The contact angle between water and soil materials
by George E Cawlfield

A THESIS Submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree
of Master of Science in Soils at Montana State College
Montana State University
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Abstract:
The contact angle of water with soil materials was studied. To study the effect of organic fractions on
contact angles, the soil materials were extracted in a soxhlet apparatus with four organic solvents and
water. Glass microscope slides were coated with these extracted soil materials. Small drops of water
were placed on the surfaces of the coated slides and height (h) and width (w) of the drops were
measured. The contact angles (θ) were computed from the formulas $\tan \theta/2 = 2h/w$ for angles less than
90° and $\sin (\theta - 90) = 2h/w - 1$ for angles greater than 90°.

The measured contact angles ranged from 14.8 degrees for a hot water extracted material to 130.2
degrees for an ether extracted material. An analysis of variance showed variation due to soils, extracts,
soils x extracts and among treatments to all be highly significant.

One-third and fifteen atmosphere equilibrium moisture contents were run on each sample before and
after extraction. Results indicate extraction increased the water holding capacity. Further information is
necessary to determine if this is from a breakdown of structure or a smaller contact angle.

Drying curves were determined for cores of four of the soils used in this study. The curves of the two
like soil samples, one cropped annually and one in grass for four years, indicate that cropping
decreased water loss.

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ABSTRACT

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were extracted in a soxhlet apparatus with four organic solvents and water.
Glass microscope slides were coated with these extracted soil materials.
Small drops of water were placed on the surfaces of the coated slides
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angles (Θ) were computed from the formulas $\tan \Theta/2 = \frac{2h}{w}$ for angles less

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An analysis of variance showed variation due to soils, extracts, soils x
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INTRODUCTION

Contact angle is the angle between the surface of a solid at the solid liquid interface and a line drawn tangent to the liquid at the intersection of the liquid and solid. It is a measure of the relative strengths of the adhesion of the liquid to the solid and cohesion of the liquid to itself. The contact angle will be zero if the liquid attracts the solid equal to or more than it attracts itself. A contact angle of 90° indicates an attraction of the liquid for the solid equal to half that for itself. Adam (1938) says that a contact angle of 180° is unrealizeable but such an angle would indicate no adhesion between the liquid and the solid. Contact angle depends on the solid material and the surface tension of the liquid.

Adam (1938), Bangham (1946), Gregg (1948) in their study of contact angles have noticed a so called hysteresis of contact angle. That is, the contact angle is a larger value when the liquid is advancing than when it is receding. Hysteresis has been explained by authors in varying ways but no one explanation seems acceptable. Bartell and Wooley (1933) showed that the magnitudes of the advancing and receding contact angles are the same if the surfaces had like treatment history. The advancing angle probably is less variable than the receding angle. (Adam 1938)

In cases where the contact angle is used in mathematical calculations of soil-water relationships, Baver (1959) states it is usually assumed to be zero. Haines (1925) verified the theory of cohesion due to capillary attraction between wetted particles with the use of experimentally ignited silt. The fact that the soil was ignited indicates that

with soil in its natural state the theory could not have been proven as he assumed zero contact angle. Many investigators have found information indicating the contact angle of water with natural soil in not zero. Linford (1930) measured the contact angle of water with soil minerals and found finite and widely varying angles of contact for old or freshly cleaned surfaces but zero for new surfaces. Robinson and Page (1951) found the contact angle of water with the materials of cold water extracts from a fence row and cropped soil to be different. Van't Woudt (1959) found that an easily wettable soil coated with the extract of an organic solvent from a difficultly wettable soil exhibited resistance to wetting in the air dry state. Linford (1930) and Langmuir (1920) say that many workers have shown solids with monomolecular films of certain substances, notably fats, oils and fatty acids had finite angles of contact. Linford also found that a soil treated with enough oleic acid to give a monomolecular layer gave much less capillary rise than an untreated soil. Keen (1927) found a soil treated with hydrogen peroxide to remove organic matter had greater cohesion between soil particles at low moisture contents than untreated soil indicating a smaller contact angle. The reverse was true at high moisture contents.

