THICKNESS OF SOIL SOLUM AS A PARAMETER OF PLANT-AVAILABLE WATER STORAGE CAPACITY IN SOILS UNDERLAIN BY CARBONATE ROCKS

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ABSTRACT

Available water storage capacities were determined by field measurement in limestone-derived soils with a range in depths to carbonate rock of 15 cm to more than 300 cm. Neutron probe access wells were installed and amounts of water were determined throughout two growing seasons. Each soil layer had a characteristic volume of water (called observed field capacity) after recharge by rain periods. At maximum depletions, water approached 15 bar contents. Equations were developed for the prediction of available water (the volume difference between observed field capacity and 15 bar water) from three soil variables; clay content, chert-stone content and depth to carbonate rock. When effects of chert and clay were accounted for the prediction equation was: Total A.W.C. = 0.11 (cm depth) for depths of 0 to 102 cm. For greater depths: Total A.W.C. = 11.2 cm + 0.04 (cm depth - 102). Depths to limestone of less than 61 cm (67 cm A.W.C.) were too shallow to support forest canopies and the natural vegetation was prairie. Forest species survived where depths were greater than 61 cm and some depletion was observed at greater than 250 cm depth.

Keywords - *Soil, *Soil water, Limestone, *Clay content, Chert, Prairie, Forest

CHAPTER I

INTRODUCTION

An understanding of the disposition of our water supply as it passes through the hydrologic cycle is an important part of the study of water resources. The soil has a significant function in the hydrologic cycle; that of absorbing the moisture received from precipitation, storing most of it for variable time periods, and releasing it to plants which ultimately return most of it to the atmosphere. More specifically, the physical characteristics of the soil affect its ability to absorb, conduct, and store moisture. This in turn greatly affects the rate at which precipitation is released to streams, ground water, and vegetation. Therefore, an understanding of the physical characteristics of the soil, and their effect on moisture movement and storage, is an important part of the study of water resources.

THE PROBLEM

There are many variables affecting the moisture storage capacity of a soil but none is as uncompromising as is depth to dense crystalline bedrock. Irregardless of how well structured a soil or how favorable the texture, the moisture storage is limited if bedrock is present within the potential depth of plant rooting. This study, then, is concerned with the moisture storage capacities of limestone derived soils as related to the depths to carbonate rock.

Shallow depth to carbonate rock is a commonly observed feature in what are known as glade areas. In such areas the vegetation consists largely of annual or drought resistant perennial species. It was theorized that the vegetative cover was largely a result of the moisture regimes of these soils which, in turn, were dependent upon the depth to carbonate rock. For this reason the major site picked for this study was an area where depth to carbonate rock decreased with distance, and where, at a critical depth to bedrock, a natural boundary between forest and prairie vegetation existed.

In the preliminary investigation of this site it was noticed that there was a high concentration of chert rock in the surface horizons of the shallow forested soil. Because this is a commonly observed condition in many limestone derived soils and because the presence of this material can lower the moisture storage capacity of a soil considerably, it was decided to study the moisture storage capacity of a deep, relatively chert-free, limestone derived soil as well. The hypothesis was that if the two soils were similar in every respect but chert content and depth to bedrock, these effects could be taken into account and the resulting soil moisture storage capacities could be predicted.

The objectives of this study then were twofold. The first was to determine the relationship between depths to carbonate rock and soil moisture storage capacity and, in turn, the relationship to vegetative cover. The second objective was to determine whether the available moisture storage capacities of limestone derived soils could be predicted after the chert content and depth to bedrock were taken into account.

CHAPTER II

REVIEW OF THE LITERATURE

Because of the nature of this study, past investigations that are related to it can be divided into four general topics. They are: first, the nature of limestone derived soils; second, methods of determining soil moisture content; third, the available moisture storage capacity; and fourth, the effect of climate on moisture demand.

THE NATURE OF LIMESTONE DERIVED SOILS

Scrivner *et al*. (30) report that carbonate rock is the dominant soil parent material in the Missouri Ozarks. They consistently describe the soils in this region as having low fertility with light colored cherty surfaces and red clay subhorizons. The soils associated with the glade areas are described as shallow dark colored stony loams.

The Soil Conservation Service has described many soils formed in carbonate rock residuum. Descriptions of the Clarksville, Baxter, and Fullerton series are examples (12, 13, and 14). These soils are all described as strongly to very strongly acid with light colored cherty surfaces and red clay subhorizons.

Miller (22) completed a detailed characterization and comparison of four limestone derived soils from Missouri. He reported that the cherty silt loam surface horizons and red clay B horizons were common to all four soils. He also documented the presence of three narrow bands near the carbonate rock in all of these soils. They consisted of one layer of partially weathered sand size carbonates immediately above the bedrock, a second redder band above it with sand size material mixed with some silts and clays, and a third darker redder layer of mostly clay size particles. After examining a great deal of physical, chemical, and mineralogical data for these soils he concluded that carbonate rock parent materials have a dominant effect on the soil forming process.

Glade areas (areas with shallow depths to carbonate rock) are found scattered throughout the Ozarks. They are a major part of the landscape in the southwestern part of the state. Scrivner and Frieze (29) report that approximately 40 percent of the soils in Taney County, located in southwest Missouri, are shallow, dark colored, glade-rock soils. Scrivner et al. (30) state that significant areas of adjoining counties are also dominated by glade areas.

METHODS OF DETERMINING SOIL MOISTURE CONTENT

There are a number of methods available for determining the moisture content of a volume of soil. The gravimetric method is the most direct but has as one of its major disadvantages the fact that the soil sample is disturbed and only one value can be obtained for a given sample in its natural state.

The development of methods which permitted moisture measurements in situ was a major improvement. Scientists were then able to obtain periodic moisture readings from an undisturbed sample in its natural environment. The first of these was a method whereby the conductivity of a porous block, buried in the soil, was used as a measure of moisture content (2, 1). It was necessary first to obtain a calibration curve for a given block in a given soil. Then the block was buried and allowed to equilibrate with the soil moisture. By recording the changes in conductivity or resistance of the blocks the moisture and changes in moisture content were determined. This method was limited in usefulness by its low precision, partially because of difficulties encountered in calibrating the blocks.

The introduction of the neutron probe has given soil scientists the best method available for accurate measurement of soil moisture *in situ*. The probe is equipped with a radioactive source which emits high energy neutrons. As they collide with hydrogen atoms they are slowed and finally absorbed into the surrounding material until, at equilibrium, there is a sphere of slowed neutrons surrounding the source. The probe is also equipped with a device which detects the number of slowed neutrons that return to the probe. The number of slowed neutrons returning is proportional to moisture content. If there is a high soil moisture content the diameter of the sphere at equilibrium is about 15 cm or 6 inches (2). As the moisture content is reduced, some of the high energy neutrons travel farther before encountering a hydrogen atom. Therefore, the size of the sphere at equilibrium increases and the volume of soil affecting the reading likewise increases. For this reason van Bavel (33) and others have cautioned against using the probe at depths of less than 7 inches to avoid including the air-soil interface within the sphere. The size of this sphere also precludes accurate measurement of the moisture content of thin layers, since the probe integrates the moisture contents for the length of the profile within its range. van Bavel (33) reported a resolution of 9 inches; that is, readings were affected by a 1 inch wet layer through 9 inches of the profile. However, these effects were considered to be insignificant for 3 of the 9 inches.

The accuracy of the neutron probe in a wide variety of soils is documented by van Bavel (34) and Gardner (2). Gardner *et al.* (15) found that some organic soils affect the accuracy of calibration curves but often the much larger amounts of moisture present render these effects insignificant. van Bavel (33, 34) states that the greatest source of error in the use of the probe is in the determination of the moisture content of the standards used in determining calibration curves. This error is estimated to be within 1 percent and cannot be significantly improved by longer counts or larger neutron sources.

AVAILABLE MOISTURE STORAGE CAPACITY

The available moisture storage capacity is one of the most useful soil characteristics. It is an estimate of the water a soil is able to retain long enough for plant usage and it precludes the water which a plant is unable to extract from the soil. This value is usually taken to be the difference between the field capacity and the wilting point.

Field Capacity. The classical definition for field capacity was given by Veihmeyer and Hendrickson (36). They defined field capacity as:

> "...the amount of water held in the soil after the excess gravitational water has drained away and after the rate of downward movement of water has materially decreased, which usually takes place within 2 or 3 days in pervious soils of uniform structure and texture."

It is defined by the American Society of Agronomy (16) as the "percentage of water remaining in a soil 2 or 3 days after having been saturated and after free drainage has practically ceased." The purpose of both of these definitions was to distinguish between water passing through the soil rapidly and that which remained in the root zone long enough for plant use.

Briggs and McLane (6) introduced the moisture equivalent as an estimate of the upper limit of plant available moisture. This was the moisture content of a sample after it had been saturated, placed in a centrifuge, and then subjected to a force 1,000 times that of gravity (1). Richards and Weaver (27) found that water retained in soils by a 1/3 atmosphere tension applied to samples on a porous plate correlated well with the moisture equivalent of medium and fine textured soils. Although, this value has become a standard laboratory estimate of field capacity, Richards and Richards (25) report that soil moisture tensions of .02 to .10 bars were measured in some soils a day or two after a deep wetting by rain or irrigation.

Since samples used for laboratory methods often differed considerably from the soil in situ, methods have been devised for estimating the field capacity of undisturbed soils. Ordinarily the soil profile is wetted and allowed to drain for 2 days with precautions taken to prevent losses due to evaporation and transpiration (2). The soil is then sampled and moisture determinations made gravimetrically, or the moisture content is determined <u>in situ</u> through the use of porous resistance blocks or a neutron probe.

Bohnert (4) used a neutron probe to measure the moisture content of soil profiles in Missouri in the spring of 1966 before the growing season began. The soil had been recharged by the winter rains and a dry appearing crust had formed at the immediate surface. He considered these moisture contents to be estimates of the field capacities. He labeled these values as observed field capacities in order to distinguish them from 1/3 bar moisture contents.

Burrows and Kirkham (7) wetted four soil profiles and took moisture readings at various times after the free water disappeared from the surface. The moisture-time curves for three of the soils very well illustrated the concept of field capacity. After periods of 24, 40, and 20 hours respectively, the moisture content of the 3 to 9 inch layers remained relatively constant with time. This indicated that downward movement had essentially ceased. The curve for a fourth profile illustrated some of the anomalies that occur when the texture is not uniform with depth. This profile had lenses of clay and sand which filled and drained intermittently and produced a wide variability in the moisture readings with time. They noted that the presence of a water table or layers of variable antecedent moisture content would also affect the shape of these curves, and thus, would affect the time necessary to achieve equilibrium at field capacity. Richards and Wadleigh (26) warn that curves of changing moisture content or soil moisture tension over time for some soils do not discernibly level off after any length of time. For this reason they suggest that field capacities determined in this manner be carefully examined before being accepted in scientific work.

Wilting Point. The permanent wilting point is defined by Peters (2) as "the water percentage of a soil when plants growing in that soil are first reduced to a wilted condition from which they cannot recover in an approximately saturated atmosphere." Richards and Weaver (27) found that the moisture content of a soil sample after it had been saturated and equilibrated at 15 bars tension correlated well with the moisture content at the permanent wilting point. The 15 bar moisture content has been accepted as the standard laboratory estimate of the permanent wilting point. Veihmeyer and Hendrickson (37) point out that although this is not a unique value for a given soil, the range of values is so small as to be insignificant. Bohnert (4) introduced the minimum field content as an estimate of the lower limit of the available moisture storage capacity. He defined it as "the minimum percentage of water measured in the soil during the growing season."

Factors Affecting the Available Moisture Storage Capacity. As mentioned previously the moisture contents at field capacity and the wilting point are the upper and lower boundaries respectively of the available moisture storage capacity of the soil. These values, and in turn the available moisture storage capacity, are affected by such soil characteristics as texture, organic matter content and bulk density.

Peterson et al. (24) reported that amounts of available moisture were lowest in the coarse textured soils, increased in fine textured soils, and reached a maximum in medium textured soils. They also found that, except for coarse textured soils, bulk density was negatively correlated with moisture content at tensions of 1/3 bar. They showed that organic carbon was positively correlated with the moisture content at tensions of 15 bars and blamed this on the ability of organic matter to retain moisture at tensions of greater than 15 bars.

Jamison and Kroth (20) stated that results for some Missouri soils showed decreasing amounts of available moisture over the textural range of coarse silt, fine silt, clay, fine sand, coarse sand. They pointed out that the organic matter content did not appear to affect the available moisture storage capacity except in samples containing 13 to 20 percent clay. The authors point out that an increase in moisture storage capacity in this case was probably due to aggregate formation resulting from the presence of organic matter.

Bulk density, texture, salt content and soil moisture flow rate were reported by Jamison (14) to be important factors affecting the availability of soil moisture. He pointed out that aggregation and structure development increased the volume of large pores and improved aeration but did little to increase the amount of available moisture.

EFFECT OF CLIMATE ON MOISTURE DEMAND

In 1944 Thornthwaite introduced the term evapotranspiration which he defined as the amount of moisture given up to the atmosphere through the processes of plant transpiration and evaporation from the soil surface. The evaluation of this quantity provided an estimate of the moisture needs of the vegetation. Many methods of varying complexity and applicability have been devised, but two methods are more widely recognized and used than the others. One is Penman's heat budget method and the other is Thornthwaite's empirical method.

The heat budget as developed by Penman (23) is based upon the assumption that the net radiation or energy supply is completely utilized by water evaporation and environmental heating. His formula for computing evapotranspiration is:

$$E_t = \frac{\Delta R_{net} + \gamma E_a}{\Delta + \gamma}$$

where E_t is evapotranspiration, R_{net} is net radiation, γ is a constant, E_a is the evaporation from a free water surface under the same atmospheric conditions, and Δ is the slope of the saturation vapor pressure over temperature curve at air temperature. This method is widely accepted and is considered to be very accurate. A major hindrance to its use is the number of refined measurements that must be made. These include net radiation, horizontal wind velocity, mean air temperature, and mean vapor pressure.

Thornthwaite (23, 31) on the other hand based his empirical method on the fact that temperature is a valid reflection of the atmospheric conditions which affect evapotranspiration. Since daily maximum and minimum temperatures are widely recorded, a method utilizing the mean temperature would have a wealth of data immediately available for estimating evapotranspiration. Thornthwaite's formula is given as:

$$E_t = 1.6\ (10\ T_A/I)^a$$

where E_t is evapotranspiration, T_A is mean air temperature, I is a heat index given by:

$$I = \sum_{i=1}^{12} (T_A/5)^{1.514}$$

and a is a cubic function of I. Although this formula is not as accurate as Penman's its advantage lies in the ready availability of the temperature data necessary for its use.

The evapotranspiration values calculated by either of these methods is for an area completely covered with an actively growing vegetation with no water restrictions. This value is the potential evapotranspiration (PET). If either of the two stated conditions for PET are lacking the E_t is something less than the potential and is called actual evapotranspiration (AET). A variety of studies have been made to devise procedures for adjusting the PET in order to get a valid estimate of AET.

Thornthwaite and Mather (31) contend that the ratio of AET/PET is decreased as soil moisture decreases and that this is a linear relationship. Veihmeyer and Hendrickson (38) show evidence that the PET rate does not decrease until the moisture content of the soil reaches the wilting point. Denmead and Shaw (9) plotted curves of the AET/PET ratio over percentage of available soil moisture content for high, average, and low PET days. The ratio of AET/PET remained close to 1 for the high, average, and low PET days until their respective available moisture contents were lowered to 70, 55, and 30 percent. At these points the slopes of the curves steepened and the ratios decreased rapidly with decreasing percentages of available moisture.

Eagleman (11) found that the ratio of AET/PET decreased almost linearly with the percentage of available moisture and exponentially with the unsaturated conductivity of a soil. The unsaturated conductivity, however, was more closely correlated to this ratio than was the percentage of available moisture.

The accuracies of Penman's and Thornthwaite's methods have been studied by many investigators. In this regard, Penman (23) makes an interesting statement when he points out that "common to all (methods of estimating evapotranspiration) is the difficulty of getting a direct measure of evaporation to compare with any calculated value." It should be remembered that all studies so far have compared different methods of indirectly evaluating evapotranspiration and that there is, as far as this author knows, no valid procedure for directly measuring the moisture lost to the atmosphere by naturally vegetated surfaces.

Van Wijk and de Vries (35) compared the two methods for 20°, 40°, and 55° latitude. The values for evapotranspiration at 40° latitude, which passes through Missouri, were lower in the winter and higher in the summer for Thornthwaite's method than those calculated by Penman's method. The maximum disagreement, however, was .04 inches/day during a period of high PET.

Decker (8) working with orchard grass, timothy, and corn in Missouri compared Penman's and Thornthwaite's methods to a water balance determined by soil moisture measurements. Thornthwaite's method more closely estimated the water balance values while Penman's method did so with less variability. Decker thought that the latter would give a better estimate than the former if the experiment was repeated. He blamed the results on fortuitous weather conditions. He felt that the exceptionally cool, clear days during a period when the soil surface was dry enhanced the Thornthwaite estimate and inhibited the heat budget estimate. Both methods overestimated E_t when the surface was dry.

Holt (18) studied the energy budget and water balance of an oak-hickory forest in Missouri. He used Penman's and Thornthwaite's methods to estimate evapotranspiration and compared them to a water balance determined by soil moisture measurements. He found no significant differences among the three methods.

Thornthwaite and Mather (31) report good agreement between actual soil moisture measurements and soil moisture contents determined with a water balance using Thornthwaite's method for estimating evapotranspiration. Considering the few data needed for Thornthwaite's method, it would appear that it is accurate enough for many applications where the data for Penman's method are lacking.

SUMMARY

In summary of the review of the literature, particularly as it applies to this problem, it appears that the following conclusions might be made. First, limestone derived soils exhibit many similarities, and therefore, it is reasonable to assume that a relationship exists between two exceptions to this statement; the depth to carbonate rock and the available moisture storage capacity. Second, the neutron moisture probe is a precision instrument capable of measuring the moisture contents of a soil profile in situ. Third, the difference between the observed field capacity and either the minimum field content or the 15 bar moisture content is a valid estimate of the available moisture storage capacity. And finally, that Thornthwaite and Mather's method for evaluating the water balance gives a reasonable estimate of the consumptive demand on the moisture stored in a soil.

CHAPTER III

SITE DESCRIPTION

The primary site was located in Camden County, southwest of Camdenton, Missouri. A topographic map and an aerial photograph of the site are shown in Figures 1 and 2 respectively. A legal description of the site appears with the soil descriptions in Appendix A.

The site itself was a 12 percent northwest slope ascending into a saddle. The depth to carbonate rock varied from greater than 9 feet near the top of the slope to outcrops in the saddle and on the side slopes. There were two soils on the site and they were classified as the Bardley series, a very fine, mixed, mesic, Typic Hapludalf (Figure 3); and the Gasconade series, a fine, mixed, mesic, Lithic Hapludoll (Figure 4). Under the old classification system these would have been classified as a red-yellow podzolic and a lithosol respectively.

The Bardley soil was forested and the Gasconade had a cover of prairie vegetation. This vegetative and soil boundary was very abrupt and distinct (Figure 5). The forest vegetation consisted of a post oak, black oak, white oak, blackjack oak, and black hickory overstory with hawthorn, sumac, and oak and hickory seedlings in the understory. Most of the trees were of very low quality being less than 40 feet tall, deformed, and limby (Figure 6). The prairie vegetation consisted of compass plant, prairie dock, big bluestem, partridge pea,

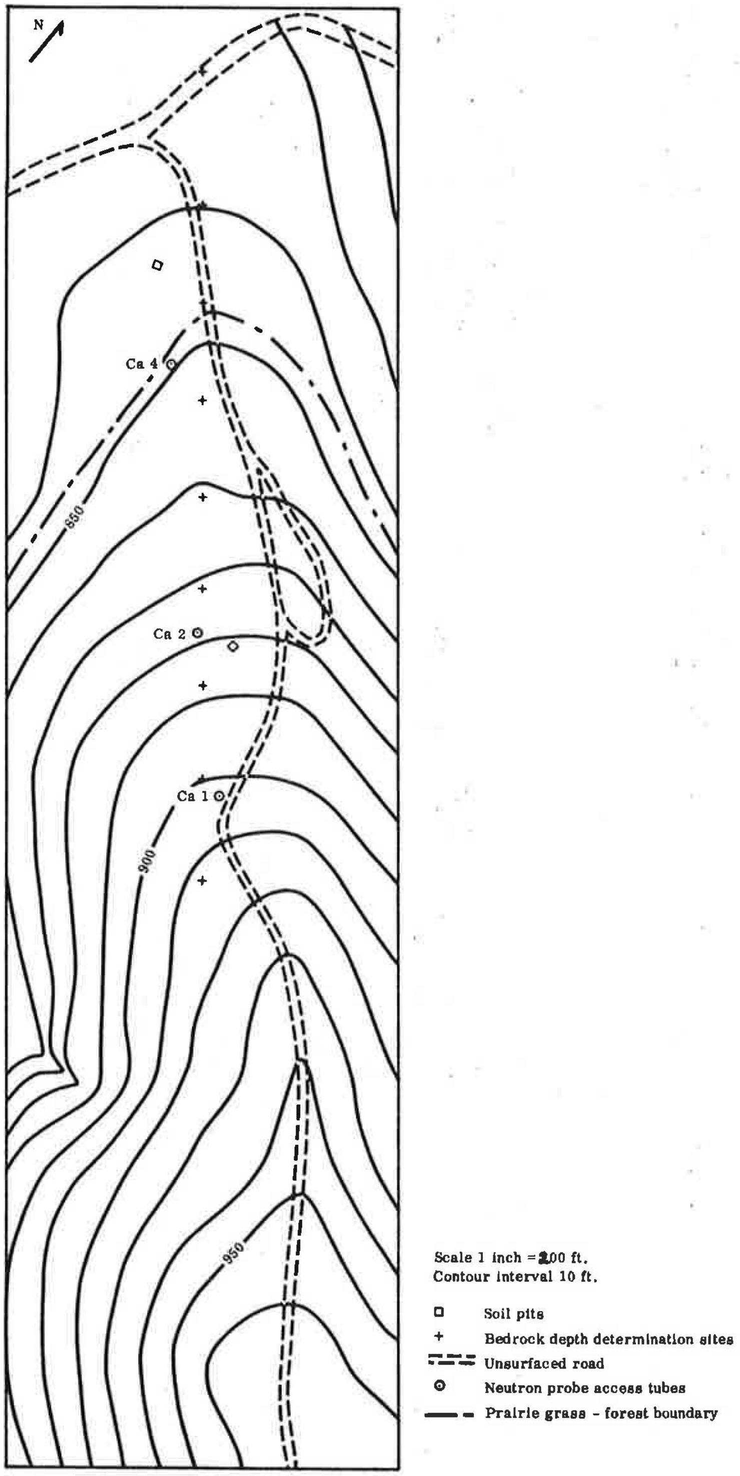

Figure 1. A topographic map of the Camdenton site showing neutron probe access tubes, bedrock depth determination sites, soil pits, and the prairie-forest boundary.

Figure 2. An aerial photograph of the Camdenton site and the surrounding area. The site is located on the ridge in the lower right hand corner. The light colored areas on the hillsides are glade areas.

Figure 3. The Bardley soil at the Camdenton site. The top arrow marks the boundary between the cherty A horizon and the high clay, relatively chert-free B horizon. The contact with carbonate bedrock is at 33 inches on the marker.

Figure 4. The Gasconade soil at the Camdenton site. The arrow marks the contact between the relatively chert-free, dark-colored A horizon and a fractured carbonate rock pinnacle.

Figure 5. The boundary between the forest and prairie vegetation at the Camdenton site.

Figure 6. The low quality timber stand at the Camdenton site.

coneflower, plantain, poverty grass, and ragweed. See Appendix B for a more complete listing of the species.

