DECEMBER, 1915. BULLETIN No. 209.

AGRICULTURAL EXPERIMENT STATION.

KANSAS STATE AGRICULTURAL COLLEGE.

The Use of Dynamite in the Improvement of Heavy Clay Soils.

MANHATTAN, KANSAS.

KANSAS STATE PRINTING PLANT.
W. R. SMITH, State Printer.
TOPEKA. 1915.
6-1862

Foreword.

THE following paper reports results of an investigation relating to the use of dynamite in the improvement of heavy clay soils. The investigation covered a period of three years and was made possible through the cooperation of the E. I. Du Pont de Nemours Powder Company, which financed the work in part by providing funds for a fellowship in this institution. The fellowship was awarded to Mr. Charles Myszka during the first two years of the investigation, and during the last year to Mr. P. E. McNall.

W. M. JARDINE, *Director*.

SUMMARY.

A series of experiments were planned to determine the effect of dynamiting on soil, the yield of crops, the moisture content of the soil, nitrate development, the bacterial flora, the physical condition of the soil, the leaching of salts in alkali soil, and the growth and vitality of fruit trees.

1. The crop planted on dynamited soil produced a higher yield in seven instances, while the crop planted on undynamited soil produced a higher yield in four instances. The greatest increase in yield on dynamited soil was obtained at this station with corn in 1914, when the dynamited plots produced thirteen percent more grain than the undynamited plots. At Agra the dynamited plots produced seventeen percent less wheat than the undynamited. In most instances the difference in yield was no greater than would occur on two areas of soil similarly treated.

2. Moisture determinations on a series of nine dynamited and four undynamited plots on the Oswego Silt Loam at Manhattan, extending over a period of three years, showed no marked difference in moisture content of the soil. An average of all the determinations gave less than one-half of one percent more moisture in the dynamited than in the undynamited land.

3. Nitrate determinations on the same plots extending over the same length of time showed no greater formation of nitrates on dynamited than on undynamited soil.

4. A count of the number of bacteria at different distances from the center of a dynamited area two years after the dynamiting was done showed a small increase in bacterial content in both the surface and second foot of soil as the dynamited area was approached.

5. A study of the effect of dynamite on the physical condition of heavy, plastic clay soil showed that the explosion forced out the soil particles at the center of the dynamite charge into the pore spaces of the soil mass adjoining, thus producing a cavity surrounded by a hard, compact mass. The soil, instead of being shattered and cracked, was compacted and puddled, and left in poorer physical condition than before the dynamiting was done. (See plate IV.)

6. An alkali soil in the Arkansas river valley dynamited in the early spring of 1912, with half sticks of dynamite placed two and one-half feet deep at the corners of fifteen-foot squares, had not been noticeably improved by the fall of 1914. However, there had been some leaching of the salts from the surrounding soil.

7. Fruit trees planted on dynamited soil at this station in the spring of 1911 made a slower growth and survived in smaller numbers during the dry seasons following than did trees planted on similar adjoining soil that had not been dynamited.

8. In no instance was there improvement sufficient to pay the expense of dynamiting.

The Use of Dynamite in the Improvement of Heavy Clay Soils.

L. E. CALL and R. I. THROCKMORTON.

INTRODUCTION.

Within the last four or five years several firms manufacturing dynamite have advocated its use for the purpose of loosening the subsoils of cultivated fields to a greater depth than it is possible to loosen them by means of the common subsoil plow or other deep-tillage implements. It has been asserted that almost any type of soil can be improved in physical condition, that better aeration and drainage will follow, that, sour soils will be sweetened, that unavailable plant food will be made available, and that injurious insects and fungous diseases can be controlled in this way. The more conservative advocates of the use of dynamite for soil improvement have admitted that it is not a universal soil panacea, but they believe that it has value in improving soils underlaid by hardpan, in digging holes for orchard planting, and in the improvement of small alkali spots common on the heavier types of soil.

It was for the purpose of obtaining definite information as to the value of dynamite for soil improvement that experimental work was started at this station in 1911 in cooperation with the E. I. Du Pont de Nemours Powder Company. Most of the dynamiting work was done on soils that are locally known as "hardpan soils." The term "hardpan" as generally used is very broad, and includes both soils that have plastic clay subsoils, and are therefore heavy, sticky, and almost impervious to water, and the true hardpans. A true hardpan is a hard, cemented layer in the soil which prevents the penetration of plant roots and water. The hardpan layer is usually of limited thickness and has been formed by materials which have cemented the soil particles together. True hardpan of this character may be successfully broken up by explosives, especially to an extent sufficient to permit trees to be grown."

The plastic clay subsoil presents a very different condition. Its impervious nature is not due to cements, but instead to the nature of the soil itself, which consists of very small-sized

* Hilgard's "Soils" (1907), 181. Macmillan Pub. Co.

particles with mom or less very fine-grained material that effectually excludes both air and water. The surface of these soils usually contains less clay and is therefore more porous and mellow than the subsoils. The clay content increases with depth from the surface downward until the heaviest, most plastic portion of the soil is encountered, at depths varying from fifteen to thirty inches. Below this depth the soil contains less clay and is less plastic. Most of the work presented in this bulletin was done on soils of this character.

OTHER STUDIES IN DYNAMITING SOILS.

Other experiment stations, notably New Jersey and Pennsylvania, conducted, simultaneously with the work at this station, a series of experiments to determine the value of dynamite in subsoiling.

The New Jersey experiment station* conducted work in 1912 and 1913 to determine the effect of dynamiting the soil on the growth of apple and peach trees. These experiments were conducted at Vineland on a gravelly loam soil of high fertility, and at New Brunswick on a very fertile red shale loam soil. During the first season the peach trees on the dynamited plots made a greater twig growth but less trunk growth than those on the undynamited plots. The second season the difference in twig and trunk growth of the trees was less pronounced. There was practically no difference between the apple trees planted with and without dynamiting the soil.

Root studies made in the fall of the second year showed that the trees planted on dynamited soil had a little deeper and broader root system than did those planted in the usual way.

During 1912 and 1913 the Pennsylvania experiment station carried on a number of experiments to determine the influence of dynamiting the soil on the growth of fruit trees and field crops.

Experiments were made on newly planted apple trees in three orchmds on a heavy silt loam. The trees were planted in the cavity formed by the explosive. The charges varied from one-third of a stick to one stick planted at a depth of from one to two feet.

The measurements of stem growth and height did not show

* A. J. Failey: Proceedings of the New Jersey State Horticultural Society. 1912.

any appreciable difference between the growth of trees planted on soil dynamited and that which was not dynamited.

The effect of dynamiting on mature trees was determined on two farms. The trees were about twenty-five years old. Dynamite was exploded in the soil on three sides of the trees at depths varying from two to four feet; the size of the charge varied from one-third of a stick to one stick,

A record was made of the yield of fruit from these trees, and the dynamited trees produced ninety-eight pounds less fruit; than did the trees that were not dynamited. The difference in the growth was slightly in favor of the dynamited trees. "The results prove nothing, but indicate strongly that the dynamite has little or no influence on yield or growth of mature trees."

The experiments by the Pennsylvania experiment station to determine the effect of dynamiting on field crops were conducted on heavy clay loam as well as on a heavy silt loam soil. Corn was the crop used on both soils. On the clay loam soil explosions were made every fifteen feet in rows which were fifteen feet apart. The charges consisted of about two ounces of dynamite placed at a depth of three feet. The rows of corn extended in the same direction as the rows of dynamite.

