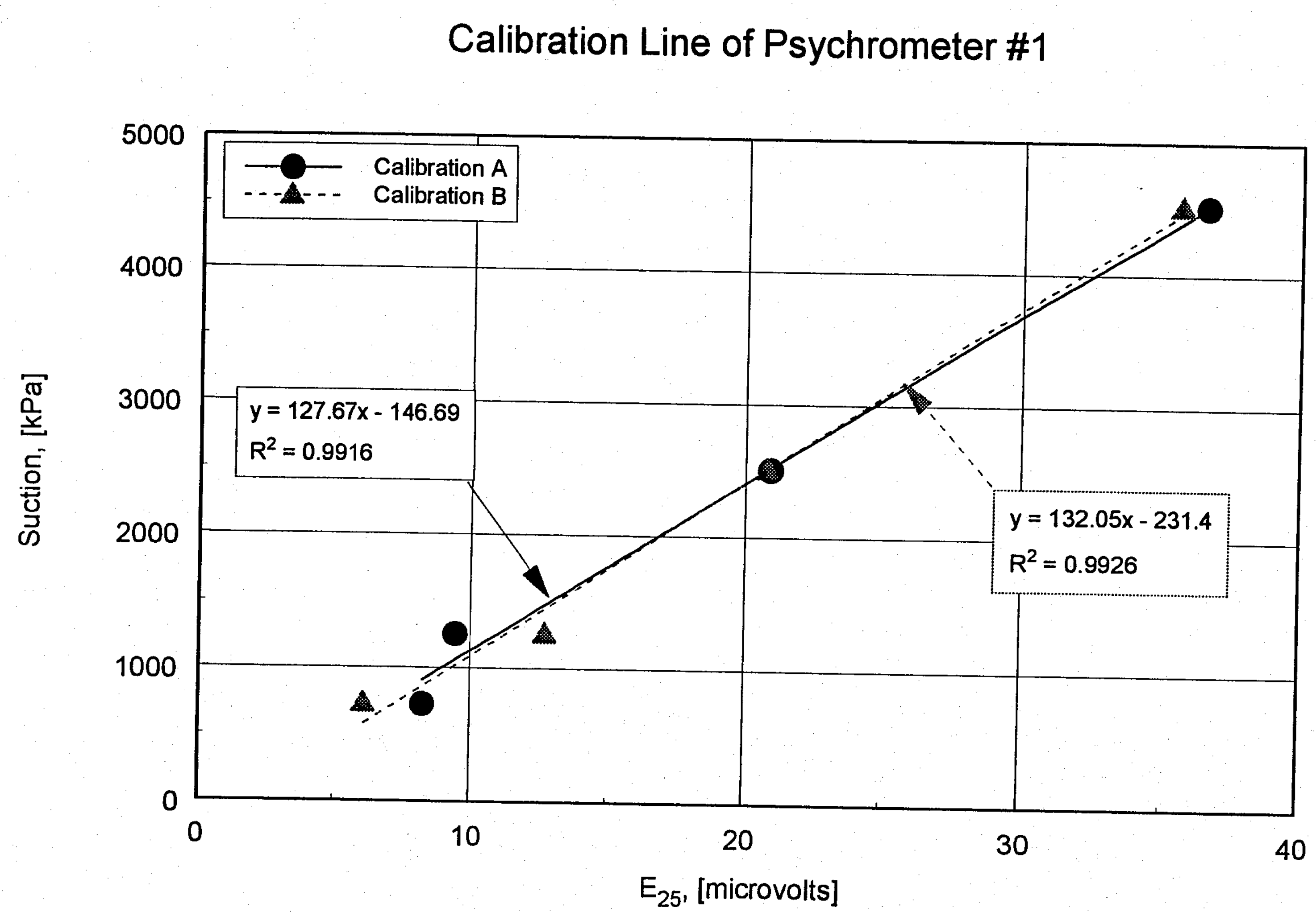

Figure B.1 : Regression lines of psychrometer #1 for Calibration A and B

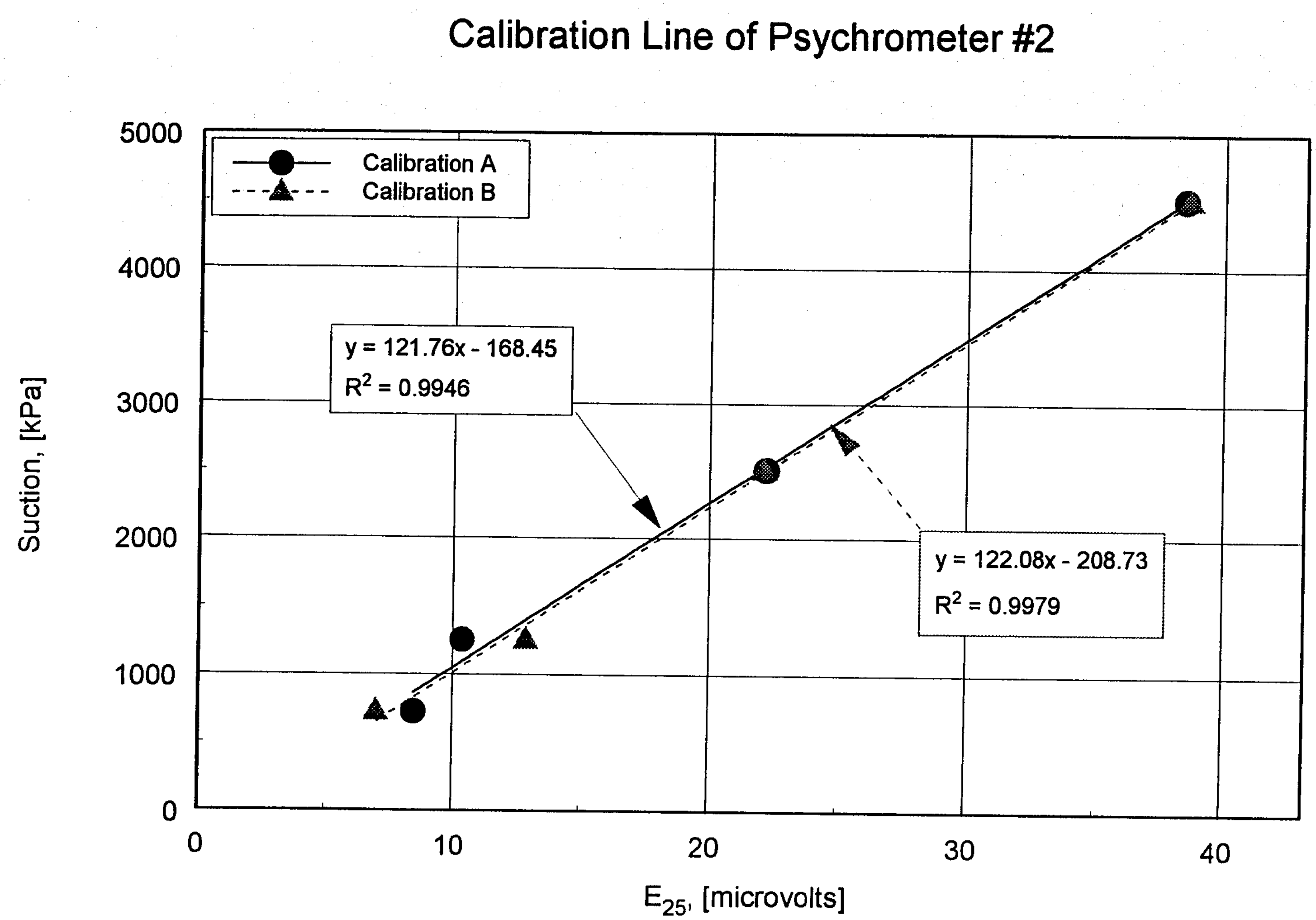

Figure B.2 : Regression lines of psychrometer #2 for Calibration A and B

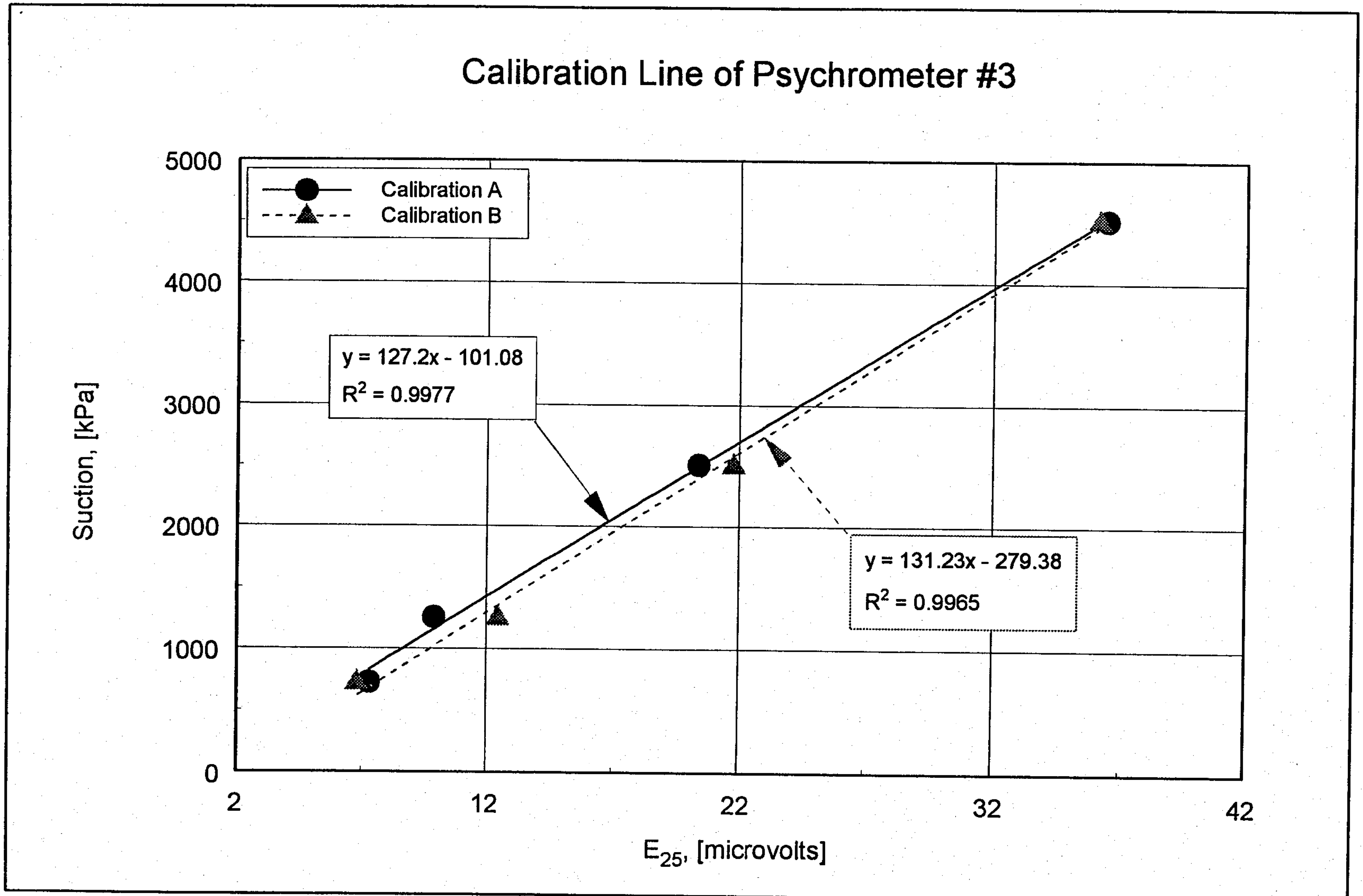

Figure B.3 : Regression lines of psychrometer #3 for Calibration A and B

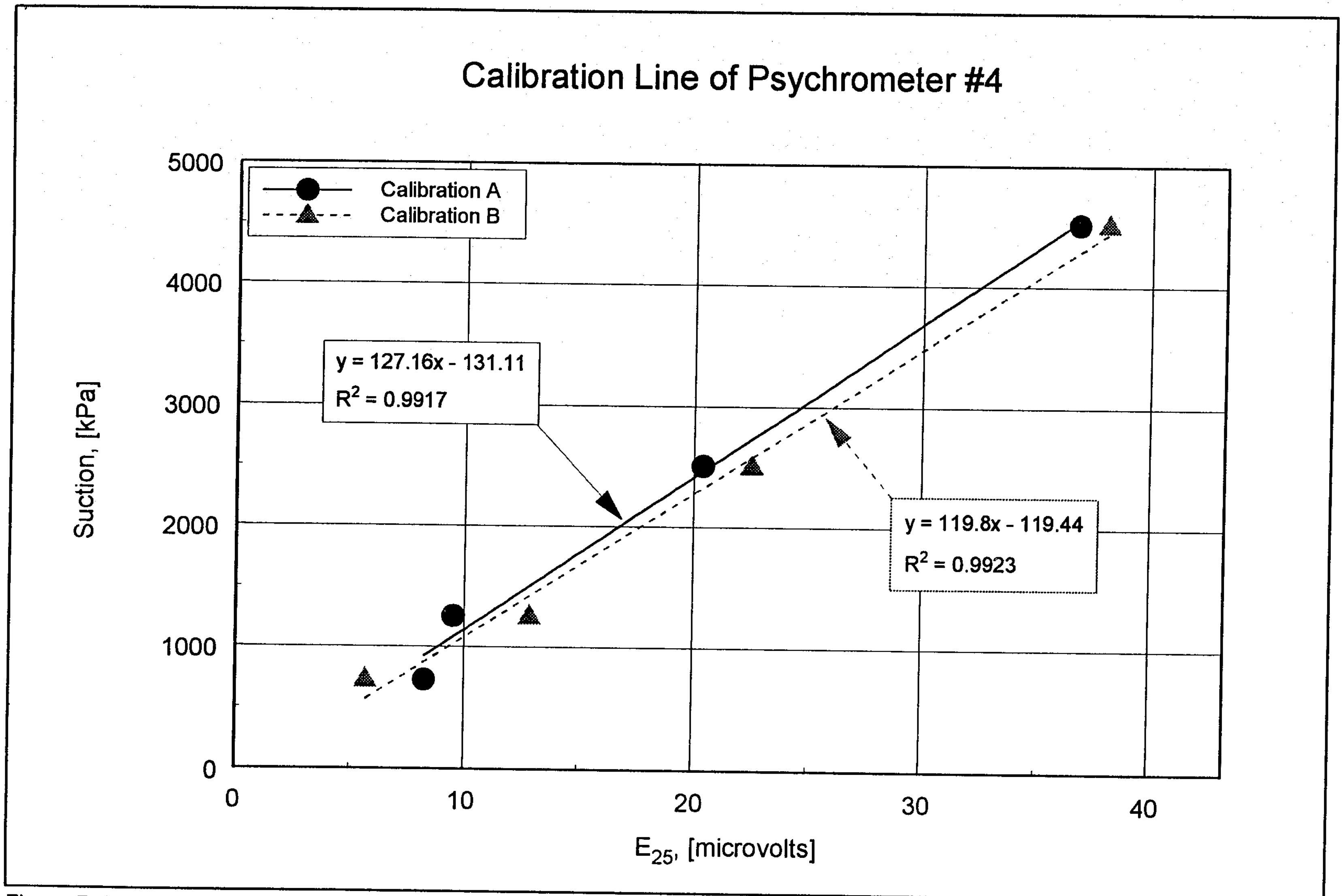

Figure B.4 : Regression lines of psychrometer #4 for Calibration A and B

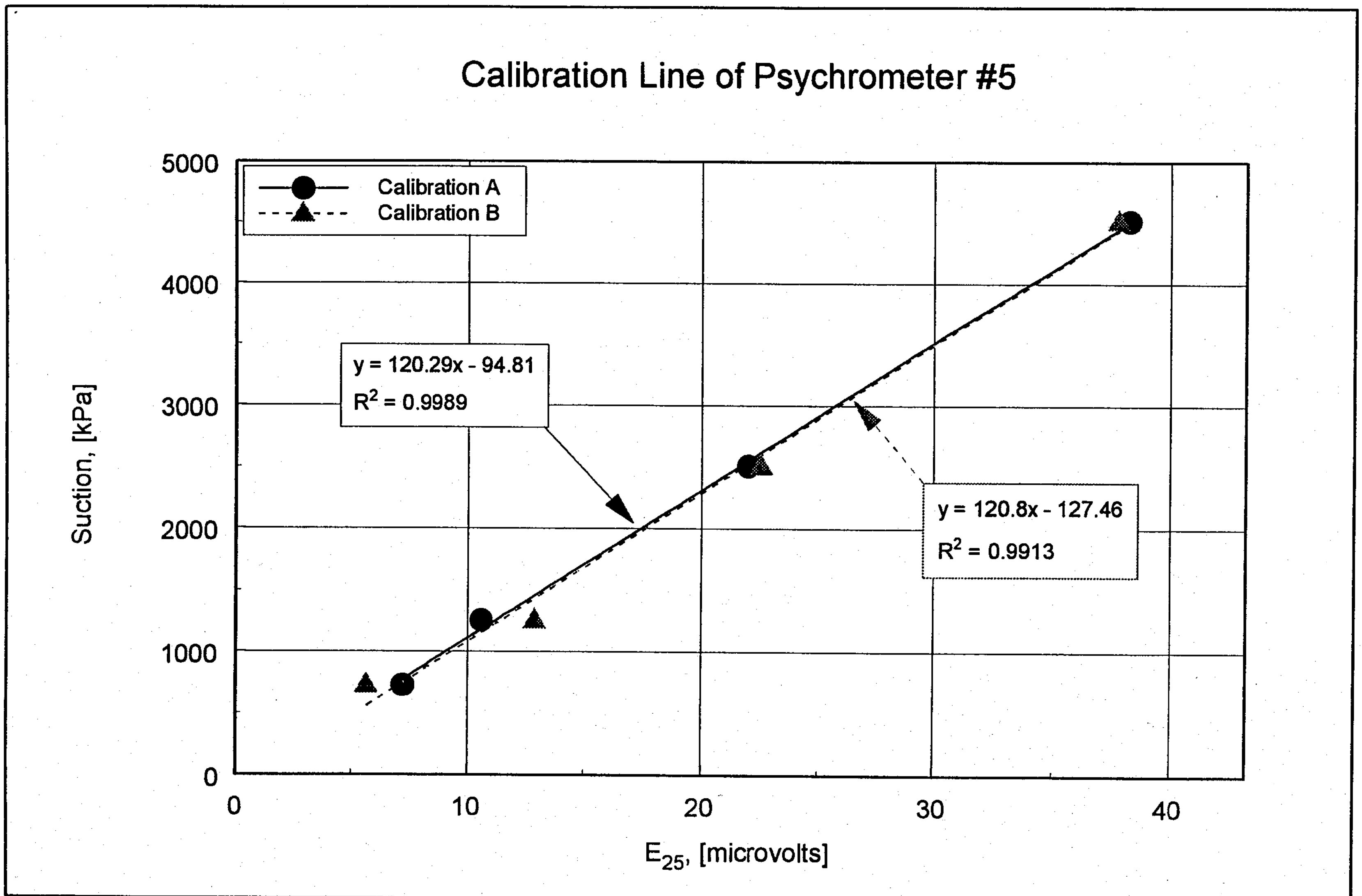

Figure B.5 : Regression lines of psychrometer #5 for Calibration A and B

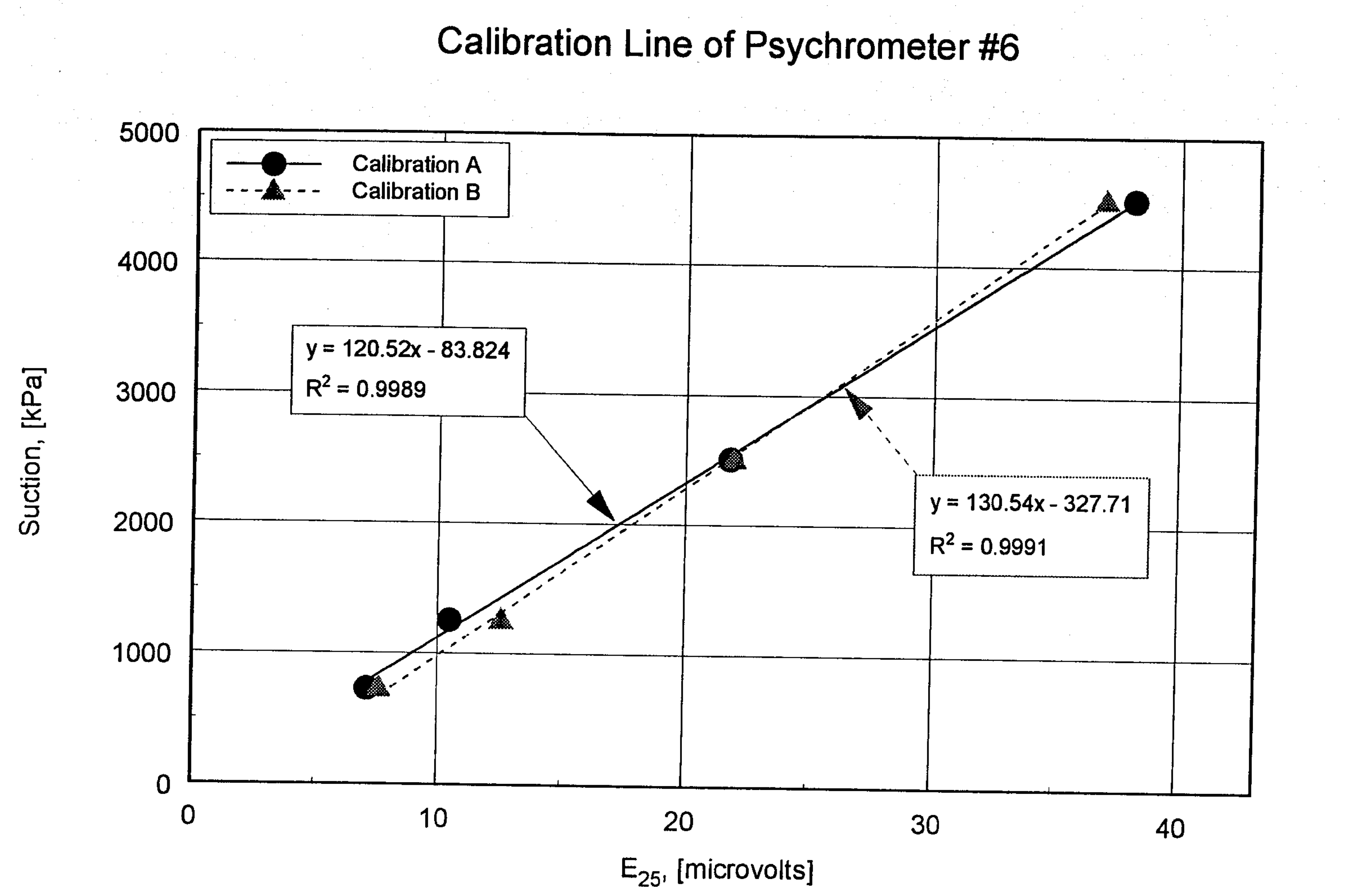

Figure B.6 : Regression lines of psychrometer #6 for Calibration A and B

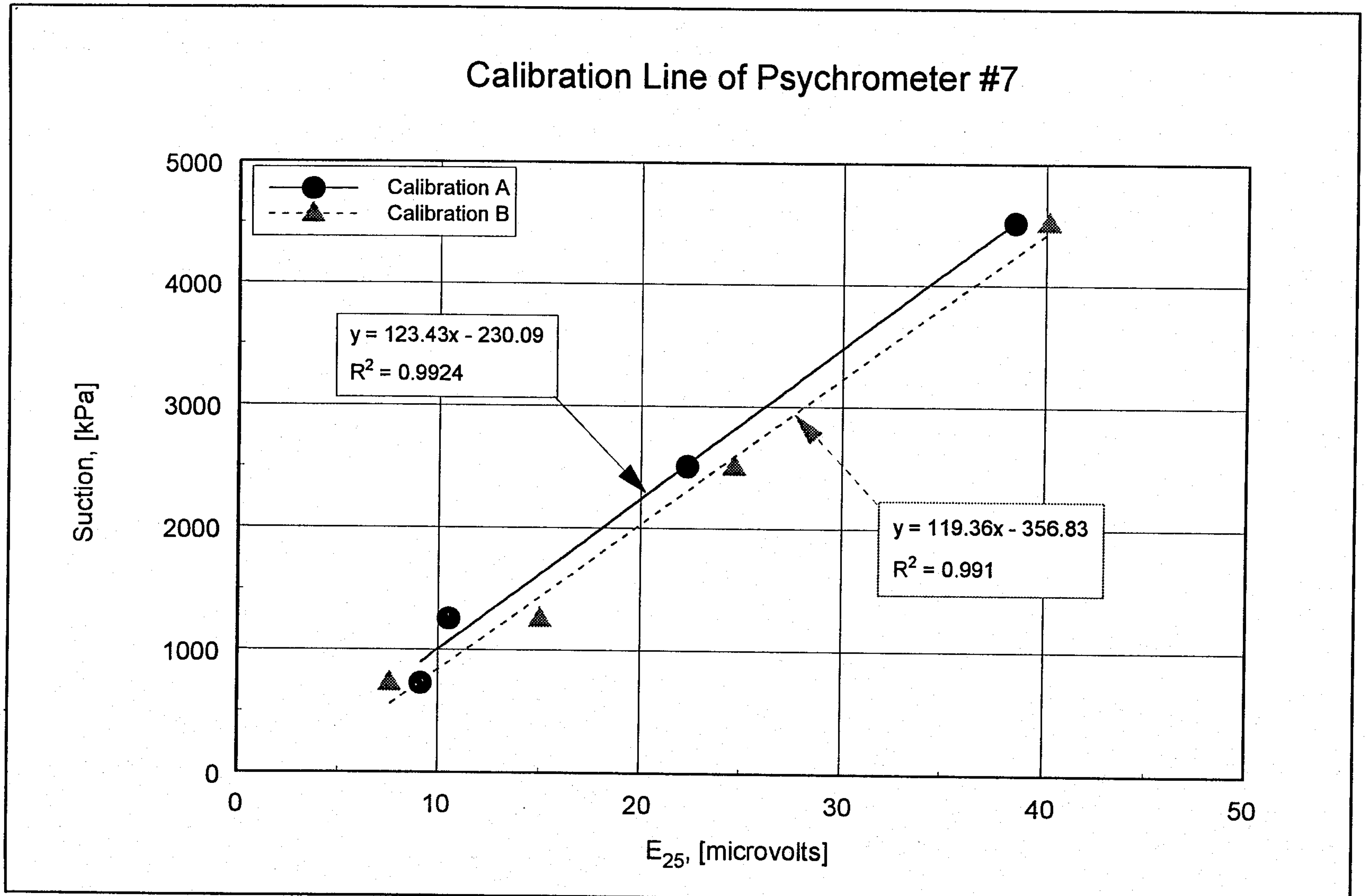

Figure B.7 : Regression lines of psychrometer #7 for Calibration A and B

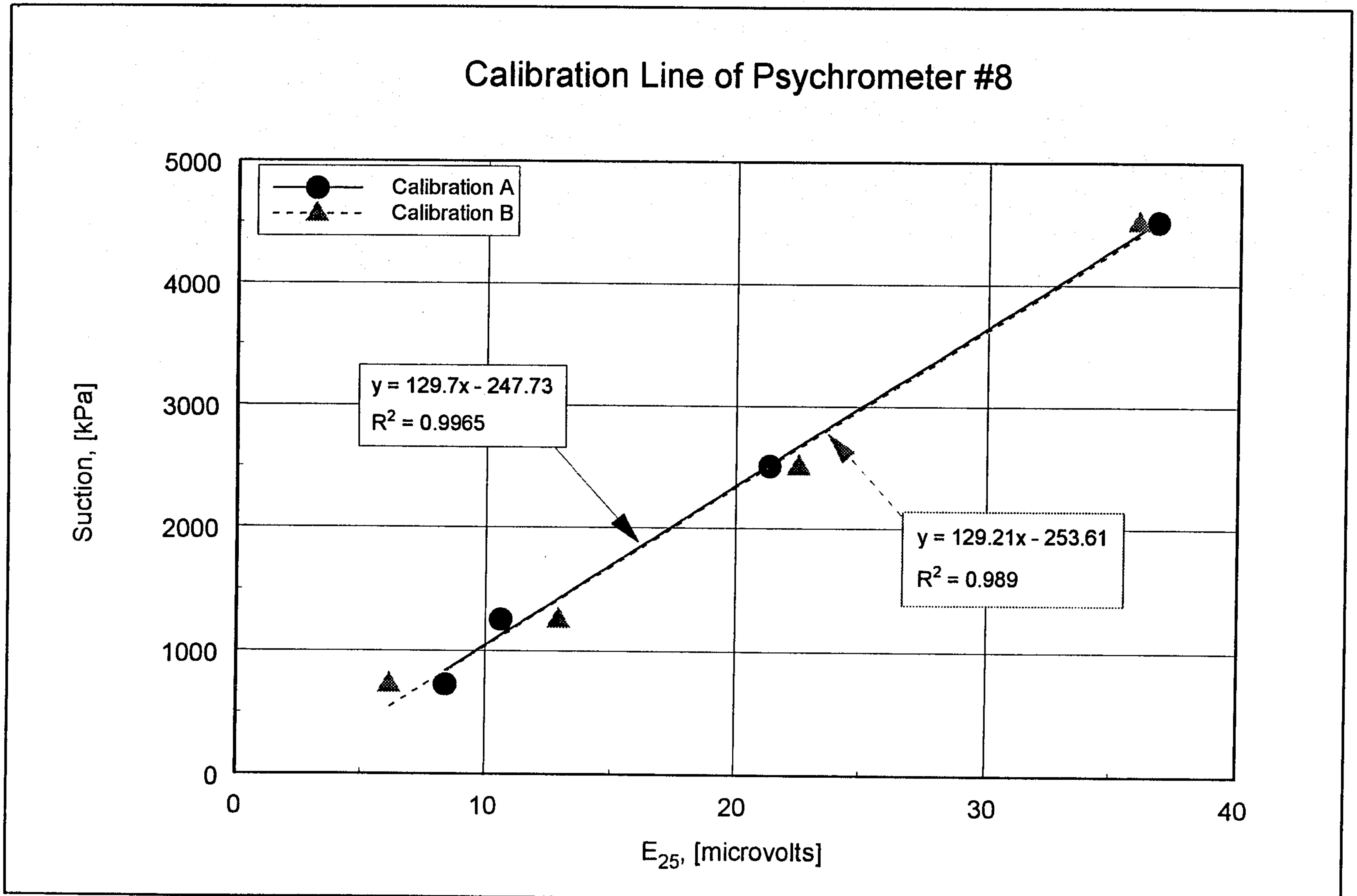

Figure B.8 : Regression lines of psychrometer #8 for Calibration A and B

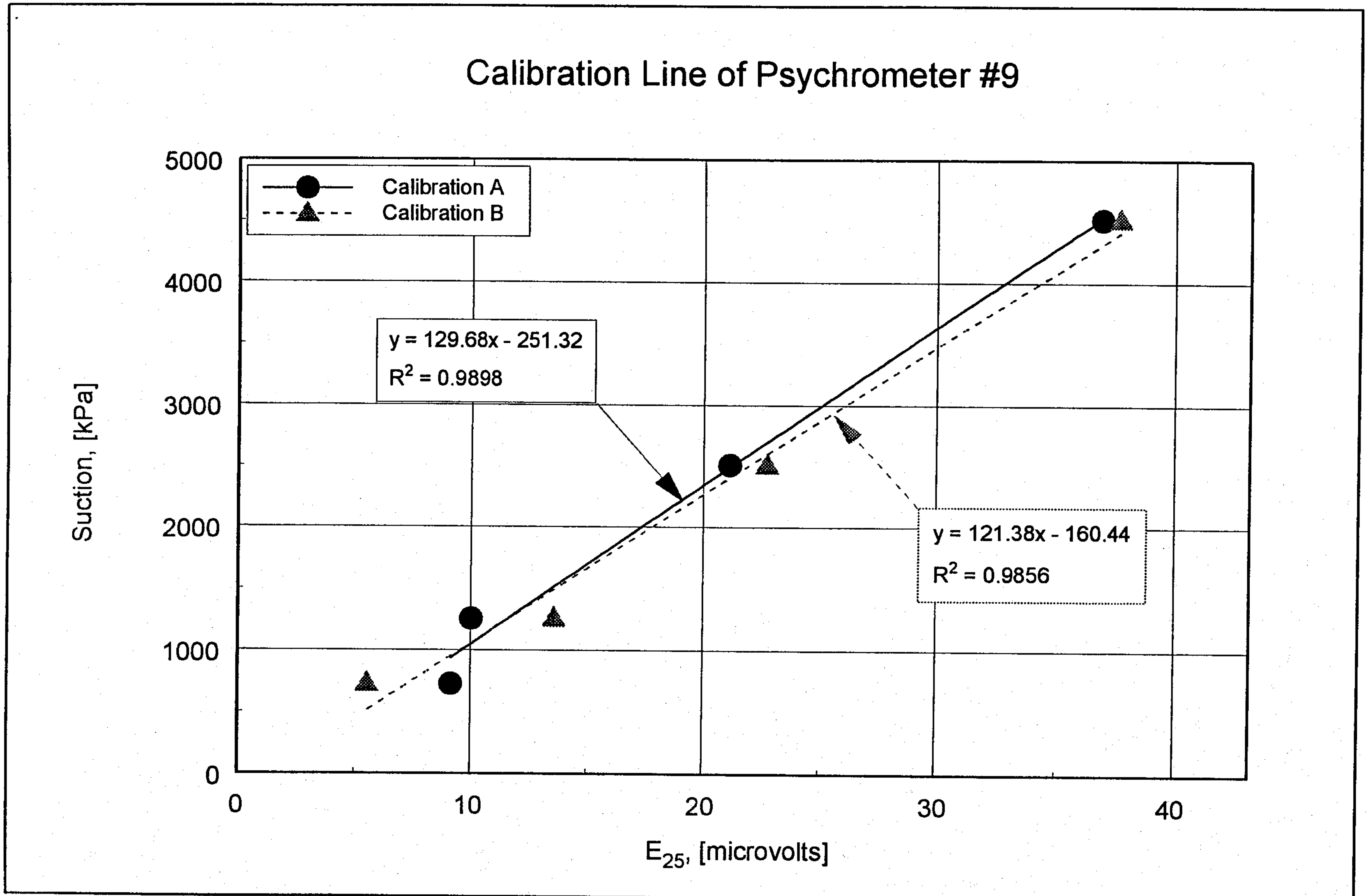

Figure B.9 : Regression lines of psychrometer #9 for Calibration A and B

APPENDIX C: SOIL SUCTION TEST RESULTS

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Table C.1(a) : Summary of soil suction, water content, and specific volume test results for Clay County soil

Series A   Dry density: 18.7 KN/m^3 Water content : 9.27%

A. Soil Suction Test										
Psychrometer No.		9B	8	7	4	5B	6	3	2	1
Sample container No.		63	63	62	60	61	61	58	55	54
Water content Increment (0, +, -)		4hr	2hr	1hr	0.5ml	N	N	1ml	2ml	4ml
E_{25}, Microvolts*		29.85	13.87	5.39	3.10	2.90	2.83	2.83	3.40	3.66
Soil Suction, Tons/ft2 (τ)		37.83	16.21	4.55	2.75	2.65	2.69	2.71	2.57	3.35
Soil Suction, kPa (τ)		3619.63	1551.21	435.20	263.09	254.03	257.25	258.90	245.53	320.58
B. Water Content										
Weight in Grams	Tare Plus Wet Soil	332.5	350.45	368.3	376.5	376.8	372.3	371.5	381.7	385.9
	Tare Plus Dry Soil	326.2	342	357.8	364.59	364.7	360.29	359.2	368	369.9
	Water (W_w)	6.3	8.45	10.5	11.91	11.92	12.01	12.3	13.7	16
	Tare	237.1	237.1	237.1	237.1	237.1	237.1	237.1	237.1	237.1
	Dry Soil (W_s)	89.1	104.9	120.7	127.49	127.6	123.2	122.1	130.9	132.8
Water Content (%)		7.07%	8.06%	8.70%	9.34%	9.34%	9.75%	10.07%	10.47%	12.05%
C. Specific Volume										
Test Temperature of Water (°C)		33°C	33°C	33°C	33°C	33°C	33°C	33°C	33°C	33°C
Weight in Grams	Wet Soil and Wax	135.6	148.2	160.5	166.7	164	168.7	151.5	165.1	172.4
	Wet Soil (W)	132.1	142.5	143.4	147.6	146.3	155.1	147.4	148	151.4
	Wax	3.5	5.7	17.1	19.1	17.7	13.6	4.1	17.1	21
	Wet Soil and Wax in Water	34.4	39.5	38.5	42	38	39	39	39	41
	Dry Soil (W_s)	123.38	131.88	131.92	134.99	133.80	141.32	133.91	133.98	135.12
Volume in CC	Wet soil and Wax	101.2	108.7	122	124.7	126	129.7	112.5	126.1	131.4
	Wax	6.36	10.36	31.09	34.73	32.18	24.73	7.45	31.09	38.18
	Wet Soil (V)	94.84	98.34	90.91	89.97	93.82	104.97	105.05	95.01	93.22
Density KN/m^3	Wet Density (γ_m) = (W/V)*9.8	13.65	14.20	15.46	16.08	15.28	14.48	13.75	15.27	15.92
	Dry Density (γ_d) = (W_s/V)*9.8	12.75	13.14	14.22	14.70	13.98	13.19	12.49	13.82	14.21
Specific Volume (V_y) =1/ρ_d		0.078	0.076	0.070	0.068	0.072	0.076	0.080	0.072	0.070

* E_{25} was calculated by averaging the last three readings from soil suction test results

Table C.1(b) : Summary of soil suction, water content, and specific volume test results for Clay County soil

Series B — Dry density: 19.5 KN/m^3 — Water content :9.1%

A. Soil Suction Test										
Psychrometer No.		1	2	3	4	5B	6	7	8	9B
Sample container No.		54	55	58	60	61	61	62	63	63
Water content Increment (0, +, -)		4hr	2hr	1hr	N	N	0.5ml	1ml	2ml	4ml
E25, Microvolts*		18.87	16.62	11.03	8.03	6.81	3.70	2.79	2.75	2.77
Soil Suction, Tons/ft2 (τ)		23.65	19.39	13.61	9.30	7.57	3.78	1.19	1.14	1.13
Soil Suction, kPa (τ)		2262.95	1855.44	1302.47	890.26	724.32	362.07	114.06	108.95	108.17
B. Water Content										
Weight in Grams	Tare Plus Wet Soil	271.9	268	258.8	249.4	248.1	257.7	271.7	246.5	253.3
	Tare Plus Dry Soil	262.2	257.9	249.1	240.3	238.9	247.7	259.8	235.8	240.6
	Water (W_w)	9.7	10.1	9.7	9.1	9.2	10	11.9	10.7	12.7
	Tare	134.2	134.2	134.2	134.2	134.2	134.2	134.2	134.1	134.1
	Dry Soil (W_s)	128	123.7	114.9	106.1	104.7	113.5	125.6	101.7	106.5
Water Content (%)		7.58%	8.16%	8.44%	8.58%	8.79%	8.81%	9.47%	10.52%	11.92%
C. Specific Volume										
Test Temperature of Water (°C)		33°C	33°C	33°C	33°C	33°C	33°C	33°C	33°C	33°C
Weight in Grams	Wet Soil and Wax	162.4	153.4	142.57	132.65	131.4	137.53	154.35	126.65	135.6
	Wet Soil (W)	138.97	142.88	125.5	115.89	114.5	124.5	138.19	112.9	119.25
	Wax	23.43	10.52	17.07	16.76	16.9	13.03	16.16	13.75	16.35
	Wet Soil and Wax in Water	45.1	55.4	44.29	39.31	39.78	44.5	51.77	38.7	40.12
	Dry Soil (W_s)	129.18	132.09	115.73	106.74	105.25	114.42	126.23	102.15	106.54
Volume in CC	Wet soil and Wax	117.3	98	98.28	93.34	91.62	93.03	102.58	87.95	95.48
	Wax	42.60	19.13	31.04	30.47	30.73	23.69	29.38	25.00	29.73
	Wet Soil (V)	74.70	78.87	67.24	62.87	60.89	69.34	73.20	62.95	65.75
Density KN/m^3	Wet Density (γ_m) = (W/V)*9.8	18.23	17.75	18.29	18.07	18.43	17.60	18.50	17.58	17.77
	Dry Density (γ_d) = (W_s/V)*9.8	16.95	16.41	16.87	16.64	16.94	16.17	16.90	15.90	15.88
Specific Volume (V_γ) =1/ρ_d		0.059	0.061	0.059	0.060	0.059	0.062	0.059	0.063	0.063

* E_{25} was calculated by averaging the last three readings from soil suction test results

Table C.2(a) : Summary of soil suction, water content, and specific volume test result for Madison County soil

Series A — Dry density: 19.1 KN/m^3 — Water content :9.0%

A. Soil Suction Test										
Psychrometer No.		1	2	3	6	4	5B	7	8	9B
Sample container No.		54	55	58	61	60	61	62	63	63
Water content Increment (0, +, -)		4ml	2ml	1ml	0.5ml	N	N	1hr	2hr	4hr
E25, Microvolts*		2.95	3.63	3.22	3.40	3.62	3.50	6.50	6.53	26.70
Soil Suction, Tons/ft2 (τ)		2.40	2.86	3.22	3.41	3.44	3.41	5.98	6.26	33.56
Soil Suction, kPa (τ)		229.94	273.54	308.50	325.94	329.21	326.21	572.21	599.21	3211.14
B. Water Content										
Weight in Grams	Tare Plus Wet Soil	313.84	296.84	377.8	348.9	354.2	348	352.76	339.6	320.8
	Tare Plus Dry Soil	305.9	291.27	365.4	339.5	344.8	338.89	344.01	332.3	315.7
	Water (W_w)	7.94	5.57	12.4	9.4	9.4	9.11	8.75	7.3	5.1
	Tare	237.1	237.1	237.1	238.1	239.1	237.1	237.1	237.1	237.1
	Dry Soil (W_s)	68.8	54.17	128.3	101.4	105.7	101.79	106.91	95.2	78.6
Water Content (%)		11.54%	10.28%	9.66%	9.27%	8.89%	8.95%	8.18%	7.67%	6.49%
C. Specific Volume										
Test Temperature of Water (°C)		30oC	38°C	37oC	32oC	30oC	30oC	30oC	32oC	31oC
Weight in Grams	Wet Soil and Wax	102.56	96.87	156.37	147.8	158.58	155.27	155.58	149.54	93.08
	Wet Soil (W)	89.54	78.7	142	136.5	140.88	140.82	139.8	139.01	83.81
	Wax	13.02	18.17	14.37	11.3	17.7	14.45	15.78	10.53	9.27
	Wet Soil and Wax in Water	27	15.9	44	43	44	43	42	42.5	25
	Dry Soil (W_s)	80.28	71.36	129.49	124.92	129.37	129.25	129.22	129.11	78.70
Volume in CC	Wet soil and Wax	75.56	80.97	112.37	104.8	114.58	112.27	113.58	107.04	68.08
	Wax	23.67	33.04	26.13	20.55	32.18	26.27	28.69	19.15	16.85
	Wet Soil (V)	51.89	47.93	86.24	84.25	82.40	86.00	84.89	87.89	51.23
Density KN/m^3	Wet Density (γ_m) = (W/V)*9.8	16.91	16.09	16.14	15.88	16.76	16.05	16.14	15.50	16.03
	Dry Density (γ_d) = (W_s/V)*9.8	15.16	14.59	14.71	14.53	15.39	14.73	14.92	14.40	15.06
Specific Volume (V_γ) =1/ρ_d		0.066	0.069	0.068	0.069	0.065	0.068	0.067	0.069	0.066

* E_{25} was calculated by averaging the last three readings from soil suction test results

Table C.2(b) : Summary of soil suction, water content, and specific volume test result for Madison County soil

Series B — Dry density: 19.1 KN/m^3 — Water content :8.6%

A. Soil Suction Test										
Psychrometer No.		1	2	3	4	5B	6	7	8	9B
Sample container No.		54	55	58	60	61	61	62	63	63
Water content Increment (0, +, -)		4hr	2hr	1hr	N	N	0.5ml	1ml	2ml	4ml
E25, Microvolts*		29.76	7.89	5.26	4.51	5.66	5.17	4.56	3.84	2.91
Soil Suction, Tons/ft2 (τ)		38.64	7.89	4.29	4.40	5.82	3.63	1.96	2.53	2.01
Soil Suction, kPa (τ)		3697.94	755.02	410.90	420.70	556.84	347.18	187.45	242.43	192.57
B. Water Content										
Weight in Grams	Tare Plus Wet Soil	268.18	276.16	274.14	280.8	282.21	284.2	283.53	285.62	284.19
	Tare Plus Dry Soil	261.36	267.07	264.53	270.19	271.16	272.54	271.47	272.61	269.54
	Water (W_w)	6.82	9.09	9.61	10.61	11.05	11.66	12.06	13.01	14.65
	Tare	139.56	139.56	139.56	139.56	139.56	139.56	139.56	139.56	139.56
	Dry Soil (W_s)	121.8	127.51	124.97	130.63	131.6	132.98	131.91	133.05	129.98
Water Content (%)		5.60%	7.13%	7.69%	8.12%	8.40%	8.77%	9.14%	9.78%	11.27%
C. Specific Volume										
Test Temperature of Water (°C)		35°C	34°C	33°C	32°C	31°C	30°C	29°C	28°C	27°C
Weight in Grams	Wet Soil and Wax	144.31	148.2	150	152.3	167.58	158.74	155.58	168.49	160.57
	Wet Soil (W)	132	138.4	139	142	143.51	144.65	145.98	147.65	145.17
	Wax	12.31	9.8	11	10.3	24.07	14.09	9.6	20.84	15.4
	Wet Soil and Wax in Water	42	41	44	43	44	43	42	42.5	44
	Dry Soil (W_s)	125.00	129.19	129.07	131.33	132.39	132.99	133.75	134.50	130.47
Volume in CC	Wet soil and Wax	102.31	107.2	106	109.3	123.58	115.74	113.58	125.99	116.57
	Wax	22.38	17.82	20.00	18.73	43.76	25.62	17.45	37.89	28.00
	Wet Soil (V)	79.93	89.38	86.00	90.57	79.82	90.12	96.13	88.10	88.57
Density KN/m^3	Wet Density (γ_m) = (W/V)*9.8	16.18	15.17	15.84	15.36	17.62	15.73	14.88	16.42	16.06
	Dry Density (γ_d) = (W_s/V)*9.8	15.33	14.16	14.71	14.21	16.26	14.46	13.64	14.96	14.44
Specific Volume (V_γ) =1/ρ_d		0.065	0.071	0.068	0.070	0.062	0.069	0.073	0.067	0.069

* E_{25} was calculated by averaging the last three readings from soil suction test results

Table C.3(a) : Summary of soil suction, water content, and specific volume test result for Jacobs Road soil

Series A — Dry density: 19.08KN/m3 — Water content: 7.8%

A. Soil Suction Test										
Psychrometer No.		1	2	3	4	5B	6	7	8	9B
Sample container No.		54	55	58	60	61	61	62	63	63
Water content Increment (0, +, -)		4hr	2hr	1hr	N	N	0.5ml	1ml	2ml	4ml
E25, Microvolts*		4.75	2.96	3.58	1.90	2.94	2.60	3.46	3.05	1.96
Soil Suction, Tons/ft2 (τ)		4.81	2.00	3.71	1.16	2.70	2.40	2.06	1.55	0.03
Soil Suction, kPa (τ)		460.15	191.62	354.78	110.69	258.70	229.53	196.66	148.38	2.85
B. Water Content										
Weight in Grams	Tare Plus Wet Soil	362	354	125	122.7	123.7	123.6	125.47	121.6	127.38
	Tare Plus Dry Soil	357.2	348	117.8	114.6	115.5	114.8	116.24	110.95	114.45
	Water (W_w)	4.8	6	7.2	8.1	8.2	8.8	9.23	10.65	12.93
	Tare	237.1	237.1	0	0	0	1	0	0	0
	Dry Soil (W_s)	120.1	110.9	117.8	114.6	115.5	113.8	116.24	110.95	114.45
Water Content (%)		4.00%	5.41%	6.11%	7.07%	7.10%	7.73%	7.94%	9.60%	11.30%
C. Specific Volume										
Test Temperature of Water (°C)		38°C	36°C	32°C	30°C	29°C	29°C	28°C	27°C	26°C
Weight in Grams	Wet Soil and Wax	136.7	143.7	140.7	137	143.5	142.9	142.2	140.9	148.35
	Wet Soil (W)	125.7	126.7	125.7	120.7	127.3	128.1	126.7	127.8	130.3
	Wax	11	17	15	16.3	16.2	14.8	15.5	13.1	18.05
	Wet Soil and Wax in Water	38	37	38	39	40	41	38.5	41	41.5
	Dry Soil (W_s)	120.87	120.20	118.46	112.73	118.86	118.91	117.38	116.61	117.07
Volume in CC	Wet soil and Wax	98.7	106.7	102.7	98	103.5	101.9	103.7	99.9	106.85
	Wax	20.00	30.91	27.27	29.64	29.45	26.91	28.18	23.82	32.82
	Wet Soil (V)	78.70	75.79	75.43	68.36	74.05	74.99	75.52	76.08	74.03
Density KN/m^3	Wet Density (γ_m) = (W/V)*9.8	15.65	16.38	16.33	17.30	16.85	16.74	16.44	16.46	17.25
	Dry Density (γ_d) = (W_s/V)*9.8	15.05	15.54	15.39	16.16	15.73	15.54	15.23	15.02	15.50
Specific Volume (V_γ) =1/ρ_d		0.066	0.064	0.065	0.062	0.064	0.064	0.066	0.067	0.065

* E_{25} was calculated by averaging the last three readings from soil suction test results

Table C.3(b) : Summary of soil suction, water content, and specific volume test result for Jacobs Road

Series B   Dry density: 19.9 KN/M^3 Water content :7.8%

A. Soil Suction Test										
Psychrometer No.		1	2	3	4	5B	6	7	8	9B
Sample container No.		54	55	58	60	61	61	62	63	63
Water content Increment (0, +, -)		4hr	2hr	1hr	N	N	0.5ml	1ml	2ml	4ml
E25, Microvolts*		6.77	5.17	4.86	3.95	4.11	4.51	5.34	3.88	3.56
Soil Suction, Tons/ft2 (τ)		6.93	4.41	3.75	3.69	3.86	2.73	2.93	2.58	2.84
Soil Suction, kPa (τ)		663.14	422.42	358.40	353.38	369.03	261.03	280.55	247.15	271.59
B. Water Content										
Weight in Grams	Tare Plus Wet Soil	276.03	280.26	279.62	285.26	287.18	273.61	282.06	286.79	286.45
	Tare Plus Dry Soil	269.16	271.81	270.53	275.1	277.04	263.57	271.05	274.34	272.24
	Water (W_w)	6.87	8.45	9.09	10.16	10.14	10.04	11.01	12.45	14.21
	Tare	139.56	139.56	139.56	139.56	139.56	139.56	139.56	139.56	139.56
	Dry Soil (W_s)	129.6	132.25	130.97	135.54	137.48	124.01	131.49	134.78	132.68
Water Content (%)		5.30%	6.39%	6.94%	7.50%	7.38%	8.10%	8.37%	9.24%	10.71%
C. Specific Volume										
Test Temperature of Water (°C)		40°C	39°C	38°C	37°C	36°C	35°C	34°C	33°C	32°C
Weight in Grams	Wet Soil and Wax	128	125.6	134.9	128	128.1	128.9	126.7	131.9	137.8
	Wet Soil (W)	117.1	113.9	120.3	117.3	116.5	116.6	112.8	122	125.5
	Wax	10.9	11.7	14.6	10.7	11.6	12.3	13.9	9.9	12.3
	Wet Soil and Wax in Water	43.9	41.6	43.9	43	41.8	42.5	39	45.3	47.3
	Dry Soil (W_s)	111.21	107.06	112.49	109.12	108.50	107.87	104.08	111.68	113.36
Volume in CC	Wet soil and Wax	84.1	84	91	85	86.3	86.4	87.7	86.6	90.5
	Wax	19.82	21.27	26.55	19.45	21.09	22.36	25.27	18.00	22.36
	Wet Soil (V)	64.28	62.73	64.45	65.55	65.21	64.04	62.43	68.60	68.14
Density KN/m^3	Wet Density (γ_m) = (W/V)*9.8	17.85	17.79	18.29	17.54	17.51	17.84	17.71	17.43	18.05
	Dry Density (γ_d) = (W_s/V)*9.8	16.95	16.73	17.10	16.32	16.31	16.51	16.34	15.95	16.30
Specific Volume(V_y) =1/ρ_d		0.059	0.060	0.058	0.061	0.061	0.061	0.061	0.063	0.061

* E_{25} was calculated by averaging the last three readings from soil suction test results

Table C.4(a) : Summary of soil suction, water content, and specific volume test result for Alford City soil

Series A — Dry density: 19.4 KN/m^3 — Water content :7.6%

A. Soil Suction Test										
Psychrometer No.		1	2	3	4	5B	6	7	8	9B
Sample container No.		54	55	58	60	61	61	62	63	63
Water content Increment (0, +, -)		4hr	2hr	1hr	N	N	0.5ml	1ml	2ml	4ml
E25, Microvolts*		4.13	3.97	3.00	3.44	3.41	3.31	3.96	4.12	3.77
Soil Suction, Tons/ft2 (τ)		3.98	3.29	2.93	3.20	3.30	3.29	2.70	3.00	2.48
Soil Suction, kPa (τ)		380.59	314.94	280.52	306.32	315.38	315.10	258.69	286.63	237.57
B. Water Content										
Weight in Grams	Tare Plus Wet Soil	267.9	332.9	283	329.3	298	301.2	334	306.9	377.6
	Tare Plus Dry Soil	266.6	327.5	280.1	322.9	293.8	296.8	326.9	301.4	364.6
	Water (W_w)	1.3	5.4	2.9	6.4	4.2	4.4	7.1	5.5	13
	Tare	237.1	237.1	237.1	237.1	237.1	238.1	237.1	237.1	237.1
	Dry Soil (W_s)	29.5	90.4	43	85.8	56.7	58.7	89.8	64.3	127.5
Water Content (%)		4.41%	5.97%	6.74%	7.46%	7.41%	7.50%	7.91%	8.55%	10.20%
C. Specific Volume										
Test Temperature of Water (°C)		45°C	40°C	39°C	37°C	35°C	34°C	33°C	31°C	30°C
Weight in Grams	Wet Soil and Wax	132.3	134.5	84.8	141.9	113.2	126.5	141.1	74.2	144.3
	Wet Soil (W)	117.8	123.3	74.3	122.3	102.6	115	127.1	65.2	127.3
	Wax	14.5	11.2	10.5	19.6	10.6	11.5	14	9	17
	Wet Soil and Wax in Water	44.5	49.5	27.8	46.7	43.8	44.8	49.5	25.4	50.1
	Dry Soil (W_s)	112.83	116.35	69.61	113.81	95.52	106.98	117.79	60.06	115.52
Volume in CC	Wet soil and Wax	87.8	85	57	95.2	69.4	81.7	91.6	48.8	94.2
	Wax	26.36	20.36	19.09	35.64	19.27	20.91	25.45	16.36	30.91
	Wet Soil (V)	61.44	64.64	37.91	59.56	50.13	60.79	66.15	32.44	63.29
Density KN/m^3	Wet Density (γ_m) = (W/V)*9.8	18.79	18.69	19.21	20.12	20.06	18.54	18.83	19.70	19.71
	Dry Density (γ_d) = (W_s/V)*9.8	18.00	17.64	17.99	18.73	18.68	17.25	17.45	18.15	17.89
Specific Volume (V_γ) =1/ρ_d		0.056	0.057	0.056	0.053	0.054	0.058	0.057	0.055	0.056

* E_{25} was calculated by averaging the last three readings from soil suction test results

Table C.4(b) : Summary of soil suction, water content, and specific volume test result for Alford City soil

Series B   Dry density: 19.4 KN/m^3 Water content :7.6%

A. Soil Suction Test										
Psychrometer No.		1	2	3	4	5B	6	7	8	9B
Sample container No.		54	55	58	60	61	61	62	63	63
Water content Increment (0, +, -)		4hr	2hr	1hr	N	N	0.5ml	1ml	2ml	4ml
E25, Microvolts*		4.88	4.30	4.10	3.25	3.34	4.29	4.86	3.83	3.12
Soil Suction, Tons/ft2 (τ)		4.32	3.30	2.70	2.82	2.88	2.43	2.33	2.52	2.28
Soil Suction, kPa (τ)		413.00	316.21	258.66	269.91	276.01	232.31	223.26	241.26	218.27
B. Water Content										
Weight in Grams	Tare Plus Wet Soil	268.5	333.4	284.1	330	299.51	301.9	334.94	307.34	378.44
	Tare Plus Dry Soil	267.2	328.1	281	323.5	295.21	297.31	327.64	301.99	365.13
	Water (W_w)	1.3	5.3	3.1	6.5	4.3	4.59	7.3	5.35	13.31
	Tare	237.1	237.1	237.1	237.1	237.1	238.1	237.1	237.1	237.1
	Dry Soil (W_s)	30.1	91	43.9	86.4	58.11	59.21	90.54	64.89	128.03
Water Content (%)		4.32%	5.82%	7.06%	7.52%	7.40%	7.75%	8.06%	8.24%	10.40%
C. Specific Volume										
Test Temperature of Water (°C)		45°C	40°C	39°C	37°C	35°C	34°C	33°C	31°C	30°C
Weight in Grams	Wet Soil and Wax	133.13	133.64	86.2	142.33	113.66	127.77	146.19	80.81	167.94
	Wet Soil (W)	118.56	123.98	76.3	122.54	102.64	115.88	129.26	71.67	143.59
	Wax	14.57	9.66	9.9	19.79	11.02	11.89	16.93	9.14	24.35
	Wet Soil and Wax in Water	44.37	49.61	27.64	44.31	43.11	44.67	48.54	25.97	52.6
	Dry Soil (W_s)	113.65	117.16	71.27	113.97	95.57	107.54	119.62	66.21	130.07
Volume in CC	Wet soil and Wax	88.76	84.03	58.56	98.02	70.55	83.1	97.65	54.84	115.34
	Wax	26.49	17.56	18.00	35.98	20.04	21.62	30.78	16.62	44.27
	Wet Soil (V)	62.27	66.47	40.56	62.04	50.51	61.48	66.87	38.22	71.07
Density KN/m^3	Wet Density (γ_m) = (W/V)*9.8	18.66	18.28	18.44	19.36	19.91	18.47	18.94	18.38	19.80
	Dry Density (γ_d) = (W_s/V)*9.8	17.89	17.27	17.22	18.00	18.54	17.14	17.53	16.98	17.94
Specific Volume (V_y) =1/ρ_d		0.056	0.058	0.058	0.056	0.054	0.058	0.057	0.059	0.056

* E_{25} was calculated by averaging the last three readings from soil suction test results

Table C.5(a) : Summary of soil suction, water content, and specific volume test result for Marion County soil

Series A — Dry density: 19.4 KN/m^3 — Water content :9.3%

A. Soil Suction Test										
Psychrometer No.		1	2	3	4	5B	6	7	8	9B
Sample container No.		54	55	58	60	61	61	62	63	63
Water content Increment (0, +, -)		4hr	2hr	1hr	N	N	0.5ml	1ml	2ml	4ml
E25, Microvolts*		6.22	4.88	4.22	4.37	3.64	3.40	3.53	3.00	3.08
Soil Suction, Tons/ft2 (τ)		6.77	4.44	4.55	4.44	3.59	3.41	2.15	1.48	1.55
Soil Suction, kPa (τ)		647.73	425.33	435.30	424.86	343.47	325.94	205.79	141.37	148.48
B. Water Content										
Weight in Grams	Tare Plus Wet Soil	271.3	266.3	278.5	277	271.3	273.5	274.5	260.4	279.9
	Tare Plus Dry Soil	263.8	257	267.4	265.3	259.9	261.7	262.4	247.7	264.1
	Water (W_w)	7.5	9.3	11.1	11.7	11.4	11.8	12.1	12.7	15.8
	Tare	134.1	134.1	134.1	134.1	134.1	134.1	134.1	134.1	134.1
	Dry Soil (W_s)	129.7	122.9	133.3	131.2	125.8	127.6	128.3	113.6	130
Water Content (%)		5.78%	7.57%	8.33%	8.92%	9.06%	9.25%	9.43%	11.18%	12.15%
C. Specific Volume										
Test Temperature of Water (^oC)		44	39	36	33	32	32	31	30	29
Weight in Grams	Wet Soil and Wax	161.3	152.7	167	166.3	156.3	153.2	161.8	141.2	170.2
	Wet Soil (W)	141.3	133.1	144.8	143.8	138.2	136	141.1	125.8	147.4
	Wax	20	19.6	22.2	22.5	18.1	17.2	20.7	15.4	22.8
	Wet Soil and Wax in Water	53.7	48.1	55.1	54.93	52.2	51.6	53.05	49	56.65
	Dry Soil (W_s)	133.58	123.74	133.67	132.03	126.72	124.49	128.94	113.15	131.43
Volume in CC	Wet soil and Wax	107.6	104.6	111.9	111.37	104.1	101.6	108.75	92.2	113.55
	Wax	36.36	35.64	40.36	40.91	32.91	31.27	37.64	28.00	41.45
	Wet Soil (V)	71.24	68.96	71.54	70.46	71.19	70.33	71.11	64.20	72.10
Density KN/m^3	Wet Density (γ_m) = (W/V)*9.8	19.44	18.91	19.84	20.00	19.02	18.95	19.44	19.20	20.04
	Dry Density (γ_d) = (W_s/V)*9.8	18.38	17.58	18.31	18.36	17.44	17.35	17.77	17.27	17.86
Specific Volume (V_γ) =1/ρ_d		0.054	0.057	0.055	0.054	0.057	0.058	0.056	0.058	0.056

