A CHEMICAL ANALYSIS OF THE SOILS OF

DENTON COUNTY, TEXAS

APPROVED:

[Signatures]

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A CHEMICAL ANALYSIS OF THE SOILS

OF

DENTON COUNTY, TEXAS

THESIS

Presented to the Graduate Council of the North Texas State Teachers College in Partial Fulfillment of the Requirements

For the Degree of

MASTER OF SCIENCE

By

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CHAPTER I

THE SOILS OF DENTON COUNTY

The strata underlying Denton County consist of marine sediments, generally calcareous. In the prairie regions of the county these strata range from calcareous clays and marls to chalk and limestone; in the East Texas Cross Timbers the strata consist for the most part of unconsolidated beds of sand and clay which have been cemented in places to iron-bearing sandstone. Under the western prairie belt we find the older and harder rocks which belong, geologically, to the Lower Cretaceous period while the formation underlying the Black Prairie in the eastern section of the county, and the Cross Timbers in the central portion belong to the Upper Cretaceous period. The following map shows the extent of each of these three physiographic divisions of the county.
The soils of Denton County are divided into three general groups with respect to origin: first, those formed in place by the weathering of consolidated rocks, second, those formed from the weathering of unconsolidated rocks including strata of sand and clays of low lime content, and marls and chalky material, third, alluvial soils which have been formed by recent deposits of soil material from the overflow of streams.

The prairie in the western part of Denton County is underlaid by the Fort Worth formation of calcareous rock. The depth of the soil varies from a few inches to several feet, depending upon its location. The black soils of the western prairie have been grouped in the San Saba series, and the brown soils in the Denton series. A narrow strip along the eastern edge of the Fort Worth prairie is somewhat different, and it is known as the Gainesville Prairie. Here the soils are reddish to brown and chocolate colored, and contain considerable amounts of ferruginous sandstone. The soils of this area are grouped in the Durant series.

The Gainesville Prairie is joined on the east by the Woodbine formation which underlies the East Texas Cross Timbers and consists of unconsolidated sediments of sand and clay. The principal soils derived from these materials are fine sandy loams ranging in color from red to brown and gray with red and yellow subsoils. These soils belong to the Kirvin, Norfolk and Tabor series.
The Black Prairie on the eastern side of the county is underlaid by the Eagle Ford formation which consists of deep bituminous or calcareous clays. The principal soils derived from these materials are black and brown in color, and belong to the Houston, Suster, and Ellis series. Most of the high, rolling surface of this prairie region is covered by an old alluvium which gives the Bell clay, high-terrace phase. The extreme southeastern portion of the county is underlaid by the Austin Chalk formation. The Austin Chalk has weathered into shallow soils, mostly dark, and generally classed with the Houston series. These soils are generally calcareous, especially the dark colored prairie soils. On steep slopes the chalk is sometimes exposed and the soil is very stony. The following map shows the extent of each of these formations and the soils found in each region.
The soils of Denton County derived entirely or to a large extent from consolidated sedimentary rocks are correlated in the San Saba, Brackett, Crawford, and Denton series. Those derived entirely or largely from unconsolidated calcareous sedimentary strata are correlated in the Houston, Wilson, Sunter, Crockett, and Ellis series. Those derived from the unconsolidated noncalcareous marine sediments are correlated in the Kirvin, Tabor, Durant, and Norfolk series. The alluvial soils along the streams are correlated with the Frio, Trinity, Ochlockonee, and Catalpa series, and the older alluvial or terrace soils above overflow are included in the Simmons, Lewisville, Cahaba, Leaf, and Bell series.

The following table gives the relative extent of the most important soils in the county as mapped by William T. Carter and H. W. Beck.

<table>
<thead>
<tr>
<th>Soil</th>
<th>acres</th>
<th>per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>San Saba clay</td>
<td>112,256</td>
<td>18.6</td>
</tr>
<tr>
<td>Denton clay</td>
<td>79,296</td>
<td>13.2</td>
</tr>
<tr>
<td>Kirvin fine sandy loam</td>
<td>52,288</td>
<td>10.5</td>
</tr>
<tr>
<td>Stony phase</td>
<td>10,016</td>
<td></td>
</tr>
<tr>
<td>Bell clay, high terrace phase</td>
<td>36,224</td>
<td>6.0</td>
</tr>
<tr>
<td>Frio clay</td>
<td>32,512</td>
<td>5.4</td>
</tr>
<tr>
<td>Houston clay</td>
<td>15,744</td>
<td></td>
</tr>
<tr>
<td>Spotted phase</td>
<td>10,316</td>
<td>5.0</td>
</tr>
<tr>
<td>Shallow phase</td>
<td>3,520</td>
<td></td>
</tr>
<tr>
<td>Trinity clay</td>
<td>27,150</td>
<td>4.5</td>
</tr>
<tr>
<td>Tabor fine sandy loam</td>
<td>24,128</td>
<td>4.0</td>
</tr>
<tr>
<td>Durant fine sandy loam</td>
<td>16,448</td>
<td>2.7</td>
</tr>
<tr>
<td>Brackett stony clay</td>
<td>16,192</td>
<td>2.7</td>
</tr>
<tr>
<td>Lewisville clay</td>
<td>15,336</td>
<td>2.6</td>
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<table>
<thead>
<tr>
<th>Soil</th>
<th>Acres</th>
<th>Per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wilson fine sandy loam</td>
<td>15,872</td>
<td>2.5</td>
</tr>
<tr>
<td>Catalpa clay</td>
<td>15,232</td>
<td>2.2</td>
</tr>
<tr>
<td>Wilson clay</td>
<td>13,576</td>
<td>2.2</td>
</tr>
<tr>
<td>Durant loam</td>
<td>11,640</td>
<td>2.0</td>
</tr>
<tr>
<td>Simmons clay</td>
<td>11,456</td>
<td>1.9</td>
</tr>
<tr>
<td>Cahaba fine sandy loam</td>
<td>9,344</td>
<td>1.6</td>
</tr>
<tr>
<td>Kirvin clay</td>
<td>9,280</td>
<td>1.5</td>
</tr>
<tr>
<td>Ochlockomes fine sandy loam</td>
<td>7,552</td>
<td>1.5</td>
</tr>
<tr>
<td>Ellis clay</td>
<td>7,286</td>
<td>1.2</td>
</tr>
<tr>
<td>Denton stony clay</td>
<td>6,528</td>
<td>1.1</td>
</tr>
<tr>
<td>Crockett clay</td>
<td>6,144</td>
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<tr>
<td>San Saba silty clay loam</td>
<td>5,760</td>
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<td>Houston black clay</td>
<td>5,312</td>
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<tr>
<td>Wilson loam</td>
<td>4,600</td>
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<td>Sumter clay</td>
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<tr>
<td>Durant clay</td>
<td>3,328</td>
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<tr>
<td>Norfork fine sand</td>
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<tr>
<td>Frio silty clay loam</td>
<td>2,368</td>
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<tr>
<td>Cahaba clay loam, black</td>
<td>2,240</td>
<td>0.4</td>
</tr>
<tr>
<td>Frio fine sandy loam</td>
<td>1,600</td>
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<tr>
<td>Leaf fine sandy loam</td>
<td>1,280</td>
<td>0.2</td>
</tr>
<tr>
<td>Crawford clay</td>
<td>1,216</td>
<td>0.2</td>
</tr>
<tr>
<td>Rough stony land</td>
<td>576</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>602,240</strong></td>
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It will be noted from the above table that the most important and extensive soils in the country are the San Saba clay, Bell clay, high-terrace phase, Denton Clay, and Kirvin fine sandy loam.
CHAPTER II

COLLECTION AND DESCRIPTION OF SAMPLES

Laboratory Sample No. 1. San Saba clay. Samples were taken of this soil because it is the most extensively occurring soil in the Fort Worth Prairie region, and it is the most typical soil found there. The sample selected was taken about three miles north and east of Denton, Texas, just off the road to Aubrey. An area was found here which Mr. W. E. Roane, soil mapper of the U.S. Soil Conservation Survey, selected as being very typical San Saba clay, and typical of the soils of the western prairie. Mr. Roane, who was present at the time the samples were taken, judged this particular area as being the most nearly virgin soil of any mapped in Denton County. Very little erosion had taken place at this point since the land was generally level and covered with vegetation.