The results of numerous investigations indicate the most probable reason for a non zero contact angle of water with soils is organic coatings of the soil mineral matter. Organic material can vary widely in chemical composition from soil to soil (Waksman and Hutchings, 1935). It is reported by Waksman and Iyer (1932) that humus consists predominantly of two chemical complexes, lignins and proteins. It also contains

fats, waxes, cellulose, hemicellulose, organic acids and alcohols. Many
investigators have tried fractionation of organic matter extracted from
soils and numerous materials have been identified. High concentrations
of waxes of the types appearing in beeswax were found by Meinschein and
Kenny (1957) in the benzene-methanol extract of soils. Schreiner and
Shorey (1909) found a yellowish waxlike substance in an ethanol extract of
soils.

Swartzendruber et al. (1954) have shown that the wetting angle is used
in calculating the capillary absorption coefficient and hydraulic conducti-
vity of a soil. Swartzendruber (1956) also says that capillary theory
can be refined by determining the wetting angle of a soil. It is
possible that contact angle between soil and water might have an effect
on water evaporation from a soil. The actual effect of contact angle on
saturated and unsaturated flow, capillary rise, vapor absorption, and
evaporation, if any, is not known but can probably be determined if
materials of known contact angle could be used to coat soils or materials.
Puri (1949) reports the contact angle increases as particle size
decreases. Effects such as this and others due to pores of molecular
dimensions will need to be evaluated before definite conclusions about the
wetting angle of soil can be drawn.

As a possible means of evaluating the effects of contact angle
between soil and water, the contact angle of water with soil materials was
studied. These materials were extracted from soils with organic solvents
and water. Glass microscope slides were coated with these materials and
the contact angle of water with these coated slides was determined by

measurements of small drops. One-third and fifteen atmosphere equilibrium moisture contents were run on the soils samples before and after extraction to determine what effect loss of soil materials with a measured contact angle had on moisture holding capacity. Drying curves were determined for four of the soils used in the study to determine what effect, if any, contact angle might have on evaporation.

LITERATURE REVIEW

Methods of Extraction

Soil organic matter as defined by Russel (1950) "is a series of products which range from undecayed plant and animal tissues through ephimeral products of decomposition to fairly stable amorphous brown to black material bearing no trace of anatomical structure from which it was derived." Schreiner and Shorey (1910) thought that the complexity of soil organic matter was not so great that its chemical nature could not be determined by modern methods of research. Broadbent (1953) says that no solvent is known which dissolves the soil organic complex completely. This is probably the most important reason that the effect of soil organic matter on soil-water relationships has not been more completely evaluated.

No one method is available for organic matter extraction, but many methods have been proposed. These come under three main groups which are: (1) strong acidic or basic extractants, (2) neutral reagent extractants, and (3) organic extractants.

Strong Acidic or Basic Extractants

Probably the best known, oldest, and most widely used procedure for extracting soil organic matter is the strong alkali method. This method consists of extraction with strong alkali and fractionation. Further details of this extraction are enumerated by Shorey (1912), Lynch et al. (1957a) and Lynch et al. (1957b). Broadbent (1953) says this method brings a considerable part of the material into solution, but suffers the disadvantage that the material is concurrently oxidized and probably altered in other ways. Evans and Russel (1959) found that extraction with chelating

reagents and alkaline solutions increased with pH and suggest that under strongly alkaline conditions oxidation and hydrolysis might be involved. Possible alteration by strong alkalies is also suggested by Bremner (1951) and Broadbent (1955).

Forsyth (1947) says the complex extractable with basic solutions "contains carboxylic, phenolic, methoxyl, acetyl, quinone, and probably tautomeric carbonyl groups. It is easily destroyed by oxidation giving simple aromatic compounds. It can be reduced to a colorless compound which reoxidizes when exposed to air. It gives characteristic nitro-, chloro-, and bromo-compounds of amorphous charcoal. It generally contains 1 to 5% N."

In recent years Schnitzer and Wright (1957), Schnitzer (1958), and Schnitzer et al. (1959) have used various extractants and found that the amount of organic matter extracted varied with horizons and extractant. Only NaOH removed appreciable amounts from the A_0 horizon; other extractants including strong acids were quite efficient in the B_{21} of a Podzol.