A second site was located in Oregon County about 12 miles south of Winona, Missouri. A topographic map and aerial photographs of the sites appear in Figures 7, 8, and 9. These sites were located on broad flat ridgetops with a depth to carbonate rock of greater than 10 feet. The soil was classified as the Dunmore series, a clayey, kaolinitic, mesic, Typic Paleudult or, under the old system of classification, a red-yellow podzolic. The vegetative cover was a forest consisting of an oak, hickory, and shortleaf pine overstory with an understory of dogwood, redbud, and seedlings of the overstory trees. Two of the sites had closed canopies but the third, identified as Wi 2, had less than 50 percent crown closure at the immediate site. This was due to a thinning operation which had removed several of the larger trees.

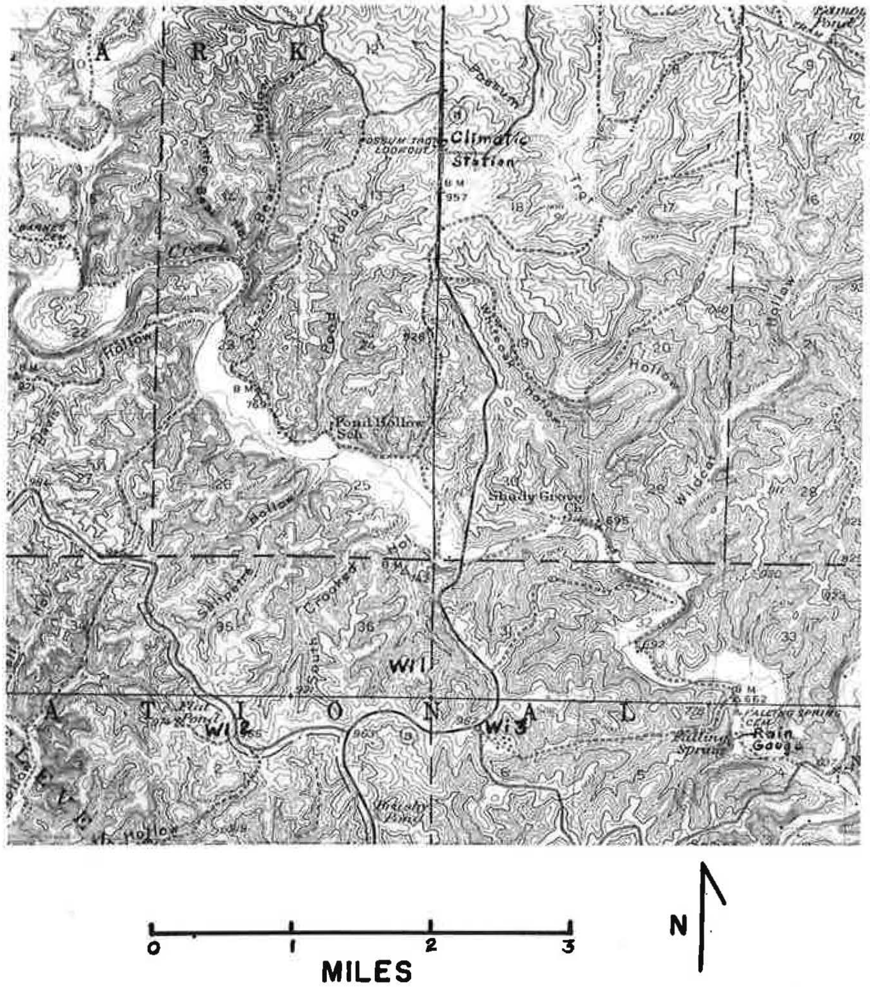

Figure 7. A topographic map of the Winona sites and the surrounding area.

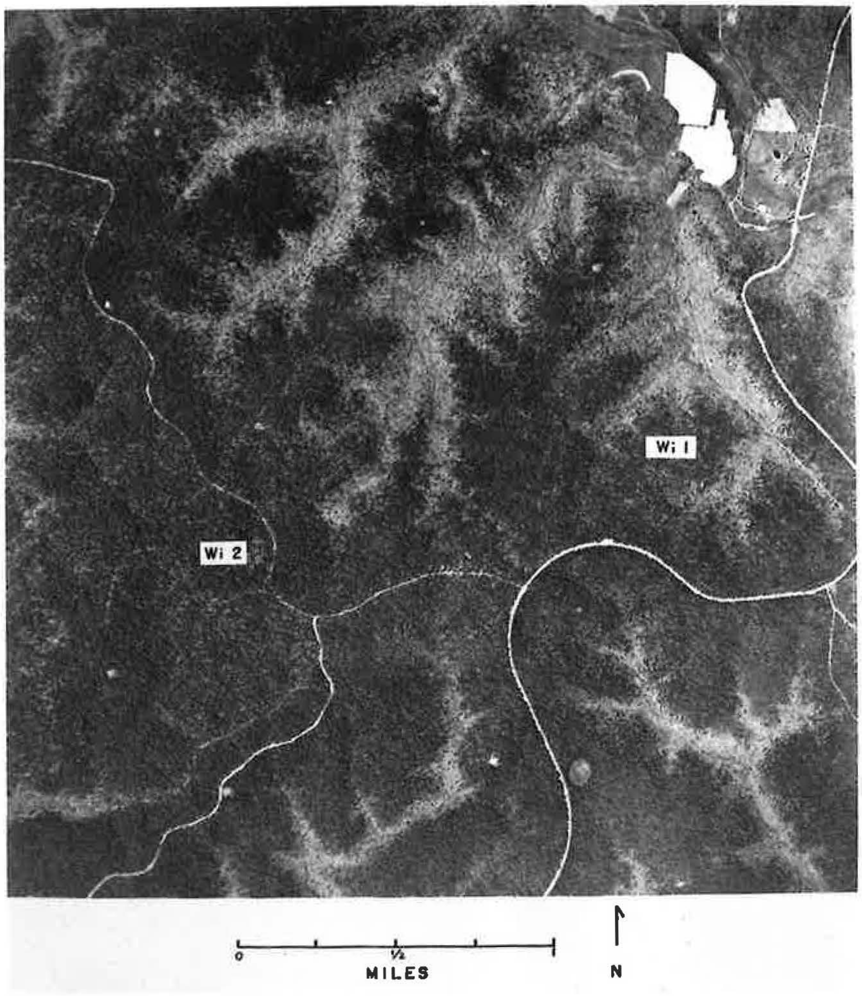

Figure 8. An aerial photograph showing two of the Winona sites and the surrounding area.

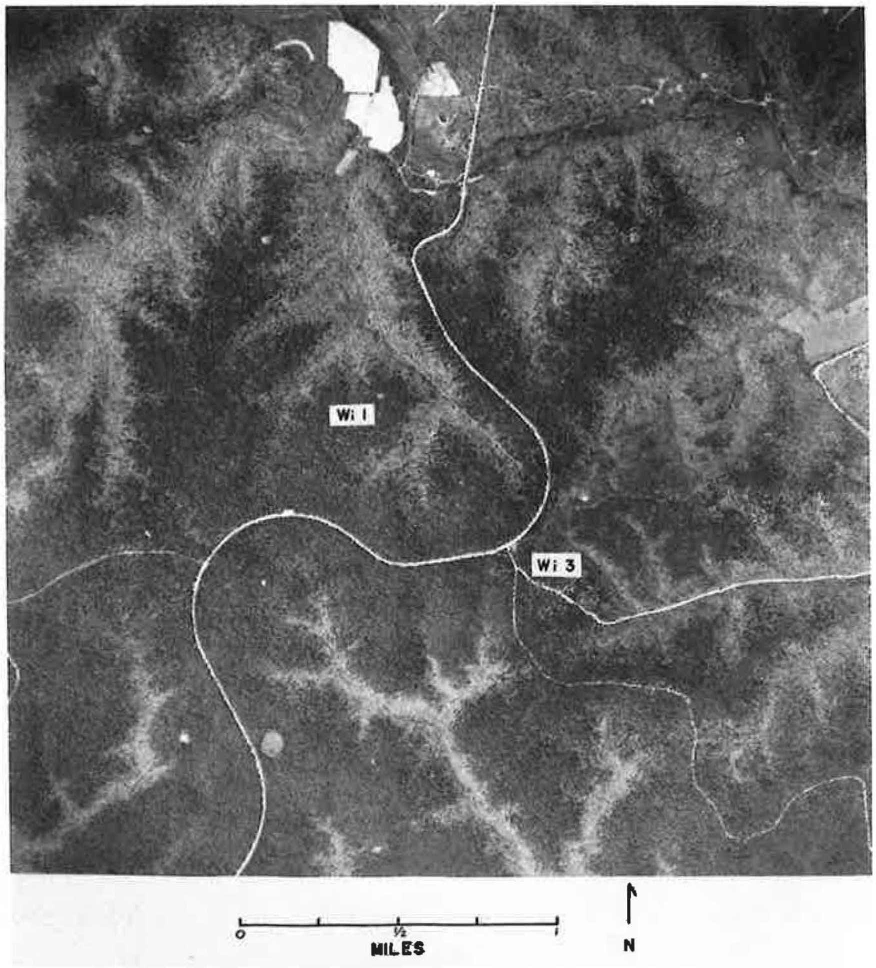

Figure 9. An aerial photograph showing sites Wi 1 and Wi 3 near Winona, Missouri.

CHAPTER IV

PROCEDURES

The data generated in this study fall roughly into five categories; soil characterization, soil moisture determinations, bedrock depths, climatic relationships and vegetation. The methods used in each of these categories will be presented in the order given.

SOIL CHARACTERIZATION

Physical Characteristics. The soil samples for this study were obtained from two pits dug on the Camdenton site and from cores extracted from the Camdenton and Winona sites while installing neutron probe access tubes. The cores were extracted with a Giddings Hydraulic Soil Probe mounted on the back of a pickup truck (Figure 10). The sampling was performed during the first and second weeks of June, 1968 when the soil moisture contents were at or below field capacity. Very little core deformation or compaction was observed and, as a result, bulk densities were determined from undeformed portions of the core. The inside diameter of the probe cutting head was used to calculate the cross-sectional area of the sample. This was multiplied by the length, as measured immediately after core extraction, to obtain its volume. The weight was determined after drying in an oven at 105°C overnight. In extracting the cores there were some instances in which chert fragments in the subsoil prevented penetration of the probe. In such instances the core was discarded and another

Figure 10. The hydraulic probe is being used to penetrate the relatively chert-free subsoil. Portions of the soil core can be seen in the tray to the left of the probe.

attempt was made in the near vicinity. Thus, the sites were not randomly selected.

It was impossible to use the hydraulic probe to remove cores of the A1 and A2 horizons because of the high concentration of chert particles larger than 2mm. Therefore, during the installation of the access tubes, these layers were removed and the probe was used on the relatively chert-free layers below. In order to obtain the bulk density of the surface horizons a quantity of soil was removed, dried in an oven at 105°C, and weighed. The volume was obtained by pouring measured volumes of plasterer's sand into the excavation. The bulk density was then calculated.

Particle size distribution was determined using a Bouyoucous hydrometer with a 50 gram sample dispersed in water and made to a total volume of 1 liter. Pretreatment consisted of organic matter removal by hydrogen peroxide digestion, salt removal by rinsing with distilled water and dispersion by adding a dispersing agent and shaking on a reciprocating shaker for 14 hours. The dispersing agent consisted of a solution of sodium hexametaphosphate (Calgon) and sodium carbonate. Hydrometer readings were taken at 2, 4, 8, 15, 30, 60, 120, 240, 480, and 960 minutes. The sand size (>0.05 mm) fraction was separated by wet sieving the sample through a 270 mesh sieve (.053 mm openings). The sand was dried, weighed, and the percentage sand was calculated. The clay fraction was determined from the 960 minute reading and the silt fraction was calculated as the difference between 100 percent and the sum of the clay and sand percentages.

Chemical Characteristics. The chemical characteristics determined were exchangeable hydrogen, calcium, magnesium, potassium, and sodium; cation exchange capacity; base saturation; salt and water pH; available phosphorous; and organic matter content.

Exchangeable cations were determined by standard, 1 normal, neutral, ammonium acetate leaching (2). Sodium and potassium were obtained in the ammonium acetate leachate by flame photometry. Calcium and magnesium were determined in the ammonium acetate leachate by atomic absorption spectrophotometry. The neutralizable hydrogen was determined using a titration technique developed by the soil survey laboratory at the University of Missouri and reported by Benham (3). The technique was essentially that of titrating with a standard $Ca(OH)_2$ solution in .01M $CaCl_2$. Neutralizable hydrogen was determined at pH 8.0. The cation exchange capacity and base saturation were computed from these data. Available phosphorous was determined using Bray's strong extracting solution and organic matter determinations were made using the wet digestion method (17).

Mineralogy. Clay mineralogy was determined on the less than 2 micron clay fraction by X-ray diffraction analysis. The dispersed samples from the particle size distribution analysis were used as sources of clay. The clay fraction was divided into 2 parts. One part was flocculated with excessive $MgCl_2$ and the flocculated clay was then washed repeatedly until the excess chlorides were removed. The other sample was prepared in a similar manner except KCl was used as the flocculating agent. Magnesium saturated clays were plated on glass slides and diffraction patterns were obtained after air drying and again after treatment with ethylene glycol. The potassium saturated sample was plated on a fused silica slide and X-ray diffraction patterns were obtained after air drying, after heating to 300°C, and again after heating to 550°C.

SOIL MOISTURE DETERMINATIONS

The soil moisture content was determined periodically with a Nuclear-Chicago Model P-19 Moisture Probe and Model 2800 Scaler (Figure 11). Access tubes for this purpose were installed at the Camdenton and Winona sites using the Giddings Hydraulic Probe. As mentioned previously, it was necessary to remove the cherty A1 and A2 horizons at all of the sites in order to use the hydraulic probe. A section of thin-wall electrical conduit 3 inches longer than the depth of the hole was installed and the surface soil was carefully replaced in the same order in which is was removed in an attempt to approximate the condition of the undisturbed soil.

Four access tubes were installed at the Camdenton site. These were arranged in a line from the top of the slope to the bottom and each extended from the surface to carbonate rock (Figures 1 and 2). Four access tubes were installed on U. S. Forest Service lands near Winona. These were installed to depths of 70, 115, 71, and 76 inches. Chance occurrences of chert rock terminated the depth of installation in each case and in no case was carbonate rock reached (Figures 7, 8, and 9).

Soil moisture determinations were made periodically with the neutron moisture probe in an attempt to establish values for the

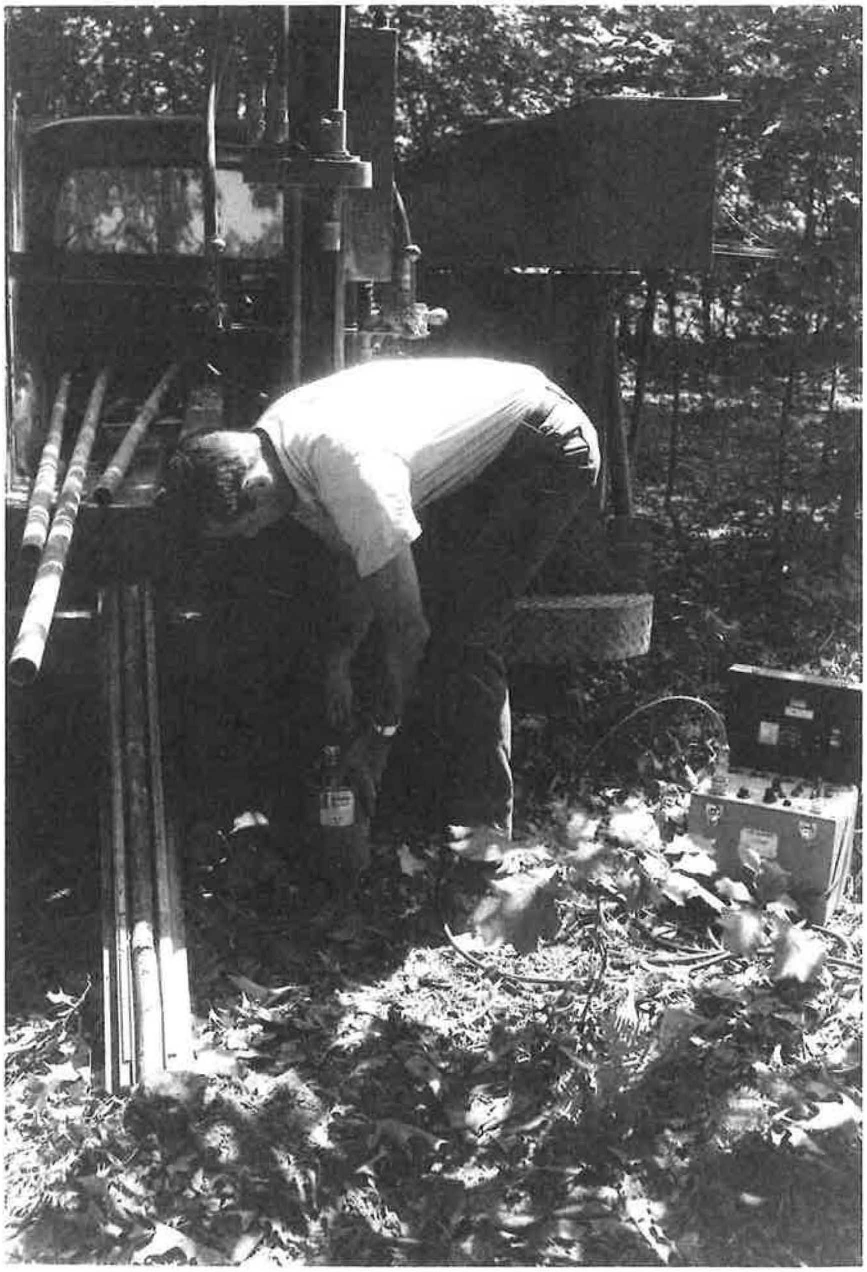

Figure 11. Moisture determinations being made using the neutron moisture probe.

observed field capacity and minimum field content as defined by Bohnert (4). The observed field capacity values were determined several days after a prolonged rain period with sufficient precipitation to more than recharge the soil moisture. Since the neutron probe was ineffective at depths of 6 inches or less the observed field capacities for the surface horizons were obtained gravimetrically. The minimum field content was determined from a series of moisture content readings taken throughout the growing season. Fifteen bar moisture content determinations were made for each site to compare with the minimum field content. These data were then used to draw soil moisture depletion profiles for all of the sites as an estimate of the available moisture storage capacity.

BEDROCK DEPTH

The depth to bedrock on the Camdenton site was determined by two methods; seismic refraction and actual measurement.

A Soiltest Terra Scout was used for the seismic refraction method (Figure 12). This consisted of setting up the Terra Scout with its geophone implanted in the ground and then hammering at increasing distances from the geophone. The Terra Scout was used to determine the time in milliseconds necessary for the first shock wave to arrive at the geophone from each point at which the hammer was used. These times were plotted on the y axis and the distances were plotted on the x axis of a graph. Changes in the slope of the plotted curve indicated that the waves were traveling through a higher density material. Then calculations based on Snell's Law were

Figure 12. The Terra Scout seismograph in use.

performed to determine the depth to the higher density material. (These calculations were made considerably less complex through the use of tables and nomograms supplied by Soiltest). This survey was run at every access tube and at mid-points between access tubes on the Camdenton site.

The second method consisted of boring through the soil with a Giddings Hydraulic Auger mounted on the back of a pickup truck (Figure 13). The depth was marked on the auger and after its removal was measured. The fact that carbonate rock had been reached was verified by treating a small amount of the material attached to the end of the auger with HCl. This method was used at grid points located on a line running up and down the slope and located close to the access tubes. Borings were made just above the deepest access tube and were taken every 100 feet to the lower boundary of the site (Figure 1).

A topographic survey was made in order to prepare a cross sectional drawing and topographic map of the site. A transit, stadia rod, and stadia tables were used for the survey. It was decided to set stakes every 100 feet in a grid pattern. The survey was started at the top of the slope above the site and progressed down the ridge. The rodman paced out 100 feet. He was moved on line by the instrumentman and the crosshair was set on the rod at instrument height. Then the rodman was directed to move forward or backward in order to get the correct intersection on the rod for 100 feet at the given vertical angle. This was repeated for each grid point. Soil pits, access tubes, and strategic road center lines were also surveyed.

Figure 13. The material on the tip of the hydraulic auger is being tested to ascertain whether or not carbonate rock has been reached.

Since relative elevations, not actual elevations, were important in this study, an elevation of 970 feet was assumed as the highest point. This was an approximation taken from a U. S. Geological Survey topographic map of smaller scale. The elevations of the grid points were calculated and plotted; and contour lines, roads, soil pits, and access tubes were drawn in.

CLIMATIC RELATIONSHIPS

The mean daily temperatures and daily precipitation for the two sites were obtained from U. S. Weather Bureau and U. S. Forest Service records. The climatic data for the Camdenton site was recorded approximately 2 miles from the site at a standard Weather Bureau station in Camdenton, Missouri (32). The temperatures for the Winona sites were recorded at a Forest Service climatic station located about 4.5 miles from the sites. The precipitation was recorded at a location due East of the sites and within 4 miles of the most distant site (Figure 7). These data were used to compute daily water balances for the sites according to the method described by Thornthwaite and Mather (31).

VEGETATION

The objective of the vegetative survey was to identify and list the most common species present. It was not considered necessary to include all of the species present or to estimate their relative abundance. Therefore, no formal plot survey was undertaken. Instead the author collected and identified species that were well represented and that were thought to reflect the true nature of the sites.

CHAPTER V

RESULTS AND DISCUSSION

The stated objectives of this study were twofold. The first was to determine the relationship between the depth to carbonate rock and the available moisture storage capacity and, in turn, their relationship to the vegetative cover. The second was to determine if the available moisture storage capacities of limestone derived soils could be predicted after the chert content and depth to bedrock were taken into account.

In order to achieve these objectives several types of investigations were initiated. First, the soils were characterized in order to establish their similarity to limestone derived soils previously studied. Second, the available moisture storage capacities of these soils were determined in order to observe the changes in available moisture storage capacity associated with varying depths to carbonate rock. Third, the consumptive demand for moisture was estimated at the soil sites in order to test the hypothesis that periods of drought existed in the shallower soils while the deeper soils were able to supply moisture throughout the growing season. Fourth, a vegetative survey was made in order to relate the vegetative pattern to the depths to bedrock, the available moisture storage capacities, and the consumptive moisture demand.

The results of these investigations will be discussed, in this chapter, in terms of what they revealed concerning the objectives of this study.

SOIL CHARACTERIZATION

Chemical Characteristics of the Soils. The data for the chemical determinations are given in Tables I and II. The pH's and base saturations for the Gasconade, Bardley, and Dunmore soils range from near neutral to extremely acid in the order given. The values for the Gasconade reflect the shallow depth to carbonate rock while those for the Bardley are comparable to values found by Miller in the Baxter and Talbott soils. The Dunmore soils had salt pH's lower than 4.0 throughout the subsoil; and base saturations, determined for 50 inches below the argillic horizon, were less than 10 percent. Base saturations lower than 35 percent at this depth indicated that the Dunmore soils were Ultisols whereas the Bardley soils were classified as Alfisols.