On the silt loam soil the charges varied from one-third to two-thirds of a stick at depths varying from two feet to three feet six inches. The yields obtained from these experiments show practically no difference between the dynamited areas and those which were not dynamited.

It is evident from these results that the use of dynamite has been of little or no value in the improvement of heavy types of soil at those stations that have tested it in an experimental way.

THE DETAILS OF THE DYNAMITING WORK AT THIS STATION.

The work at this station has been done partly in cooperation with farmers in different sections of the state, partly at the Fort Hays Branch Experiment Station at Hays, Kan., and partly upon the station farm at Manhattan. The cooperative work with farmers was done at Fredonia, Agra, Emporia, and Hutchinson.

The Fredonia Experiment.

The experiment at Fredonia, Kan., was conducted on the farm of J. E. Thompson. The soil upon which the work was done was Oswego Silt Loam, which consists of a mellow, dark-gray silt loam to a depth of twelve inches. The subsoil to a depth of thirty inches is a dark-brown to drab silty clay which is very tough and plastic when wet. Below thirty inches the subsoil becomes lighter in texture and color. Acidity determinations showed the soil to be slightly acid.

The dynamiting was done April 29, 1912, on one-half of a field which is eighty rods long and eight rods wide. The charges consisted of one-half stick of dynamite placed in holes thirty inches deep, placed fifteen feet apart in rows. The distance between rows was sixteen feet.

At the time the dynamiting was done the soil and subsoil were very wet. The subsoil was not shattered or broken by the force of the explosion. The effect of the charge was to form a cavity about eighteen inches in diameter, the walls of which were puddled and compacted very hard.

The field upon which the dynamiting was done was in flax in the summer of 1911, and produced a good crop. During the early fall it was top-dressed with barnyard manure and then plowed. Shortly after the spring dynamiting the field was disked, and was drilled to sweet sorghums the first of June.

The field was visited at various times during the growing season, but there was no perceptible variation between the crops on the dynamited and undynamited soil. The following table shows the yield of sorghums obtained:

TABLE I. Yield of sorghums on dynamited and undynamited ground at Fredonia, Kan., 1912.

Treatment.	Weight in pounds.	Tons per acre.
Dynamited	7,942	3.97
Undynamited	7,742	3.87

The difference in yield is small and may be classed within the limits of experimental error.

In 1913 and 1914 yields could not be obtained from these fields. Kafir was grown both years and there was no noticeable difference in growth or vigor.

The Agra Experiment.

The work at Agra, Kan., was conducted on the farm of Marion Scott, located two and one-half miles southeast of Agra. The soil on this farm is the Colby Silt Loam, which consists of a loose silt loam to a depth of ten to fifteen inches, The subsoil from fifteen to twenty-six inches is a clay loam which increases in clay content with depth; below this and extending to a depth of thirty-three inches is an impervious layer which becomes very hard when dry.

The portion of the field used was divided into three areas, each of which is 200 feet long and 150 feet wide. One of these areas was dynamited and the other two left as check plots. The charges were placed two and one-half feet deep and fifteen feet apart.

The field was top-dressed with manure during the winter of 1909 and 1910, and grew an excellent crop of oats in the season of 1910. In the fall of 1910 the area was dynamited. In 1911 one-third of the area was planted to oats, one-third to corn, and one-third to potatoes. Because of a hailstorm and lack of moisture, none of the crops were successful.

Wheat was grown on the plots in 1912, and the following yields obtained:

TABLE II. Yield of wheat on dynamited and undynamited ground at Agra, Kan., 1912.

Plot.	Treatment.	Bushels per acre.
1	Undynamited	12.5
2	Dynamited	10.4
3	Undynamited	15.6

It is noted from these results that the dynamited plot gave a slightly decreased yield. The larger yield on plot 3 was due to snow drifting upon this plot to a greater extent than upon either plots 1 or 2, and thus supplying this plot with more moisture. Yields have not been obtained since 1912, but from observations made from time to time it has been impossible to observe any difference in growth of the crops upon the different plots.

The Emporia Experiment.

The third cooperative experiment with dynamite was conducted at Emporia, Kan., on the farm of J. R. Cannon, five miles northeast of the city. The soil upon which the work was done was the same in general characteristics as the soil at Fredonia, being the Oswego Silt Loam. The surface soil to a depth of nine inches is a brown, silty clay loam, which is underlaid by a dark-brown to black plastic silty clay to a depth of thirty inches. Below thirty inches the subsoil becomes yellowish in color and is of a more friable nature.

The area used for this experiment was 990 feet long and 176 feet wide. One-half the area was dynamited and the other half left as a check. The charges consisted of one-half stick of dynamite placed thirty inches deep. The distance between charges was fifteen feet. The effect of the explosion on the soil was much the same as that at Fredonia, that is, a cavity about eighteen or twenty inches in diameter was formed with hard, compact walls.

The field was plowed early in the spring of 1911 and planted to corn. In the fall the corn was harvested and the stalks pastured. The ground was plowed early in the spring of 1912 and then dynamited. One-half of the dynamited area and one-half of the check area was planted to corn and the other half to sugar beets and cowpeas.

The corn was destroyed during the summer, but the yield of sugar beets was obtained and is given in the following table:

TABLE III. Yield of sugar beets on dynamited and undynamited ground at Emporia, Kan., 1912.

TREATMENT OF SOIL.	Pounds per acre of sugar beets.	Tons per acre.
Dynamited	6,800	3.4
Undynamited	6,300	3.1

In the spring of 1913 the entire area was planted to corn. In harvesting the crop the portion of the field which produced corn after cowpeas was harvested separately. The following table gives the yields of green fodder for the different treatments:

TABLE IV. Yield of corn on dynamited and undynamited ground at Emporia, Kan., 1913.

TREATMENT.	Previous crop.	Yield per acre. silage. Pounds.
Dynamited	Corn	5803
Undynamited	Corn	5426
Dynamited	Cowpeas	6624
Undynamited	Cowpeas	6063

The untreated plot which had previously grown corn produced the lowest yield, while the check plot which had previously grown cowpeas produced a higher yield than the dynamited plot which had previously grown corn. The greatest differences in yield are noticed between the dynamited plots which had previously grown corn and those which were previously in cowpeas. There is an advantage of 821 pounds per acre on the dynamited plots in favor of cowpeas, while on the undynamited the increase is 637 pounds. On the corn ground, due to dynamiting, there was an increase of 377 pounds, while on the cowpea ground this advantage was 561 pounds. It would thus seem that although there was an increase in the dynamited plots over the undynamited, the greatest variance was due to the beneficial effect of the cowpeas the previous year.

The entire field was planted to kafir in 1914. It was impossible to obtain yields this season, but there was no noticeable variation between the dynamited and check plots,

The Hutchinson Experiment.

The experiment was conducted on the farm of H. A. Pennington, four miles west of Hutchinson, Kan. The area is located in the Arkansas river valley. The soil is the Arkansas clay, the surface of which to a depth of twelve inches is a dark-brown heavy clay loam. The subsoil from twelve to twenty-four inches is a dark-colored clay containing alkaline material and calcareous concretions.

