A STUDY OF THE GRANULATION OF SOILS

BY

ROBERT CLINTON LLOYD

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Robert Clinton Lloyd

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Cyril G. Hopkins

HEAD OF DEPARTMENT OF Agronomy
A STUDY OF THE GRANULATION OF SOILS.

In the study of the field condition of certain soils one characteristic which is very noticable is that the soil grains are grouped into composite clusters forming kernels, crumbs, or granules, which greatly change the physical condition of the soil from what it would be if this property was not present. From an agricultural point of view, this is a valuable property and in certain soils if possible it should be increased. Of some soils, especially that type known as Yazoo clay (1) and some glacial soils, this characteristic is so common that they are known as granular soils. In other soils, the granulation is not so marked, yet it is very noticable, and in still others granulation is entirely lacking.

As stated by Professor F.H. King, Bureau of Soils, Department of Agriculture, this characteristic of granulation has a very great influence in determining the physical property of soils and their agricultural value (2). Taking a specific case, as Yazoo clay, a heavy clay soil which from a study of the mechanical analysis appears as if it would be difficult to drain and to cultivate, yet because of this granulating property it drains nearly as readily as a sandy or gravelly soil. The gravitational or hydrostatic water readily passes off between the granules leaving the soil in good condition to cultivate although containing a high percent of moisture. This is because of the large amount of capillary and hygroscopic water held within the granules due to the large content of clay. The above condition of the soil moisture is an ideal condition for the growth of agricultural plants.

(2) Physics of Agriculture, Professor F.H. King Page 108.
OBJECT OF INVESTIGATIONS. Because of this valuable property being present in some soils and absent in others the writer made observations in the field and carried on laboratory investigations to determine if possible some of the factors which influence the granulation of these soils.

TYPES OF SOIL STUDIED. In the field many classes of soil were studied, types from sandy loams to heavy clays, while in the laboratory, two soils received the principal study, Yazoo clay and a silt loam, both representing certain forms of granulation. Yazoo clay was selected because it possessed this property to a greater degree than any other soil. Following is a description of this type of soil given by Dr. Jay A. Bonsteel of the Bureau of Soils, Department of Agriculture who first described and classified this type in the soil survey (1):

"The Yazoo clay occupies the low-lying border of the front lands and the higher ridges through the open country between streams. It occupies flats lying between the natural levees along the major stream courses. During the inundations of the delta country the courser materials are deposited in considerable quantities along the stream courses, forming the bars or ridges already described. At the same time the finest particles of clay, which can be held in suspension by slowly moving water are carried farther from the streams to the interior.***

The Yazoo clay consists of a drab or bluish clay soil having a depth of about five inches. This is underlain by a lighter colored waxy clay to a depth of several feet.
The surface soil is very stiff and sticky when wet, showing the plastic properties of true clay.

As it dries out the soil particles are drawn close together, forming large or small compact masses. In many cases sun cracks form to a depth of several inches, and the surface is divided up into polygonal blocks. If the cracks are nearer together small masses result, which give the soil a sandy or pebbly character during the dry weather. From the color and size of these clay masses certain portions of the Yazoo clay have been called "buckshot soil".

The peculiar coagulated condition of the surface soil exists only under conditions of average dryness. When the "buckshot" mass becomes moistened by fall rains the grains melt down to a fairly homogeneous mass and do not reassume their characteristic state until the next season.

Other areas in which the phenomenon is not fully developed are locally said to be "bucky" in character though not forming typical "buckshot lands".

From the foregoing we learn that granulation is one of the principal characteristics of Yazoo clay and that there is a variation in the character of the granulation.
Granulation is a common characteristic of the type of black clay loam which occupies the most level portions of upland prairies of Central Illinois. It has been formed by the slight wash from the higher ground, and by the accumulation of decaying vegetable matter. This soil consists of a heavy black, sticky clay loam and it readily granulates when drained. The brown silt loam of the prairies shows this tendency to granulate. The last mentioned was the second soil selected and used in the laboratory investigations, as it shows less tendency to granulate than the type of black clay loam of the Wisconsin Glaciation. This type is commonly called the soil of the Rolling Prairies of the Wisconsin Moraines.