The samples were taken with the soil auger, the surface soil being taken down to 14 inches before striking subsoil. Samples from two nearby points were taken, and were later mixed in equal proportions with the first.

This soil is black, contains small calcareous concretions, and is apparently quite fertile.

Laboratory Sample No. 2. Bell clay, high-terrace phase. The prevailing soil type of the eastern part of the county is the Bell clay, high-terrace phase. This soil is black, or
a dark bluish grey, and this color extends downward 10 to
12 inches in most localities.

A sample was taken from the Bell clay about one mile west
of Navo, just off the road to Denton. The surface soil in the
area sampled extended downward 12 inches where bluish-grey,
plastic subsoil is found. The samples were taken with
the soil auger in the usual way to a depth of 12 inches. Vir-
gin soil was impossible to find; hence a sample was taken from
a level field where little erosion had taken place.

Laboratory Sample No. 3. Kirvin Fine Sandy Loam. Kirvin
fine sandy loam is the prevailing type of soil derived from
the Woodbine formation. It is generally a brown to reddish
brown in color, noncalcareous, with a red to yellowish plas-
tic clay subsoil. The surface soil has a loamy texture.

Samples of surface Kirvin were taken as usual with the
soil auger in a sparsely wooded section about one mile west
of the Elm Fork bridge of the Fishtrap road. Several samples
were taken from different localities and mixed in equal pro-
portions.

This soil had never been cultivated and was the nearest
approach, apparently, to virgin soil that could be found.
However, some sheet erosion had evidently taken place here
and some leaching might be expected. The soils are, as a
rule, badly eroded.
CHAPTER III
CHEMICAL ANALYSIS

Preparation of Samples for Analysis. The soil samples collected as previously described were placed in cardboard boxes, the soil spread out, and allowed to air-dry in the balance room of the Science Building, away from laboratory fumes, for eight days. After this time the samples were taken separately and ground in porcelain mortars. Rocks of appreciable size were removed by hand and later by screening. After the lumps of soil were reduced to a fine state they were passed through a sieve of 1 mm. openings. Rocks and roots were removed by this method as well as by hand picking. The soil was sifted on to a square piece of cotton cloth. The soils in each case were resifted, and caught again on the cloth. Then the soil was intimately mixed by pulling up the corners of the cloth and rolling it from corner to corner, mixed with a large horn spoon and rolled again. This was to insure complete mixing of the coarse and fine particles of the soil since they might possibly be of different composition.\footnote{Silt, sand, clay, and other components would tend to sift out separately.}

The soil was in a fine, pulverized state after sifting, and seemed to be perfectly air dried. In each case the samples were put in bottles having air-tight lids and then
labeled. The samples were then stored for later analysis. The samples prepared were San Saba clay surface soil, Kirvin fine sandy loam surface soil, and Bell clay surface soil.

**Determination of Moisture at 100°.** A sample of two grams of soil was taken, placed in a wide-mouth weighing bottle, and heated at 100° to constant weight. The loss in weight was calculated as percentage of moisture in the moisture-free sample.

**Loss on Ignition.** A small sample of soil was ignited to full redness in a porcelain crucible until all organic matter was destroyed. Since appreciable amounts of carbonates were destroyed, the samples were cooled, moistened with a few drops of saturated ammonium carbonate solution, dried and heated to a dull redness to expel the ammonium salts. The samples were then cooled, weighed, and the loss in weight calculated to percentage on the moisture-free basis. This result was recorded as "loss on ignition".

**Carbonate Carbon.** This determination necessitated the building of a duplicate shaking apparatus so that all the gaseous CO₂ might be evolved and collected. This apparatus consisted of a horizontal holder some 20 inches in length, having properly placed slots made to fit loosely the neck of a 300 cc. Erlenmeyer flask taking a No. 6 rubber stopper. This horizontal holder was suspended from a horizontal bar by brass

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1 This is a rough measure of organic matter if little combined water is present. It also includes ammonia and other gases.
strips two inches wide and some 24 inches in length. In each of the two flasks there was a dropping funnel of 100 cc. capacity and a tube connected the openings of the dropping funnel to a 300 cc. flask half filled with concentrated NaOH solution. Air was made to pass through the alkali before being swept into the evolution flasks to purify it of atmospheric CO₂.

The driving wheel of the agitator was some seven inches in diameter and 3/4 inch thick. The driving shaft attached to its face was made of wood of 3/4 inch thickness and was about 18 inches in length. It was connected to one end of the horizontal holder with a wooden pin which permitted free rotation. The driving wheel was connected by means of a short shaft to an electric motor which had an adjustment so that the motion of the holder could be regulated at will.

The outlet for the evolution flasks passed through a safety bulb, and then on to the bottom of the absorption towers which were some 25 inches in height and 3/4 inch in diameter. They contained alternating pockets of glass rods and bits of crushed porcelain. The tops of the absorption towers were fitted with corks carrying glass tubing which led to the suction apparatus.

The above apparatus was a modification of the apparatus suggested by the Association of Official Agricultural Chemists, designed by Thos. A. Willard, and constructed by the author of this paper.

1 Official and Tentative Methods of Analysis, P. 2.
Samples of soil, prepared as heretofore described, were weighed, 25 grams of Kivin fine sandy loam, 25 grams of Bell clay, and a 5 gram sample of San Saba clay. The smaller sample in the last was necessitated by the large amount of carbonate found in it.

The samples were introduced into the 300 cc. evolution flask and the entire apparatus aspirated for five minutes to free it of atmospheric CO₂. Then 25 cc. of approximately 0.5 N NaOH solution was introduced into the absorption towers. Then 60 cc. of HCl (1+9) containing 5 per cent of SnCl₂ was introduced upon the soil. Suction was applied and the intake of air regulated to 3-4 bubbles per second. Agitation and aspiration were continued for 60 minutes. The absorbent solution was then drawn off and the towers thoroughly rinsed with CO₂-free water. Sufficient BaCl₂ solution was added to precipitate all of the carbonate, the solution made up to volume, and allowed to stand four hours. Then an aliquot part was titrated for excess of alkali. The author made the following change from the method of the Association of Official Agricultural Chemists in standardizing the absorbent solution. Standard NaOH solution, free from carbonates, is difficult to prepare, so a fairly pure solution of NaOH was used for the absorbent solution though it contained small amounts of carbonates. The same volume of approximately 0.5 N NaOH as was used in the absorption towers was pipetted into the 250 cc. flask. Water was added and the solution

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treated with BaCl₂ solution, and allowed to stand four hours in the case of the absorbent solutions. Then the excess of alkali in each case, both absorbent and standard solutions, was titrated with standard HCl. From the difference in the original alkali solution and the absorbent solution the amount of carbon dioxide evolved was calculated. Determination of the equivalent quantity of acid needed to titrate the original alkali solution was made with each determination and thus prevented slight changes in the concentration of free NaOH in the solution from vitiating the results.

The results were reported as percentage of carbonate carbon or CO₂. The limit of precision in this analysis as computed from the variations in the analyses is about 2 parts per thousand.

A photograph of the apparatus used in this determination is shown on page 13.