From twenty-four to thirty-six inches it contains considerable sand, and in places a large amount of calcareous substance. Below thirty-six inches a very loamy sand occurs. Areas of this nature are locally known as “alkali spots” and occur commonly throughout the Arkansas valley on the heavy soil types. They are very poorly drained and are covered with salt grass. The area used for this experiment was a triangular piece of prairie grass sod of the following dimensions: Base, 444 feet; perpendicular, 530 feet; and hypotenuse, 684 feet. The portion dynamited was 435 feet long and 120 feet wide. The charges consisted of one-half stick of dynamite placed two and one-half feet deep every fifteen feet. The effectof the explosion on the physical condition of the soil was the same as that noted at Fredonia and Emporia. The dynamiting was done in the early spring of 1912.

At the end of the first season there was apparently no difference in the growth of prairie grasses on the dynamited and the undynamited plots. After the plots had leached for a period of eighteen months the total soluble alkali salts were determined. Samples of soil mere taken for these determinations in one-foot sections to a depth of three feet. The first sample was taken one foot from the center of the blasted hole, and others at distances of three feet, six feet, and ten feet. In addition to these determinations made at different distances from the dynamited hole, samples were taken on the undynamited area to a depth of three feet. The following were the results obtained:

TABLE V. The percentage of total soluble salts at different distances from the center of a dynamite charge eighteen months after dynamiting. Hutchinson, Kan., 1913.

Distance from Center of Charge.	Percentace of total soluble salts at various depths.		
	0 in. to 12 in.	12 in. to 24 in.	24 in. to 36 in.
1 foot	.4590	.5856	.4890
3 feet	.6768	.6636	.3700
6 feet	.7300	.6640	.3790
10 feet	.7930	.6464	.3600
Undynamited plot	.7888	.7274	.4760

Although there was very little rainfall during this period, it is evident that there was some leaching of alkali salts because of the increase in percent of salts in the first foot as the distance from the charge increases. The second foot also shows an increase in the amount of salts present from the first foot to the third from the charge. The sample taken one foot from the charge and from twenty-four to thirty-six inches deep shows an accumulation of salts in the third foot. It appears from these results that the dynamiting aided in the leaching of the salts to some extent from the surface soil to a depth of two feet. Below this there was some accumulation of salts.

In August, 1914, moisture samples were taken on the plots, At this time there had been no rain for a period of about five weeks, but the soil in the center of the dynamited hole contained so much moisture that the samples were extremely wet. Samples taken three, six and ten feet from the center of the plot were very dry and crumbled when removed with the auger.

The following table gives the results of the determination :

TABLE VI. Percentage of moisture in the soil at different distances from the dynamite charge two years after dynamiting. Hutchinson, Kan., 1914.

DISTANCES FROM CHARGE.	Depth in inches.		
	0 in. to 12 in.	12 in. to 24 in.	24 in. to 36 in.
	Percent of water.	Percent of water.	Percent of water.
Center of charge	10.8	20.3	16.8
1 foot from center	8.8	13.0	11.5
3 feet from center	8.6	12.3	9.6
6 feet from center	7.6	11.2	8.3
10 feet from center	8.6	12.8	9.8
Check	12.7	16.6	10.8

The higher water content at the center of the charge would indicate that the water drained towards the dynamited spot. However, the figures do not show that the dynamiting allowed the water to pass through the heavy subsoil, but that it formed a basin into which the water drained to some extent.

From the results given above it is very doubtful if such soils as the alkali areas of the Arkansas clay can be corrected by dynamiting. Mr. Pennington made the following statement in a letter regarding the work on his farm: "The experiment seems to be a failure because the soil runs together again and cements up the holes in the subsoil so the rainwater can not work down through the soil. I found water standing in the blasted hole at least ten days after a rain."

The Hays Experiment.

The work at Hays, Kan., is being conducted in cooperation with the Office of Dry-land Agriculture, Bureau of Plant Industry, under the direction of A. L. Halstead, of the Fort Hays Branch Experiment Station. The soil upon which the work is being done is residual, having been formed by the weathering of limestone and shale, and was mapped by the Bureau of Soils as Summit Silt Loam. The surface soil consists of a dark-brown heavy silt loam to a depth of about twelve inches. The subsoil is a heavy, compact silty clay loam which becomes more friable below three feet.

The area used for the work consists of six one-tenth acre plots, each of which is 33 feet wide and 132 feet long. Three of these areas are undynamited and are used as check plots, while the other three are to be dynamited. One plot is to be dynamited each fall, beginning with 1913.

The dynamite charges consist of one-half stick of dynamite placed at a depth of three feet, sixteen and one-half feet apart, in rows which are sixteen and one-half feet apart. The location of the shots in one row alternate with those in the adjoining row.

A three-year rotation consisting of fallow one year, wheat one year, followed by kafir one year, is followed. The dynamiting is done each fall after removing the kafir, which is the beginning of the fallow period. Thus each plot will be dynamited every third year, or once in the rotation.

Moisture determinations are made shortly before the dynamiting is done, and at various times during the spring, summer and fall months following.

The following table gives the moisture content and the yield of wheat from the plots which grew kafir in 1913, which were dynamited that fall, fallowed in 1914, and produced wheat in 1915.

TABLE VII. Moisture content and yield of plots dynamited October 23, 1913.

Treatment.	Average percent of moisture to a depth of six feet.					Wheat yield, 1915.	
	Kafir, Sept. 11, 1913.	Fallow.		Winter wheat.		Grain, bushels.	Straw, pounds.
		Aug. 10, 1914.	Sept. 28, 1914.	Apr. 20, 1915.	July 31, 1915.		
Dynamited	19.0	22.2	22.2	23.2	25.1	13.5	4,400
Undynamited	20.0	21.9	22.1	23.3	25.4	14.4	5,350

These figures show practically no variation in moisture content. As seen from these results the yield of grain was slightly in favor of the undynamited plot, while the increase in straw is much greater.

Moisture determinations were also made on the plots dynamited November 11, 1914, and the following results were obtained:

TABLE VIII. Moisture content of plots dynamited November 11, 1914.

Treatment.	Average percent of moisture to a depth of 6 feet.		
	Kafir.		Fallow, June 14, 1915.
	Sept. 7, 1914.	Oct. 27, 1914.	
Dynamited	14.8	15.1	22.1
Undynamited	14.0	14.7	22.7

The variation in moisture content in all determinations is exceedingly small, and apparently the use of dynamite has had no effect whatever on the moisture content of the soil.

Experiments at the Kansas Experiment Station, Manhattan.

The dynamite work done at the Kansas Experiment Station was conducted on two distinctly different types of soil, the Marshall Silt Loam and the Oswego Silt Loam. The Marshall Silt Loam area is located on the agronomy farm, while the Oswego Silt Loam is located on the farm of F. A. Marlatt, which joins the agronomy farm on the south.

PLATE I.—Dynamiting soil. The explosion of a charge of one stick of twenty per-cent "Red Cross" dynamite placed at a depth of three feet.

The Marshall Silt Loam is of loessial origin and is characterized by a reddish-brown to brown silt loam surface soil to a depth of six to ten inches, underlaid by a reddish-brown to yellowish-red silty clay loam, which becomes lighter in color and texture with increase in depth below thirty-six inches. The soil is mellow and open, has good natural drainage, and has no tendency toward the plastic clay subsoil condition so characteristic of the Oswego Silt Loam.