* E_{25} was calculated by averaging the last three readings from soil suction test results

Table C.5(b) : Summary of soil suction, water content, and specific volume test result for Marion County soil

Series B — Dry density: 19.4 KN/m^3 — Water content :9.3%

A. Soil Suction Test										
Psychrometer No.		1	2	3	4	5B	6	7	8	9B
Sample container No.		54	55	58	60	61	61	62	63	63
Water content Increment (0, +, -)		4hr	2hr	1hr	N	N	0.5ml	1ml	2ml	4ml
E25, Microvolts*		6.54	5.36	5.31	4.01	4.11	4.50	4.97	3.61	2.88
Soil Suction, Tons/ft2 (τ)		6.61	4.66	4.36	3.77	3.86	2.71	2.47	2.22	1.98
Soil Suction, kPa (τ)		632.21	445.62	417.45	360.96	369.03	259.72	236.39	212.84	189.13
B. Water Content										
Weight in Grams	Tare Plus Wet Soil	270.6	265.7	277.9	276.5	270.6	268.7	274.4	258.4	278.9
	Tare Plus Dry Soil	262.5	256.4	266.8	264.5	259.1	257.2	261.9	246.5	263.4
	Water (W_w)	8.1	9.3	11.1	12	11.5	11.5	12.5	11.9	15.5
	Tare	134.1	134.1	134.1	134.1	134.1	134.1	134.1	134.1	134.1
	Dry Soil (W_s)	128.4	122.3	132.7	130.4	125	123.1	127.8	112.4	129.3
Water Content (%)		6.31%	7.60%	8.36%	9.20%	9.20%	9.34%	9.78%	10.59%	11.99%
C. Specific Volume										
Test Temperature of Water (°C)		44	39	36	33	32	32	31	30	29
Weight in Grams	Wet Soil and Wax	160.8	151.6	166	165.9	155.6	152.4	161.3	140.9	169.4
	Wet Soil (W)	140.7	132.8	143.9	142.8	137.8	135.4	140.5	124.8	146.5
	Wax	20.1	18.8	22.1	23.1	17.8	17	20.8	16.1	22.9
	Wet Soil and Wax in Water	51.2	47.6	54.3	54.3	51.8	51.2	53.1	48.5	56.1
	Dry Soil (W_s)	132.35	123.42	132.79	130.77	126.19	123.83	127.98	112.85	130.82
Volume in CC	Wet soil and Wax	109.6	104	111.7	111.6	103.8	101.2	108.2	92.4	113.3
	Wax	36.55	34.18	40.18	42.00	32.36	30.91	37.82	29.27	41.64
	Wet Soil (V)	73.05	69.82	71.52	69.60	71.44	70.29	70.38	63.13	71.66
Density KN/m^3	Wet Density (γ_m) = (W/V)*9.8	18.87	18.64	19.72	20.11	18.90	18.88	19.56	19.37	20.03
	Dry Density (γ_d) = (W_s/V)*9.8	17.75	17.32	18.20	18.41	17.31	17.26	17.82	17.52	17.89
Specific Volume (V_γ) =1/ρ_d		0.056	0.058	0.055	0.054	0.058	0.058	0.056	0.057	0.056

* E_{25} was calculated by averaging the last three readings from soil suction test results

Table C.6(a) : Summary of soil suction, water content, and specific volume test result for Brevard County soil

Series A | Dry density: 18.9 KN/m^3 | Water content: 9.3%

A. Soil Suction Test										
Psychrometer No.		1	2	3	4	5B	6	7	8	9B
Sample container No.		54	55	58	60	61	61	62	63	63
Water content Increment (0, +, -)		4hr	2hr	1hr	N	N	0.5ml	1ml	2ml	4ml
E25, Microvolts*		5.74	4.67	4.29	3.07	2.56	2.78	3.60	2.27	2.73
Soil Suction, Tons/ft2 (τ)		6.13	4.18	4.65	2.71	2.23	2.63	2.24	0.49	1.07
Soil Suction, kPa (τ)		586.14	400.17	444.61	259.27	213.13	251.22	214.26	46.69	102.71
B. Water Content										
Weight in Grams	Tare Plus Wet Soil	264.42	257.65	249.6	270.4	269.5	268.4	256	268.2	269.6
	Tare Plus Dry Soil	256.85	249.61	241.3	259.1	258.3	256.7	244.8	255.4	255.1
	Water (W_w)	7.57	8.04	8.3	11.3	11.2	11.7	11.2	12.8	14.5
	Tare	134.25	134.25	134.25	134.25	134.25	134.25	134.25	134.25	134.25
	Dry Soil (W_s)	122.6	115.36	107.05	124.85	124.05	122.45	110.55	121.15	120.85
Water Content (%)		6.17%	6.97%	7.75%	9.05%	9.03%	9.55%	10.13%	10.57%	12.00%
C. Specific Volume										
Test Temperature of Water (°C)		36	34.2	32.4	31.2	33	30.7	33.5	32.6	31.3
Weight in Grams	Wet Soil and Wax	149.61	146.94	136.29	163.9	159.2	156.7	149.1	156.6	160.7
	Wet Soil (W)	130.42	125.38	116.24	137.02	136.9	136.2	126.2	135.3	136.4
	Wax	19.19	21.56	20.05	26.88	22.3	20.5	22.9	21.3	24.3
	Wet Soil and Wax in Water	45.46	40.84	36.65	47.4	48.52	47.56	43.6	49.4	49.63
	Dry Soil (W_s)	122.84	117.21	107.88	125.65	125.56	124.32	114.59	122.37	121.79
Volume in CC	Wet soil and Wax	104.15	106.1	99.64	116.5	110.68	109.14	105.5	107.2	111.07
	Wax	34.89	39.20	36.45	48.87	40.55	37.27	41.64	38.73	44.18
	Wet Soil (V)	69.26	66.90	63.19	67.63	70.13	71.87	63.86	68.47	66.89
Density KN/m^3	Wet Density (γ_m) = (W/V)*9.8	18.45	18.37	18.03	19.86	19.13	18.57	19.37	19.36	19.98
	Dry Density (γ_d) = (W_s/V)*9.8	17.38	17.17	16.73	18.21	17.55	16.95	17.58	17.51	17.84
Specific Volume (V_γ) =1/ρ_d		0.058	0.058	0.060	0.055	0.057	0.059	0.057	0.057	0.056

* E_{25} was calculated by averaging the last three readings from soil suction test results

Table C.6(b) : Summary of soil suction, water content, and specific volume test result for Brevard County soil

Series B | Dry density: 18.9 KN/m^3 | Water content: 9.3%

A. Soil Suction Test										
Psychrometer No.		1	2	3	4	5B	6	7	8	9B
Sample container No.		54	55	58	60	61	61	62	63	63
Water content Increment (0, +, -)		4hr	2hr	1hr	N	N	0.5ml	1ml	2ml	4ml
E25, Microvolts*		6.55	5.87	5.57	4.87	5.14	5.39	6.61	5.28	4.11
Soil Suction, Tons/ft2 (τ)		6.62	5.31	4.72	4.85	5.16	3.93	4.52	4.47	3.54
Soil Suction, kPa (τ)		633.82	507.88	451.57	464.07	493.45	375.90	432.17	428.18	338.43
B. Water Content										
Weight in Grams	Tare Plus Wet Soil	274.86	278.97	279.72	281.41	272.15	281.29	283.29	279.82	279.23
	Tare Plus Dry Soil	266.49	268.99	268.99	269.78	261.41	269.24	270.42	266.24	264.59
	Water (W_w)	8.37	9.98	10.73	11.63	10.74	12.05	12.87	13.58	14.64
	Tare	139.55	139.55	139.55	139.55	139.55	139.55	139.55	139.55	139.55
	Dry Soil (W_s)	126.94	129.44	129.44	130.23	121.86	129.69	130.87	126.69	125.04
Water Content (%)		6.59%	7.71%	8.29%	8.93%	8.81%	9.29%	9.83%	10.72%	11.71%
C. Specific Volume										
Test Temperature of Water (°C)		36	34.2	32.4	31.2	33	30.7	33.5	32.6	31.3
Weight in Grams	Wet Soil and Wax	149.61	146.94	136.29	163.9	159.2	156.7	149.1	156.6	160.7
	Wet Soil (W)	130.42	125.38	116.24	137.02	136.9	136.2	126.2	135.3	136.4
	Wax	19.19	21.56	20.05	26.88	22.3	20.5	22.9	21.3	24.3
	Wet Soil and Wax in Water	45.46	40.84	36.65	47.4	48.52	47.56	43.6	49.4	49.63
	Dry Soil (W_s)	122.35	116.41	107.34	125.79	125.81	124.62	114.90	122.20	122.10
Volume in CC	Wet soil and Wax	104.15	106.1	99.64	116.5	110.68	109.14	105.5	107.2	111.07
	Wax	34.89	39.20	36.45	48.87	40.55	37.27	41.64	38.73	44.18
	Wet Soil (V)	69.26	66.90	63.19	67.63	70.13	71.87	63.86	68.47	66.89
Density KN/m^3	Wet Density (γ_m) = (W/V)*9.8	18.45	18.37	18.03	19.86	19.13	18.57	19.37	19.36	19.98
	Dry Density (γ_d) = (W_s/V)*9.8	17.31	17.05	16.65	18.23	17.58	16.99	17.63	17.49	17.89
Specific Volume(V_γ) =1/ρ_d		0.058	0.059	0.060	0.055	0.057	0.059	0.057	0.057	0.056

* E_{25} was calculated by averaging the last three readings from soil suction test results

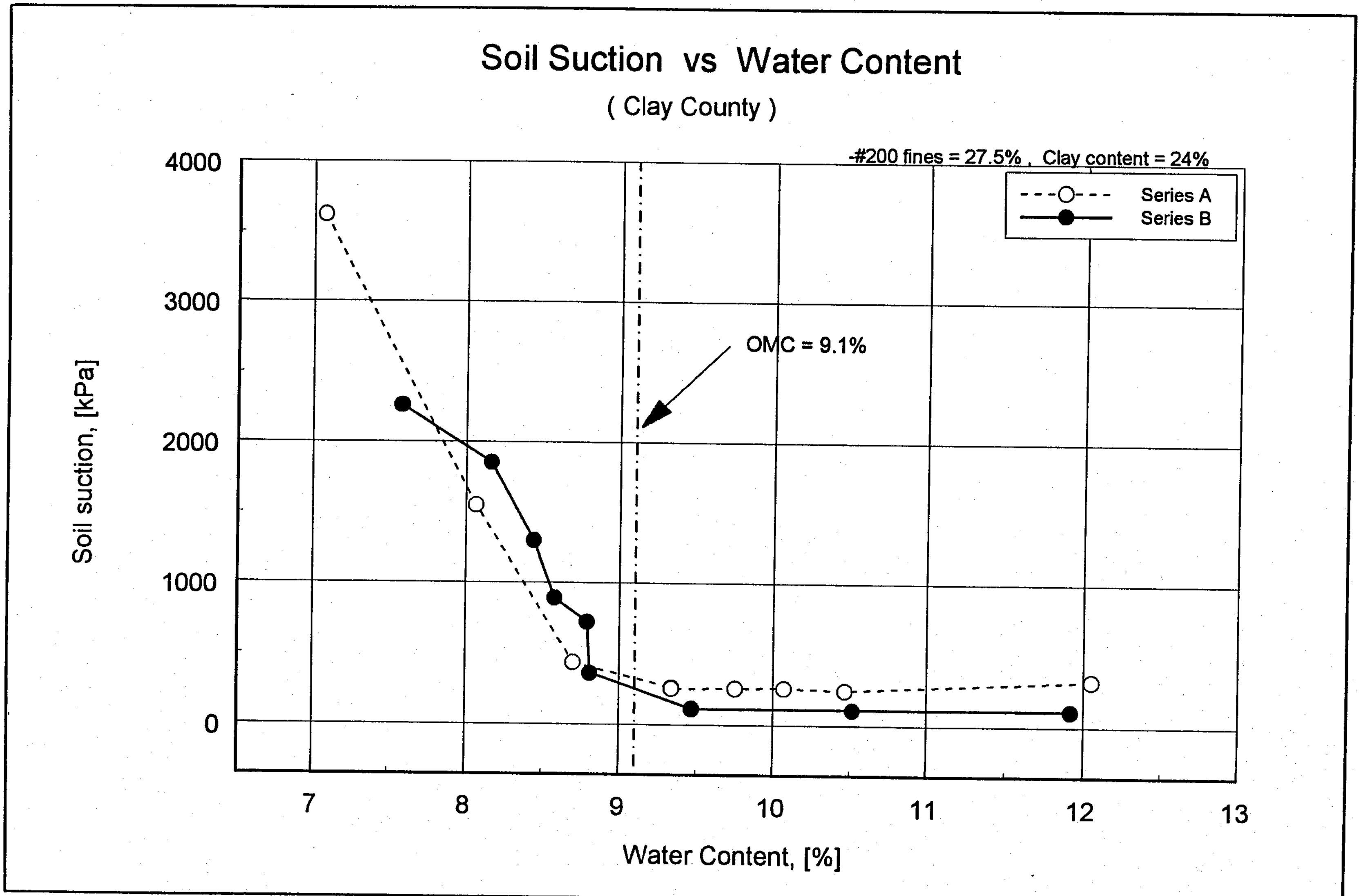

Figure C.1 : Comparison of suction values from Series A and Series B for Clay County soil

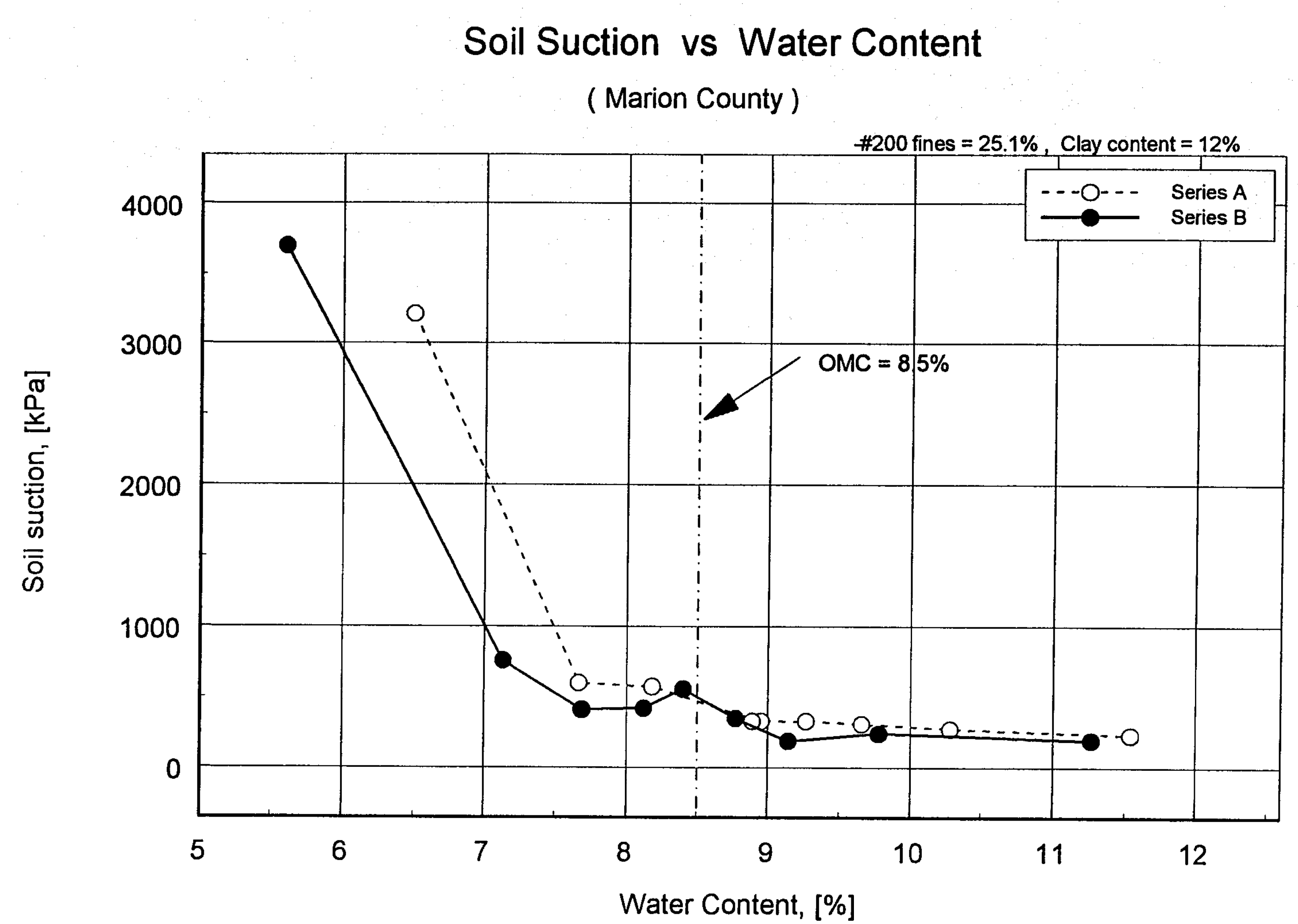

Figure C.2 : Comparison of suction values from Series A and Series B for Marion County soil

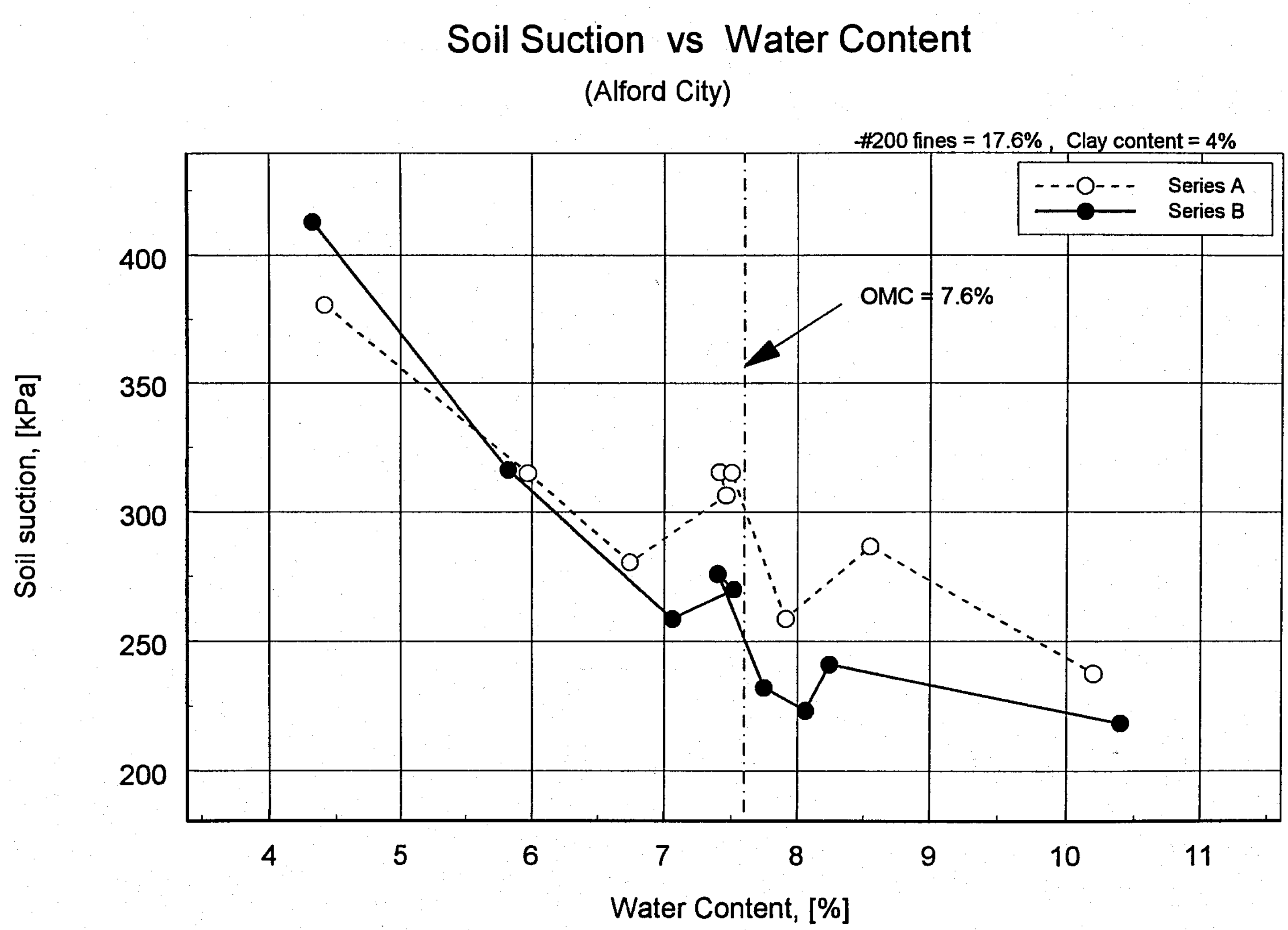

Figure C.3 : Comparison of suction values from Series A and Series B for Alford City soil

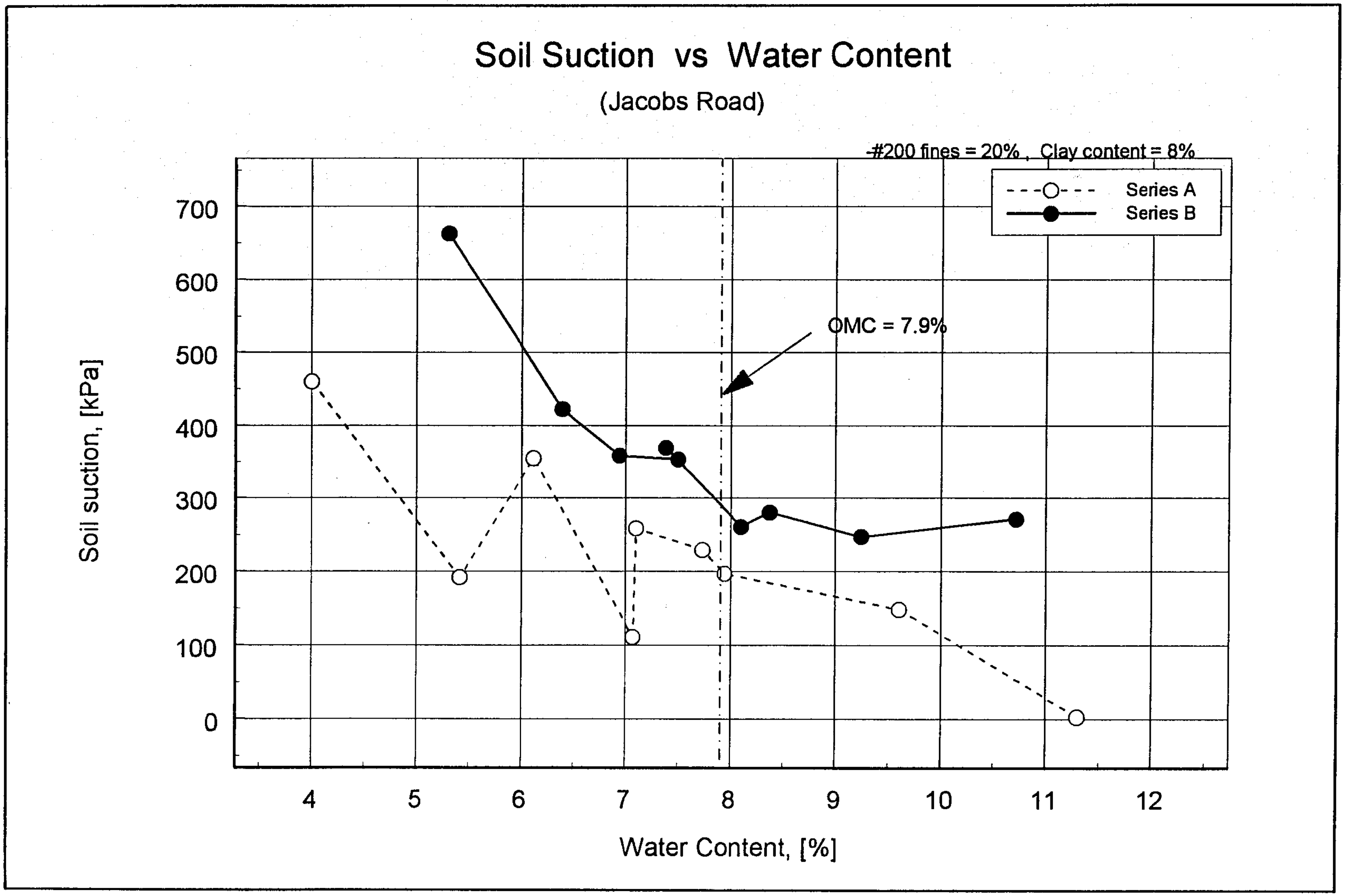

Figure C.4 : Comparison of suction values from Series A and Series B for Jacobs Road soil

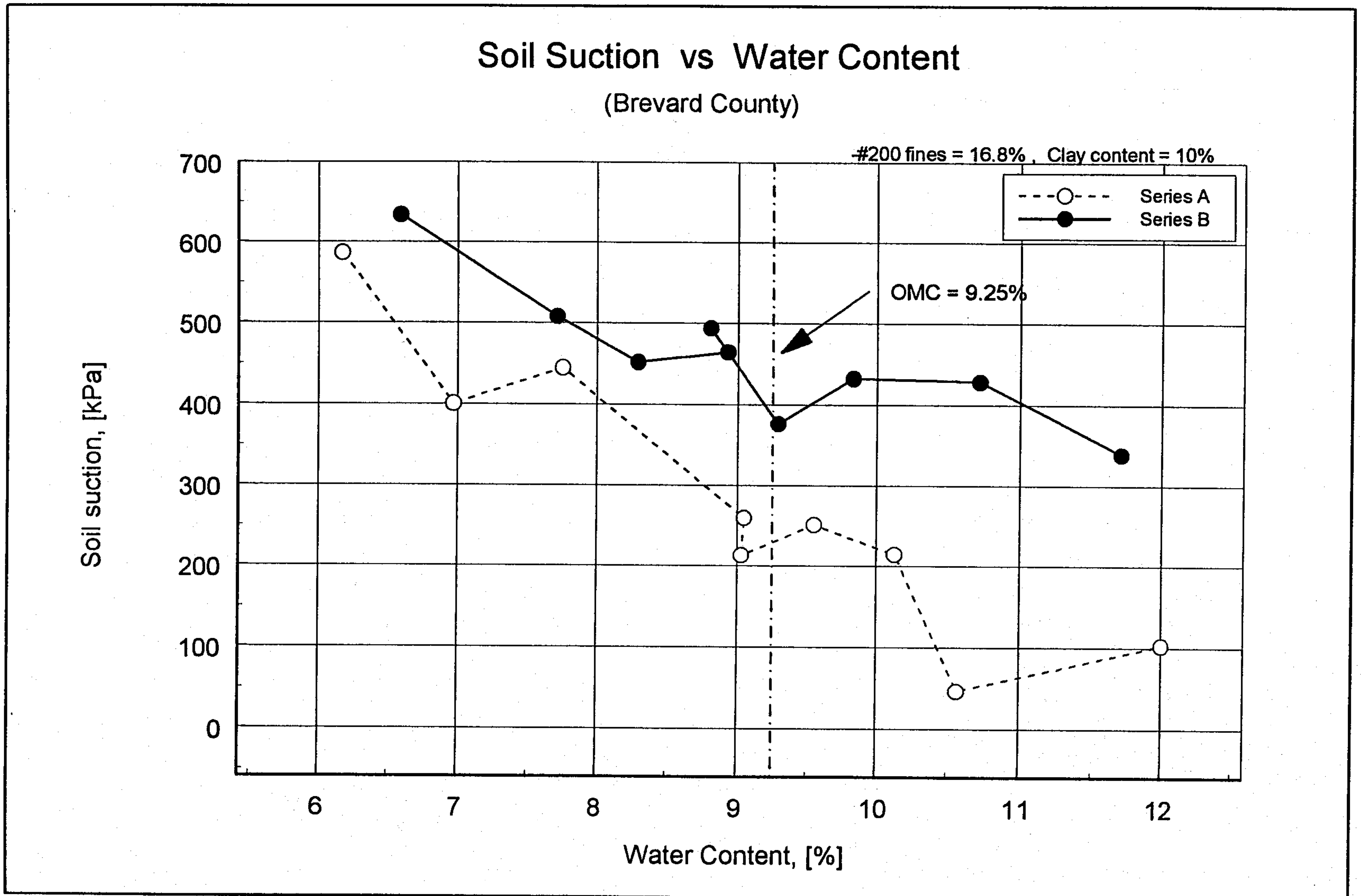

Figure C.5 : Comparison of suction values from Series A and Series B for Brevard County soil

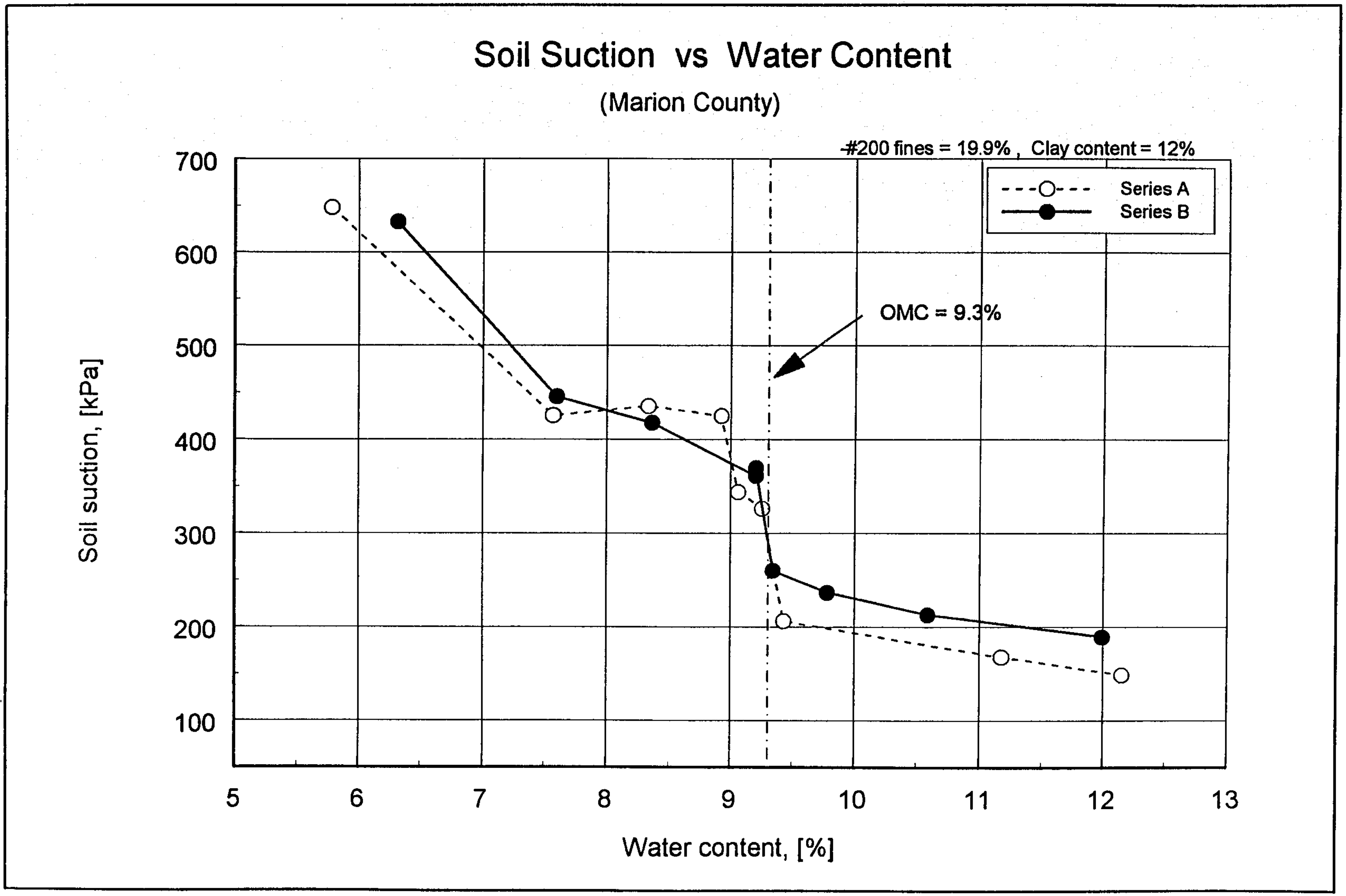

Figure C.6 : Comparison of suction values from Series A and Series B for Marion County soil

APPENDIX D: DRYING RATE GROUP I TEST RESULTS

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Table D.1 : Summary of soil drying rate (Group I) test results

(Temperature : 0^oC, Relative Humidity : 95%)

Sample Surface Area = 0.487 ft^2

	Clay	Madison	Jacobs	Alford	Marion	Brevard
Dry density [KN/m3]	19.4	20.1	20.1	20.0	20.0	18.8
Initial water content [%]	9.10	8.50	7.90	9.20	9.20	9.25
Initial water weight (gram)	169.92	164.49	152.68	177.37	177.37	166.90
Total elapsed time [hour]	282.60	280.60	254.78	255.45	254.30	253.62
Total water loss [gram]	127.60	96.80	100.00	114.00	83.90	99.70
Average drying rate , [gram per hour per ft^2]						
Within first 90 hours	2.07	1.74	1.60	1.96	1.47	1.34
Within first 200 hours	1.23	0.94	0.99	1.13	0.84	0.94
Drying rate, [gram per hour per ft^2]						
@ water content = 2%	-	-	-	0.29	-	-
@ water content = 4%	1.06	0.29	0.92	1.63	-	0.58
@ water content = 6%	1.93	1.93	1.54	2.50	0.77	0.77
@ water content = 8%	8.08	6.35	3.65	-	2.50	2.50
@ optimum water content	14.78	6.98	3.70	3.70	3.49	3.59

Table D.2 : Summary of soil drying rate (Group I) test results

(Temperature : $10^{o}C$, Relative Humidity : 75%)

Sample Surface Area = 0.487 ft^2

	Clay	Madison	Jacobs	Alford	Marion	Brevard
Dry density [KN/m3]	19.3	20.1	19.7	19.5	19.8	18.6
Initial water content [%]	9.10	8.50	7.90	7.60	9.30	9.20
Initial water weight [gram]	169.00	164.36	150.11	143.02	177.01	164.72
Total elapsed time [hour]	240.15	239.55	238.52	238.98	238.07	237.30
Total water loss [gram]	141.00	129.10	119.60	118.10	105.60	123.00
Average drying rate , [gram per hour per ft^2]						
Within first 90 hours	2.74	2.60	2.42	2.43	2.14	2.33
Within first 200 hours	1.43	1.31	1.21	1.19	1.09	1.25
Drying rate, [gram per hour per ft^2]						
@ water content = 2%	0.32	0.18	0.25	0.42	-	-
@ water content = 4%	2.40	2.83	2.80	4.71	0.19	1.12
@ water content = 6%	5.25	5.39	5.42	5.45	3.05	3.85
@ water content = 8%	8.64	12.82	-	-	6.42	7.74
@ optimum water content	12.94	14.37	17.04	13.04	27.72	11.09

Table D.3 : Summary of soil drying rate (Group I) test results

(Temperature : $10^{O}C$, Relative Humidity : 95%)

Sample Surface Area = 0.487 ft^2

	Clay	Madison	Jacobs	Alford	Marion	Brevard
Dry density [KN/m3]	19.1	20.2	20.2	19.6	20.1	18.7
Initial water content [%]	9.10	8.50	7.90	7.60	9.30	9.20
Initial water weight [gram]	167.18	165.15	153.39	143.44	180.04	165.57
Total elapsed time [hour]	236.37	236.09	235.22	235.82	234.44	233.59
Total water loss [gram]	118.10	105.40	112.00	108.20	78.50	96.60
Average drying rate , [gram per hour per ft^2]						
Within first 90 hours	1.89	2.02	2.02	2.09	1.96	1.65
Within first 200 hours	1.17	1.07	1.13	1.09	0.80	0.97
Drying rate, [gram per hour per ft^2]						
@ water content = 2%	-	-	-	0.14	-	-
@ water content = 4%	0.95	1.00	1.66	2.19	-	0.22
@ water content = 6%	1.79	2.40	2.25	2.42	0.80	1.30
@ water content = 8%	2.43	5.67	-	-	2.00	2.11
@ optimum water content	7.60	7.80	9.86	7.91	15.91	5.54

Table D.4 : Summary of soil drying rate (Group I) test results

(Temperature : 25°C, Relative Humidity : 55%)

Sample Surface Area = 0.487 ft^2

	Clay	Madison	Jacobs	Alford	Marion	Brevard
Dry density [KN/m3]	19.5	19.9	19.8	19.7	20.0	18.9
Initial water content [%]	9.10	8.50	7.90	7.60	9.30	9.20
Initial water weight [gram]	171.00	162.70	150.40	155.35	178.90	167.80
Total elapsed time [hour]	237.13	236.73	234.70	233.57	239.58	233.68
Total water loss [gram]	154.90	132.50	119.90	132.60	130.00	139.50
Average drying rate , [gram per hour per ft^2]						
Within first 90 hours	3.22	3.29	2.52	2.84	2.70	2.88
Within first 200 hours	1.58	1.36	1.21	1.36	1.31	1.42
Drying rate, [(gram per hour per ft^2]						
@ water content = 2%	0.84	0.26	0.25	1.50	-	0.37
@ water content = 4%	7.02	6.12	7.39	10.44	1.34	2.28
@ water content = 6%	11.01	11.78	14.20	13.42	7.06	9.11
@ water content = 8%	17.00	17.30	-	-	18.73	14.93
@ optimum water content	17.45	17.45	16.22	14.37	20.53	16.43

Table D.5 : Summary of soil drying rate (Group I) test results

(Temperature : 25°C, Relative Humidity : 75%)

Sample Surface Area = 0.487 ft^2

	Clay	Madison	Jacobs	Alford	Marion	Brevard
Dry density [KN/m3]	19.9	19.9	20.2	19.9	19.9	18.8
Initial water content [%]	9.15	8.50	7.90	7.60	9.30	9.25
Initial water weight [gram]	172.30	163.15	153.53	145.21	178.23	167.03
Total elapsed time [hour]	257.93	230.33	253.82	250.48	340.10	236.45
Total water loss [gram]	153.90	125.70	124.10	125.20	119.30	129.90
Average drying rate , [gram per hour per ft^2]						
Within first 90 hours	3.08	2.51	2.56	2.62	2.45	2.65
Within first 200 hours	1.54	1.26	1.25	1.27	1.18	1.31
Drying rate, [gram per hour per ft^2]						
@ water content = 2%	0.58	0.27	0.27	0.67	-	-
@ water content = 4%	3.75	2.08	4.98	8.65	0.47	2.05
@ water content = 6%	7.65	8.12	9.14	11.22	4.99	7.21
@ water content = 8%	9.20	9.95	-	-	8.82	9.20
@ optimum water content	10.27	10.27	10.27	12.32	9.04	10.27

Table D.6 : Summary of soil drying rate (Group I) test results

(Temperature : 25°C, Relative Humidity : 95%)

Sample Surface Area = 0.487 ft^2

	Clay	Madison	Jacobs	Alford	Marion	Brevard
Dry density [KN/m3]	19.6	20.0	20.0	19.9	20.1	19.0
Initial water content [%]	9.10	8.50	7.90	7.60	9.20	9.25
Initial water weight [gram]	172.10	164.30	152.50	145.30	178.20	169.60
Total elapsed time [hour]	214.25	214.70	260.33	240.83	211.33	239.47
Total water loss [gram]	113.80	77.60	107.10	112.40	79.60	121.00
Average drying rate , [gram per hour per ft^2]						
Within first 90 hours	1.84	1.65	2.09	2.22	1.65	2.17
Within first 200 hours	1.15	0.80	1.09	1.13	0.82	1.31
Drying rate, [gram per hour per ft^2]						
@ water content = 2%	-	-	-	0.23	-	-
@ water content = 4%	0.75	-	1.84	2.22	-	1.16
@ water content = 6%	1.49	1.96	0.55	3.21	1.27	2.30
@ water content = 8%	3.51	4.86	-	-	2.58	3.00
@ optimum water content	6.16	5.54	4.72	2.87	10.88	3.08

Table D.7 : Summary of soil drying rate (Group I) test results

(Temperature : 40^{O}C, Relative Humidity : 55%)

Sample Surface Area = 0.487 ft^2

	Clay	Madison	Jacobs	Alford	Marion	Brevard
Dry density [KN/m3]	19.7	20.3	20.1	19.9	20.0	19.1
Initial water content [%]	9.10	8.50	7.90	7.60	9.30	9.20
Initial water weight [gram]	172.51	165.89	152.68	145.41	179.59	168.97
Total elapsed time [hour]	248.90	247.75	248.62	248.95	248.43	248.88
Total water loss [gram]	160.50	148.50	132.00	131.90	134.50	147.40
Average drying rate , [gram per hour per ft^2]						
Within first 90 hours	3.45	3.17	2.87	2.91	2.90	3.23
Within first 200 hours	1.64	1.52	1.36	1.36	1.38	1.52
Drying rate, [gram per hour per ft^2]						
@ water content = 2%	1.61	1.10	1.17	2.46	-	1.04
@ water content = 4%	9.29	10.81	12.74	15.53	2.80	4.80
@ water content = 6%	15.70	17.22	13.93	13.72	15.10	13.52
@ water content = 8%	13.32	19.05	-	-	14.31	15.79
@ optimum water content	20.54	19.51	19.51	20.54	22.59	16.84

Table D.8 : Measured soil weight at temperature 0°C & humidity 95% (Group I)

Date	Time	Temp. °C	Humidity (%)	Weight (g)					
				Clay (19.4,9.1%)	Madison (20.1,8.5%)	Alford (20,7.6%)	Jacobs (20.1,7.9%)	Brevard (18.8,9.25%)	Marion (20,9.2%)
27-Jun	12:35	0.0	95	2037.2					
	14:35	0.0	95	2024.1					
	15:31	0.0	95		2099.7				
	23:00	0.0	95	2010.5	2079.4				
28-Jun	8:30	0.0	95	2000.6	2068.3				
	17:20	0.0	95	1991.7	2058.9				
	18:23	0.0	95			2064.9			
	19:03	0.0	95				2085.3		
	19:32	0.0	95						2105.3
	20:13	0.0	95					1971.2	
29-Jun	10:15	0.0	95	1977.6	2046.4	2041.4	2063.6	1951.7	2085.3
	22:35	0.0	95	1968.2	2038.5	2029.5	2054.2	1943.2	2075.4
30-Jun	10:30	0.0	95	1960.0	2032.4	2018.7	2045.7	1936.1	2067.4
	23:20	0.0	95	1951.6	2027.0	2006.5	2036.8	1929.0	2058.8
1-Jul	11:00	0.0	95	1945.6	2023.5	1997.0	2029.6	1923.6	2052.5
2-Jul	1:00	0.0	95	1939.1	2019.9	1986.3	2021.5	1917.4	2045.7
	9:45	0.0	95	1935.5	2017.4	1980.8	2017.0	1913.9	2042.5
	22:40	0.0	95	1931.6	2015.0	1974.1	2011.5	1910.3	2038.3
3-Jul	11:55	0.0	95	1927.6	2012.5	1968.2	2005.1	1904.0	2033.4
	22:45	0.0	95	1925.1	2011.2	1965.1	2002.1	1900.3	2031.3
4-Jul	10:40	0.0	95	1923.1	2010.3	1962.5	1999.0	1896.8	2029.7
	21:35	0.0	95	1921.4	2009.3	1960.6	1996.7	1893.8	2028.3
5-Jul	14:25	0.0	95	1918.8	2008.0	1958.1	1993.6	1889.6	2026.3
6-Jul	9:45	0.0	95	1916.2	2006.6	1956.1	1991.1	1884.2	2024.6
7-Jul	21:30	0.0	95	1913.5	2004.7	1953.7	1988.5	1878.9	2022.8
	22:55	0.0	95	1912.2	2004.3	1953.0	1987.7	1876.6	2022.5
8-Jul	8:50	0.0	95	1911.4	2003.8	1952.4	1986.6	1875.0	2022.0
	21:20	0.0	95	1910.5	2003.4	1951.3	1985.8	1873.2	2021.7
9-Jul	9:50	0.0	95	1909.6	2002.9	1950.9	1985.3	1871.5	2021.4

Table D.9 : Measured soil weight at temperature 10°C & humidity 75% (Group I)

Date	Time	Temp. °C	Humidity (%)	Weigth (g)					
				Clay (19.3,9.1%)	Madison (20.1,8.5%)	Alford (19.5,7.6%)	Jacobs (19.7,7.9%)	Brevard (18.6,9.2%)	Marion (19.8,9.3%)
7-Aug	10:54	10.1	78	2026.6					
	11:30	10.0	73		2098.0				
	12:04	10.0	73			2024.8			
	12:32	10.0	73				2050.3		
	12:59	10.0	73						2080.4
	13:45	10.0	73	2011.7	2084.6	2014.8	2040.4	1955.1	2071.5
	17:20	10.0	73	2000.4	2073.7	2004.3	2029.8	1938.7	2059.3
	21:35	10.0	78	1988.9	2061.4	1993.2	2018.3	1927.1	2048.4
8-Aug	11:50	10.0	78	1954.1	2026.8	1959.1	1987.2	1899.0	2021.6
	15:00	10.0	70	1947.6	2020.0	1952.5	1981.3	1894.0	2016.9
	20:05	10.0	75	1940.1	2012.8	1944.9	1974.5	1888.4	2011.8
9-Aug	11:57	10.0	73	1924.5	1998.2	1931.1	1959.6	1874.0	2000.4
	23:28	10.0	73	1917.5	1992.7	1926.3	1953.6	1866.8	1995.3
10-Aug	11:55	10.0	77	1911.9	1988.2	1922.5	1949.1	1860.4	1991.3
	21:18	10.0	76	1908.6	1986.3	1920.6	1946.7	1856.7	1989.1
11-Aug	10:50	10.1	74	1904.5	1983.1	1917.8	1943.8	1852.0	1986.3
	21:20	10.0	68	1901.2	1980.4	1916.0	1941.4	1848.2	1983.1
12-Aug	11:30	9.8	77	1898.7	1978.9	1914.5	1939.6	1845.5	1982.2
	21:20	10.0	76	1896.8	1977.6	1913.5	1938.4	1843.4	1981.1
13-Aug	12:15	9.9	71	1894.5	1975.9	1912.0	1936.9	1840.7	1979.7
	21:55	9.9	74	1893.1	1974.8	1911.2	1936.0	1839.5	1978.9
14-Aug	12:17	10.0	77	1891..4	1973.4	1910.0	1934.7	1837.6	1977.9
15-Aug	10:48	9.8	72	1889.0	1971.6	1808.7	1933.0	1835.2	1976.6
16-Aug	9:50	10.0	73	1887.0	1969.9	1907.6	1931.6	1833.2	1975.1
17-Aug	11:03	10.0	75	1885.6	1968.9	1906.7	1930.7	1832.1	1974.8

Table D.10 : Measured soil weight at temperature 10°C & humidity 95% (Group I)

Date	Time	Temp. °C	Humidity (%)	Weight (g)					
				Clay (19.1,9.1%)	Madison (20.2,8.5%)	Alford (19.6,7.6%)	Jacobs (20.2,7.9%)	Brevard (18.7,9.2%)	Marion (20.1,9.3%)
25-Aug	16:20	10.0	94	2004.3					
	16:37	9.9	96		2108.1				
	16:53	10.0	96			2030.8			
	17:29	10.0	96				2095.0		
	18:16	10.0	95						2116.0
	19:07	10.2	94	1995.9	2099.9	2023.4	2087.8	1965.3	2109.7
	23:28	10.0	96	1990.3	2094.1	2017.9	2082.3	1955.4	2104.1
26-Aug	10:25	10.0	97	1978.4	2080.8	2005.0	2070.6	1944.1	2093.3
	15:05	10.0	96	1973.8	2075.3	1999.5	2065.7	1939.5	2088.8
27-Aug	0:05	10.0	95	1964.9	2064.4	1988.9	2055.7	1930.7	2080.2
	8:00	10.0	96	1957.4	2055.4	1979.6	2047.1	1923.7	2074.3
28-Aug	0:57	10.0	96	1943.2	2039.1	1961.7	2030.7	1911.2	2063.3
	9:25	10.0	95	1937.4	2033.1	1954.6	2023.4	1906.2	2059.2
	20:28	10.0	95	1929.7	2026.0	1946.3	2015.0	1899.9	2054.1
29-Aug	10:10	10.0	95	1921.6	2019.7	1939.5	2007.2	1894.1	2049.9
	17:02	10.0	95	1917.7	2017.3	1937.3	2003.5	1891.5	2048.2
	22:41	10.0	95	1914.5	2015.3	1935.4	2001.1	1889.5	2046.9
30-Aug	15:36	10.0	95	1907.9	2012.1	1932.0	1995.6	1884.7	2043.7
	22:10	10.0	94	1905.4	2010.8	1931.0	1994.1	1883.0	2042.8
31-Aug	10:26	10.0	95	1901.7	2008.8	1929.2	1991.6	1880.3	2041.5
	20:46	10.0	94	1899.3	2007.5	1927.9	1990.1	1878.4	2040.8
1-Sep	9:40	10.0	95	1896.2	2006.8	1926.9	1988.8	1876.5	2040.1
	20:56	10.0	95	1894.1	2005.6	1926.1	1987.2	1874.7	2039.1
2-Sep	10:01	10.0	96	1892.0	2005.2	1925.2	1986.4	1873.1	2038.9
3-Sep	13:03	10.0	95	1888.4	2003.6	1923.6	1984.3	1870.6	2038.1
4-Sep	12:42	10.0	96	1886.2	2002.7	1922.6	1983.0	1868.7	2037.5

Table D.11 : Measured soil weight at temperature 25°C & humidity 55% (Group I)

Date	Time	Temp. (°C)	Humidity (%)	Weight (g)					
				Clay (19.5,9.1%)	Madison (19.9,8.5%)	Alford (19.7,7.6%)	Jacobs (19.8,7.9%)	Brevard (18.9,9.2%)	Marion (20.0,9.3%)
21-Jul	10:45	25.0	55						2102.1
	13:12	25.0	55	2049.6					
	13:36	25.0	55		2076.4				
	15:38	25.0	55				2053.6		
	16:31	25.0	55					1992.0	
	16:46	25.0	54	2020.4	2050.1	2044.1			2056.5
	21:45	25.0	58	1993.2	2024.1	2011.7	2012.5	1957.1	2039.2
22-Jul	10:15	25.0	55	1951.8	1988.4	1957.2	1973.9	1919.6	2014.8
	16:40	25.0	55	1943.3	1981.7	1947.6	1966.7	1909.5	2008.5
	21:10	25.0	55	1937.9	1978.2	1943.2	1963.3	1903.8	2005.1
23-Jul	1:37	25.0	55	1933.8	1975.1	1939.7	1960.3	1898.7	2002.2
	13:47	25.0	55	1925.5	1968.7	1932.8	1954.5	1887.6	1995.5
24-Jul	8:45	25.0	53	1917.4	1963.0	1927.0	1949.5	1877.2	1990.2
	21:05	25.0	57	1913.1	1959.6	1923.9	1946.6	1871.6	1986.7
25-Jul	8:05	25.0	55	1907.3	1954.9	1919.9	1942.8	1864.6	1982.3
26-Jul	10:00	25.0	54	1904.9	1952.9	1918.1	1941.1	1861.8	1980.4
	20:05	25.0	54	1903.2	1951.7	1917.1	1940.1	1860.1	1979.3
27-Jul	10:30	25.0	55	1901.4	1950.0	1915.8	1938.8	1858.1	1977.7
	20:07	25.0	54	1900.2	1949.1	1915.0	1938.0	1857.1	1976.9
28-Jul	10:48	25.0	54	1898.8	1948.0	1914.2	1937.1	1856.0	1976.2
	21:00	25.0	58	1898.0	1947.2	1913.5	1936.3	1855.3	1975.3
29-Jul	10:30	25.0	56	1896.9	1946.1	1912.8	1935.3	1854.1	1974.1
30-Jul	10:12	25.0	53	1895.6	1944.9	1911.9	1934.5	1853.0	1972.7
31-Jul	10:20	25.0	54	1894.7	1943.9	1911.5	1933.7	1852.5	1972.1

Table D.12 : Measured soil weight (Group I) at temperature 25°C & humidity 75%

Date	Time	Weight (g)		
		Marion (19.9,9.3%)	Clay (19.9,9.15%)	Madison (19.9,8.5%)
20-Mar	14:25	2094.7		
	16:36	2085.5		
	18:50	2074.9		
	21:10	2065.7		
	23:40	2056.9		
21-Mar	1:00	2052.3		
	7:10	2034.8		
	9:40	2029.4		
	12:00	2025.0		
	14:26	2021.4		
	16:28	2018.9		
	22:28	2011.7		
22-Mar	1:18	2009.2		
	2:18	2008.3		
	8:18	2004.2		
	11:35	2002.2		
	14:23	2000.9		
	17:06	1999.6		
	22:12	1997.6		
23-Mar	7:50	1994.4		
	11:25	1993.6		
	19:50	1991.6		
24-Mar	8:56	1987.0		
	10:44	1986.8	2054.8	
	13:48	1986.6	2040.7	
	20:05	1986.0	2014.4	
	23:43	1985.5	2000.5	
25-Mar	11:35	1984.7	1964.1	
	13:15	1984.4	1960.8	
	14:20			2082.6
	21:34	1983.9	1949.2	2050.2
26-Mar	9:05	1983.1	1938.9	2013.1
	11:15	1982.9	1937.3	2008.4
	13:15	1982.8	1936.1	2004.9
	17:30	1982.6	1933.5	1999.1
	19:20	1982.4	1932.4	1997.2
	23:08	1982.2	1930.4	1993.6
27-Mar	9:23	1981.7	1925.9	1987.2
	11:40	1981.6	1925.2	1986.0
	13:45	1981.5	1924.5	1985.0
	16:24	1981.3	1923.4	1983.8
	19:55	1981.2	1922.5	1982.3

Date	Time	Weight (g)		
		Alford (19.9,7.6%)	Jacobs (20.2,7.9%)	Brevard (18.8,9.25%)
9-Apr	13:00			1972.8
	13:20		2097.0	
	17:25		2077.7	1952.7
	17:40	2055.9		
10-Apr	9:30	1989.1	2026.4	1908.7
	11:45	1982.0	2021.7	1904.8
	13:51	1976.3	2017.4	1901.2
	22:40	1962.7	2006.1	1889.7
11-Apr	9:20	1955.4	1999.2	1879.8
	13:35	1953.3	1997.0	1876.5
	16:30	1952.0	1995.7	1874.7
	22:30	1950.2	1993.8	1871.4
12-Apr	10:20	1945.6	1990.2	1865.1
	16:45	1945.6	1988.9	1862.7
	22:15	1943.9	1987.4	1860.5
13-Apr	13:50	1941.4	1984.7	1856.1
	15:57	1940.8	1984.3	1855.5
	17:45	1940.6	1984.0	1855.1
14-Apr	9:50	1938.8	1982.0	1851.9
	12:20	1938.4	1981.6	1851.2
	19:25	1937.7	1980.9	1850.3
15-Apr	9:10	1936.5	1979.7	1848.6
	11:20	1936.3	1979.3	1848.2
	13:16	1936.0	1979.2	1848.1
	16:43	1935.7	1979.0	1847.7
	20:20	1935.5	1978.6	1847.4
	22:16	1935.3	1978.3	1847.2
16-Apr	9:15	1934.6	1977.5	1846.4
	12:45	1934.4	1977.3	1846.1
	16:45	1934.2	1977.1	1845.9
17-Apr	0:10	1933.7	1976.5	1845.3
	9:10	1933.3	1976.1	1844.8
	15:32	1933.0	1975.8	1844.5
18-Apr	9:35	1932.4	1974.8	1844.0
	17:00	1932.0	1974.6	1843.6
19-Apr	16:33	1931.1	1973.1	1842.9
20-Apr	10:15	1930.7	1972.9	1842.7

Table D.12 : Measured soil weight (Group I) at temperature 25°C & humidity 75% (Cont'd)

Date	Time	Weight (g)			Date	Time	Weight (g)		
		Marion (19.9,9.3%)	Clay (19.9,9.15%)	Madison (19.9,8.5%)			Alford (19.9,7.6%)	Jacobs (20.2,7.9%)	Brevard (18.8,9.25%)
	22:54	1980.9	1921.6	1981.1					
28-Mar	9:35	1980.4	1918.8	1977.8					
	13:20	1980.1	1918.0	1976.8					
	16:33	1980.1	1917.6	1975.9					
	19:50	1979.9	1916.6	1975.3					
	22:55	1979.7	1916.1	1974.4					
29-Mar	10:46	1979.1	1913.9	1972.2					
	13:27	1979.0	1913.4	1971.6					
	16:45	1978.9	1913.0	1971.0					
	19:56	1978.8	1912.3	1970.6					
	23:00	1978.8	1912.0	1970.2					
30-Mar	10:36	1978.1	1910.3	1968.2					
	13:47	1978.1	1910.0	1967.8					
	17:00	1977.9	1909.5	1967.3					
31-Mar	10:40	1977.3	1907.6	1965.5					
	17:05	1977.1	1907.4	1964.7					
1-Apr	11:03	1976.7	1905.8	1963.1					
	20:55	1976.4	1905.0	1962.5					
2-Apr	0:45	1975.9	1904.0	1960.9					
	10:20	1975.4	1902.9	1959.7					
	20:33	1975.4	1902.5	1959.2					
3-Apr	8:40		1900.8	1956.9					

Table D.13 : Measured soil weight (Group I) at temperature 25°C & humidity 95%

Date	Time	Temp. °C	Humidity %	Weight (g)					
				Clay (19.6,9.1%)	Madison (20.0,8.56%)	Alford (19.9,7.6%)	Jacobs (20.0,7.9%)	Brevard (19.0,9.25%)	Marion (20.1,9.2%)
16-Jun	14:30	25.0	95				2082.6		
	15:40	25.0	95				2080.0		
	16:55	25.0	95				2077.8		
17-Jun	9:24	25.0	95				2047.1		
	10:00	25.0	95			2057.3			
	11:22	25.0	95					2003.0	
	13:47	25.0	95			2052.2	2041.6	2000.0	
	15:55	25.0	95			2047.1	2037.1	1995.1	
	23:25	25.0	95			2035.2	2027.1	1984.1	
18-Jun	10:30	25.0	95			2018.2	2014.1	1968.1	
	12:08	25.0	95		2083.5				
	12:35	25.0	95	2063.8					
	14:30	25.0	95	2058.3	2077.2	2011.4	2010.0	1961.8	
	15:30	25.0	95						2115.4
19-Jun	10:40	25.0	95	2035.6	2054.4	1989.8	1999.5	1940.6	2092.0
	13:45	25.0	95	2032.1	2050.7	1986.4	1997.9	1937.2	2088.3
	14:30	25.0	95	2031.0	2049.4	1985.2	1997.2	1936.2	2087.0
	15:55	25.0	95	2029.4	2047.6	1983.3	1996.4	1934.5	2085.0
	20:07	25.0	95	2024.7	2042.6	1978.7	1994.7	1930.4	2079.4
20-Jun	10:45	25.0	95	2013.6	2030.3	1968.4	1990.6	1919.4	2066.1
	15:30	25.0	95	2009.7	2026.6	1965.7	1989.0	1916.1	2062.2
	23:50	25.0	95	2003.9	2021.6	1961.9	1987.2	1911.1	2056.4
21-Jun	7:00	25.0	95	1998.3	2017.8	1959.1	1985.3	1907.0	2052.2
	14:10	25.0	95	1993.4	2015.3	1957.0	1984.2	1903.8	2049.1
	21:40	25.0	95	1988.4	2013.1	1955.1	1982.9	1900.7	2046.3
22-Jun	11:55	25.0	95	1980.1	2010.2	1952.4	1980.8	1895.9	2042.6
	21:00	25.0	95	1975.4	2008.8	1950.9	1979.7	1893.6	2040.6
23-Jun	9:45	25.0	95	1970.1	2007.9	1949.8	1978.9	1891.0	2039.2
	22:10	25.0	95	1965.9	2007.4	1948.9	1978.2	1889.1	2038.3
24-Jun	10:10	25.0	95	1962.6	2006.9	1948.2	1977.8	1887.4	2037.7
25-Jun	9:40	25.0	95	1957.7	2006.6	1946.9	1977.2	1885.2	2036.9
26-Jun	9:45	25.0	95	1953.1	2005.9	1945.8	1976.1	1883.4	2036.2
27-Jun	10:50	25.0	95	1950.0	2005.9	1944.9	1975.5	1882.0	2035.8