The cation exchange capacities in Tables I and II appear to be related to the organic matter content, clay content, and clay mineralogy. Subsequent sections of this chapter will describe clay content and clay mineralogy. It is sufficient to note here that the high exchange capacities of the Bardley and Gasconade soils are related to a large component of montmorillonite in the clay fractions. When total exhange capacities of the subsoils are corrected to 100 percent clay, it can be shown that the Bardley clays have 42 to 55 milliequivalents of exchange capacity per 100 grams of clay. The cation exchange capacity values for the Dunmore soil were 33 to 38 milliequivalents per 100 grams of clay and they compared favorably

TABLE I

CHEMICAL ANALYSIS RESULTS FOR THE BARDLEY AND GASCONADE SOILS

Soil	Depth Inches	C.E.C.*	Ca	Mg	Na	K	Base* Sat. %	pH (water)	pH ($CaCl_2$)	Phosphorous ppm	O.M. %
		Milliequivalents/100g									
Bardley	0-2	26.44	19.10	3.12	.09	.70	87.02	6.4	5.8	25.20	6.1
	2-9	6.56	.75	1.45	.00	.20	36.92	4.8	4.3	1.89	1.4
	11-15	36.12	13.75	10.30	.11	.60	68.55	4.8	4.3	.42	.6
	15-19	39.45	13.90	10.60	.21	.75	64.54	4.9	4.1	.42	.8
	19-23	42.48	13.75	10.70	.09	.64	59.27	4.6	4.1	.42	.7
	23-29	48.43	19.10	16.22	.10	.95	75.10	4.9	4.5	.56	.7
	29-30	48.73	27.50	18.71	.12	.68	96.47	6.4	6.2	5.53	.9
Gasconade	0-5	27.34	22.50	10.91	.09	.81	100.0	7.3	7.2	7.63	5.2
	5-9	23.51	18.75	10.30	.10	.64	100.0	7.5	7.1	6.16	3.9

*Cation exchange capacity and base saturation computed on the basis of ammonia distillation.

TABLE II

CHEMICAL ANALYSIS RESULTS FOR THE DUNMORE SOILS

Site	Depth Inches	pH (water)	pH ($CaCl_2$)	Sum of Cations C.E.C.	Ca	Mg	Na	K	H $Ca(OH)_2$-$CaCl_2$ Titration (at pH 8.0)	Base Sat. %
				Milliequivalents/100 grams						
Wi 1	24-33	4.2	3.6							
	38-45	4.1	3.5							
	45-54	4.1	3.6							
	54-70	3.9	3.4	23.48	0	1.79	.01	.18	21.5	8.4
Wi 2	26-35	4.1	3.6							
	35-44	4.1	3.5							
	46-55	4.1	3.6							
	56-66	4.0	3.5	27.78	0	1.08	.07	.23	26.4	5.0
	66-75	4.1	3.3							
	76-84	4.0	3.4							
	86-93	4.0	3.4							
	96-106	3.8	3.4							
	106-115	3.8	3.3							
Wi 2_2	21-30	4.2	3.8							
	30-37	4.3	3.6							
	37-46	4.3	3.7							
	46-53	4.3	3.6							
	53-60	4.3	3.6	11.34	0	.56	0	.08	10.7	5.6
	62-71	4.2	3.6							
	71-80	4.4	3.7							
	80-93	4.3	3.6							
Wi 3	36-44	4.4	3.8							
	44-52	4.4	3.7							
	52-62	4.4	3.8	17.25	0	1.37	0	.18	15.7	9.0
	69-76	4.4	3.6							

with those obtained by Miller (22) who considered his values to be low for the amounts of clay present.

Phosphorous and organic matter determinations were made for the Gasconade and Bardley soils only. The results are given in Table I and Figures 14 and 15. The Gasconade soil had a relatively high phosphorous content because of its high organic matter content which, in turn, was due to the presence of a prairie type of vegetation. The data for the Bardley soil compared favorably with the limestone derived soils Miller studied. The results for the Bardley surface horizon were interrelated in much the same manner as the Gasconade soil except that the nature of the forest vegetation resulted in the concentration of these substances in a thinner layer at the surface. The higher concentrations of phosphorous close to the carbonate rock were probably due to the higher pH's in this region which caused the precipitation of the phosphates leached from above.

Particle Size Distribution. The data for particle size distribution in all of the soils studied are presented in Tables III and IV. Contents of coarse fragments of chert and contents of clay are shown to be variables.

The chert contents shown in Table IV emphasize the lower amounts in the Gasconade soil. The Bardley and Dunmore soils are shown to have coarse chert fragments in amounts of from 10 to 36 percent of the volumes of the surface horizons. Amounts in the Bardley soil were greater than in the Dunmore soil. Subsoil amounts of chert were low in all cases.

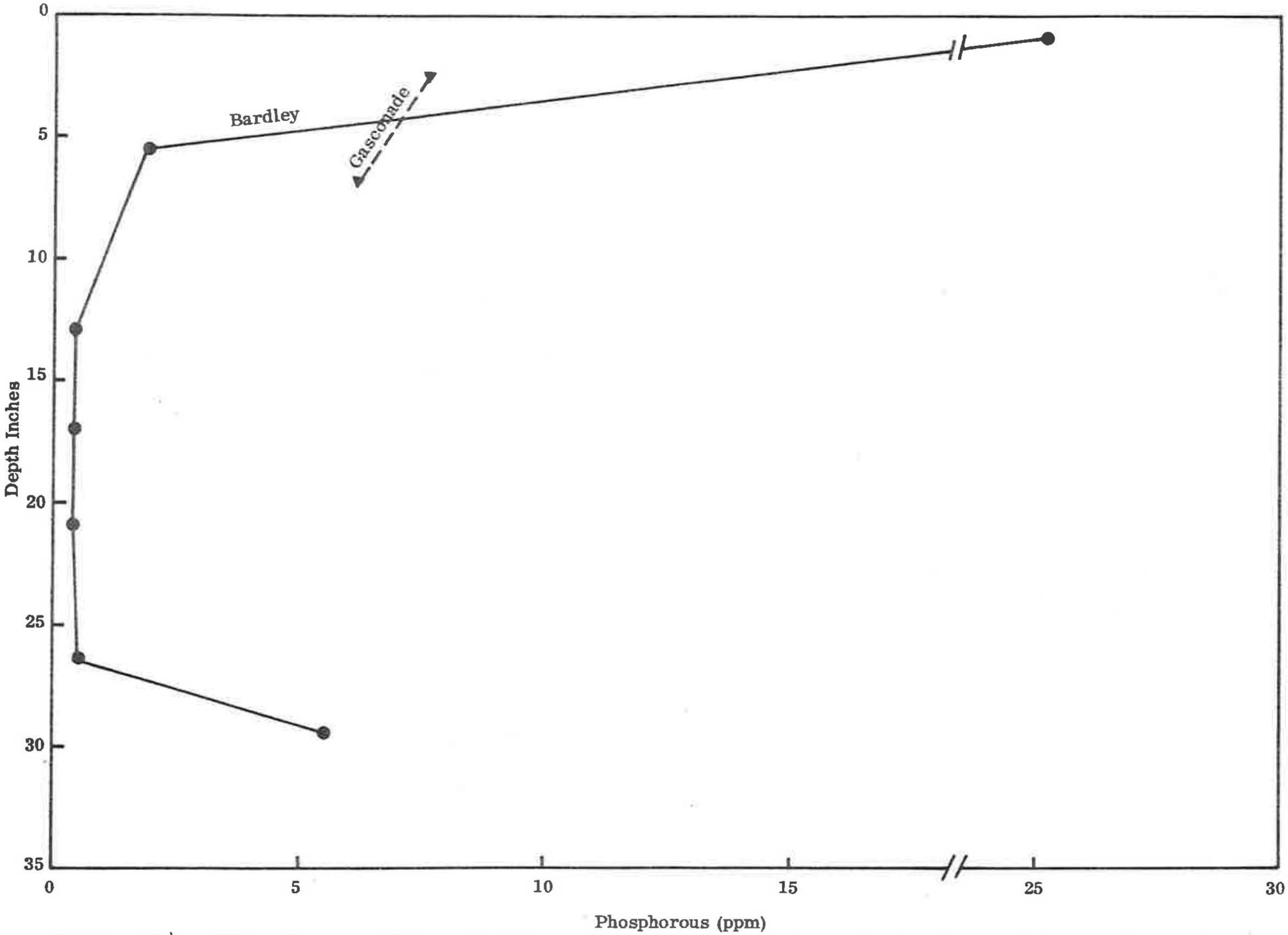

Figure 14. Phosphorous determinations for the Gasconade and Bardley soils at Camdenton

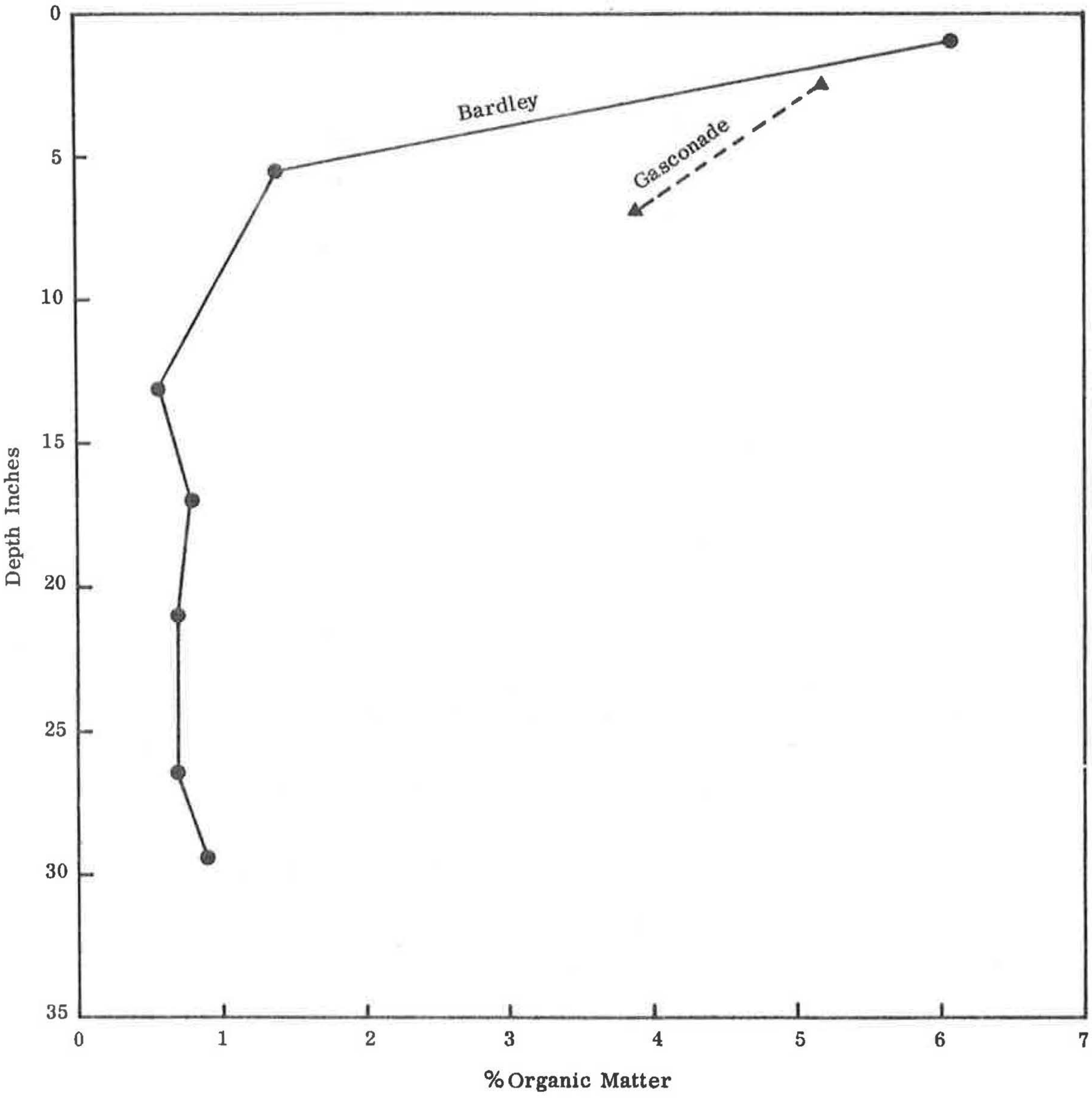

Figure 15. Organic matter determinations for the Gasconade and Bardley soils at Camdenton.

TABLE III

PHYSICAL DETERMINATIONS FOR THE SOIL PITS AT CAMDENTON

Site	Depth Inches	Particle Size Distribution Sand % Wt.	Silt % Wt.	Clay % Wt.	15 Bar Moist. Cont. % Vol.
Gasconade	0-5	29.9	30.1	40.0	17.1
	5-9	43.5	21.5	35.0	15.8
Bardley	0-2	21.1	55.9	23.0	13.5
	2-9	13.8	66.2	20.0	5.6
	11-15	2.1	10.9	87.0	30.9
	15-19	2.5	10.5	87.0	33.3
	19-23	1.0	11.0	88.0	35.5
	23-30	1.4	9.6	89.0	35.5

TABLE IV

PHYSICAL DETERMINATIONS FOR BULK DENSITY SAMPLES FROM CAMDENTON AND WINONA

Soil Name and Site	Depth Inches	Particle Size Distribution			Bulk Density gm/cc	15 Bar Moisture Content		2mm Chert % Vol.
		Sand % Wt.	Silt % Wt.	Clay % Wt.		W/O Chert % Vol.	With Chert % Vol.	
Gasconade								
Gas 1	1-10	26.1	28.9	45.0	.88	17.9	17.1	4.4
Gas 2	1-10	8.1	35.9	56.0	.92	26.3	26.3	.4
Bardley								
Ca 1	1-10				1.33	7.2	5.3	26.7
	20-26				1.26	32.8		
	29-31				1.33	35.8		
	33-37				1.32	37.1		
Ca 2	$1\text{-}10_1$				1.45	9.0	5.8	35.8
	$1\text{-}10_2$				1.35	10.3	7.1	30.6
	18-25				1.10	33.2		
	26-29				1.10	32.1		
Ca 4	10-16				1.14	37.5		
	16-21				1.26	35.2		
Dunmore								
Wi 1	0-12	23.2	61.8	15.0	1.45	6.5	5.0	22.1
	24-33	13.9	9.1	77.0	1.46	35.5		
	38-45	6.7	10.3	83.0	1.44	37.4		
	45-54	17.4	8.6	74.0				
	54-70	23.4	7.6	69.0	1.48	33.0		

TABLE IV -- CONTINUED

Soil Name and Site	Depth Inches	Particle Size Distribution			Bulk Density	15 Bar Moisture Content		2mm
		Sand % Wt.	Silt % Wt.	Clay % Wt.	gm/cc	W/O Chert % Vol.	With Chert % Vol.	Chert % Vol.
Dunmore								
Wi 2_1	0-10	19.8	62.2	18.0	1.51	7.9	6.1	22.6
	26-35	6.9	21.1	72.0	1.39	34.3		
	35-44	5.0	14.0	81.0	1.40	37.3		
	46-55	4.8	24.2	71.0	1.50	35.3		
	56-66	1.0	14.0	85.0	1.42	39.6		
	66-75	2.8	21.2	76.0	1.49	36.4		
	76-84	1.6	26.4	72.0				
	86-93	1.6	31.4	67.0	1.56	37.2		
	96-106	1.2	25.8	73.0	1.46	38.9		
	106-115	1.0	27.0	72.0	1.54	38.0		
Wi 2_2	0-10	25.7	62.3	12.0	1.43	5.3	4.0	25.2
	21-30	8.7	29.3	62.0	1.37	31.9		
	30-37	10.0	33.0	57.0	1.42	30.3		
	37-46	16.0	51.0	33.0	1.67	16.2		
	46-53	16.4	54.6	29.0	1.68	13.8		
	53-60	15.3	51.7	33.0				
	62-71	15.3	50.7	34.0	1.58	16.6		
	71-80	16.7	52.3	31.0	1.71	15.2		
	80-93	18.4	52.6	29.0				
Wi 3	0-10	19.1	67.9	13.0	1.43	6.0	5.4	10.8
	36-44	10.0	42.0	48.0	1.61	26.6		
	44-52	10.5	41.5	48.0	1.53	24.0		
	52-62	10.1	43.9	46.0	1.44	23.9		
	69-76	10.7	40.3	49.0	1.45	24.9		

The concentration of chert at the surface of the Bardley soil was thought to be the result of the weathering of the cherty dolomitic bedrock. As the weathering proceeded at the dolomite surface, geologic erosion at the soil surface removed the finer material. The larger chert rock remained and as a result it was concentrated at the surface. The relatively small amounts of chert in the B horizon were thought to be the result of a decrease in the rate of weathering of the dolomite. As the depth of soil over the dolomite increased, more of the precipitation would have been retained by the soil and released again to the atmosphere through evapotranspiration. Therefore, less would reach the dolomitic bedrock and the rate of decomposition would have been decreased. This meant that the chert rock weathered from the dolomite would remain within the band of high pH for a longer period. Since these conditions favor decomposition of chert, a great deal of it may have been eliminated from the subsurface horizons in this manner, (22, 28).

The clay contents shown in Tables III and IV are presented graphically in Figure 16. The Gasconade soil is shown to have little profile differentiation in clay amounts but to have place to place variations in clay contents that range from 35 to 56 percent. The Bardley and Dunmore soils, on the other hand, have profile differentiations in clay contents that are well illustrated in Figure 16. The Bardley soil has the greatest amount of clay in the subsoil but even so, amounts and profile distribution of clay are similar for the Bardley and Dunmore sites. The low amount of clay at two of the Dunmore sites (Wi 2_2 and Wi 3) emphasize the fact that amounts do

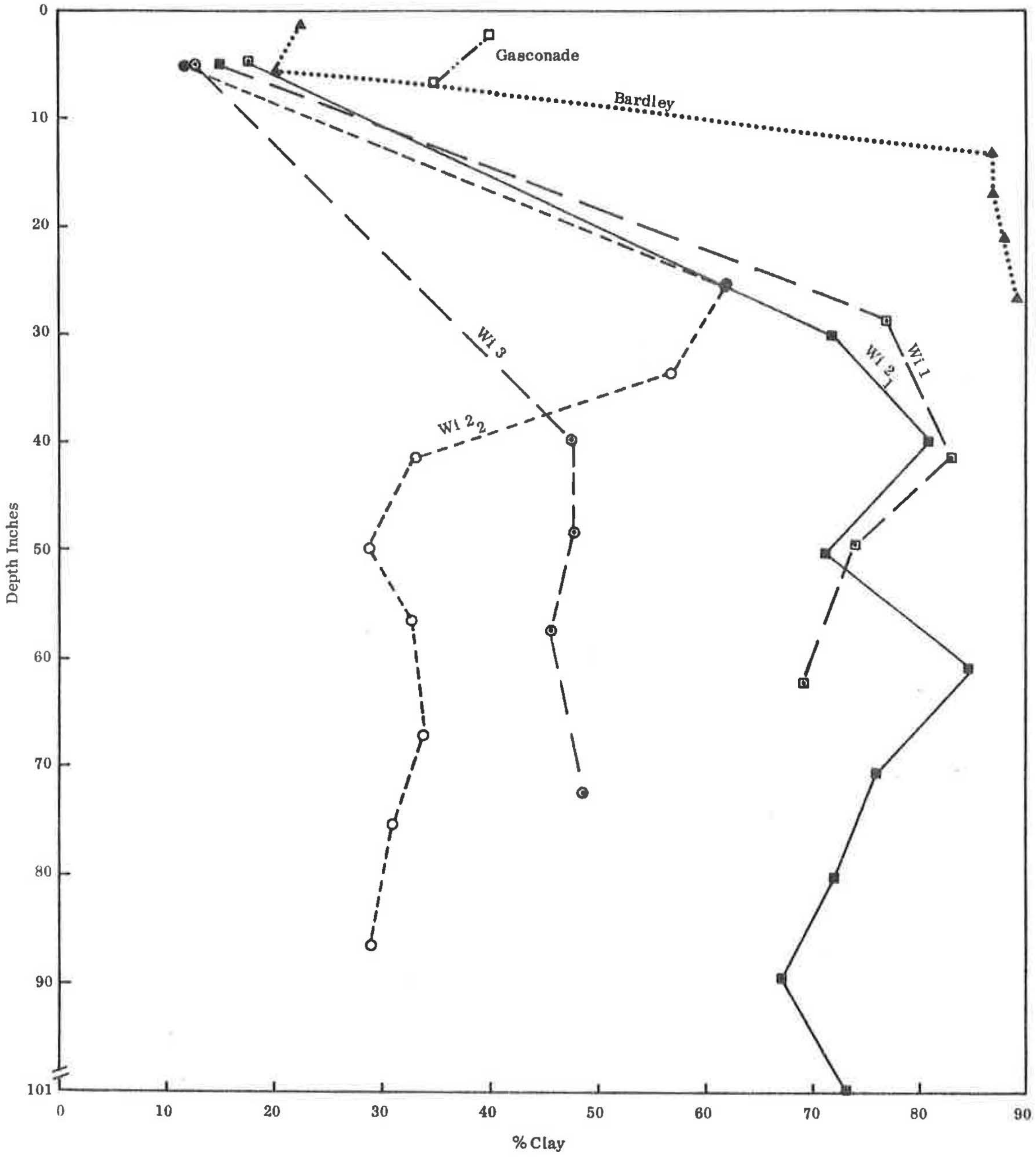

Figure 16. Clay (<0.002mm) distribution in the Gasconade and Bardley soils at Camdenton and the Dunmore soils at sites Wi 1, Wi 2_1, Wi 2_2, and Wi 3 at Winona.

vary from place to place even over short lateral distances (Wi 2_2 and Wi 2_1 were less than 50 feet apart). The low contents of clay in the two cases are thought to be related to localized concentrations of weathered chert which contributed to larger amounts of silt and sand sized particles.

Bulk Densities. Bulk densities for all samples are given in Table IV. These determinations were made in order to arrive at values for valumes of solids and pore space and in order to convert moisture content values from weight percent to volume percent. Much of the significance of the bulk density values will be discussed in later sections. Some general observations can be made, however, if one studies the array of bulk density values shown in Table IV. The bulk densities appear to vary as functions of chert content and of depth to carbonate rock.

High bulk densities are characteristic in those surface horizons with high chert contents. The Gasconade soil represents the low-chert extreme in this relationship and bulk densities were less than 1.0 g/cc. When bulk densities were calculated on a chert-free basis it was shown that both the Bardley and Gasconade surface horizons had densities of 0.8 to 0.9 g/cc. When bulk densities of the surface horizons of the Dunmore soils were calculated in a similar manner they were shown to range from 1.0 to 1.3 g/cc.

The variations in bulk densities appear to have a reasonable order if effects of variable chert contents are removed. It appears from the data that as the depth to carbonate rock varies from 10-50 inches the maximum bulk density of the soil profile increases from .8 to

1.5 g/cc. The Dunmore sites had depths much greater than 50 inches to carbonate rock but bulk densities centered around 1.5 g/cc with a range of 1.4 to 1.7 g/cc. The higher values are in the range of those for soils with fragipans.

Fifteen Bar Moisture Contents. The 15 bar moisture contents are expressed as percentages by volume in Tables III and IV. There are two values given for the surface horizons; one is the moisture content expressed as percent of the less than 2mm fraction, the other is the moisture content expressed as percent of the total soil including the greater than 2mm fraction.

Figure 17 shows the plot of clay content and 15 bar moisture volumes both as percent on a chert-free basis. The regression line suggests that 15 bar moisture volumes can be estimated as being one half of the clay percentage in the range of 10 to 70 percent clay.