Previous to the time of dynamiting the area had grown alfalfa. The alfalfa was plowed under in the fall of 1911, and the plots were dynamited the following spring and fall.

The entire area consisted of twelve plots, three of which were left undynamited, and nine of which were dynamited The east one-half of each plot was dynamited April 29, 1912 and the west one-half September 12, 1912. Three plots were dynamited with one-half stick at ten-, fifteen- and twenty-foot intervals; three plots with two thirds of a stick at ten-, fifteen- and twenty-foot intervals; and three plots with one stick each, two of which were at fifteen-foot intervals and the other at twenty-foot intervals.

All plots were sown to barley in the spring of 1912. Chinch bugs very seriously injured the crop, and the yields were very low. The nine dynamited plots gave an average yield per acre of .78 of a ton of barley hay, while the average of the three undynamited plots was .83 of a ton per acre. Thus the undynamited plots gave a slightly higher yield than the dynamited plots. The lower yield on the dynamited area was no doubt due to the failure of the barley to grow directly over the dynamited holes. The size of the charge or distance between charges made no marked difference in the yields,

All plots, including both fall and spring dynamiting, were seeded to wheat in the fall of 1912. Frequent observations were made of the plots during the growing season, but no consistent variation could be noticed. The following table gives the average yield of the fall and spring dynamited and undynamited plots :

TABLE IX. Yield of wheat on spring and fall dynamited and undynamited ground, season of 1913.

TREATMENT.	Wheat.—Yield per acre.	
	Grain, bushels.	Straw, pounds.
Spring—Dynamited	10.49	1,527
Undynamited	10.40	1,483
Fall—Dynamited	11.60	1,673
Undynamited	12.65	1,714

The spring dynamiting had practically no effect on the yield of grain or straw, while the fall-dynamited plots gave a slightly lower yield than the corresponding check plots. Here again the lower yield of the portions of the plot dynamited in the fall was a result of the wheat not growing well directly over the dynamited holes. On the portion of the plot dynamited in the spring the soil had filled the dynamited holes and the crop grew satisfactorily over the entire area of the plot. The size of the charge and the distance between charges had no effect on the crop. The plots were planted to corn in the spring of 1914, but the young plants were destroyed by chinch bugs. The field was then plowed and planted to kafir, but the stand was too uneven to be used in comparing yields.

EXPERIMENTS ON THE OSWEGO SILT LOAM SOIL.

The work conducted on the Oswego Silt Loam was much more extensive than that on the Marshall Silt Loam. It included many moisture, nitrate and bacteriological determinations, as well as studies on the effect of the dynamiting on the physical condition of the soil and rooting system of the plants grown on the area.

The surface soil of the Oswego Silt Loam to a depth of ten inches is a dark-brown silt loam. The subsoil is a very heavy tenacious silty clay to clay to a depth of twenty-four inches, where it becomes lighter in color and texture.

The following table gives the mechanical analyses of this soil:

TABLE X. Mechanical analyses of Oswego silt loam soil.

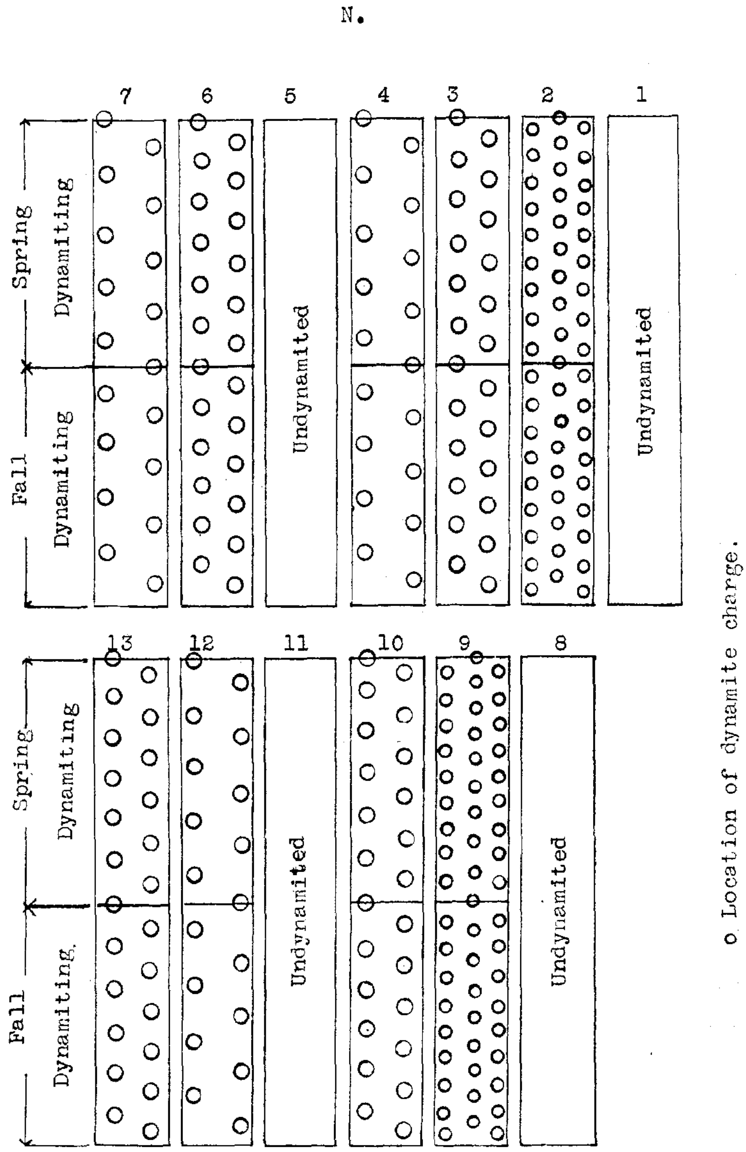
SOIL DEPTH.	Percentages of—						
	Fine gravel.	Coarse sand.	Medium sand.	Fine sand.	Very fine sand.	Silt.	Clay.
0 in. to 12 in.	0.00	0.40	0.17	1.06	2.80	71.05	24.52
12 in. to 24 in.	0.00	0.10	0.10	0.77	0.88	52.67	45.49
24 in. to 36 in.	0.00	0.11	0.06	0.44	0.74	56.39	42.26

The field upon which these plots are located was in bluegrass pasture until the spring of 1912, when it was plowed. The north half of each plot was dynamited April 15, 1912, and the south half in the fall, September 5, 1912. The entire area was seeded to millet in the spring of 1912.

The area used for this experiment consisted of thirteen one-tenth-acre plots, four of which were undynamited and used as check plots.

The following diagram illustrates the relative position of the various plots and the location of the dynamite charges:

PLATE II.



Map Showing the Plotting and Dynamiting on Oswego Silt Loam, Manhattan, Kansas.

The charges were placed at a depth of thirty-six inches, except on plot 13, where they were placed at a depth of five feet.

The millet made a very heavy growth the first year, but there was no noticeable difference in growth between the variously treated plots.

The entire area was seeded to corn in 1913 and 1914. Because of extremely dry weather, it was necessary to harvest the crop in 1913 as forage. The plots were plowed in the fall of 1913.

The following table gives the treatment of all plots, and the yields for each plot for 1912, 1913 and 1914:

TABLE XI. Yield of crops grown on dynamited and undynamited ground, Oswego Silt Loam soil. 1913-1914.