Table D.14 : Measured soil weight (Group I) at temperature 40°C & humidity 55%

Date	Time	Temp. oC	Humidity %	Weight(g)					
				Clay (19.7,9.1%)	Madison (20.3,8.5%)	Alford (19.9,7.6%)	Jacobs (20.1,7.9%)	Brevard (19.1,9.2%)	Marion (20.0,9.3%)
6-Sep	1:29	40.0	55			2058.7			
	1:32	40.1	55	2068.2					
	1:33	40.0	55					2005.6	
	1:49	39.9	54				2085.3		
	2:00	40.0	55						2110.7
	2:41	40.0	53		2117.6				
	2:47	40.0	53	2060.6		2050.7	2079.7	1995.6	2105.4
	11:17	40.0	54	1990.6	2049.3	1985.6	2016.1	1940.7	2042.5
	17:18	40.1	57	1967.8	2023.1	1966.1	1996.0	1922.1	2025.0
7-Sep	1:39	40.0	55	1951.9	2008.1	1954.3	1983.6	1905.2	2011.7
	20:05	40.0	53	1939.0	1997.5	1945.4	1974.5	1889.4	2001.1
8-Sep	13:30	40.0	53	1931.0	1991.2	1940.4	1969.2	1879.8	1995.0
	15:01	40.0	53	1925.1	1986.4	1936.8	1965.3	1873.1	1990.4
9-Sep	8:15	40.1	54	1919.6	1981.7	1933.3	1961.7	1867.2	1986.2
	22:40	40.0	53	1916.1	1978.6	1931.4	1959.4	1863.9	1983.7
10-Sep	11:01	40.0	51	1914.0	1976.7	1929.9	1957.8	1862.1	1981.4
	21:20	39.9	55	1912.5	1975.5	1929.2	1956.9	1861.3	1980.8
11-Sep	9:40	40.0	55	1911.2	1974.3	1928.7	1956.2	1860.5	1979.8
	20:00	40.1	55	1910.3	1973.3	1928.3	1955.7	1860.0	1979.2
12-Sep	14:19	40.1	55	1909.2	1972.2	1927.6	1954.7	1859.3	1978.4
13-Sep	13:42	40.0	55	1908.5	1971.1	1927.4	1954.1	1858.8	1977.5
14-Sep	13:09	40.0	55	1908.1	1970.2	1927.2	1953.7	1858.5	1977.1
15-Sep	12:47	40.1	55	1907.8	1969.6	1926.8	1953.4	1858.5	1976.7
16-Sep	10:26	40.0	55	1907.7	1969.1	1926.8	1953.3	1858.2	1976.2

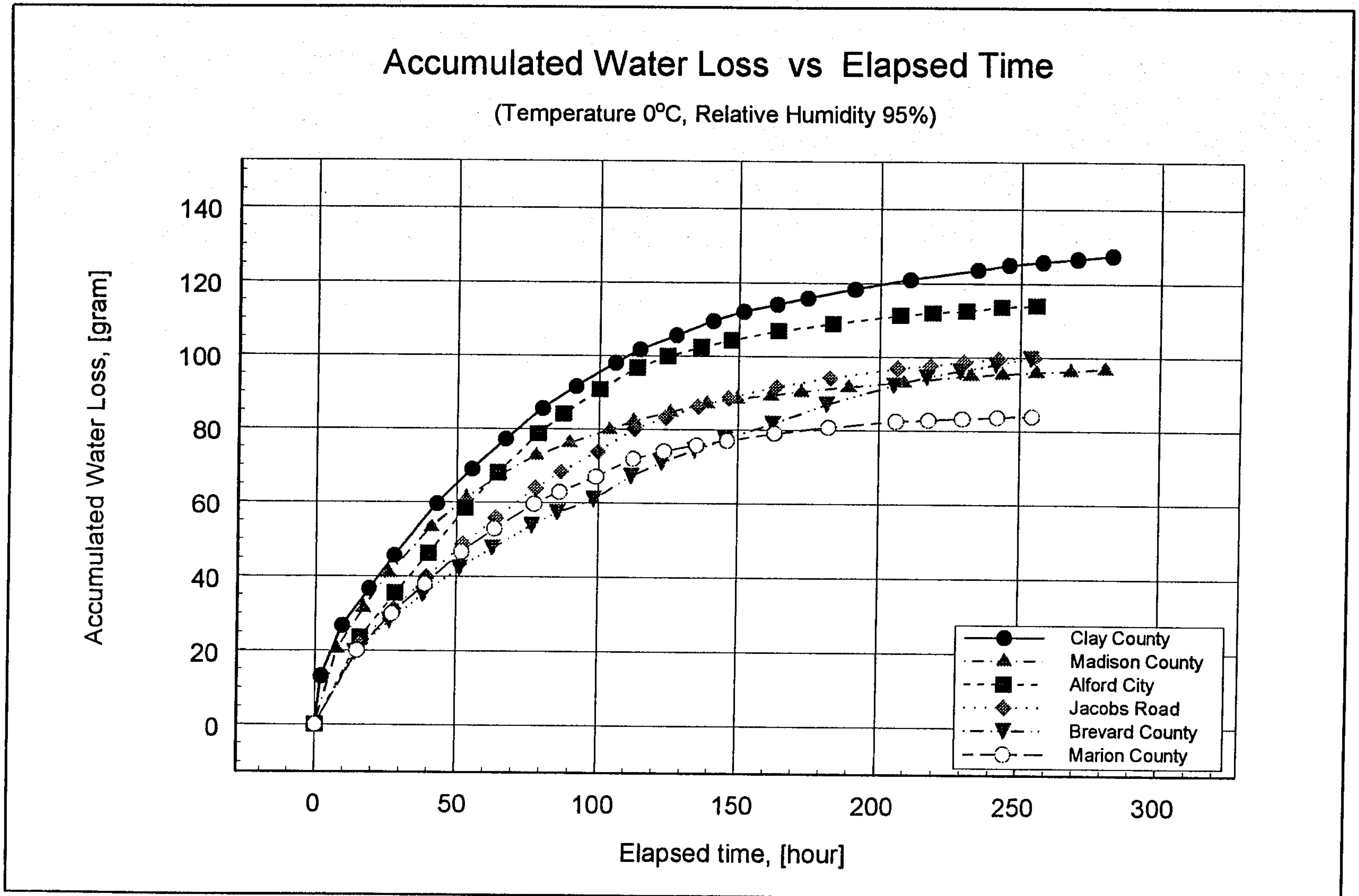

Figure D.1(a) : Water loss versus elapsed time at temperature 0°C and 95% relative humidity for six soils (Group I)

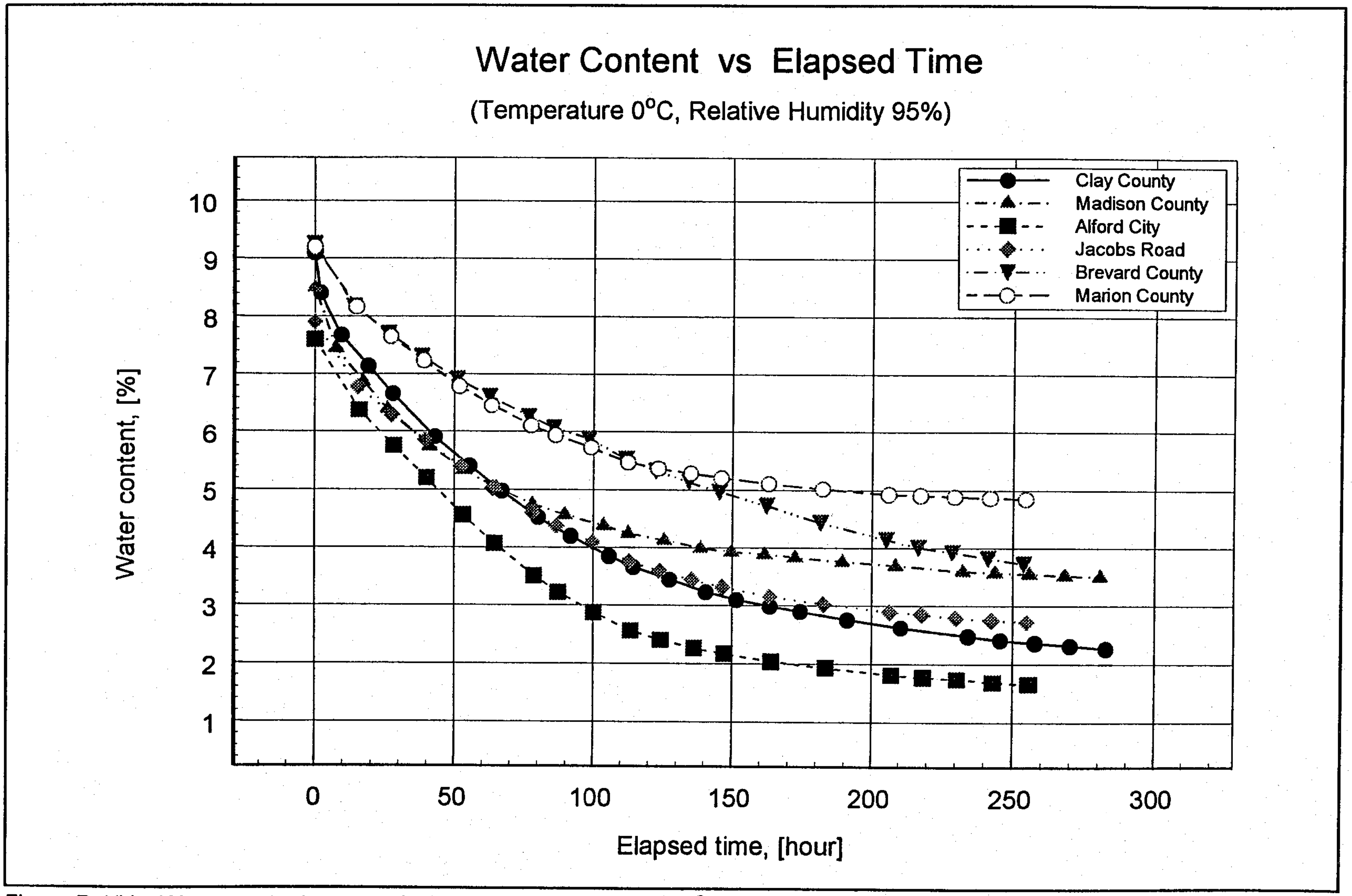

Figure D.1(b) : Water content versus elapsed time at temperature 0°C and relative humidity 95% for six soils (Group I)

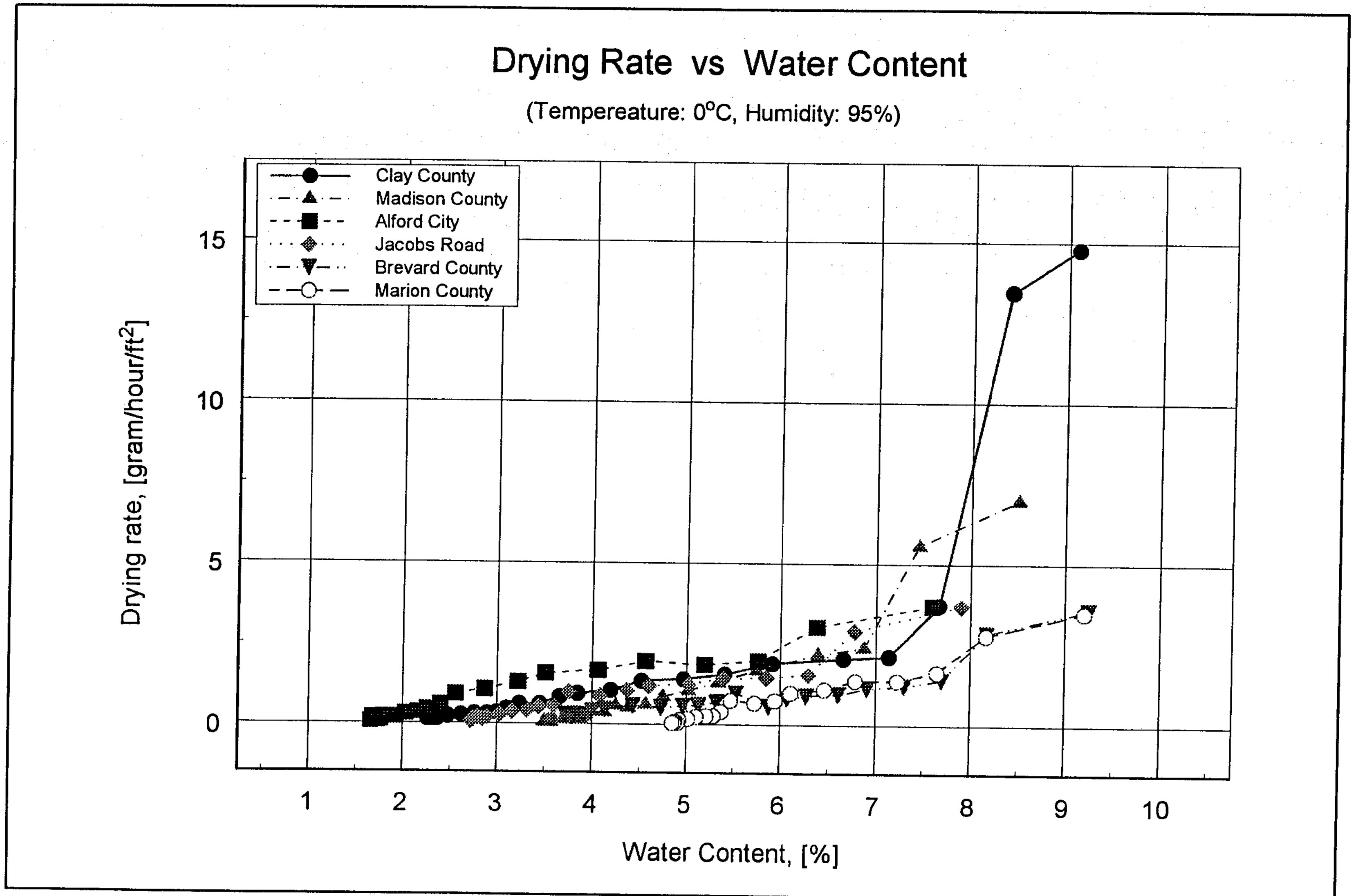

Figure D.1(c) : Drying rate versus water content for six soils at temperature 0°C and 95% relative humidity (Group I)

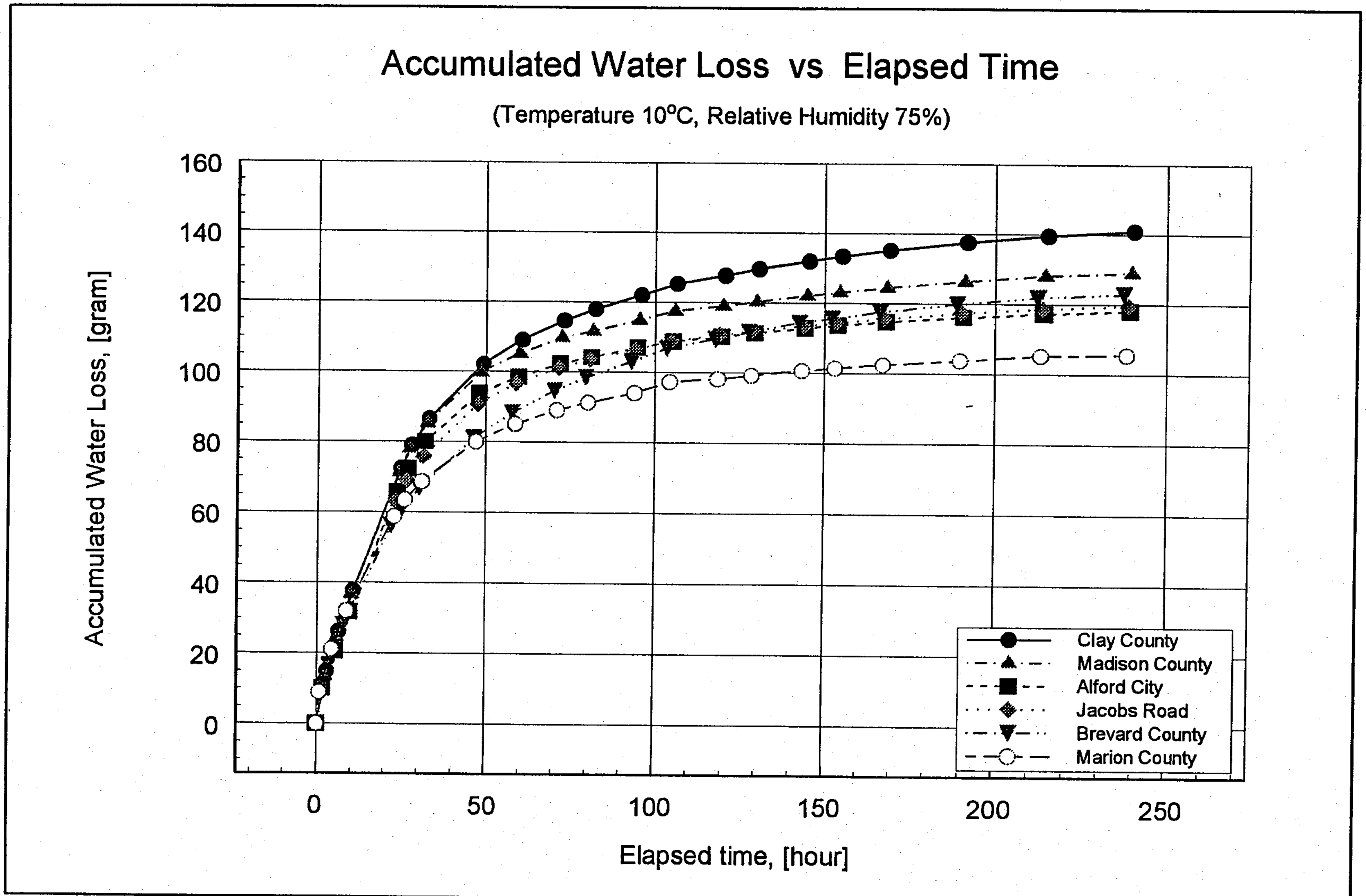

Figure D.2(a) : Water loss versus elapsed time at temperature 10°C and 75% relative humidity for six soils (Group I)

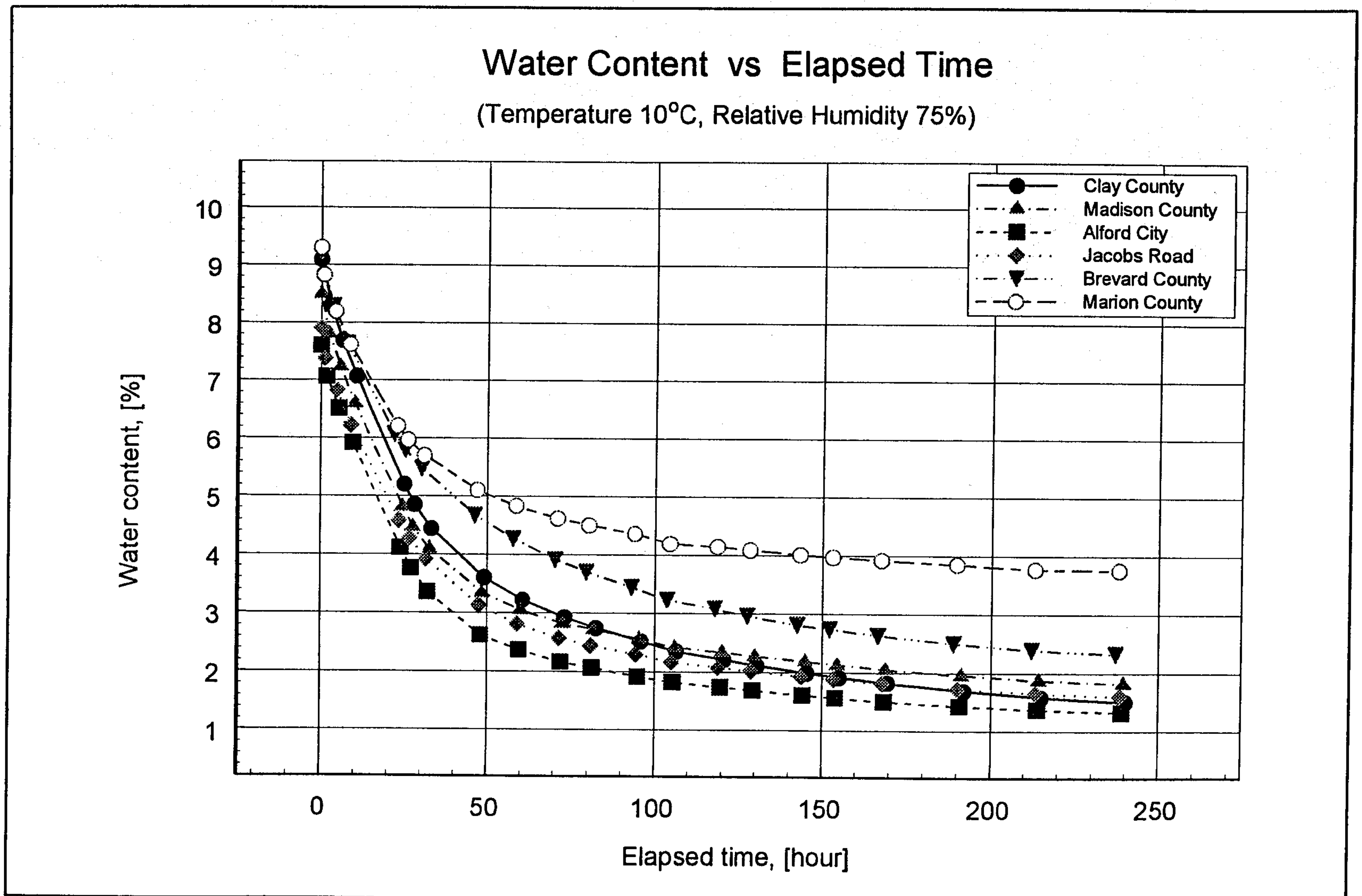

Figure D.2(b) : Water content versus elapsed time at temperature 10°C and relative humidity 75% for six soils (Group I)

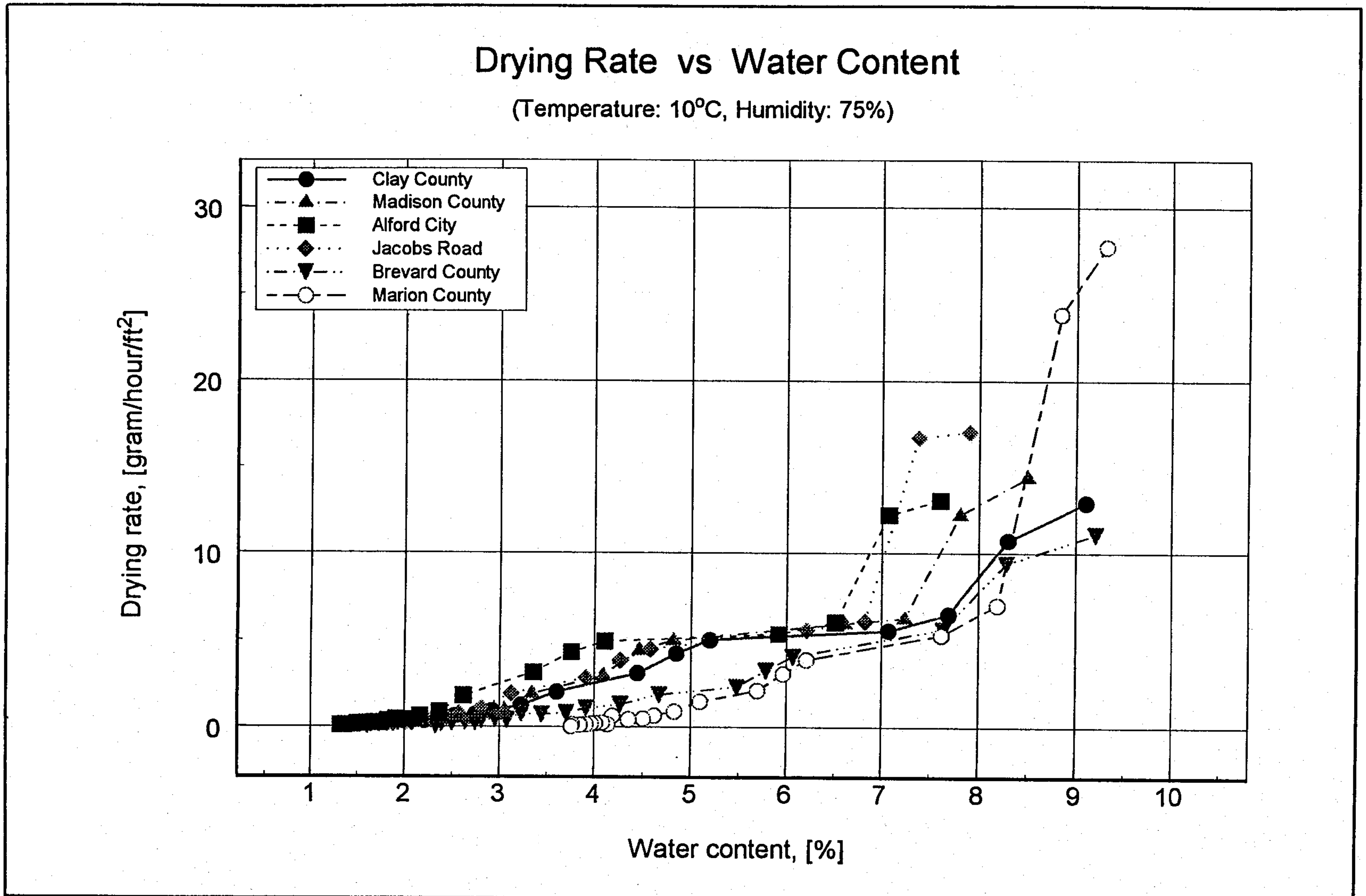

Figure D.2(c) : Drying rate versus water content for six soils at temperature 10°C and 75% relative humidity (Group I)

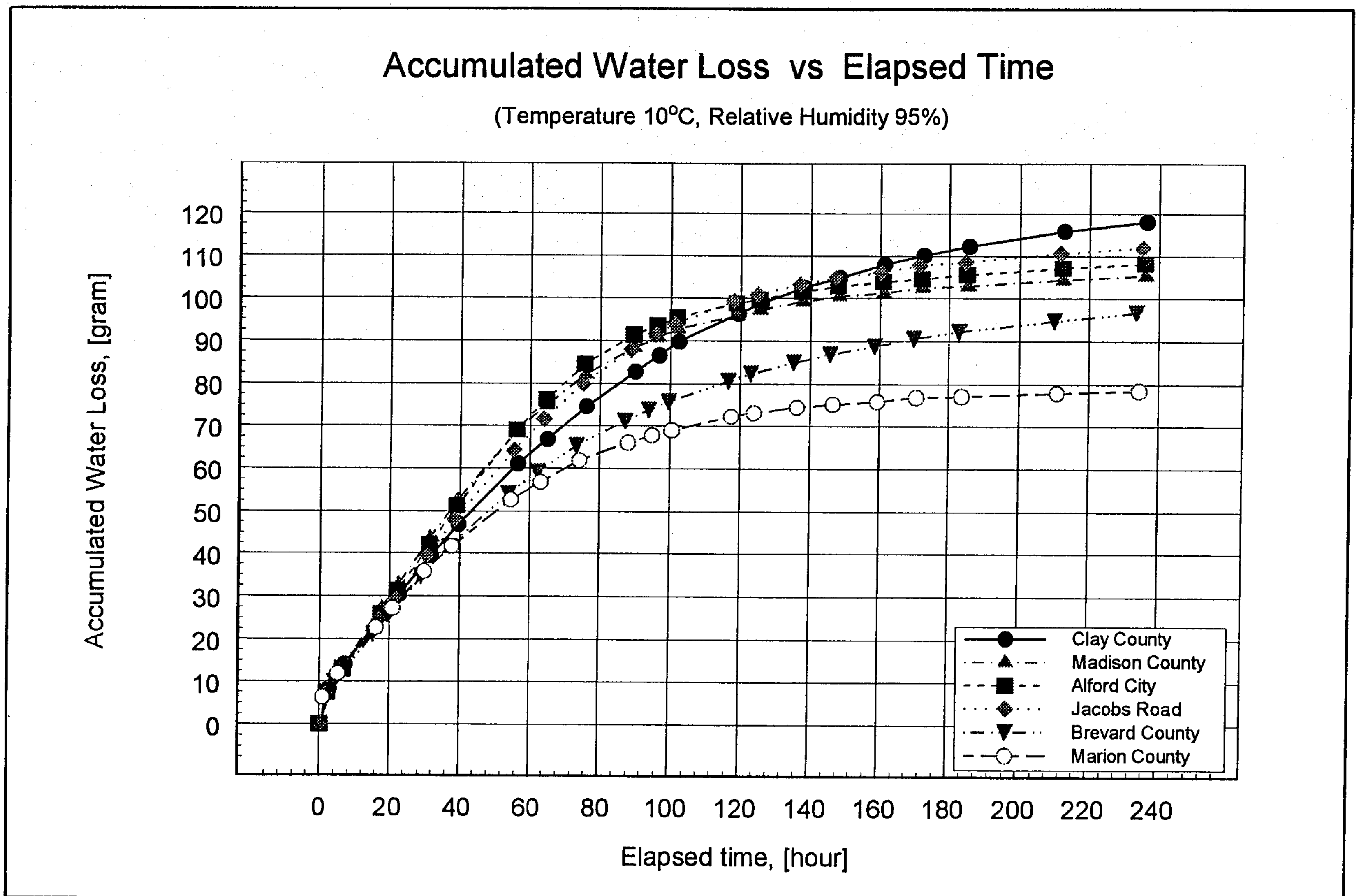

Figure D.3(a) : Water loss versus elapsed time at temperature 10°C and 95% relative humidity for six soils (Group I)

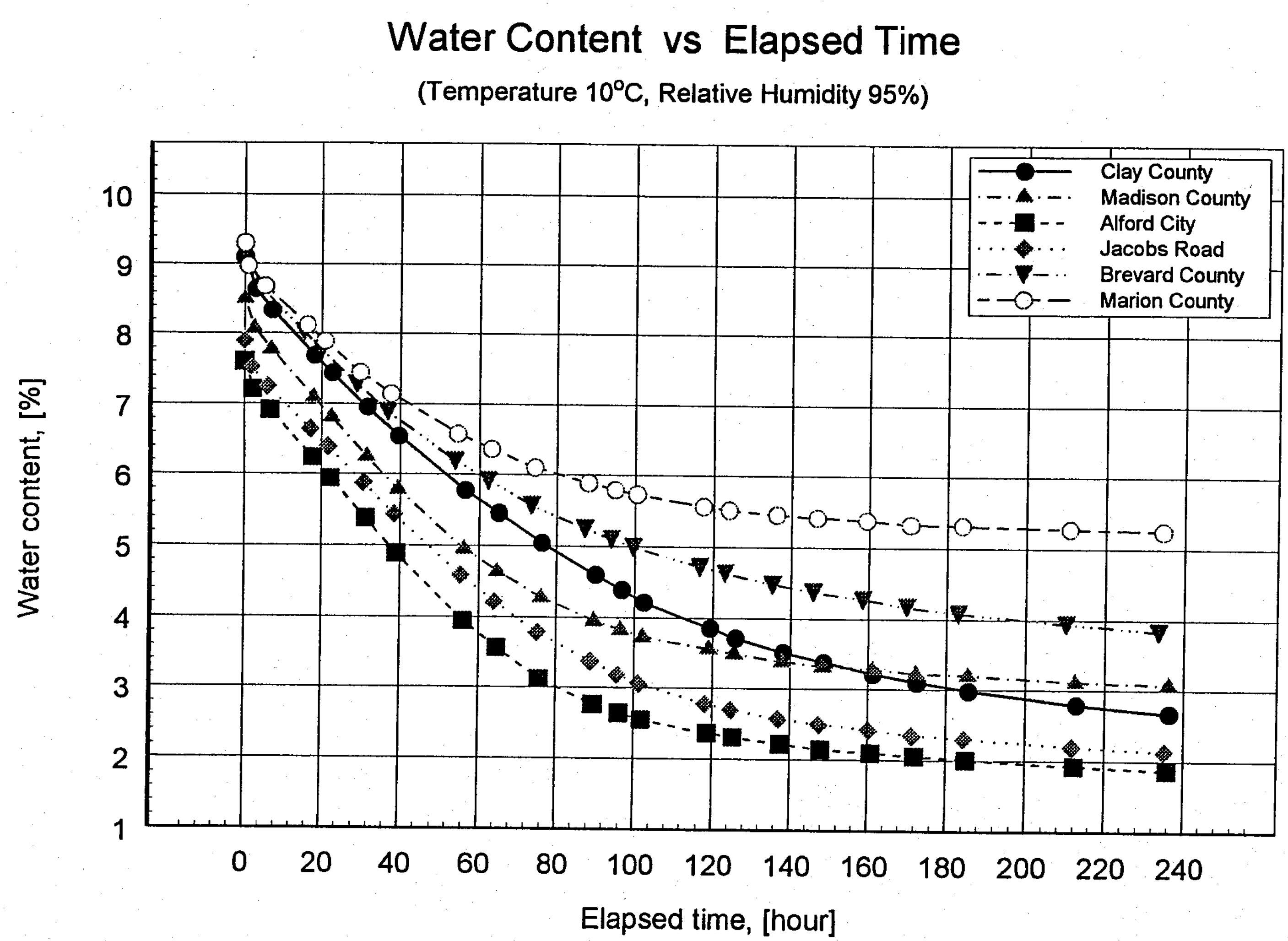

Figure D.3(b) : Water content versus elapsed time at temperature 10°C and relative humidity 95% for six soils (Group I)

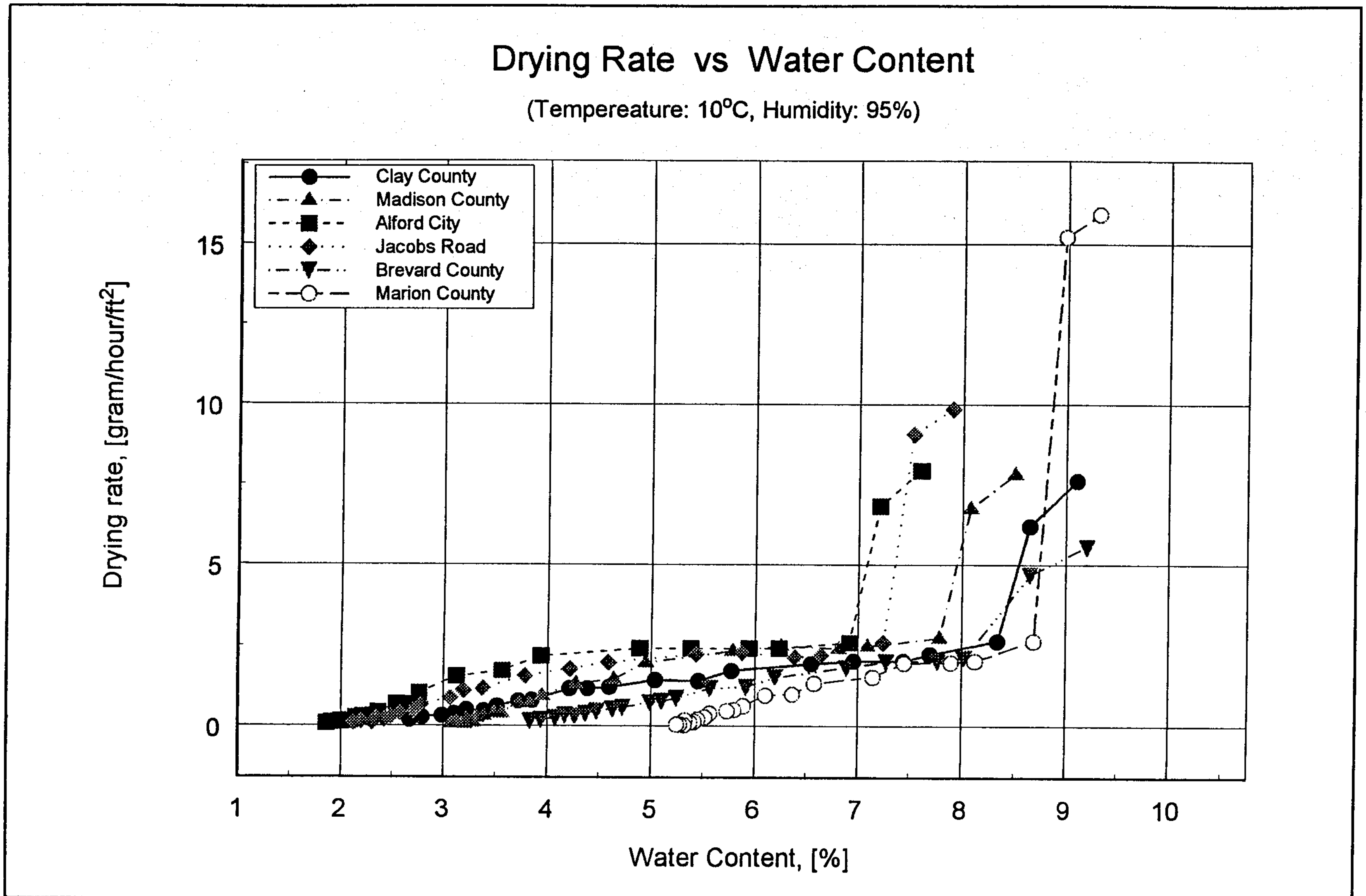

Figure D.3(c) : Drying rate versus water content for six soils at temperature 10°C and 95% relative humidity (Group I)

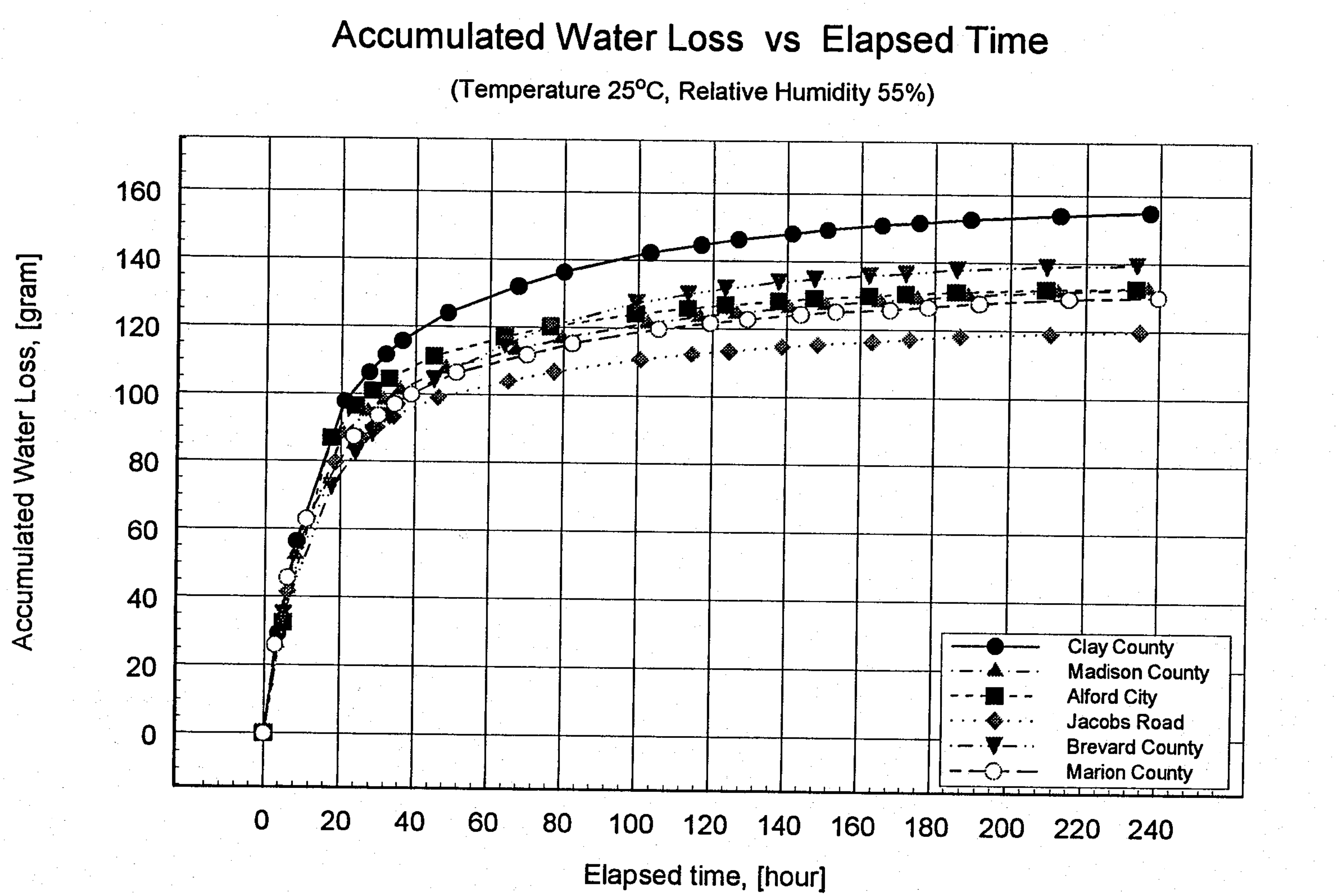

Figure D.4(a) : Water loss versus elapsed time at temperature 25°C and 55% relative humidity for six soils (Group I)

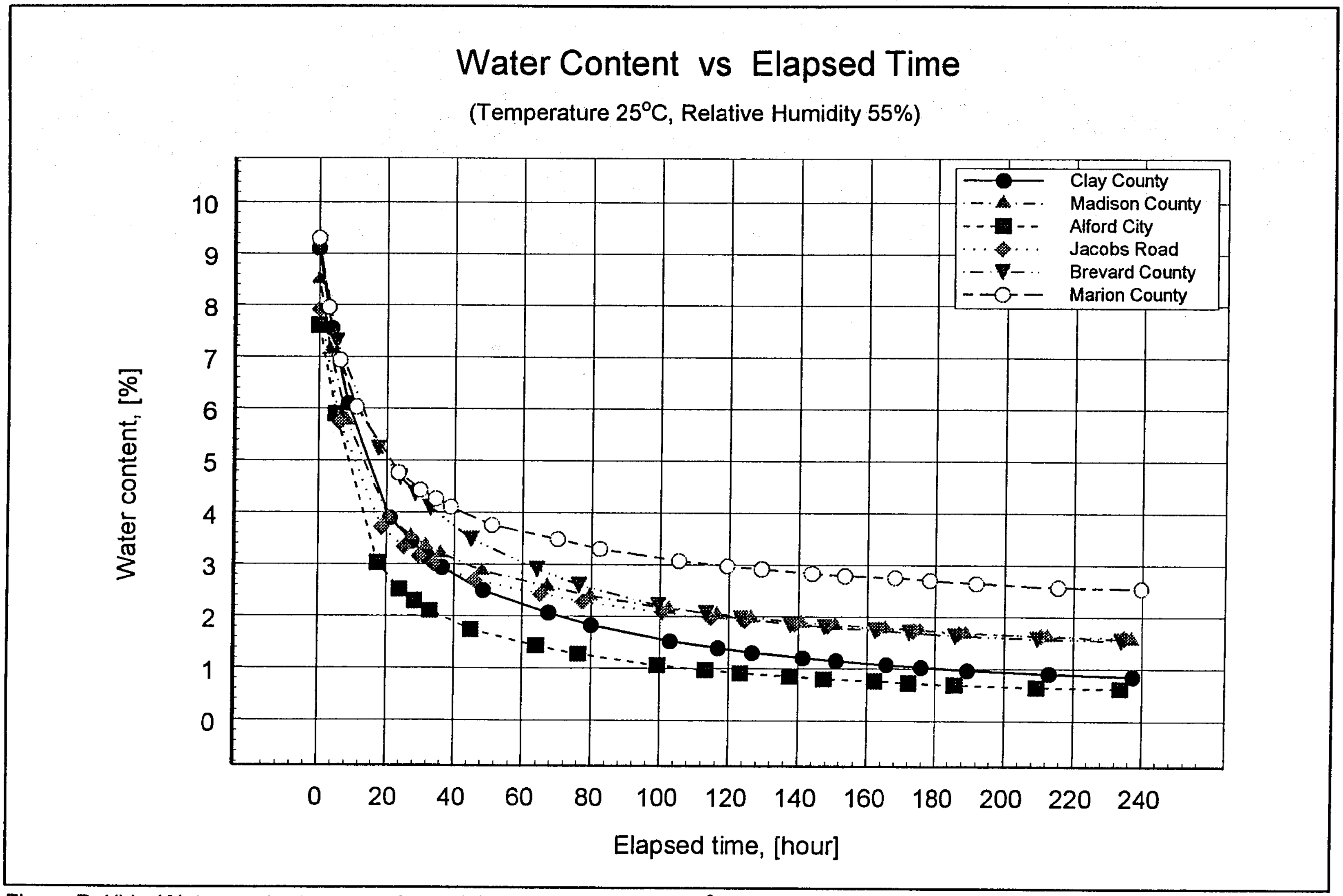

Figure D.4(b) : Water content versus elapsed time at temperature 25°C and relative humidity 55% for six soils (Group I)

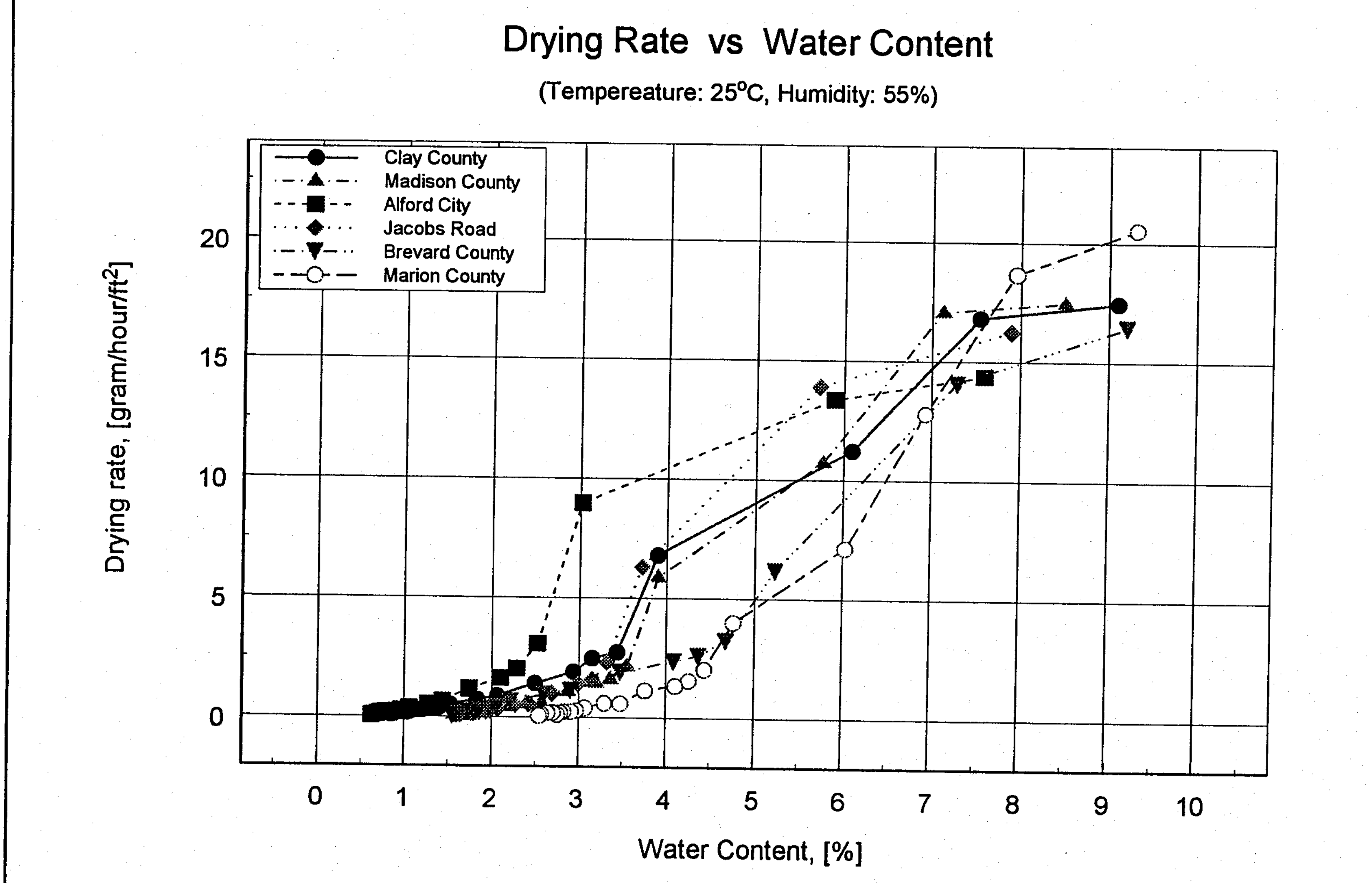

Figure D.4(c) : Drying rate versus water content for six soils at temperature 25°C and 55% relative humidity (Group I)

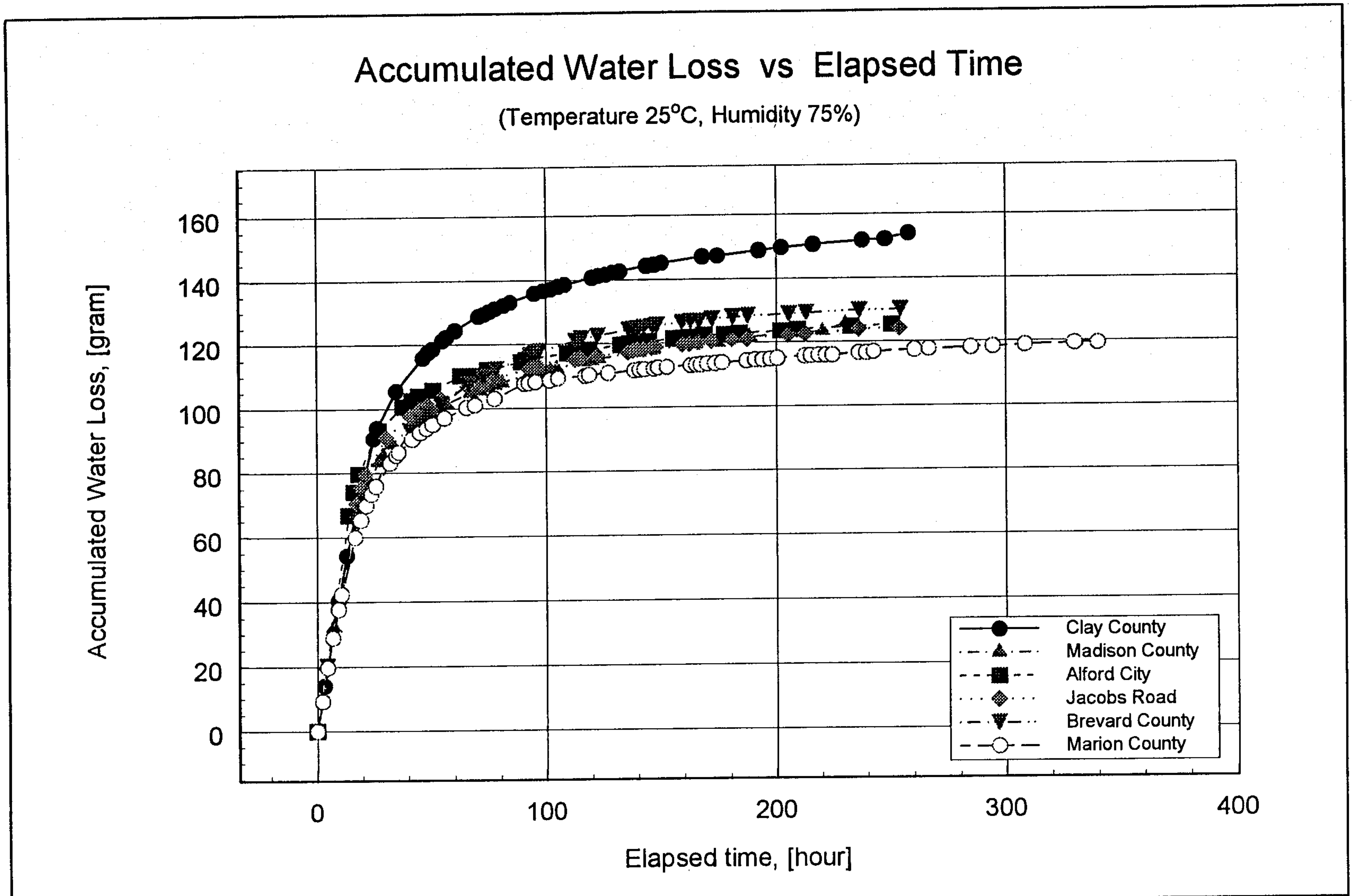

Figure D.5(a) : Water loss versus elapsed time at temperature 25°C and 75% relative humidity for six soils (Group I)

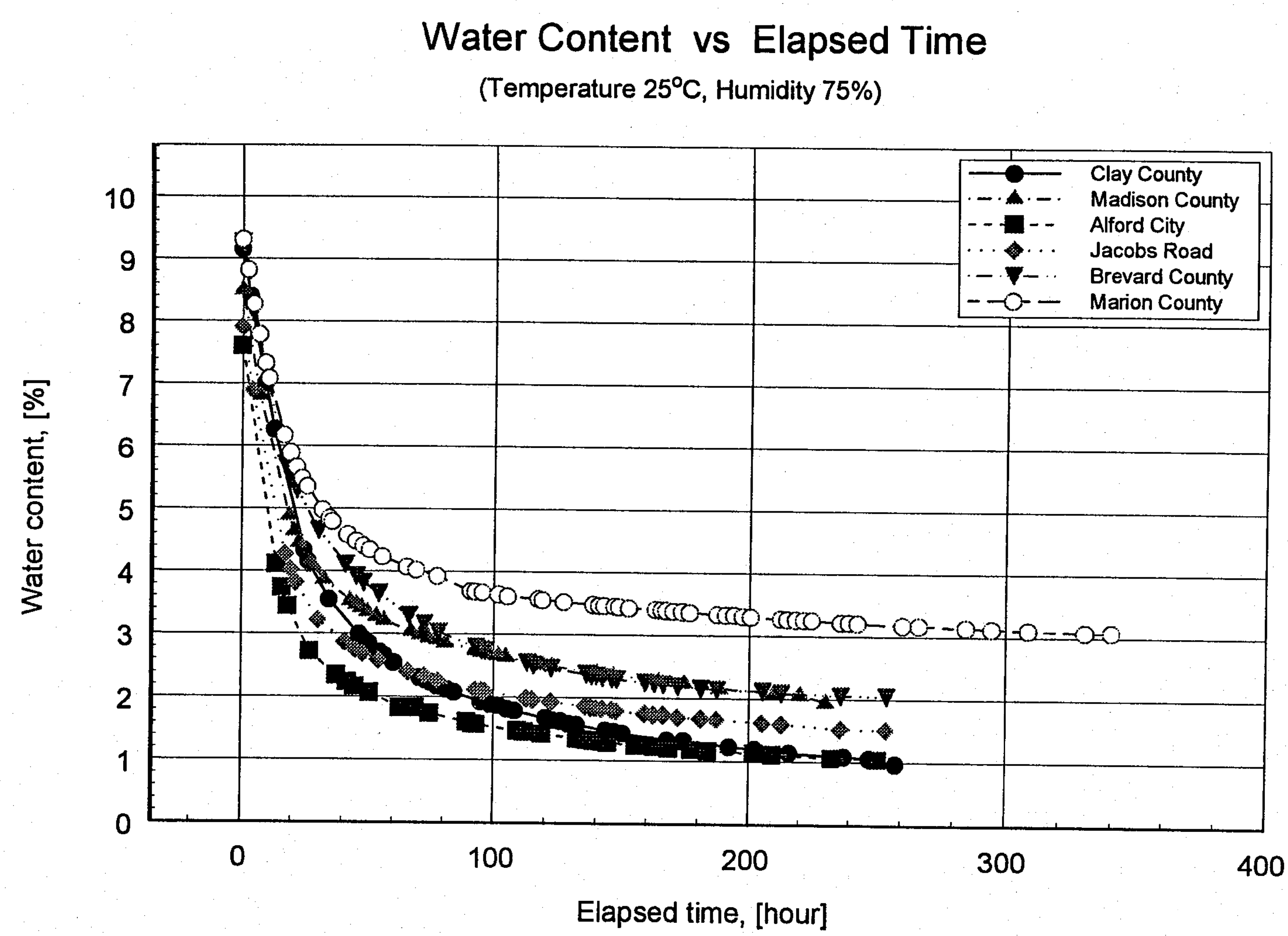

Figure D.5(b) : Water content versus elapsed time at temperature 25°C and relative humidity 75% for six soils (Group I)

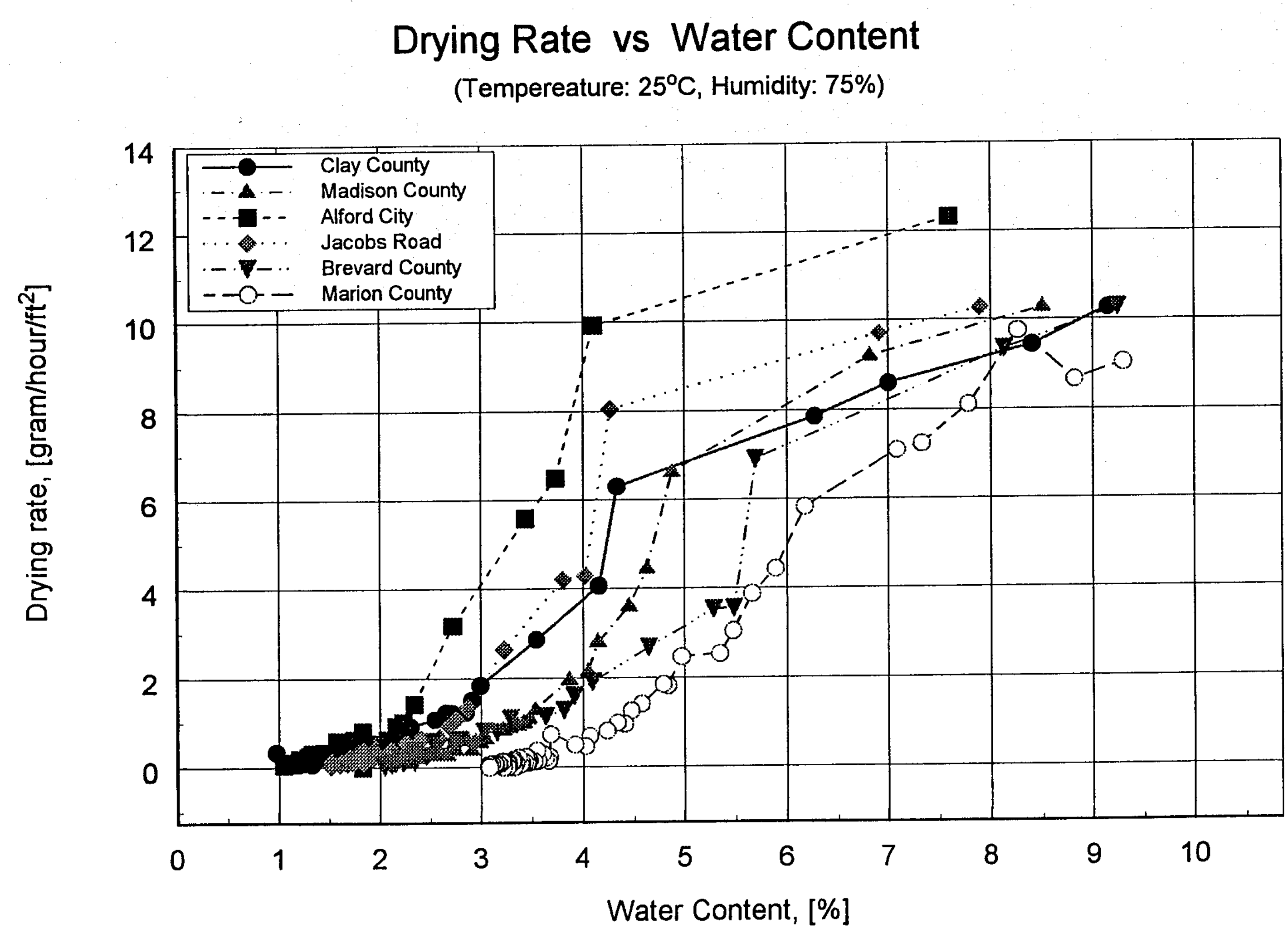

Figure D.5(c) : Drying rate versus water content for six soils at temperature 25°C and 75% relative humidity (Group I)