Clay Mineralogy. X-ray diffraction patterns of the less than 2 micron fraction of the Bardley, Gasconade, and Dunmore soils are presented in Figures 18 through 24. Five minerals were identified. These were quartz, illite, montmorillonite, kaolinite, and vermiculite. Quartz was identified on the basis of peaks indicating spacings of 4.26 and 3.34 angstroms. Illite was identified by the appearance of a peak corresponding to the 10 angstrom spacing which was not affected by cation saturation, heat treatments, or glycolation. Montmorillonite was identified when the potassium saturated sample produced peaks corresponding to a 10-13 angstrom spacing, which collapsed to 10 angstroms upon heating. Expansion to 14 angstroms when magnesium saturated and to 17 angstroms when glycolated confirmed

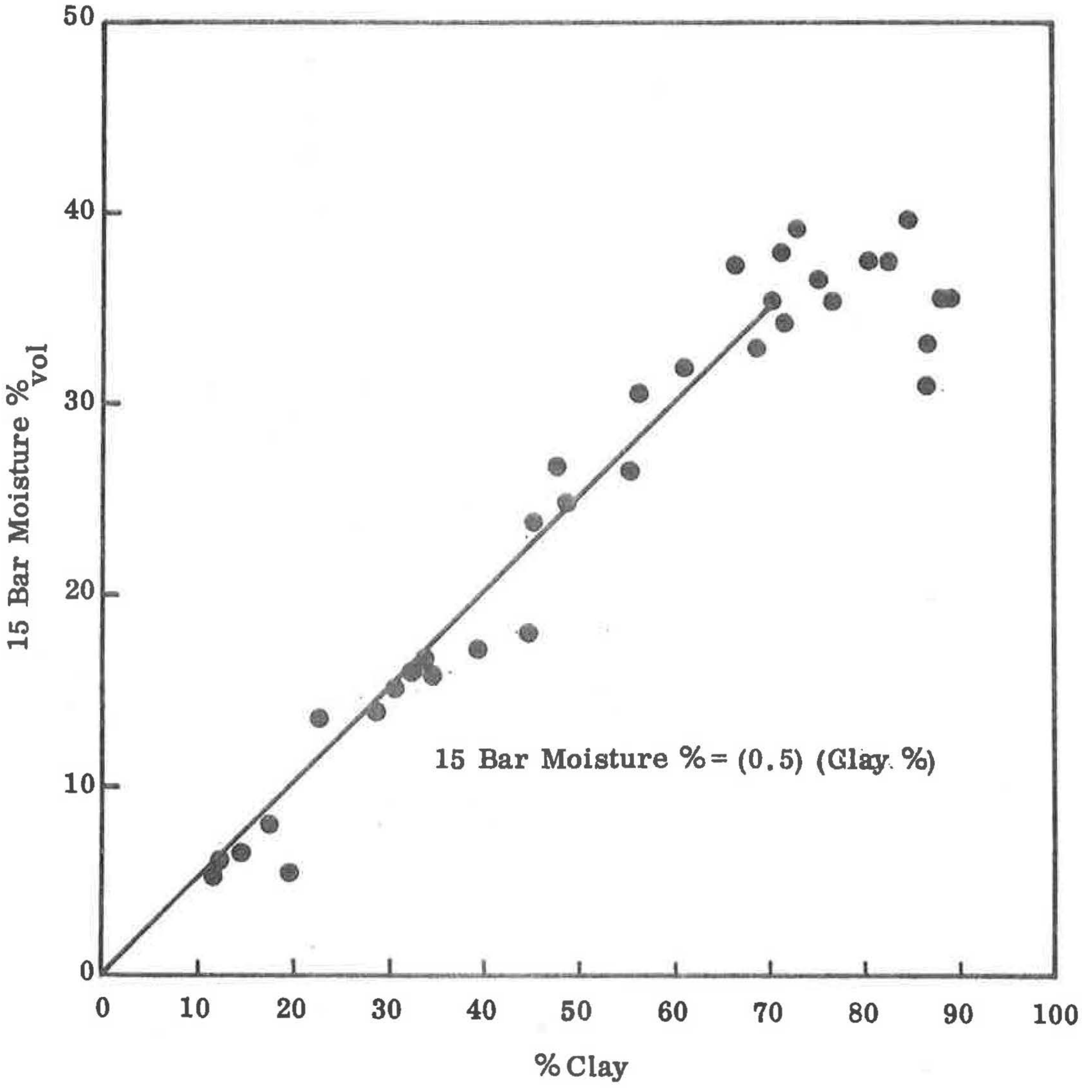

Figure 17. Regression of 15 bar moisture content on percent clay for all of the samples from Camdenton and Winona.

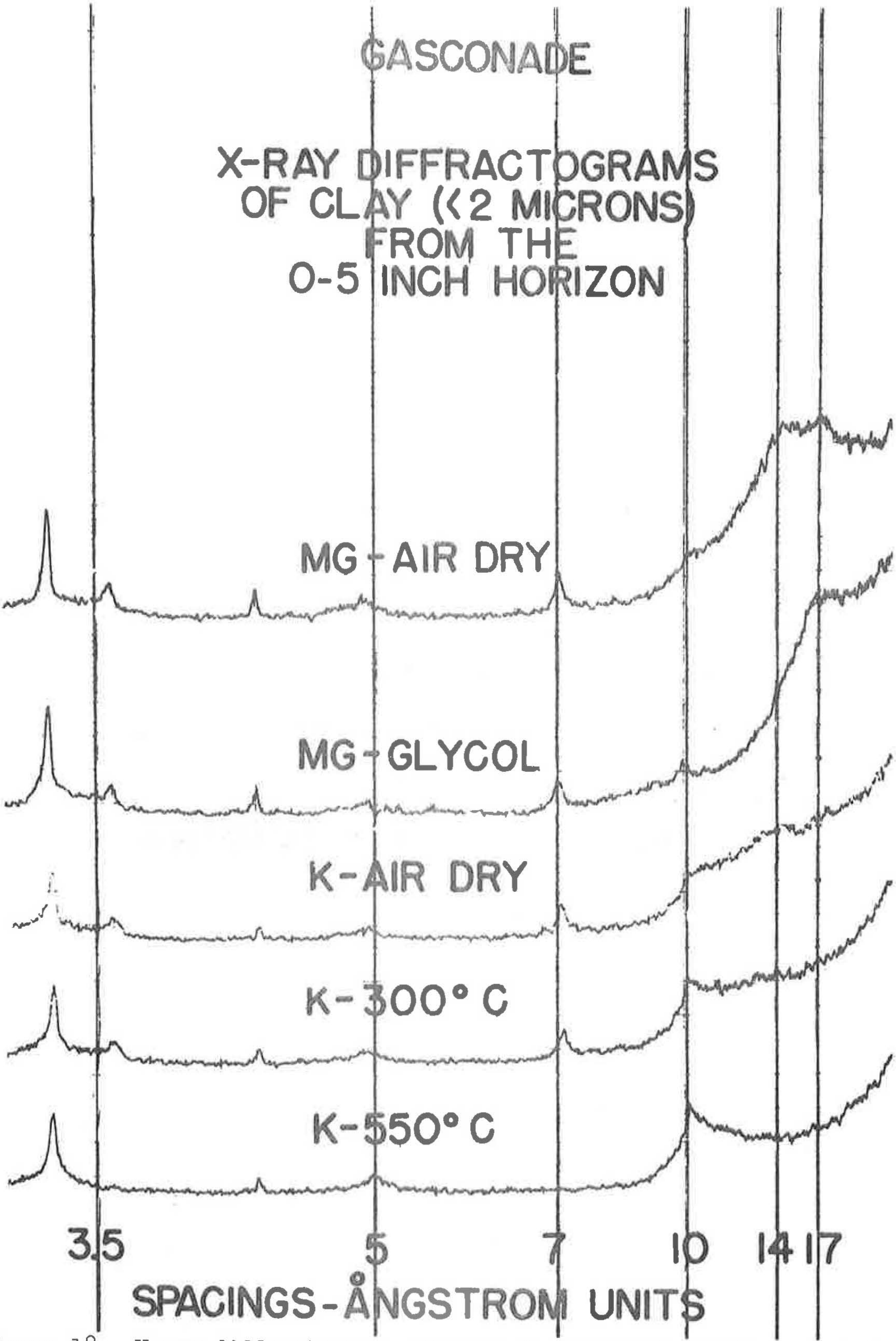

Figure 18. X-ray diffractograms after each treatment of the oriented clays (<0.002mm) from the 0-5 inch horizon of the Gasconade soil.

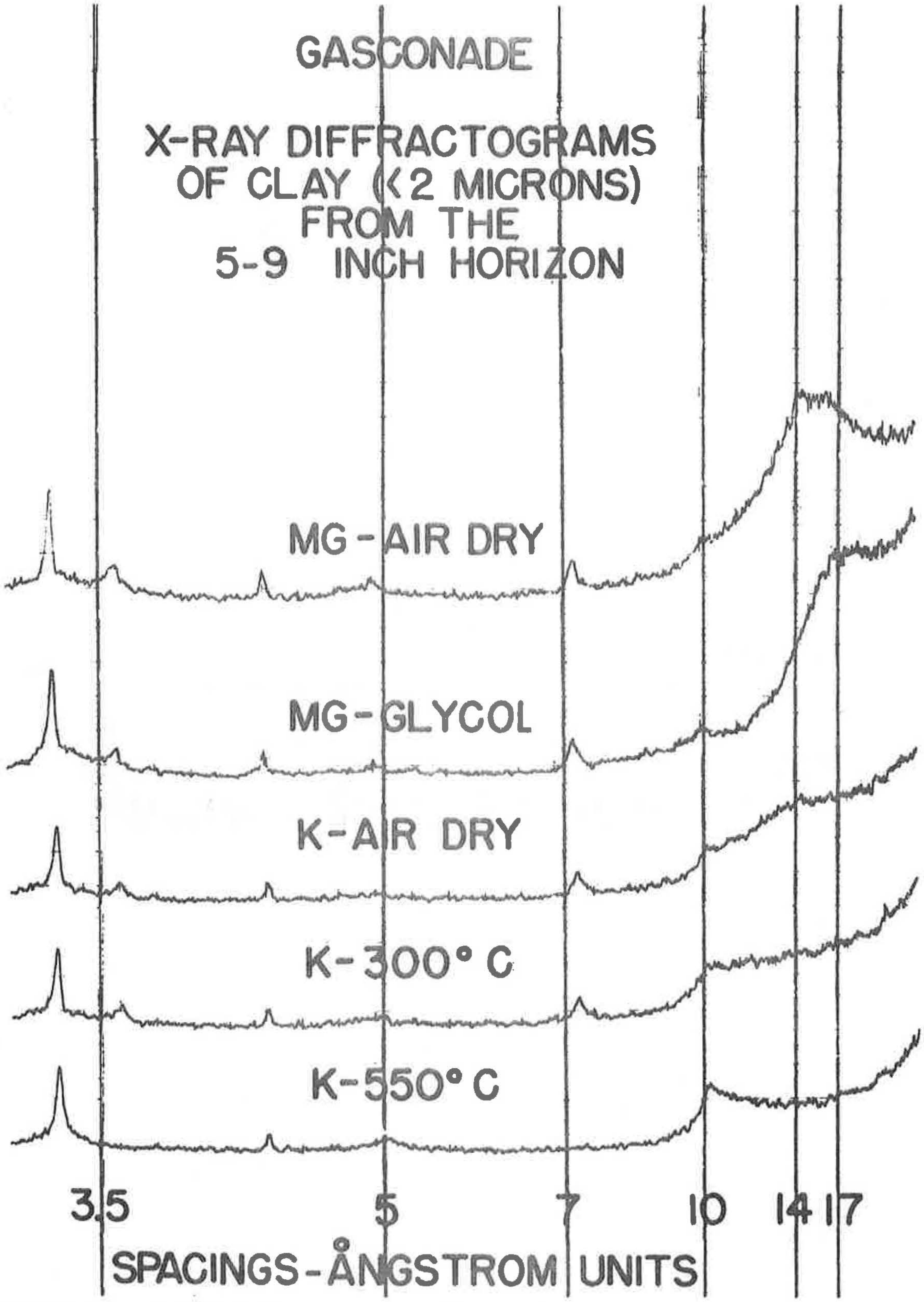

Figure 19. X-ray diffractograms after each treatment of the oriented clays (<0.002mm) from the 5-9 inch horizon of the Gasconade soil.

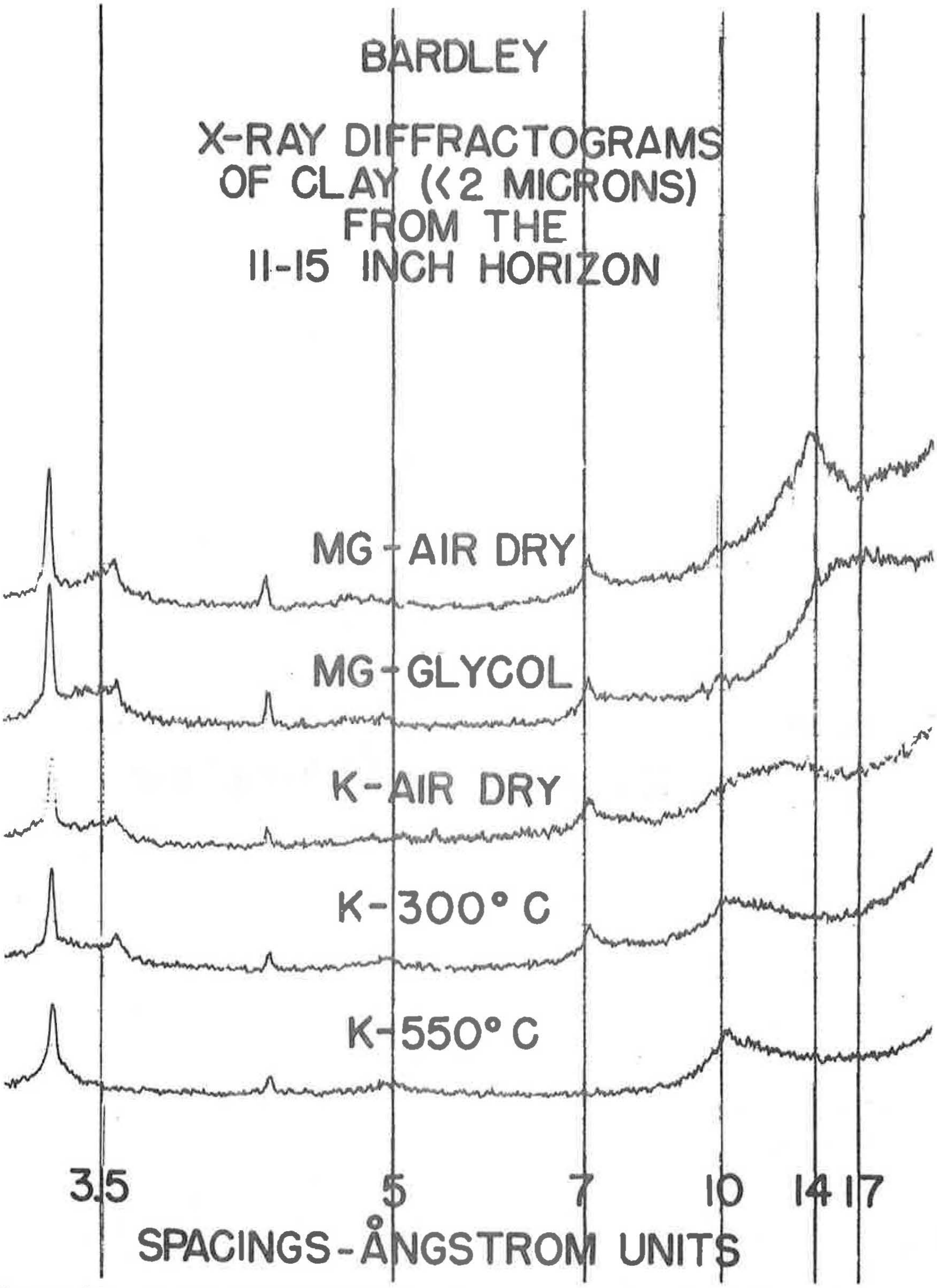

Figure 20. X-ray diffractograms after each treatment of the oriented clays (<0.002mm) from the 11-15 inch horizon of the Bardley soil.

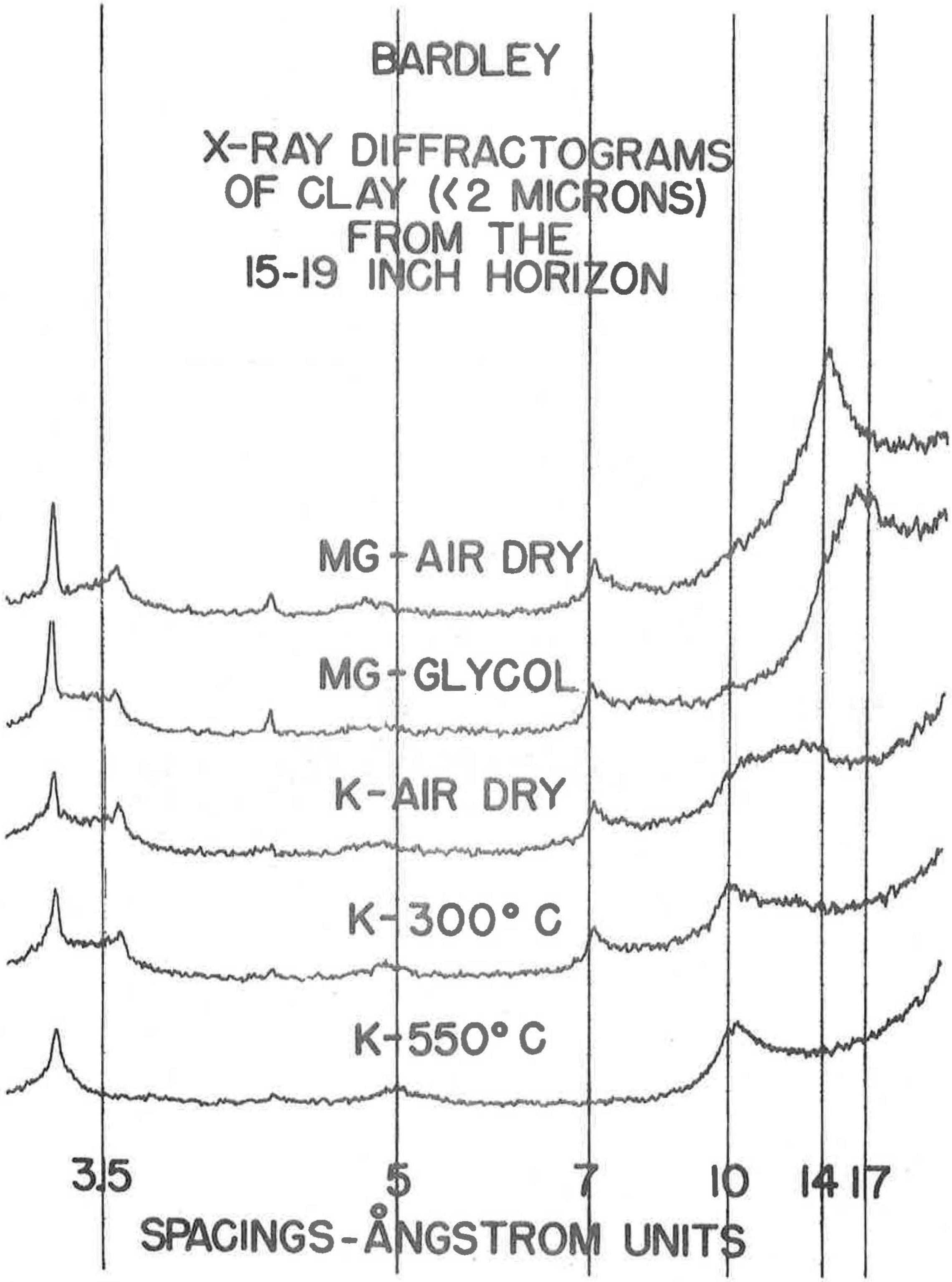

Figure 21. X-ray diffractograms after each treatment of the oriented clays (<0.002mm) from the 15-19 inch horizon of the Bardley soil.

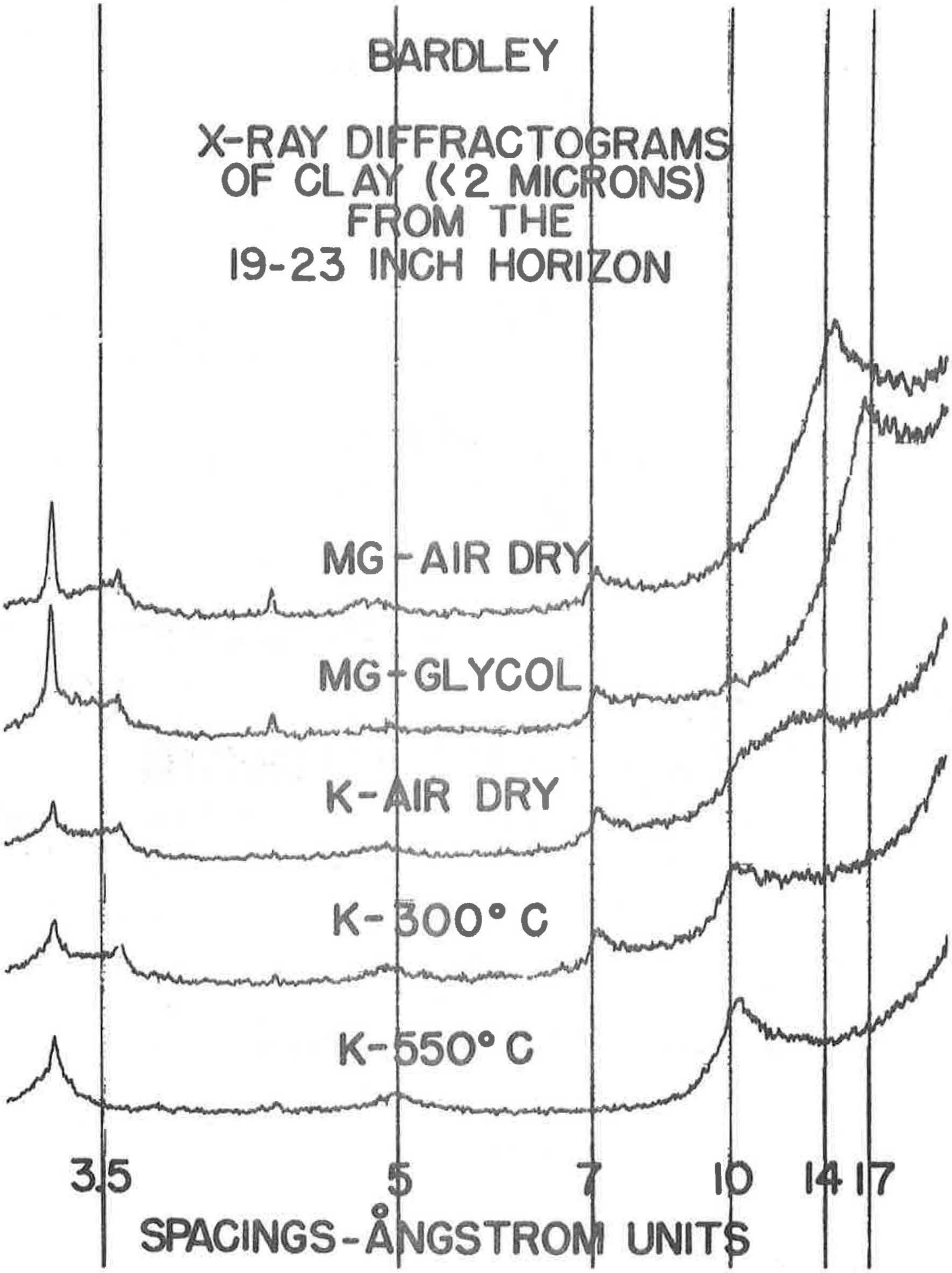

Figure 22. X-ray diffractograms after each treatment of the oriented calys (< 0.002mm) from the 19-23 inch horizon of the Bardley soil.