**Organic Carbon.** The determination of organic carbon necessitated a modification of the apparatus used for the determination of carbonate carbon due to the fact that heat must be applied to oxidize the organic matter even in the presence of strong oxidizing agents. This, of course, produces acid fumes which must be prevented from entering the absorption towers, and to trap these fumes certain modifications were devised by the author after finding the tentative method offered by the Association of Official Agricultural

---

1 Official and Tentative Methods of Analysis, pp. 4-5
A photograph of the apparatus used in the determination of carbonate carbon dioxide in the soil. The parts numbered are:

1. Suction flask with suction hose attached.
2. Delivery tubes from evolution flask.
3. Absorption towers.
4. Horizontal flask holder.
5. Driving wheel of motor.
6. Dropping funnels.
7. Brass strips.
8. Air inlet tube from purification flask.
9. CO₂ trap for incoming air.
10. Evolution flasks.
Chemists unsatisfactory. This method called for the insertion of a safety bulb and an empty bead-filled tower between the evolution flasks and the absorbent towers; this was found incapable of stopping the acid fumes which were produced when the oxidizing solution was boiled. Blanks were run using the above apparatus with the absorbent towers filled with distilled water, it was found that in the process of aspiration enough acid fumes were carried over to give a decidedly acid reaction even in the course of a few minutes.

To trap the acid fumes a short spiral water condenser was first inserted in between the evolution flasks and the absorbent towers at a higher level so that the water vapor condensed could return to the evolution flasks. Following the water condenser were a series of three traps, two of concentrated sulphuric acid and chronic acid mixed, and one of pure sulphuric acid. The purpose of these traps was to catch the fumes which might come over, and at the same time to oxidize any carbon monoxide, hydrocarbons, or other gases that might come over. The oxidizing mixture used in the evolution flasks was concentrated sulphuric acid (50 cc.), and 10 grams of $K_2Cr_2O_7$ per sample. After passing through these traps and the gas was led as usual into the absorbent towers, and determined as described in the determination of carbonate carbon.

1 Official and Tentative Methods of Analysis, pp. 4-5.
Smaller samples were used in this analysis than in the preceding one, two grams of Kirvin, and one gram each of Bell and San Saba clay being taken. This determination gives total carbon as carbon dioxide, hence the organic carbon in the total as found here less the amount of carbonate carbon present. The weight of CO₂ due to organic carbon was multiplied by the Van Bemmelen factor of 0.491 to give the percentage of organic carbon.¹ This value is reported as organic matter in the soil.

**Total Nitrogen.** Samples of soil of twenty times the factor weight of nitrogen were weighed out, and placed in a Kjeldahl digestion flask. Then 30 cc. of H₂SO₄ containing two grams of salicylic acid were added, and the mixture allowed to stand for 30 minutes with frequent shaking. Then two grams of zinc dust were added, and the flask shaken vigorously. The mixture was heated over a low flame for some time and then boiled briskly until white fumes no longer escaped from the flask. Then 0.7 gm. of HgO was added and boiling continued until the contents of the flask were almost colorless. Next, sufficient NaOH solution (sp. gr. 1.45) to make the solution strongly alkaline was added by pouring it down the neck of the flask which was inclined so that the liquids in the flask did not mix. The flask was then connected to the condenser by means of a Kjeldahl connecting bulb, care being taken that the tip of the condenser was

¹Robinson, W. O., Methods and procedures of Soil Analysis Used in the Division of Soil Chemistry and Physics, U. S. Department Agri. Circular No. 139.
below the surface of the standard acid in the receiver. The contents of the flask were mixed by shaking, and 150 cc. of liquid distilled over. This generally contains all of the NH₄⁺. The excess of acid was titrated and the per cent of nitrogen calculated.

**Organic and Ammoniacal Nitrogen.** Samples of soil of twenty times the factor weight were weighed and placed in Kjeldahl digestion flasks. Then 0.7 gram of HgO was added and 25 cc. of concentrated H₂SO₄. The flask was then placed in an inclined position and heated below the boiling point of the acid until frothing ceased; then it was boiled briskly until the solution was straw colored. This digestion took approximately two hours.

After the mixture was cooled, it was diluted with 200 cc. of water, a few pieces of granulated zinc were added to prevent bumping, then 25 cc. of Na₂S solution (40 gm. per liter) to precipitate the mercury, and sufficient NaOH poured in as directed above to make the solution strongly basic. The procedure from this point is identical as in the determination of total nitrogen. The percentage of N as organic and ammoniacal was reported.

**Nitrate Nitrogen.** Samples of 50 grams of soil, air dried and prepared as described under "Preparation of Samples" were placed in 600 cc. beakers, and stirred vigorously for five minutes. Then two grams of powdered CaCO₃ were added as a flocculating reagent, the mixture stirred thoroughly, and allowed to stand 20 minutes before filtering.
A very retentive filter paper had to be used (Balistón, No 44) to obtain a clear filtrate.

The filtrate when tested with 1 N HNO₃ solution gave no visible precipitate so the phenoldisulfonic acid method of determination of nitrate nitrogen was chosen.

A volume of 10 cc. of the filtrate was evaporated to dryness over a steam bath; when cool the residue was treated with 2 cc. of the standard phenoldisulfonic acid solution (1 cc. = 0.01 mg. of N). The standard 1 was prepared as follows: Dissolve 0.6070 gram of NaN₃ in one liter of NO₃-free water. Evaporate 50 cc. of this solution to dryness; when cool treat with 2 cc. of the phenoldisulfonic acid solution, rubbing to insure intimate contact, and dilute to 500 cc. One cc. = 0.01 mg. of N. This is a permanent solution. Standards are prepared by adding NH₄OH to measured volumes until maximum color is developed in 100 cc. Nessler tubes. ¹

The soil solution above was diluted with water, and NH₄OH added until maximum color was developed. The solution was transferred to 100 cc. Nessler tubes and made to volume as in the standard solution preparation described above. The amount of nitrogen as nitrates is determined by comparison with the standards.

The method above as outlined by the A. O. A. C. was found to give a low percentage of nitrates due to the fact that the soil was not washed on the filter. The author

¹A. O. A. C., Cit., p. 405
would like to point out the necessity of washing 15 or 20
times on the filter since it was found that otherwise all
of the nitrates will not be obtained in the extract. This
suggestion is supported by the work of Fraps and Sterges in
their estimation of nitric and nitrous nitrogen in the soil. 1

Determination of Silica, Iron, Aluminium, Manganese,
Phosphorus, and Titanium. Two and one half grams of soil,
ground to a fine powder, was mixed with 12.5 grams of
Na₂CO₃ and transferred to a platinum crucible. The cruci-
cible was covered and heated to low redness until fusion
began, and then the heat was increased until a clear, quiet
fusion resulted; finally, the full heat of a Bunsen burner
was applied for 20 minutes. The crucible was removed and
carefully placed in cold water to cool, and then into a
400 cc. beaker. The crucible was covered with water, and
50 cc. of HCl were added to the contents of the beaker. The
beaker was put on a water bath and heated until the fused
mass disintegrated. The crucible was thoroughly washed
and removed, and the contents of the beaker evaporated to
dryness on the steam bath.