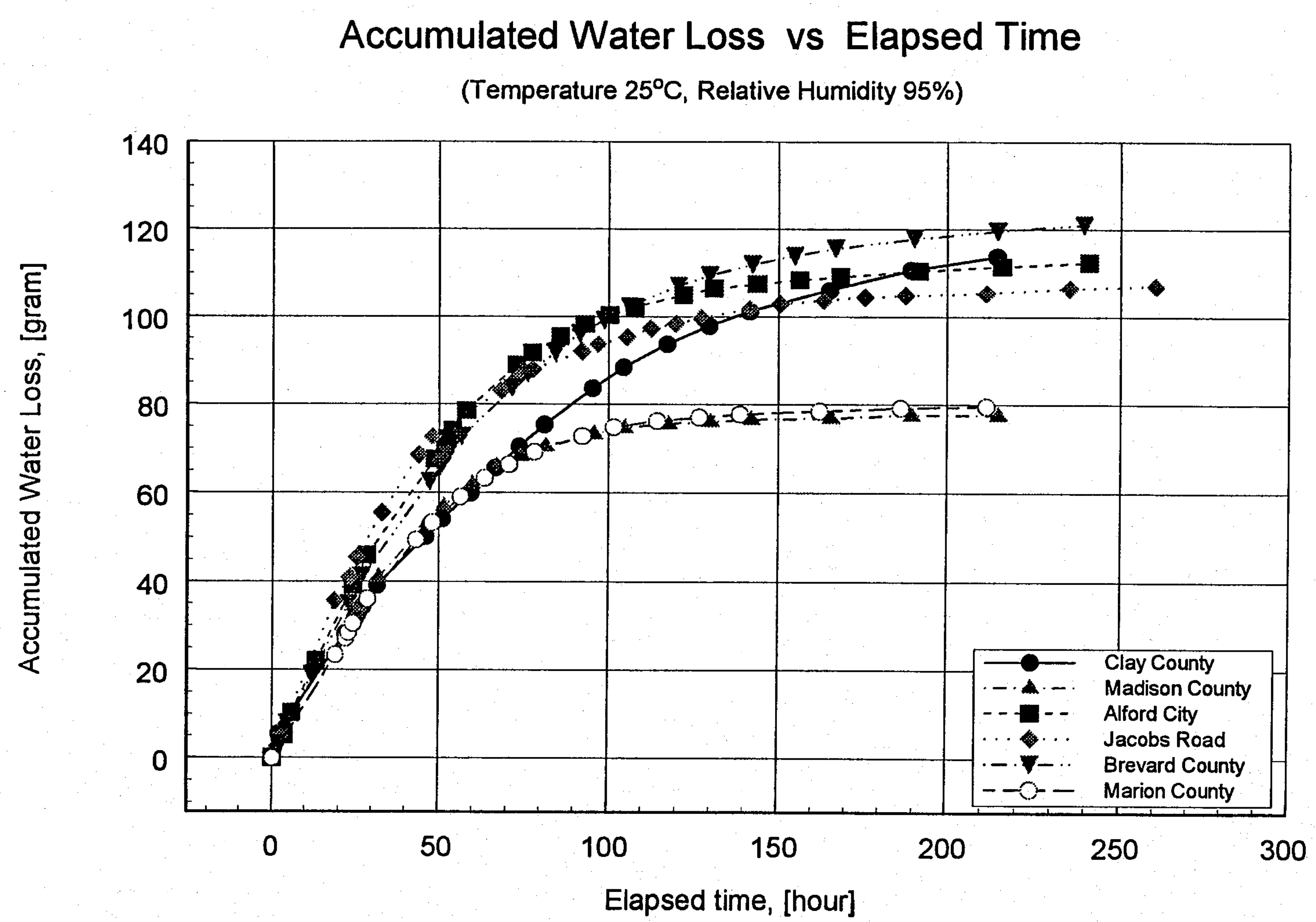

Figure D.6(a) : Water loss versus elapsed time at temperature 25°C and 95% relative humidity for six soils (Group I)

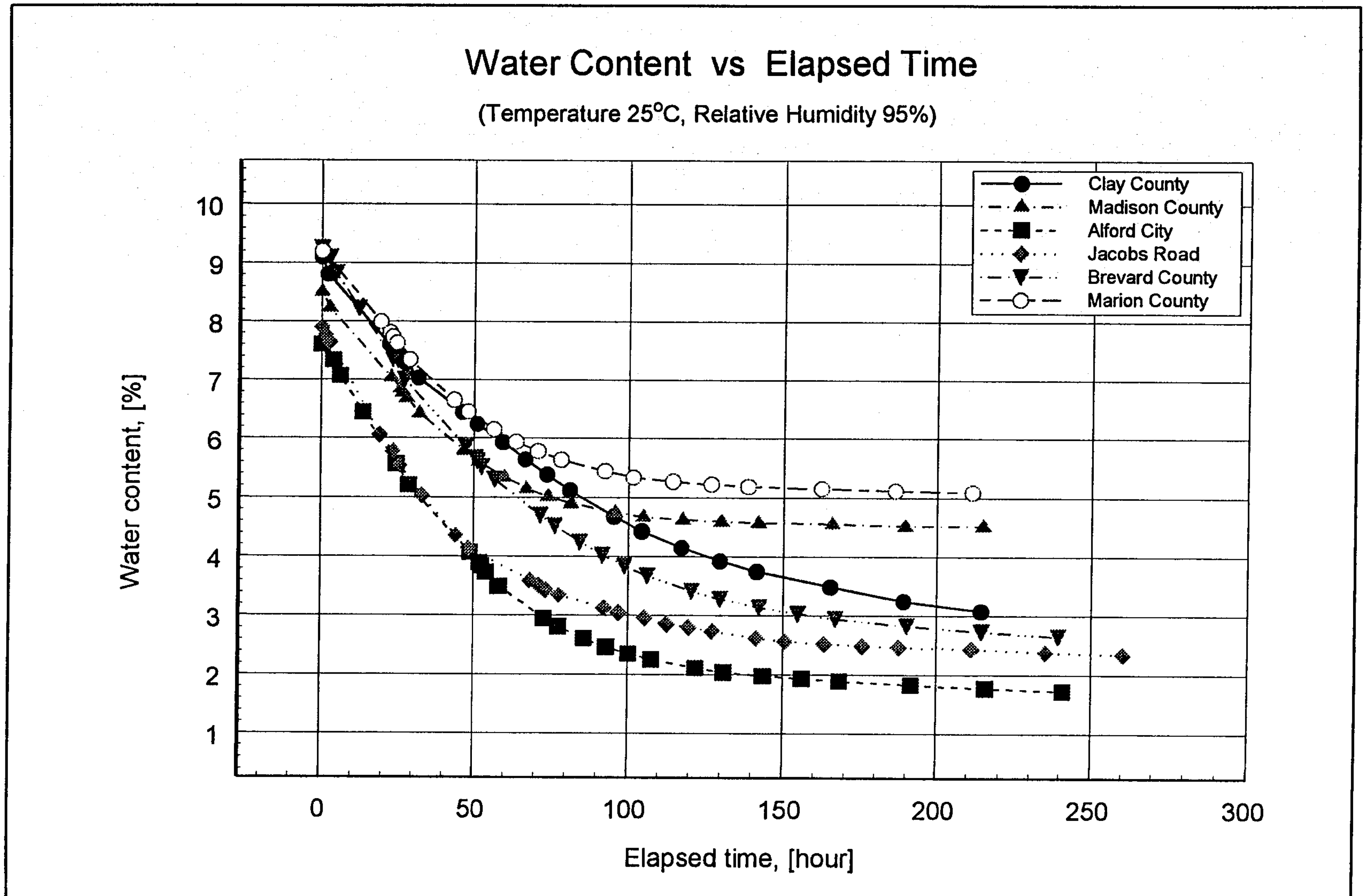

Figure D.6(b) : Water content versus elapsed time at temperature 25°C and relative humidity 95% for six soils (Group I)

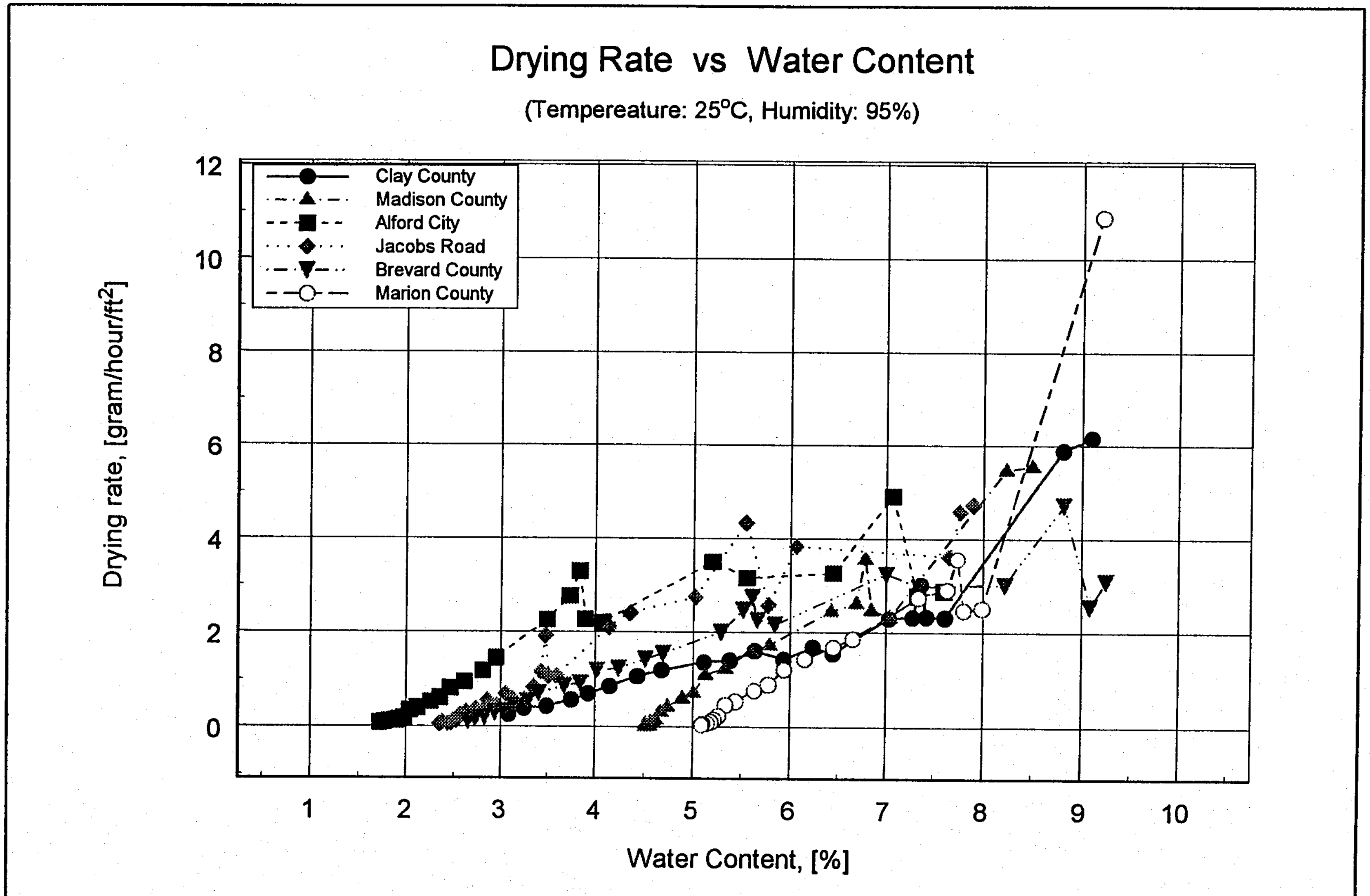

Figure D.6(c) : Drying rate versus water content for six soils at temperature 25°C and 95% relative humidity (Group I)

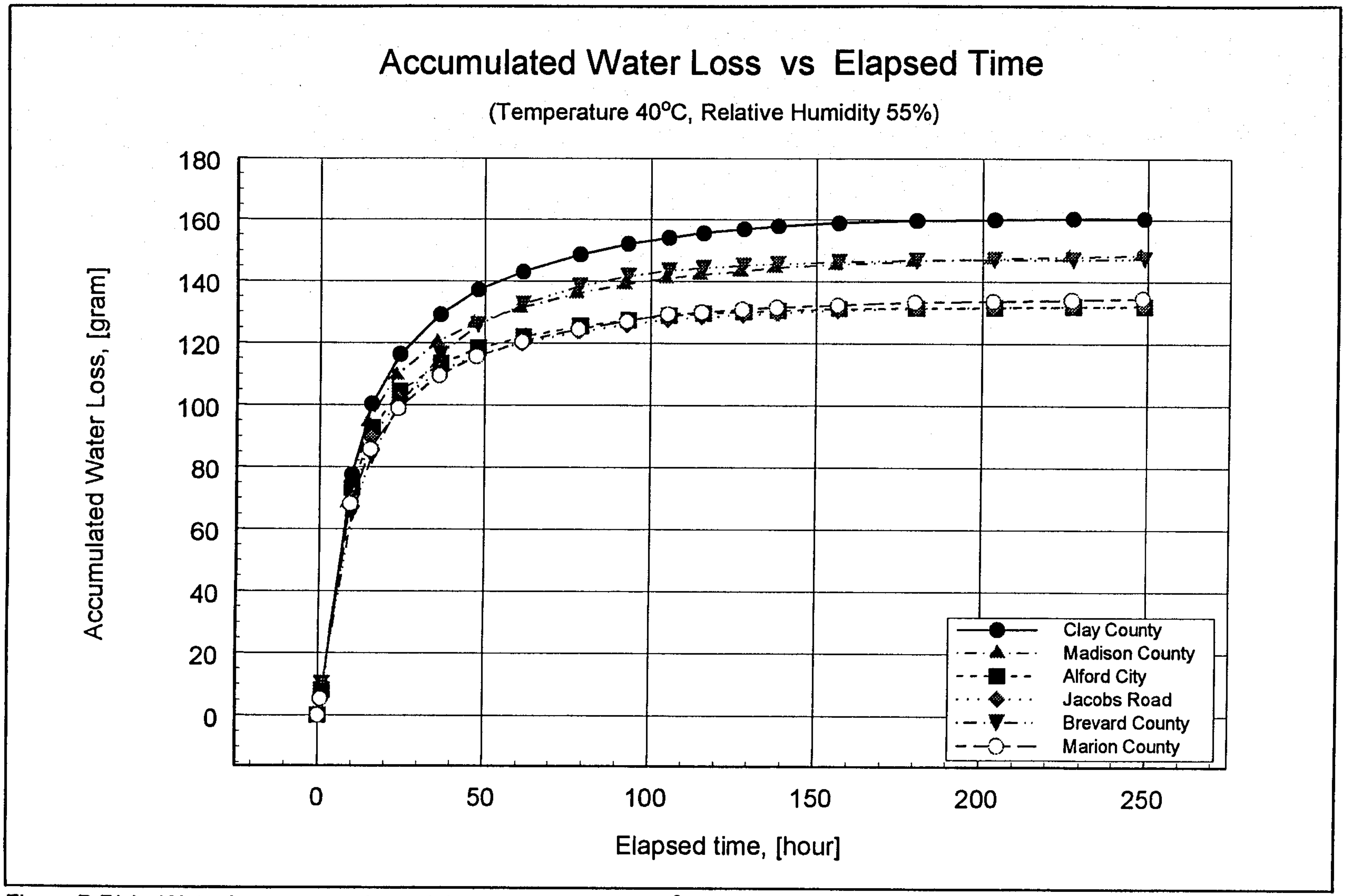

Figure D.7(a) : Water loss versus elapsed time at temperature 40°C and 55% relative humidity for six soils (Group I)

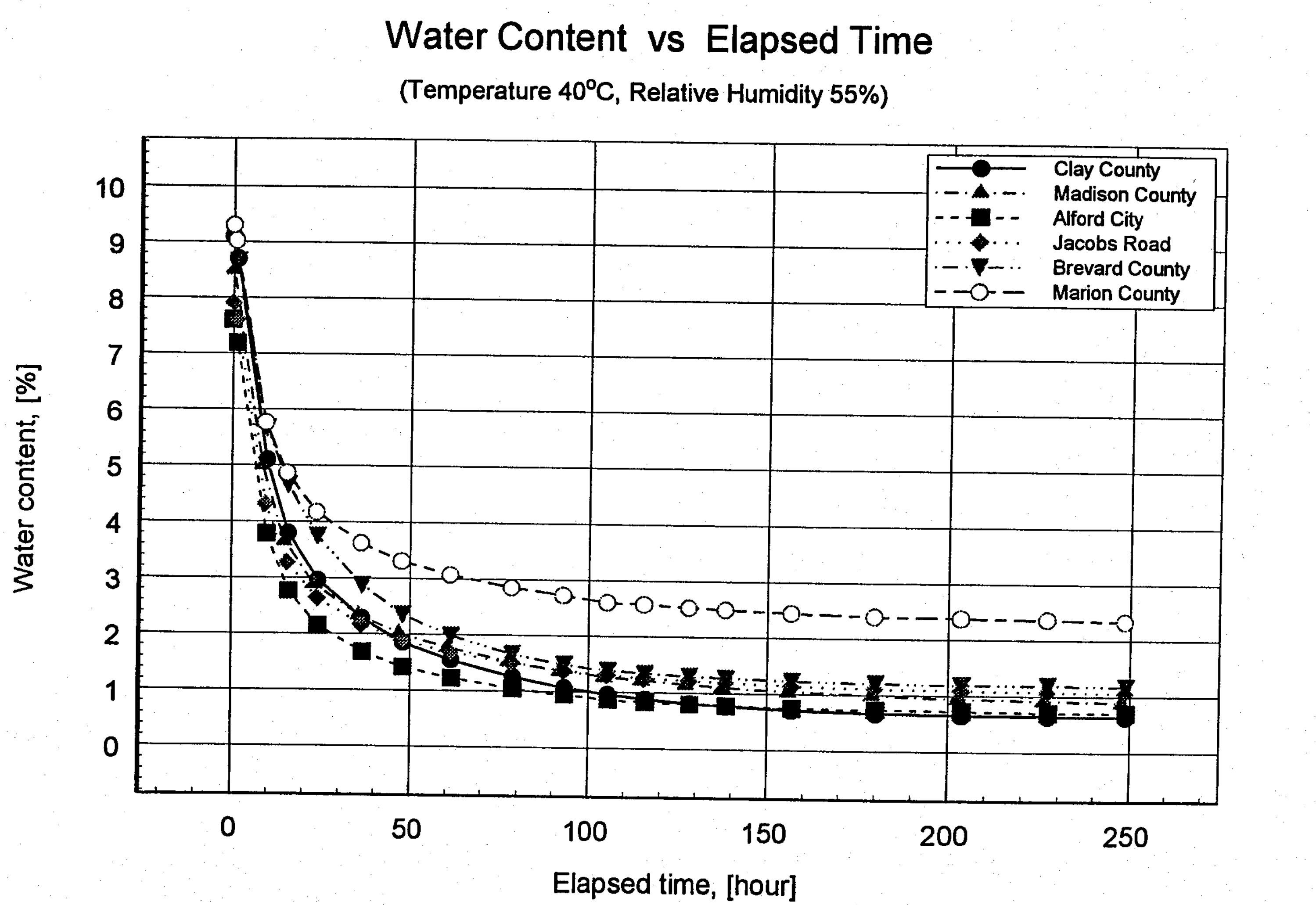

Figure D.7(b) : Water content versus elapsed time at temperature 40°C and relative humidity 55% for six soils (Group I)

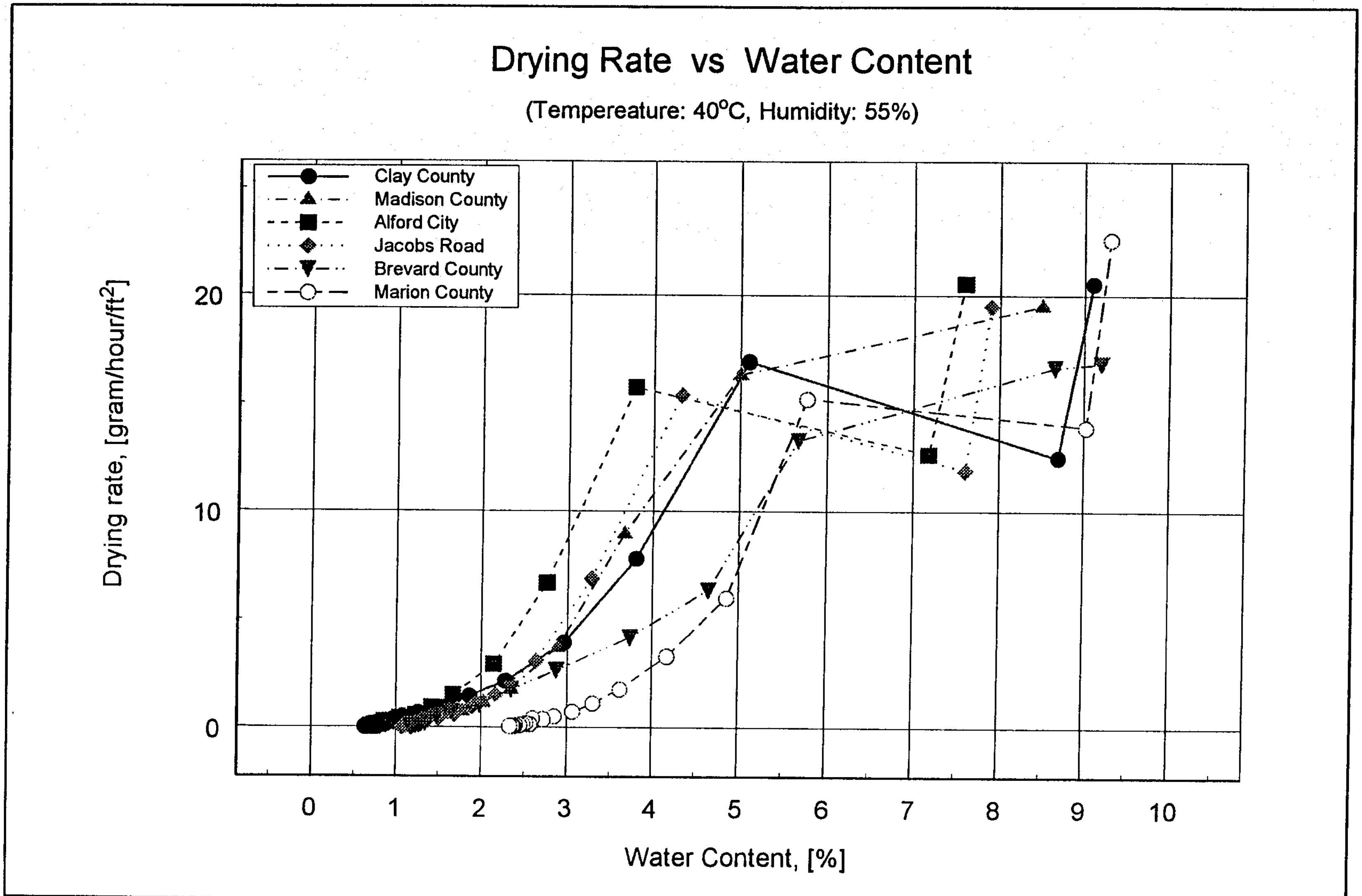

Figure D.7(c) : Drying rate versus water content for six soils at temperature 40°C and 55% relative humidity (Group I)

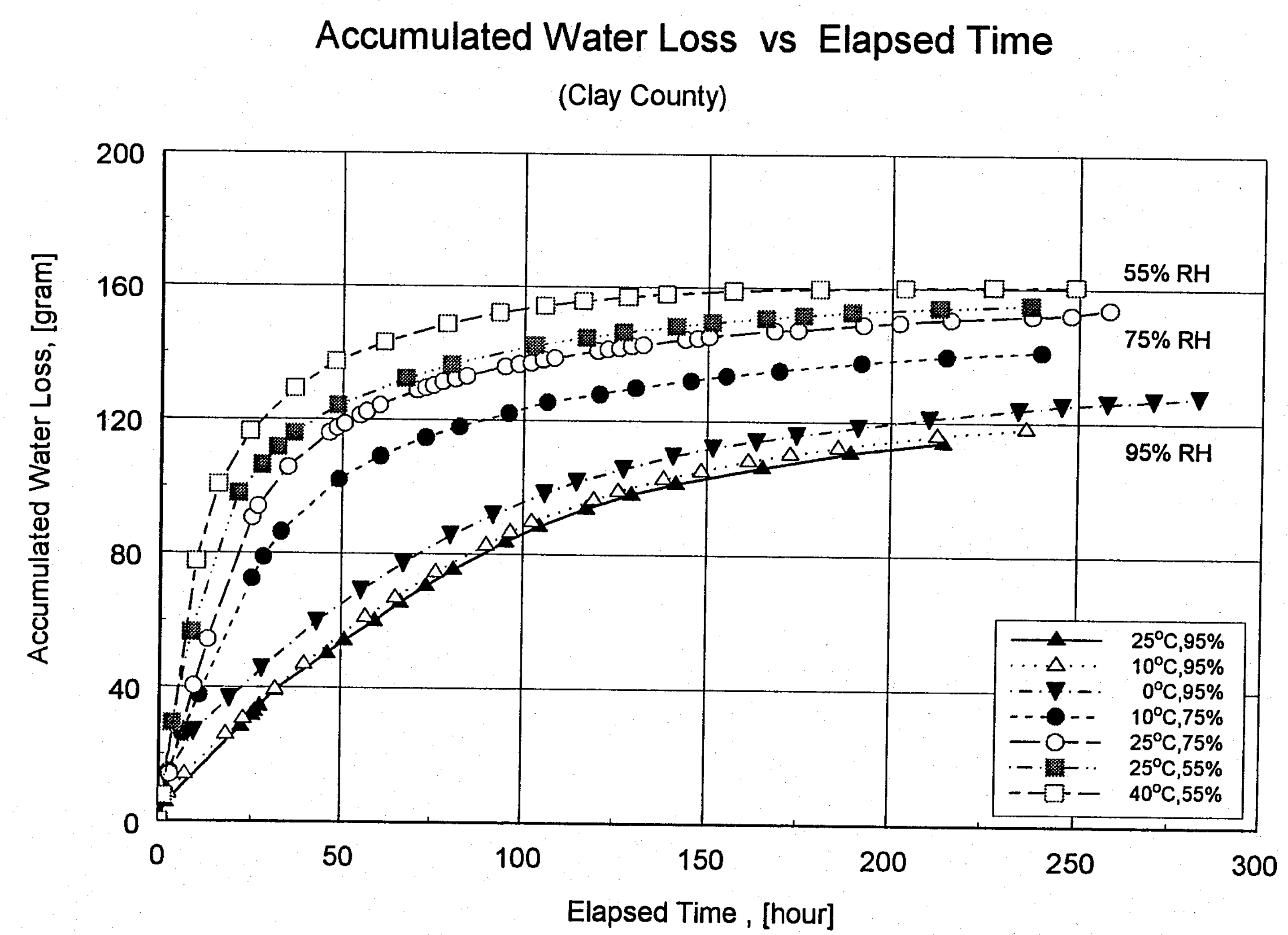

Figure D.8(a): Comparison of water loss at different temperature and relative humidity for Clay County soil (Group I)

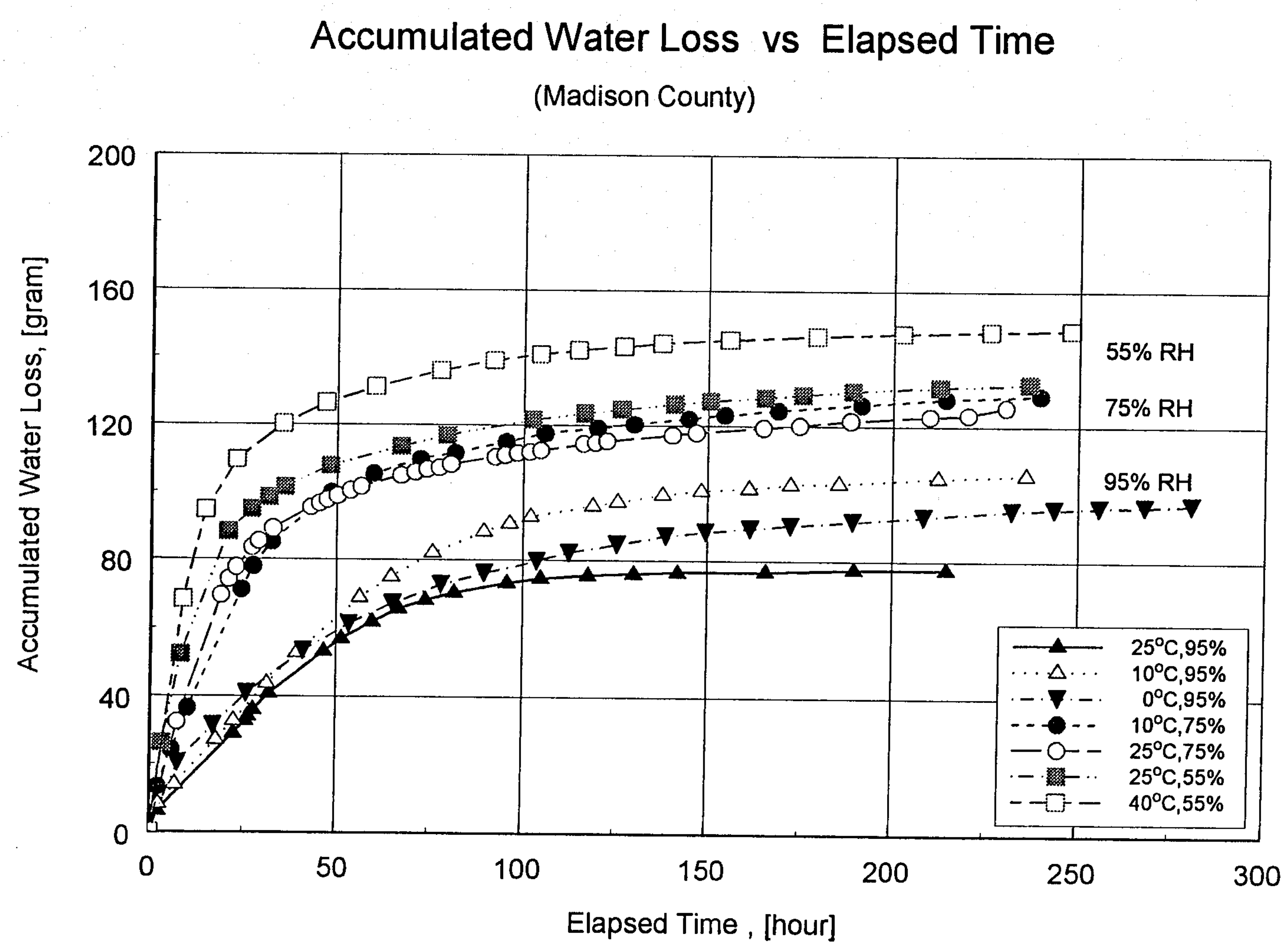

Figure D.8(b): Comparison of water loss at different temperature and relative humidity for Madison County soil (Group I)

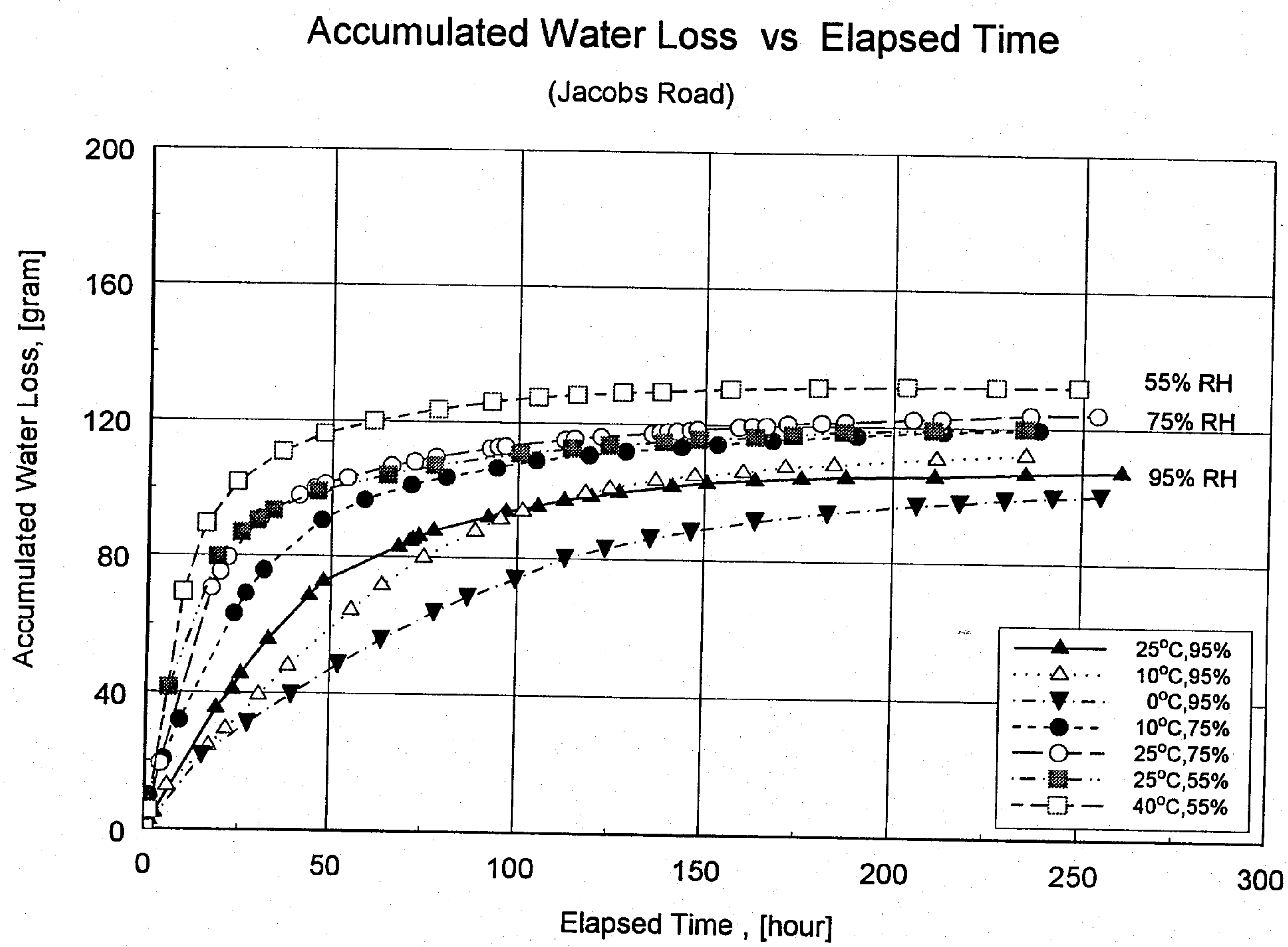

Figure D.8(c): Comparison of water loss at different temperature and relative humidity for Jacobs Road soil (Group I)

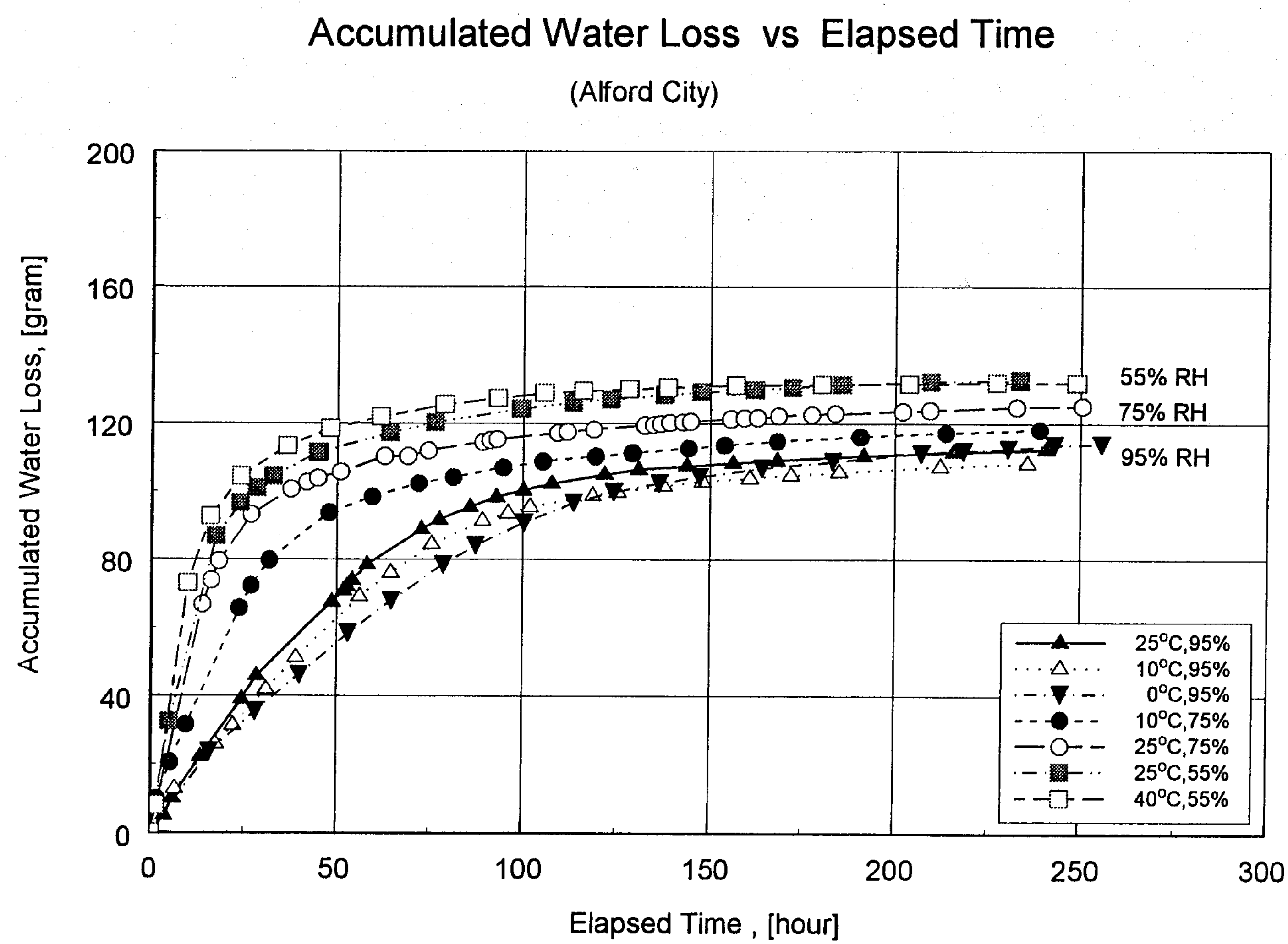

Figure D.8(d): Comparison of water loss at different temperature and relative humidity for Alford City soil (Group I)

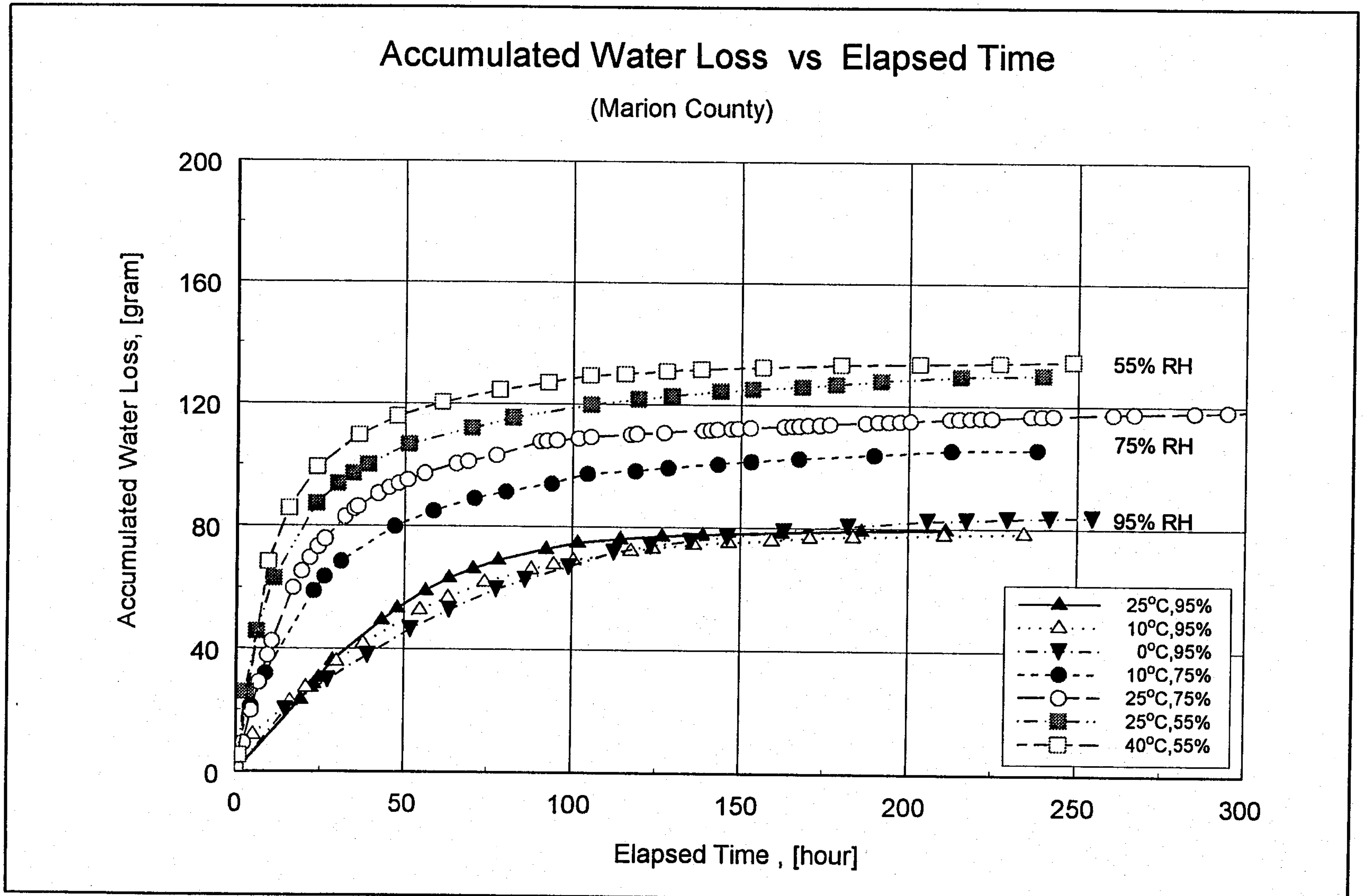

Figure D.8(e): Comparison of water loss at different temperature and relative humidity for Marion County soil (Group I)

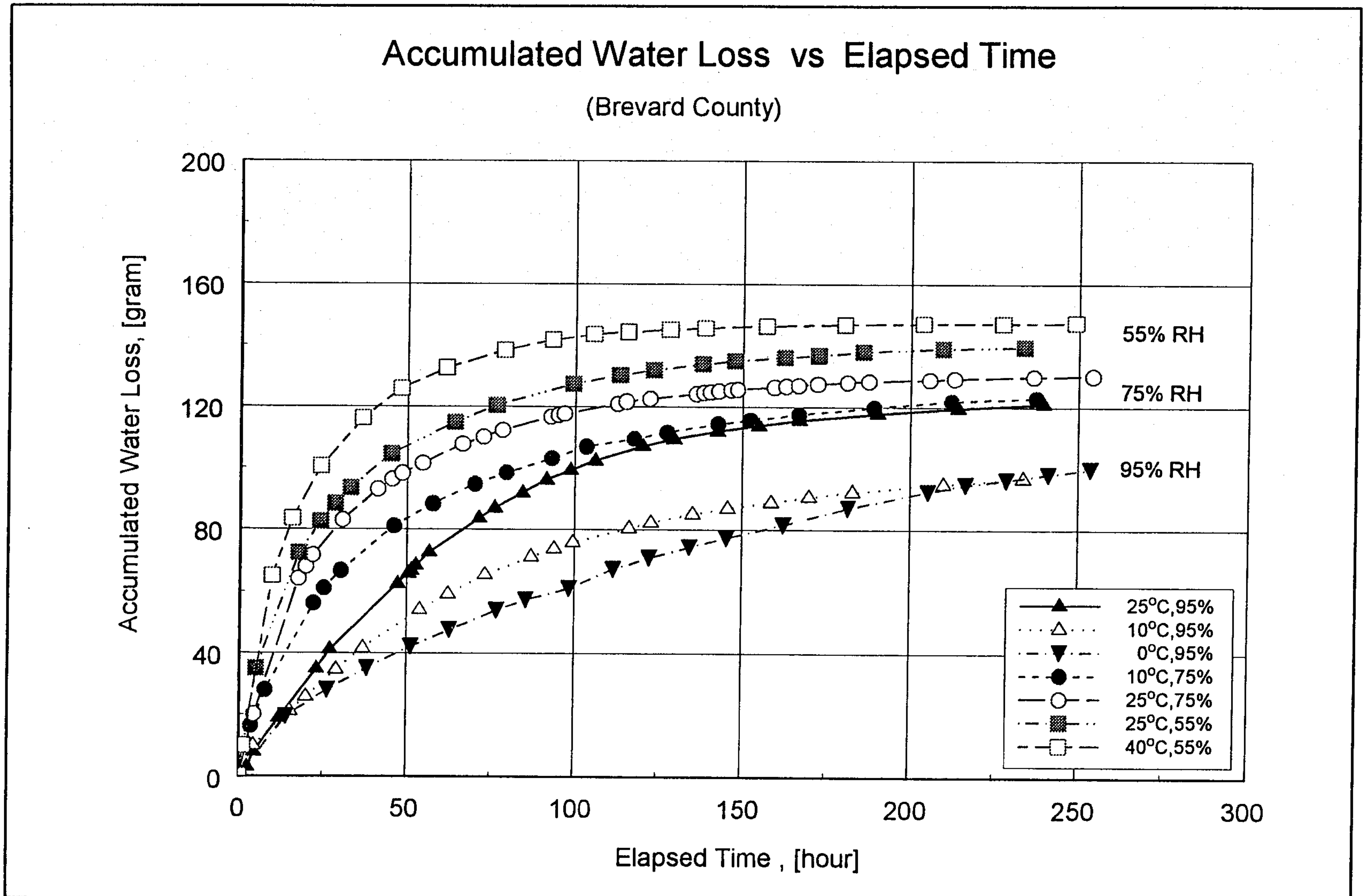

Figure D.8(f): Comparison of water loss at different temperature and relative humidity for Brevard County soil (Group I)

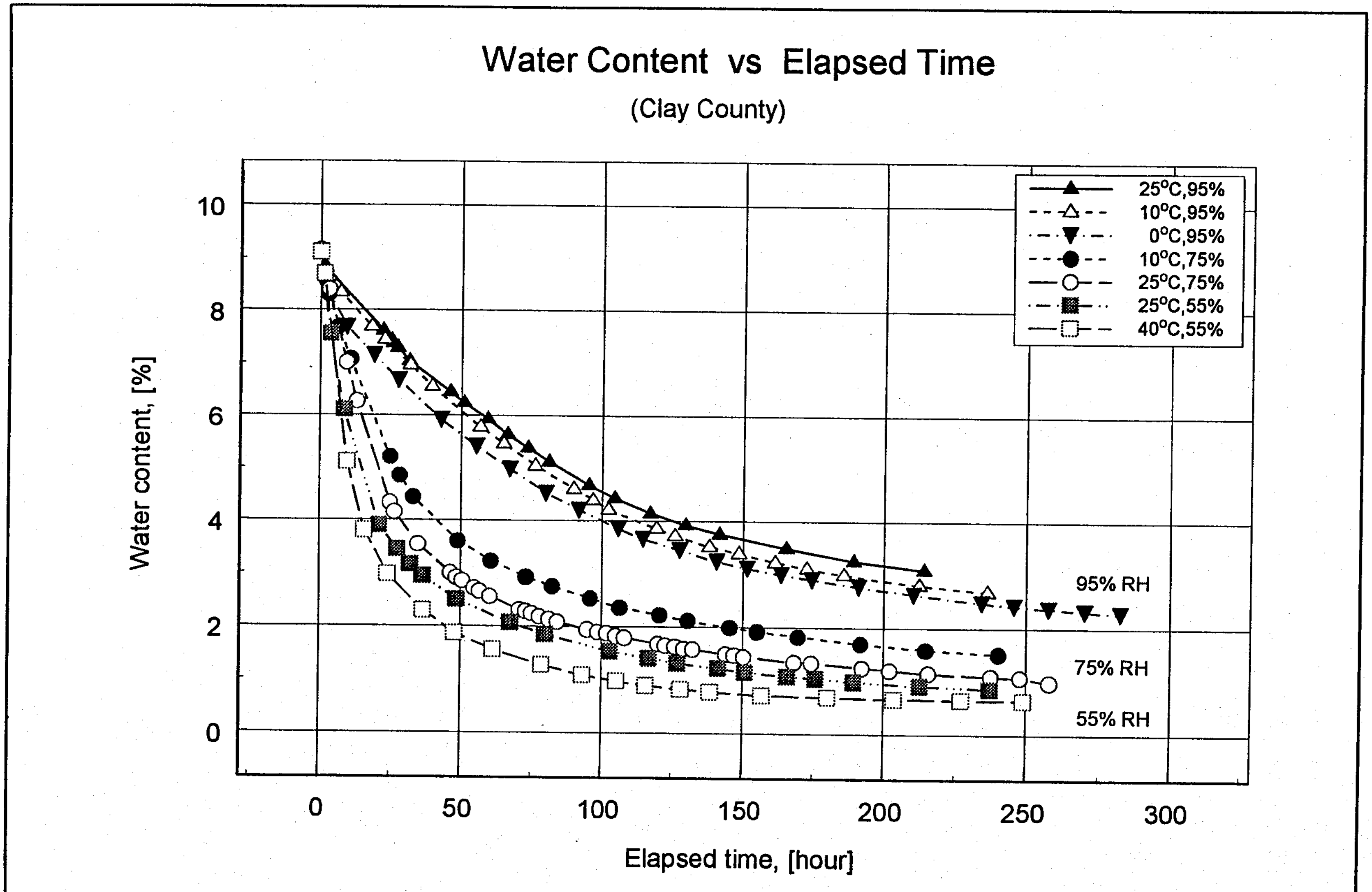

Figure D.9(a) : Comparison of the change of water content at different temperature and relative humidity for Clay County soil (Group I)

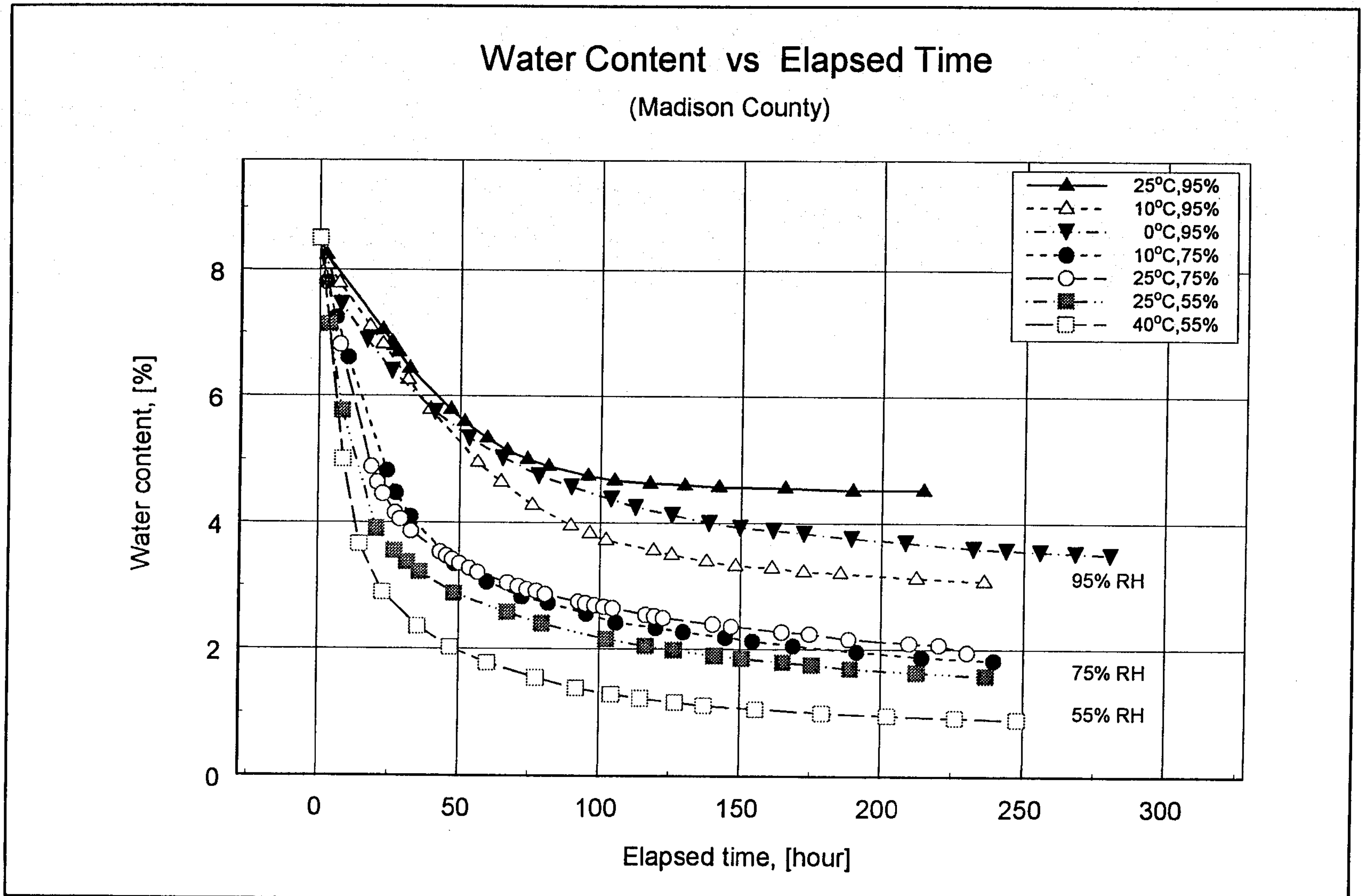

Figure D.9(b) : Comparison of the change of water content at different temperature and relative humidity for Madison County soil (Group I)

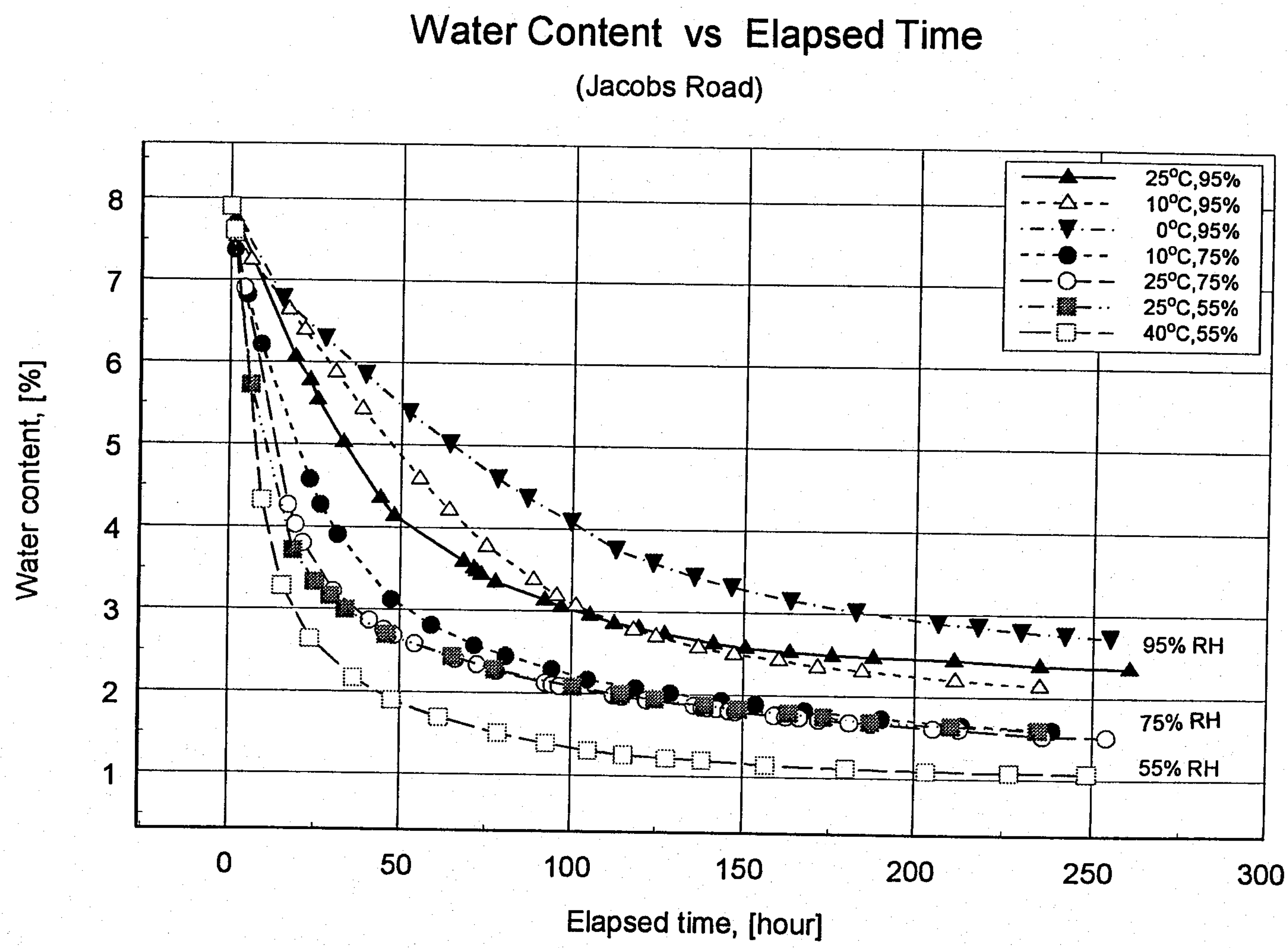

Figure D.9(c) : Comparison of the change of water content at different temperature and relative humidity for Jacobs Road soil (Group I)

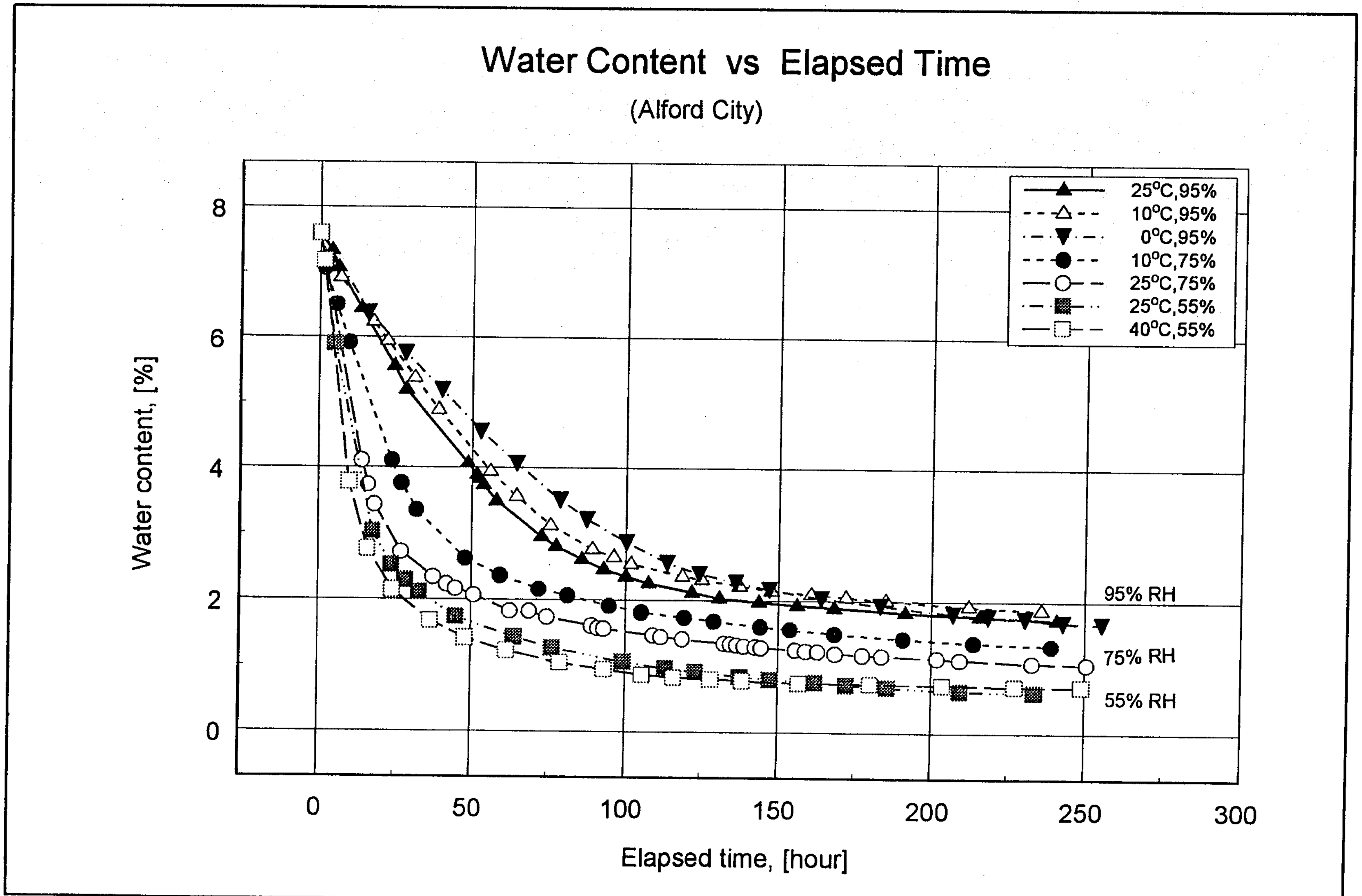

Figure D.9(d) : Comparison of the change of water content at different temperature and relative humidity for Alford City soil (Group I)