Neutral Reagent Extractants

The extraction of soil organic matter with neutral reagents such as sodium pyrophosphate has been found by Stevenson et al. (1953) to be especially suitable because the organic complexes pass into solution without peptonization. Schnitzer et al. (1959) found that the pH had little effect on the extraction from a podzolic B provided the yield is sufficiently high and an excess of the reagent can be satisfactorily removed. Evans (1959) says the results of extraction with pyrophosphate indicate good efficiency and suggest that the pyrophosphate anion's chelating

abilities might have been involved.

Organic Solvents

Organic solvents have been used about as long as strong alkali for extraction and fractionation of soil organic matter. Fraps and Rather (1913) used ether and chloroform and extracted with a soxhlet apparatus. They found the ether extract contains fatty acids and waxes. Meinschein and Kenny (1957) used a mixture of benzene and methanol and extracted waxes of the types appearing in beeswax. They state that the principle constituents of the waxes are normal aliphatic acids, normal primary aliphatic alcohols and sterols. Schreiner and Shorey (1909)(1911) extracted soil organic matter with boiling 95% alcohol. They found that a yellowish microcrystalline precipitate separated out on cooling. It contained mineral and organic matter which were alumina and a mixture of so called fatty acids respectively. The filtrate contained a yellowish waxlike substance which was agrosterol. Waksman and Stevens (1930) also extracted soil organic matter with ether, alcohol and a 1:1 benzene-alcohol mixture and found that the benzene-alcohol mixture extracted nearly equivalent fats and resins as the combined extracts of ether and alcohol.

Coating the Slides

The subject of coating glass slides is a relatively unexplored field. Bigelow and Brockway (1956) coated glass slides with thin films of fatty acids by adsorption. Ihrig and Lai (1957) obtained a good paraffin coating by keeping paraffin just above the melting point and leaving the slides in paraffin a few minutes in order to heat them through. O'Kane

et al. (1930) coated slides by evaporation of the extract on the slide as did Robinson and Page (1951). It appears that no one method is satisfactory for all conditions. The method used should depend on the type of material with which the slide is to be coated. The method of O'Kane et al. (1930) was chosen for this study as the extracted materials were in solution, which made this method lend itself to the situation.

Measuring Contact Angles

Numerous methods of measuring contact angles are available. Most researchers have limited these methods to only two or three depending on the angle size and surfaces available. These main methods are capillary rise, tilting plate, and drop on plate.

Capillary rise

This method consists of calculating the contact angle from the experimental rise of liquid of known surface tension in a capillary tube with a known radius. Puri (1949) used this method to calculate the contact angle of sand particles of uniform size coated with stearic, palmetic and myriatic acids.

Numerous investigators have used micro-photography of the liquid surface to measure the contact angle by capillary rise. Exact dimensions of the capillary must be accurately known for this method and a smooth even organic coating in the capillary may be difficult to obtain.

Tilting plate

This method seems to be quite popular and accurate for measuring small angles of contact. It consists of tilting a plate, coated with solid material to be tested, in the liquid until the surface of the liquid at the

solid liquid interface shows no curvature. The angle is then measured with a protractor mounted on the tilting plate. Certain refinements have been used for accurate measurements of small angles and are described by Adam and Jessop (1925) and Ihrig and Lai (1957). This method also necessitates a smooth even surface for good results which may be difficult to obtain with many materials.

Drop on plate

This method is quite widely used. The contact angle can be found by direct measurement of photographs of the drops as was done by O'Kane et al. (1930) or can be calculated with measured dimensions of the drops as had been done by Adam (1938), Baruël (1953), Bartell and Zuidema (1936), Bigelow and Brockway (1956), Mack (1936), Mankowich (1953), and numerous others.

One variation of this method which is the measurement of height and width of a small drop as was used by Bigelow and Brockway (1956), Mack (1936), and Mankowich (1953) was chosen for this study because of the following reasons as enumerated by Mack (1936).

1. The methods applicability is largely independent of the form of the solid surface.

2. Small drops may be applied to small plane areas on irregular surfaces.

3. Small drops show a greater variation in height for small angle changes.

4. Small drops assume the advancing angle of contact while large drops fluctuate between the advancing and receding angles.