The residue from the sodium carbonate fusion was
taken up with HCl (1+9) and filtered. The residue was
washed with hot water containing 5 cc. of HCl per liter.
The filtrate and washings were collected and dehydrated
upon the steam bath until the SiO₂ assumed a crystalline

---

1 Estimation of Nitric and Nitrous Nitrogen in Soils, p. 15.
appearance. The residue was again moistened with HCl and the dehydration repeated for two hours. The residue was then heated at 125° for an hour or more to effect the complete breaking down of the silicic acid. The latter step was found necessary for a reasonably quick determination of silica, and is suggested by W. W. Scott. To the residue was added 5 cc. of HCl and 100 cc. of hot water, the mixture stirred thoroughly, and filtered. The residue was added to the main portion of SiO₂ obtained from the first filtration. The combined filtrate and washings were made up to 250 cc. and saved for subsequent determinations. The two residues of SiO₂ were placed in platinum crucibles with the filter papers and ignited until all of the paper was destroyed, and then heated with a strong flame to constant weight. The weight of the residue was obtained, and then it was treated with HF until all of the silicate was destroyed. The residue from this treatment was weighed and the loss reported as true silica, SiO₂. The residue was fused with K₂SiO₄ and added to the filtrate above.

An aliquot portion of 50 cc. of the filtrate from the silica determination was taken, and to this NH₄OH was added dropwise until the precipitate formed required several seconds to dissolve; thus, the solution was left faintly acid. Then 0.5 gram of ammonium persulphate was added, heated almost to boiling for a few minutes, and NH₄OH was added until

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the odor of NH₃ could be detected. The precipitate was poured immediately upon the filter, and washed with a fine stream of hot 2.5 per cent NH₄NO₃ solution. The precipitate and filter were returned to the original beaker, and 5 cc. of HCl added. The filter was macerated quickly, 50 cc. of water added, and the mixture heated. The oxides were then reprecipitated with ammonium persulphate and NH₄OH as above, filtered, washed with hot 2.5 per cent solution of NH₄NO₃. The filtrate and washings were reserved for the determination of calcium and magnesium.

The precipitate was dried, and then ignited carefully, and then to bright redness after the carbon had been oxidized. The residue was weighed and reported as Fe₂O₃, Al₂O₃, Mn₃O₄, TiO₂, and P₂O₅ combined.

Another aliquot portion of the 50 cc. of the filtrate from the silica determination was evaporated with H₂SO₄ until all of the HCl had been expelled. The solution was diluted, reduced by zinc in the Jones reductor, and titrated with standard KMnO₄ solution. The percentage of Fe₂O₃ was calculated and reported.

The percentages of the oxides of manganese and phosphorus were determined, the procedure for which follows in separate discussions, and the sum of the total weight of oxides. The remainder was reported as the combined oxides of aluminium, Al₂O₃, and titanium, TiO₂.
**Calcium Determination.** The combined filtrates and washings from the determination of the oxides described above were concentrated to about 50 cc. and made slightly alkaline with \( \text{NH}_4\text{OH} \) (1+1). While still hot saturated ammonium oxalate was added to the solution in excess so as to convert both the calcium and magnesium salts into oxalates. The mixture was heated to boiling, and allowed to stand three hours, decanted, and the precipitate rinsed with 15 cc. of hot water. The solution was again decanted through the filter. The precipitate was dissolved in a few drops of \( \text{HCl} \), a little water added, and again ammonium oxalate and \( \text{NH}_4\text{OH} \) boiling hot were added to the solution. The contents of the beaker were allowed to stand as before, and filtered through the same filter. Chlorides were washed out with hot water. The filtrate and washings were reserved for the determination of magnesium.

The determination of calcium was completed by dissolving the precipitate on the filter with hot \( \text{H}_2\text{SO}_4 \) (1+1), collecting in the beaker employed for precipitation, and titrating with standard 0.1 \( \text{N} \) \( \text{KMnO}_4 \). The percentage of \( \text{CaO} \) was calculated and reported.

**Magnesium Determination.** The combined filtrates and washings from the preceding determinations were evaporated to dryness and heated carefully to expel ammonium salts. Then 5 cc. of \( \text{HCl} \) were added and the solution evaporated
almost to dryness again. The salts were dissolved in hot water and a small quantity of HCl. The solution was filtered, and the magnesium of the filtrate and washings precipitated as MgNH₄PO₄ by the addition of 3 cc. of a 10 per cent solution of ammonium phosphate, and sufficient NH₄OH was added, and the precipitation allowed to proceed overnight. The solution was filtered, and the precipitates washed with NH₄OH (1+9), transferred to a porcelain crucible, ignited, cooled, and weighed as Mg₂P₂O₇. The percentage of MgO was calculated and reported.

**Determination of Manganese.** The colorimetric method is perhaps the best method to determine such very small amounts of manganese as is found in these soils. This determination requires that a standard manganous sulphate solution be prepared as follows: 0.2877 grams of pure KMnO₄ are dissolved in about 100 cc. of water, the solution acidified with H₂SO₄ (1+1) and then slowly heated to boiling. Sufficient 10 per cent oxalic acid solution is let in slowly from a burette in sufficient quantity to just discharge the color. The solution is cooled, and diluted to one liter. One cubic centimeter of this solution is equivalent to 0.1 mg. of manganese.

Soil samples dried at 100° for several hours were weighed (5 gram samples) into a porcelain crucible. About 12.5 grams of manganese-free KHSO₄ were mixed with the contents of the crucible, and gently heated for about five
minutes. The heat was gradually increased until a red heat was attained; this temperature was maintained for 20 minutes. A quiet, clear fusion resulted. The contents of the crucible were immersed in about 25 cc. of H₂SO₄ (1+1) in a 250 cc. beaker and digested for an hour on the water bath. The solution was diluted and filtered, and the insoluble residue washed thoroughly. The residue was white, therefore it was discarded.

The filtrate and washings were made up to 250 cc. An aliquot part of 20 cc. was taken, and about 0.5 gram of KIO₄ was added. The solution was boiled until the purplish color of permanganic acid appeared, and then it was heated on the water bath for an hour to complete oxidation. The solution was diluted and transferred to a Nessler tube. Standard solutions of manganese were prepared by boiling aliquot parts of the manganous solution with KIO₄, and aliquot portions of these in Nessler tubes were compared with those of the samples. The per cent of manganese as MnO₂ was calculated and reported.

**Determination of Sulphur.** Ten gram samples of soil, dried at 100° were placed in large nickel crucibles, and mixed with an equal weight of Na₂CO₃. About 4 cc. of water were added carefully to the soil and stirred so as to make the mixture into a stiff paste. Na₂O₂ was added in about one gram portions until the mixture became dry and granular, and a layer of K₂O₂ was then spread over the sample
so as to make the total amount of peroxide about 25 grams. The mixture was heated with two burners to about 400°-500° for 30 minutes, and to 900° for 10 minutes. The cooled contents of the crucible were removed by boiling in water to which 5 cc. of 95 per cent alcohol had been added to decompose any NaMnO₄ that might have been formed. When the suspension was filtered immediately through a Buchner funnel with suction. When no more liquid could be drawn from the residue it was again filtered through the Buchner with suction, and the residue was washed thoroughly with hot water until a total volume of about 700 cc. was attained.

To the filtrate above HCl was added slowly from a burette until all of the carbonate had been neutralized as shown by methyl red. An excess of 0.5 cc. of the HCl was added and the solution evaporated to 400 cc. The solution was heated to boiling, and 10 cc. of a 5 per cent solution of BaCl₂ were added. The precipitation was allowed to proceed overnight.