In the field, in St. Clair County, Illinois, the writer made observations on the Yazoo clay most of which have been given in the description of that type. It is also noticeable that Yazoo clay that had been inundated seems to have the soil grouped into granules even before the hydrostatic water has passed out of the soil, and that upon slight drying, breaks into polygonal blocks, showing perfect granulation. However, if this clay is puddled, granulation does not take place upon drying, and a breaking up of this puddled condition either by freezing or the action of water is necessary to restore it to its former condition. When the soil becomes dry, because of its granulated condition, it works during cultivation nearly as easily as a sandy or gravelly soil.

(3) Field Operations, Bureau of Soils Department of Agriculture, 1902, St. Clair County Sheet (In Press).
After the soil granules form the first time in the spring, continued freezing and thawing or changes of the moisture content of the soil cause the individual granules to break up into smaller granules similar in shape to those from which they were formed.

The effect of freezing on the surface soil, subsurface soil, and subsoil of the silt loam was studied from a ditch six feet deep which was dug during the fall and remained open all winter. The freezing and thawing caused the soil of the sides of the ditch to granulate, break loose from its former position and the ditch was gradually filled up by the accumulation in the bottom of the soil broken loose from the sides, until the ditch which was at first six feet deep was three feet or less in depth while the width had increased in some places from eighteen inches to forty inches. Photographs A and B, show the appearance of the ditch in the spring.

The surface soil granulated readily by the freezing, the granules being angular and similar in shape to the granules of Yazoo clay yet very much smaller. These granules were very hard when dried and did not break up easily. When water was applied the broke apart and melted into a mass slowly. However when this mass was exposed again to the action of the weather granulation took place again. Photograph C-1.

The soil at a lower depth did not form into such large granules and when exposed to action of the frost broke apart forming granules of the same shape but smaller. Photograph C-2.
Photograph A.

The silt loam of the rolling prairies of the Wisconsin glaciation. Effect of freezing and thawing.
Photograph B.
Photograph C.

Granules of the surface, subsurface, and subsoil shown in photographs A and B.
The earth lying between the true soil and subsoil when exposed to successive freezing and thawing formed into small granules, but not so distinct and so angular as those of the surface soil.

Photograph C-3. The gravelly till subsoil when examined showed a granular structure, the granules being large but the action of frost broke them up into smaller granules much more rapidly than those of the surface soil. The granules of the subsoil were quite different from those of the surface soil, in that they were not angular, were more easily broken up, crumbled and when water was applied to them they readily disintegrated, ran together and the granulated structure was destroyed. With the action of water this mass did not show the tendency to granulate that was shown in the surface soil. Photographs C-4, 5, and 6 show the largest granules of the subsoil, and the smaller granules formed by freezing and thawing of large granules.

The conclusions drawn from these and other observations of the same soil are that the surface soil granulates much more readily and the granules are of different form from those formed of the soil of lower depths, in that they are more angular, harder to break apart, they do not run together as rapidly when water is applied and when the granulated structure is destroyed it is again brought about by the action of water alone or water and frost.

Other conclusions drawn from this work after conducting the laboratory experiments are given later.
LABORATORY INVESTIGATIONS. In preparing the Yazoo clay and the silt loam for the experiments the soils were air dried carefully pestled in a mortar until all the particles passed through a one millimeter sieve. This was done to entirely destroy any granules that existed in the soil when taken from the field.

EFFECT OF FROST ON GRANULATION. To determine the effect of the amount of freezing and thawing on thoroughly puddled prepared Yazoo clay, the soil was moistened with distilled water and worked thoroughly into a sticky, plastic condition. Then it was molded with pressure into sticks three inches long. One stick was dried at 100°C., the second was frozen, allowed to thaw and then was dried under the same conditions, another was frozen two times and so on. Photograph D shows the broken sticks and the condition of the interior particles. However it should be stated that as the freezing was continued the surface of the sticks became more broken up with small cracks, and at the end of the third freezing stick number five had been broken in two by the action of the frost. In Photograph D beginning at the left stick number one shows the condition of the soil particles of the interior of the stick before freezing took place - a solid compact mass. Number two having been once frozen and thawed shows that the mass has been somewhat broken up and that the soil particles had formed or grouped about certain centers showing a decided change. Number three was twice frozen and thawed. Number four was frozen and thawed three times as was also number five. In number three a great change
Photograph D.