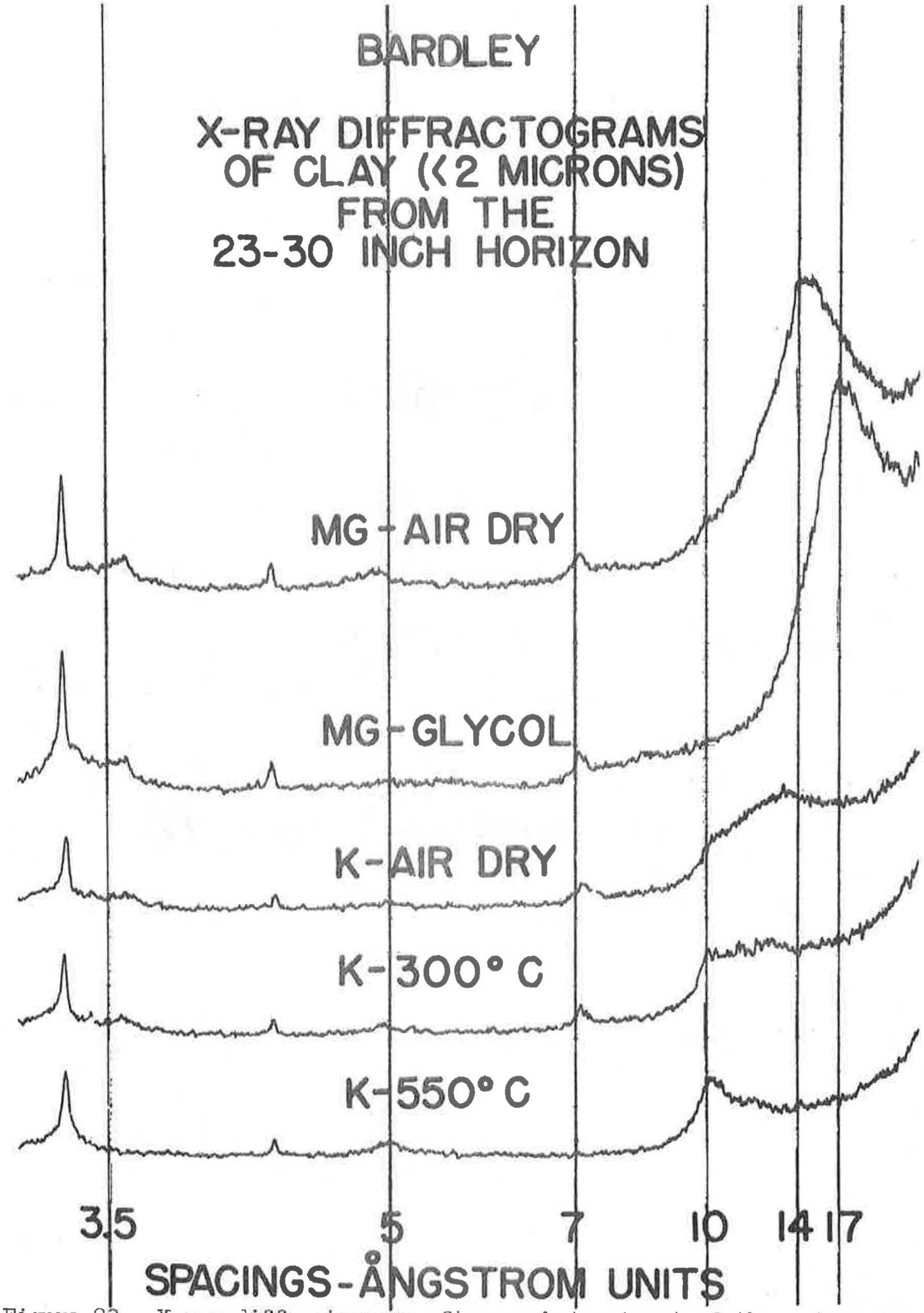

Figure 23. X-ray diffractograms after each treatment of the oriented clays (<0.002mm) from the 23-30 inch horizon of the Bardley soil.

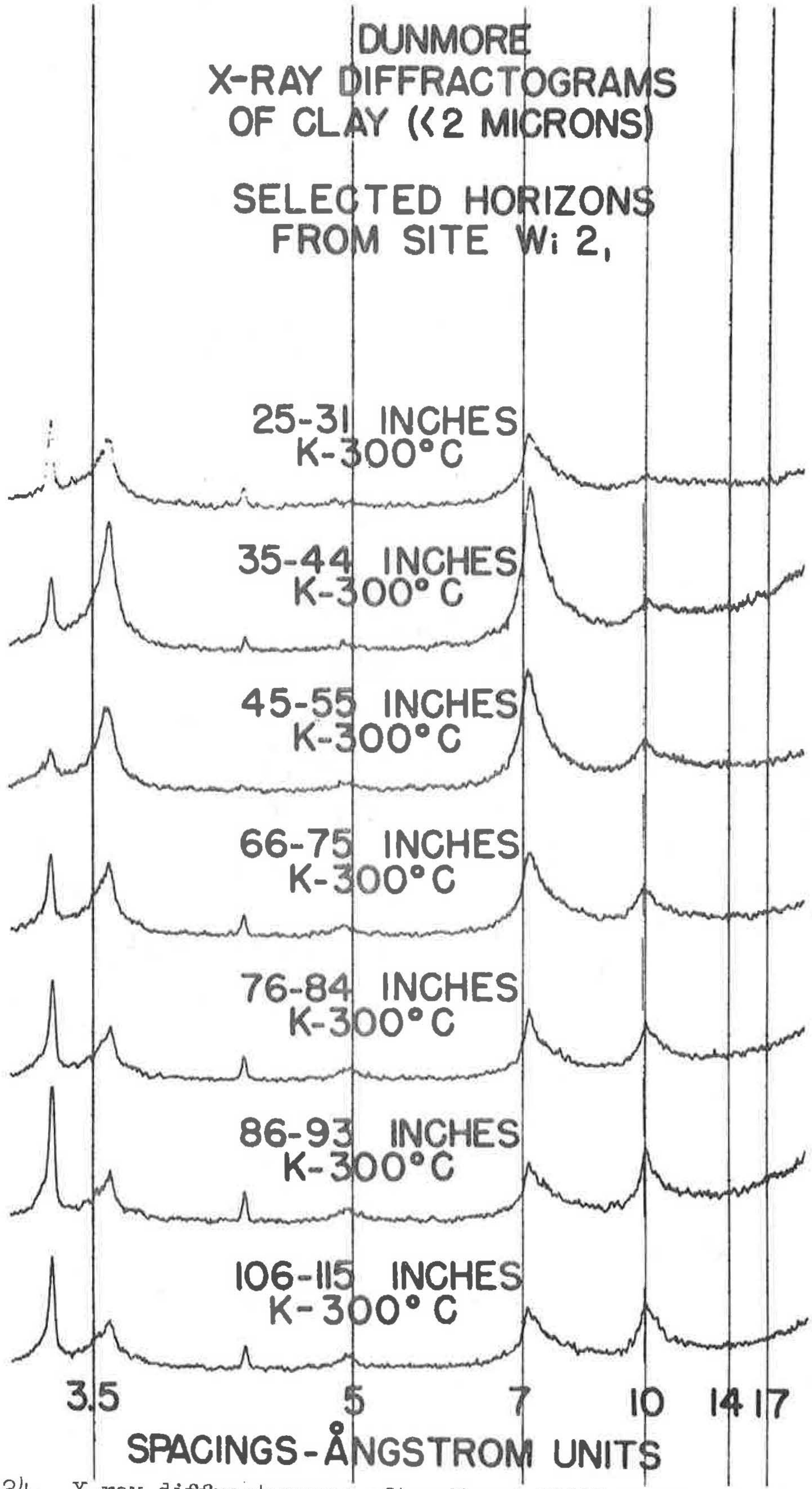

Figure 24. X-ray diffractograms after K and 300°C treatment of oriented clays (<0.002mm) from selected horizons of the Dunmore soil.

the presence of montmorillonite. A 7 angstrom first order and a 3.5 angstrom second order peak denoted the presence of kaolinite if it disappeared after the sample was heated to 550°C and was unaffected by other treatments. A peak at 14 to 15 angstroms which collapsed to 10 angstroms upon heating, but which remained stable upon magnesium saturation and glycolation, was identified as vermiculite.

It appears that depth to carbonate rock has a definite influence upon the clay mineralogy. The shallow Gasconade and Bardley soils have very little illite or kaolinite in the clays of the subsoils. The predominant mineral is an expanding lattice montmorillonite-like mineral with traces of 14 angstrom and 10 angstrom minerals. The deeper Dunmore profile has prominent kaolinite amounts throughout with lesser amounts of interstratified illite, montmorillonite, and 14 angstrom minerals. Illite was most prominent in deeper horizons of the Dunmore, and 14 angstrom minerals were most prominent near the surface. The mineralogy of the Dunmore series compared favorably with that found by Miller in several limestone derived soils.

It is not surprising that varying depths to carbonate rock should be related to differing mineralogies. The process of mineral formation envisioned by Scrivner and Miller (28, 22) was related to the carbonate rock. They concluded from their data that illite was the predominant clay mineral in the limestone bedrock and that this mineral was altered to a form of an expandable lattice mineral within several inches of the bedrock. Continued alteration was thought to result in the formation of a 14 angstrom mineral at a greater distance above the limestone. The prominence of kaolinite throughout the profile was thought to be largely the result of a destruction of clay minerals at the surface, with ultimate recrystallization of kaolinite in the vicinity of the carbonate bedrock.

The shallow Gasconade and Bardley soils of this study appear to be at the point in evolution where most of the illites have undergone alteration to montmorillonite minerals. The deeper Dunmore soils of this study have evolved to the point that much of the 2:1 lattice minerals have been destroyed and kaolinite, through the process of recrystallization, has become a prominent mineral.

Depth to Bedrock. Figure 25 shows that the depths to bedrock at the Camdenton site ranged from greater than 9 feet to outcrops of carbonate rock. The positions and depths to bedrock of Ca 1, Ca 2, and Ca 4 are also shown. The depths to carbonate rock at the Winona sites were not determined. They were thought to be greater than 10 feet, however, and were known to exceed 6 feet at sites Wi 1, Wi 2_2, and Wi 3, and 9 feet at Wi 2_1. The Baxter and Talbott soils studied by Miller were about 4 feet deep while the Clarksville and Nixa soils were almost 10 feet deep. Therefore, the samples taken from the Camdenton site were from soils shallower than those studied by Miller while those from the Winona sites more closely approached the depths of the Clarksville and Nixa soils.

The data used in Figure 25 were obtained using the hydraulic auger. Results from the seismic survey were found to be incorrect because of two factors; the shallow depths to bedrock and the high bulk densities at the surface of the soil. When the seismograph was used over shallow depths to bedrock it was necessary to use the hammer within 10 feet of the geophone. At these short distances an

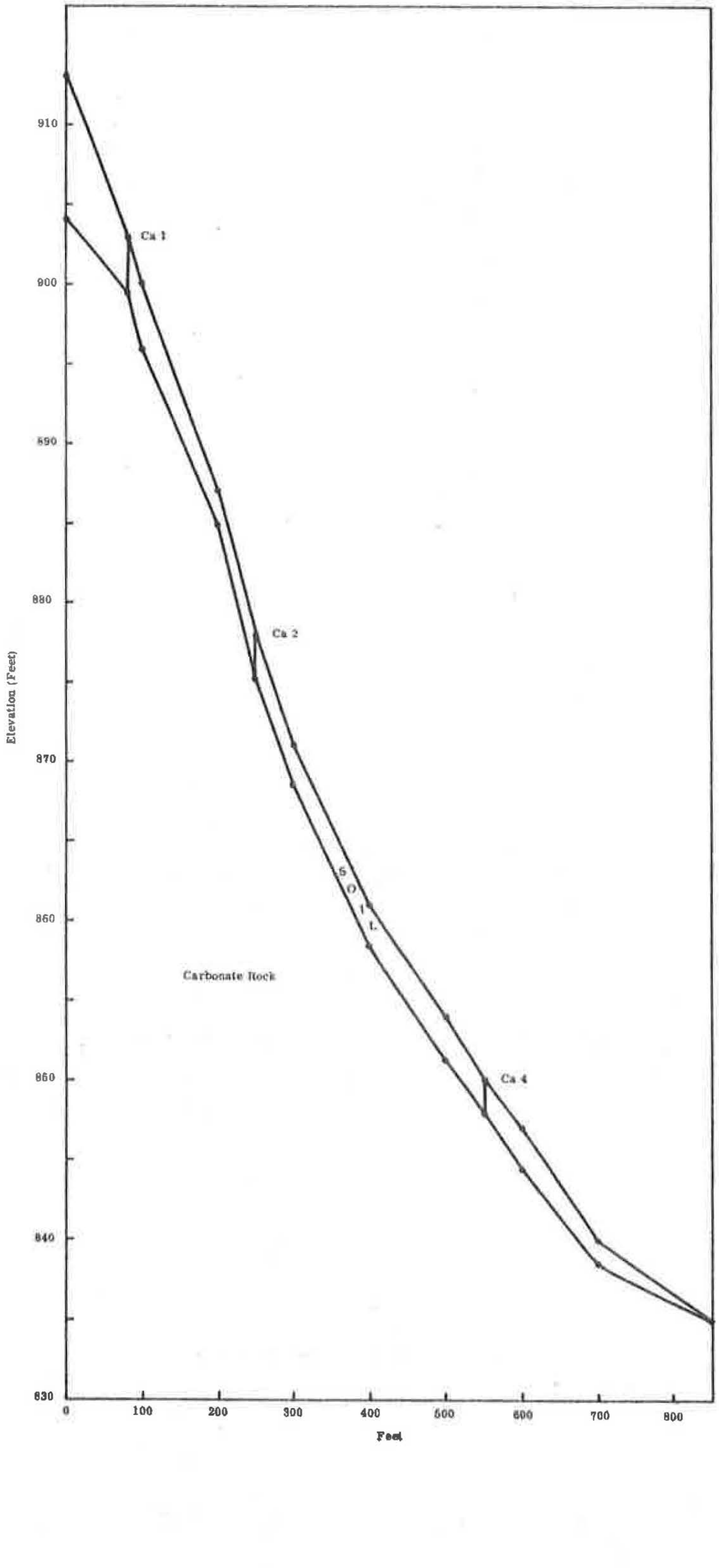

Figure 25. Cross sectional drawing of the Camdenton site.

resembled the characteristics of these other limestone derived soils. Important differences were the cation exchange capacities, the clay mineralogy, subsoil bulk densities, and depths to carbonate rock.

The determinations made for the Dunmore soils indicated that they were very similar to the limestone derived soils studied by Miller.

SOIL MOISTURE DETERMINATIONS

The differences between the observed field capacities and the wilting point estimates were used to calculate the available moisture storage capacities of the Gasconade, Bardley, and Dunmore soils. Data for the field capacities, wilting points, and available moisture storage capacities will be presented and discussed in that order.

Field Capacity Estimates. The observed field capacities (OFC) of the surface horizons were obtained gravimetrically. In the case of the Bardley and Gasconade soils they were sampled in early June, two days after a 1.30 inch rain. The Dunmore soils were sampled in late July and had to be moistened artificially.

A method was devised whereby it was possible, after the soil had been moistened, to determine when moisture movement had essentially ceased and the soil was ready to be sampled. To accomplish this a berm was formed in the shape of a circle and a tensiometer was installed in the center at about 6 inches depth. Enough water was added to bring the surface 12 inches to an estimated field capacity. The wetted portion was then covered with polyethylene and cardboard and left to equilibrate (Figures 26 and 27). Ordinarily, changes in soil moisture suction with time would have been recorded until such air wave generated by the hammer distorted the signals from the shock wave; and, as a result, incorrect velocity determinations were made. This distortion could probably have been eliminated by placing a protective device around the geophone but the error caused by a second factor persuaded the author to use the power auger instead.

The second source of error was the high bulk density at the surface of the Bardley. This was a deviation from the basic assumption necessary for the use of the seismograph; namely that the layers increase in density with depth. As was noted in the section on bulk density, the surface horizons of the Bardley soil had higher bulk densities than the subsurface layers. If the standard procedure for calculating the depth to a denser layer (i.e., bedrock) is followed this depth is exaggerated. Therefore, the decision was made to use the power auger instead of attempting to make the corrections necessary to obtain accurate data from the seismograph.

Summary of the Soil Characterization. Some general observations can be made concerning the soils used in this study as related to other soils developed in carbonate rock residuum.

The Gasconade soil was obviously very different from all of the others because of its relative youth, shallow depth to carbonate rock, and type of vegetative cover.

The Bardley soil displayed some important similarities to the Dunmore soils and the soils studied by Miller. The concentration of chert, high bulk densities, and silt loam textures of the surface horizons; the red, high clay B horizon; and the base saturation, pH, organic matter, and phosphorous data for the Bardley very much

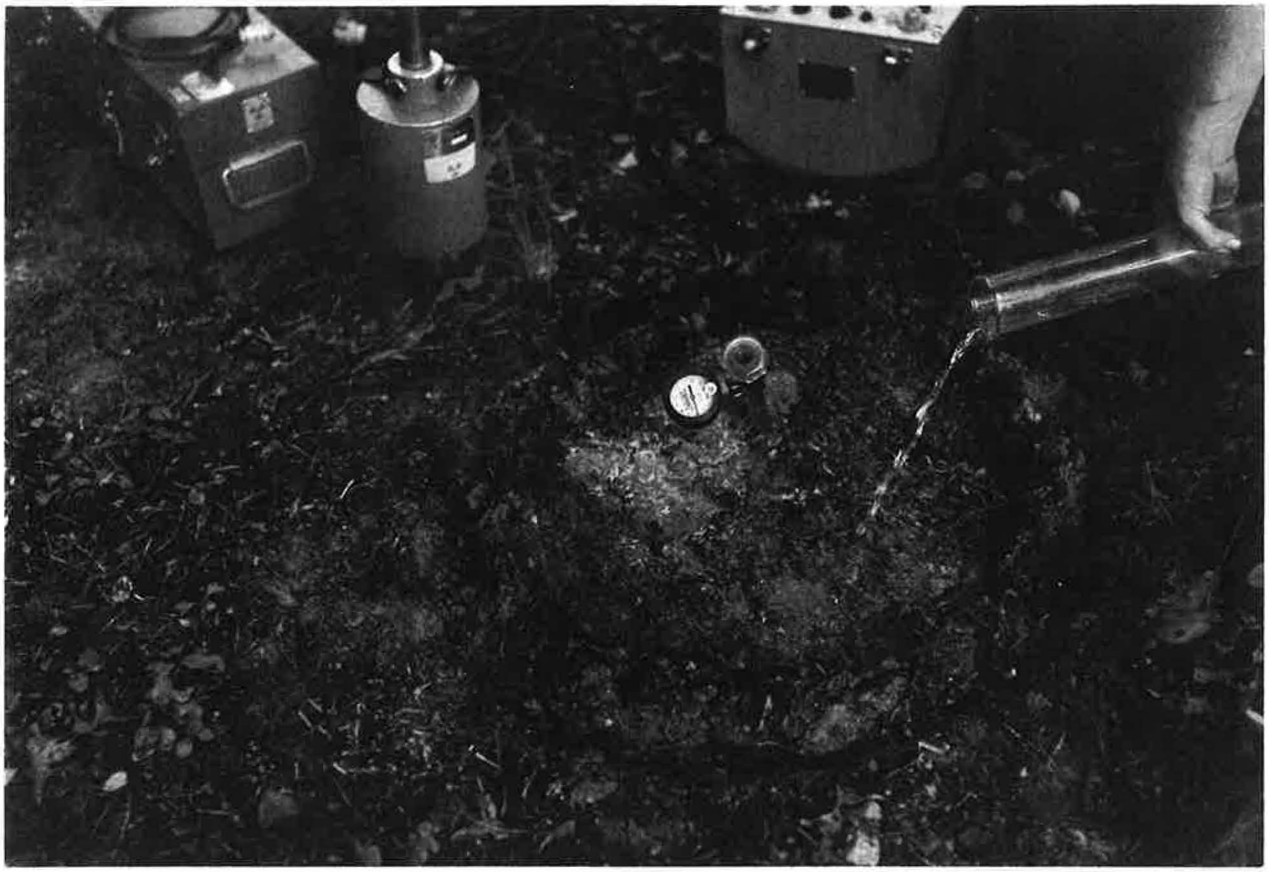

Figure 26. A tensiometer is installed in the soil within a berm and water is being added in order to bring the soil within the berm to field capacity.

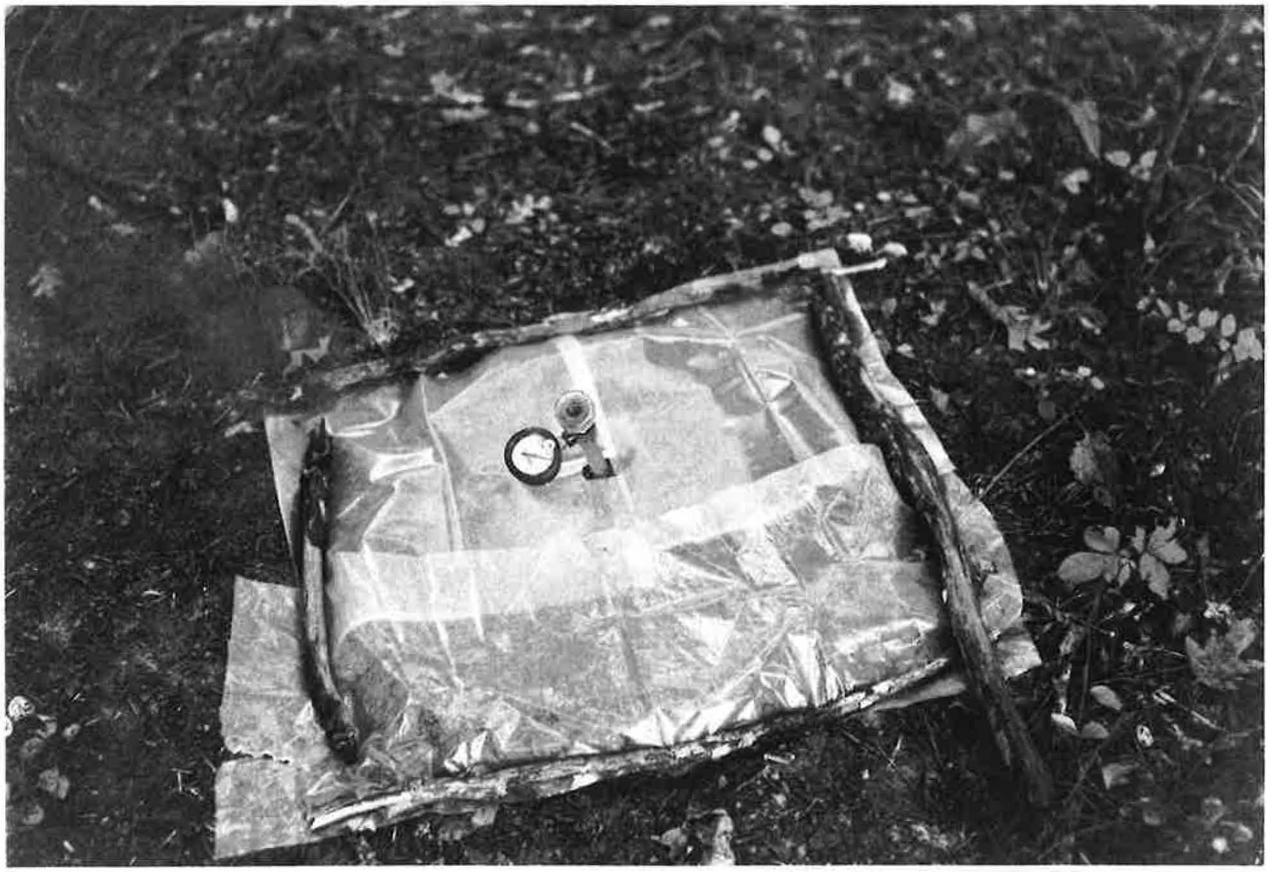

Figure 27. The sampling site prior to being covered with cardboard.

changes were small. However, because of time limitations and the distances between sites, a previously determined curve of soil moisture suction over time was used to estimate the equilibration time. This curve indicated that the soils should be sampled 20-23 hours after saturation. The tensiometers were read at least twice over a 4 hour period prior to sampling to ensure that no significant changes were taking place. Then the tensiometer readings were recorded and converted to bars of suction, and the soil moisture contents were determined for each site.

The OFC's for the surface horizons, both with and without greater than 2mm chert contents, are given in Table V. The values with the greater than 2mm chert included seemed to be related to the textural class. When the greater than 2mm chert contents were calculated out by attributing all of the moisture to the less than 2mm fraction, the range of the moisture contents widened and the values demonstrated a lesser relationship to texture or chert contents.

The OFC's of the subsurface horizons were determined from neutron probe moisture readings which were taken in the winter of 1968, after rain had recharged the soil moisture, and again in the spring of 1969. Data are given in Table VI. The winter and spring values at Camdenton agree very well for sites Ca 1 and Ca 2 which suggests that these moisture measurements are valid estimates of the observed field. capacity. Site Ca 4 was wetter in the spring than it had been in the winter but this was probably due to lateral water flow from upslope.