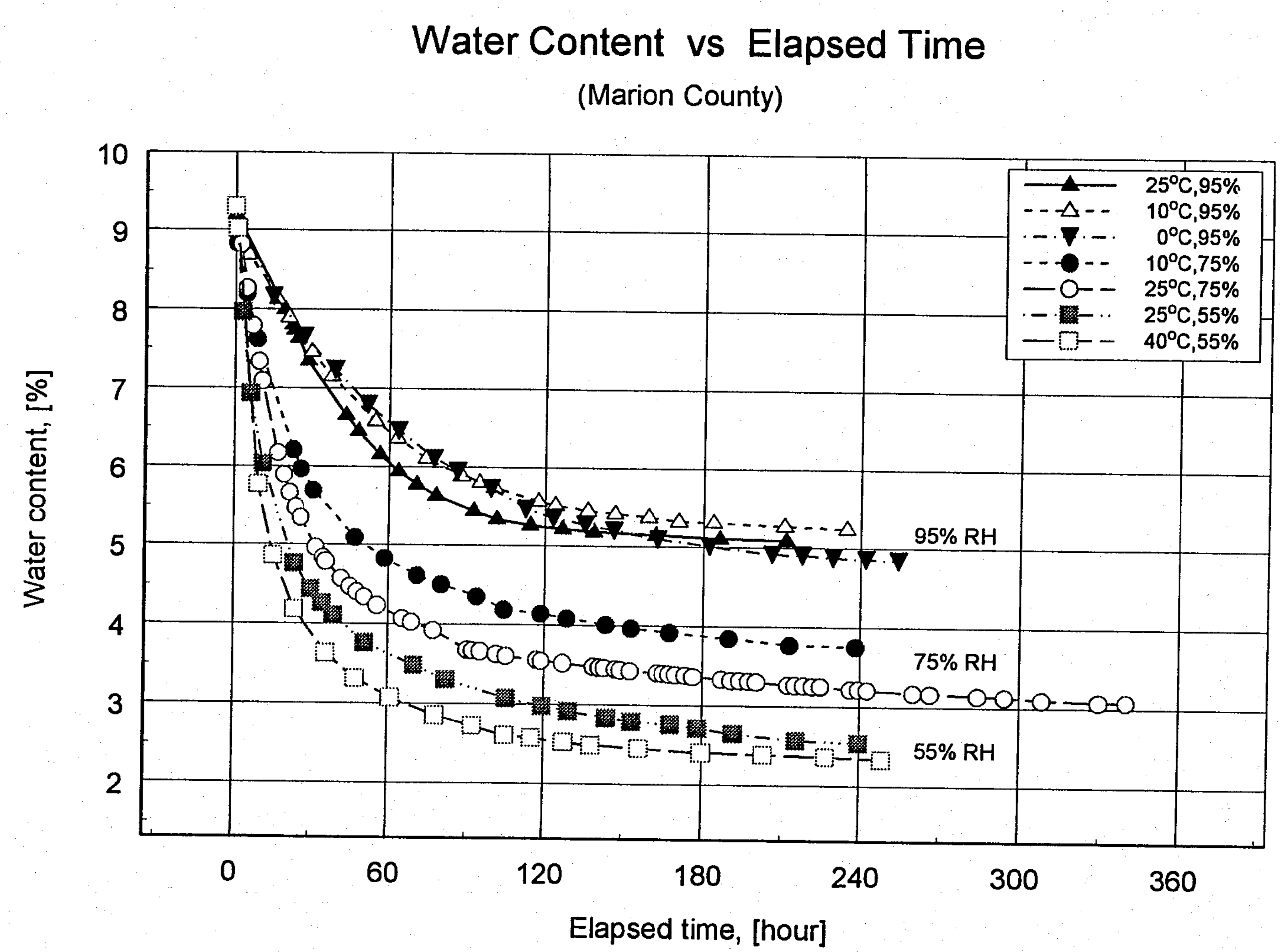

Figure D.9(e) : Comparison of the change of water content at different temperature and relative humidity for Marion County soil (Group I)

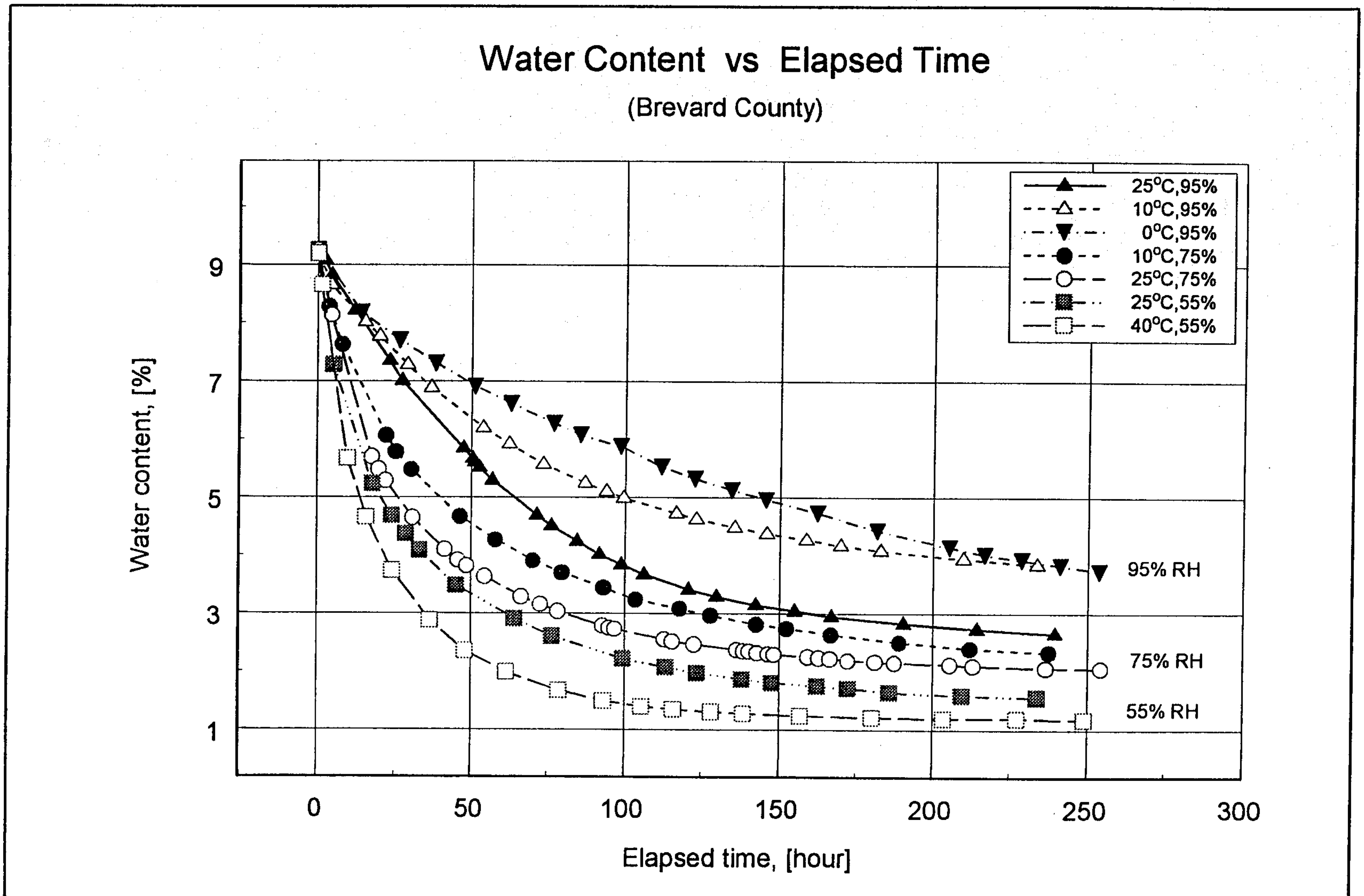

Figure D.9(f) : Comparison of the change of water content at different temperature and relative humidity for Brevard County soil (Group I)

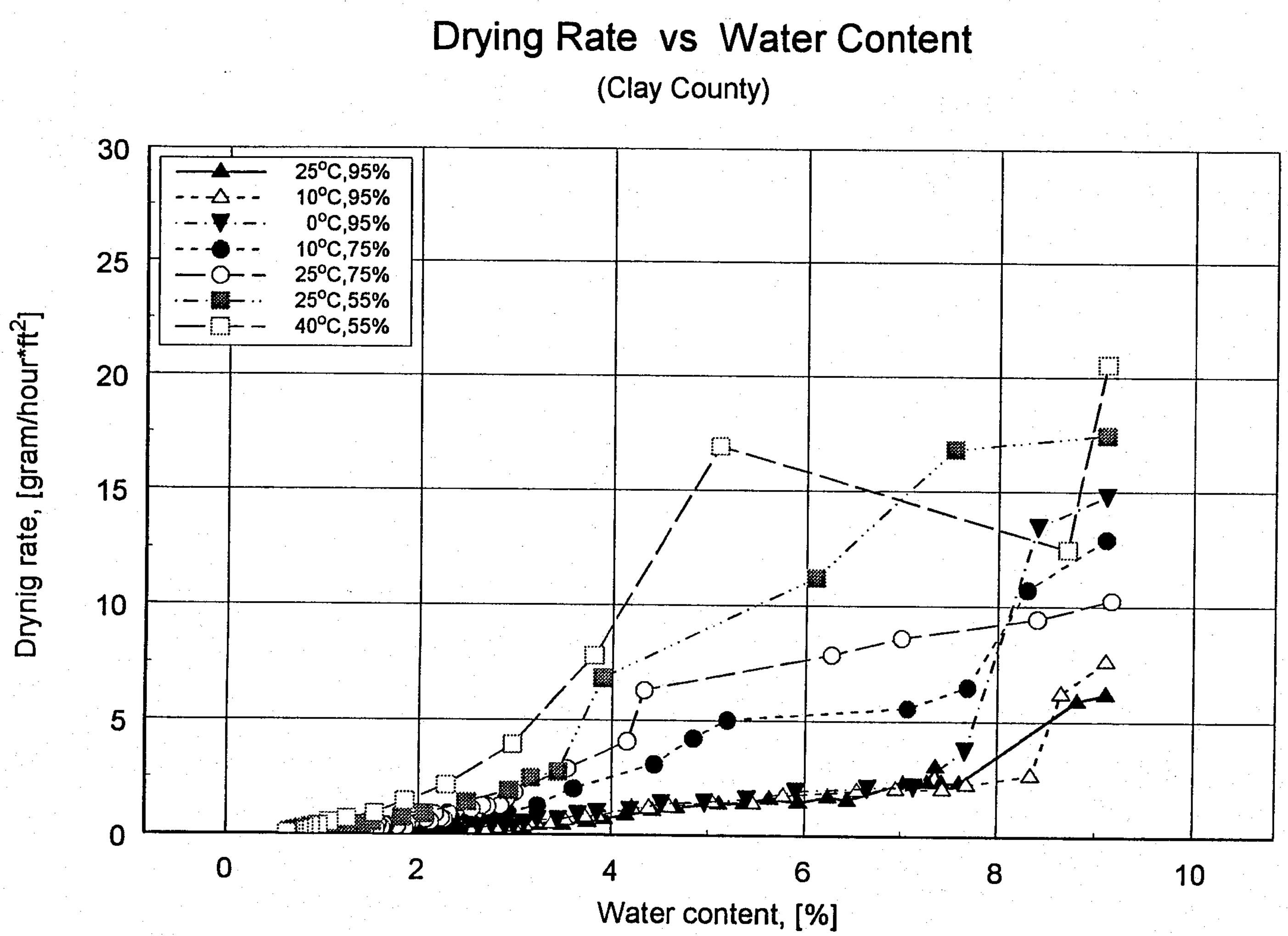

Figure D.10(a) : Comparison of drying rate at different temperature and relative humidity for Clay County soil (Group I)

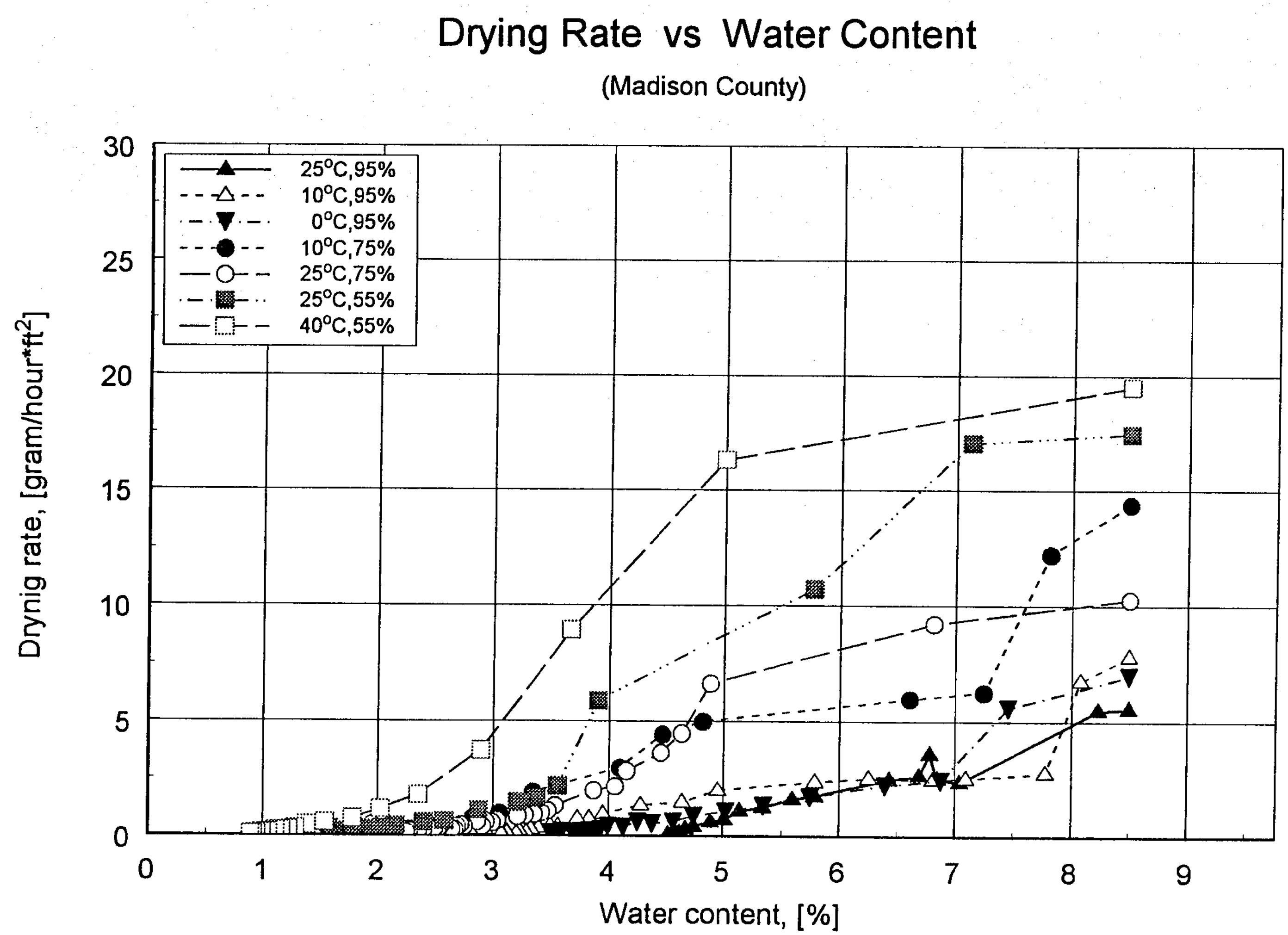

Figure D.10(b) : Comparison of drying rate at different temperature and relative humidity for Madison County soil (Group I)

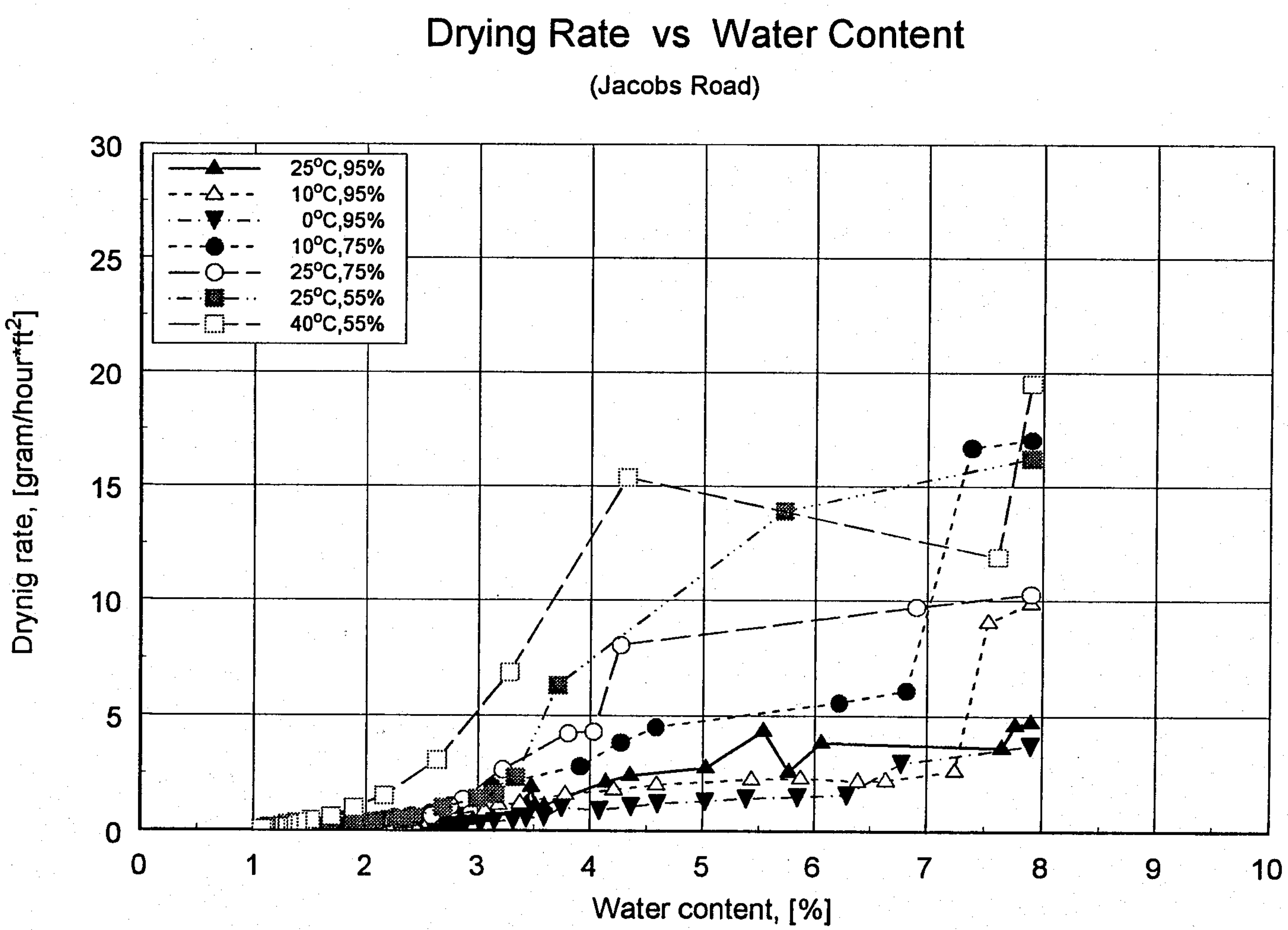

Figure D.10(c) : Comparison of drying rate at different temperature and relative humidity for Jacobs Road soil (Group I)

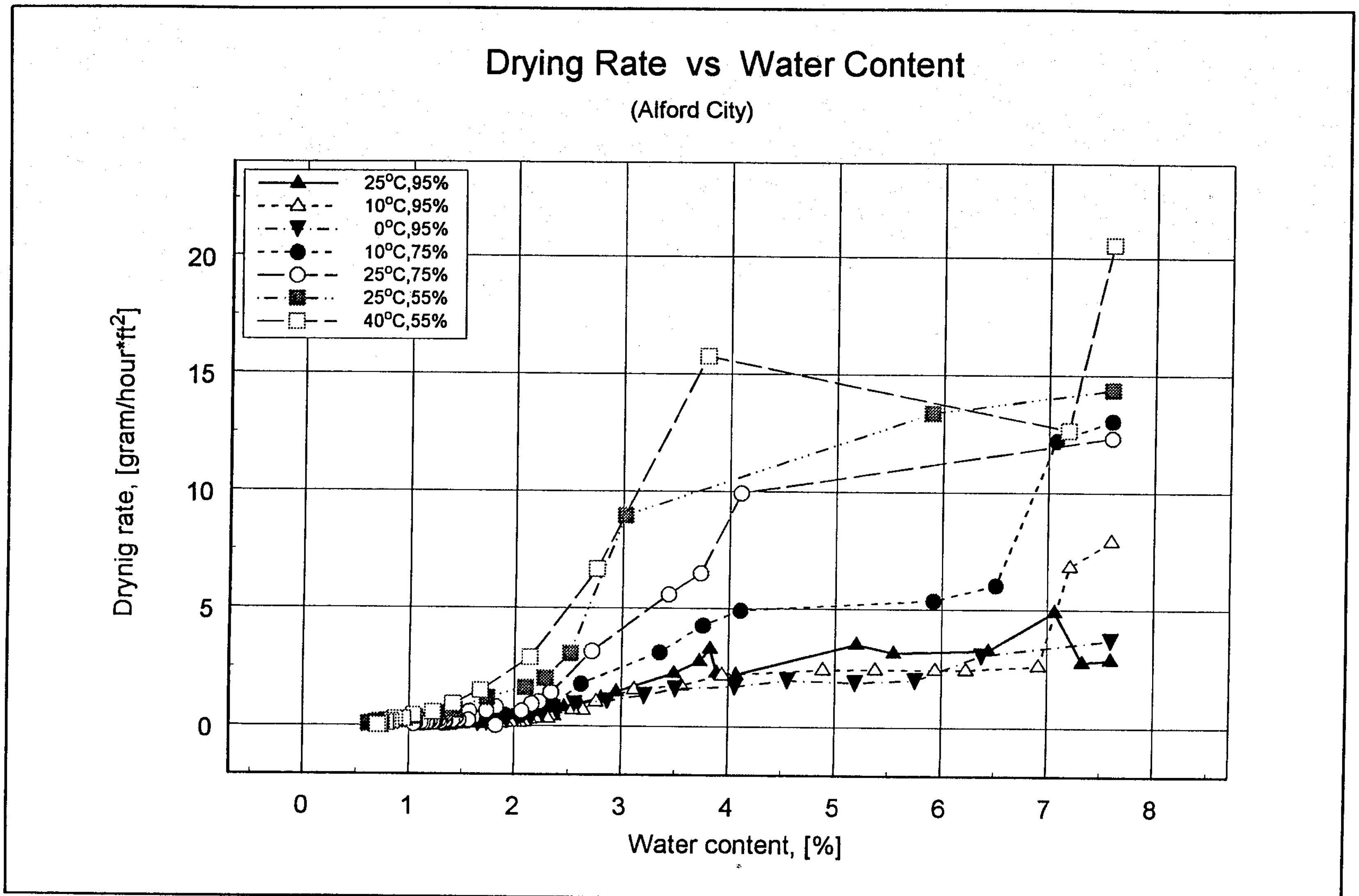

Figure D.10(d) : Comparison of drying rate at different temperature and relative humidity for Alford City soil (Group I)

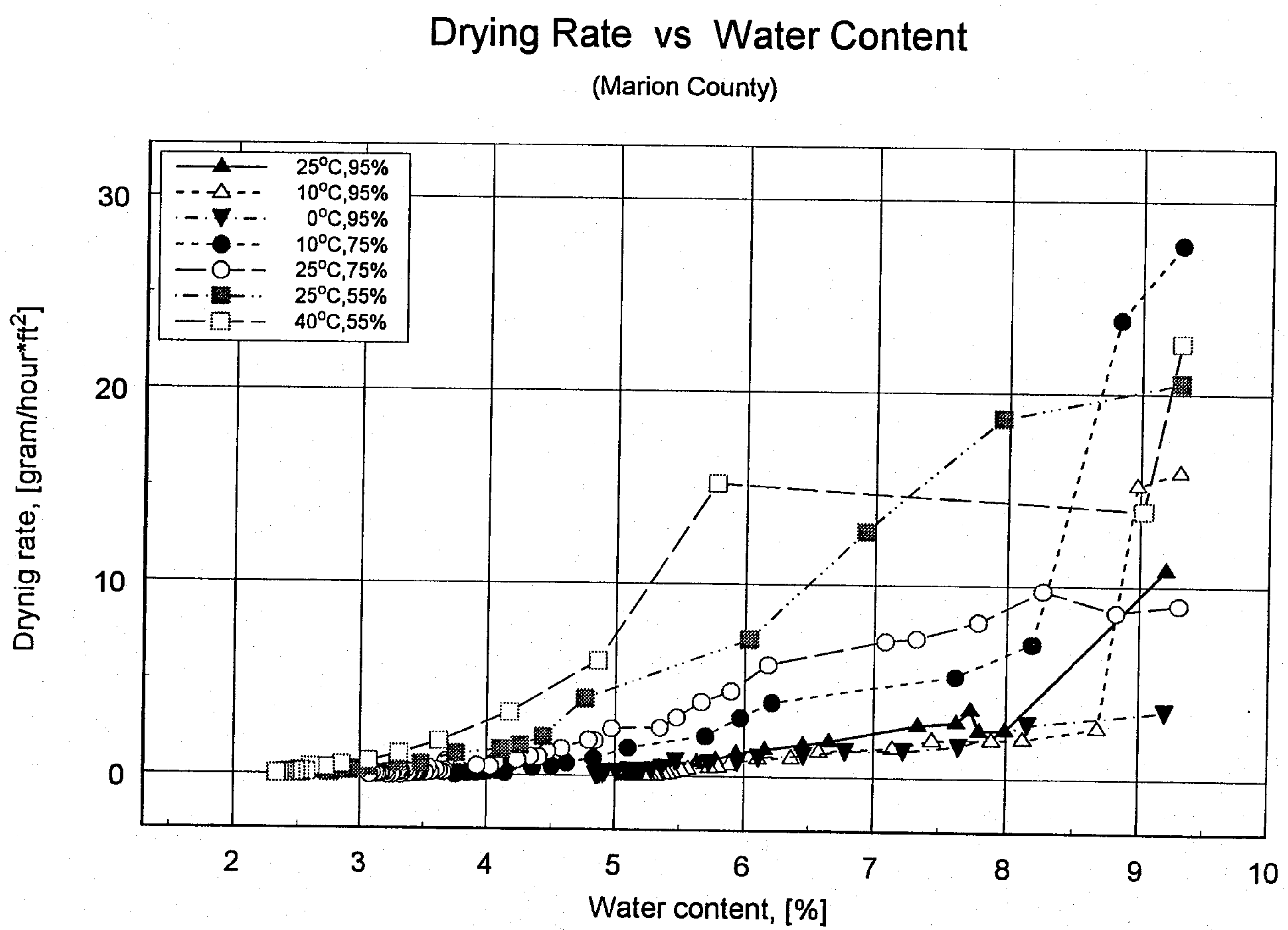

Figure D.10(e) : Comparison of drying rate at different temperature and relative humidity for Marion County soil (Group I)

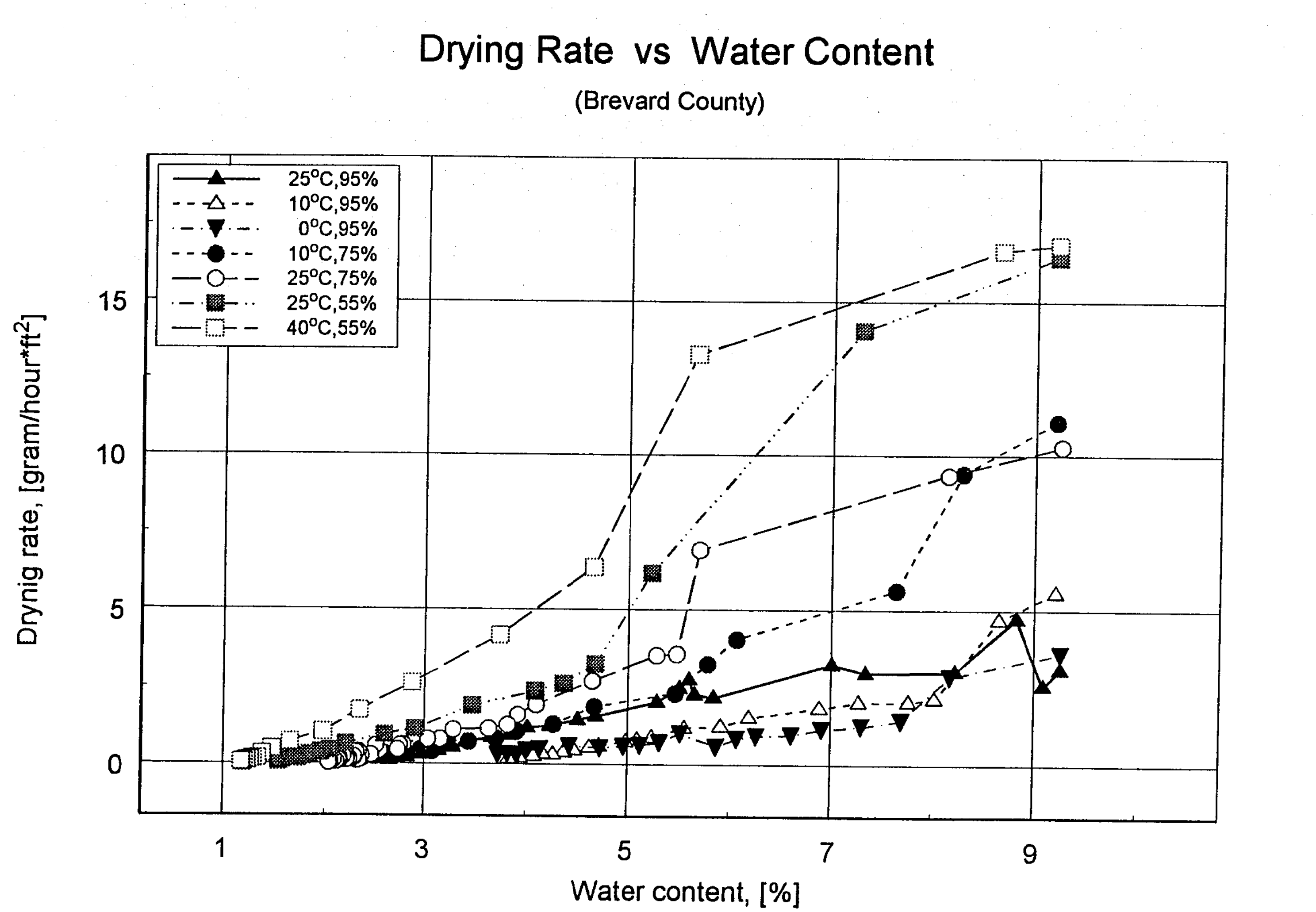

Figure D.10(f) : Comparison of drying rate at different temperature and relative humidity for Brevard County soil (Group I)

APPENDIX E: DRYING RATE GROUP II TEST RESULTS

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Table E.1 : Summary of soil drying rate Group II test results

(Temperature : 10^{O}C, Relative Humidity : 75%)

Sample Surface Area =0.487 ft^2

	Clay	Madison	Jacobs	Alford	Marion	Brevard
Dry density [KN/m^3]	18.6	18.7	19.1	19.1	18.4	18.2
Initial water content [%]	12.96	12.22	11.69	11.29	12.97	12.70
Initial water weight [gram]	262.12	246.69	239.74	231.61	259.37	251.10
Total elapsed time [hr]	118.8	119.5	116.9	118.3	117.6	116.6
Total water loss [gram]	186.1	172.0	178.1	177.2	171.1	172.3
Average drying rate , [gram per hour per ft^2]						
Within first 90 hours	4.03	3.79	3.95	3.97	3.80	3.72
Within first 200 hours	-	-	-	-	-	-
Drying rate, [gram per hour per ft^2]						
@ water content = 2%	-	-	0.52	0.65	-	-
@ water content = 4%	2.98	3.05	3.92	6.71	1.36	1.78
@ water content = 6%	4.94	4.89	5.21	7.57	4.42	4.07
@ water content = 8%	5.28	5.39	5.74	7.11	6.37	5.50
@ water content = 10%	5.60	5.76	6.28	7.33	7.57	6.29
@ water content = 12%	7.11	21.55	-	-	13.46	13.64
@ water content = optimum water content	5.50	5.49	5.74	7.04	8.24	6.09

Table E.2 : Summary of soil drying rate Group II test results

(Temperature : 10^{o}C, Relative Humidity : 95%)

Sample Surface Area =0.487 ft^2

	Clay	Madison	Jacobs	Alford	Marion	Brevard
Dry density [KN/m^3]	18.6	19.1	19.1	19.1	18.5	18.3
Initial water content [%]	13.02	11.83	11.64	11.11	12.81	12.60
Initial water weight [gram]	262.00	241.90	238.68	227.29	257.25	250.24
Total elapsed time [hr]	87.0	231.6	232.5	232.7	235.2	231.2
Total water loss [gram]	174.1	147.4	160.4	167.9	145.3	161.3
Average drying rate , [gram per hour per ft^2]						
Within first 90 hours	2.23	2.34	2.20	2.73	2.32	2.16
Within first 200 hours	1.68	1.60	1.61	1.70	1.47	1.59
Drying rate, [gram per hour per ft^2]						
@ water content = 2%	-	-	-	1.50	-	-
@ water content = 4%	0.86	0.33	1.06	2.30	-	0.67
@ water content = 6%	1.44	1.98	1.97	2.51	1.23	1.55
@ water content = 8%	1.88	2.15	1.99	2.62	2.04	1.94
@ water content = 10%	2.15	2.29	2.15	2.77	2.25	2.04
@ water content = 12%	2.38	-	-	-	2.51	5.25
@ water content = optimum water content	1.96	2.15	1.99	2.56	2.10	1.94

Table E.3 : Summary of soil drying rate Group II test results

(Temperature : $25^{o}C$, Relative Humidity : 75%)

Sample Surface Area =0.487 ft^2

	Clay	Madison	Jacobs	Alford	Marion	Brevard
Dry density [KN/m^3]	18.5	19.0	19.0	19.0	18.3	18.1
Initial water content [%]	13.30	11.70	12.00	11.70	13.20	12.90
Initial water weight [gram]	236.10	213.00	219.10	214.50	232.50	225.30
Total elapsed time [hr]	95.6	95.2	94.2	93.0	93.4	90.3
Total water loss [gram]	195.0	168.0	185.6	186.0	177.0	180.6
Average drying rate , [gram per hour per ft^2]						
Within first 90 hours	4.43	3.74	4.18	4.18	3.99	3.99
Within first 200 hours	-	-	-	-	-	-
Drying rate, [gram per hour per ft^2]						
@ water content = 2%	-	-	0.75	1.02	-	-
@ water content = 4%	4.00	4.00	5.30	7.44	1.99	2.82
@ water content = 6%	6.50	7.00	7.60	9.53	6.20	5.94
@ water content = 8%	7.30	8.40	8.36	10.74	9.30	7.93
@ water content = 10%	7.52	8.00	8.86	10.67	11.20	9.98
@ water content = 12%	7.80	-	14.37	10.52	11.60	10.86
@ water content = optimum water content	7.53	8.30	8.67	10.60	11.20	9.13

Table E.4 : Summary of soil drying rate Group II test results

(Temperature : 25^{O}C, Relative Humidity : 95%)

Sample Surface Area =0.487 ft^2

	Clay	Madison	Jacobs	Alford	Marion	Brevard
Dry density [KN/m^3]	18.2	18.5	18.7	18.6	18.5	18.0
Initial water content [%]	13.87	12.56	12.14	12.66	13.05	13.47
Initial water weight [gram]	372.30	251.95	245.11	255.20	263.22	264.65
Total elapsed time [hr]	287.5	285.3	286.2	286.5	285.0	287.0
Total water loss [gram]	162.3	144.0	159.4	186.5	142.0	179.0
Average drying rate , [gram per hour per ft^2]						
Within first 90 hours	2.03	2.17	2.00	2.57	2.20	2.00
Within first 200 hours	1.47	1.45	1.59	1.87	1.43	1.67
Drying rate, [gram per hour per ft^2]						
@ water content = 2%	-	-	-	-	-	-
@ water content = 4%	-	-	0.81	2.05	-	0.76
@ water content = 6%	0.70	1.73	1.91	2.45	1.04	1.61
@ water content = 8%	1.55	2.21	2.02	2.76	2.01	1.84
@ water content = 10%	2.02	1.90	1.85	2.37	1.92	1.93
@ water content = 12%	2.17	3.09	2.81	3.10	2.62	2.05
@ water content = optimum water content	1.92	2.30	2.00	2.74	2.22	2.07

Table E.5 : Measured soil weight at temperature 10°C & humidity 75% (Group II)

Date	Time	Temp. °C	Humidity %	Weight (g) Clay (18.6,13%)	Madison (18.7,12.2%)	Alford (19,11.3%)	Jacobs (19.1,11.7%)	Brevard (18.2,12.7%)	Marion (18.4,13%)
15-Apr	1:45p	10.0	82		2018.7				
	2:25p	10.0	76	2022.5					
	3:00p	10.0	82	2015.5	2007.8	2051.5			
	3:40p	10.0	77						1999.8
	4:20p	10.0	73	2009.8	2003.1	2039.4	2050.8		1989.9
	4:40p	10.0	74					1977.2	
	6:45p	10.0	77	2002.6	1996.3	2030.8	2036.6	1963.7	1980.4
	8:55p	10.0	73	1996.5	1990.1	2023.0	2029.8	1956.7	1971.9
16-Apr	8:55a	9.9	73	1964.0	1957.6	1981.9	1995.2	1920.6	1929.6
	3:45p	9.9	75	1946.1	1939.8	1959.4	1976.4	1901.5	1908.9
	10:15p	10.1	75	1929.5	1923.3	1929.5	1959.0	1885.2	1892.3
17-Apr	1:50p	10.0	75	1892.4	1888.8	1903.4	1923.5	1855.6	1863.7
18-Apr	9:00a	10.0	73	1863.2	1864.9	1887.0	1894.5	1832.9	1845.9
	10:55p	10.0	75	1852.4	1857.5	1882.0	1884.1	1822.2	1838.5
19-Apr	8:30p	9.9	74	1842.0	1850.4	1877.0	1875.8	1811.1	1831.9
20-Apr	1:15p	9.9	74	1836.4	1846.7	1874.3	1872.1	1804.9	1828.7
Total elapsed time				118.84	119.50	118.25	116.92	116.58	117.59
Dry Soil				1790.5	1798.9	1843.4	1836.1	1754.4	1770.2
Initial Water Content				12.96%	12.22%	11.29%	11.69%	12.70%	12.97%
Dry Unit Weight				18.59	18.68	19.14	19.06	18.21	18.38

Table E.6 : Measured soil weight at temperature10°C & humidity 95% (Group II)

Date	Time	Temp. °C	Humidity %	Weight (g) Clay (18.6,13.0%)	Madison (19,11.8%)	Alford (19,11.1%)	Jacobs (19.1,11.6%)	Brevard (18.3,12.6%)	Marion (18.5,12.8%)
				13.3%	11.7%	11.7%	12.0%	12.9%	13.2%
21-Apr	1:27p	10.0	95	2019.0					
	2:30p	10.0	95	2011.7					2008.2
	4:17p	10.0	95	2009.2					1999.7
	4:57p	10.0	95			2045.8			
	5:09p	10.0	95				2050.5		
	6:05p	10.0	95	2006.8	2041.3	2038.1	2043.2		1997.5
	6:25p	10.0	95					1986.0	
	10:55p	10.0	95	2001.2	2029.4	2031.5	2037.6	1974.7	1991.6
22-Apr	11:12a	10.0	95	1987.4	2015.5	2015.3	2024.7	1961.8	1977.2
	7:56p	10.0	95	1978.0	2005.8	2004.2	2015.6	1953.1	1967.5
23-Apr	11:57a	10.0	95	1961.4	1988.2	1983.8	1999.6	1937.2	1950.2
	8:20p	10.1	95	1953.3	1979.5	1973.4	1991.5	1929.3	1941.7
24-Apr	10:25a	10.2	95	1940.1	1964.6	1955.8	1977.8	1915.9	1927.5
25-Apr	8:50a	10.0	95	1920.0	1941.9	1928.5	1956.6	1894.8	1906.2
	11:23p	10.0	95	1907.7	1928.5	1912.5	1942.6	1881.9	1894.3
26-Apr	10:25a	10.0	95	1899.7	1920.6	1903.4	1933.8	1873.3	1887.6
	p	10.0	95	1891.7	1913.7	1896.5	1925.0	1865.0	1881.7
27-Apr	12:45p	10.0	95	1882.4	1907.4	1890.7	1916.1	1855.7	1876.1
	9:55p	10.0	95	1877.0	1904.4	1888.1	1911.2	1850.4	1873.4
28-Apr	10:30a	10.0	95	1870.3	1901.3	1885.6	1905.7	1844.6	1870.5
29-Apr	10:35a	10.0	95	1859.7	1897.8	1881.9	1898.3	1836.3	1866.7
30-Apr	11:03a	10.0	94	1851.2	1895.6	1879.4	1892.0	1829.4	1864.2
1-May	9:40a	10.0	95	1844.9	1893.9	1877.9	1890.1	1824.7	1862.9
Total elapsed time				236.2	231.6	232.7	232.5	231.2	235.2
Dry Soil				1786.4	1825.4	1841.3	1836.7	1763.7	1780.1
Initial Water Content				13.02%	11.83%	11.11%	11.64%	12.60%	12.81%
Dry Unit Weight				18.55	18.95	19.12	19.07	18.31	18.48

Table E.7 : Measured soil weight at temperature 25°C & humidity 75% (GroupII)

Date	Time	Temp. °C	Humidity %	Soil Weight [gram]					
				Clay	Madison	Jacobs	Alford	Marion	Brevard
				(18.5,13.3%)	(19,11.7%)	(19,12%)	(19,11.7%)	(18.3,13.2%)	(18.1,12.9%)
26-Mar	10:25	25.0	75	2013.3					
	10:50	25.0	75		2041.3				
	11:02	25.0	75	2010.3	2039.6				
	11:30	25.0	75	2008.1	2037.2				
	11:51	25.0	75			2044.8			
	12:05	25.0	75	2006.0	2034.7	2043.3			
	12:38	25.0	75					1999.4	
	13:00	25.0	75	2002.4	2030.9	2039.3	2046.8	1996.6	
	15:00	25.0	75	1994.7	2022.4	2030.5	2035.1	1985.0	
	15:40	25.0	75						1967.9
	17:40	25.0	75	1984.7	2012.0	2019.1	2021.4	1970.5	1957.2
27-Mar	9:35	25.0	75	1926.4	1951.3	1952.3	1942.6	1895.5	1887.0
	12:35	25.0	75	1915.8	1940.9	1940.8	1929.4	1884.8	1875.6
	17:00	25.0	75	1901.0	1927.1	1925.9	1911.7	1871.7	1860.5
28-Mar	0:50	25.0	75	1876.7	1908.4	1903.6	1890.7	1855.2	1840.0
	9:50	25.0	75	1855.5	1895.2	1886.2	1879.7	1843.4	1823.4
	22:35	25.0	75	1838.8	1885.6	1873.0	1871.3	1833.8	1808.2
29-Mar	8:20	25.0	75	1830.8	1881.0	1867.3	1867.4	1829.1	1800.2
	20:15	25.0	75	1824.1	1876.8	1862.9	1864.0	1825.7	1793.2
30-Mar	10:00	25.0	75	1818.3	1873.3	1859.2	1860.8	1822.4	1787.3
Total elapsed time [hr]				95.59	95.17	94.16	93.01	93.37	90.34
Dry Soil weight [gram]				1777.2	1828.3	1825.7	1832.3	1766.9	1742.6
Initial Water Content				13.28%	11.65%	12.00%	11.71%	13.16%	12.93%
Dry Unit Weight [KN/m^3]				18.45	18.98	18.96	19.02	18.34	18.09

Table E.8 : Measured soil weight at temperature 25°C & humidity 95% (GroupII)

Date	Time	Temp. °C	Humidity %	Weight (g)					
				Clay	Madison	Alford	Jacobs	Brevard	Marion
				(18.2,13.9%)	(18.5,12.6%)	(18.6,12.7%)	(18.7,12.1%)	(18,13.5%)	(18.5,13.1%)
3-Apr	1:47p	25.0	95	1990.9					
	2:15p	25.0	95					1964.7	
	2:45p	25.0	95			2015.9			
	3:05p	25.0	95	1988.4			2019.0	1962.4	
	3:55p	25.0	95		2006.0				
	4:15p	25.0	95						2017.0
	8:45p	25.0	95	1981.9	1998.4	2006.6	2011.6	1956.0	2009.9
4-Apr	11:30a	25.0	95	1965.6	1981.9	1988.1	1996.9	1941.1	1993.1
	9:40p	25.0	95	1955.1	1971.2	1975.6	1986.8	1931.3	1982.0
5-Apr	3:12p	25.0	95	1940.5	1955.9	1957.3	1972.9	1917.7	1966.4
6-Apr	10:50a	25.0	95	1920.7	1933.8	1930.4	1952.5	1897.5	1943.6
	8:10p	25.0	95	1911.7	1923.8	1918.4	1943.4	1888.2	1933.9
7-Apr	11:40a	25.0	95	1899.2	1909.0	1899.9	1928.9	1874.3	1919.6
8-Apr	1:00p	25.0	95	1881.0	1887.8	1870.0	1905.6	1851.7	1900.5
9-Apr	8:45a	25.0	95	1870.1	1877.1	1853.4	1891.1	1836.1	1890.8
	0:00a	25.0	95	1863.5	1871.7	1845.1	1881.8	1825.2	1885.6
10-Apr	10:22a	25.0	95	1859.2	1868.9	1841.1	1876.6	1818.6	1883.1
11-Apr	1:40p	25.0	95	1850.7	1865.7	1836.1	1869.1	1805.7	1879.3
	10:50p	25.0	95	1847.2	1864.3	1834.1	1866.8	1802.0	1878.0
13-Apr	2:55p	25.0	95	1838.1	1863.3	1831.7	1862.5	1792.1	1876.3
	8:45p	25.0	95	1836.8	1863.1	1831.3	1861.9	1791.0	1876.1
14-Apr	11:55a	25.0	95	1833.4	1862.5	1830.3	1860.9	1788.5	1875.8
15-Apr	1:15p	25.0	95	1828.6	1862.0	1829.4	1859.6	1785.7	1875.0
Total elapsed time				287.47	285.33	286.50	286.16	287.00	285.00
Dry Soil				1748.4	1782.1	1789.4	1800.4	1731.5	1784.2
Initial Water Content				13.87%	12.56%	12.66%	12.14%	13.47%	13.05%
Dry Unit Weight				18.15	18.50	18.58	18.69	17.98	18.52

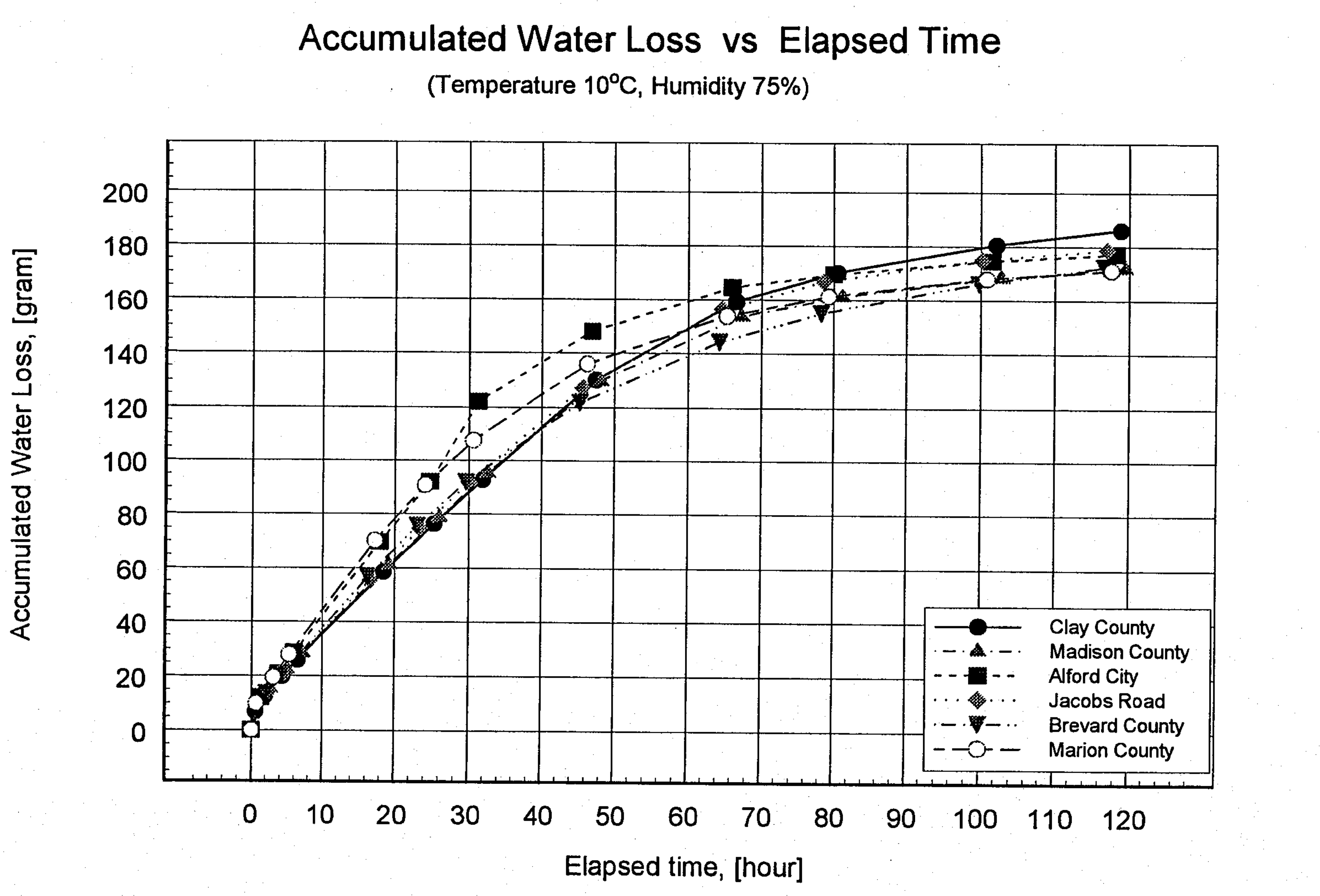

Figure E.1(a) : Water loss versus elapsed time at temperature 10°C and 75% relative humidity for six soils (Group II)

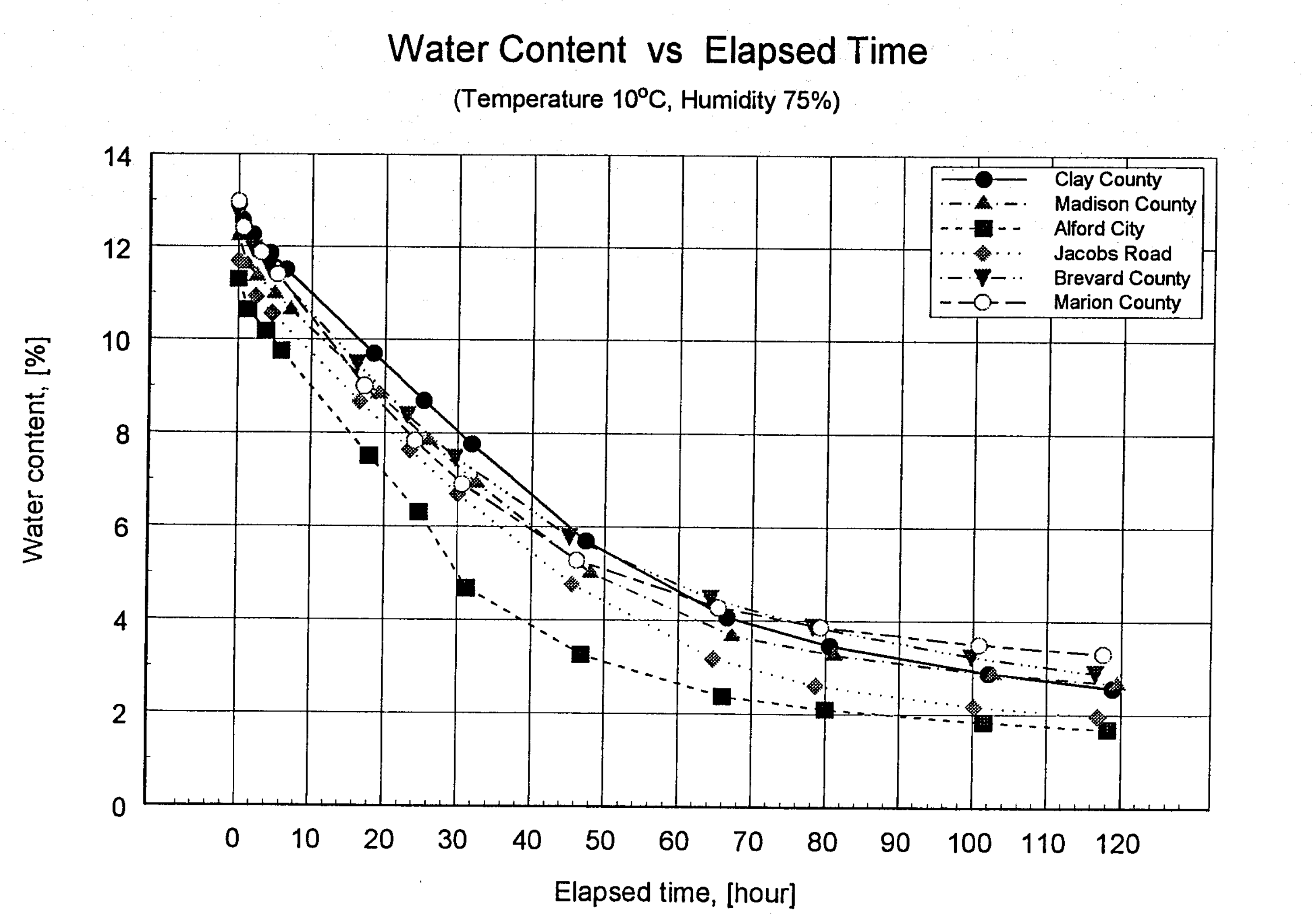

Figure E.1(b) : Water content versus elapsed time at temperature 10°C and relative humidity 75% for six soils (Group II)

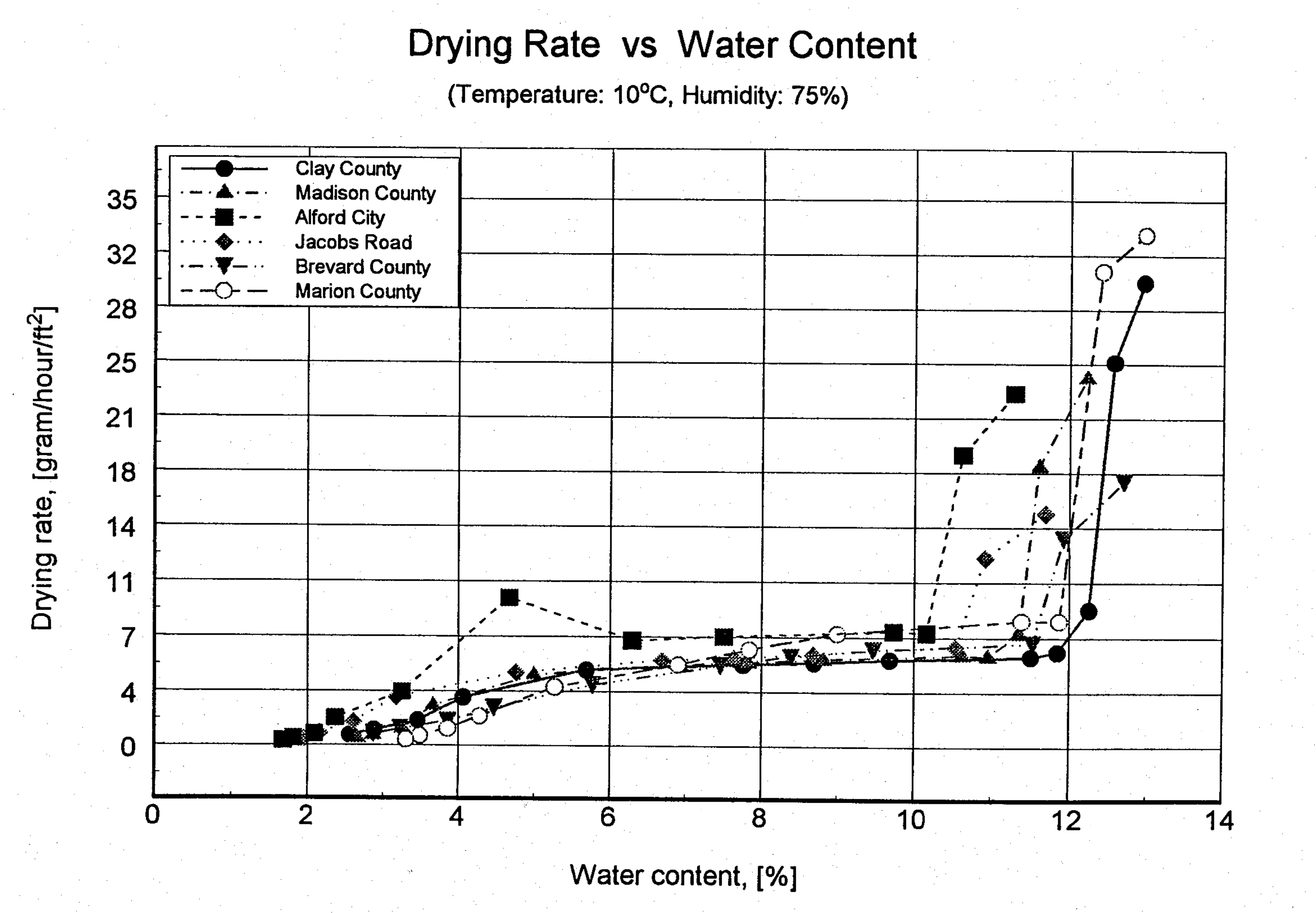

Figure E.1(c) : Drying rate versus water content for six soils at temperature 10°C and 75% relative humidity (Group II)

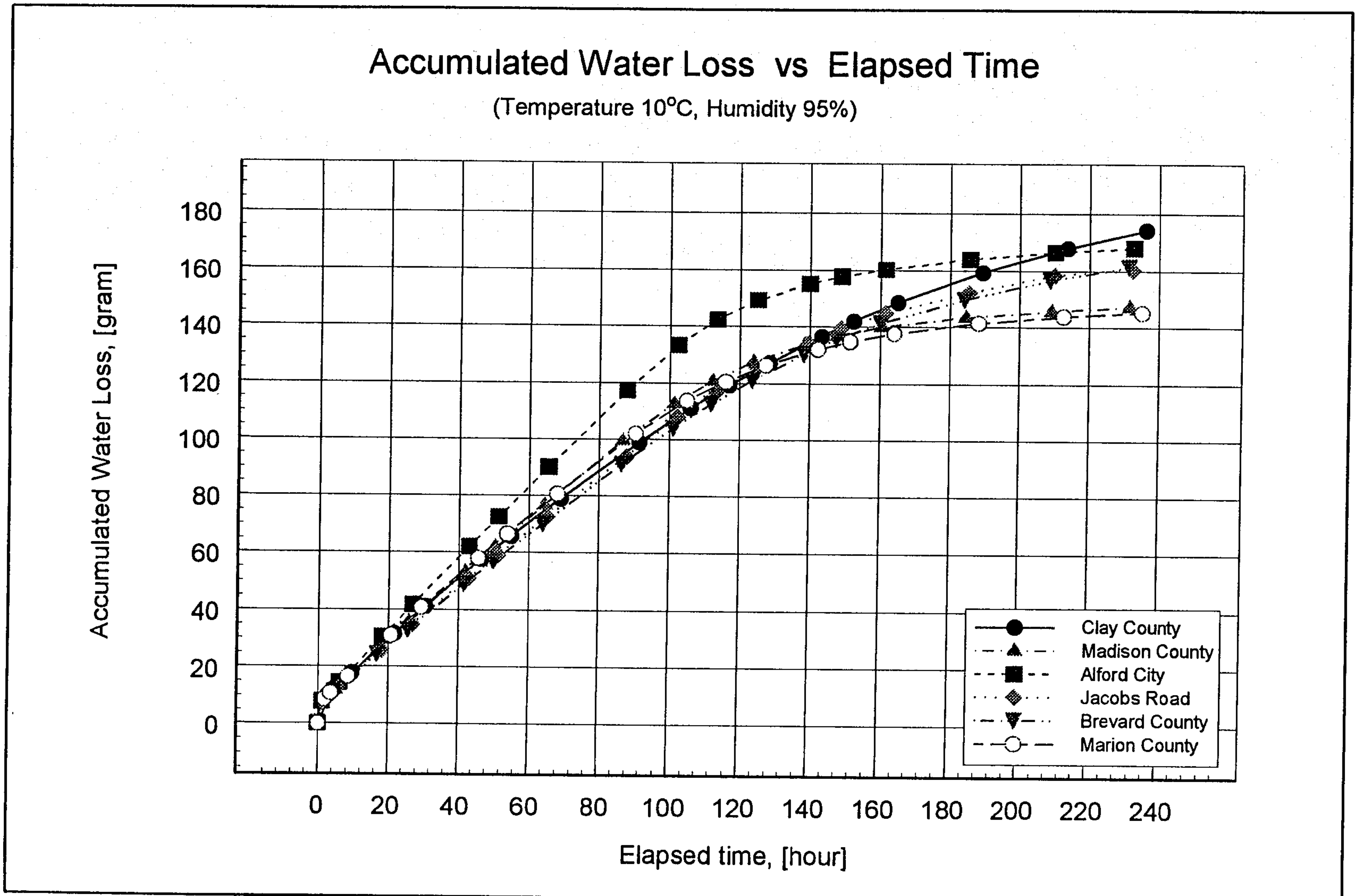

Figure E.2(a) : Water loss versus elapsed time at temperature 10°C and 95% relative humidity for six soils (Group II)