5. The theory of a spheroidal segment method of calculation can be used because the shape of a small drop having an acute angle of contact is only slightly affected by gravity.

Other Factors to be Considered

Evaporation

If the dimensions of the drop are not measured quickly, it would be expected that they would change radically due to evaporation unless they were in a saturated atmosphere. Kawasaki (1958) studied drop evaporation from surfaces of high polymer solids and found that the size of the droplet decreases vertically as evaporation proceeds on the surface of ebonite or Bakelite whereas the lateral dimensions of the droplet decrease only at the last stage of evaporation. He found from the surface of petrolatum or paraffin the droplet got smaller uniformly. It took more time for a droplet to evaporate completely with large contact angles.

Roughness

Adam (1938) has found that if surfaces are markedly rough, the calculated contact angle will not be the true angle but will be larger than the true angle if the true angle is greater than 90° and vice versa. This is substantiated by Cassie (1948) and Wenzel (1936).

Bikerman (1950) and Shuttleworth and Bailey (1948) do not agree with this. Bikerman (1950) found that surface roughness had no definite effect due to mutual cancellation of grooves and ridges. Shuttleworth and Bailey (1948) say that inevitable roughness of solids is sufficient to explain hysteresis. Further research is necessary to be sure of effects of roughness.

MATERIALS AND METHODS

Six soils were used in this experiment. The six soils were chosen because of their expected organic differences due to the soil forming factors. Two sets of soils with similar soil forming factors were chosen to study possible differences which might be encountered. A description of each of the soils is presented in the Appendix. Two of the samples taken from the Mocassin station had different treatment history over the previous four years. One sample had been cropped annually for four years and the other sample had been in grass for four years. These two samples were from a Judith-Danvers complex. The treatment history of the other soils is not known.

For extraction of the organic material for contact angle study the soil samples were air dried and crushed to pass a 2 mm sieve. Rocks and fibrous material not passing through the sieve were discarded. The soils were thoroughly leached with cold distilled water to remove any excess salts and cold water soluble organic matter by mixing fifty grams of soil and 200 ml of water in an Erlenmeyer flask and agitating for 30 minutes on a rotating shaker. The samples were then decanted and filtered under suction until a total of one liter of water had been used for leaching. The soil was then transferred to Buchner funnels and washed with an additional 250 ml of cold distilled water. The samples were then dried and crushed to pass a 2 mm sieve.

Three pure organic solvents, one mixture of organic solvents, and hot water were used to extract the organic matter each on a fresh soil sample. These solvents were chosen rather than alkalies or acids because the

materials extracted should be less susceptible to chemical change and on
evaporation should leave no residue of the solvent. The pure solvents
were: ethanol, chloroform, and ether. The mixture was benzene and
methanol in a ratio of 10:1 respectively. After extraction, a precipitate
was noticed in the ethanol extract so the cold soluble and insoluble were
separated by centrifugation. This made a total of five organic extracts.
The hot water was used on just two soils to find if it would give an extract
with a measurable contact angle. It was found that these angles were small
and difficultly measurable by the method used so this extract was excluded
from further study.

All extractions were carried out in soxhlet apparatus. The extraction
thimble of a soxhlet apparatus was filled with approximately 100
grams of soil. Enough extractant was used to maintain a safe level in
the evaporating flask at all times. Cheese cloth was placed on top of
each sample to prevent splashing of the soil out of the extraction capsule.
A thermometer was placed in the sample for one extraction with each solvent
except ether to determine the approximate temperature at which the extrac-
tion was taking place. Since the boiling point of ether is approximately
room temperature, the extraction temperature was not measured. This is
because the increase in temperature for extraction would have been
negligible. The extraction temperatures are presented in Table 1. After
extraction, each solution was concentrated by evaporation. The extracts
were then stored in the refrigerator until such time as the slides were
coated.

Three inch by one inch glass microscope slides were used for bases

Table I. Extraction Temperatures (in degrees centigrade) of solvents
used in extraction of soil materials with a soxhlet apparatus.