TABLE V

PHYSICAL CHARACTERISTICS OF THE SURFACE HORIZONS OF THE GASCONADE, BARDLEY, AND DUNMORE SOILS

Site	Textural Class	Observed Field Capacity % by Volume		2mm Chert Content % Vol.	Soil Moist. Tension at Field Capacity Bars
		With Chert	W/O Chert		
Gasconade					
Gas.	Clay	27.7	29.1	4.4	
Gas.	Clay	37.6	37.6	.4	
Bardley					
Ca 1	Cherty silt loam	21.4	29.5	26.7	
Ca 2_1	Cherty silt loam	19.1	31.1	35.8	
Ca 2_2	Cherty silt loam	20.0	29.1	30.6	
Dunmore					
Wi 1	Cherty silt loam	19.5	24.8	22.1	.22
Wi 2_1	Cherty silt loam	22.7	29.4	22.6	.27
Wi 2_2	Cherty silt loam	23.9	31.9	25.2	.12
Wi 3	Silt loam	23.3	26.1	10.8	.41

TABLE VI

SUBSURFACE OBSERVED FIELD CAPACITIES AS MEASURED WITH THE NEUTRON PROBE

Soil Name and Site	Depth Inches	Date		Soil Name and Site	Depth Inches	Date	
		12-14-68	4-13-69			12-14-68	5-28-69
		% by Volume				% by Volume	
Bardley				Dunmore			
Ca 1	12	19.1	20.0	Wi 2_1	12	34.7	34.0
	18	25.0	25.4		18	41.8	38.6
	24	38.8	41.4		24	42.7	41.2
	30	37.7	38.2		30	45.3	44.1
	36	42.6	44.1		36	44.7	45.0
					42	45.4	44.3
					48	41.5	43.0
Ca 2	12	20.9	20.7		54	44.8	44.9
	18	44.1	43.9		60	45.2	43.9
	24	46.8	45.1		66	41.2	41.6
					72	40.2	40.7
					78	41.2	41.5
Ca 4	12	43.2	45.4		84	40.7	41.2
	14	43.1	Water		90	40.7	41.2
					96	40.2	41.5
					102	39.6	Water

TABLE VI -- CONTINUED

Soil Name and Site	Depth Inches	Date 12-14-68	Date 5-28-69	Soil Name and Site	Depth Inches	Date 12-14-68	Date 5-28-69
		% by Volume				% by Volume	
Dunmore				Dunmore			
Wi 1	12	28.5	29.4	Wi 2_2	12	27.8	29.1
	18	39.7	37.1		18	37.9	39.0
	24	42.3	38.9		24	41.8	42.7
	30	40.1	38.9		30	41.8	40.6
	36	41.8	41.2		36	40.3	41.8
	42	40.3	38.5		42	32.6	31.5
	48	41.3	41.8		48	30.1	30.4
	54	42.2	39.7		54	31.0	31.9
	60	Water	Water		60	30.2	31.5
	62				68	29.8	Water
Wi 3	12	26.2	19.4				
	18	26.6	22.4				
	24	25.7	23.5				
	30	29.2	30.1				
	36	33.4	33.7				
	42	35.0	34.8				
	48	35.4	35.5				
	54		36.5				
	60	Water	35.3				
	66		36.5				

The moisture determinations for the upper layers of the Winona sites were lower in the spring than they had been the preceding winter. This was thought to be due to the removal of some moisture from these layers by the vegetation. There was good agreement between the winter and spring determinations for the deeper layers.

The December 14, 1968 determinations were used as the OFC's because measurements on that date were at a maximum throughout all profiles at both Winona and Camdenton.

Wilting Point Estimates. Minimum field contents (MFC) of moisture as determined with the neutron moisture probe were the basic source of estimates of wilting points. Values of MFC's are presented in Table VII. Data in that table show that the MFC's observed at three different times during two growing seasons deviated very little. The deviation was least at Winona sites Wi 1 and Wi 3 where subsoil moisture contents remained essentially constant from August 12 to September 4, 1969, a period during which there was no significant precipitation except on September 3. This lack of deviation, as well as the similarity between the 15 bar moisture contents and the MFC's at sites Ca 2 and Wi 1, led to confidence in the MFC's as estimates of the wilting point. Therefore, the MFC's reported in Table VII will be used as estimates of the lower limit of AMSC's as discussed in later sections. There will be two kinds of exceptions to this method of estimates. The first will be in the surface horizons where neutron probe moisture readings were not made and hence MFC's were not determined. The second kind of exception occurred in the subsoils at sites Wi 2_1 and Wi 2_2,

TABLE VII

SUBSURFACE MINIMUM FIELD CONTENTS AS MEASURED WITH THE NEUTRON PROBE

Site	Depth Inches	Date			Site	Depth Inches	Date		
		9-13-68	8-10-69	9-2-69			9-13-68	8-12-69	9-4-69
		% by Volume					% by Volume		
Ca 1	12	10.8	11.5	11.6	Wi 2_1	12	30.0	24.7	27.5
	18	18.0	19.8	19.1		18	37.0	35.5	35.8
	24	31.7	33.8	33.1		24	38.7	37.6	37.4
	30	30.7	31.8	31.2		30	40.3	36.3	35.4
	36	33.3	36.2	35.2		36	43.0	40.1	38.8
						42	43.8	41.6	41.8
						48	40.7	38.0	37.3
Ca 2	12	12.3	12.3	13.5		54	44.6	42.2	42.5
	18	32.7	33.8	33.6		60	44.8	44.3	43.6
	24	35.5	35.7	35.4		66	40.7	40.3	39.7
						72	40.3	40.4	38.3
						78	40.2	40.0	39.2
Ca 4	12	No reading	33.0	35.0		84	40.5	40.7	39.3
	14		43.2	35.5		90	41.6	41.6	40.3
						96	41.0	41.4	39.7
						102	39.7	40.2	38.8

TABLE VII -- CONTINUED

Site	Depth Inches	Date			Site	Depth Inches	Date		
		9-13-68	8-12-69	9-4-69			9-13-68	8-12-69	9-4-69
		% by Volume					% by Volume		
Wi 1	12	21.3	21.6	22.7	Wi 2_2	12	25.3	20.7	27.5
	18	34.2	34.6	34.9		18	36.6	33.5	36.7
	24	36.8	38.0	37.4		24	40.4	38.2	40.2
	30	35.4	35.8	36.3		30	39.8	37.1	38.2
	36	36.3	36.9	37.0		36	39.2	36.8	37.9
	42	36.7	35.6	35.0		42	29.8	26.3	26.7
	48	37.1	37.5	36.2		48	28.4	25.7	25.0
	54	38.4	38.2	37.1		54	29.3	27.9	27.2
	60	34.4	35.2	35.1		60	28.1	27.7	26.7
	62	37.5	38.4	37.7		66	28.0	28.0	26.7
						68	27.2	27.3	27.0
Wi 3	12	12.7	12.4	15.1					
	18	17.5	17.5	18.5					
	24	18.0	17.6	18.4					
	30	22.6	21.7	22.3					
	36	28.4	28.1	27.9					
	42	30.5	30.5	29.8					
	48	30.6	29.9	29.8					
	54	30.8	30.4	30.2					
	60	29.1	29.0	28.9					
	66	29.9	29.4	29.2					

where the partial plant canopy failed to reduce the moisture content to the wilting point. In both exceptions the 15 bar moisture contents will be used as the lower limit of the AMSC's.

Available Moisture Storage Capacity. Most of the data used in the final estimate of available moisture storage capacity are presented graphically in Figures 28 through 33. Profile volumes of solids and pore space are graphed, and superimposed upon them are percentages of moisture by volume at the OFC, MFC, and 15 bar moisture content. The area between the OFC curves and the MFC curves or the 15 bar moisture curves is equal to the available moisture storage capacity (AMSC) of the soil. Curves were not drawn for the Gasconade and Ca 4 sites because of the shallow depths to carbonate rock at these locations.

The final estimates of the AMSC's are presented in Table VIII. The depth increments shown were based upon similarities in profile features and the data for each depth increment represents an average of the observations for that increment.

The AMSC's in general were higher at the surface than they were in the subsoils because of textural differences. However, larger bulk densities, associated with greater depths to bedrock, appeared to have influenced the AMSC's of the subsoils. As a result, soils with depths to carbonate rock greater than 40 inches had lower AMSC's on a per unit depth basis than shallower soils. Comparison of the AMSC's of the Gasconade, Ca 4, Ca 2, Ca 1, and Wi 1 with their respective depths to bedrock and associated bulk densities will illustrate this. All of those sites had clay textured subsoils, which are the usual case in

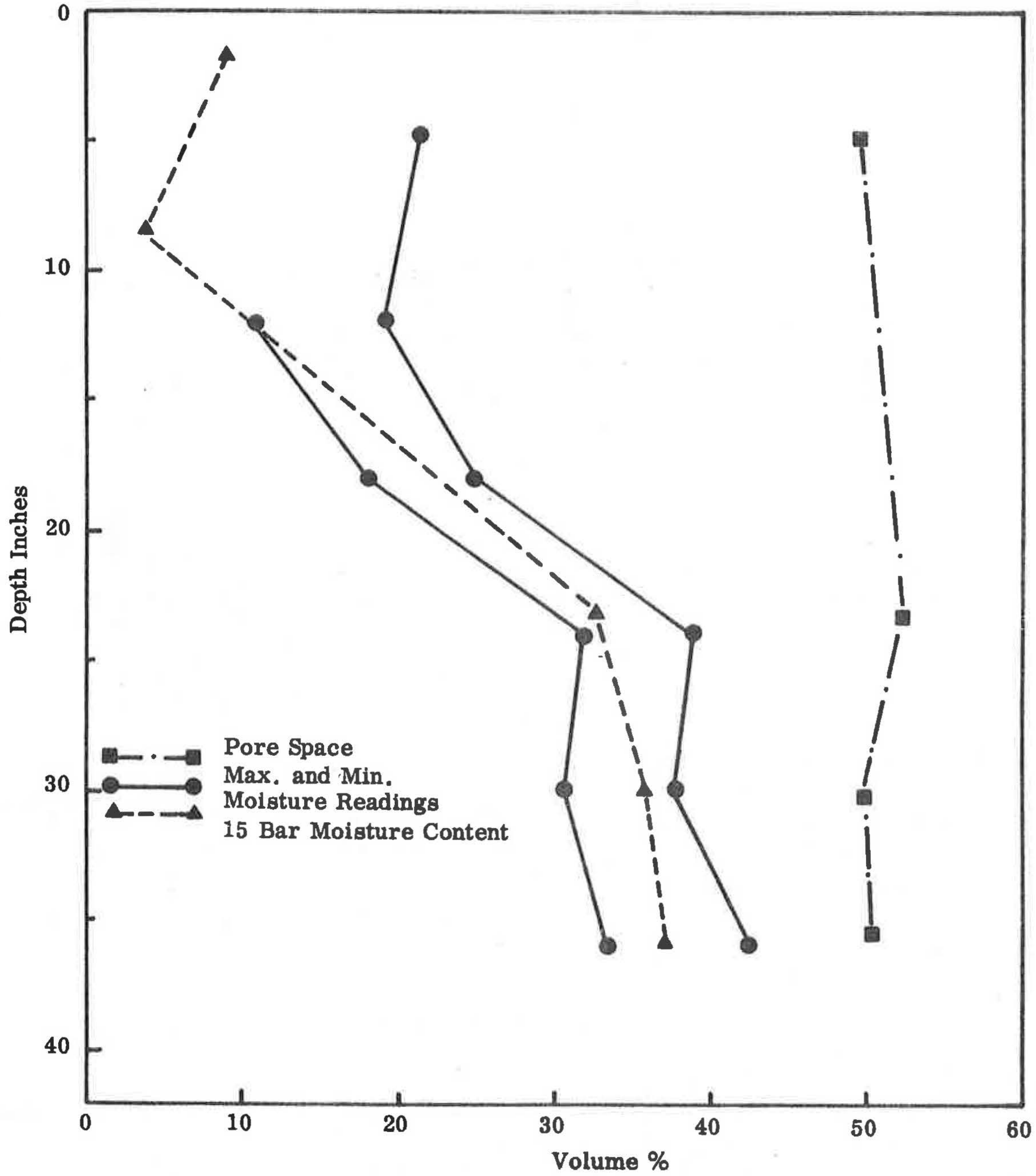

Figure 28. Profile volumes of pore space; 15 bar moisture content; maximum and minimum neutron moisture probe determinations for Ca 1.

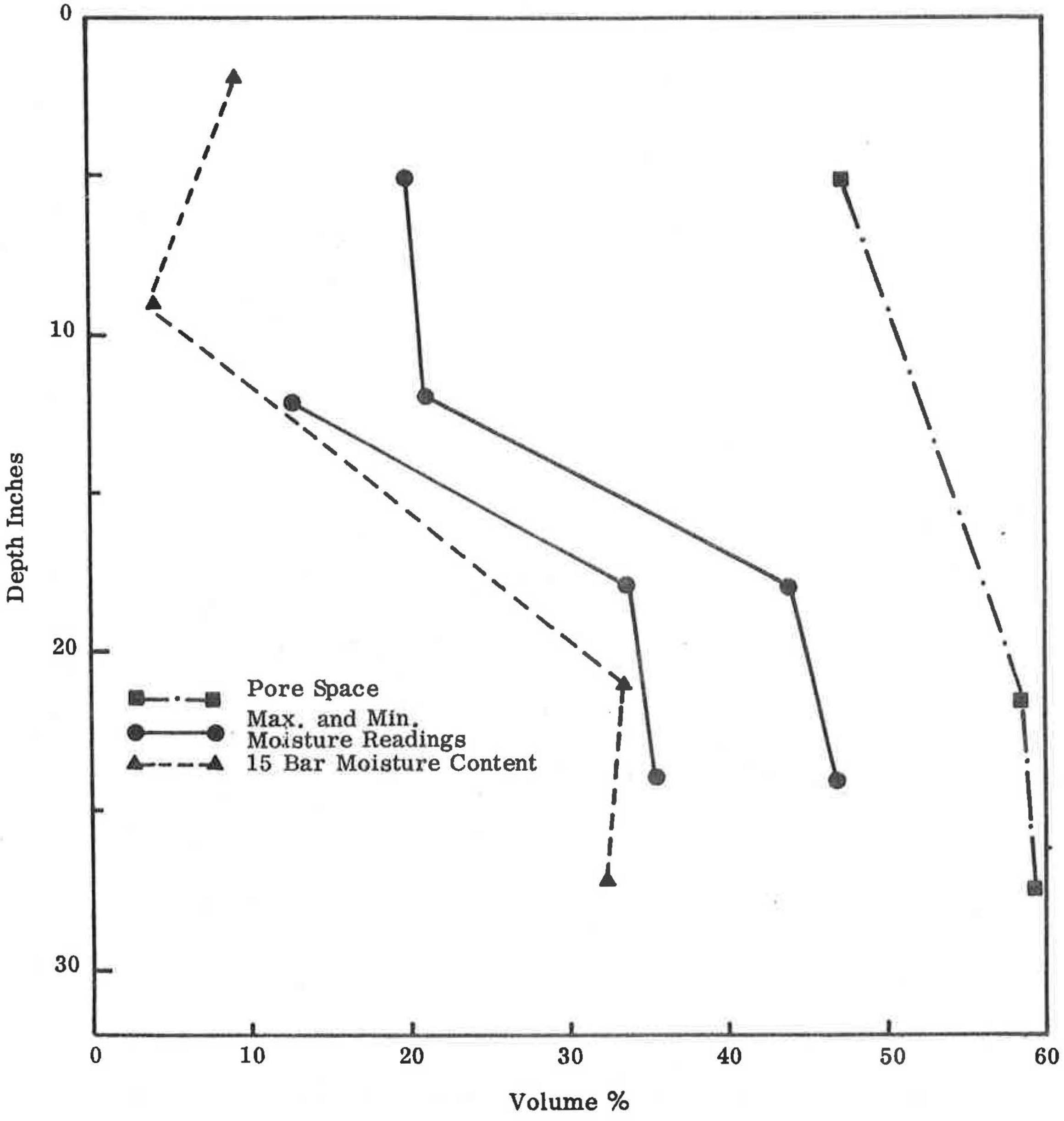

Figure 29. Profile volumes of pore space; 15 bar moisture content; maximum and minimum neutron moisture probe determinations for Ca 2.

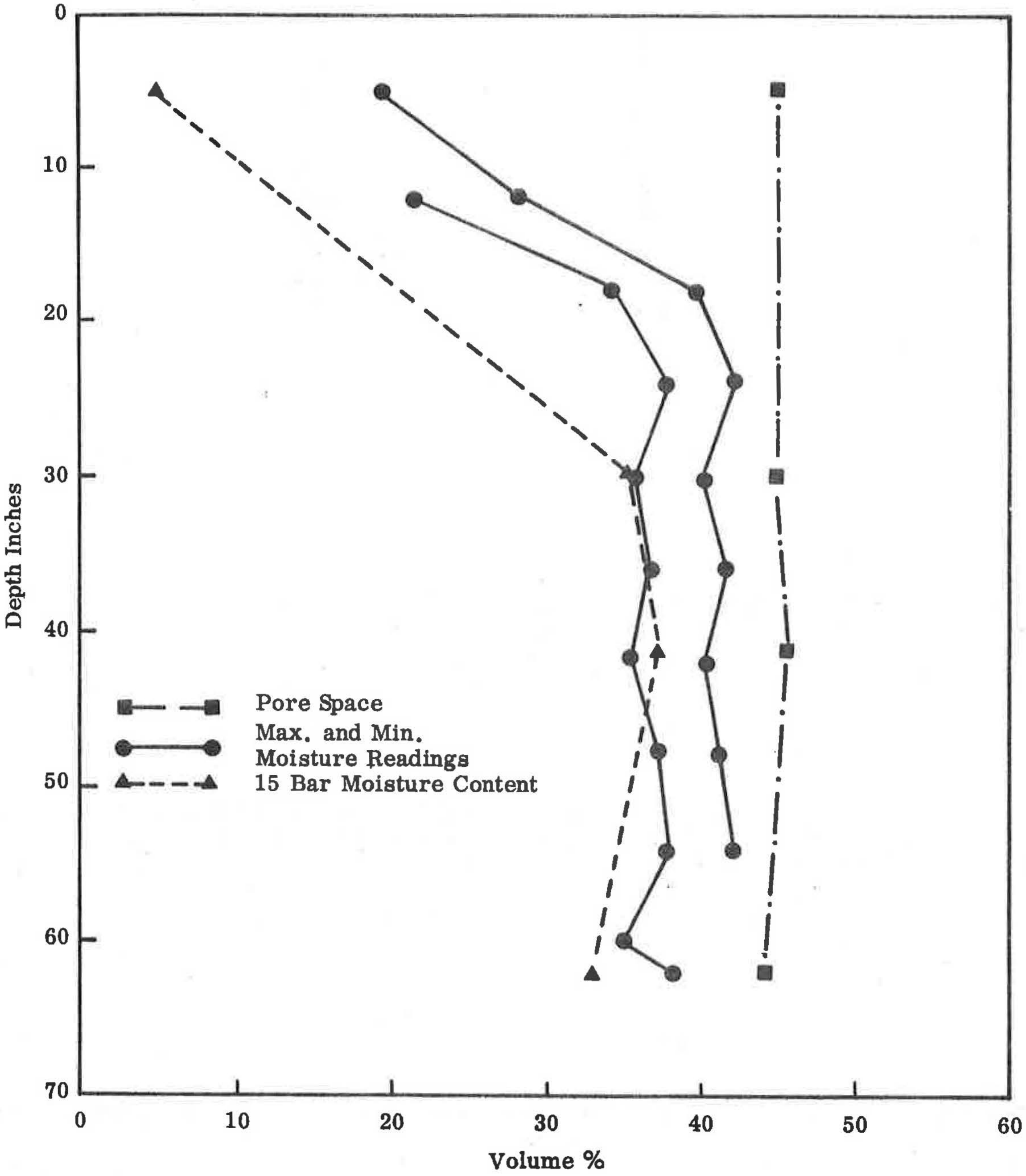

Figure 30. Profile volumes of pore space; 15 bar moisture content; maximum and minimum neutron moisture probe determinations for Wi 1.

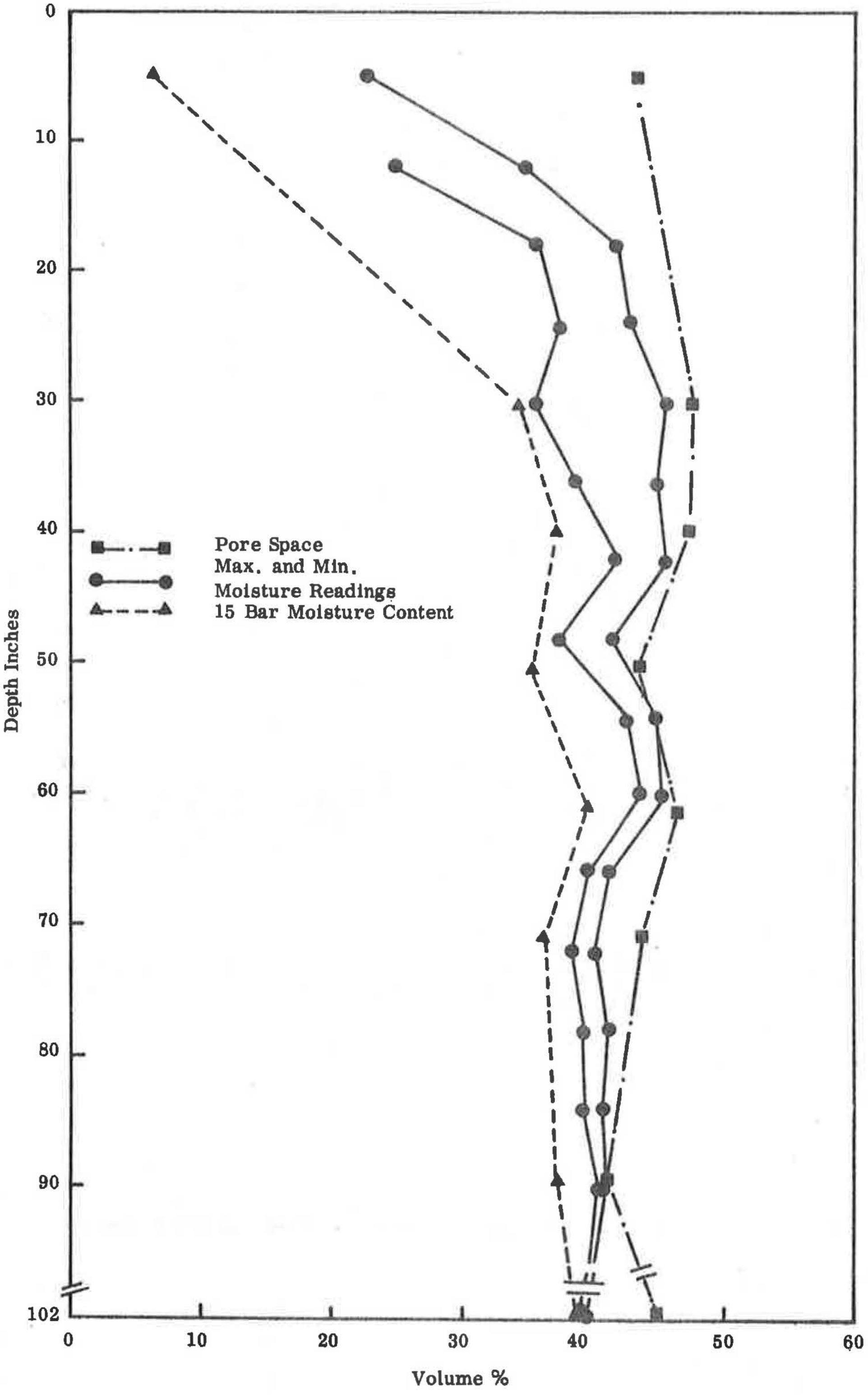

Figure 31. Profile volumes of pore space; 15 bar moisture content; maximum and minimum neutron moisture probe determinations for Wi 2.