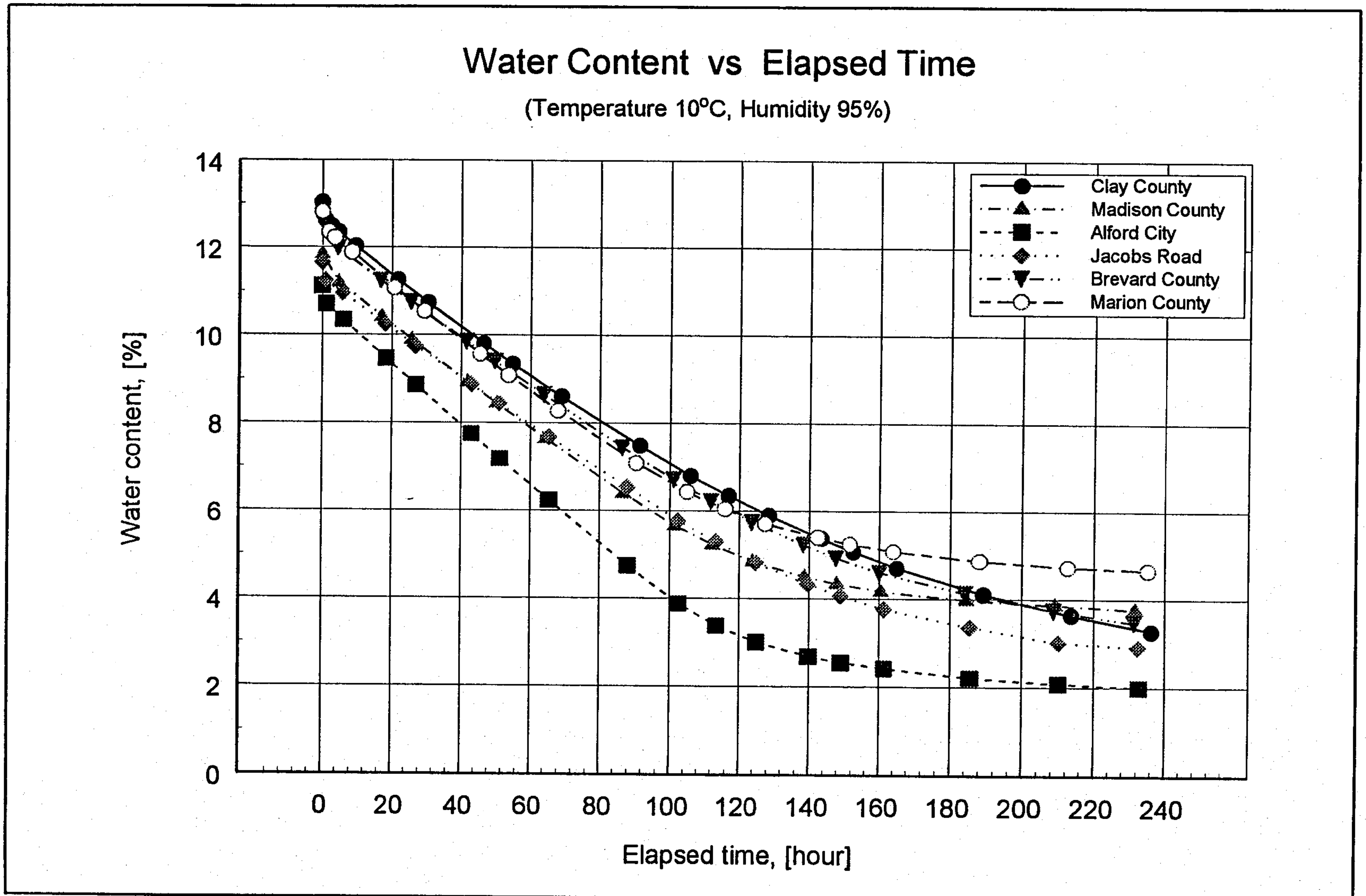

Figure E.2(b) : Water content versus elapsed time at temperature 10°C and relative humidity 95% for six soils (Group II)

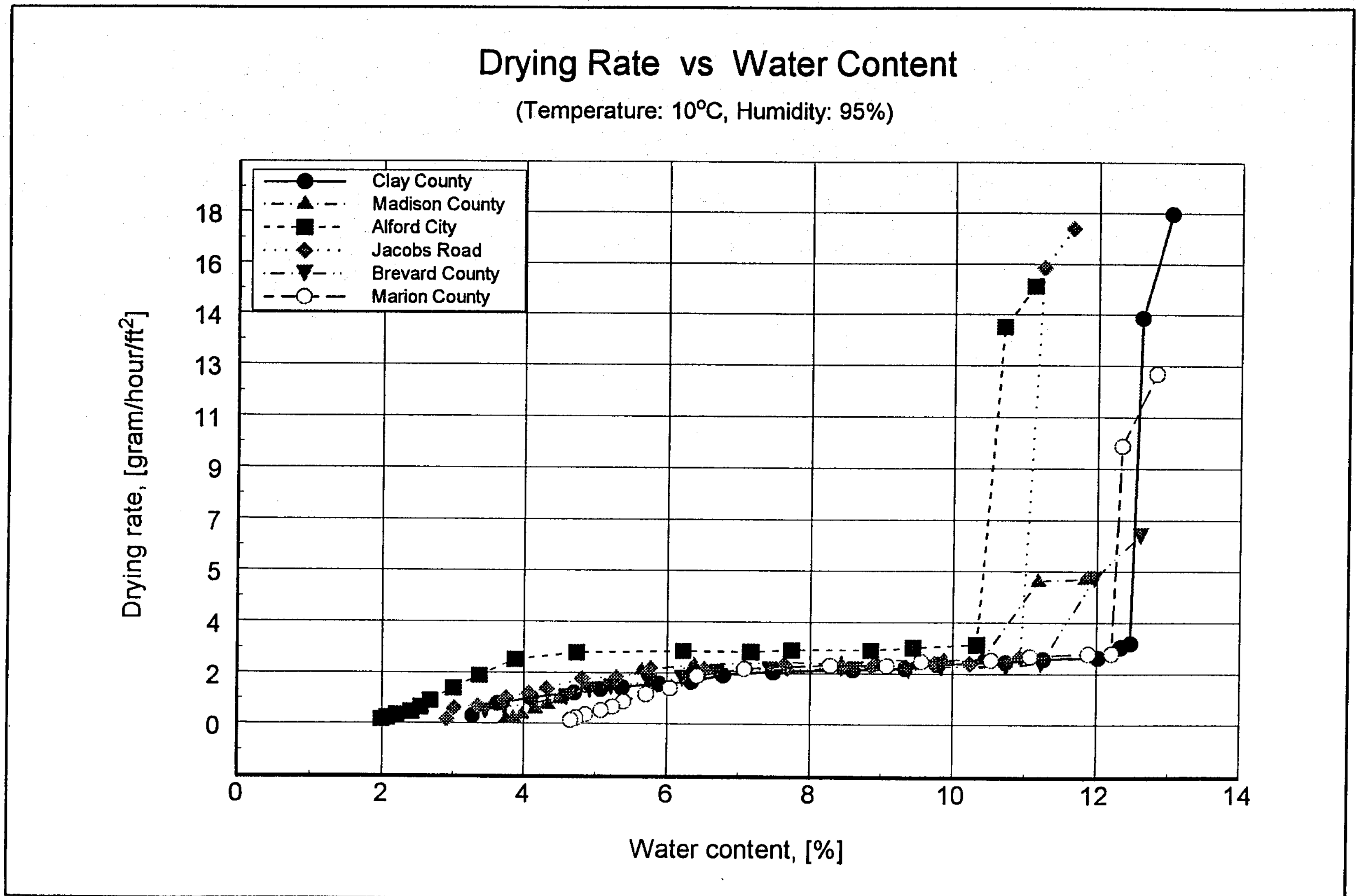

Figure E.2(c) : Drying rate versus water content for six soils at temperature 10°C and 95% relative humidity (Group II)

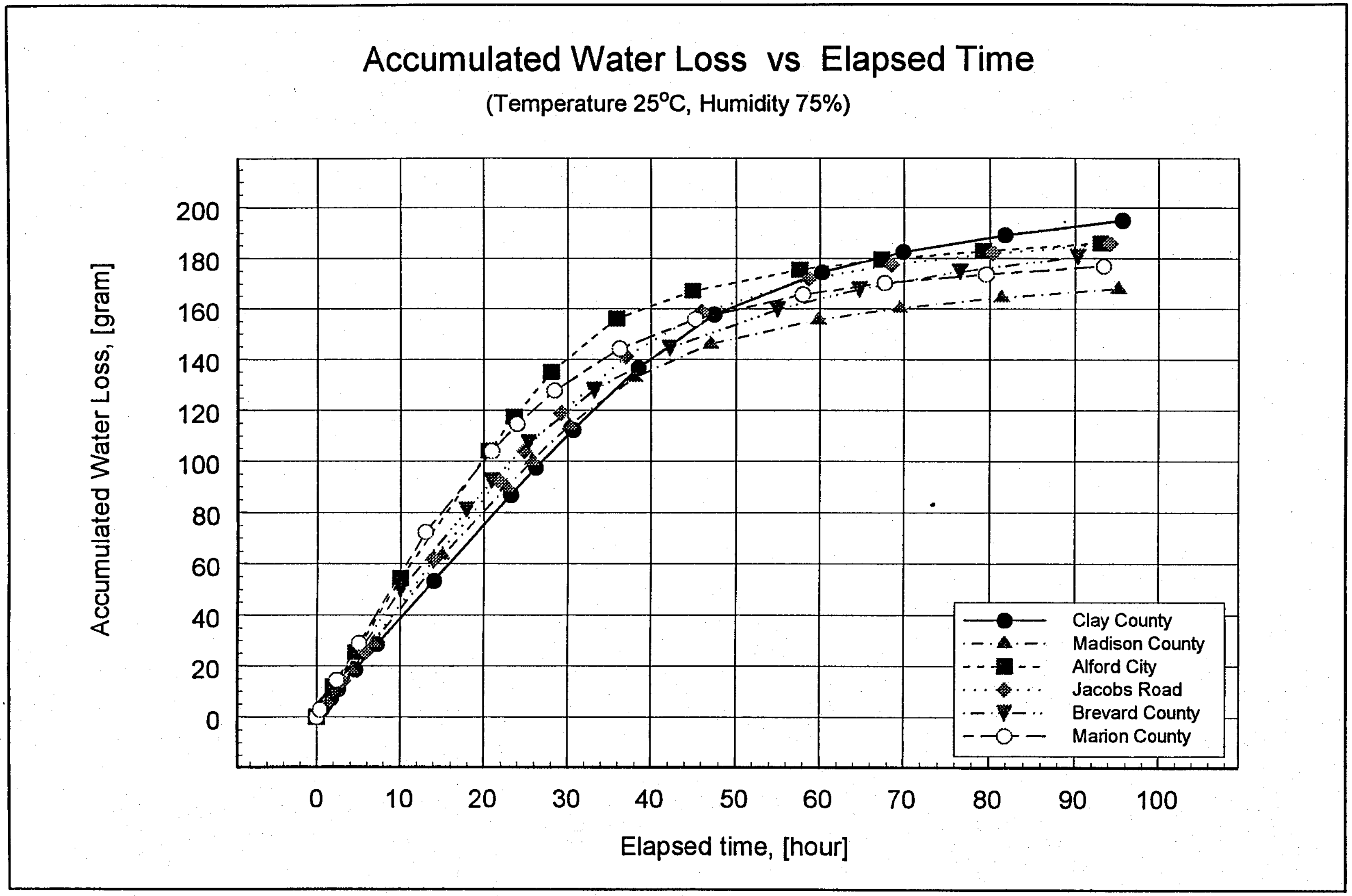

Figure E.3(a) : Water loss versus elapsed time at temperature 25°C and 75% relative humidity for six soils (Group II)

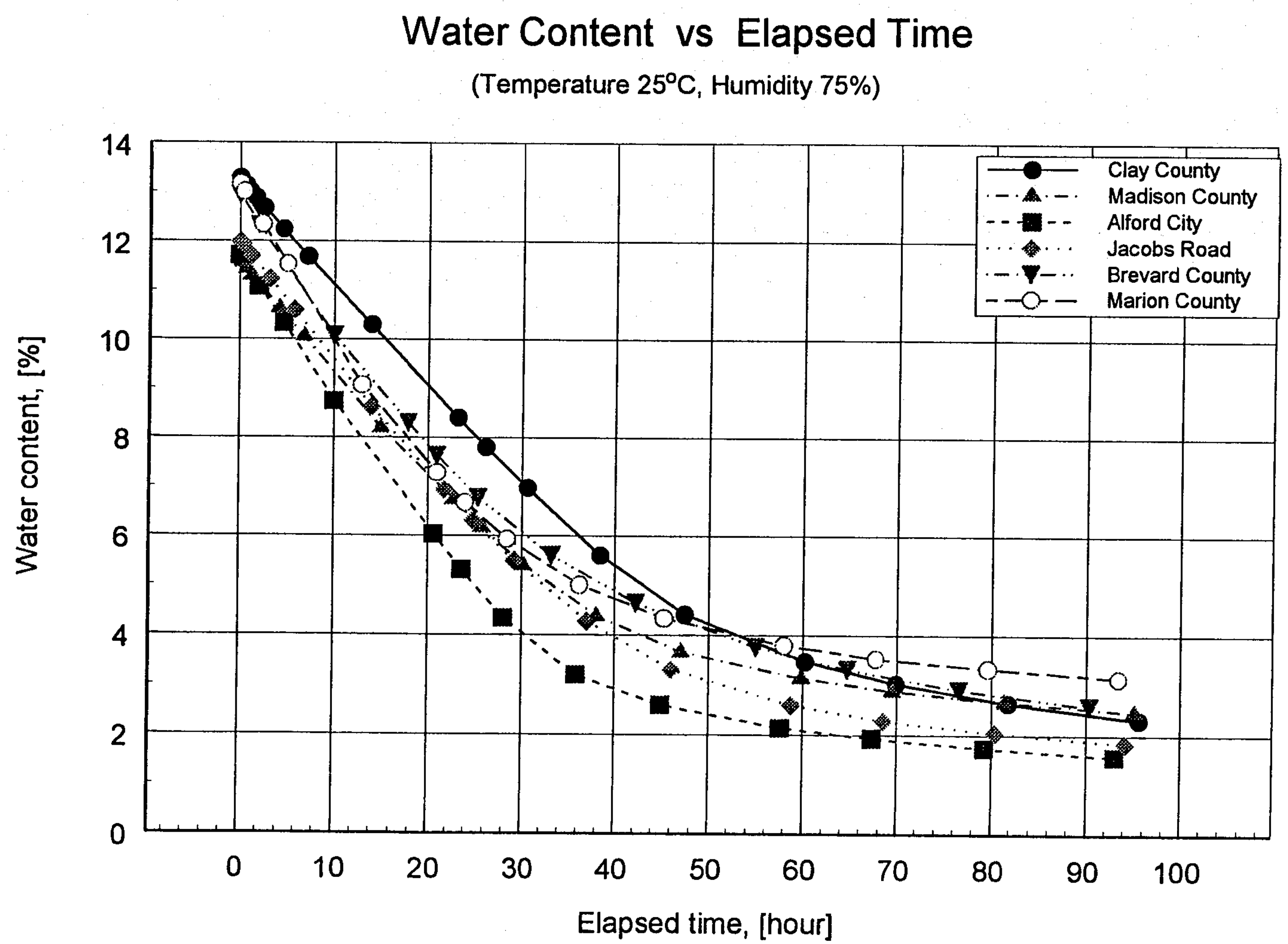

Figure E.3(b) : Water content versus elapsed time at temperature 25°C and relative humidity 75% for six soils (Group II)

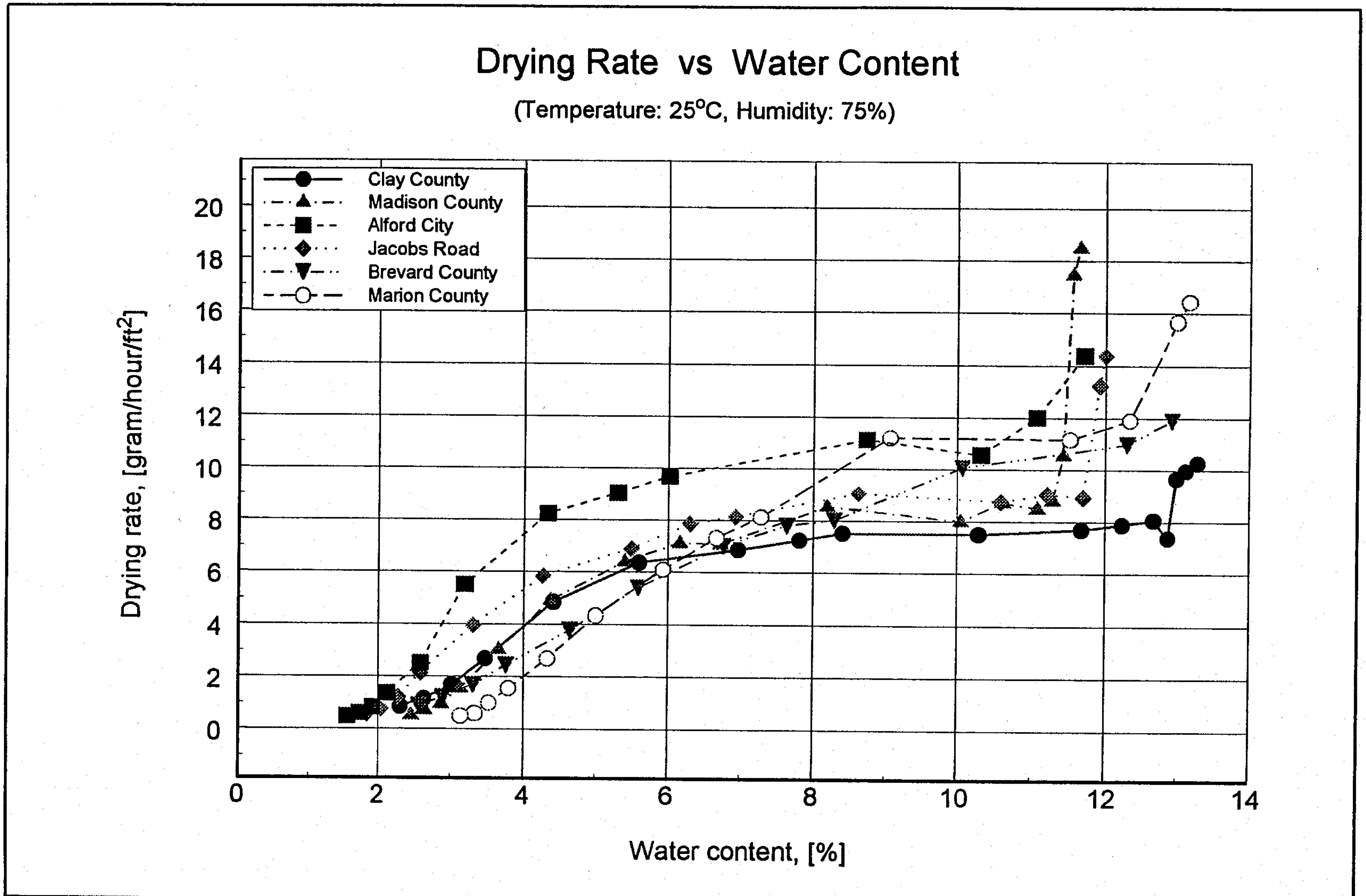

Figure E.3(c) : Drying rate versus water content for six soils at temperature 25°C and 75% relative humidity (Group II)

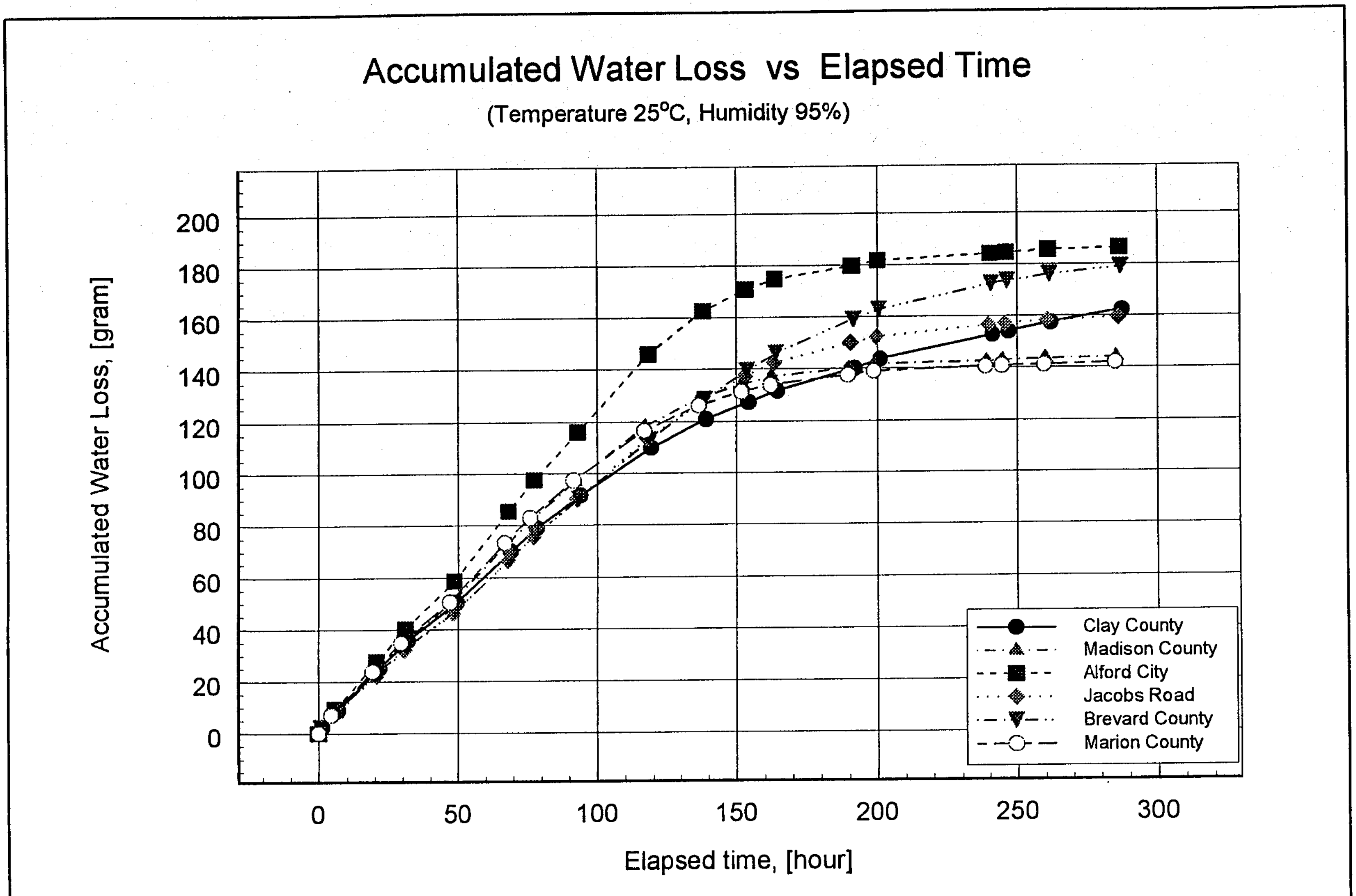

Figure E.4(a) : Water loss versus elapsed time at temperature 25°C and 95% relative humidity for six soils (Group II)

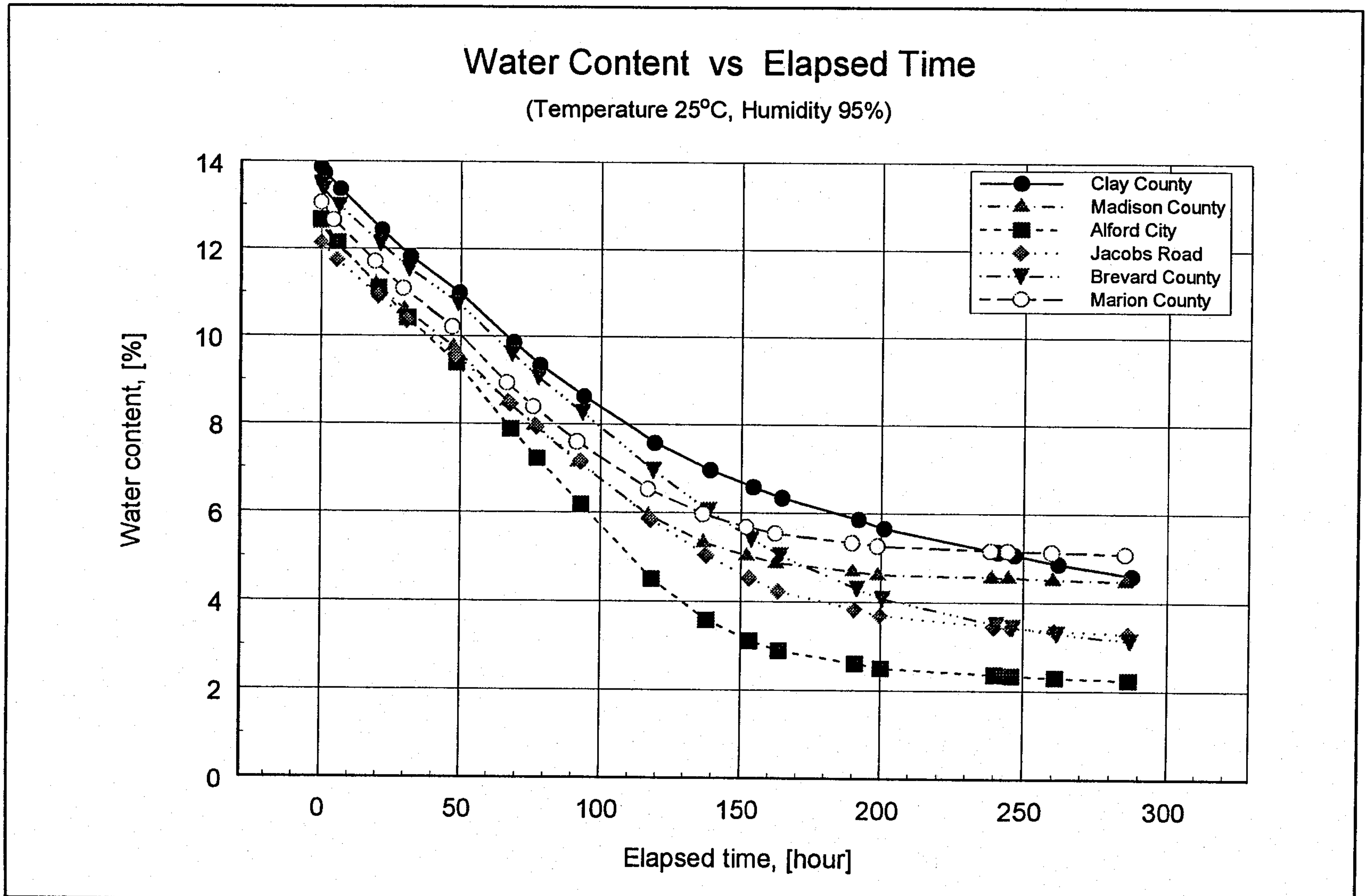

Figure E.4(b) : Water content versus elapsed time at temperature 25°C and relative humidity 95% for six soils (Group II)

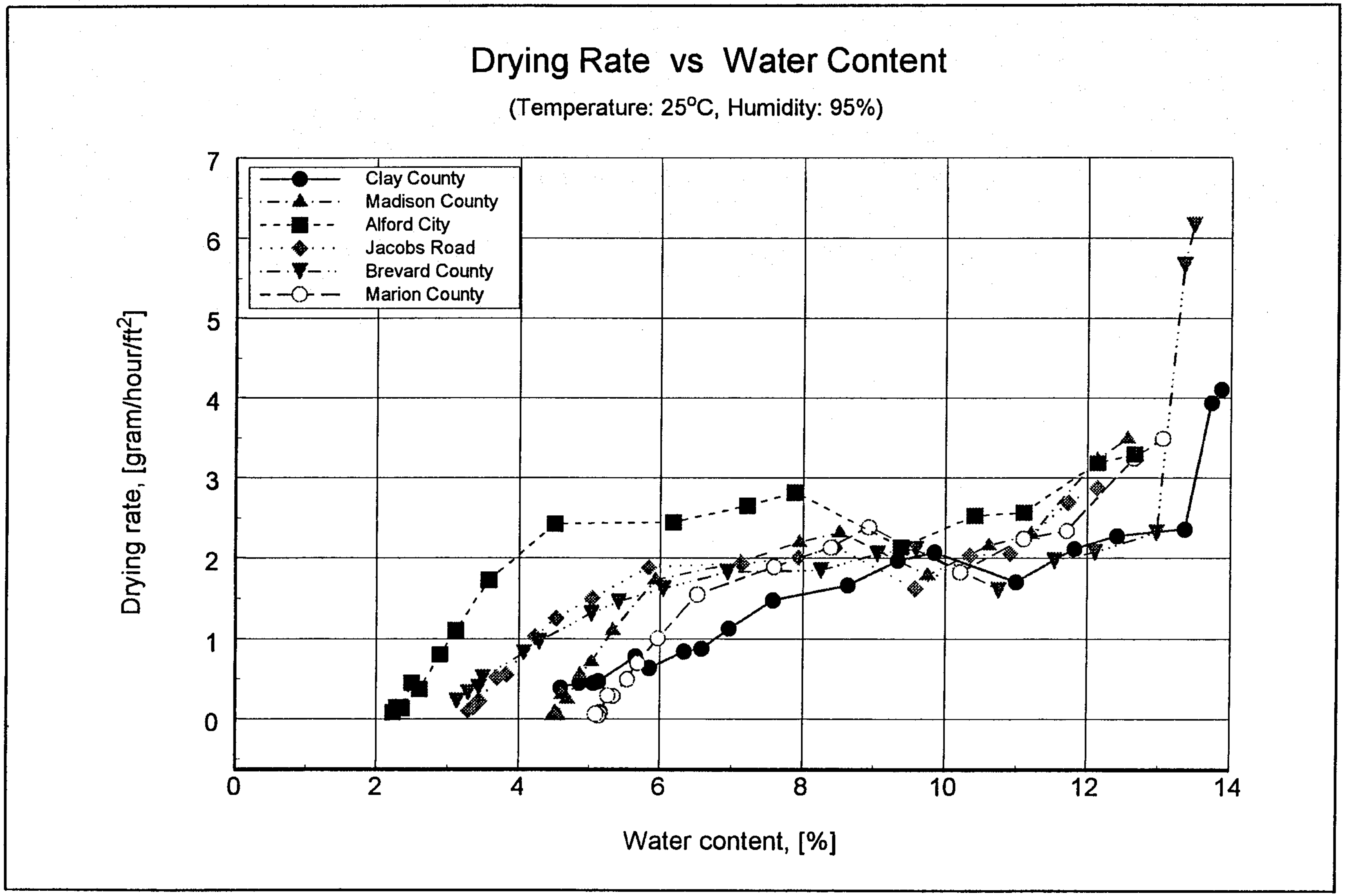

Figure E.4(c) : Drying rate versus water content for six soils at temperature 25°C and 95% relative humidity (Group II)

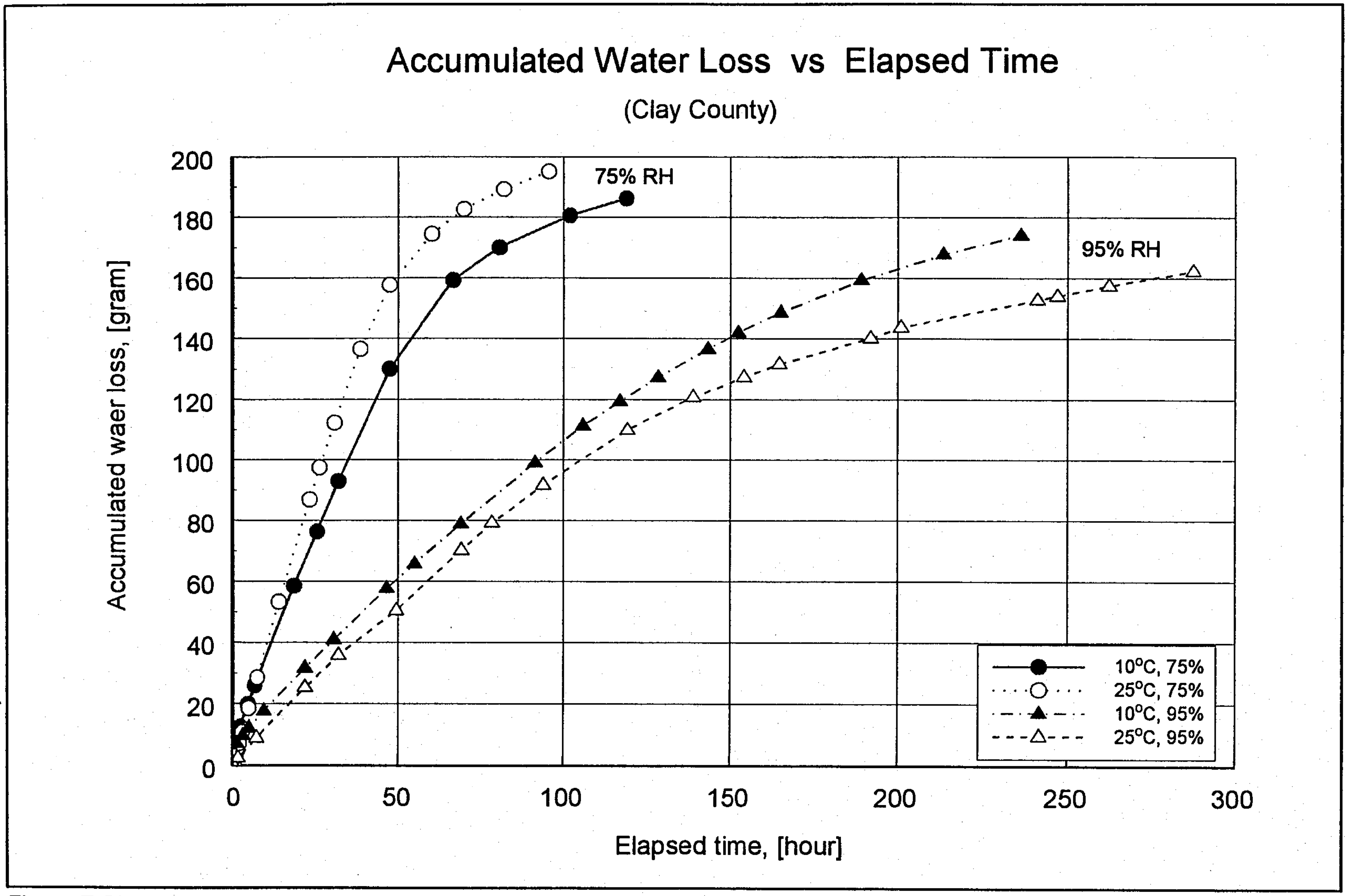

Figure E.5(a) : Comparison of water loss at different temperature and relative humidity for Clay County soil(Group II)

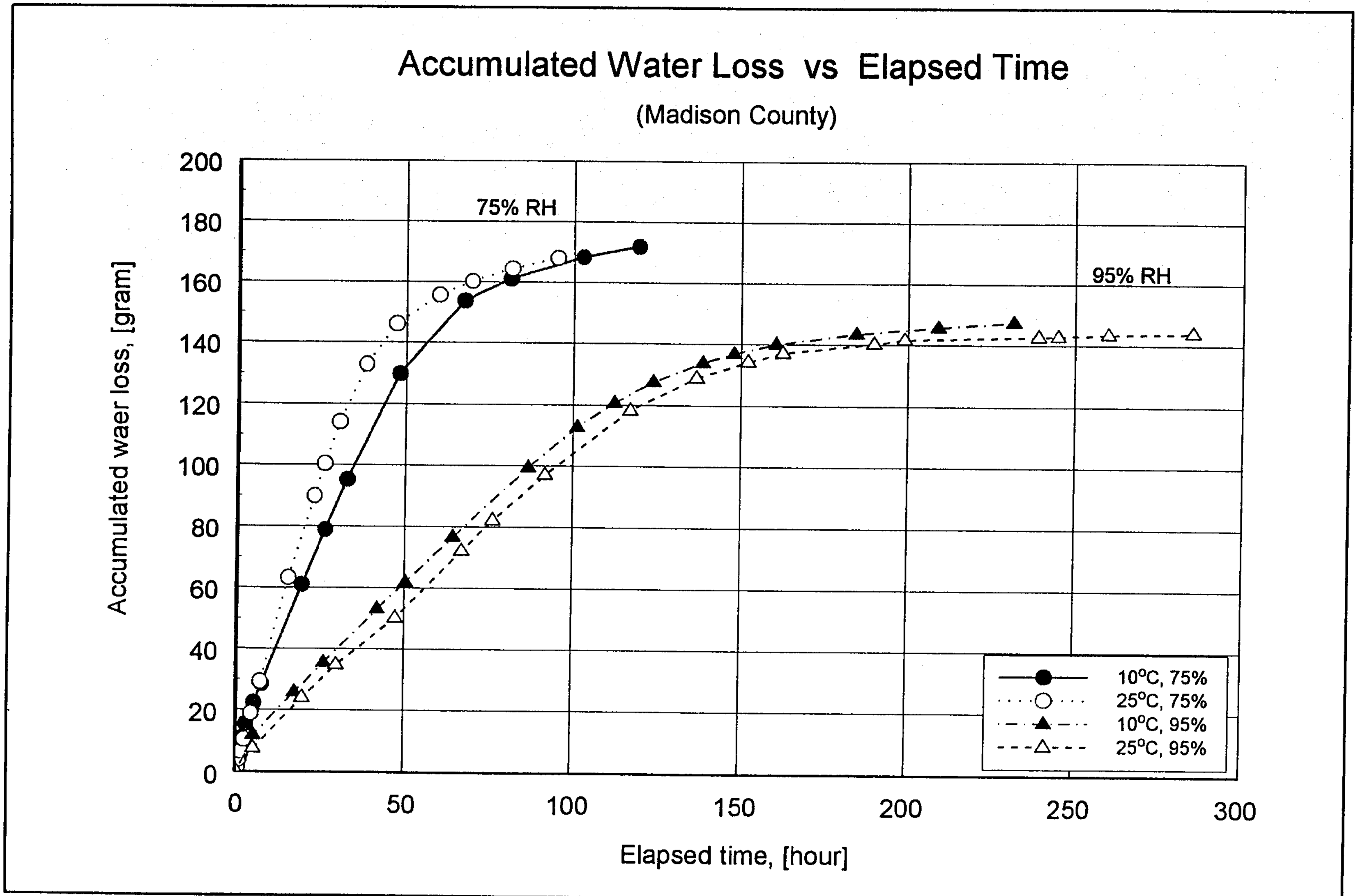

Figure E.5(b) : Comparison of water loss at different temperature and relative humidity for Madison County soil(Group II)

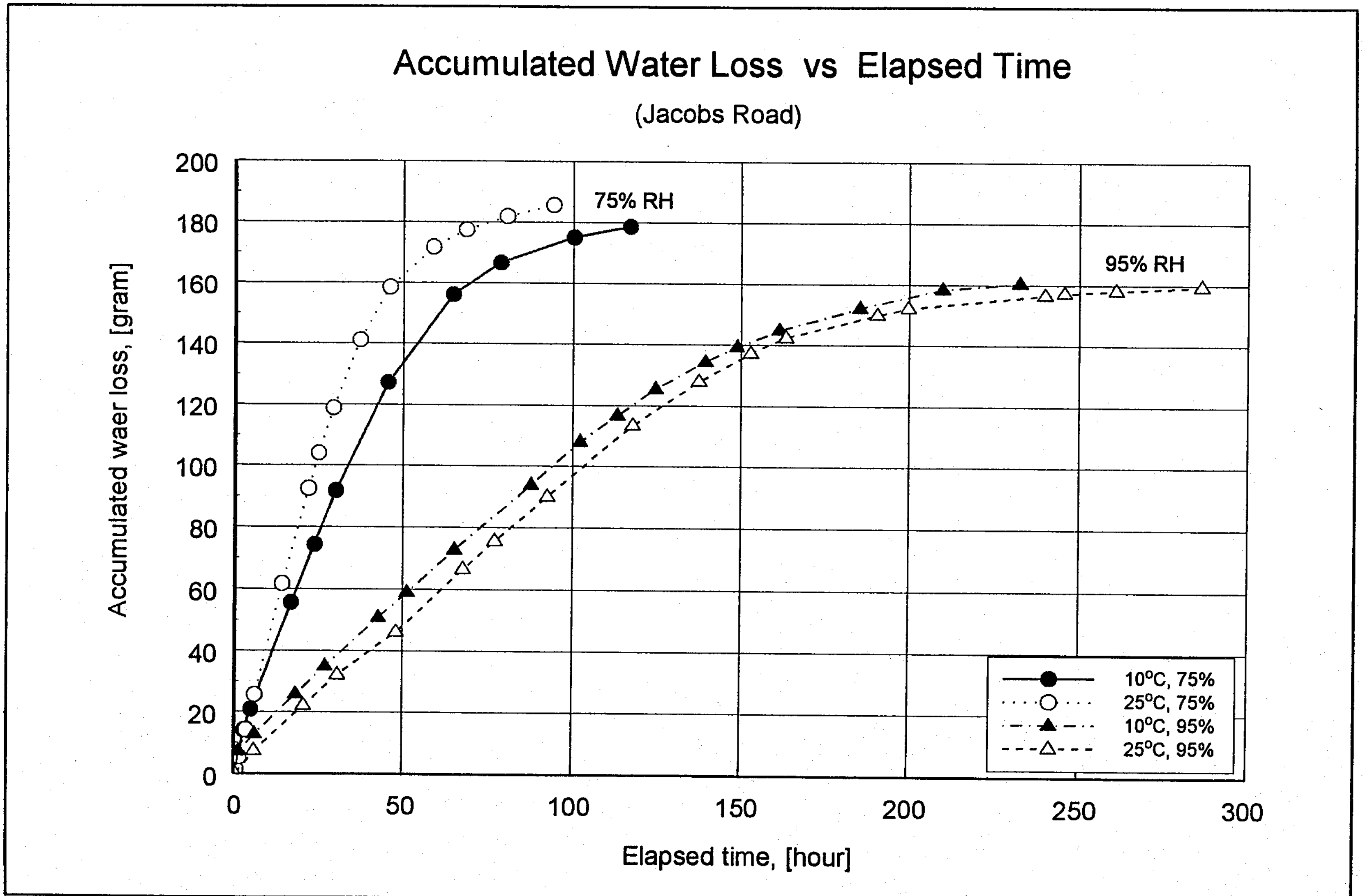

Figure E.5(c) : Comparison of water loss at different temperature and relative humidity for Jacobs Road soil (Group II)

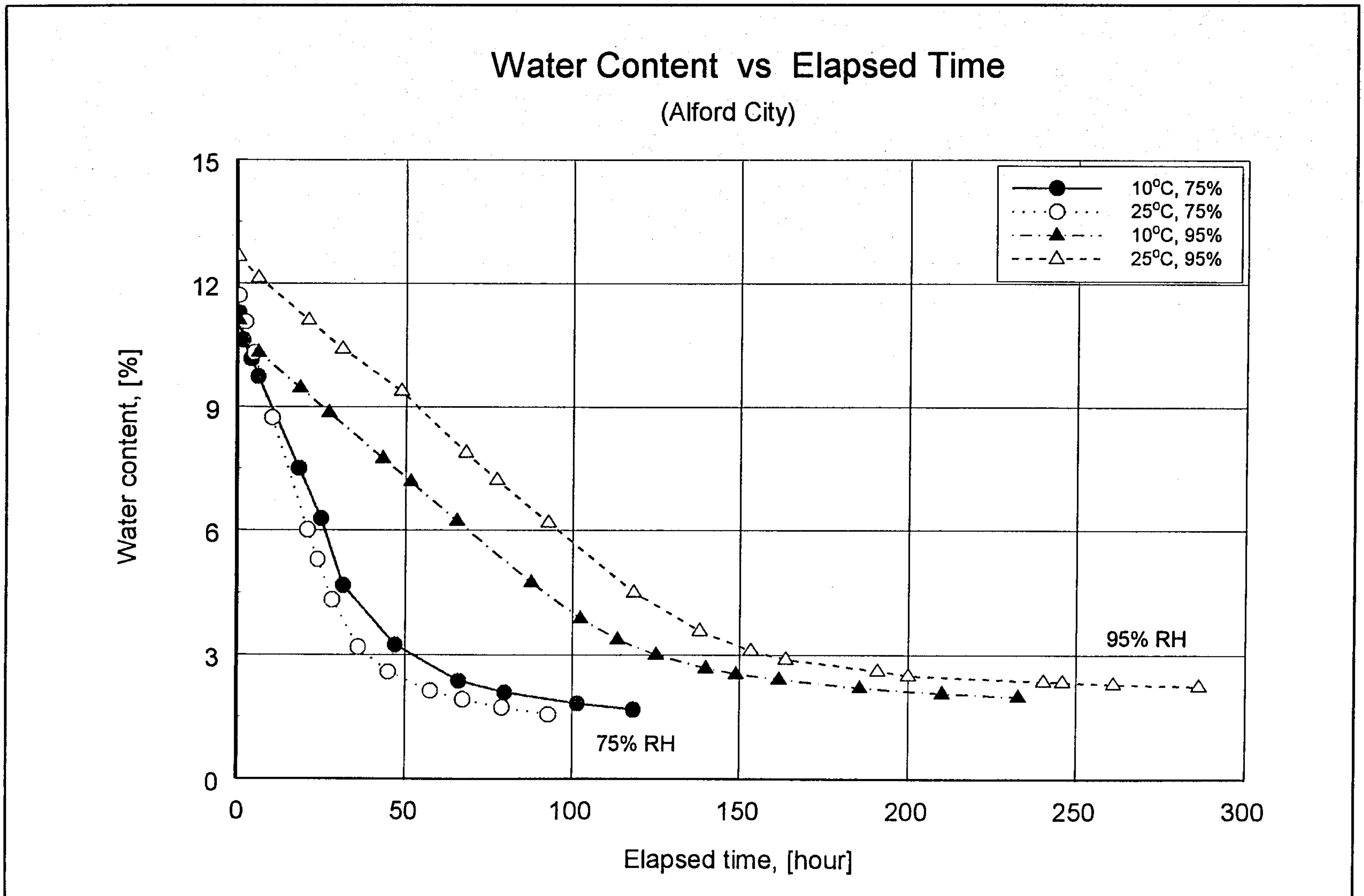

Figure E.6(d) : Comparison of change of water content at different temperature and relative humidity for Alford City soil (Group II)

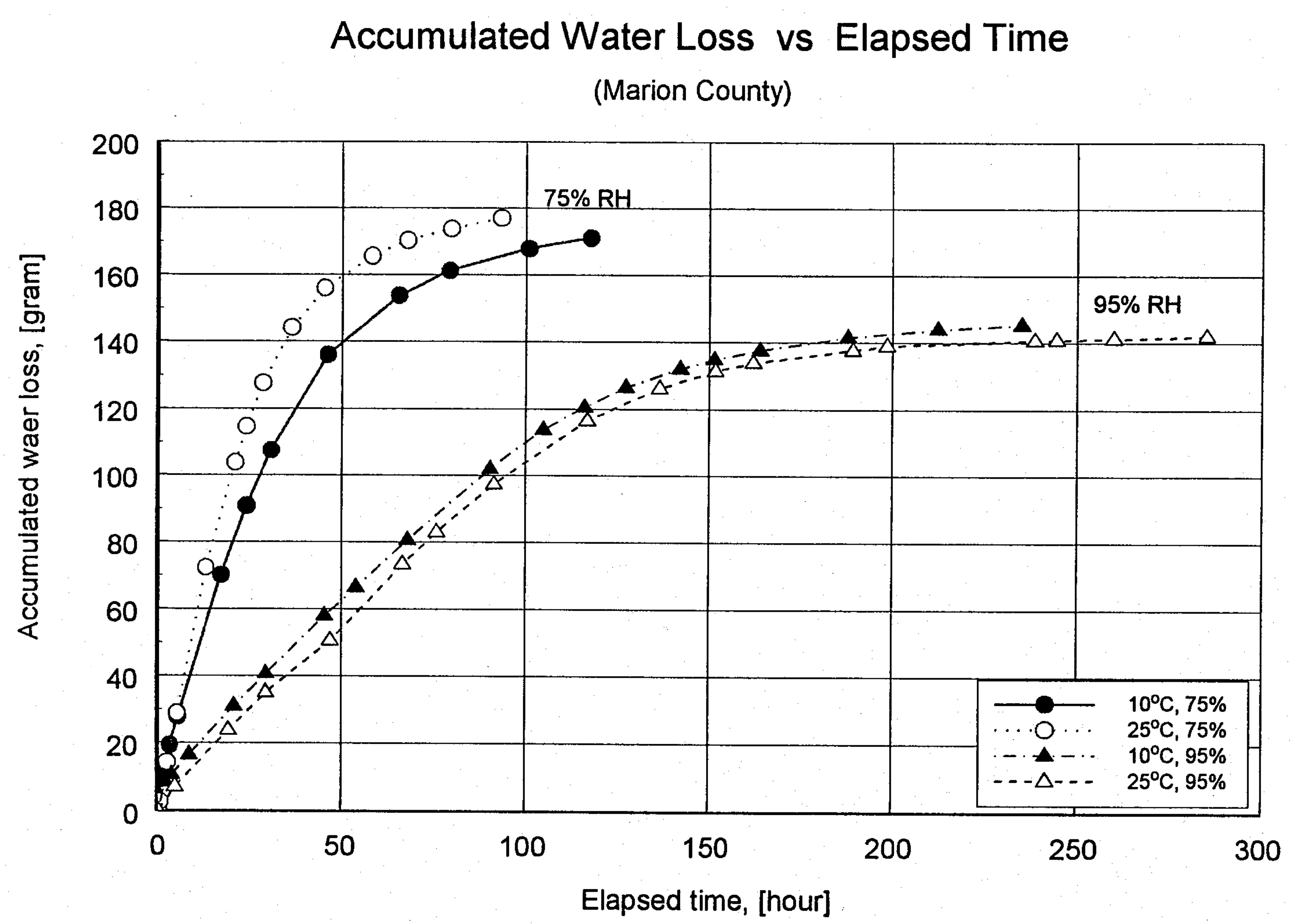

Figure E.5(e) : Comparison of water loss at different temperature and relative humidity for Marion County soil (Group II)

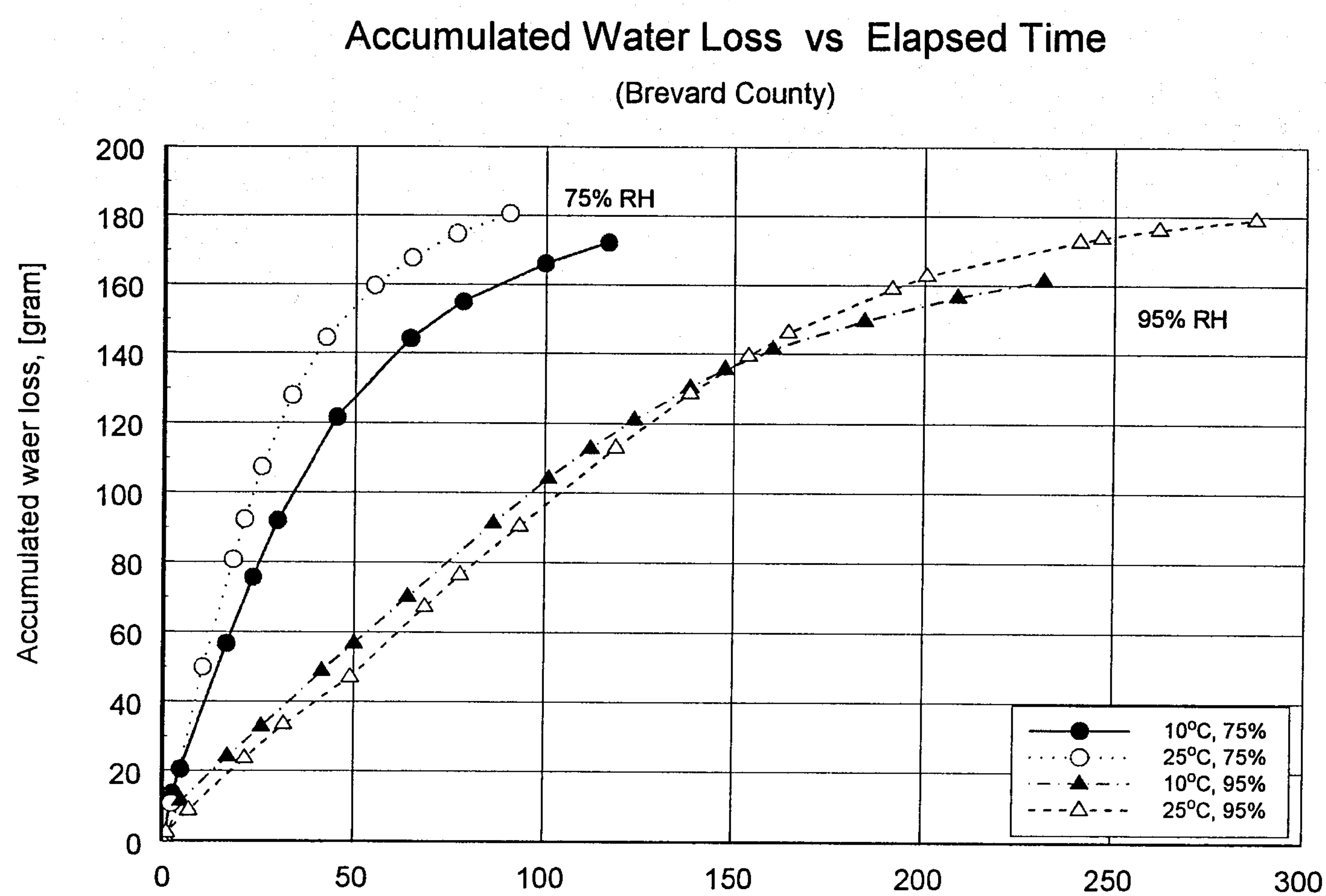

Figure E.5(f) : Comparison of water loss at different temperature and relative humidity for Brevard County soil (Group II)

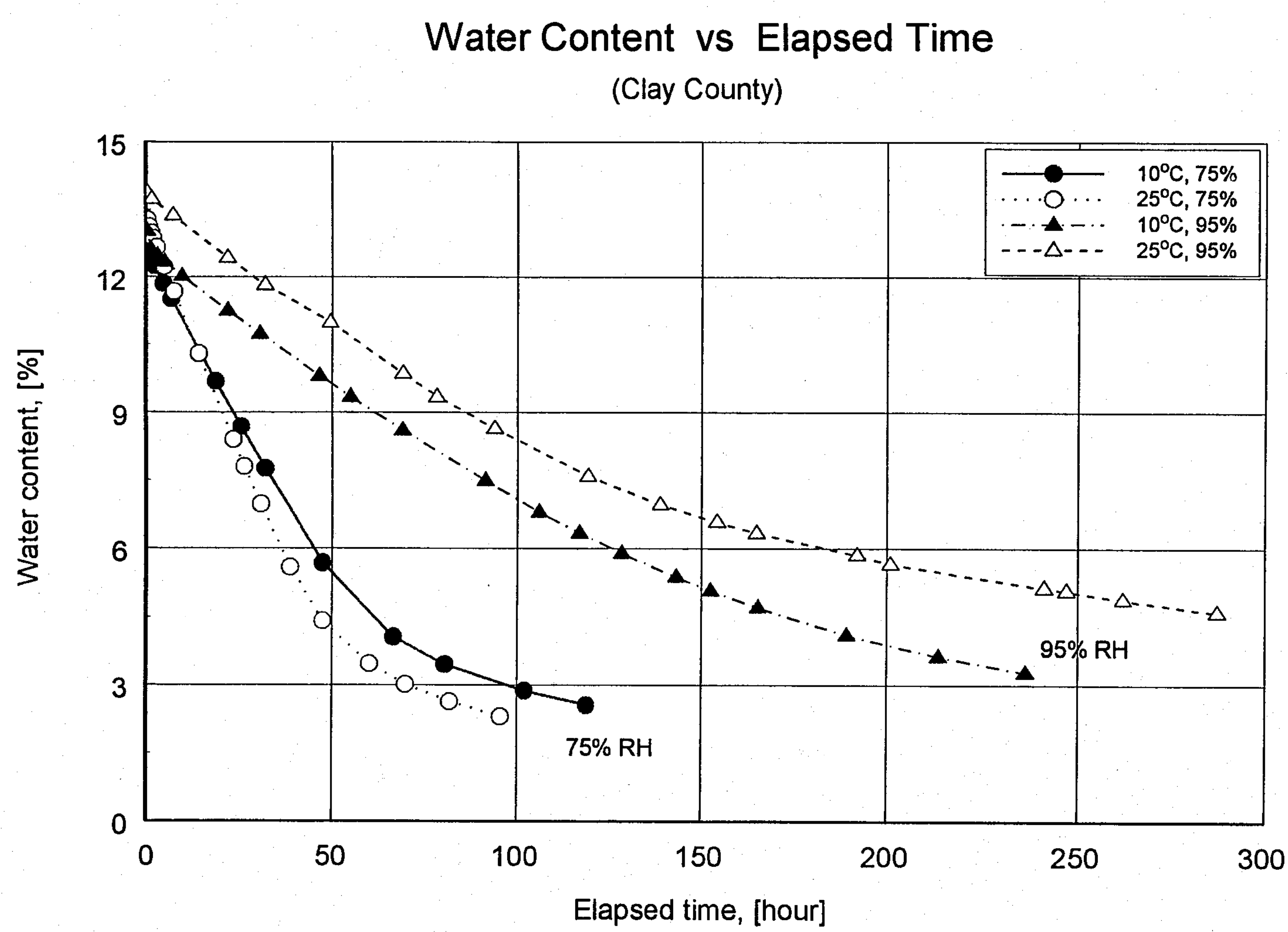

Figure E.6(a) : Comparison of change of water content at different temperature and relative humidity for Clay County soil (Group II)