Solvent	Boiling Point STP	Extraction Temperature
Ethanol	78.5	70.0
Chloroform	61.3	53.9
Ether	34.6	
Benzene-Methanol 10:1	80.1-64.7	55.6
Water	100	70.0

to coat with the extracted organic materials. Bigelow and Brockway (1956) report that glass microscope slides have surfaces which are highly polished to a uniform smooth condition. The slides were washed in hot detergent, rinsed in hot water, and placed into cleaning solution for a period of 15 minutes, rinsed again in hot water, distilled water, and finally hot distilled water before being dried in an especially clean oven as was done by Bigelow and Brockway (1956).

To coat the slides the extracts were heated to boiling and enough of the extract was put on the slides to facilitate as good a coating as possible. The solvents were then allowed to evaporate and the coated slides were stored in a dessicator until used for contact angle measurements.

The contact angle was determined with small drops of distilled water placed on the slides by means of a hypodermic syringe with an especially fine hypodermic needle and micrometer screw controls allowing the size of the drop to be controlled. In placing the drops, homogenous appearing areas were used for best duplication of results. The height (h) and width (w) of the drops were measured with a Gaertner measuring microscope with filar micrometer eyepiece. The height of the drop was always measured first. The equipment had a total magnification of 32 diameters which is sufficiently accurate for readings to within .001 mm. Readings should be multiplied by approximately .78 to convert to mm. This was not done as a ratio is used in calculating contact angle.

The slides were mounted on a microscope stage and could be moved in two directions horizontally for adjustment. The microscope was mounted

so that it could be adjusted in elevation. An adjustable fluorescent lamp was used for lighting. Humidity and temperature were not controlled nor were records kept of them during drop measurements.

The acute contact angles (Θ) were calculated from their maximum height (h) and width (w) by use of the formula $\tan \Theta/2 = \frac{2h}{w}$. This formula was originally derived by Mack (1936) and according to Bigelow and Brockway (1956) is applicable to drops up to .5 mm in diameter. Bartell and Zuidema (1936) report this formula is accurate for larger drops provided the contact angle is less than 90o. The drop sizes were less than .5 mm in diameter.

The obtuse contact angles (Θ) were calculated from their maximum height (h) and width (w) also by the formula $\sin (\Theta - 90) = \frac{2h}{w} - 1$. This was done because the formula $\tan \Theta/2 = \frac{2h}{w}$ is only true for angles less than or equal to 90°. If the width (w) is the width of the solid-liquid interface instead of the width of the drop, it is also true for angles greater than 90°. All measurements taken were drop width and not solid-liquid interface widths. A brief derivation of each formula is given in the Appendix. The angles reported are an average of the computed angle from measurements of 20 or 30 drops.

Standard statistical analysis of variance with an F test and Duncan's multiple range test was run on the average contact angle values.

One-third and fifteen atmosphere moisture holding capacities of each soil before extraction and after extraction with each solvent were determined.

The drying curves of four of the soils were determined. These dry-

ing curves were determined in triplicate for cores 3 inches in diameter by 3 inches high after being wetted under 5 cm. tension. The cores were then made air tight except for the 3 inch diameter surface and weighed daily for 40 days. At the end of the drying period the final moisture content was determined.

RESULTS AND DISCUSSION

Table II shows the average value of the calculated contact angles from measurements of 20 or 30 drops (10 drops per slide) for each extract. All slides coated with the materials extracted had finite angles of contact with distilled water when originally dry. Except with the materials extracted with hot water, the contact angles were quite different from zero. The results of an analysis of variance and Duncan's multiple range test are presented in Tables III and IV respectively. If the mean contact angle of water with an extracted material was at least 5.22 degrees different from another mean, according to Duncan's multiple range test the two are different at the 1% level. It was not necessary in all cases for the difference to be as great as 5.22 degrees but in no case could it be less than 4.59 degrees and still be significantly different at the 1% level. As the table is presented, letters of the alphabet are used to show differences. If the set of letters for one treatment (a treatment is the average contact angle of the material extracted with a given solvent from a given soil) has at least one like letter in the set of letters for the treatment with which it is being compared, then the two treatments are not significantly different at the 1% level. If there are no like letters in any two sets, then they are different.