Effect of repeated freezing and thawing on Ya oo clay.
is noticed from number two although complete granules had not been formed. Number four complete granulation had taken place yet the granules were much smaller than those of number five which were very large but very characteristic of Yazoo clay.

Conclusion. Puddled Yazoo clay forms into granules when exposed to action of frost, the completeness of granulation varying with the number of times frozen.

In a similar experiment Yazoo clay was prepared as in the preceding experiment but was molded into the form of a sphere about three inches in diameter. Then it was exposed to the action of frost six times. Photograph E shows the condition of the Yazoo clay. The ball contained many deep, broad cracks and granulation was complete on the under surface.

To determine the effect of the change of moisture content, the Yazoo clay shown in Photograph E, was thoroughly dried, then it was thoroughly saturated with distilled water and within a few minutes very large deep cracks appeared in the ball and large pieces broke loose from the mass. Photograph F. When the soil was again thoroughly dried and a second time thoroughly saturated with water again a distinct change took place. Photograph G. In a very short time the ball broke apart showing a very marked granular structure. Photograph H, is an enlargement of a portion of that shown in photograph G. The soil was again dried and water was applied a third time with the result shown in Photograph I. Granulation was perfect and even the masses of larger size when slightly pressed crumbled
Photograph E.

Effect of repeated freezing and thawing puddled Yazoo clay.
Photograph F.
Photograph G.
Photograph H.
Photograph 1.
Photograph J.
into granules. Photograph J is an enlargement of a portion of I which shows the granules and granular structure of Yazoo clay at the close of the experiment.

Conclusions. The first part of the experiment was a further proof of the conclusion drawn from the preceding experiment. Completeness of granulation varies in proportion to the number of times frozen.

After a soil has been frozen, repeated saturating and drying causes a rapid granulation of the soil particles, the completeness of granulation varying in proportion to the number of times saturated and dried.

After a soil has been completely granulated further application of water causes a breaking up of the granules into smaller granules similar to those from which they were formed.

The third experiment was to determine the effect of freezing on the granulation of soils treated as described below. The work was carried on in cold storage so as to have uniform conditions, and, because of the better conditions, the effect of freezing was much more marked than that in the preceding experiments.

Both the Yazoo clay and the loam were given the same treatment. Soil with no treatment was molded into balls as described before. A second lot of soil was leached with one per cent solution hydrochloric acid. This was done to remove soluble salts and all matter soluble in one per cent hydrochloric acid.
After leaching with the acid the soil was leached free from acid with distilled water, then dried, passed through one millemeter sieve and then molded. For the third part of experiment soil treated the same as last described was leached with ammonium hydroxide to dissolve the soluble humus. After a large part of the humus was dissolved the soil was dried, passed through the sieve and made up in the same form as the others. Then all were exposed to the same temperature for a sufficient time for them to become thoroughly frozen, when they were removed and were allowed to thaw. Before thawing the ball of untreated Yazoo clay was filled with deep broad cracks showing that it had been greatly effected by the action of the frost. The ball made from soil having been leached with hydrochloric acid, showed no marked difference, perhaps the cracks were slightly more numerous but they were not so broad and deep as in the untreated soil. The ball from which the humus had been extracted had but very few slight cracks and these were surface cracks only, not extending far into the ball.

With the loam the results were the same except the cracks were not so numerous.

The soil was thoroughly frozen a second time and was allowed to thaw a second time. Photograph K shows the appearance of the soil at this stage. The large pieces or granules formed during the first freezing were broken up into smaller pieces by the second freezing. The balls from which the humus had been extracted were only slightly changed.
Photograph K.
In photograph K. 1, silt loam; 3 silt loam, having been leached with hydrochloric acid; 5, silt loam from which humus had been extracted; 6, Yazoo clay; 4, Yazoo clay having been leached with acid; 2, Yazoo clay from which humus had been extracted.

In comparing the Yazoo clay of different treatments it was noticed that no great difference was apparent between the untreated and that which had been leached with hydrochloric acid. When humus had been extracted a great change in granulating properties had taken place. The ball although subjected to the same conditions showed no tendency to granulate. The same statements are true of the loam, but the form of granulation of loam was somewhat different from that of the clay as may be seen by the photographs. Photograph L shows the granules of the Yazoo clay, 4, 6 and the loam 1, and 3.