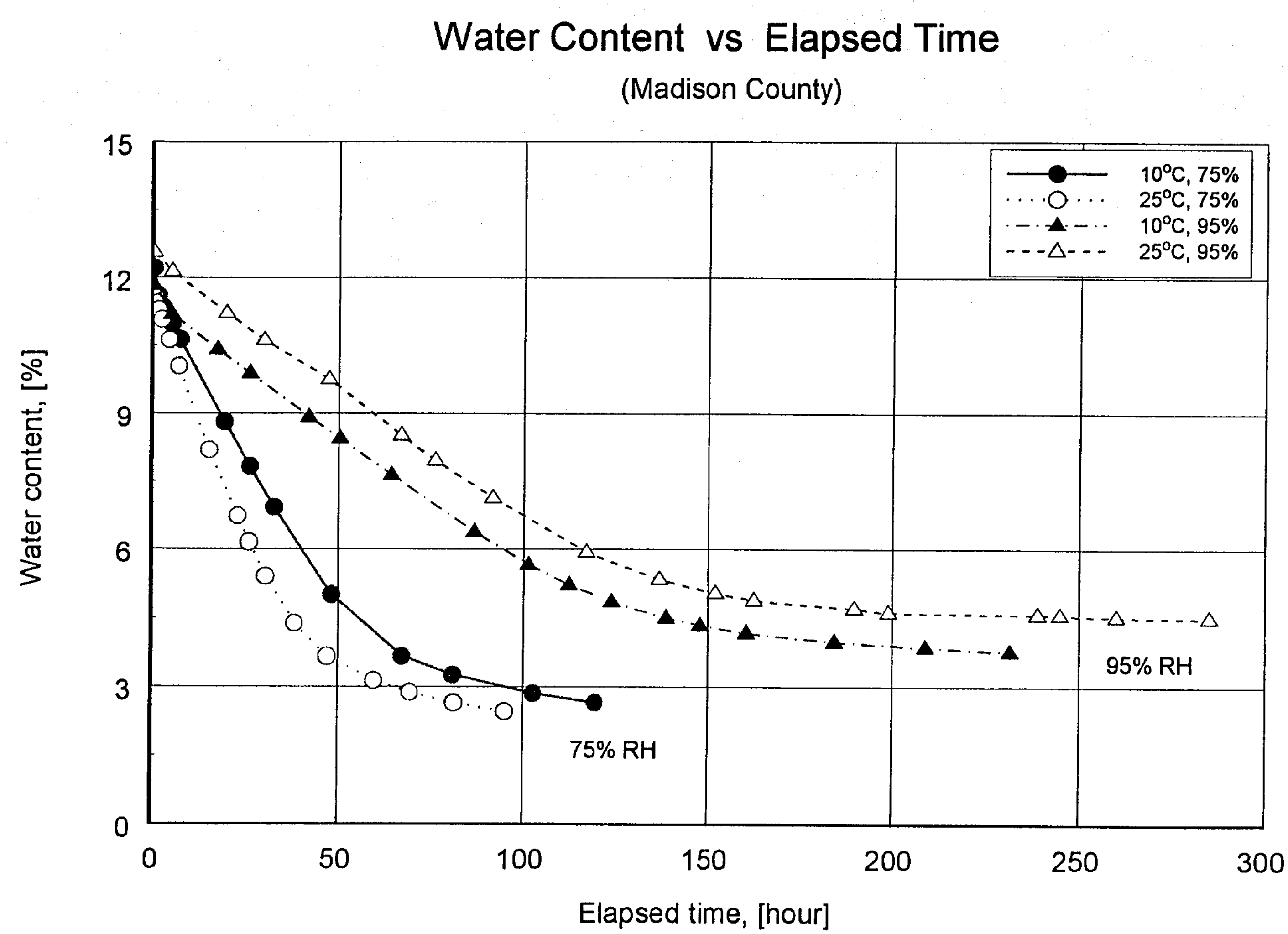

Figure E.6(b) : Comparison of change of water content at different temperature and relative humidity for Madison County soil (Group II)

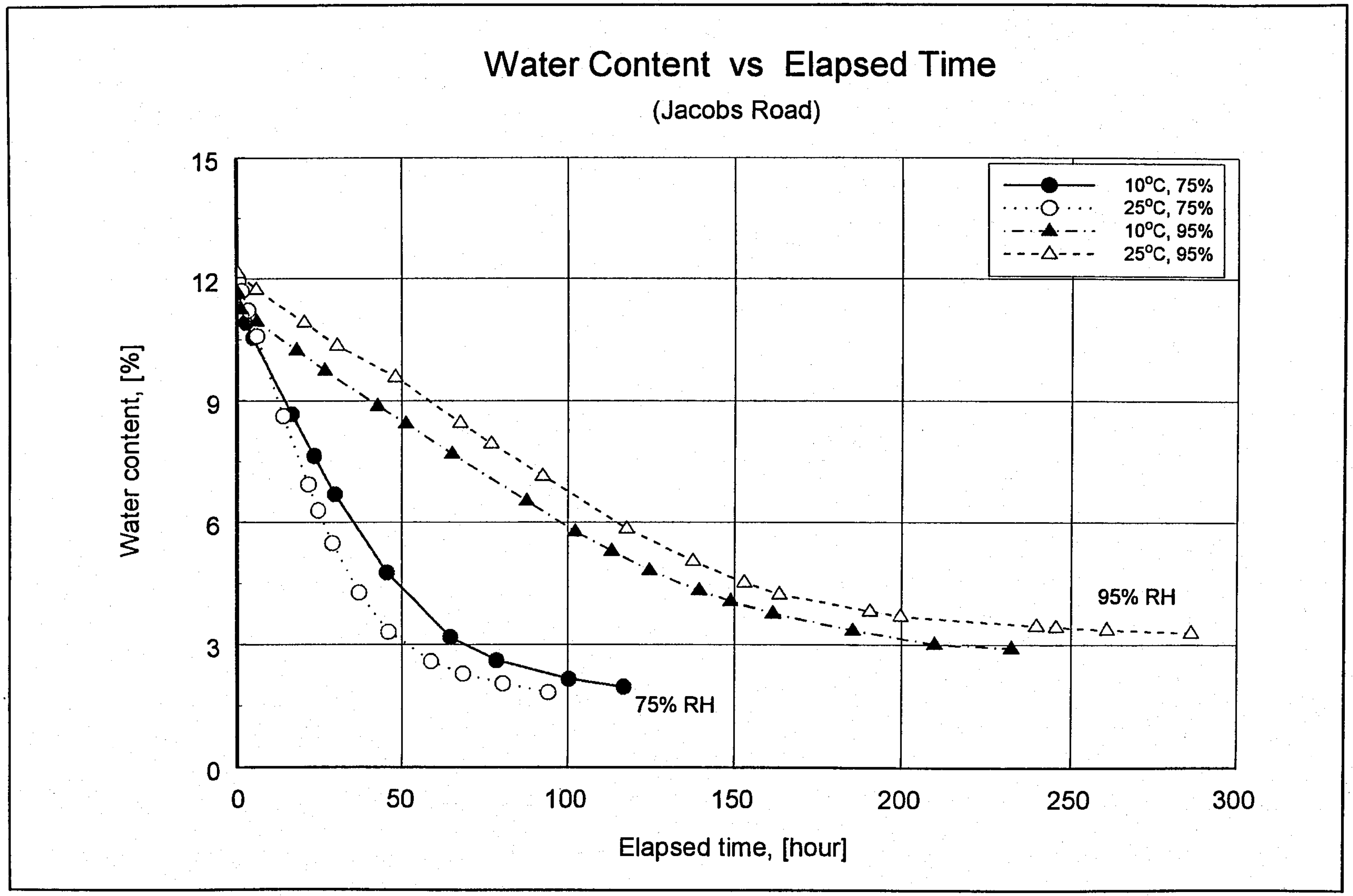

Figure E.6(c) : Comparison of change of water content at different temperature and relative humidity for Jacobs Road soil (Group II)

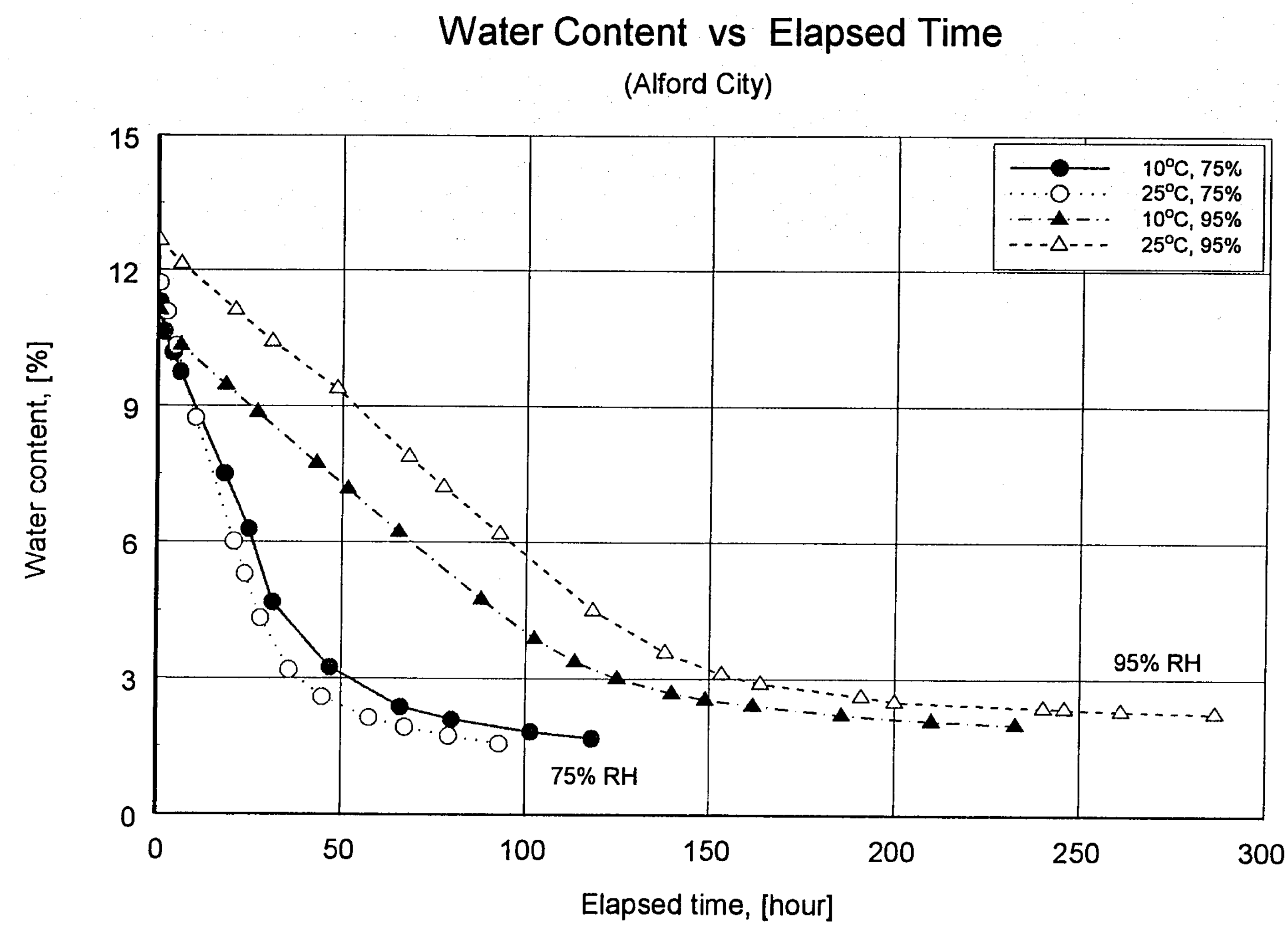

Figure E.6(d) : Comparison of the change of water content at different temperature and relative humidity for Alford City soil (Group II)

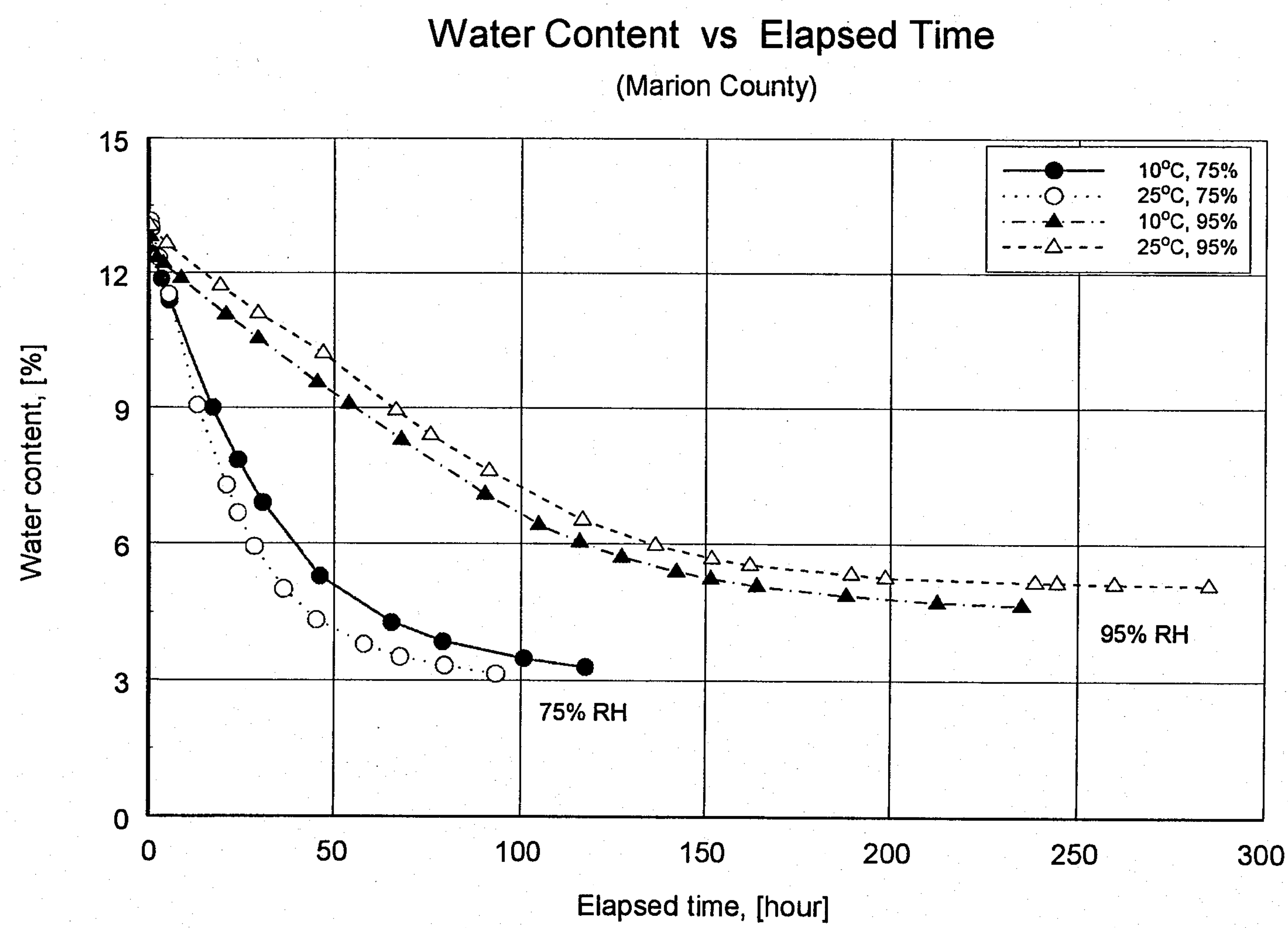

Figure E.6(e) : Comparison of change of water content at different temperature and relative humidity for Marion County soil (Group II)

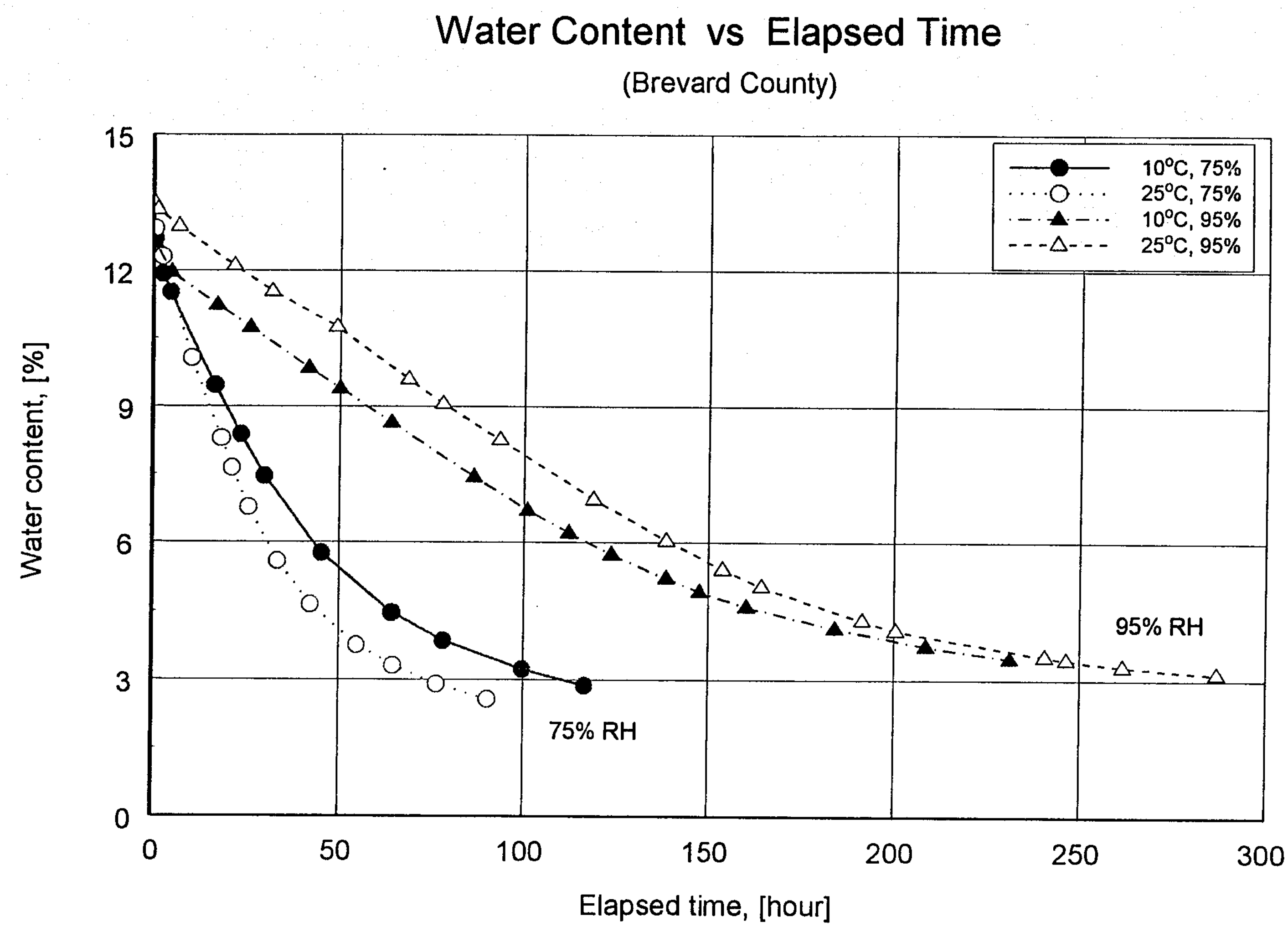

Figure E.6(f) : Comparison of change of water content at different temperature and relative humidity for Brevard County soil (Group II)

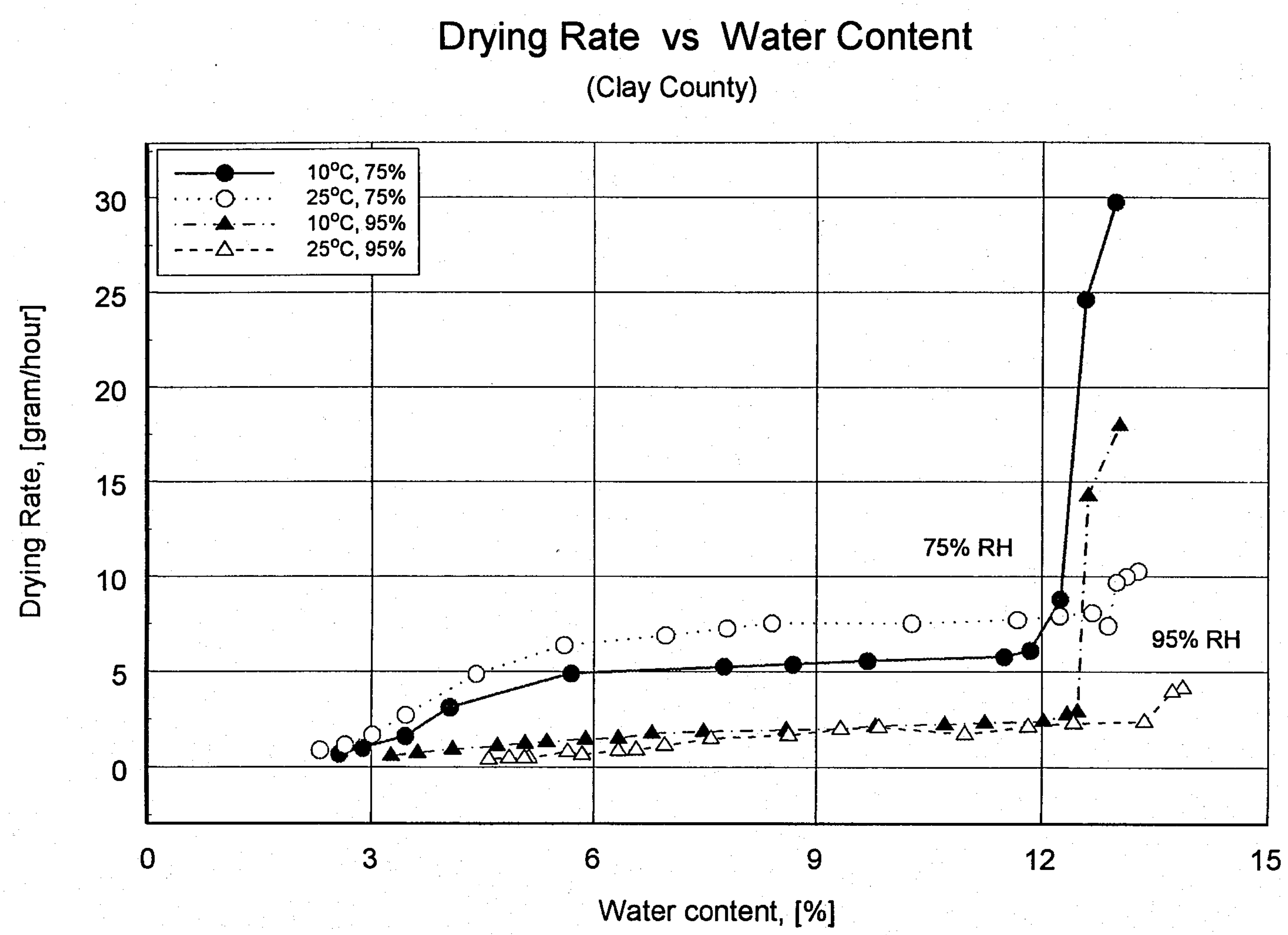

Figure E.7(a) : Comparison of drying rate at different temperature and relative humidity for Clay County soil (Group II)

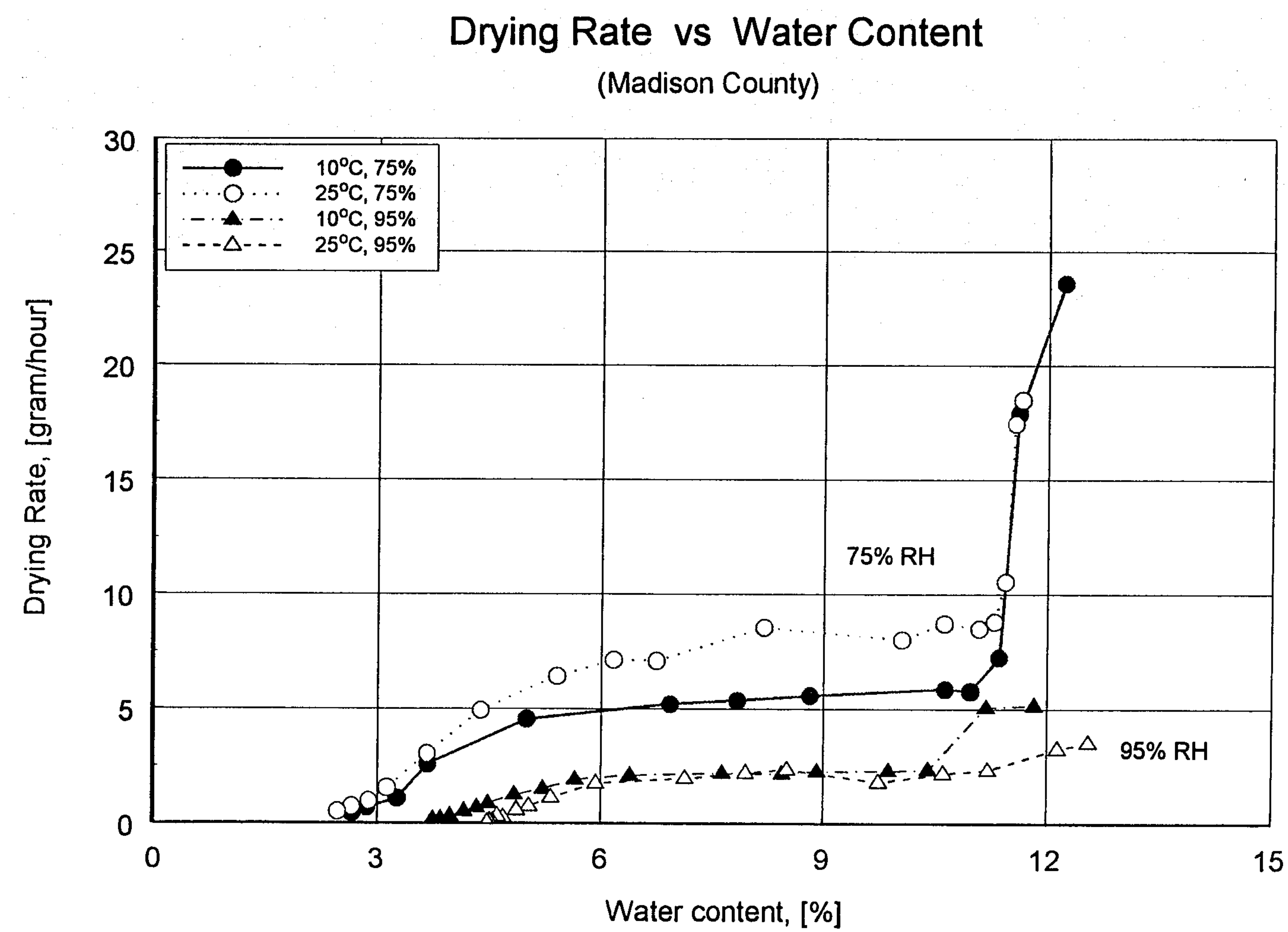

Figure E.7(b) : Comparison of drying rate at different temperature and relative humidity for Madison County soil (Group II)

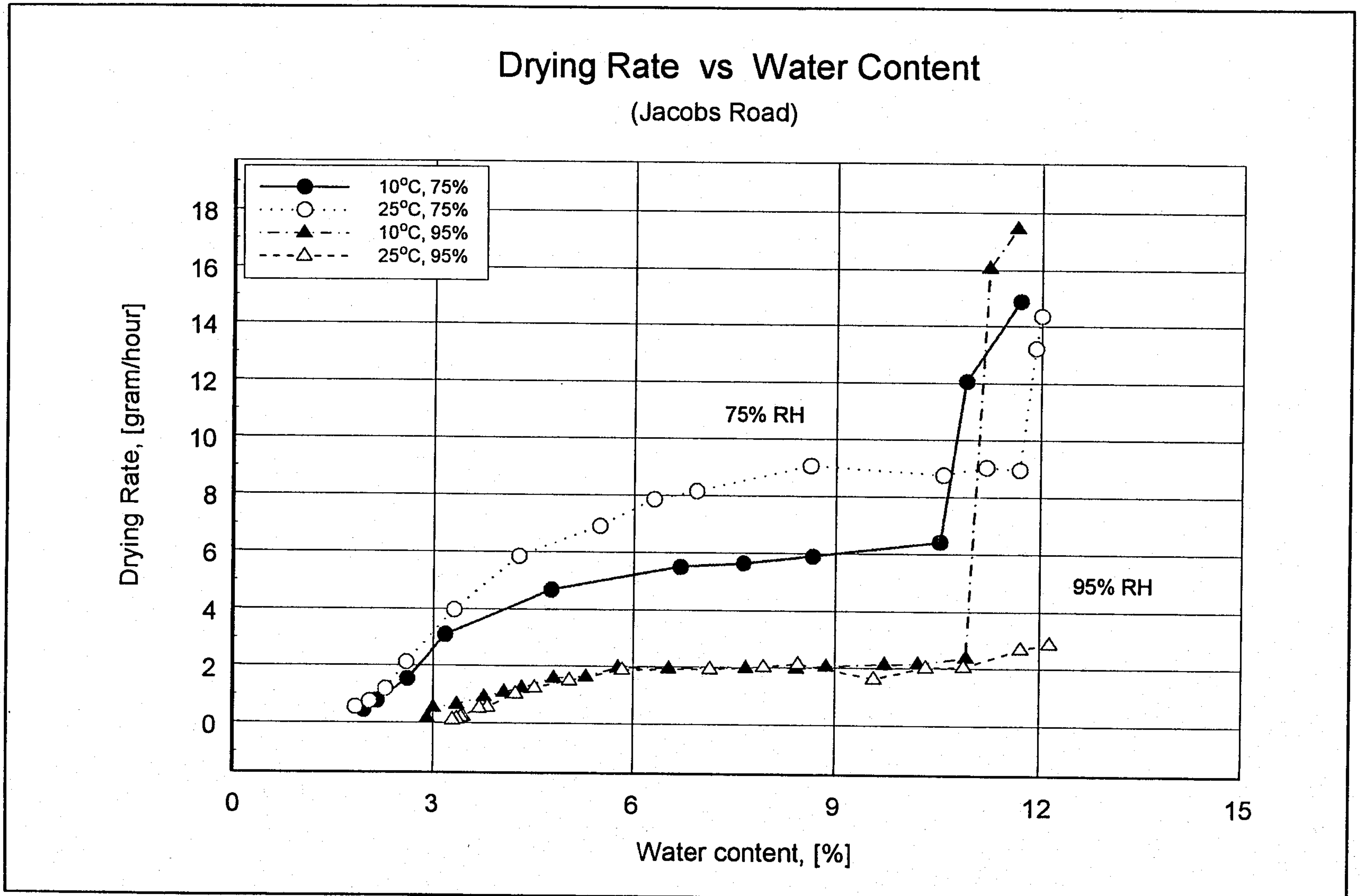

Figure E.7(c) : Comparison of drying rate at different temperature and relative humidity for Jacobs Road soil (Group II)

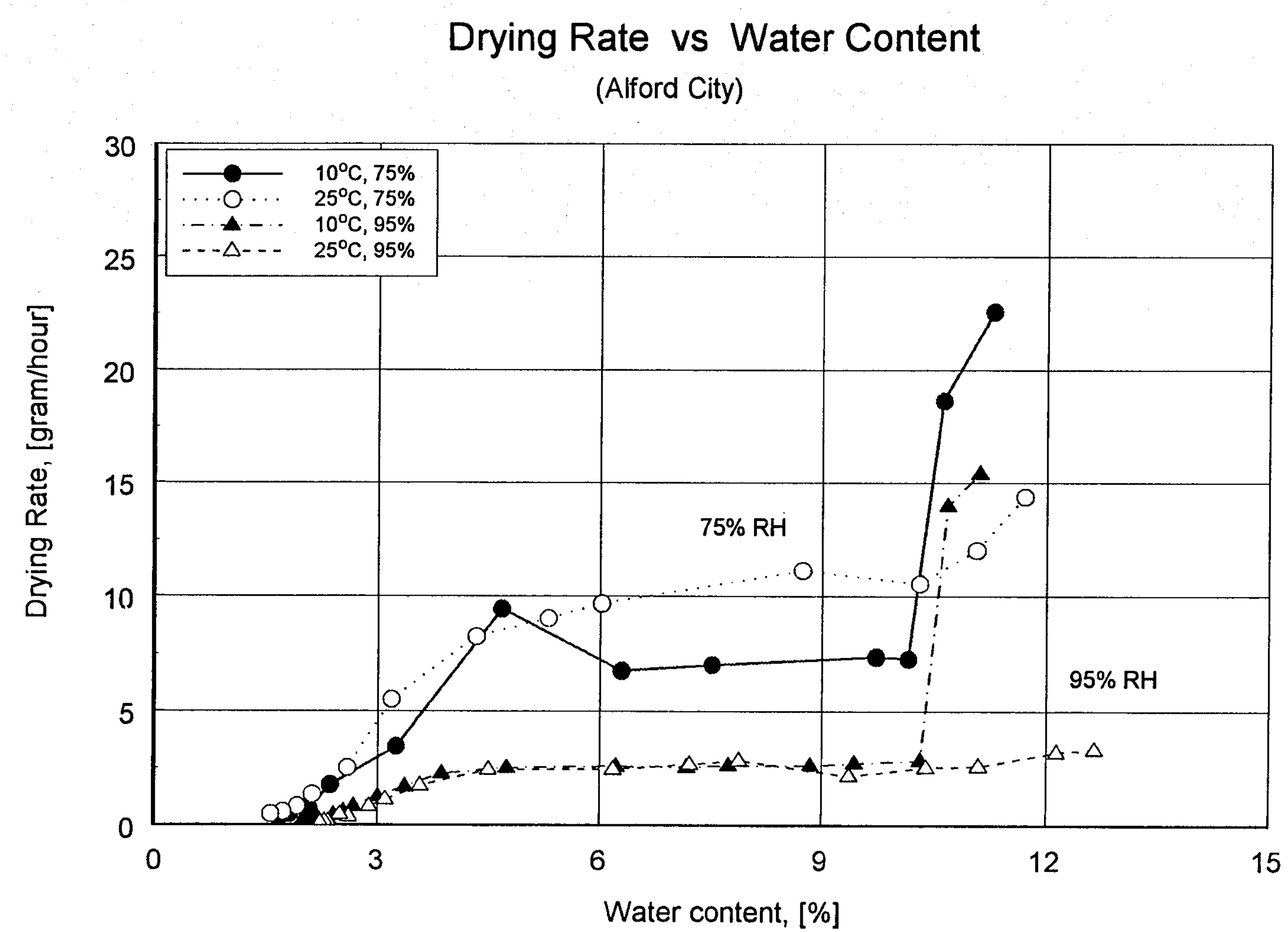

Figure E.7(d) : Comparison of drying rate at different temperature and relative humidity for Alford City soil (Group II)

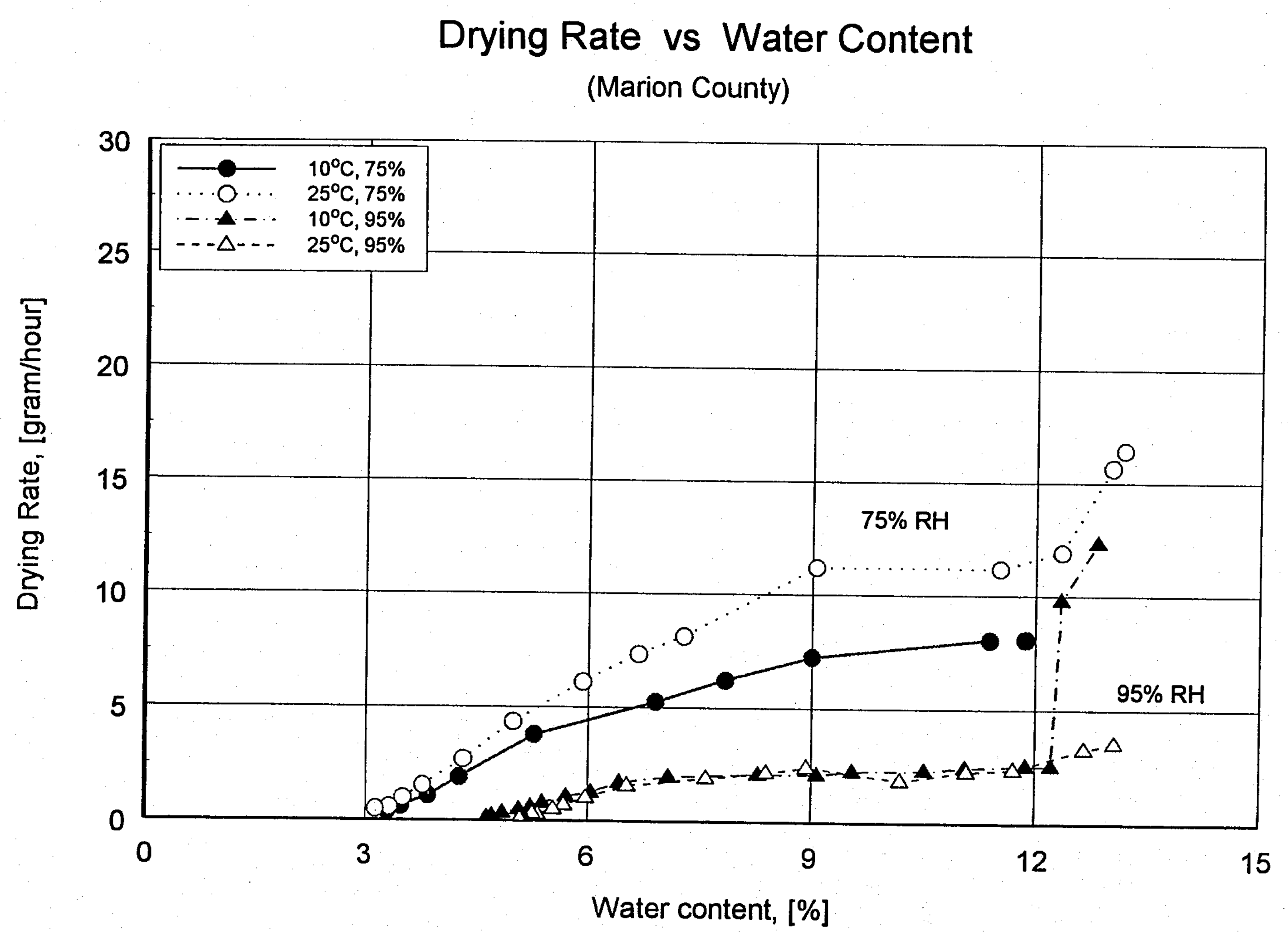

Figure E.7(e) : Comparison of drying rate at different temperature and relative humidity for Marion County soil (Group II)

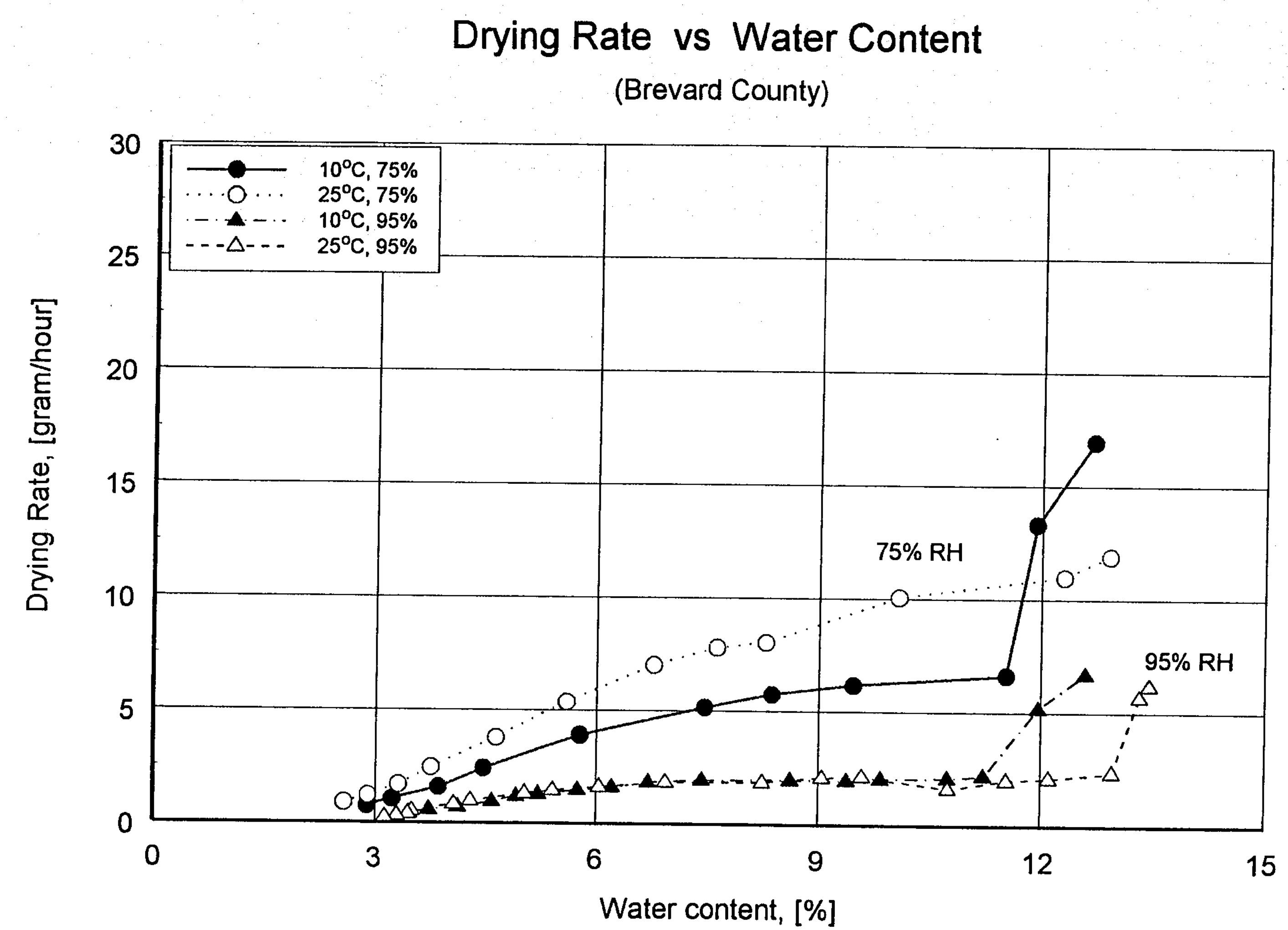

Figure E.7(f) : Comparison of drying rate at different temperature and relative humidity for Brevard County soil (Group II)

APPENDIX F: CORRELATION OF SUCTION AND DRYING RATE TEST RESULTS

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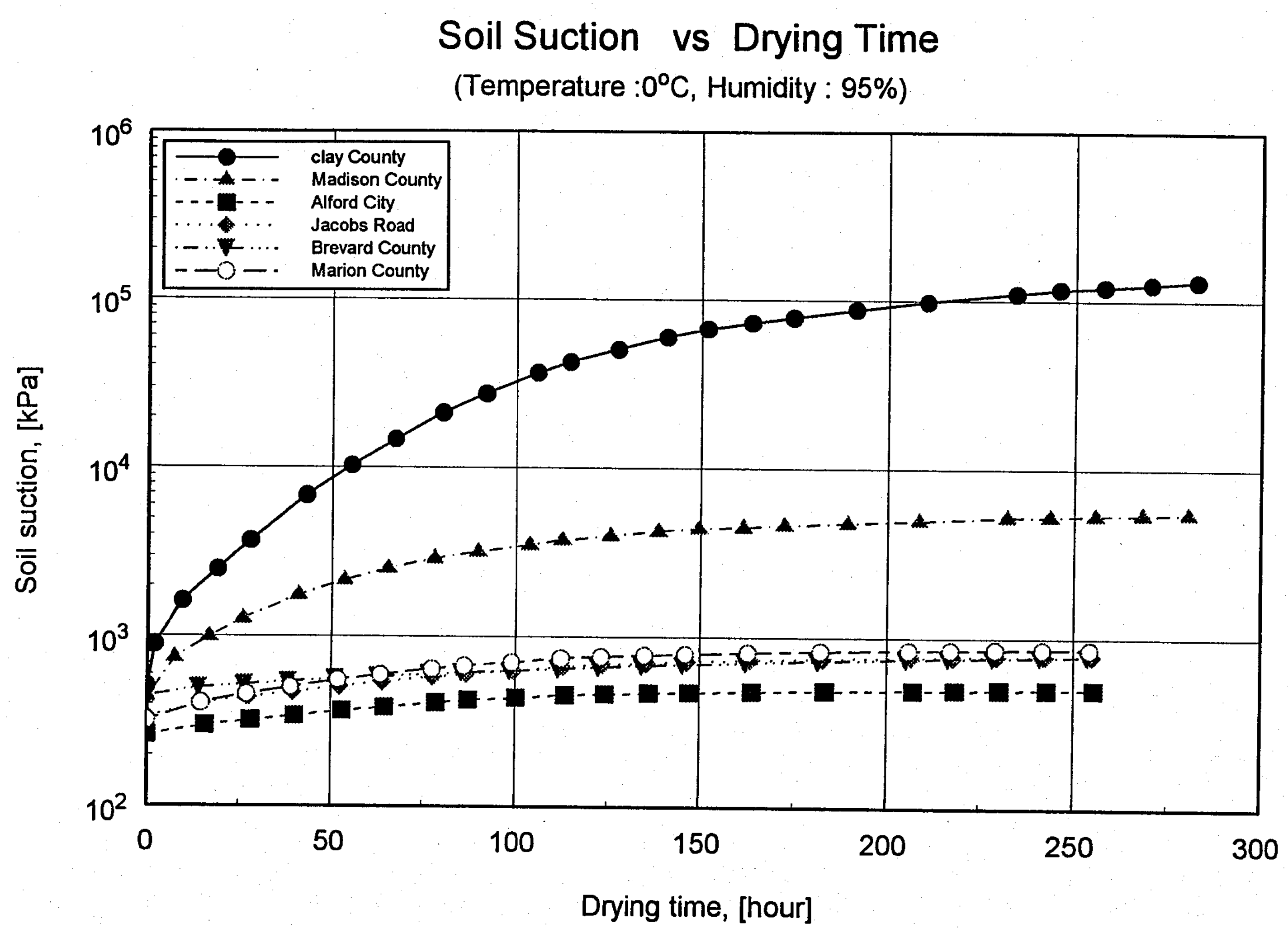


Figure F.1 : Soil suction versus drying time for six soils at temperature 0°C and 95% relative humidity (Group I)

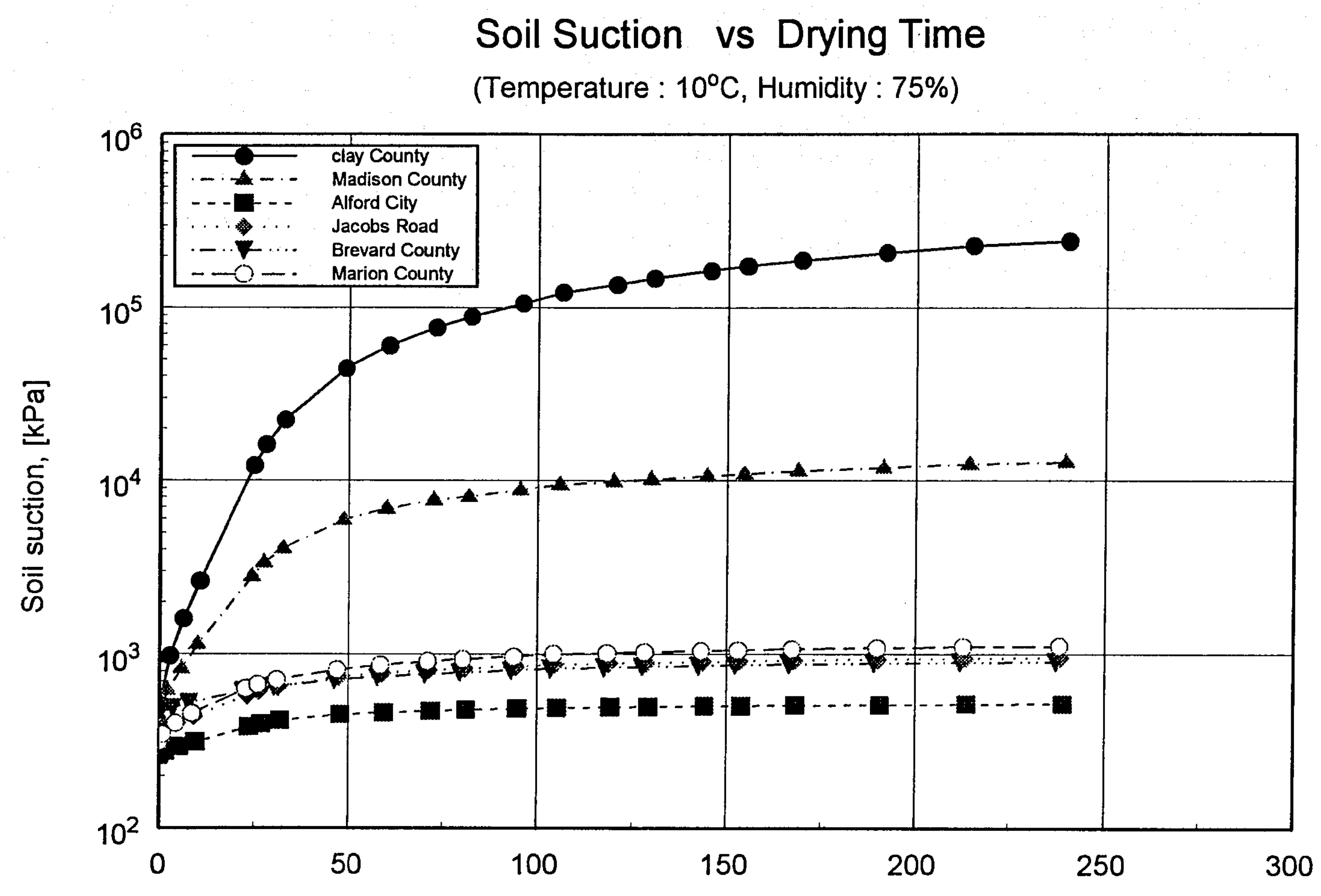


Figure F.2 : Soil suction versus drying time for six soils at temperature 10°C and 75% relative humidity (Group I)

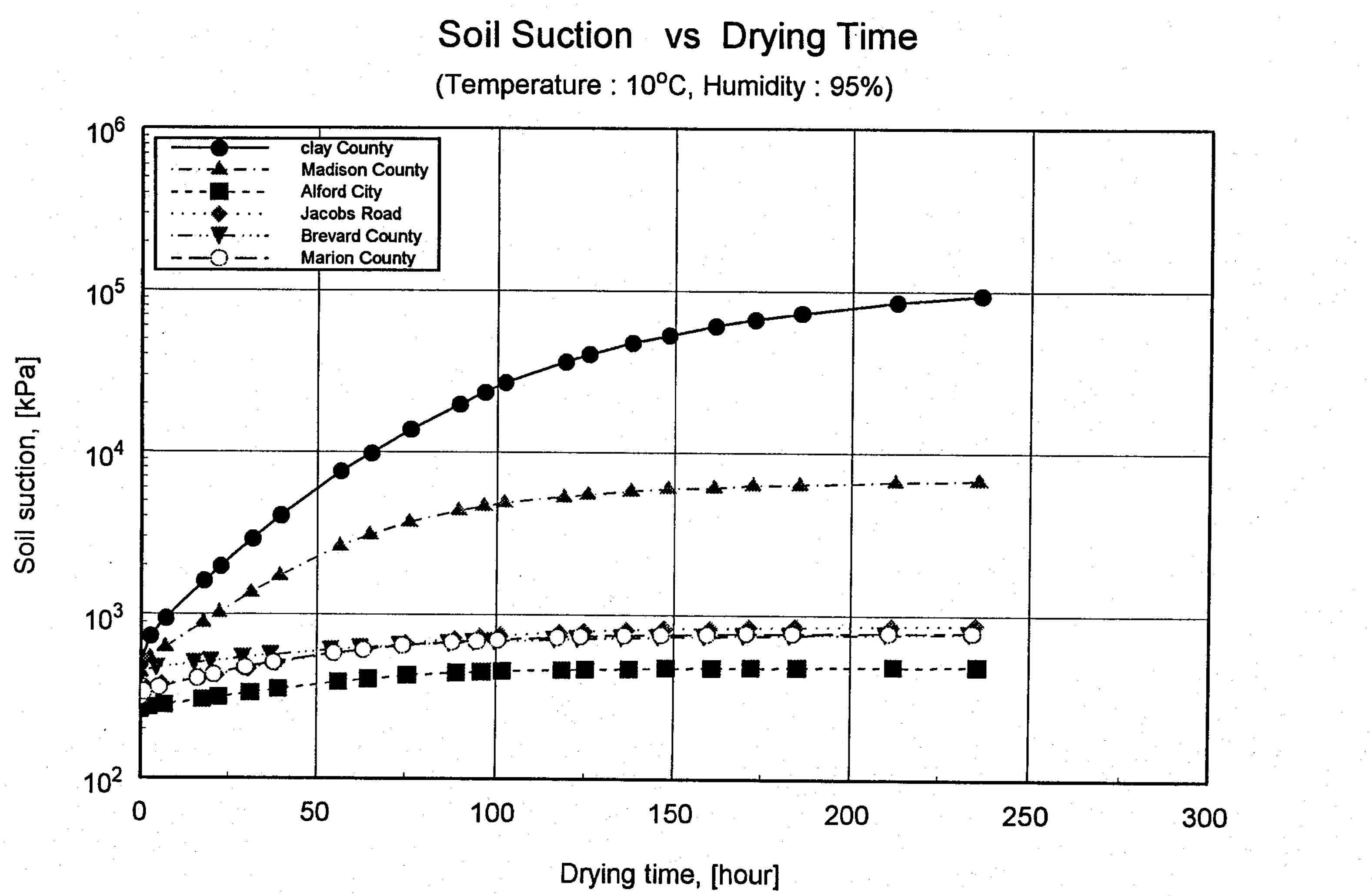


Figure F.3 : Soil suction versus drying time for six soils at temperature 10°C and 95% relative humidity (Group I)

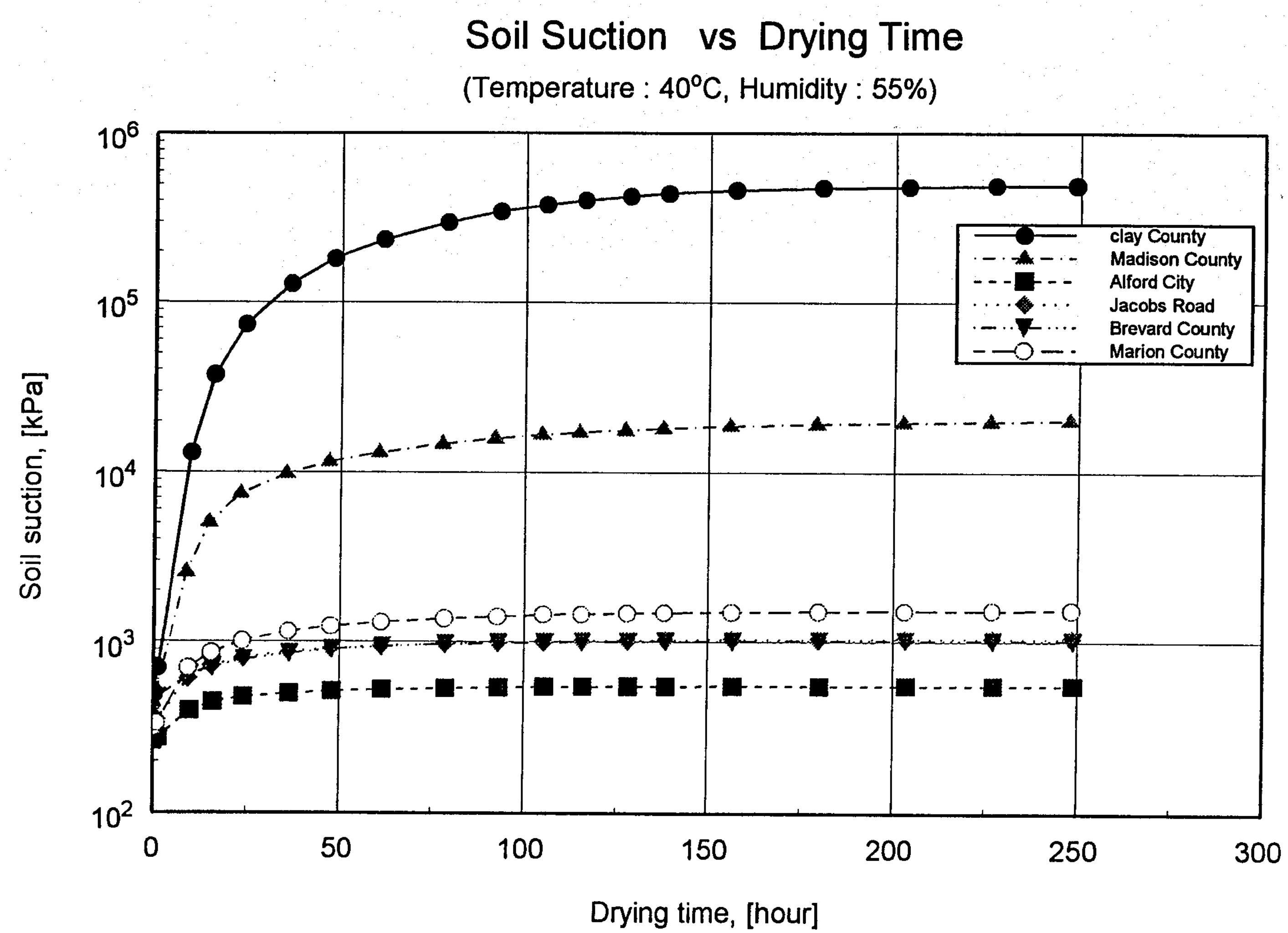


Figure F.4 : Soil suction versus drying time for six soils at temperature 40°C and 55% relative humidity (Group I)

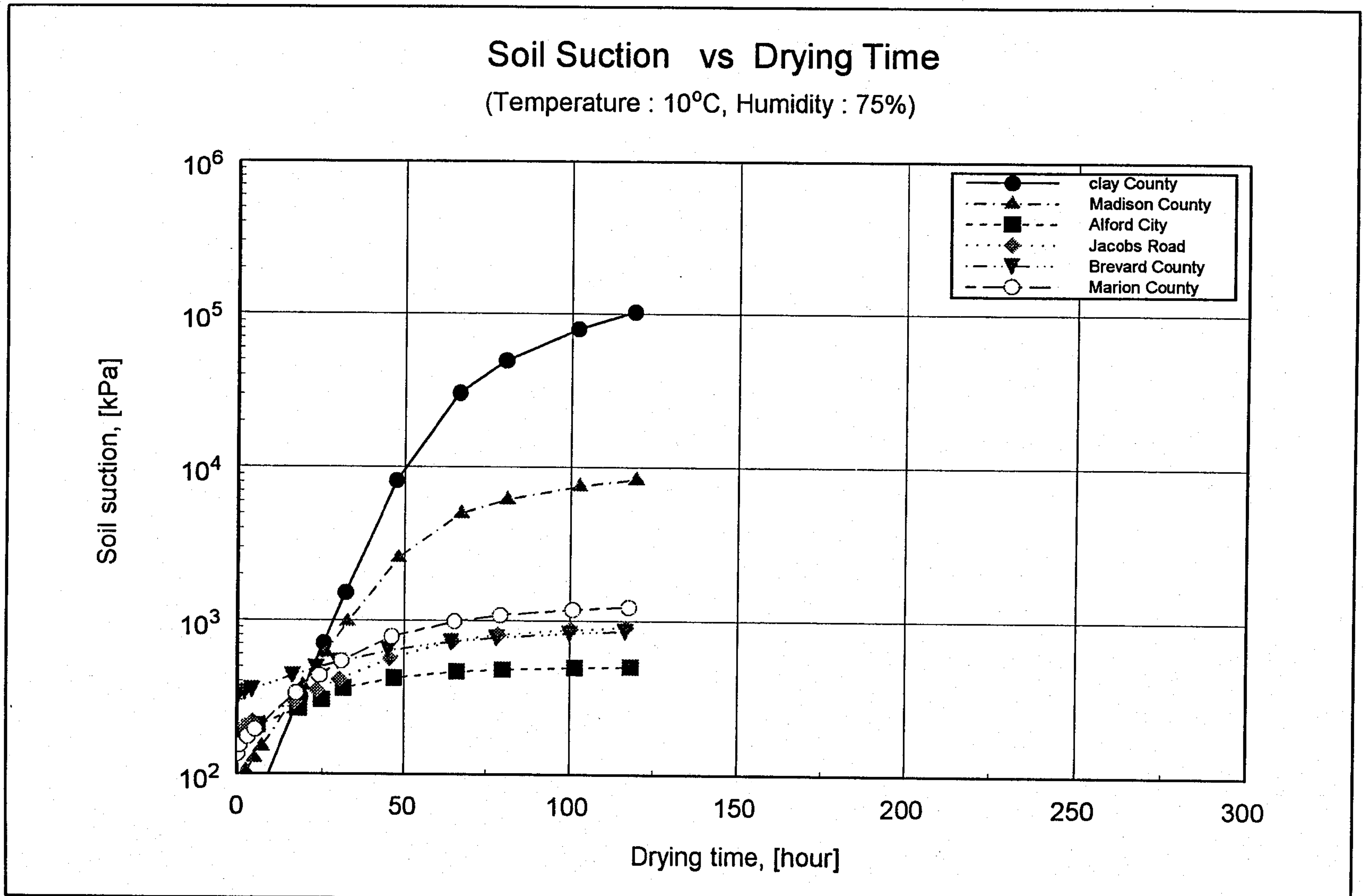


Figure F.5 : Soil suction versus drying time for six soils at temperature 10°C and 75% relative humidity (Group II)