Plot No.	TREATMENT.	Yield of millet per acre, 1912.	Yield of green forage per acre—corn, 1913.		Yield of corn per acre in 1914.			
					Dry fodder.		Corn.	
			Fall-dynamited.	Spring-dynamited.	Spring-dynamited.	Fall-dynamited.	Spring-dynamited.	Fall-dynamited.
		Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Bushels.*	*Bushels.*
1	Undynamited	7,560	6,000	5,200	3,300	3,400	11.1	14.7
2	Two-thirds stick at 10-foot intervals,	8,120	8,000	6,400	3,340	3,940	12.4	18.4
3	Two-thirds stick at 15-foot intervals,	7,720	6,200	6,000	3,140	4,160	12.0	13.0
4	Two-thirds stick at 20-foot intervals,	7,100	6,000	6,400	3,280	4,120	10.8	13.1
5	Undynamited	7,840	5,800	6,400	3,340	3,520	12.2	13.6
6	One stick at 15-foot intervals	7,320	6,800	6,600	3,760	3,960	17.5	14.7
7	One stick at 20-foot intervals	7,240	6,000	5,800	3,640	3,840	13.2	14.7
8	Undynamited	7,360	8,400	6,200	3,800	3,160	12.0	15.6
9	Half stick at 10-foot intervals	6,940	6,800	6,600	3,640	3,160	11.1	14.0
10	Half stick at 15-foot intervals	8,040	9,000	7,200	3,120	3,920	13.5	24.0
11	Undynamited	8,080	8,000	7,200	3,880	3,320	14.2	16.1
12	Half stick at 20-foot intervals	8,600	8,800	8,600	4,060	4,500	22.4	25.9
13	Two sticks at 15-foot intervals	9,100	8,800	7,800	3,520	3,980	17.8	20.3
	Average of all dynamited	7,797	7,378	6,822	3,480	3,953	14.5	17.5
	Average of all undynamited	7,710	7,050	6,250	3,380	3,350	12.4	15.0

The yield of millet in 1912 and forage corn in 1913 show a slight variation in favor of the dynamited plots. These increases were not consistent in all cases and were not influenced by the size of the charge or the distance between charges.

A comparison of results obtained in 1914 shows that the yields of corn obtained on the fall-dynamited plots were

PLATE III.—Millet growing on dynamited and undynamited plots, Manhattan, Kan., 1912.

greater than those obtained on the spring-dynamited, and in most cases the yields were as high or higher than the check plots, but that the increase is not proportional to the size of dynamite charge used. The variance between the check plots used in connection with spring and fall dynamiting was practically as great as that on the plots of spring and fall dynamiting. It appears, therefore, that the same factors which caused the fall dynamiting to give higher yields than the spring dynamiting also caused the yields of the check plots of the same series to be higher.

Even if increases in yield equal to the preceding could be secured in all cases by dynamiting, it is questionable if it would be practical for field crops because of the cost. The dynamite, fuse and caps necessary to treat an acre of soil at fifteen-foot intervals with charges of one-half stick of twenty percent dynamite is approximately $12.20. The labor will make an additional cost of $5 per acre, or a total cost of approximately $17.20 per acre.

Moisture Content.

Moisture studies were made on the Oswego Silt Loam during the growing seasons of 1912, 1913 and 1914 to determine if dynamiting with different size charges and different distances had any effect on the moisture content of the soil. The soil was unusually low in moisture during the entire period of these determinations, because of light rainfall.

The following table gives the monthly rainfall from 1911 to 1914, inclusive, and the average monthly rainfall for a period of fifty years:

TABLE XII. Showing monthly and annual rainfall at Manhattan, Kan., 1911 to 1914, and fifty-year average.

Year.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1911.......	0.61	5.78	0.85	1.89	2.18	0.10	2.13	5.53	4.49	1.55	1.05	2.35	28.51
1912.......	0.30	2.47	6.49	1.40	1.93	3.53	3.23	3.40	3.50	3.37	0.05	0.41	30.08
1913.......	0.15	0.66	0.58	2.41	5.01	2.24	0.07	0.37	4.81	2.67	1.55	3.07	23.59
1914.......	0.08	0.31	1.57	1.46	2.29	3.72	1.37	2.78	4.41	1.31	0.00	0.71	20.01
Average, 50 years..	0.70	1.31	1.35	2.54	4.54	4.64	4.65	3.88	3.10	2.22	1.34	0.80	30.81

The first moisture determinations were made on spring-dynamited plots June 20, 1912, about four weeks after the plots were seeded to millet and before the crop had used very much moisture. Samples were also taken August 31, 1912, just after the crop was harvested. These determinations show that there was very little difference in the moisture content of the various plots, and the average moisture content of the dynamited and undynamited plots was practically the same. The determinations of November 5 were made on both fall- and spring-dynamited plots. The former were dynamited September 5, 1912, and the latter April 15, 1912. All of the plots had been cropped in the same way during the season. The variation in the different plots is very small, and the fall- and spring-dynamited plots have practically the same moisture content. The averages of the dynamited plots and undynamited plots show the dynamited to have about one percent more moisture than the checks, a variation often found between different plots of ground treated alike.

TABLE XIII. Average percent of moisture to a depth of four feet on dynamited and undynamited plots, season of 1912.

Date, 1912.	Plot No.	CHARGE.	Average percent of moisture to depth of 4 feet. June 20, 1912. Spring-dynamited.	Aug. 31, 1912. Spring-dynamited.	Nov. 5, 1912. Spring-dynamited.	Nov. 5, 1912. Fall-dynamited.
June 21.	1	Check	25.33	18.39	21.28	21.26
June 21.	2	Two-thirds stick, 10-foot center	26.70	18.09	22.38	24.45
June 20.	3	Two-thirds stick, 15-foot center	27.53	18.17	22.02	22.16
June 20.	4	Two-thirds stick, 20-foot center	25.60	17.92	22.98	22.46
June 21.	5	Check	26.45	19.67	22.00	22.06
June 21.	6	One stick, 15-foot center	26.14	19.61	21.53	22.21
June 20.	7	One stick, 20-foot center	25.84	17.76	21.10	21.31
June 20.	8	Check	25.55	16.75	22.45	22.70
June 21.	9	Half stick, 10-foot center	28.08	18.24	22.44	22.30
June 21.	10	Half stick, 15-foot center	28.25	18.50	21.62	23.44
June 21.	11	Check	27.58	18.56	20.72	20.79
June 21.	12	Half stick, 20-foot center	28.41	19.84	24.15	22.29
June 21.	13	Two sticks, 15-foot center	28.06	19.12	22.83	23.22
		Average of undynamited	26.23	18.34	21.36	21.66
		Average of dynamited	27.18	18.59	22.34	22.65

The moisture determinations for 1913 were made August 29, after the corn had been harvested. Two fall-dynamited, two spring-dynamited, and one check plot were sampled. The charges on the dynamited plots were two-thirds of a stick with twenty-foot centers, and one stick with a fifteen-foot center.

The following table gives the results of these determinations :

TABLE XIV. Average percent of moisture to a depth of three feet on dynamited and undynamited plots. August 29, 1913.

Plot No.	TREATMENT.	Spring dynamiting.	Fall dynamiting.
4	Two-thirds stick, 20-foot center	18.04	17.43
6	One stick, 15-foot centers	17.17	17.63
5	Undynamited	17.33	17.33

The moisture content of the ground at this time was very low, and there is but little variation between the dynamited and the undynamited plots.