Conclusion. Both Yazoo clay and the silt loam although puddled and even compressed, granulate readily when acted upon by frost.

Soils having been leached with one percent hydrochloric acid granulate as readily as before treated, showing that the absence of soluble salts does not hinder or decrease the amount of granulation.

The absence of soluble humus prevents granulation from taking place.
Photograph L.
To determine if the former granular condition of the soil could be restored by returning the soluble humus that had been extracted from the soil, the extracted humus was dried, thoroughly pulverized, and returned to the soil from which it was extracted, in the same proportion as it was in the soil originally. (Photograph M shows the dried humus which had been extracted from the soil, 1, humus from loam, 2, humus from Yazoo clay), and to determine the effect of calcium carbonate and calcium hydroxide the soils were prepared as follows:

To a portion of the soil from which the soluble humus had been extracted, and which did not granulate when exposed to the action of the frost, the same amount of humus was added that had been extracted. To a second lot of untreated Yazoo clay and loam one half percent calcium carbonate was added and to another set the same molecular proportion of calcium oxide. The soil was then subjected to the action of the frost. The granulation in the soil where lime had been added was very similar to that of the experiment where lime was not added. No marked effect was caused by either form of lime. However where humus had been added the balls contained numerous small cracks showing that the soil was much more effected by frost than when humus was absent. By a slight pressure the balls were partially broken showing a distinctly granular
Photograph N.
Photograph 0.
structure. See photograph No. 1, Loam, with Calcium hydroxide; 2, Loam, with Calcium carbonate; 3, Loam from which humus had been extracted and then returned. Yazoo clay 4, 5, 6 in the same order as the loam. The soil was frozen a second time and when thawed the soil to which humus had been added readily granulated as is shown in photograph 0. The granules being much smaller than those of the loam and clay which had not been treated. The granules of the soil to which lime had been added were easier to break apart than where lime had not been added, but no difference was apparent in the granulation caused by the different forms of lime.

Conclusion. When granulation is caused by freezing alone a small application of lime in the form of carbonate and the hydroxide has but little if any effect, but later granulation, caused by water, seems to be increased by the application of lime.

With the soils investigated humus is the greatest factor in causing granulation.

In all the experiments the conclusion was that the moisture content of a soil has a great influence on the granulation. In the work with the soil made into balls the greatest granulation was on the underside of the ball, that is, the portion resting on the support as is shown in photograph 0, due to the greater content of moisture.

No experiments were conducted to determine the effect on granulation of soils of a variation in clay content,
but from the observations in the field it appears that in
soils of the same humus content granulation becomes more
distinct and increases as the proportion of clay increases.

SUMMARY OF CONCLUSIONS.

1.- The surface soil granulates much more readily and the
granules are of a different form, from those granules formed
from the subsurface and subsoil, in that they are more angular,
harder to break apart, they donot disintegrate and run together
so rapidly when water is applied and when the granular struc-
ture is destroyed it is again brought about by the action of
water alone or water and frost.

2.- Yazoo clay when puddled and compressed forms into gran-
ules when exposed to the action of frost. The completeness
of granulation being in proportion to the number of times
frozen.

3.- After a soil has been frozen, repeated saturating and
drying causes a rapid granulation of the soil particles.
The completeness of granulation being in proportion to the
number of times saturated and dried.

4.- After a soil is completely granulated further appli-
cation of water causes a breaking up of the granules into
smaller granules similar to those from which they were formed.

5.- Soils, having been leached with one percent hydrochloric
acid, granulate as readily as before treated, showing that the
absence of acid-soluble salts does not effect granulation.

6.- When granulation is caused by freezing alone a small
amount of lime in the form of the carbonate or hydroxid has
but little if any effect but later when water is applied to
the same soil, granulation seems to be increased by the presence of lime.

7.- Other things being equal, granulation by freezing varies in proportion to the moisture content of soil.

8.- From field observations it appears that in soil of about the same humus content granulation becomes more distinct and increases as the amount of clay increases.

9.- When the content of clay remains unchanged granulation varies with the humus content, humus being the greatest factor in causing granulation of clay soil.