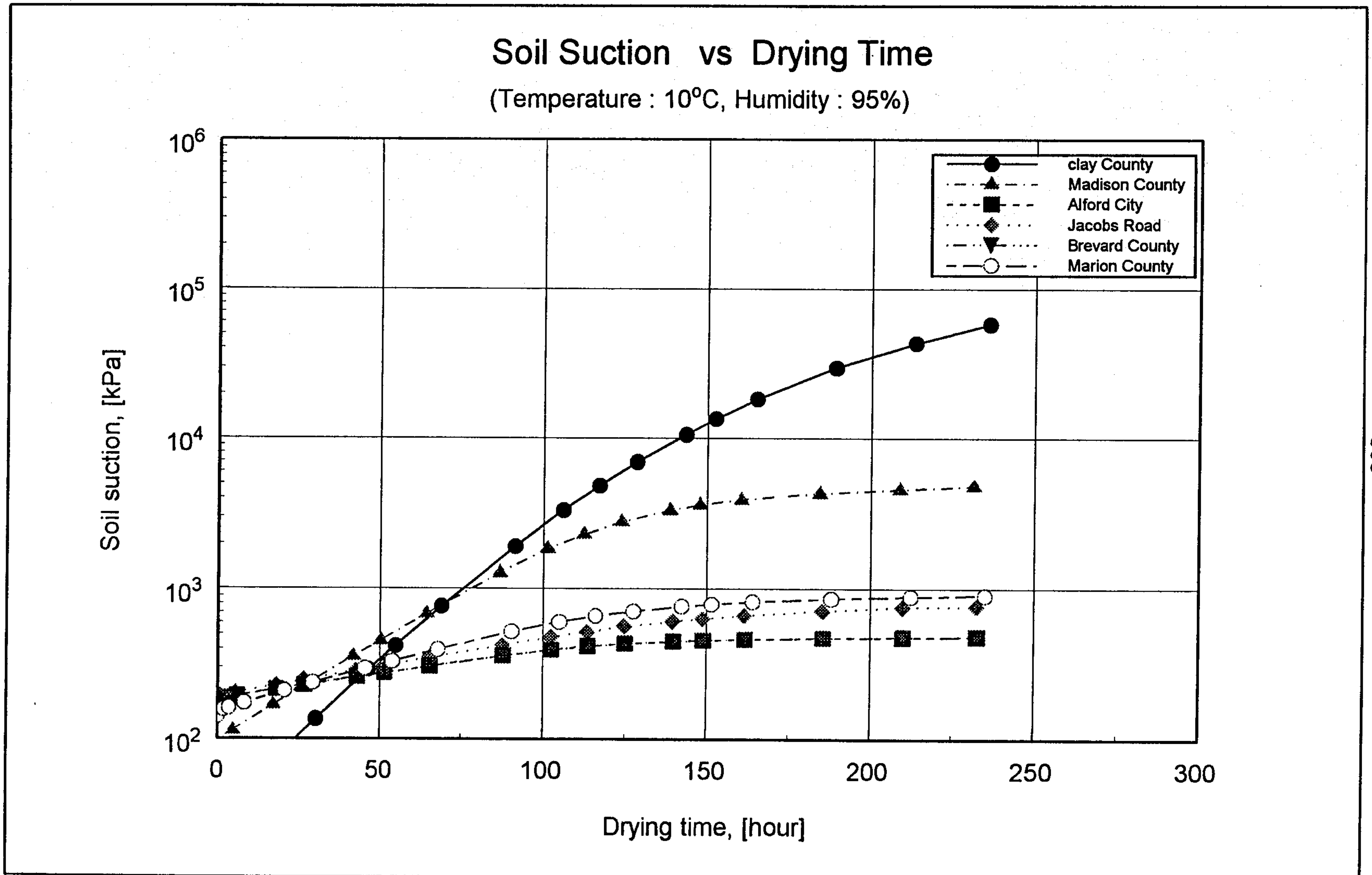


Figure F.6 : Soil suction versus drying time for six soils at temperature 10°C and 95% relative humidity (Group II)

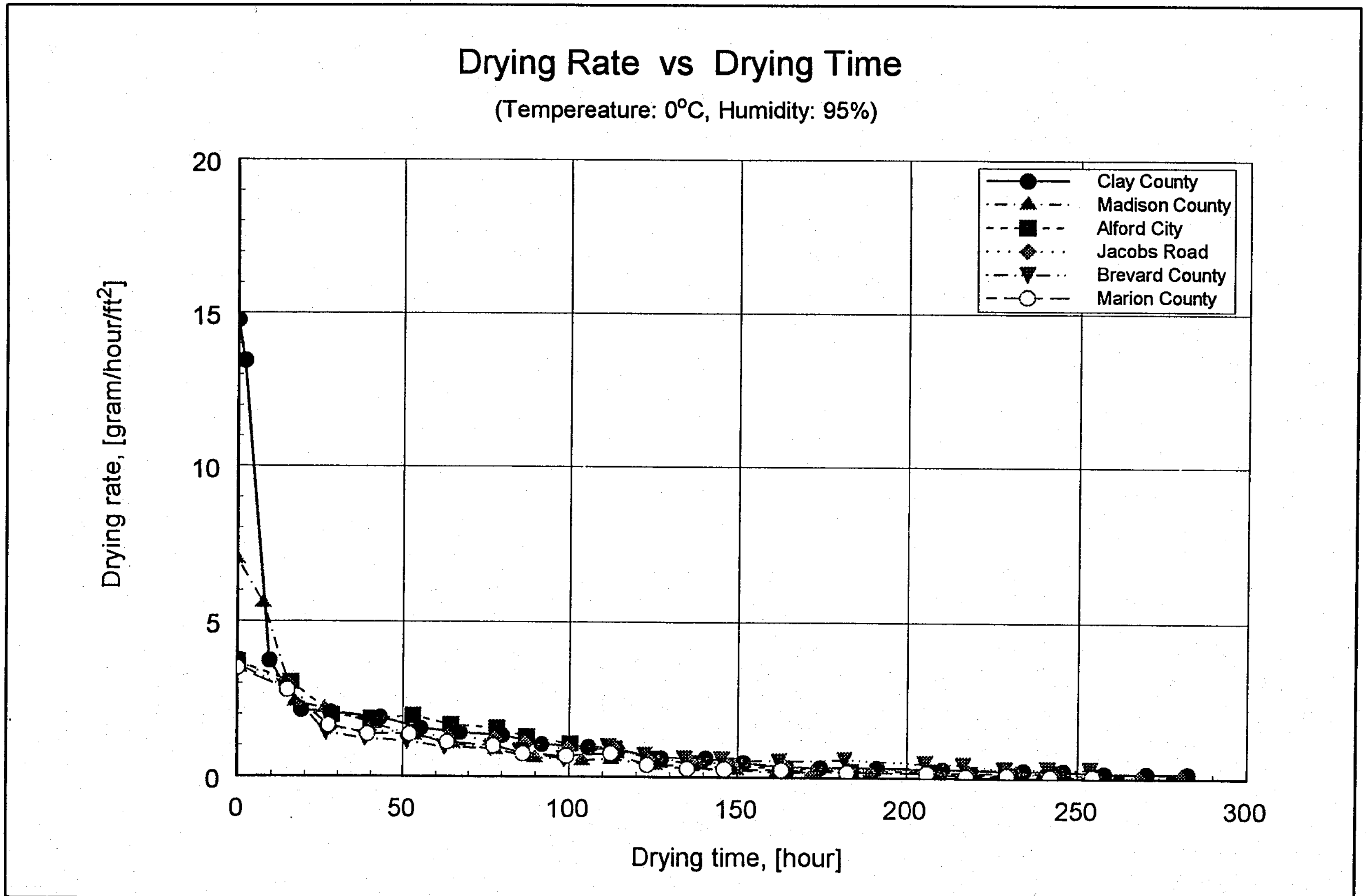


Figure F.7 : Drying rate vs drying time for six soils at temperature 0°C and 95% relative humidity (Group I)

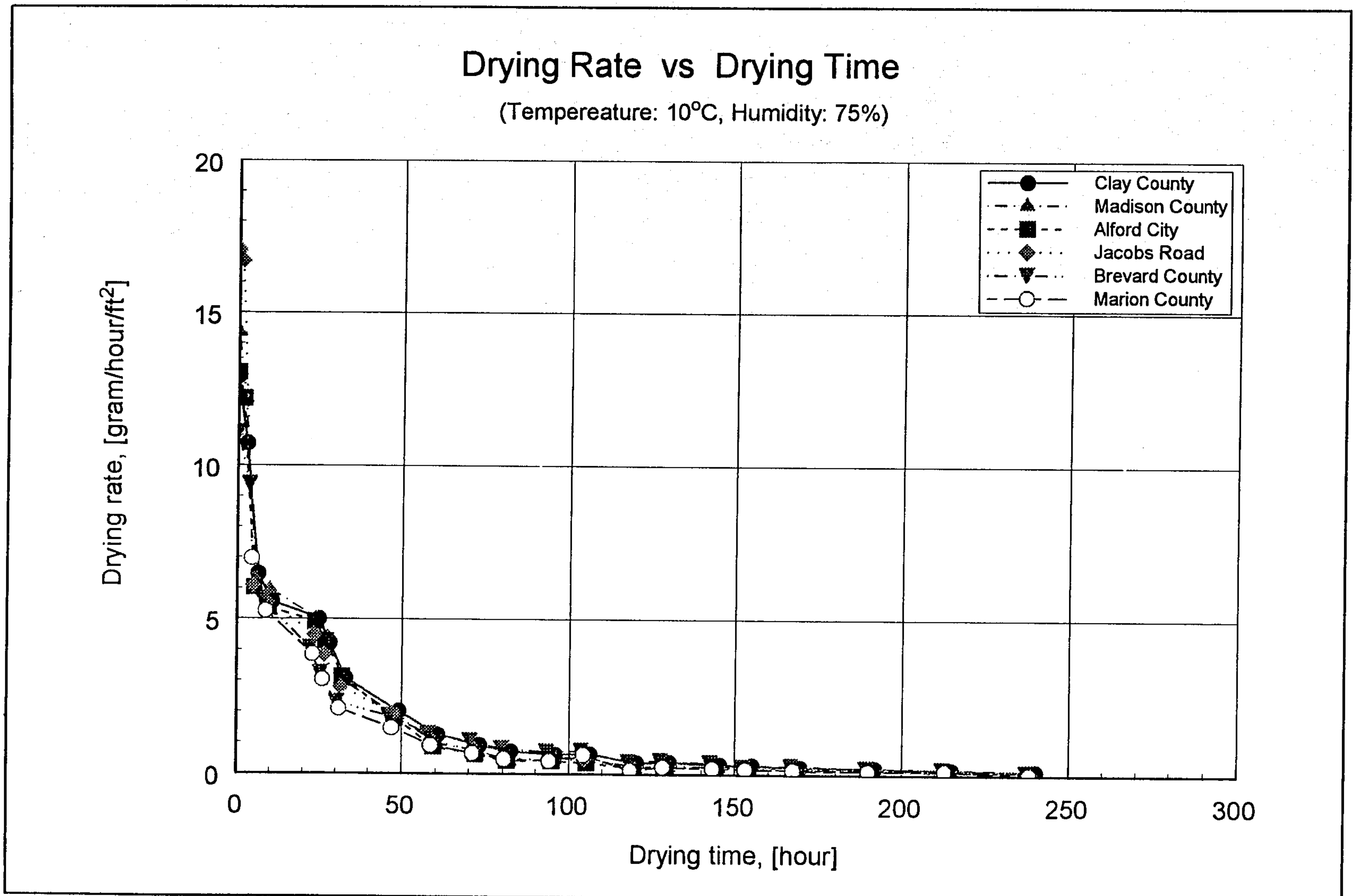


Figure F.8 : Drying rate vs drying time for six soils at temperature 10°C and 75% relative humidity (Group I)

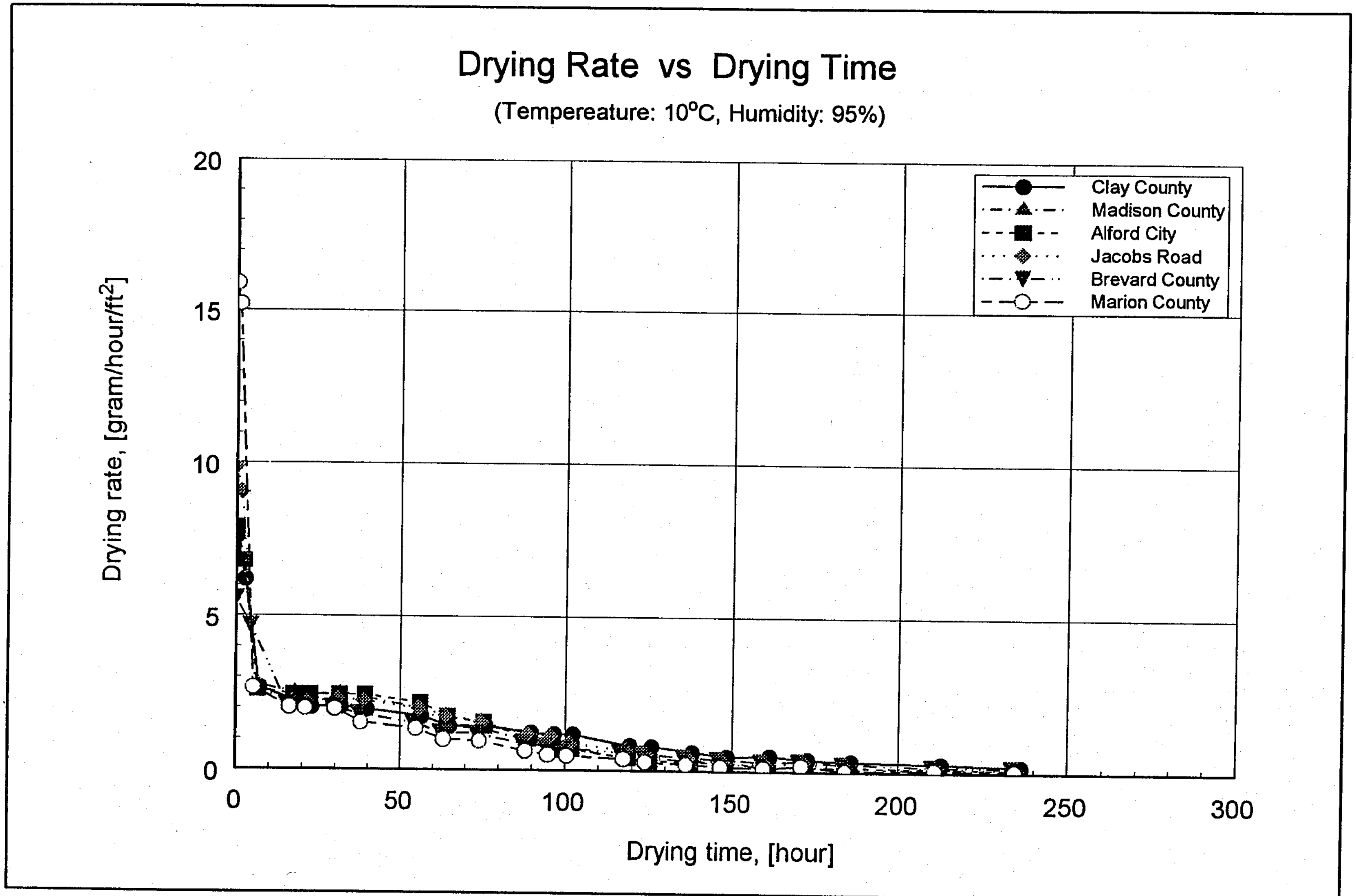
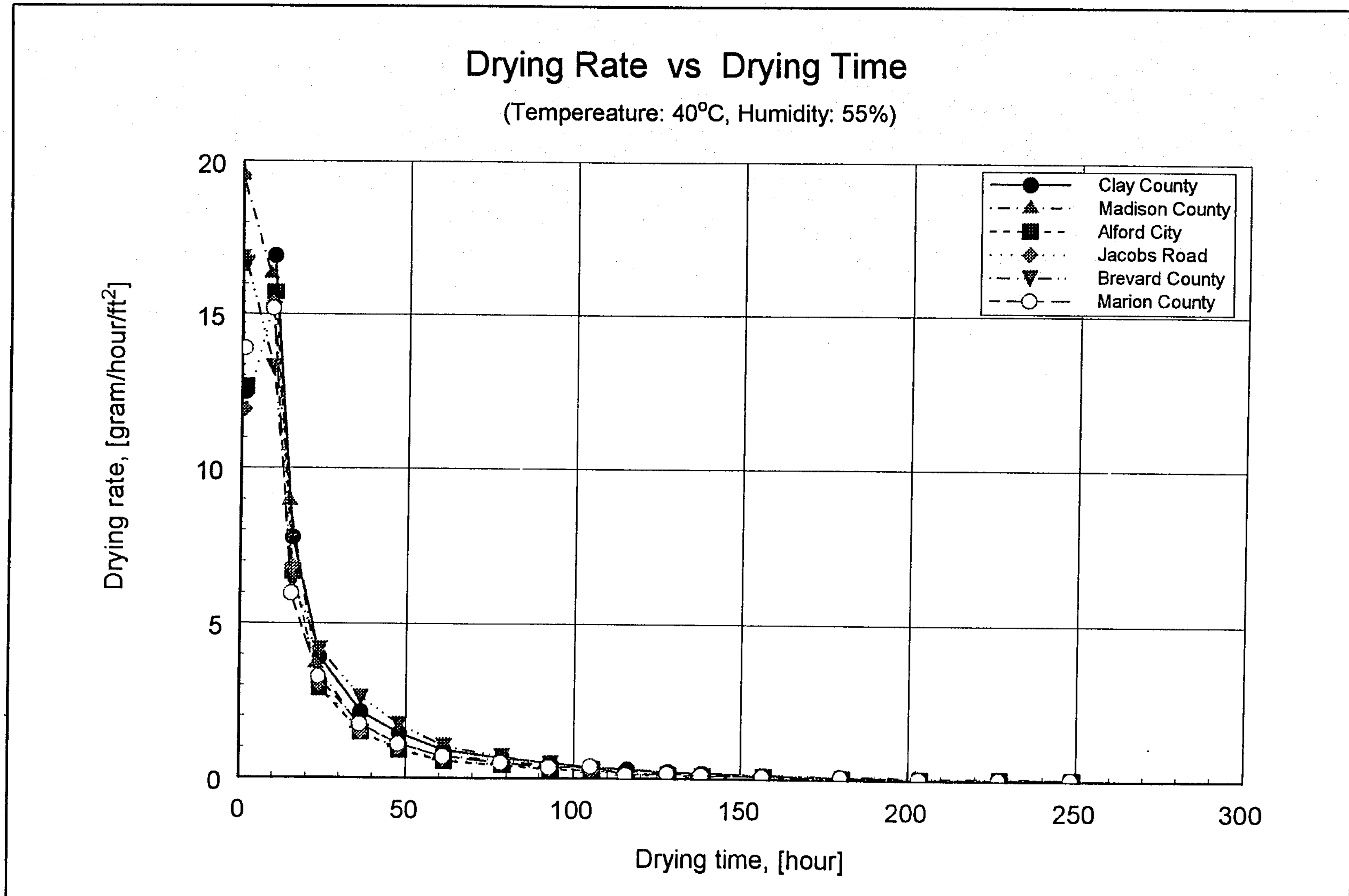


Figure F.9 : Drying rate vs drying time for six soils at temperature 10°C and 95% relative humidity (Group I)



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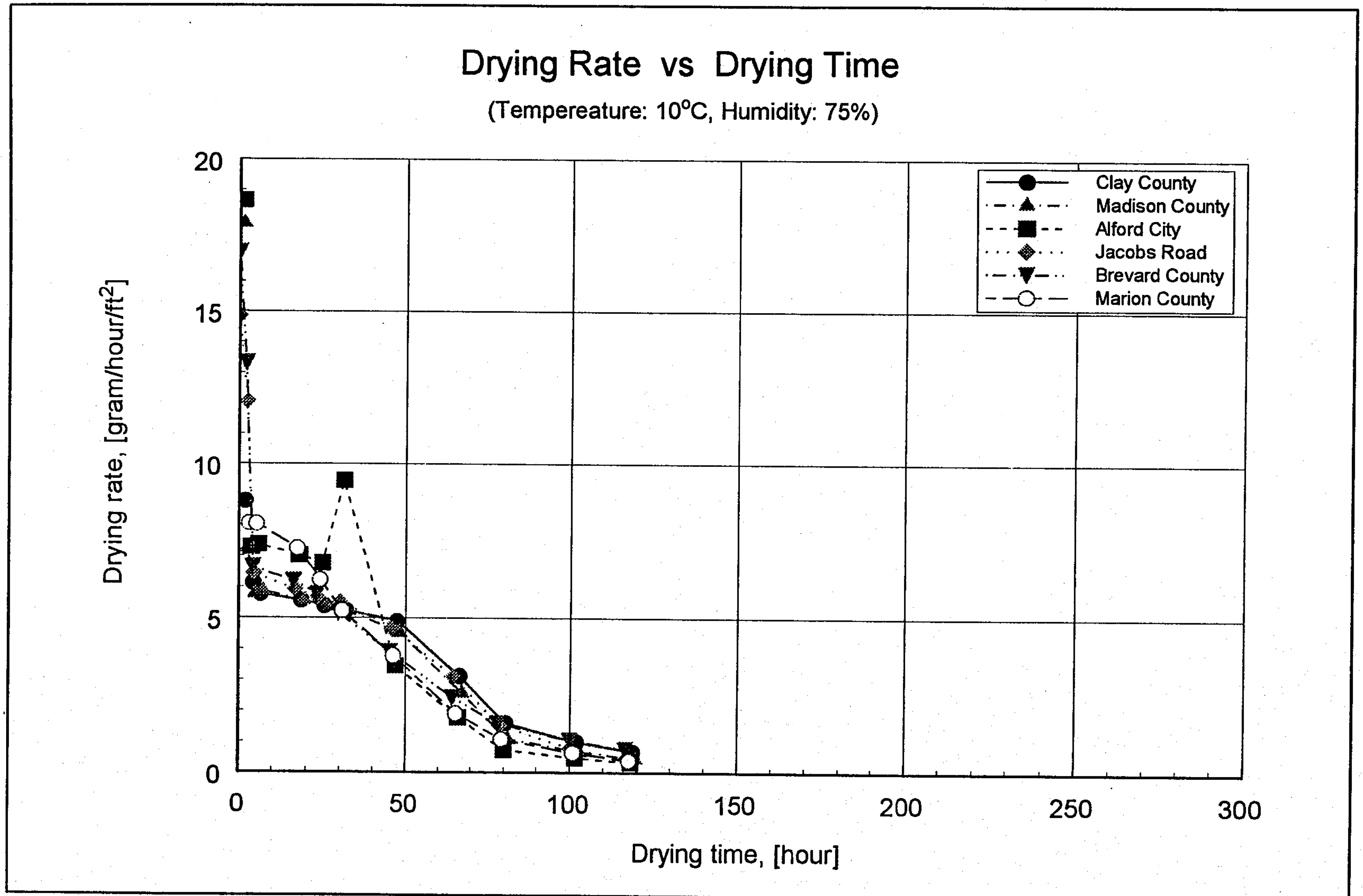

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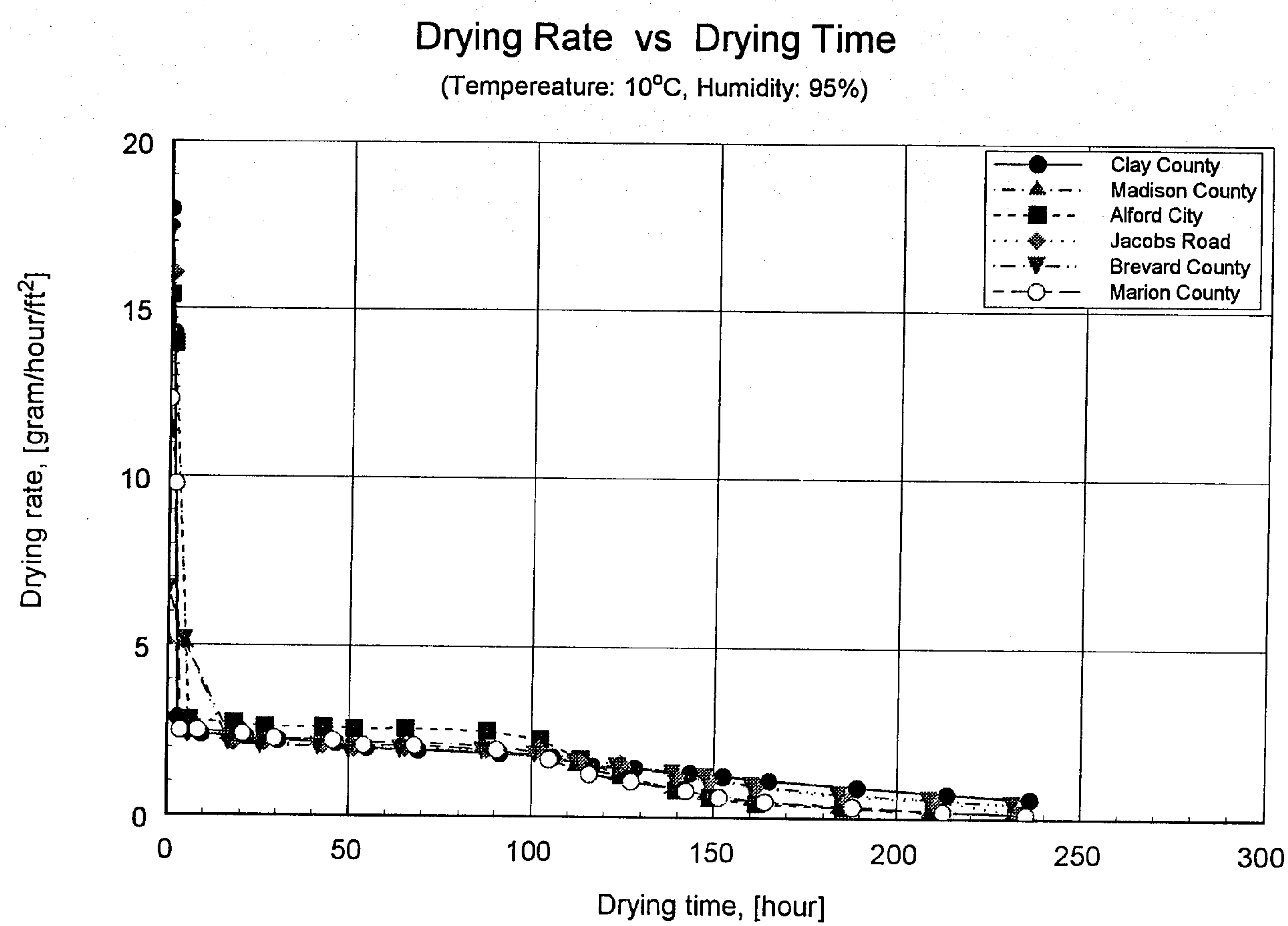

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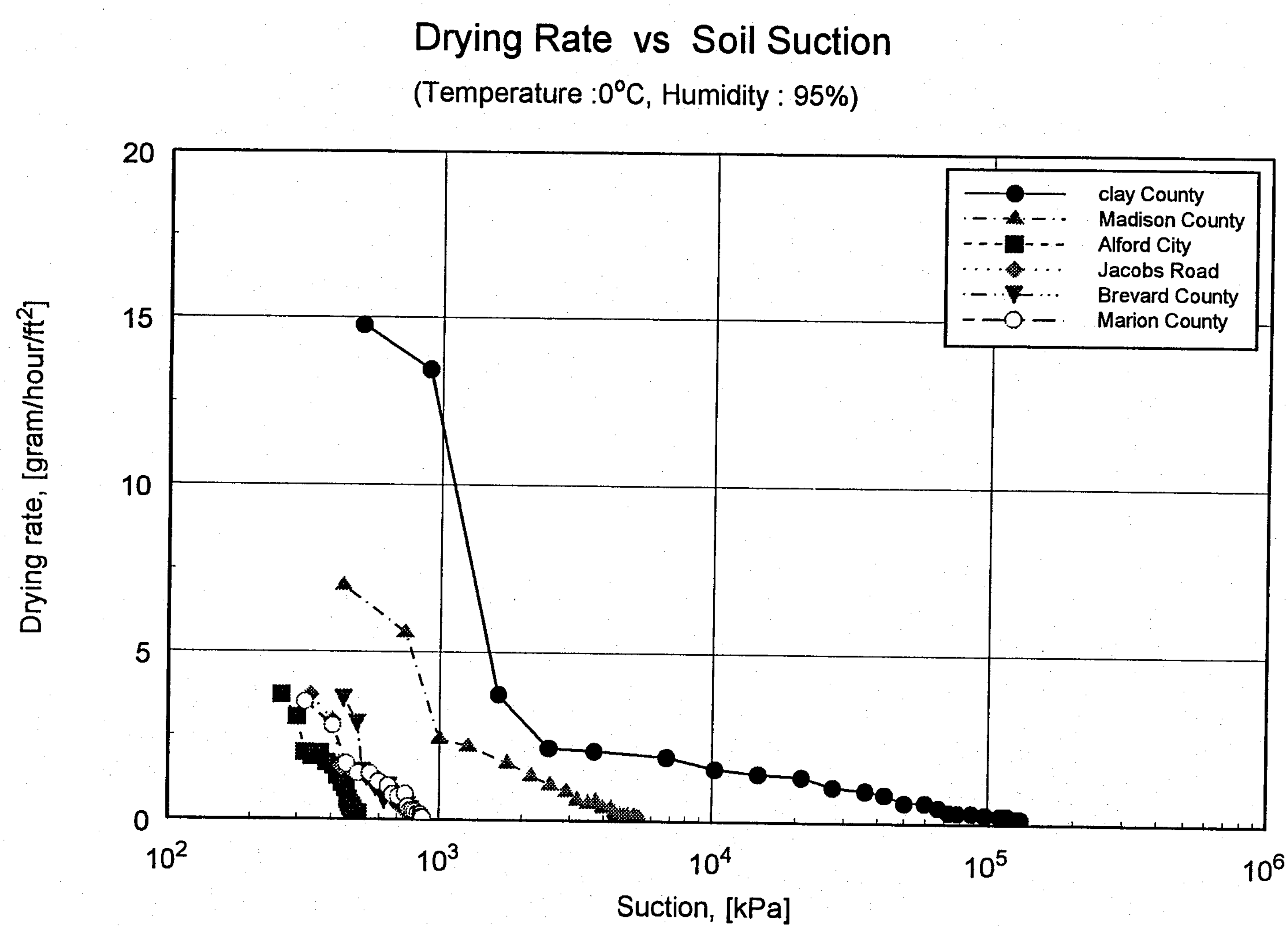


Figure F.13 : Drying rate versus soil suction for six soils at temperature 0°C and 95% relative humidity (Group I)

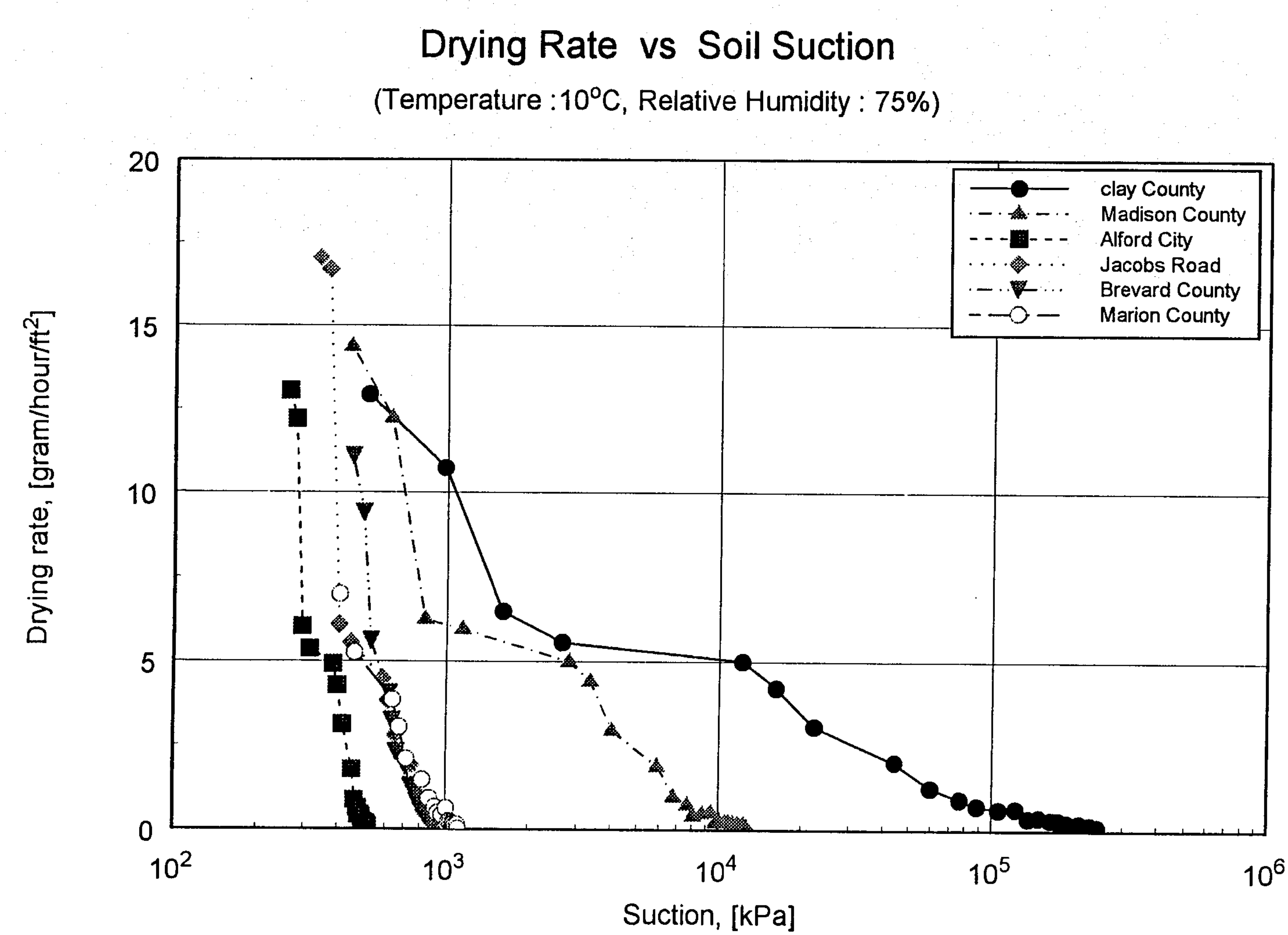


Figure F.14 : Drying rate versus soil suction for six soils at temperature 10°C and 75% relative humidity (Group I)

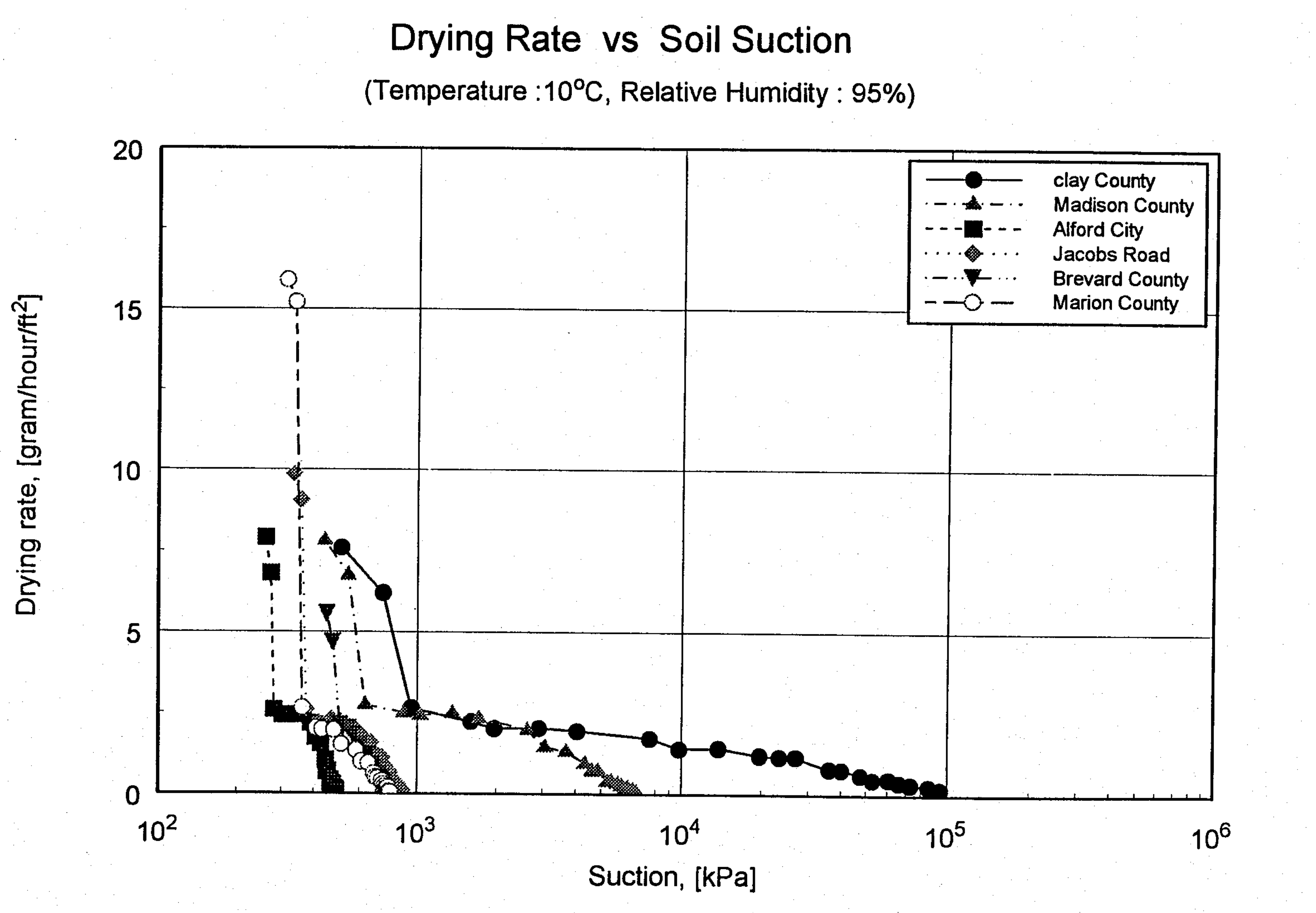
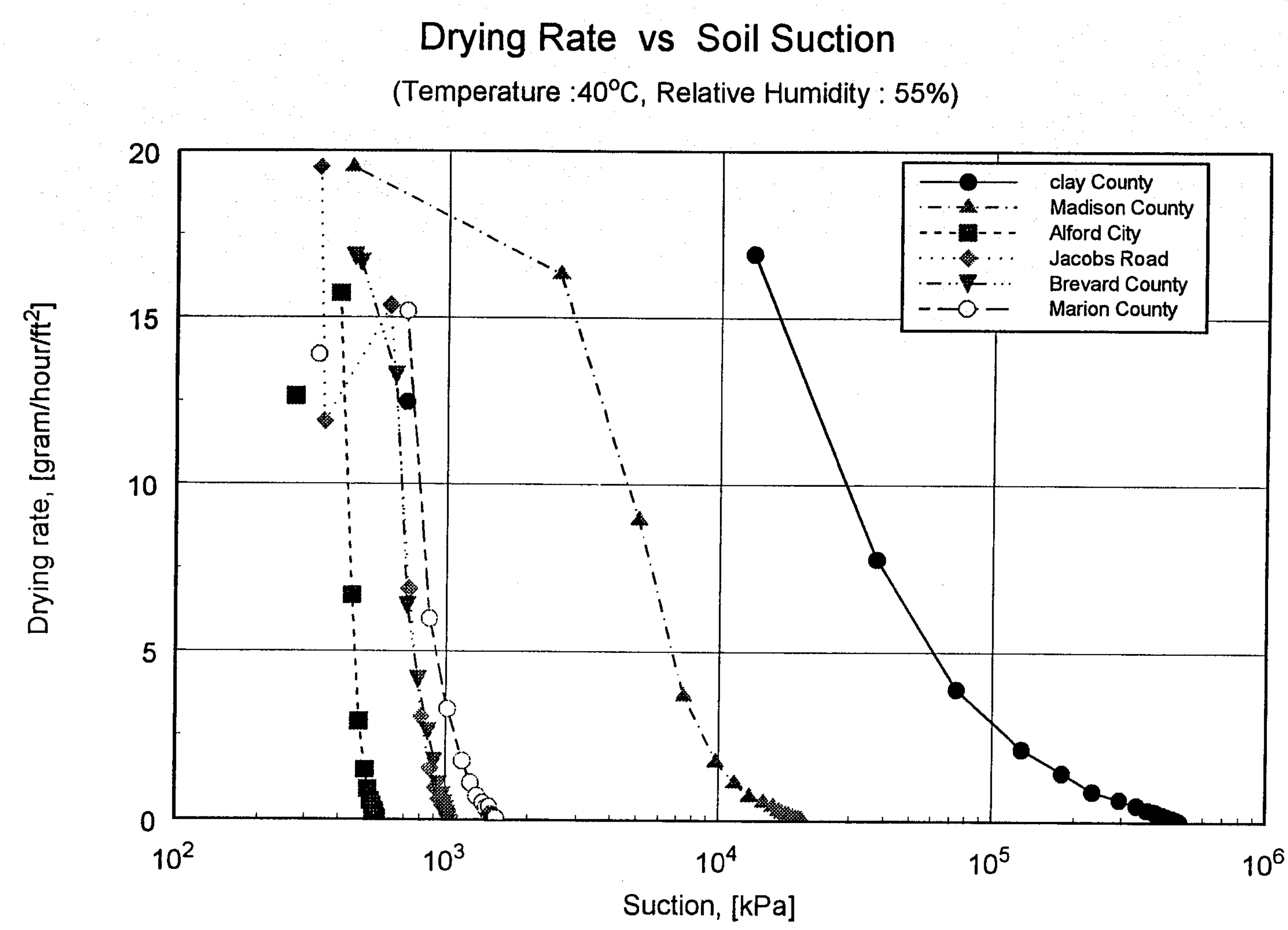


Figure F.15 : Drying rate versus soil suction for six soils at temperature 10°C and 95% relative humidity (Group I)



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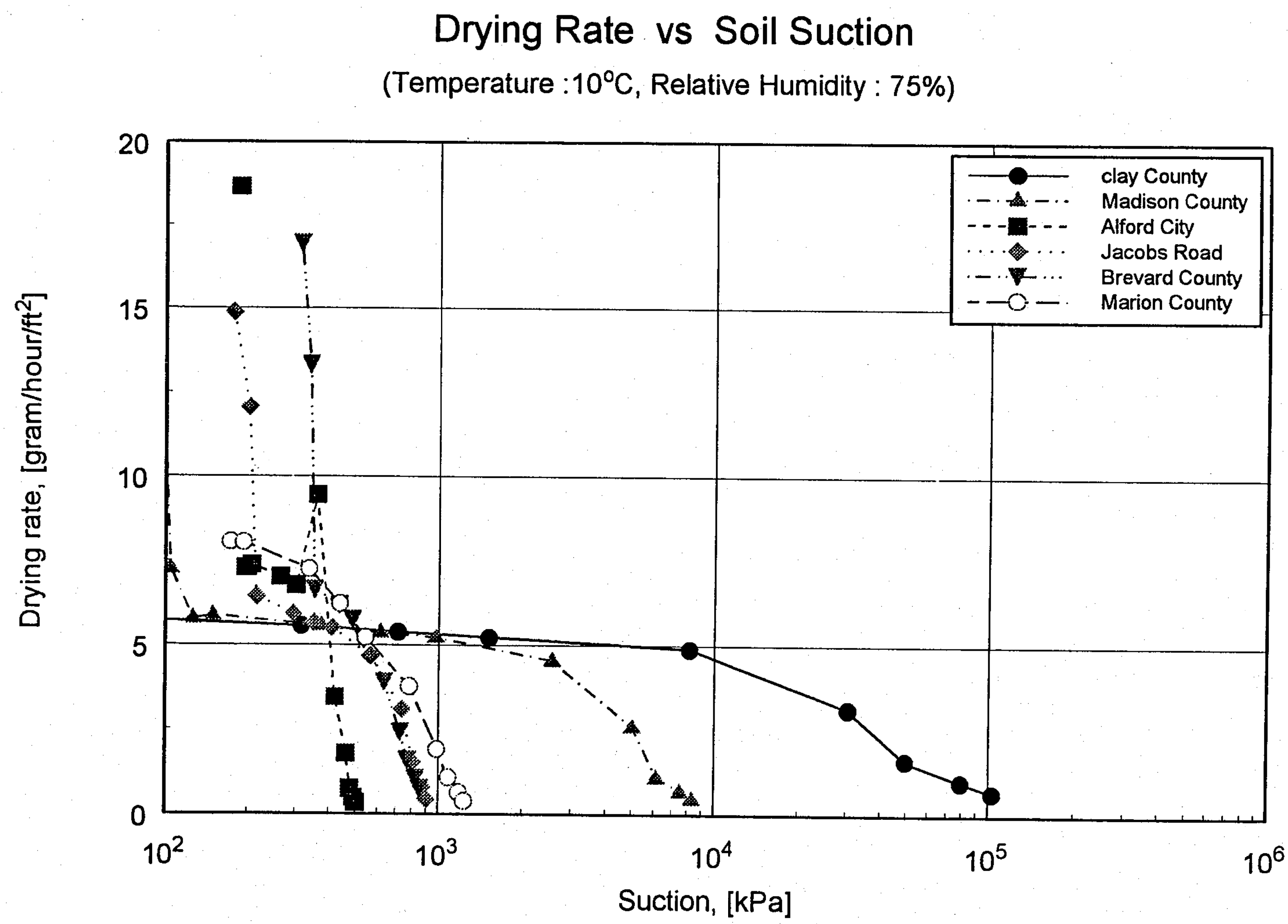

Figure F.17 : Drying rate versus soil suction for six soils at temperature 10°C and 75% relative humidity (Group II)

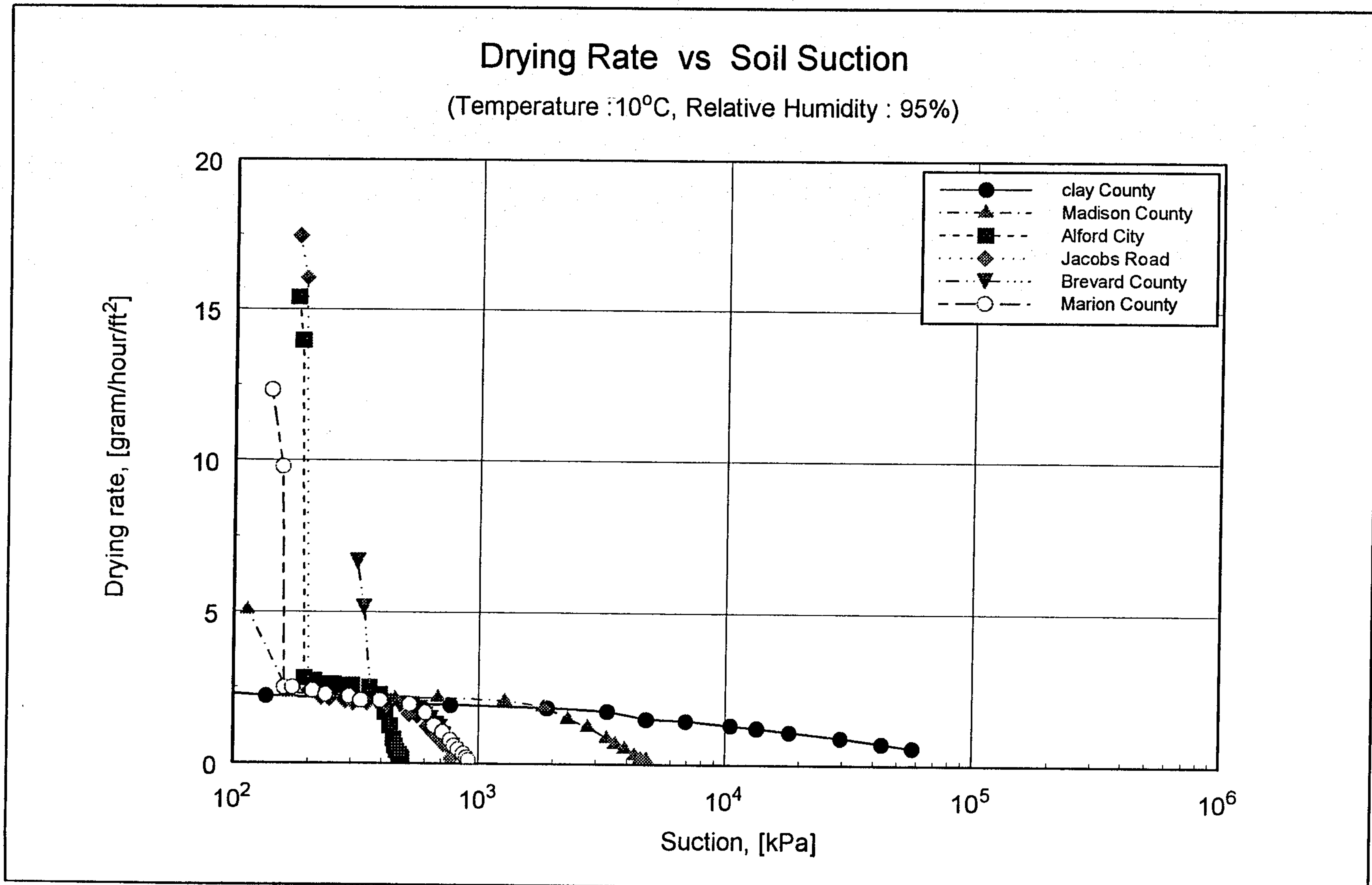

Figure F.18 : Drying rate versus soil suction for six soils at temperature 10°C and 95% relative humidity (Group II)

BIBLIOGRAPHY

AASHTO (1993), "Standard Method of Test for Soil Suction", AASHTO Designation: T 273-86, Washington, D.C.

Acar, Y. B., and Nyeretse, P., "Total Suction of Artificial Mixtures of Soil Compacted at Optimum Water Content", Geotech Test Journal, v15, n1, Mar <1992> p65-73.

Braud, I. and Dantas-Antonino, A. C., "Stochastic Approach to Studying the Influence of the Spatial Variability of Soil Hydraulic Properties on Surface Fluxes, Temperature and Humidity", Journal of Hydrology v165, n1-4, Feb <1995>, p283-310.

Briscoe, R. D., "Thermocouple Psychrometers for Water Potential Measurements", Proceedings of the NATO Advanced Study Institute on Advanced Agricultural Instrumentation,' II Ciocco (Pisa), Italy, <1984>

Bumb, A. C., "A Comparison of Three Functional Forms for Representing Soil Moisture Characteristics", Ground Water March-April <1992>, v30, n2, P177(9)

Campbell, G. and Gardner W. H., " Psychrometer Measurement of Soil Water Potential: Temperature and Bulk Density Effects", <1971>

Cary, J. W., "Using an Electro-Optical Switch to Measure Soil Water Suction", Soil Science Society of America, v55, n6, Nov-Dec <1991>, p1798-1800

Cook, C. A., Cundy, V. A., Larsen, F. L. & Lighty, J. S., "A Comprehensive Heat Transfer Model for Rotary Desorbers"

Daniel, D. E., Hamilton, J. M., and Olson, R. E., "Suitability of Thermocouple Psychrometers for Studying Moisture Movement in Unsaturated Soils", Permeability and groundwater Contaminant Transport, ASTM STP 746, T. F. Zimmie and C. O. Riggs, Eds., American Society for Testing and Materials, <1981>, pp. 84-100.

Davidson, J. L., Elfino, M. K. & Gallet, A. M., "An Evaluation of Design Highwater Clearances for Pavements", Engineering & Industrial Experiment Station, May <1986>

Day, R. W., "Evaluation of In-Place Wetting Using Soil Suction Measurements", Journal of Geotechnical Engineering v120, n9, Sep <1994>. 1648(3)

Day, R. W., "Disscussion Theory for Soft Cohesive Soils", Journal of Geotechnical Engineering, Nov <1996>. pp. 943-946

Dhowian, A. W., "Soil-Suction-Potential model", Journal of Geotechnical Engineering v118, n4, Apr <1992>. P521-539

Edil, T. B. and Motan, S. E., "Laboratory Evaluation of Soil Suction Components", Geotechnical Testing Journal, GTJODJ, Vol. 7, No. $, Dec. 1984, pp. 173-181.

Fleureau, J. M., "Behavior of Clayey Soils on Drying-Wetting Paths", Canadian Geotechnical Journal v30, n2, Apr <1993>. P287-296

Fredlund, D. G., Gan, J. K. M., and Gallen, P., "Suction Measurements on Compacted Till Specimens and Indirect Filter Paper Calibration Technique", Transportation Research Record, 1418, Sep <1995>. P3-9

Fredlund, D. G., Xing, A., "Equations for the Soil-water Characteristic Curve", Canadian Geotechnical Journal v31, n4, Aug <1994>. P521-532

Fredlund, G., Xing, A., and Barbour S. L., "The Relationship of the Unsaturated Soil Shear Strength to the Soil-water Characteristic Curve", Canadian Geotechnical Journal v32, <1995>, P440-448.

Fredlund, D. G., Xing, A., Huang, S., "Predicting the Permeability Function for Unsaturated Soils Using the Soil-water Characteristic Curve", Canadian Geotechnical Journal v31, n4, Aug <1994>, P533-546.

Frazer, J. C. W., Taylor, R. K., and Grollman, A., "Two-Phase Liquid-Vapor Isothermal Systems, Vapor-Pressure Lowering", International Critical Table.

Granger, R. J., "An Examination of the Concept of Potential Evaporation", J. Hydrology, 111:9-19, <1989>

Granger, R. J., and Gray, D. M., "Evaporation from Natural Nonsaturated Surfaces", J. Hydrology, 111:21-29, <1989>

Granger, R. J., and Gray, "A complementary Relationship Approach for Evaporation from Nonsaturated Surfaces", J. Hydrol., 111:31-38, <1989>

Henderson, S. J., "Values of In-Situ Soil Suction", n3, July <1991>

Houston, S. L., Houston, W. N., and Wagner, A.-M., "Laboratory Filter Paper Suction Measurements", Geotechnical Testing Journal, GTJODJ, v17, n2, pp.185-194, June <1994>

Iwata, S., Tabuchi, T., & Warkentin, B. P., "Soil-Water Interactions: mechanics and applications", New York, <1988>

Janssen, D. J. & Dempsey, B. J., "Soil-Moisture Properties of Subgrade Soil", Transportation Research Record 790, P61-66

Johnson, L. D., "Influence of Suction on Heave of Expansive Soils", Soils and Pavements Laboratory, U.S. Army Engineer Waterways Experiment Station Missippi, Apr. <1973>

Johnson, L. D., "An Evaluation of the Thermocouple Psychrometric Technique for the Measurement of Suction in Clay Soil", Soils and Pavements Laboratory, U.S. Army Engineer Waterways Experiment Station, Missippi, Jan. <1974>

Khire, M. V., Meerdink, J. S., Benson, C. H., and Bosscher, P. J., "Unsaturated Hydraulic Conductivity and Water Balance Predictions for Earthen Landfill Final Covers", Soil Suction Applications in Geotechnical Engineering Practice, Proceedings of a session sponsored the Committees on Shallow Foundations and Soil Properties of the Geotechnical Engineering Division of the American Society of Civil Engineers in conjunction with the ASCE Convention, San Diego, California, <1995>

Klute, A., "Method of Soil Analysis: Part I - Physical and Mineralogical Methods, Second Edition", Soil Science Society of American Inc, Madison, <1986>

Krahn, J., and Fredlund, D. G., "On Total, Matric, and Osmotic Suction", v114, n3, <1972>

Lee, H. C., and Wray, W. K., "Techniques to Evaluate Soil Suction-A Vital Unsaturated Soil Water Variable", <1995>

Lim, T. T., Rahardjo, H. Chang, M. F., and Fredlund, D. G., "Effect of Rainfall on Matric Suction in a Residual Soil Slope", Canadian Geotechnical Journal, v33, <1996>

Marmaras, F., Truong, H. V. P., Richards, B. G., and Holden, J. C., "Role of Soil Suction in Cracking of West Gate Freeway Pavements", Proceedings 17th ARRB Conference, Part 2.

Mou, C. H. & Chu, T. Y., "Soil Suction Approach for Evaluation of Swelling Potential", Transportation Research Record 790, P54-60

Nevels, B. Jr., "The Use of Soil Suction in Analysis of Pavement Cracking", Soil Suction Applications in Geotechnical Engineering Practice, Proceedings of a session sponsored the Committees on Shallow Foundations and Soil Properties of the Geotechnical Engineering Division of the American Society of Civil Engineers in conjunction with the ASCE Convention, San Diego, California, <1995>

Park, S. W., Lytton, R. L., and Button, J. W., "Identifying the Cause of Swelling Soils Using Soil Suction", Texas A&M University, Texas, <1997>.

Phene, C. J., Hoffman, G. I., and Rawlins, S. L., "Measuring Soil Matric Potential In-Situ by Sensing Heat Dissipation within a Porous Body: I. Theory and Sensor Construction", Soil Science Society American Procedure, v35, <1971>

Ping, W. V., and McDonald, S., "An Evaluation of Engineering Properties of Problematic Soils in Highway Construction", A final draft report for the Florida Department of Transportation, <1996>

Reece, C. F., "Evaluation of a line heat dissipation sensor for measuring Soil Matric Potential", Soil Science Society of America Journal, July-August <1996>, v60, n4, p1022(7)

Reed, F., and Kelley, M., "Application of Soil suction in Dallas/Fort Worth", Soil Suction Applications in Geotechnical Engineering Practice, Proceedings of a session sponsored the Committees on Shallow Foundations and Soil Properties of the Geotechnical Engineering Division of the American Society of Civil Engineers in conjunction with the ASCE Convention, San Diego, California, <1995>

Russam, K., and Coleman, J. D., "The Effect of Climatic Factors on Subgrade Moisture Conditions", Road Research.

Sattler, P., Fredlund, D. G., Klassen M. J., and Rowan, W. G., "Bearing Capacity Approach to Railway Design Using Subgrade Matric Suction", Transportation Research Record 1241

Sattler, P., and Fredlund, D. G., "Use of Thermal Conductivity Sensors to Measure Matric Suction in the Laboratory", Canadian Geotechnical Journal, v26, <1989>, PP491-498

Savage, M. J., and Cass, A., "Measurement of Water Potential Using Thermocouple Hygrometers", South African Journal of Science, v77, Jan. <1981>

Sibley, J. W., and Williams, D. J., "A New Filter Material for Measuring Soil Suction", Geotechnical Testing Journal, GTJOTJ, v13, n4, pp.381-384, December <1990>

Snethen, D. R., "Characterization of Expansive Soil Using Soil Suction Data"

Snethen, D. R., "An Evaluation of Methodology for prediction and Minimization of Detrimental Volume Change of Expansive Soils in Highway Subgrades", Geotechnical laboratory, U.S. Army Engineer Waterways Experiment Station Missippi, Mar. <1979>

Snethen, D. R., "Technical Guidelines for Expansive Soils in Highway Subgrades", ", Geotechnical laboratory, U.S. Army Engineer Waterways Experiment Station Missippi, Jun. <1979>

Snethen, D. R., and Huang, G., "Evaluation of Soil Suction-Heave Prediction Methods", 7th International Conference on Expansive Soils

Snethen, D. R., and Johnson, L. D., "Evaluation of Soil Suction from Filter Paper", Geotechnical laboratory, U.S. Army Engineer Waterways Experiment Station Missippi, Jun. <1980>

Spangler, G., and Handy, R. L., " Soil Engineering", <1982>

Thompson, R. W., and Mckeen, R. G., "Heave Prediction Using Soil Suction: A Case History", Soil Suction Applications in Geotechnical Engineering Practice, Proceedings of a session sponsored the Committees on Shallow Foundations and Soil Properties of the Geotechnical Engineering Division of the American Society of Civil Engineers in conjunction with the ASCE Convention, San Diego, California, <1995>

Tsai, C. H., and Petry, T. M., "Suction Study on Compacted Clay Using Three Measurement Methods", Transportation Research Record 1481, P28-34

Ueda, M., "A Simple Thermoelectric Psychrometer for Measurement of Equilibrium Humidity", Drying Technology, 9(4), 875-881, <1991>

Vanapalli, S. K., Fredlund, D. G., Pufahl, D. E., and Clifton, A. W., "Model for the Prediction of Shear Strength with Respect to Soil Suction", Canada Geotechnical Journal, 33: 379-392, <1996>

Walsh, K. D., "Evaluation of in-place wetting using soil suction measurements", Journal of Geotechnical Engineering v119, n5, P862-873, May <1993>

Wescor Inc., "Hr33t Dew Point Microvoltmeter Instruction / Service Manual", <1986>

Wescor Inc., "Water Potential System", <1988>

Wescor Inc. "Preparation of Calibration Electrolyte Solution"

Wilson, G. W., Fredlund, D. G., and Barbour, S. L., "The Effect of Soil Suction on Evaporative Fluxes from Soil Surfaces", Canadian Geotechnical Journal, v34, <1997>, P145-155.

Wilson, G. W., Fredlund, D. G., and Barbour, S. L., "Coupled Soil-Atmosphere Modelling for Soil Evaporation", Canadian Geotechnical Journal, v31, <1994>, P151-161.

Winsberg, Morton D., "Florida Weather", University of Florida, <1990>

Woodburn, J. A., Holden, J. C., and Peter, P., "The Transistor Psychrometer: A New Instrument for Measuring Soil Suction"

Wray, W. K., "The Principle of Soil Suction and its Geotechnical Engineering Application", Fifth International Conference on Expansive Soils, Adelaide, South Australia, 21-23 May 1984