Moisture determinations were made frequently during the growing season of 1914 on the plots dynamited September 5,

1912. The plots were in corn during this period. Two dynamited plots and two adjoining undynamited plots were used for these determinations.

TABLE XV. Average percent of moisture to a depth of three feet on dynamited and undynamited plots, season of 1914.

Plot No.	CHARGE.	April 17, 1914. Fall dyna-miting.	May 6, 1914. Fall dyna-miting.	May 16, 1914. Fall dyna-miting.	June 3, 1914. Fall dyna-miting.	July 10, 1914. Fall dyna-miting.	July 24, 1914. Fall dyna-miting.	Aug. 17, 1914. Fall dyna-miting.
8	Check	25.6	26.0	27.7	26.0	23.0	19.1	17.6
9	Half stick, 10-foot center	26.1	26.3	30.3	25.3	23.3	19.7	17.4
10	Half stick, 15-foot center	26.0	26.1	29.1	26.9	22.8	20.3	17.0
11	Check	24.4	25.5	29.0	27.0	23.4	20.3	17.1

The variations in the moisture content for this season are very small; in fact, so small that the differences are within the limits of experimental error.

It is evident from the results of the three years' work that dynamiting has had very little, if any, effect on the moisture content of the soil. Any differences that have occurred in the moisture content of the different plots have been no greater than would be found on any series of adjoining plots treated in the same manner.

NITRATE DETERMINATIONS.

The first nitrate determinations were made June 22, 1912, four weeks after seeding the millet, on the undynamited plots and the plots dynamited that spring. The average nitrate content of the undynamited plots was 325.29 pounds per acre to a depth of four feet, while the average of the dynamited plots was 361.11 pounds per acre. On September 2, 1912, or shortly after harvesting the millet, determinations were made again. The average of the undynamited plots was 192.57 pounds of nitrates per acre to a depth of four feet, and that of the undynamited plots averaged 244 pounds per acre. The decrease in nitrates from June 22 to September 2 is due to the millet using such large quantities during the growing season.

Determinations were made November 7, 1912, on the undynamited plots, spring-dynamited plots, and plots dynamited September 5, 1912. The average of the total nitrates per acre to a depth of four feet was 280.56 pounds on the undynamited plots, 281.56 pounds on the spring-dynamited plots, and 229.54 pounds on the fall-dynamited plots.

The nitrate work in 1913, when the entire area was in corn, was conducted to determine whether there was any difference in nitrate development at various distances from. the charge, The samples were taken July 18 to a depth of three feet, at one, three, six and ten feet from the center of the charge. The plots on which these determinations were made were dynamited in 1912. The following table shows the results of these determinations :

TABLE XVI. Total pounds of nitrates per acre to a depth of three feet at various distances from the center of the charge.

DATE.	Size of charge.	Distance from center charge.	Pounds of nitrates.	
			Fall dynamiting.	Spring dynamiting.
July 18, 1913	Half stick	1 foot	406.48	314.09
July 18, 1913	Half stick	3 feet	325.40	301.50
July 18, 1913	Half stick	6 feet	352.48	382.27
July 18, 1913	Half stick	10 feet	373.21	400.76

Although there are some variations at different distances from the center of the charge, they can not be said to be due to the effect of the explosion. On the fall-dynamited plot the nitrate content is higher ten feet from the charge than either three or six feet. The highest nitrate content is one foot from the center of the charge, but this may be due to the fact that the corn did not make a strong growth in the immediate vicinity of the charge, and therefore did not use nitrates in such large quantities.

The determinations of 1914 were made frequently during the growing season on two of the plots that were dynamited in the fall of 1912 and on two adjoining undynamited plots. The following table gives the results of these determinations:

TABLE XVII. Total pounds of nitrates per acre to a depth of three feet on dynamited and undynamited plots, season of 1914.

Plot.	TREATMENT.	April 17, 1914. Fall dyna-miting.	May 6, 1914. Fall dyna-miting.	May 16, 1914. Fall dyna-miting.	June 3, 1914. Fall dyna-miting.	July 10, 1914. Fall dyna-miting.	July 24, 1914. Fall dyna-miting.	Aug. 17, 1914. Fall dyna-miting.
8	Undynamited	897.92	841.10	911.00	1053.49	494.76	551.23	809.82
9	Half stick, 10-foot center	807.03	770.19	869.34	799.22	450.93	654.96	600.38
10	Half stick, 15-foot center	696.54	662.29	470.06	879.43	577.97	643.87	633.68
11	Undynamited	657.53	729.19	753.20	871.74	428.36	667.16	765.14
	Average of undynamited	777.72	785.14	832.10	967.61	461.56	609.24	787.48
	Average of dynamited	751.78	716.24	669.70	839.32	514.45	649.41	617.03

The results given above show some variations on the different plots, but these variations, like those of 1912 and 1913, are not consistent, and apparently are not due to the effect of the dynamite. The great decrease in nitrate content from June 3 to July 10 is due to the fact that the corn made its fastest growth during this period, and therefore required large amounts of nitrates.

The results of nitrate determinations for these years indicate that the use of explosives has had little, if any, influence on the development of nitrates in the soil, regardless of the size of charge or distance between charges. Also, that there is no marked difference in nitrate development at various distances from the dynamiting charge.

EFFECT OF DYNAMITING ON BACTERIAL CONTENT OF THE SOIL.

A study was made of the bacterial content of the soil at different distances from the center of the dynamite charge and at different depths in the soil. These determinations were made in the summer of 1914 on ground that had been dynamited two years before.

The following table gives the average bacterial count for four determinations made at intervals of one month during May, June, July, and August, 1914:

TABLE XVIII. Number of bacteria in a gram of moist soil at different depths and at different distances from the dynamite charge.—Average of the season of 1914.

DISTANCE FROM CENTER OF CHARGE.	Depth from surface.		
	0 in. to 12 in.	12 in. to 24 in.	24 in. to 36 in.
1 foot	3,960,000	1,317,000	481,000
3 feet	3,987,000	1,129,000	562,000
6 feet	3,383,000	1,055,000	378,000
10 feet	3,138,000	710,000	412,000

The bacterial count for the first foot shows a decrease in the average number of bacteria from 3,960,000 at one foot from center of charge to 3,138,000 at ten feet from center of charge. In the second foot there is a decrease of 607,000 bacteria in a gram of moist soil as the distance from the center of the charge increases from one foot to ten feet. The third foot shows practically no change in the total count.

It is evident from these results that bacterial development has been slightly favored by dynamiting, and that this effect is the most marked in the second foot of soil.

THE EFFECT OF DYNAMITE ON THE PHYSICAL CONDITION OF THE SOIL.