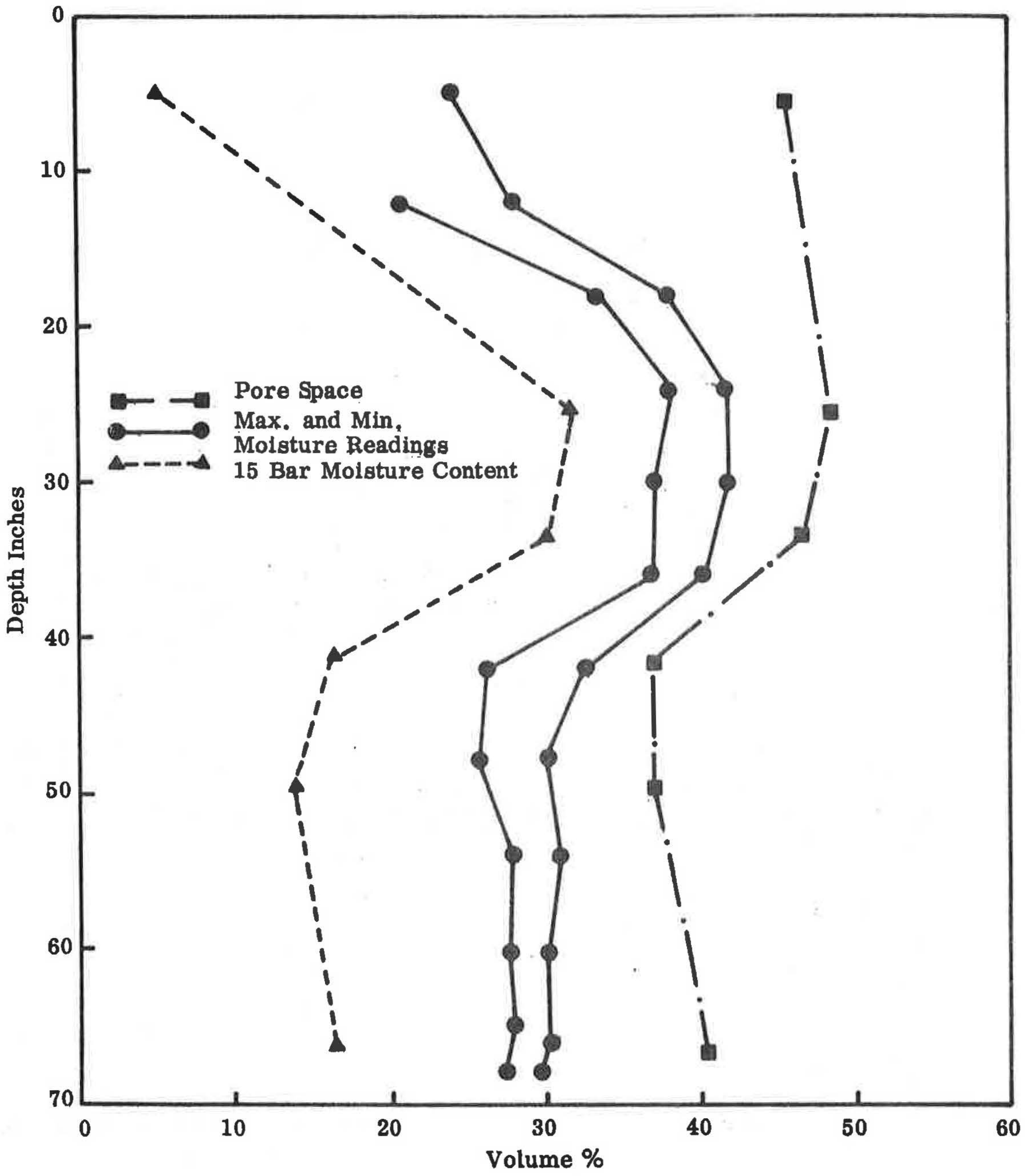

Figure 32. Profile volumes of pore space; 15 bar moisture content; maximum and minimum neutron moisture probe determinations for Wi 2_2.

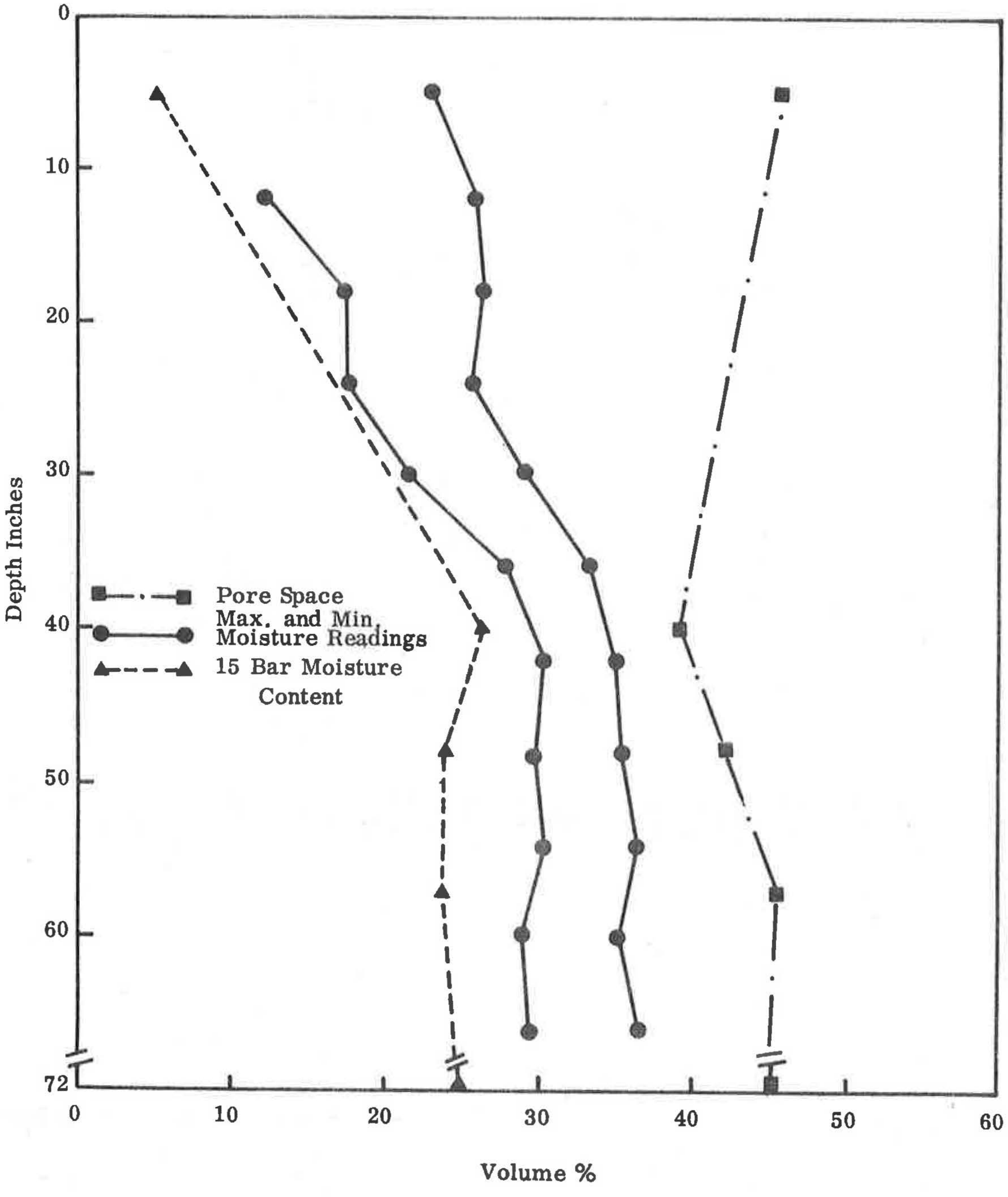

Figure 33. Profile volumes of pore space; 15 bar moisture content; maximum and minimum neutron moisture probe determinations for Wi 3.

TABLE VIII

AVAILABLE MOISTURE STORAGE CAPACITY DATA

Soil Name and Site	Depth Increment Inches	Observed Field Capacity % Vol.	Wilting Point Estimate		Available Moisture		Total Available Moisture Inches
			MFC % Vol.	15 Bar % Vol.	% Vol.	Inches	
Gasconade							
Gas. 1	0-9	27.7		17.1	10.6	.95	.95
Gas. 2	0-9	37.6		26.3	11.3	1.02	1.02
Bardley							
Ca 4	0-5	19.6		6.5	13.1	.66	
	5-24	43.2	33.0		10.2	1.94	2.60
Ca 2	0-15	19.6		6.5	13.1	1.96	
	15-32	45.4	32.7		12.7	2.16	4.12
Ca 1	0-14	21.4		5.3	16.1	2.25	
	14-19	25.0	17.0		7.0	.35	
	19-42	40.7	32.5		8.2	1.89	4.49
Dunmore							
Wi 1	0-12	19.5		5.0	14.5	1.74	
	12-21	39.7	34.6		5.1	.46	
	21-27	42.3	38.0		4.3	.26	
	27-33	40.1	35.8		4.3	.26	
	33-39	41.8	36.9		4.9	.29	
	39-45	40.3	35.6		4.7	.28	
	45-51	41.3	37.5		3.8	.23	
	51-70	42.2	38.2		4.0	.67	4.28

TABLE VIII -- CONTINUED

Soil Name and Site	Depth Increment Inches	Observed Field Capacity % Vol.	Wilting Point Estimate		Available Moisture		Total Available Moisture Inches
			MFC % Vol.	15 Bar % Vol.	% Vol.	Inches	
Wi 2_1	0-8	22.7		6.1	16.6	1.33	
	8-15	34.7	24.7		10.0	.70	
	15-27	42.2	36.6		5.6	.67	
	27-33	45.3		34.3	11.0	.66	
	33-45	45.0		37.3	7.7	.92	
	45-51	41.5		35.3	6.2	.37	
	51-63	45.0		39.6	5.4	.65	
	63-115	40.6		36.8	3.8	1.98	7.28
Wi 2_2	0-8	23.9		4.0	19.9	1.59	
	8-18	27.8	20.7		7.1	.71	
	18-39	41.3		31.1	10.2	2.14	
	39-70	30.9		15.6	15.3	4.74	9.18
Wi 3	0-10	23.3		5.4	17.9	1.79	
	10-15	26.2	12.4		13.8	.83	
	15-21	26.6	17.5		9.1	.55	
	21-27	25.7	17.6		8.1	.54	
	27-33	29.2	21.7		7.5	.45	
	33-39	33.4	28.1		5.3	.32	
	39-45	35.0	30.5		4.5	.27	
	45-51	35.4	29.9		5.5	.33	
	51-57	36.5	30.4		6.1	.37	
	57-63	35.3	29.0		6.3	.38	6.26
	63-76	36.5	29.4		7.1	.43	

limestone derived soils.

Sites Wi 2_2 and Wi 3 deviated from the usual. Both had coarser textured subhorizons and, as a result, had larger AMSC's per unit volume of soil than the other Winona sites.

CLIMATE AND SOIL MOISTURE

Table IX compares the measured amounts of available moisture with those predicted by a Thornthwaite's water balance. The water balance predicted the available moisture content at the Camdenton site with a reasonable amount of accuracy except when the available moisture content was low. Because of the lack of correlation at the Winona sites only the data for Wi 1 are included in Table IX.

The method of computing AET from PET, and the distance between the sites and the weather station may have been the factors responsible for most of the large errors at the Camdenton sites. One gross error appeared to have been caused by the latter. The measured and calculated available moisture contents for September 2, 1969 vary greatly. This error was due to a 2.25 inch rain which was reported at the weather station and which, from all appearances, was much heavier than was experienced at the site. Similar occurrences of lesser magnitudes may have contributed to some of the other differences between measured and calculated moisture content values.

At the Winona sites another factor contributed to the difference between measured and calculated available moisture contents. This was the fact that the trees removed moisture from depths greater than those measured. There was no way of estimating the available moisture remaining in the soil below the access tube nor was it possible to

TABLE IX

MEASURED AND CALCULATED* AVAILABLE MOISTURE CONTENTS AT VARIOUS DATES

Date	Ca 1		Ca 2		Ca 4		Wi 1	
	Measured	Calculated	Measured	Calculated	Measured	Calculated	Measured	Calculated
	Inches		Inches		Inches		Inches	
6-6-68	4.16	3.61	3.58	3.35	1.86	1.77		
7-5-68	3.93	2.99	2.72	2.80	1.39	1.56	1.10	1.35
7-31-68	4.42	3.91	3.49	3.54	1.77	2.04		
9-13-68	0.00	1.54	.26	1.29	0.00	.51	.43	1.66
9-27-68	4.49	4.16	3.89	3.79	2.60	2.27	2.23	4.09
10-25-68	4.47	4.06	3.68	3.69	2.60	2.20	2.75	3.65
12-14-68	4.49	4.42	4.12	4.05	2.60	2.53	4.28	4.28
4-13-69	4.49	4.06	3.97	3.58	2.60	2.22		
5-28-69							3.50	2.30
8-10-69	.86	1.53	.36	.96	0.00	.27		
9-2-69	.67	2.70	.58	2.35	.38	1.46		

*The calculated values were determined using Thornthwaite's estimate of actual evapotranspiration.

determine the greatest depth of moisture removal. As a result there was very little correlation between the calculated and measured estimates of the available moisture content at these sites.

It was hypothesized that the shallow Gasconade soils were unable to supply the needed moisture throughout the growing season while the deeper Bardley soils were. In order to test the hypothesis, daily water balances were computed for the Gasconade and for the shallowest Bardley site, Ca 4. The computed amounts of available moisture for the two are compared in Table X. Dates for the comparisons were those when the Gasconade soil was predicted to be either completely recharged or depleted to some very low available moisture content. These data show that while the Gasconade exhibited drought conditions 4 times in 1968 and 1 time in 1969 the Bardley soils were never reduced below 0.19 inches of available moisture. In the climatic setting at Camdenton, it appears that the AMSC at site Ca 4 is the critical value for the survival of plants throughout the growing season. The AMSC at this site is limited by limestone at a depth of 24 inches.

RELATIONSHIP BETWEEN DEPTH TO CARBONATE ROCK AND AVAILABLE MOISTURE STORAGE CAPACITY AND THEIR RELATIONSHIP TO THE VEGETATIVE COVER

One of the objectives of this study was to determine the effect of depth to carbonate rock on the AMSC. From data given in Table VIII it is obvious that there is a relationship at the Camdenton sites. That relationship can be expressed by the equation:

$$AW_T = 0.11D \qquad (1)$$

where AW_T equals total AMSC in inches and D equals depth

TABLE X

MAXIMUM AND MINIMUM MOISTURE CONTENTS AS PREDICTED BY THE WATER BALANCE* FOR THE BARDLEY SOIL AT Ca 4 AND THE GASCONADE SOIL

Date	Gasconade Inches	Bardley Ca 4 Inches
6-1-68	.98	2.60
6-24-68	.02	.47
6-25-68	.98	2.60
7-15-68	.02	.70
7-25-68	.98	2.60
8-9-68	.05	.94
8-11-68	.98	2.16
9-16-68	.03	.44
9-17-68	.98	2.60
6-12-69	.16	1.01
6-24-69	.98	2.46
6-30-69	.36	1.70
7-1-69	.98	2.60
8-15-69	.02	.19
8-21-69	.98	2.60
9-1-69	.13	1.25

*The predicted moisture contents were obtained from a daily water balance utilizing Thornthwaite's estimate of actual evapotranspiration.

to carbonate rock in inches. Equation 1 appears to be valid for the depth range of 0 to 40 inches but not for depths greater than 40 inches. Although depths to carbonate rock were not determined at the Winona sites it can be seen from the depletion curves and volume analyses in Figures 30 to 33 that equation 1 could not be valid for those soils. The lower pH's, and the larger component of non-expanding clay appear to be correlated with lower AMSC's. The deepest site at Camdenton (Ca 1) demonstrated some of the trends characteristic of the deeper Winona sites and led to the conclusion that the 40 inch depth is the upper limit for validity of equation 1. A second equation that may predict total AMSC's for deeper sites is proposed as follows:

$$AW_T = 4.4 + 0.04(D-40) \qquad (2)$$

The equation will require testing but it does appear to fit those few values that have been observed. It is thought that equations 1 and 2 may be valid for several limestone derived soils that have surface horizons with less than 40 percent coarse chert fragments and that have clayey subsurface horizons.

Depth to carbonate rock and AMSC were related to vegetative cover. A list of the plant species identified on each soil is given in Appendix B. In the section on Climate and Soil Moisture it was shown that the 24 inch depth to carbonate rock at Camdenton site Ca 4 was the critical depth for survival of plants throughout the summer growing season. At Camdenton, the sites with depths of less than 24 inches (Gasconade soils) had plant canopies composed primarily of prairie species, each having the ability to complete its growth prior to the normal peak summer demand for moisture. Such species can, during this period of moisture deficit, either become dormant or produce seed and die. Most tree species cannot survive under such conditions.

The Bardley sites at Camdenton had depths to carbonate rock of 24 to 42 inches and had AMSC's that were large enough to keep perennials alive through the dry part of the summer. Those sites supported a stand of blackjack oak, post oak, and black hickory. These species are known for their ability to exist in areas of low moisture availability, and their external appearance (short, tapered, and limby) indicated that this was the case on the Bardley soil.

Large, well-formed, white, black, and scarlet oaks and shortleaf pine were found on the Dunmore soils at Winona. There the depth to carbonate rock was great enough that, in this climatic setting, the AMSC was not a limiting factor in determining the species composition.

In the preceding paragraphs critical depths to carbonate rock have been identified at 24 and 40 inches. The first is that associated with the boundary between prairie and forest plant canopies, and the second is that depth associated with a change in the relationship between depth and total available moisture storage capacity. The two critical depths may have greater significance when examined in terms of predicted annual frequencies of moist-dry cycles at those depths. Brees (5) made such a prediction based on long term weather records assuming that evapotranspiration took place at the potential rate. His equation for the climate at Salem, Missouri predicts two annual cycles of wetting and drying at 24 inches depth whereas only one cycle was predicted at 48 inches depth.

PREDICTION OF THE AVAILABLE MOISTURE STORAGE CAPACITIES OF LIMESTONE DERIVED SOILS

Equations 1 and 2 of the preceding section were developed to predict total AMSC from depth to carbonate rock. Those prediction equations assumed that chert contents might vary from 0 to 40 percent of the volume in surface horizons. No seemingly valid prediction equations involving chert contents could be developed. Estimated AMSC's for the fine fraction (less than 2mm) were excessive when compared with accepted values for similar textures in non-cherty soils. This was shown by the data in Table XI. The coarse fragments themselves appear to make some contribution to the AMSC but data from this study were too limited to quantify the relationship. It may be that none of the sites had large enough chert contents to adversely affect the AMSC. Soil series descriptions indicate that many limestone derived soils have much greater chert contents than those at the sites studied.

TABLE XI

AVAILABLE MOISTURE STORAGE CAPACITIES FOR THE SURFACE HORIZONS WITH AND WITHOUT CHERT FRAGMENTS ⊳2mm

Soil Name and Site	Moisture Content						⊳ 2mm Chert Content
	15 Bar		Field Capacity		Available Moisture		
	With Chert ⊳ 2mm	Without Chert ⊳ 2mm	With Chert ⊳ 2mm	Without Chert ⊳ 2mm	With Chert ⊳ 2mm	Without Chert ⊳ 2mm	
	% by Volume		% by Volume		% by Volume		
Bardley							
Ca 1	5.3	7.2	21.4	29.5	16.1	22.3	26.7
Ca 2	5.8	9.0	19.1	31.1	13.3	22.1	35.8
Ca 2	7.1	10.3	20.0	29.1	12.9	18.8	30.6
Gasconade							
Gas 1	17.1	17.9	27.7	29.1	10.6	11.2	4.4
Gas 2	26.3	26.3	37.6	37.6	11.3	11.3	.4
Dunmore							
Wi 1	5.0	6.5	19.5	24.8	14.5	18.3	22.1
Wi 2_1	6.1	7.9	22.7	29.4	16.6	21.5	22.6
Wi 2_2	4.0	5.3	23.9	31.9	19.9	26.6	25.2
Wi 3	5.4	6.0	23.3	26.1	17.9	20.1	10.8

CHAPTER VI

SUMMARY AND CONCLUSIONS

The data generated by this study led to several conclusions about limestone derived soils and their relationships with soil moisture, climate, and vegetation.

This study extended the knowledge of limestone derived soils to those with shallow depths to carbonate rock. It showed that they had relatively larger amounts of expanding lattice clays and lower bulk densities than the deeper limestone derived soils previously studied.

The 15 bar moisture content determinations exhibited a very good correlation with clay content. A regression line from 10 to 70 percent clay indicated that this relationship was of the form:

$$MC = 0.5(\% \text{ clay})$$

where MC equals the 15 bar moisture content in percent by volume.

Bulk densities obtained for the deep, relatively chert-free subsoils centered around 1.45 g/cc and were thought to be typical for limestone derived soils with low chert contents.

The use of the neutron moisture probe to obtain the observed field capacities and the minimum field contents appears to be a simple, accurate method of determining the available moisture storage capacity of limestone derived soils. The advantages over laboratory determinations are that moisture measurements can be made repeatedly _in situ_. One disadvantage is the difficulty of installing access tubes in soils containing high volumes of chert.

Thornthwaite's water balance seems to be a relatively accurate method of predicting available soil moisture for these soils. The method of computing actual evapotranspiration from potential evapotranspiration seems to produce sizeable errors when high moisture deficits exist. In order to better evaluate this method more frequent soil moisture measurements would have to be made and temperature and precipitation would have to be recorded on the sites.

There were not enough data to determine the relationship between chert content and the available moisture storage capacity. However, the data do suggest that coarse chert fragments contribute slightly to available moisture storage capacity and it is therefore, incorrect to assume that the total available moisture storage capacity is attributable to the less than 2mm fraction.

Two equations were developed from the data in order to predict the available moisture storage capacities of limestone derived soils. The first is for soils with less than 40 inches of depth to carbonate rock and can be stated as:

$$AW_T = 0.11D$$

where AW_T is total available moisture storage capacity in inches and D is depth to carbonate rock in inches. The second takes into account the changes in soil characteristics occurring at depths greater than 40 inches and is stated as:

$$AW_T = 4.4 + 0.04(D-40)$$

These equations were thought to be valid for limestone derived soils that have less than 40 percent coarse chert fragments in the surface and that have clayey subsurface horizons.

The 24 inch depth to carbonate rock was found to be the critical depth for survival of plants that require moisture throughout the growing season. In the climatic setting at Camdenton, soils shallower than this were not capable of supplying moisture through the dry part of the growing season while deeper soils were. The prairie-forest vegetative pattern at the Camdenton site is the result of such an interrelationship.

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APPENDIX A

SOIL PROFILE DESCRIPTIONS

Bardley Cherty Silt Loam

This soil was sampled from a pit located 500 feet east of an unsurfaced road and 40 feet south of a primitive road at the western edge of the NE $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 2, T37N, R17W in Camden County, Missouri.

Soil Profile:

A1	0-2"	Dark grayish brown (10YR4/2); cherty (35% chert) silt loam with a strong fine granular structure; clear wavy boundary.
A2	2-9"	Light yellowish brown (10YR6/4); cherty (35% chert) silt loam with a weak fine granular structure; abrupt wavy boundary.
B1	9-11"	Red (2.5YR4/6) with silty coats of light brown (7.5YR6/4); light silty clay with a moderate fine sub-angular blocky structure; abrupt wavy boundary.
B21	11-23"	Red (2.5YR4/6); clay with a weak fine blocky structure; gradual wavy boundary.
B22	23-30"	Reddish brown (5YR4/3) with common fine faint reddish gray (5YR5/2) mottles; clay with a weak fine blocky structure; abrupt wavy boundary.
B31	30-32"	Light reddish brown (5YR6/4) with seams of reddish brown (5YR4/4); dolomite sand with seams of clay loam; abrupt wavy boundary.