The very small precipitate was filtered on dense filter paper, ignited, and weighed as BaSO₄. The residue was treated with two drops of hydrofluoric acid and one drop of H₂SO₄ (1+1) and heated again to guard against possible inclusion of SiO₂. The crucible was then reignited and the precipitate weighed as BaSO₄. The percentage of SO₃ was calculated and reported.
Determination of Phosphorus by the Magnesium Nitrate Method. Soil samples of five grams were taken for this determination. The soil samples were treated in a porcelain dish with 7 cc. of magnesium nitrate mixture. This mixture was dried on the water bath and then heated to low redness to drive off organic matter. The dish was then cooled, and 10 cc. of water, 10 cc. of HCl, and 5 cc. of HNO₃ were added. The dish was covered and allowed to digest for two hours on the water bath with occasional stirring. The solution was diluted and filtered. The filtrate was evaporated to dryness in a porcelain dish on the water bath. The residue was taken up with HNO₃ (1+4), and again evaporated to dryness, and heated for one hour at 110°-120°. The residue was taken up with dilute HNO₃ and filtered. The combined volume of filtrate and washings was reduced to 30-40 cc. The solution was made alkaline with NH₄OH (1+1), and the precipitate dissolved in HNO₃. About 15 cc. of the ammonium molybdate solution were added, and the solution was kept at 40°-50° for an hour, and let stand overnight at room temperature. The solution was filtered, and the precipitate washed well with cold water. The filter paper and precipitate were returned to the same container, and the precipitate dissolved in an excess of standard NaOH. The excess alkali was titrated with standard HNO₃ phenolphthalein being used as the indicator. The percentage of P₂O₅

1 This was made by dissolving 150 grams of MgO in HNO₃ (1+1), and avoiding an excess of the acid; a little MgO was added in excess, then the mixture was boiled and filtered. The filtrate made to 1000 cc.
was calculated and reported.

The ammonium molybdate solution used in the precipitation of the phosphorus was made according to the method of Fales, and a brief description is given here of the preparation. Two solutions were made: Solution I consists of ammoniacal solution of ammonium molybdate, made by dissolving 100 grams of ammonium molybdate in 400 cc. of water and 90 cc. of 15 M \( \text{NH}_4\text{OH} \); Solution II is made by mixing 400 cc. of 16 M \( \text{HNO}_3 \) with 600 cc. of water. The solutions are mixed when ready to use by using two volumes of II to one volume of I.

Determination of Potassium and Sodium. Samples of one gram of soil were ground gently with a mixture of 1 gram of \( \text{NH}_4\text{Cl} \) and 8 grams of \( \text{CaCO}_3 \). The mixture was transferred to a platinum crucible, and heated gradually until fumes of \( \text{NH}_3 \) no longer came off, and the lower 3/4 of the crucible brought to red heat. This temperature was maintained for one hour. The fused mass was then transferred to a porcelain dish, slaked with hot water, and ground thoroughly with an agate pestle. The residue was washed five times by decantation with hot water, transferred to a filter, and washed with about 300 cc. of water. Enough ammonium carbonate solution was added to the filtrate to precipitate the calcium and magnesium, and the precipitate allowed to settle. The clear

liquid was decanted and evaporated to 30-40 cc. The precipitate was then transferred to the dish containing the solution, and the volume reduced to 30-40 cc. again and filtered, the filtrate being caught in a porcelain dish. The filtrate was evaporated to dryness on the water bath, and the salts ignited to expel all ammonium salts.

The residual alkali chlorides were dissolved in 5 cc. of water, and 2-3 drops of ammonium carbonate solution and NH₄OH added to the warm solution which was then filtered into a weighed porcelain crucible. The solution was evaporated to dryness on the water bath, and then heated to expel all ammonium salts. The residue was weighed as sodium and potassium chlorides combined.

The combined chlorides were dissolved in 30 cc. of water, and 1.5 cc. of H₂PtCl₆ solution (10 per cent) added. The mixture was evaporated to a sirupy consistency. 15 cc. of 2.25 N acidulated alcohol (prepared by passing HCl into a mixture of 100 cc. of alcohol and 7.6 cc. of HCl) were added, and the solution filtered through an asbestos Gooch. The residue was washed with 80 per cent alcohol, placed in an oven and dried for one hour. The platinic chloride was then dissolved in hot water and the Gooch washed in alcohol again and dried in the oven as before. The difference in weight gives the weight of K₂PtCl₆. The weight of the K₂PtCl₆ was multiplied by the factor 0.194 to obtain K₂O and by 0.307 to obtain KCl.
The amount of NaCl is determined by subtracting the weight of HCl from the weight of combined chlorides. The NaCl was converted to Na₂O and reported as percentage Na₂O.

**Determination of Alkaline Salts.** One hundred grams of soil were weighed out and mixed with 250 cc. of water in a 500 cc. bottle, shaken thoroughly, and allowed to stand overnight. The solution was filtered through an ordinary paper filter due to the fact that no Pasteur-Chamberlain filter was available; consequently, a clear filtrate was not obtainable, and some fine material, especially in the Kirvin soil, could not be retained even with several filtrations through the most dense filter papers.

A 10 cc. portion of the filtrate was given a preliminary test with 1 M AgNO₃ solution. No soluble chlorides seemed to be present for not the slightest precipitate was formed.

Another 10 cc. portion of the filtrate was titrated with 0.1237 N HCl and the result reported as percentage of Na₂CO₃.

**Determination of pH.** The quinhydrone electrode coupled with the calomel half cell was used in the determination of the pH values of the soils. The apparatus was set up as described in Daniels, Mathews and Williams' "Experimental Physical Chemistry". The diagram following
Apparatus for pH Determination
shows the set-up used: B, a battery of two dry cells; R, a slide wire rheostat; G, a galvanometer; E, a salt bridge of saturated KCl solution; C, a calomel (normal) half cell; Q, the quinhydrone electrode; V, a voltmeter; and S, a switch.

Soil samples which had been collected moist and let air dry for 24 hours were used in the determination; all samples were from the same locality as the samples for the chemical analysis. They were ground in a porcelain mortar, and sifted through a 2 mm. sieve. A soil-water ratio of 1 to 2 was used and the mixture was shaken in a test tube for one minute and allowed to stand 20 minutes. The quinhydrone was then added (about 0.15 gram) and the mixture shaken vigorously for ten seconds. The uncoated platinum electrode, and the KCl bridge connecting the two half cells were washed off with distilled water and inserted into the test tube so that the electrode was immersed in the settled soil, and the tip of the potassium chloride bridge was in the upper region of the supernatant liquid. The potential was measured at 10, 20 and 60 seconds from the time of the addition of the quinhydrone to see if the soil was suitable for the quinhydrone method. No cases of "adaptation lag" were found so the values were taken as the correct pH for the three soils.¹ The values of the pH were calculated

from the following formula where $E$ is the measured potential; $t$ represents the temperature in Centigrade:

$$\text{pH} = \frac{0.4143 - 0.00050(t - 25)}{0.0591 + 0.0002(t - 25)} - E$$

Results of Analysis: Average Percentage Composition of Three Soils. The tabulated results below show the composition of the soils analysed as described heretofore:

<table>
<thead>
<tr>
<th></th>
<th>Kirvin fine sandy loam</th>
<th>Bell clay</th>
<th>San Saba clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO$_2$</td>
<td>90.45</td>
<td>77.94</td>
<td>60.97</td>
</tr>
<tr>
<td>Al$_2$O$_3$ + TiO$_2$</td>
<td>2.12</td>
<td>9.49</td>
<td>12.76</td>
</tr>
<tr>
<td>Fe$_2$O$_3$</td>
<td>2.42</td>
<td>4.09</td>
<td>5.11</td>
</tr>
<tr>
<td>CaO</td>
<td>1.34</td>
<td>2.02</td>
<td>7.28</td>
</tr>
<tr>
<td>MgO</td>
<td>0.34</td>
<td>0.57</td>
<td>1.31</td>
</tr>
<tr>
<td>MnO$_2$</td>
<td>0.033</td>
<td>0.025</td>
<td>0.075</td>
</tr>
<tr>
<td>K$_2$O</td>
<td>0.42</td>
<td>0.74</td>
<td>1.10</td>
</tr>
<tr>
<td>Na$_2$O</td>
<td>0.22</td>
<td>0.60</td>
<td>0.66</td>
</tr>
<tr>
<td>P$_2$O$_5$</td>
<td>0.069</td>
<td>0.092</td>
<td>0.16</td>
</tr>
<tr>
<td>SO$_3$</td>
<td>0.12</td>
<td>0.17</td>
<td>0.24</td>
</tr>
<tr>
<td>Ignition loss</td>
<td>2.07</td>
<td>5.52</td>
<td>10.58</td>
</tr>
<tr>
<td>Total</td>
<td>99.60</td>
<td>101.26</td>
<td>100.25</td>
</tr>
<tr>
<td>Total N</td>
<td>0.067</td>
<td>0.086</td>
<td>0.182</td>
</tr>
<tr>
<td>Organic and NH$_3$ N</td>
<td>0.017</td>
<td>0.042</td>
<td>0.153</td>
</tr>
<tr>
<td>Nitrate N</td>
<td>0.028</td>
<td>0.045</td>
<td>0.020</td>
</tr>
<tr>
<td>Organic Matter</td>
<td>1.90</td>
<td>2.43</td>
<td>3.38</td>
</tr>
<tr>
<td>Carbonate CO$_2$</td>
<td>0.00</td>
<td>0.23</td>
<td>3.85</td>
</tr>
<tr>
<td>Loss at 100$^\circ$</td>
<td>0.93</td>
<td>6.18</td>
<td>8.26</td>
</tr>
<tr>
<td>pH</td>
<td>5.93</td>
<td>7.46</td>
<td>7.73</td>
</tr>
<tr>
<td>Na$_2$CO$_3$</td>
<td>0.383</td>
<td>1.15</td>
<td>1.22</td>
</tr>
</tbody>
</table>

*Kolthoff, I. M.,* The Colorimetric and Potentiometric Determination of pH, p. 103.
Remarks and Observations on Results and Methods of Analysis. All percentages in these analyses were calculated on the moisture-free basis. Each sample was dried before weighing except in those cases in which drying at 100° would cause a deviation of results. From the results of an independent determination of the loss of moisture at 100° we get an approximation of the relative amount of water held by each soil. Thus we see that the Kirvin fine sandy loam held very little water, namely 0.93 per cent, while Bell clay held 6.18 per cent of water, and San Saba clay held 8.28 per cent water. This would be expected because Kirvin is largely silica and of coarse, grainy particles of soil of little water-holding capacity, while the two clays are soils of very fine particles which would give them a much greater water-holding capacity.

The loss on ignition in these three soils when compared with the determination of organic matter gives some interesting facts concerning the determination of organic carbon in the soil. Thus it will be seen that in Kirvin, a sandy soil, the loss on ignition closely approximates the determination of of organic carbon, while in the two clays, Bell and San Saba, the loss on ignition was much greater than the organic matter found by the determination of carbon dioxide. This is undoubtedly due to large amounts of combined water which clays are known to carry.  

It is interesting to note how well the amount of combined water in each case correlates with the amount of alumina in the soil.

The determination of the amount of CO₂ in the soil, both as carbonates and as organic matter, was made by the volumetric method rather than the gravimetric, and in the determination of CO₂ as organic matter the "wet oxidation" method was used. Though these proceedings are not generally preferable or widely used, they were used in this work because of the other methods required equipment not available. The accuracy of this method has been previously discussed under methods of analysis, and was shown to be about 2 parts per thousand as derived from the deviations in results. The principal objection to this method is that it is extremely tedious and time-consuming; eight hours of hard work were required to run duplicate determinations on three different soils.

A view of the results on a preceding page shows a very striking difference in the three soils in regard to the carbonate content. Kirvin showed no detectable amount of CO₂ from carbonates; Bell clay had a small amount of CO₂, 0.23 per cent, but the carbonate content of the San Saba clay was very high in comparison, namely, 3.85 per cent. The latter two soils are derived from calcareous rocks, but the first has a noncalcareous origin as previously described. An examination of the calcium content
bears out these results in some measure for we see that the San Saba clay has a high percentage of CaO while the other two soils have a relatively low content. Though calcium exists in a silicate form to some extent, in the two clays analyzed we would expect it to occur in the form of carbonates to some extent, due to the calcareous origin of the soil. The Bell and San Saba soils effervesce with HCl.

The much higher content of carbonate matter in the San Saba as compared to the Bell is likely due to the fact that the latter was sampled from cultivated soil where weathering could take place to a greater extent. Also the Bell clay is an older soil and alluvial in origin. The results seem to concur with the facts which we know about the origin and geology of these three soils.

The determination of CO₂ as organic matter by the wet oxidation and volumetric method used called for a very complicated apparatus previously described. Good checks were obtained by this method, but it is a particularly difficult and time-consuming procedure. The precision of this method is about that of the carbonate determination, namely about 2 parts per thousand. This determination gives the total CO₂; to obtain the CO₂ due to organic matter the percentage of carbonate CO₂ was deducted, and the remainder of the CO₂ multiplied by the Van Bemmelen factor.

*1Merrill, George P., Rocks, Rock-Weathering, and Soils, p.36.
of 0.471. This factor is used by the Bureau of Chemistry, Department of Agriculture, in the calculation of organic matter in the soil.\footnote{Robinson, W.O. op. cit. p. 16.} It is generally recognized that this factor does not take care of all cases, but it is supposed to represent quite satisfactorily the mean ration of CO$_2$ to organic matter.

The San Saba clay contains the greatest amount of organic matter as determined by this method, Bell next and Kirvin least of all. This was due to the fact that the San Saba was not a cultivated soil, but had a heavy covering of wild vegetative matter; the Bell was cultivated, and hence had less opportunity for gaining organic matter from the decay of plant life; the Kirvin, being sampled in a sparsely wooded, noncalcareous area, had even less chance for a high content of organic matter. Very little covering of vegetative matter was found on the soil. Such would not be the case in level, and more heavily wooded areas where accumulations of the leafmold and decaying tree-trunks would materially increase the amount of organic matter.

The determination of silica was found to be a time-consuming process, and one which demanded careful attention. A slight deviation from the procedure recommended by the A. O. A. C.\footnote{Association of Official Agri. Chemists, op. cit., p. 6.} was made, and the author found that in all cases
except those requiring the most painstaking accuracy that some time might be gained by heating the residue from the evaporation of the HCl solution of the fusion mass in an oven at 125° for one hour after subsequent heating of the residue on the water bath. This temperature very effectively breaks down the silicic acid into crystalline SiO₂ far better than several hours on the water bath, or several precipitations with HCl. By following such a procedure it was found that a subsequent evaporation and treatment of the residue with HCl yielded only a negligible amount of SiO₂ in the case where the percentage of SiO₂ was over 90 per cent, and an undetectable amount where the percentages were below 75. Evaporation in large porcelain dishes rather than in beakers was found to greatly increase the rate of evaporation.

The very high percentage of SiO₂ in the Kirvin soil is somewhat abnormal, it seems, due likely to erosion and lack of organic matter in the soil. But it is to be remembered that the origin of this soil is from sandstone and clay, and hence a high percentage of silica would be expected in the sandy soil. A distinct difference would be found in the analysis of the plastic red clay underlying the sandy topsoil, and a higher percentage of ferric oxide and alumina would be expected.

The combined oxides of aluminium and titanium were
determined together by difference as directed by the
Association of Official Agricultural Chemists and as pre-
viously described. The percentage of the latter is gener-
ally small, and need not usually be determined separately.\(^1\) It will be noted that in the three soils that the existence
of these two oxides is much greater in the two clays than in
the sand. Alumina is one of the chief components of clay,\(^3\)
and these results would be expected.