It is of interest to note that all sources of variation have a highly significant F value. This highly significant F value for variation due to extracts might not be expected in light of the work of Schnitzer et al. (1958). They used various extractants on the B_2

Table II.   Average contact angle (in degrees) for materials extracted with
            different solvents from six soils.

Soil	Ethanol* Hot Soluble	Ether	Benzene Methanol	Chloroform	Ethanol** Cold Soluble	Water
Loberg	117.3	110.2	109.6	109.0	38.9	20.8
Bozeman	109.0	81.8	89.9	98.8	58.8	
Mocassin(Grass last 4 years)	124.4	108.8	112.8	123.5	42.6	
Mocassin(Cropped last 4 years)	122.1	110.5	90.9	102.1	40.6	
Huffine	124.4	130.2	102.2	101.4	59.1	
Amsterdam	128.7	122.0	97.8	103.0	64.5	14.8

*   Ethanol Hot Soluble – These are the materials extracted with hot ethanol
     which precipitated out on cooling.

**   Ethanol Cold Soluble – These are the materials extracted with hot ethanol
     which did not precipitate out on cooling.

Table III. Analysis of variance for contact angles of materials extracted
with different solvents from six soils.

Source of Variation	D. F.	Sum of Squares	Mean Square	Calculated F Value
Among Treatments∤	29	471,773.25	16,268.0	470.2*
Extracts	4	414,596.97	103,640.2	2,995.6*
Soils	5	27,267.06	5,453.4	157.6*
Soils x Extracts	20	29,909.22	1,495.5	43.2*
Within Treatments (Error)	620	21,468.06	34.6	
Total	649	493,241.31		

∤ A treatment is the average contact angle of the material extracted with
a given solvent from a given soil.

* Significant at 1% level.

Table IV. Multiple range test for contact angles of extracts of six
soils. See explanation below.

Soil	Ethanol* Hot Soluble	Ether	Benzene Methanol	Chloroform	Ethanol** Cold Soluble
Amsterdam	A B	C D E	I	H	L
Huffine	B C	A	H I	H I	M
Mocassin(Grass last 4 years)	B C D	G	F G	H	N
Mocassin(Cropped last 4 years)	C D E	G	J	H I	N
Loberg	F	G	G	G	N
Bozeman	G	K	J	H I	M

If any treatment has at least one letter like one letter of another treat-
ment, the treatment means are not significantly different at the 1% level.
If no letters are alike, they are significantly different.

* Ethanol Hot Soluble - These are the materials extracted with hot
ethanol which precipitated out on cooling.

** Ethanol Cold Soluble - These are the materials extracted with hot
ethanol which did not precipitate out on cooling.

horizon of a podzol profile and found that the non-dialyzable portion
of the extracts had carbon contents which ranged between 40 and 50 per-
cent. They said this suggested that all extractants removed essentially
a similar type of material. This highly significant F value indicates
that fractionation with different solvents might be plausible. The most
notable difference between extracts is between the hot ethanol and cold
ethanol treatments. At the time of drop measurement it was noted that
hot ethanol extracted materials which were insoluble when cold appeared
waxlike whereas the materials soluble when cold appeared more like a
grease. Except for one low treatment value from the other extractable
materials and two low treatment values from the benzene-methanol
extractable materials, all of the materials extracted with one solvent
were generally in the same range. In general, materials extracted with
hot ethanol had the largest contact angles. The materials extracted
with hot ethanol and soluble in cold ethanol had the smallest contact
angles.