When a charge of dynamite is exploded in a plastic clay soil the sudden expansion of the gases forces the soil back from the center of charge, producing in the soil a cavity, the size of which is determined partly by the size of charge and composition of the powder used, and partly by the moisture content

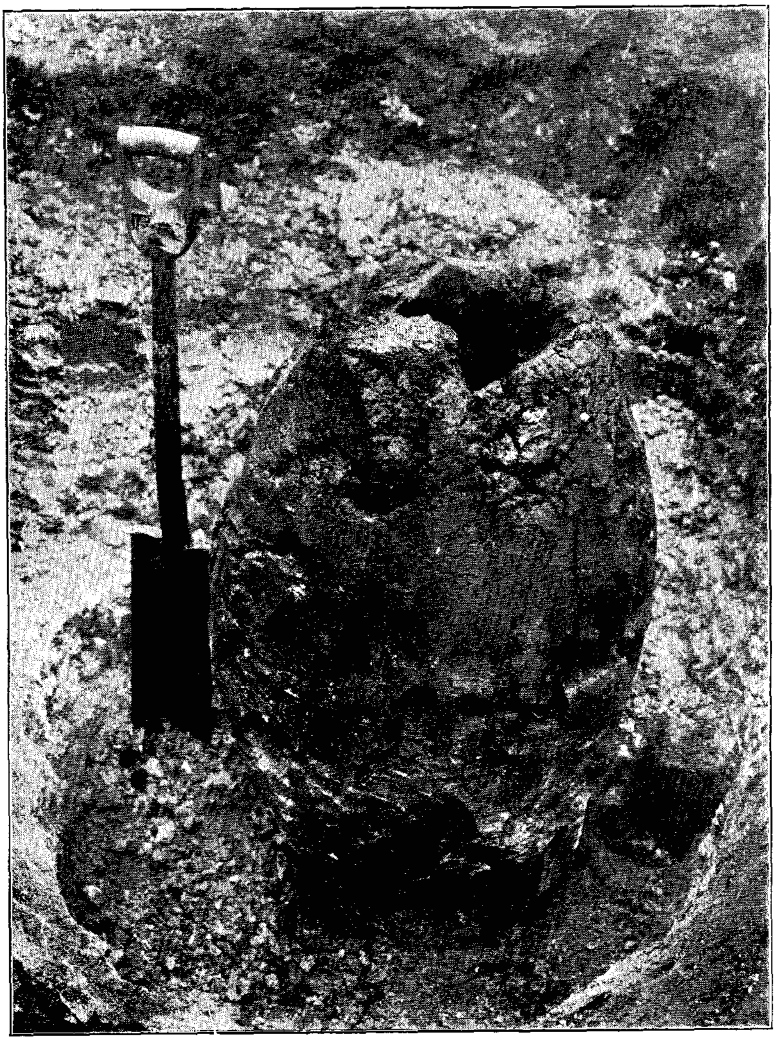


PLATE IV.—A dynamite jug in Oswego Silt Loam soil, produced by one stick of 20 percent "Red Cross" powder placed in the soil at a depth of three feet. Photographed November 28, 1913.

and physical nature of the soil. The soil particles driven out from the center of charge are forced into the pore spaces between the soil particles in the mass of soil adjoining. Thus a cavity is formed, the walls of which consist of a hard, compact mass of soil. This cavity, with its surrounding mass of soil, is often spoken of as the "dynamite jug." The soil composing its walls is not only very hard and badly puddled, but is so changed in physical condition from the rest of the soil

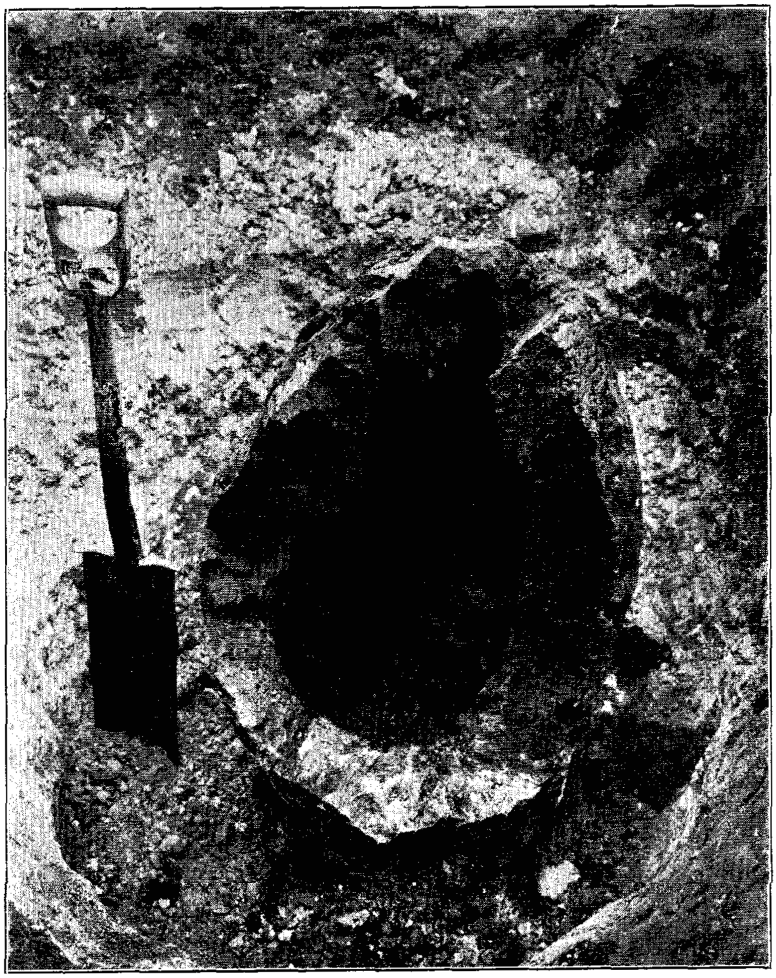


PLATE V.—A partly broken dynamite jug in Oswego Silt Loam soil, produced by one stick of 20 percent "Red Cross" powder placed in the soil at a depth of three feet. Photographed November 28, 1913. Cavity eighteen inches wide and twenty inches deep; thickness of walls varied from four to eight inches.