The amount of ferric oxide is much larger in the two
clays than in the sandy Kirvin, but the content of this
substance is generally higher in the clays than in the
sands; therefore, this result is expected.\(^4\)

In the determination of calcium it is to be noted that
two precipitations were used. This was to free the cal-
cium oxalate precipitate of all magnesium oxalate which is;
to some extent, precipitated simultaneously. This greatly
increases the accuracy of the determination for otherwise
0.1 to 0.2 per cent of the magnesium present is precipi-
tated.\(^5\) Though the amount of calcium oxalate was small in
this case, the mass handled here is good to 2 parts per
thousand.\(^6\)

The respective amounts of calcium oxide found in each

\(^2\) Ibid., p. 6.
\(^3\) Wiley, Harvey W., op. cit., p. 254.
\(^4\) Ibid., p. 254.
\(^5\) Fales, op. cit., p. 235.
\(^6\) Ibid., p. 235.
of the soils has been previously discussed in regard to carbonate content.

The amount of magnesium pyrophosphate handled in the determination of magnesium oxide was of necessity small; it would have been difficult to remove all interfering elements if much larger samples had been taken. This method is reputedly good, however, for amounts of magnesium varying from 0.0004 grams to 0.120 grams, though the limits of precision are probably less than 5 parts per thousand. ¹ The smallest amount of the pyrophosphate weighed was 9.7 mg, and the largest was 36.3 mg.; hence we cannot assume that this percentage reported is highly accurate, but perhaps around the 5 parts per thousand limit described above. Fales shows that the greatest error attends here of any determination. ²

The determination of manganese in the soil demanded a method whereby very small quantities of this element could be detected. The colorimetric method offered the most practical way to estimate the occurrence of this element. The accuracy of this method is indicated by the fact that a very distinct difference could be determined in color between 100 cc. of solution containing a difference of only 0.025 mg. of manganese. The fact that only about 1 cc. or more of the standard was used to develop a

¹ Fales, H. A., op. cit. p. 240
² Ibid., p. 240.
a good color in the colorimetric tubes of 100 cc. capacity also indicates the accuracy of this analysis.¹

The occurrence of manganese in such small amounts as reported is interesting only from an academic viewpoint, but it is believed that manganese is indirectly essential as a catalytic agent in certain oxidation processes in the soil and in the plant.²

The occurrence of potash in the soil is highly important, and the value of the soil is dependent upon the amount present. From the results of the analysis it is shown that the Kirvin soil has a low content of potassium, Bell a somewhat higher content and San Saba has a relatively high potash content. The latter soil is known to be more productive than the Kirvin, though it is not always the case in comparison to the Bell clay.

From the procedure it will be noted that a sample of five grams of soil was taken for the analysis of phosphorus. This was due to the very low percentage of phosphorus found in these soils, the percentages ranging from 0.069 to 0.160 of P₂O₅. Due to the small amount of phosphorus encountered here, the alkalimetric method was chosen. The degree of accuracy is about 1 part per thousand.

² Dutcher and Haley, Agricultural Biochemistry, pp. 160-1.
It is to be noted the same general rating of the soils as regards phosphorus hold with the potash content. Again the highest fertility is indicated in the San Saba, Bell next, and Kirvin last.

The total nitrogen content indicates a ranking for each soil in the order, from low to high, Kirvin, Bell, and San Saba. The fact that nitrogen is highly essential to plant growth indicates a fertility ranking which coincides with the ranking in percentage of phosphorus and potassium.

Samples of considerable mass (20 times the factor weight) were taken for the analysis of nitrogen so that the amount of nitrogen would be sufficient to lend to the accuracy of the determination.

Attention might be called to the agreement of the content of ammoniacal and organic nitrogen, determined separately, with the content of organic matter in the soil as determined by previously described methods. On the other hand the percentages of nitrates in the soils do not correspond to the percentages of total nitrogen, but from low to high they are San Saba, Kirvin, and Bell clay. This characteristic, however, may have its explanation in the aerobic conditions of the soil, the moisture content of the soil, and the alkalinity of the soil.¹

Since the San Saba soil sample came from unstirred

soil of almost plastic nature it can be assumed that it did not have access to air as did the more porous Kirvin sand, and not nearly so well as the cultivated Bell clay. Further, moisture conditions are better in the eastern part of the county than in the middle portion and western part of the county.

The determination of the pH of the soil by the quinhydrone method is readily adaptable to use in soil analysis for suspended matter does not interfere. In soils where the content of manganese dioxide is high this method is not usable due to a constant shifting of potential caused by the presence of this oxidizing substance. But in all the soils analyzed here the content of manganese was not sufficiently high to cause an "adaptation lag" in potential.

--Snyder, E. F., op. cit., p. 23.
CHAPTER IV
DISCUSSION

Geology and Origin. San Saba clay is derived from consolidated sedimentary rock of calcareous nature. Kirvin fine sandy loam has its origin in unconsolidated non-calcareous sediments. Bell clay is a high-terrace soil; the alluvium forming this soil has been washed from regions having different origins, but evidently some of these soils were calcareous.

The analyses of the above soils yield results that show a strict correlation with the origin of the soils. San Saba clay being derived from calcareous sediments directly would be expected to have the highest content of calcium and carbonates. Likewise, the content of magnesium agrees in the same respect for this element is generally found in calcareous strata in the form of carbonates. The content of silica would not be excessively high in such a soil, and the percentage found agrees with this supposition.

The lower content of calcium and carbonate carbon in Bell clay agrees with the origin of this soil for it is an alluvial soil, and made up partially at least of soils derived from rocks of different origin. The lack of a layer of calcareous rock immediately underlying this soil as in the San Saba series prevents the formation of further soils through the various agencies of weathering. A very
noticeable decrease in the content of magnesium is found for the same reasons. A higher content of silica is found as would be expected in an alluvial soil.

Kirvin, a soil derived from noncalcareous, unconsolidated sandstone and clays, has a high content of silica but no detectable carbonate carbon; it has a very low content of calcium in comparison with the other soils.

These facts agree with the origin and formation of these soils.

Fertility. According to Hilgard 1 a highly fertile soil is one containing about one per cent of lime, 0.15 per cent phosphoric anhydride, and 0.50 per cent of potash. Due to the fact that a large part of the nitrogen is in the form of compounds which cannot be taken up by plants it is difficult to say how much nitrogen should be present since its change into compounds easily assimilated by the plants depends upon the physical conditions of the soil. However, 0.1 per cent is regarded as adequate 2 but less than 0.07 per cent indicates a need for fertilizer. Further, less than 0.05 per cent of P₂O₅ indicates a serious deficiency in the soil unless large amounts of lime are present. Soils may contain as little as 0.45 percent potash, but less than this is indicative of a great need for fertilizer. The availability of potash is strengthened

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1 Hilgard, E. W., Soils, pp. 352-369.
2 ibid., pp. 354-356.
by lime.¹

According to the above standards the San Saba clay analyzed is a highly fertile soil, for it has 1.10 per cent $K_2O$, 0.16 per cent $P_2O_5$, 7.28 per cent $CaO$, and 0.182 per cent nitrogen. These exceed all the standards for a fertile soil given by Hilgard.

Bell clay has an excess of potash, 0.74 per cent, and plenty of lime, namely 2.02 per cent. It is slightly deficient in nitrogen, having less than 0.1 per cent, and is slightly deficient in phosphorus, though this shortage is not serious in the presence of the amount of lime found here.

Kirvin fine sandy loam has a sufficient quantity of $CaO$ according to the analysis, but the fact that this calcium is not in the carbonate form might indicate a deficiency in this respect. Furthermore, it is deficient in all of the other essential elements, having only 0.42 per cent $K_2O$, 0.069 per cent $P_2O_5$, and 0.067 per cent nitrogen. The deficiency is greatest in the last two elements, and the application of these in fertilizer is needed.