The highly significant F value for variation among treatments also
points out interesting information. Although the hot ethanol soluble
materials had the largest overall contact angle, the largest individual
contact angle was with the ether extracted material from the Huffine
soil. The lowest individual contact angle was with the cold ethanol
extracted materials from the Loberg soil. The Loberg soil, having a
forest vegetation, had the greatest amount of oxidizable organic matter
of all soils used. (Table V) Thus, kind rather than amount of organic
matter appears to control contact angles. This might be explained by the

Table V. Oxidizable organic matter (in percent)*

Soil	% Organic Matter
Amsterdam	3.0
Huffine	2.1
Mocassin (Grass last 4 years)	3.5
Mocassin (Cropped last 4 years)	3.4
Loberg	10.8
Bozeman	5.5

* Modified Walkley-Black method, Jackson, M. L., Soil Chemical Analysis, Prentice-Hall, Inc. Englewood Cliffs, N. J. 1958. P. 219-221.

fact that the organic matter had not reached the advanced stage of decomposition in the forest soils that it had in the cultivated soils. It is possible that the materials more resistant to decomposition have a larger contact angle. Further study would be necessary to prove or disprove this.

The variation due to soils had a highly significant calculated F value also. In general the materials extracted from the Amsterdam and Huffine soils had the largest contact angles and the materials from the Bozeman sample had the smallest contact angles. Again it is interesting to note that materials extracted from soils with the smallest amount of organic matter (Huffine and Amsterdam) had the largest contact angles and the materials extracted from a soil with a larger amount of organic matter (Bozeman) had the smallest contact angles. The contact angles of materials extracted from the Bozeman and Huffine soils (two genetically similar soils) had different values.

The variation due to soils by extracts had an F value which was also significant at the 1 percent level. This indicates that soils do not have a similar distribution of the same organic materials because the contact angles of the extracted materials did not have the same trend for all soils with the different extractants. Some noticeable differences are the values of the contact angles of like extracts from similar soils. The two similar Chernozems (Huffine and Bozeman) had different contact angles for three of the five extracts. The materials from the Bozeman sample had lower contact angles in every case. The contact angle of the benzene-methanol extracted materials from the two

Mocassin samples had different values with the annually cropped sample having the lower value.

The small value of the error term should be mentioned. This small value indicates good precision of the calculated contact angles. The hot water extracted materials had the smallest contact angles but were not included in the statistics due to insufficient data.

The results of one-third and fifteen atmosphere moisture contents are presented in Tables VI and VII respectively. These samples were run in duplicate. There is a tendency for all extracted soils to hold more water than unextracted soils. This might be due to structural deterioration resulting from removal of part of the organic material or it might be due to a change in the wetting characteristic of the soils. Further study is needed on this point.

The drying curves of the two sets of similar soils are shown in Figures 1 and 2. The Bozeman and Huffine samples had different drying curves but at the end of forty days had lost a difference of only a few grams. The final moisture contents were 3.2% for the Bozeman sample compared to 4.1% for the huffine sample. In contrast the two Mocassin samples had similar shaped curves but the sample which had been in grass for the last four years lost about twenty grams of water more than the other. The final moisture contents were 4.5% for the sample cropped for the last four years compared to 5.1% for the sample in grass. In both cases the samples which had lost the most water had the higher amount left and therefore held more water originally. The drying curves indicate soils, from which materials with generally larger

Table VI. One-third atmosphere moisture content (in percent) for soils before and after extraction with each solvent.

Soil	Before Extraction	Ethanol	Ether	Benzene Methanol	Chloroform	Water
Loberg	38.8	43.9	40.7	38.8	41.8	44.0
Bozeman	32.8	34.6	35.0	33.2	38.9	
Mocassin(Grass last 4 years)	27.3	29.7	33.5	25.6	29.7	
Mocassin(Cropped last 4 years)	29.6	29.6	28.6	26.3	24.5	
Huffine	33.0	33.5	28.1	36.8	30.2	
Amsterdam	26.3	30.0	34.5	30.4	36.5	30.5

Table VII. Fifteen atmosphere moisture contents (in percent) for soils before and after extraction with each solvent.

Soil	Before Extraction	Ethanol	Ether	Benzene Methanol	Chloroform	Water
Loberg	16.2	19.0	20.4	21.0	18.6	21.1
Bozeman	12.5	12.0	15.4	13.9	14.2	
Mocassin(Grass last 4 years)	15.3	15.8	16.4	14.4	14.9	
Mocassin(Cropped last 4 years)	16.7	15.0	20.5	14.9	14.3	
Huffine	12.4	13.0	12.1	12.0	12.8	
Amsterdam	13.3	13.3	15.4	16.0	11.9	14.0