Soil Profile:

B32	32-33"	Light brownish gray (10YR6/2); sand; partly indurated dolomite sand with an accumulation of reddish materials in pores and channels; abrupt wavy boundary.
R+	33"	Dolomitic limestone.

Gasconade Clay Loam

This soil was sampled from a pit located 100 feet east of an unsurfaced road and 40 feet south of a primitive road at the western edge of the NE $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 2, T37N, R17W in Camden County, Missouri.

Soil Profile:

A1	0-9"	Very dark brown (10YR2/2); clay loam (5% chert fragments) with a strong very fine sub-angular blocky structure; abrupt wavy boundary.
AC	9-14"	Brown (10YR4/3); red and reddish brown stained dolomite with sandy coatings on the edges and in cracks and cleavage planes and with seams of clay loam between the dolomite fragments.
R	14"	Dolomitic limestone.

APPENDIX B

DOMINANT VEGETATIVE SPECIES AS IDENTIFIED ON THE VARIOUS SOILS

Scientific Binomial	Common Name
Gasconade Soil	
Ambrosia artemisiifolia	common ragweed
Ambrosia bidentata	lance-leaf ragweed
Amorpha canescens	common lead plant
Andropogon gerardi	big bluestem
Apocynum cannabinum	indian hemp, dogbane
Cassia fasciculata	partridge pea
Coreopsis palmata	tickseed
Danthonia spicata	poverty grass
Echinacea spp.	coneflower
Euphorbia corollata	spurge
Hieracium spp.	hawkweed
Liatris aspera	gayfeather, blazing star
Liatris squarrosa	gayfeather, blazing star
Lobelia siphilitica	blue cardinal flower
Parthenium spp.	American feverfew
Phlox pilosa	phlox
Plantago spp.	buckhorn, plantain, ribgrass
Rhus aromatica	fragrant sumac
Rudbeckia missouriensis	coneflower, black-eyed Susan
Shrankia uncinata	sensitive briar
Silphium laciniatum	compass plant
Silphium terrabinthinaceum	prairie dock
Solidago gattingeri	goldenrod
Bardley Soil	
Carya texana	black hickory
Crataegus spp.	hawthorn
Quercus alba	white oak
Quercus marilandica	blackjack oak
Quercus stellata	post oak
Quercus velutina	black oak
Rhus aromatica	fragrant sumac
Dunmore Soil	
Cornus spp.	dogwood
Pinus echinata	shortleaf pine
Quercus alba	white oak
Quercus coccinea	scarlet oak
Quercus stellata	post oak
Quercus velutina	black oak
Sassafras albidum	sassafras

APPENDIX C

DAILY WATER BALANCES FOR THE BARDLEY SOIL AT Ca 4 AND THE GASCONADE SOIL. JUNE, 1968

						Bardley at Ca 4		Gasconade	
Date	Mean T °C	Unadj. PE	Adj. PE	P	P-PE	Soil Moist. ST	Actual △ ST	Soil Moist. ST	Actual △ ST
6/7	24.4	.16	.20		-.20	1.63	-.14	.26	-.07
6/8	25.0	.17	.21		-.21	1.50	-.13	.21	-.05
6/9	26.7	.18	.22		-.22	1.37	-.13	.16	-.05
6/10	25.6	.17	.21		-.21	1.26	-.11	.13	-.03
6/11	24.8	.16	.20	.25	+.05	1.31	+.05	.18	+.05
6/12	23.6	.15	.18		-.18	1.22	-.09	.15	-.03
6/13	23.6	.15	.18		-.18	1.14	-.08	.12	-.03
6/14	27.5	.19	.23		-.23	1.04	-.10	.09	-.03
6/15	26.9	.18	.22		-.22	.95	-.09	.07	-.02
6/16	20.8	.12	.15		-.15	.90	-.05	.06	-.01
6/17	21.1	.13	.16		-.16	.84	-.06	.05	-.01
6/18	22.8	.14	.17		-.17	.79	-.05	.04	-.01
6/19	25.0	.17	.21		-.21	.73	-.06	.03	-.01
6/20	26.9	.18	.22		-.22	.67	-.06	.02	-.01
6/21	26.4	.18	.22		-.22	.61	-.06	.02	0
6/22	27.8	.19	.23		-.23	.56	-.05	.02	0
6/23	27.8	.19	.23		-.23	.51	-.05	.02	0
6/24	26.1	.18	.22		-.22	.47	-.04	.02	0
6/25	21.7	.13	.16	2.46	+2.30	2.60	2.13	.98	+.96
6/26	18.1	.10	.12		-.12	2.48	-.12	.86	-.12
6/27	17.0	.09	.11		-.11	2.38	-.10	.76	-.10
6/28	24.4	.16	.20		-.20	2.20	-.18	.60	-.16
6/29	27.5	.19	.23		-.23	2.00	-.20	.46	-.14
6/30	27.8	.19	.23		-.23	1.82	-.18	.35	-.11

T = Temperature
PE = Potential evapotranspiration
P = Precipitation
ST = Storage

DAILY WATER BALANCES FOR THE BARDLEY SOIL AT Ca 4 AND THE GASCONATE SOIL. JULY, 1968

						Bardley at Ca 4		Gasconade	
Date	Mean T oC	Unadj. PE	Adj. PE	P	P-PE	Soil Moist. ST	Actual △ ST	Soil Moist. ST	Actual △ ST
7/1	25.0	.17	.21	.36	+.15	1.97	+.15	.50	+.15
7/2	22.2	.14	.17		-.17	1.84	-.13	.41	-.09
7/3	18.9	.11	.14		-.41	1.74	-.10	.35	-.06
7/4	19.4	.11	.14		-.14	1.65	-.09	.30	-.05
7/5	20.6	.12	.15		-.15	1.56	-.09	.25	-.05
7/6	24.4	.16	.20		-.20	1.44	-.12	.20	-.05
7/7	25.0	.17	.21		-.21	1.32	-.12	.16	-.04
7/8	24.2	.16	.20		-.20	1.22	-.10	.13	-.03
7/9	25.6	.17	.21		-.21	1.12	-.10	.10	-.03
7/10	24.4	.16	.20		-.20	1.03	-.09	.08	-.02
7/11	23.9	.15	.18		-.18	.96	-.07	.07	-.01
7/12	26.1	.18	.22		-.22	.88	-.08	.05	-.02
7/13	26.4	.18	.22		-.22	.81	-.07	.04	-.01
7/14	27.8	.19	.23		-.23	.74	-.07	.03	-.01
7/15	25.6	.17	.21	.05	-.16	.70	-.04	.03	0
7/16	28.6	.20	.24		-.24	.64	-.06	.02	-.01
7/17	29.2	.21	.25		-.25	.58	-.06	.02	-.01
7/18	25.6	.17	.20	.27	+.07	.65	+.07	.09	+.07
7/19	26.7	.18	.22		-.22	.59	-.06	.07	-.02
7/20	25.6	.17	.20		-.20	.54	-.05	.06	-.01
7/21	25.8	.17	.20		-.20	.50	-.04	.05	-.01
7/22	27.8	.19	.23	.82	+.59	1.09	+.59	.64	+.59
7/23	28.1	.20	.24		-.24	.99	-.10	.48	-.16
7/24	27.8	.19	.23		-.23	.90	-.09	.37	-.11
7/25	25.3	.17	.20	2.47	+2.27	2.60	+1.70	.98	+.61
7/26	26.9	.18	.21	.20	-.01	2.59	-.01	.97	-.01
7/27	26.4	.18	.21	1.38	+1.17	2.60	+.01	.98	+.01
7/28	26.1	.18	.21		-.21	2.39	-.21	.77	-.21
7/29	20.8	.12	.14		-.14	2.26	-.13	.66	-.11
7/30	23.1	.15	.18	.12	-.06	2.21	-.05	.62	-.04
7/31	25.8	.17	.20		-.20	204	-.17	.49	-.13

T = Temperature
PE = Potential evapotranspiration
P = Precipitation
ST = Storage

DAILY WATER BALANCES FOR THE BARDLEY SOIL AT Ca 4 AND THE GASCONADE SOIL. AUGUST, 1968

						Bardley at Ca 4		Gasconade	
Date	Mean T °C	Unadj. PE	Adj. PE	P	P-PE	Soil Moist. ST	Actual △ ST	Soil Moist. ST	Actual △ ST
8/1	20.0	.12	.14		-.14	1.93	-.11	.42	-.07
8/2	23.3	.15	.18		-.18	1.80	-.13	.34	-.08
8/3	28.6	.20	.24		-.24	1.64	-.16	.26	-.08
8/4	28.3	.20	.24		-.24	1.49	-.15	.20	-.06
8/5	28.9	.20	.23		-.23	1.36	-.13	.15	-.05
8/6	28.6	.20	.23		-.23	1.24	-.12	.12	-.03
8/7	29.4	.21	.24		-.24	1.12	-.12	.09	-.03
8/8	29.4	.21	.24		-.24	1.02	-.10	.07	-.02
8/9	28.6	.20	.23	.02	-.21	.94	-.08	.05	-.02
8/10	24.4	.16	.18	.90	+.72	1.66	+.72	.77	+.72
8/11	19.2	.11	.13	.63	+.50	2.16	+.50	.98	+.21
8/12	19.4	.11	.13	.04	-.09	2.09	-.07	.89	-.09
8/13	24.2	.16	.18		-.18	1.95	-.14	.73	-.16
8/24	24.8	.16	.18	.04	-.14	1.85	-.10	.63	-.10
8/15	26.1	.18	.20	.60	+.40	2.25	+.40	.98	+.35
8/16	28.6	.20	.23		-.23	2.05	-.20	.75	-.23
8/17	27.8	.19	.21		-.21	1.89	-.16	.59	-.16
8/18	26.7	.18	.20		-.20	1.74	-.15	.47	-.12
8/19	26.9	.18	.20		-.20	1.61	-.13	.37	-.10
8/20	28.6	.20	.23		-.23	1.47	-.14	.28	-.09
8/21	28.3	.20	.22		-.22	1.35	-.12	.22	-.06
8/22	28.3	.20	.22		-.22	1.24	-.11	.17	-.05
8/23	29.4	.21	.24		-.24	1.12	-.12	.13	-.04
8/24	28.3	.20	.22		-.22	1.03	-.09	.12	-.01
8/25	22.5	.14	.16		-.16	.97	-.06	.10	-.02
8/26	21.9	.13	.14		-.14	.92	-.05	-.09	-.01
8/27	22.5	.14	.16		-.16	.86	-.06	.08	-.01
8/28	20.6	.12	.13		-.13	.82	-.04	.04	-.01
8/29	20.6	.12	.13		-.13	.78	-.04	.06	-.01
8/30	21.4	.13	.14	.23	+.09	.87	+.09	.15	+.09
8/31	19.8	.12	.13	.15	+.02	.89	+.02	.17	+.02

T = Temperature
PE = Potential evapotranspiration
P = Precipitation
ST = Storage

DAILY WATER BALANCES FOR THE BARDLEY SOIL AT Ca 4 AND THE GASCONADE SOIL. SEPTEMBER, 1968

Date	Mean T °C	Unadj. PE	Adj. PE	P	P-PE	Bardley at Ca 4 Soil Moist. ST	Bardley at Ca 4 Actual △ ST	Gasconade Soil Moist. ST	Gasconade Actual △ ST
9/1	19.8	.12	.14		-.14	.84	-.05	.15	-.02
9/2	23.3	.15	.18		-.18	.78	-.06	.12	-.03
9/3	24.2	.16	.19		-.19	.72	-.06	.10	-.02
9/4	23.6	.15	.18	.16	-.02	.72	0	.10	0
9/5	19.4	.11	.13	.08	-.08	.71	-.01	.09	-.01
9/6	18.9	.11	.13		-.13	.67	-.04	.08	-.01
9/7	22.0	.14	.16		-.16	.63	-.04	.07	-.01
9/8	23.0	.15	.18		-.18	.59	-.04	.06	-.01
9/9	16.4	.09	.10		-.10	.57	-.02	.05	-.01
9/10	15.6	.08	.09		-.09	.55	-.02	.05	0
9/11	15.8	.08	.09		-.09	.53	-.02	.05	0
9/12	17.8	.10	.12		-.12	.53	0	.05	0
9/13	19.7	.11	.12		-.12	.51	-.02	.04	-.01
9/14	20.6	.12	.14		-.14	.48	-.03	.03	-.01
9/15	20.6	.12	.14	.05	-.09	.46	-.02	.03	0
9/16	22.5	.14	.16	.02	-.14	.44	-.02	.03	0
9/17	20.0	.12	.14	2.69	+2.55	2.60	+2.16	.98	+.95
9/18	17.8	.10	.11		-.11	2.49	-.11	.87	-.11
9/19	20.6	.12	.14	.05	-.08	2.40	-.09	.79	-.08
9/20	22.2	.14	.16		-.16	2.25	-.15	.66	-.13
9/21	23.9	.15	.17	.56	+.39	2.60	+.35	.98	+.32
9/22	23.9	.15	.17	.86	+.69	2.60	0	.98	0
9/23	23.9	.15	.17	.10	-.07	2.53	-.07	.91	-.07
9/24	22.0	.14	.16	1.42	+1.26	2.60	+.07	.98	+.07
9/25	17.8	.10	.11		-.11	2.49	-.11	.87	-.11
9/26	18.9	.11	.12		-.12	2.37	-.12	.76	-.11
9/27	17.8	.10	.11		-.11	2.27	-.10	.68	-.08
9/28	20.6	.12	.13		-.13	2.16	-.11	.59	-.09
9/29	22.0	.14	.15		-.15	2.04	-.12	.50	-.09
9/30	20.3	.12	.13		-.13	1.94	-.10	.43	-.07

T = Temperature
PE = Potential evapotranspiration
P = Precipitation
ST = Storage

DAILY WATER BALANCES FOR THE BARDLEY SOIL AT Ca 4 AND THE GASCONADE SOIL. JUNE, 1969

Date	Mean T °C	Unadj. PE	Adj. PE	P	P-PE	Bardley at Ca 4		Gasconade	
						Soil Moist. ST	Actual △ ST	Soil Moist. ST	Actual △ ST
6/1	18.9	.11	.13	.73	+.60	1.93	+.60	.98	+.55
6/2	17.2	.09	.11		-.11	1.85	-.08	.87	-.11
6/3	15.8	.08	.10		-.10	1.78	-.07	.78	-.09
6/4	18.9	.11	.13		-.13	1.69	-.09	.68	-.10
6/5	23.3	.15	.18	.01	-.17	1.58	-.11	.56	-.12
6/6	24.8	.16	.20		-.20	1.46	-.12	.45	-.11
6/7	25.3	.17	.21		-.21	1.34	-.12	.35	-.10
6/8	25.3	.17	.21		-.21	1.23	-.11	.27	-.08
6/9	20.6	.12	.15	.16	+.01	1.24	+.01	.28	+.01
6/10	19.7	.11	.14		-.14	1.17	-.07	.24	-.04
6/11	25.0	.17	.21		-.21	1.08	-.09	.19	-.05
6/12	24.8	.16	.20	.04	-.16	1.01	-.07	.16	-.03
6/13	18.6	.11	.14	.37	+.23	1.24	+.23	.39	+.23
6/14	16.9	.09	.11	.39	+.28	1.52	+.28	.67	+.28
6/15	15.6	.08	.10	.08	-.02	1.51	-.01	.65	-.02
6/16	15.6	.08	.10		-.10	1.45	-.06	.58	-.07
6/17	17.8	.10	.12		-.12	1.38	-.07	.51	-.07
6/18	21.1	.13	.16	.42	+.26	1.64	+.26	.77	+.26
6/19	22.8	.14	.17		-.17	1.53	-.11	.64	-.13
6/20	23.9	.15	.18		-.18	1.42	-.11	.52	-.12
6/21	19.2	.11	.14	.21	+.07	1.49	+.07	.59	+.07
6/22	21.7	.13	.16	.49	+.33	1.82	+.33	.92	+.33
6/23	25.3	.17	.21		-.21	1.67	-.15	.72	-.20
6/24	24.2	.16	.20	.99	+.79	2.46	+.79	.98	+.26
6/25	27.8	.19	.23		-.23	2.24	-.22	.75	-.23
6/26	28.6	.20	.25		-.25	2.02	-.22	.56	-.19
6/27	25.8	.17	.21	.36	+.15	2.17	+.15	.71	+.15
6/28	28.9	.20	.25	.09	-.16	2.04	-.13	.60	-.11
6/29	27.8	.19	.23		-.23	1.86	-.18	.46	-.14
6/30	26.1	.18	.22		-.22	1.70	-.16	.36	-.10

T = Temperature
PE = Potential evapotranspiration
P = Precipitation
ST = Storage

DAILY WATER BALANCES FOR THE BARDLEY SOIL AT Ca 4 AND THE GASCONADE SOIL. JULY, 1969

						Bardley at Ca 4		Gasconade	
Date	Mean T °C	Unadj. PE	Adj. PE	P	P-PE	Soil Moist. ST	Actual △ ST	Soil Moist. ST	Actual △ ST
7/1	25.0	.17	.21	1.34	+2.13	2.60	+.90	.98	+.62
7/2	24.2	.16	.20	2.13	+1.93	2.60	0	.98	0
7/3	25.3	.17	.21	1.26	+1.05	2.60	0	.98	0
7/4	30.0	.22	.27		-.27	2.33	-.27	.71	-.27
7/5	29.2	.21	.26		-.26	2.10	-.23	.52	-.19
7/6	27.5	.19	.23	.41	+.18	2.28	+.18	.70	+.18
7/7	27.2	.19	.23	.13	-.10	2.19	-.09	.63	-.07
7/8	28.3	.20	.25		-.25	1.98	-.21	.47	-.16
7/9	29.7	.21	.26		-.26	1.78	-.20	.35	-.12
7/10	28.1	.20	.24		-.24	1.62	-.16	.26	-.09
7/11	26.7	.18	.22	.82	+.60	2.22	+.60	.86	+.60
7/12	28.9	.20	.24		-.24	2.02	-.20	.65	-.21
7/13	29.2	.21	.26		-.26	1.82	-.20	.48	-.17
7/14	29.4	.21	.26		-.26	1.64	-.18	.35	-.13
7/15	27.8	.19	.23		-.23	1.50	-.14	.27	-.08
7/16	29.4	.21	.26		-.26	1.35	-.15	.20	-.07
7/17	29.4	.21	.25		-.25	1.22	-.13	.15	-.05
7/18	28.3	.20	.24		-.24	1.11	-.11	.11	-.04
7/19	27.2	.19	.23		-.23	1.01	-.10	.09	-.02
7/20	25.6	.17	.20	.39	+.19	1.20	+.19	.28	+.19
7/21	24.7	.16	.19		-.19	1.11	-.09	.23	-.05
7/22	25.3	.17	.20		-.20	1.02	-.09	.18	-.05
7/23	25.8	.17	.20		-.20	.94	-.08	.14	-.04
7/24	25.6	.17	.20	.13	-.07	.92	-.02	.13	-.01
7/25	24.7	.16	.19		-.19	.85	-.07	.11	-.02
7/26	27.8	.19	.23		-.23	.77	-.08	.09	-.02
7/27	27.2	.19	.23	.01	-.22	.70	-.07	.07	-.02
7/28	22.8	.14	.17		-.17	.66	-.04	.06	-.01
7/29	21.4	.13	.15		-.15	.62	-.04	.05	-.01
7/30	23.6	.15	.18		-.18	.58	-.04	.04	-.01
7/31	25.0	.17	.20		-.20	.54	-.04	.03	-.01

T = Temperature
PE = Potential evapotranspiration
P = Precipitation
ST = Storage

DAILY WATER BALANCES FOR THE BARDLEY SOIL AT Ca 4 AND THE GASCONADE SOIL. AUGUST, 1969

Date	Mean T °C	Unadj. PE	Adj. PE	P	P-PE	Bardley at Ca 4		Gasconade	
						Soil Moist. ST	Actual Δ ST	Soil Moist. ST	Actual Δ ST
8/1	23.3	.15	.18		-.18	.50	-.04	.03	0
8/2	22.8	.14	.16	.09	-.07	.49	-.01	.03	0
8/3	22.5	.14	.16	.06	-.10	.47	-.02	.03	0
8/4	22.8	.14	.16		-.16	.44	-.03	.03	0
8/5	25.0	.17	.20		-.20	.41	-.03	.02	-.01
8/6	26.9	.18	.21		-.21	.38	-.03	.02	0
8/7	26.1	.18	.21		-.21	.35	-.03	.02	0
8/8	30.0	.22	.26		-.26	.32	-.03	.02	0
8/9	30.0	.22	.26		-.26	.29	-.03	.02	0
8/10	23.3	.15	.17		-.17	.27	-.02	.02	0
8/11	23.3	.15	.17		-.17	.25	-.02	.02	0
8/12	25.0	.17	.20		-.20	.23	-.02	.02	0
8/13	24.7	.16	.18		-.18	.21	-.02	.02	0
8/14	26.4	.18	.20		-.20	.19	-.02	.02	0
8/15	22.8	.14	.16	.13	-.03	.19	0	.02	0
8/16	22.0	.14	.16	.78	+.62	.81	+.62	.64	+.62
8/17	23.3	.15	.17		-.17	.76	-.05	.53	-.11
8/18	24.7	.16	.18		-.18	.71	-.05	.43	-.10
8/19	26.4	.18	.20		-.20	.66	-.05	.34	-.09
8/20	28.6	.20	.23		-.23	.60	-.06	.26	-.08
8/21	26.9	.18	.21	2.25	+2.04	2.60	+2.00	.98	+.72
8/22	21.4	.13	.14		-.14	2.46	-.14	.84	-.14
8/23	20.8	.12	.13		-.13	2.34	-.12	.73	-.11
8/24	22.8	.14	.16		-.16	2.20	-.14	.61	-.12
8/25	23.1	.15	.17		-.17	2.06	-.14	.51	-.10
8/26	22.8	.14	.16		-.16	1.93	-.13	.43	-.08
8/27	23.3	.15	.17		-.17	1.81	-.12	.36	-.07
8/28	25.6	.17	.19		-.19	1.68	-.13	.29	-.07
8/29	26.1	.18	.20		-.20	1.55	-.13	.23	-.06
8/30	26.7	.18	.20		-.20	1.43	-.12	.18	-.05
8/31	25.6	.17	.18		-.18	1.33	-.10	.15	-.03

T = Temperature
PE = Potential evaptranspiration
P = Precipitation
ST = Storage

PUBLICATIONS, REPORTS, PAPERS, TALKS PRESENTED

(1) Brees, Dwayne R., "Soil Formation and Climate in Missouri," University of Missouri Master's Thesis (1968)

(2) Ruppert, David A., "Available Moisture Storage Capacities of Some Limestone-Derived Soils," University of Missouri Master's Thesis (1970)

(3) "A Method for the Estimation of Time-Depth Distribution of Moist and Dry Zones in Soils," Presentation by C. L. Scrivner and D. R. Brees at the National Technical Work Planning Conference of the Cooperative Soil Survey, Charleston, South Carolina, January 27-30, 1969.

(4) "A Study of Temperature, Precipitation and Evapotranspiration Characteristics of Areas of Missouri," Presentation by C. L. Scrivner and D. R. Brees at the National Technical Work Planning Conference of the Cooperative Soil Survey, Charleston, South Carolina, January 27-30, 1969.

(5) "Soils and Their Relationships to Potentials for Supplemental Irrigation in Missouri," Presentation by C. L. Scrivner to the Missouri Basin Inter-Agency Committee, Jefferson City, Missouri, March 20, 1969.

TRAINING ACCOMPLISHED

Mr. David A. Ruppert, partially because of his training in this research is now employed as a Soil Scientist with the U. S. Forest Service. His work responsibilities include soil and hydrologic survey in U. S. Forest Service lands.