High silica content and low colloidal percentage as found in sandy soil such as Kirvin have been shown to

be highly susceptible to erosion. This, perhaps, explains the low fertility of this soil. High colloidal content as found in clays and low silica would tend to retard erosion in the Bell and San Saba soils, though the higher percolation rate in these soils would accentuate erosion to some extent. These soils are known to retain their fertility much longer than Kirvin.

Crops and Vegetation. "Next to climatic conditions, chief among which are temperature and moisture, the physical and chemical nature of the soils and subsoil is the most potent factor in determining the natural vegetation of any region." We see that a preliminary examination of the soil may determine what crops and vegetation will grow best on it.

The pH of soils and the content of lime is so invariably and intimately connected that this feature will be discussed together in relation to vegetation and crops. Bell and San Saba clays are both prairie soils having an adequate supply of lime, and a pH of 7.47 and 7.73 respectively, while Kirvin fine sandy loam is an acid soil of pH 5.93 with an evident deficiency in lime. Now the lime content of soils has long ago been shown to have a distinct difference in natural vegetation, due possibly

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1 Middleton, Slater, and Byers, op. cit., pp. 19-20.
2 Hilgard, op. cit., p. 487.
3 Ibid., p. 492.
to lime content and pH, and, of course, due to difference in moisture conditions. Bell and San Saba soils are similar in regard to vegetation while Kirvin soils exhibit a different flora. Thus on the first two the most important trees growing, though these are found growing only along the streams and lowlands, are burr oak, box elder, and green ash. The grasses in these regions occurring most abundantly are mesquite grass, big blue stem, golden fruit-ed grass, purple awn grass, and most important of all the side oats grama grass. The most important herbs are the broom weed, snow on the mountain, and Croton. Now in the Kirvin soils the trees occurring most frequently are the black-jack oak, post oak, hickory, and water oak. Hilgard states that the black-jack oak and post oak are good mark-ers for the sandy soils of Mississippi which are deficient in lime and the other essential elements.

The difference in the grasses and trees of these two regions is probably due as much to moisture conditions as anything else since on the open prairie there are no trees to speak of, but the whole of the Woodbine was once, or still remains, forested. The sandy covering of top-soil does much to retain the water in the lower soils for

1 Op. cit., p. 497
it is composed mainly of large grainy particles of sand which are not conducive to capillary movement of water. The fine-grained clays of the prairie regions dry out rapidly due to the rapid movement of water by capillary attractions toward the surface. Thus the prairie soils are likely to become very dry in the summer months, while subsoil water is maintained somewhat better in the Woodbine. Such vegetation as cannot stand long periods of drought is eliminated in time. Trees are very susceptible to drought; hence we can understand their absence in the prairies. "Hard pan" underlying a large part of the Western prairie would not be conducive to tree growth. We might conclude, therefore, that both the chemical and physical nature of the soil have their influence on natural vegetation.

Most cultivated crops grow best in an alkaline soil, but some do best in an acid soil; however, some plants will thrive in either acid or alkaline soils. A few plants are extremely sensitive in regard to the pH of the soil medium. The following data give the optimum condition of alkalinity or acidity in which several crops grow:

<table>
<thead>
<tr>
<th>Crops</th>
<th>Average soil reaction preference in terms of pH</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alfalfa</td>
<td>Neutral</td>
<td>7.0</td>
</tr>
<tr>
<td>Asparagus</td>
<td>Slightly alkaline</td>
<td>7.5-8.0</td>
</tr>
<tr>
<td>Barley</td>
<td>Do.</td>
<td></td>
</tr>
<tr>
<td>Beets</td>
<td>Slightly alkaline</td>
<td>7.5-8.0</td>
</tr>
<tr>
<td>Blueberries</td>
<td>Strongly acid</td>
<td>4.0-5.0</td>
</tr>
<tr>
<td>Cabbage</td>
<td>Slightly alkaline</td>
<td>7.5-8.0</td>
</tr>
<tr>
<td>Carrots</td>
<td>Neutral</td>
<td>7.0</td>
</tr>
<tr>
<td>Cauliflowers</td>
<td>Slightly alkaline</td>
<td>7.1-8.0</td>
</tr>
<tr>
<td>Celery</td>
<td>Do.</td>
<td></td>
</tr>
<tr>
<td>Corn</td>
<td>Neutral</td>
<td>7.0</td>
</tr>
<tr>
<td>Cranberries</td>
<td>Strongly acid</td>
<td>4.0-5.0</td>
</tr>
<tr>
<td>Lettuce</td>
<td>Slightly alkaline</td>
<td>7.1-8.0</td>
</tr>
<tr>
<td>Lima beans</td>
<td>Slightly acid</td>
<td>6.0-6.9</td>
</tr>
<tr>
<td>Oats</td>
<td>Decidedly acid</td>
<td>5.0-6.0</td>
</tr>
<tr>
<td>Onions</td>
<td>Slightly alkaline</td>
<td>7.1-8.0</td>
</tr>
<tr>
<td>Peas</td>
<td>Slightly acid</td>
<td>6.0-6.9</td>
</tr>
<tr>
<td>Potatoes</td>
<td>Decidedly acid</td>
<td>5.0-6.0</td>
</tr>
<tr>
<td>Radishes</td>
<td>Neutral</td>
<td>7.0</td>
</tr>
<tr>
<td>Raspberries</td>
<td>Slightly acid</td>
<td>6.0-6.9</td>
</tr>
<tr>
<td>Red clover</td>
<td>Do.</td>
<td></td>
</tr>
<tr>
<td>Rye</td>
<td>Do.</td>
<td></td>
</tr>
<tr>
<td>Spinach</td>
<td>Do.</td>
<td></td>
</tr>
<tr>
<td>Sugar beets</td>
<td>Neutral</td>
<td>7.0</td>
</tr>
<tr>
<td>Watermelons</td>
<td>Slightly acid</td>
<td>6.0-6.9</td>
</tr>
<tr>
<td>Wheat</td>
<td>Neutral</td>
<td>7.0</td>
</tr>
</tbody>
</table>

The reaction preference for cotton is not given though judging from the fact that the highest yields in the county come from the Bell clays which are alkaline, it would seem logical to assume that such a medium would be best for the growth of cotton.

From the results above we see that water melons, raspberries, potatoes, peas, lima beans, blueberries, and

1 Both yield and quality reported superior at reaction given.
2 Soil Survey of Denton County, op. cit., p. 12.
oats might grow well in the Kirvin soils if the essential elements and moisture were present in sufficient quantity. Undoubtedly fertilizers would be needed in most areas of this soil.

We see that alfalfa, asparagus, beets, cabbage, carrots, cauliflower, lettuce, onions, radishes, sugar beets, and wheat might well grow in the San Saba soils and in the Bell soils as far as pH is concerned. All of the last group have been proved to benefit from the presence of lime, but lime applications are hardly necessary in the prairie regions, but in the Kirvin soils the various fruits, peas, and oats grown would benefit from an application of lime.\(^1\) On the other hand water melons, cowpeas, cranberries and Irish potatoes are injured by lime applications; therefore, it would be assumed that these crops would grow best in the Kirvin soils, but not so well in the calcareous soils, Bell and San Saba clay.

\(^1\) Fraps, op. cit., p. 252
\(^2\) Ibid., p. 252.
SUMMARY

1. A chemical analysis of representative samples of Bell clay, Kirvin fine sandy loam, and San Saba clay has been made, and shown to have a strict correlation with their respective geological origins.

2. The analyses of the different soils have shown Kirvin fine sandy loam to be highly deficient in all of the essential elements, while Bell clay has an adequate supply of all the plant foods but one, namely, phosphorus. The analysis of the San Saba clay has shown it to be highly fertile.

3. From a consideration of the lime content and the pH of the soils it has been determined just what crops might grow best in each soil.
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