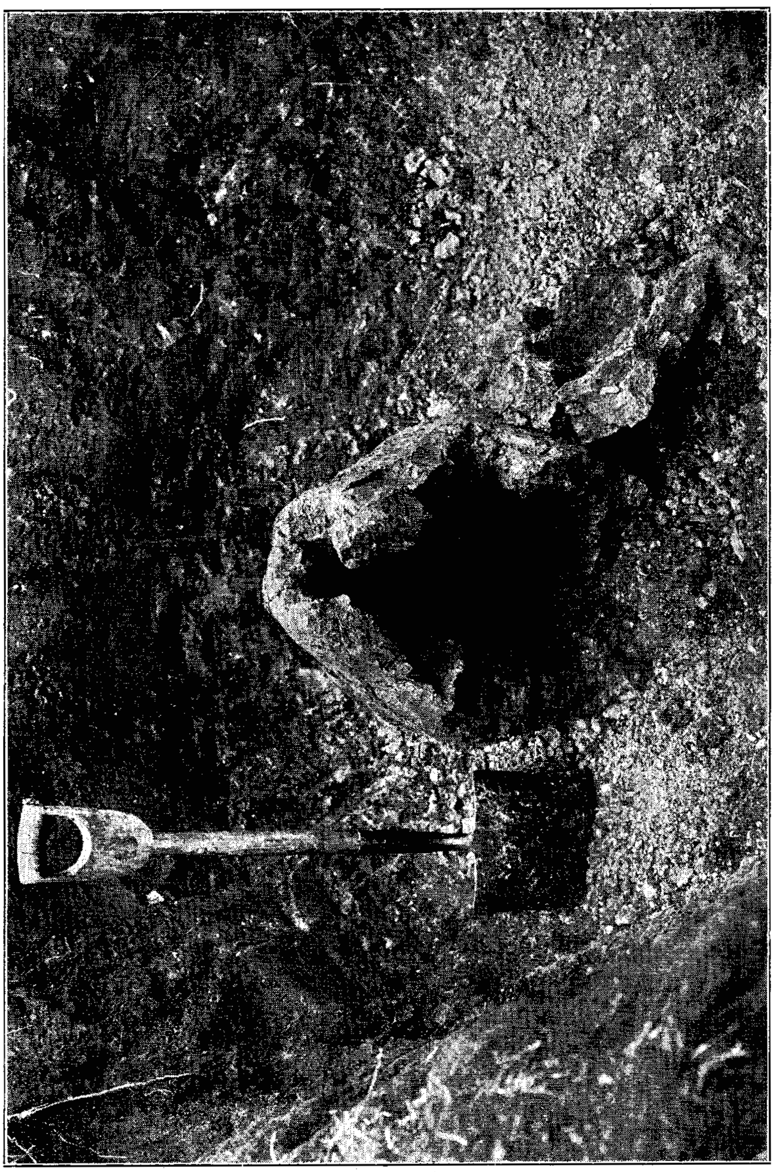


PLATE VI.—A partly broken dynamite jug in Oswego Silt Loam, produced by one-half stick of 20 percent "Red Cross" powder placed in the soil at a depth of three feet. Photographed November 28, 1913. Cavity twelve inches wide and fifteen inches deep; thickness of walls varied from two to six inches.

mass that it is possible to dig away the soil surrounding and separate it from the walls of the jug without difficulty. Plate IV shows a dynamite jug after removing the surrounding soil.

The walls of the jug vary in thickness with the size of the charge and character of powder used, with the texture and moisture content of the soil, and with the depth of the charge. In the Oswego Silt Loam soil one stick of twenty percent "Red Cross" dynamite placed at a depth of three feet produced a cavity eighteen inches wide and twenty-one inches deep, the walls of which varied from four to eight inches in thickness. (See plate V.) In the same soil one-half stick of twenty percent "Red Cross" dynamite placed at a depth of three feet produced a cavity twelve inches wide and fifteen inches deep, the walls of which varied from two inches to six inches in thickness. (See plate VI.) The thickness of the walls and the compactness of the soil composing them produces a jug which is almost impervious to water and through which the roots of plants penetrate with difficulty.

The dynamite jug always contains a small opening or cavity at the top produced by the gases which escape following the explosion. This cavity furnishes a ready entrance for water, which, following a heavy rain, drains into and completely fills the jug. The impervious nature of the jug prevents the percolation of the water; consequently, each dynamite hole in a heavy clay soil remains filled with water for several days following heavy rains. This condition causes the drowning out of fruit trees planted in dynamited holes in a soil of this character, and even corn and small grain fail to grow over the dynamited holes the first season after dynamiting, unless the dynamited hole is filled with soil.

The second season following the dynamiting, corn planted over the dynamited holes made a satisfactory growth, but there is a tendency for the roots to spread less, especially in the surface soil, than is the case with roots of plants growing in a normal soil. Plate VIII shows the roots of a corn plant planted in a normal soil, while plate VII shows the typical growth of a corn plant planted in a dynamited hole the second season after the dynamiting was done.

It is evident from these observations that dynamiting does not crack and loosen plastic clay subsoils. In fact, the opposite effect is produced. The soil, instead of being shattered and cracked, is compacted and puddled, and the soil left in poorer physical condition than before the dynamiting was done. The area of soil influenced by the charge of dynamite is so small, even when the charges are placed at ten-foot centers, that there is no noticeable effect upon the yield of succeeding crops, but if the dynamite charges were placed close enough together that the jugs produced would occupy practically the entire subsoil, very detrimental results would undoubtedly follow.

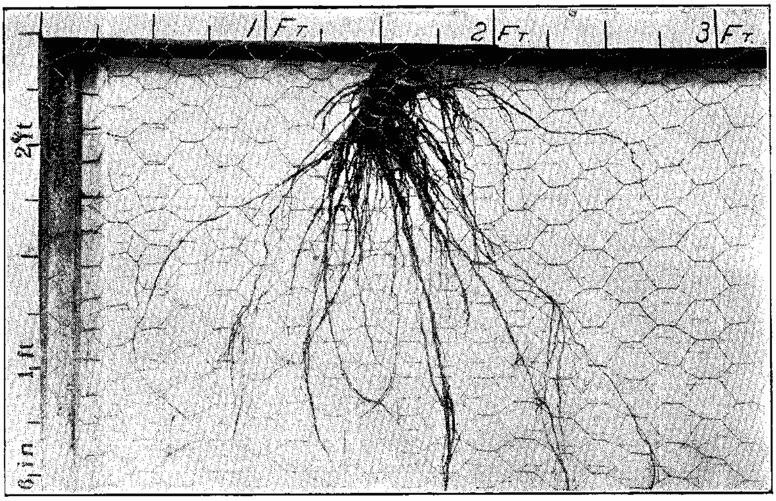


PLATE VII.—Roots of a corn plant planted over a dynamited hole in the season of 1913 on Oswego silt loam soil. Dynamiting done in the spring of 1912. Observe the clumped appearance of the roots in the upper portions of the soil.

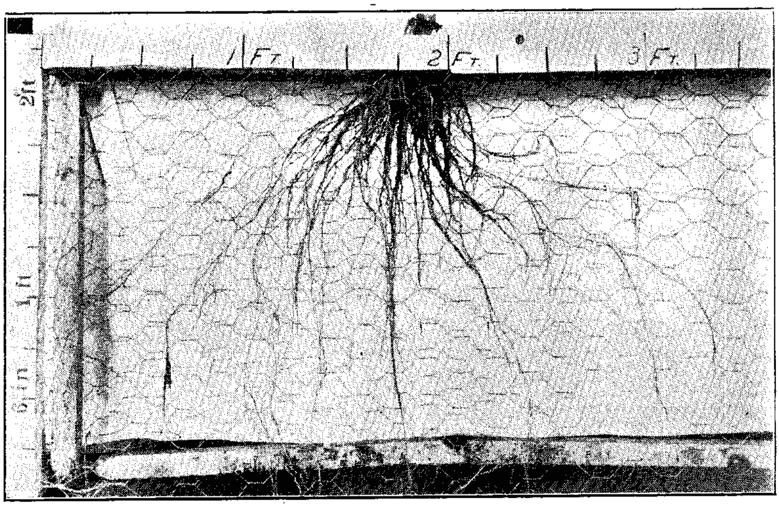


PLATE VIII.—Roots of a corn plant grown on undynamited Oswego silt loam in the season of 1913. Observe the greater spread and more normal appearance of the roots.

The moisture content of the soil at the time the dynamiting is done is a very important factor in determining the effect of the dynamite upon the physical condition of the soil. If the ground was reasonably dry it is doubtful if the dynamite would have any injurious effect; certainly dynamite jugs such as those shown would not be found. But it is impossible under field conditions to find absolutely dry soil, and it is doubtful if a heavy clay soil could be found under field conditions in a humid climate with such a low moisture content that the soil surrounding the dynamite charge would not be compacted and puddled. It would certainly have been difficult to have found the soil under local conditions much drier than it was on November 28, 1913, when the dynamiting photographed in plate V was done. The season of 1913 was one of the driest in the history of the state. The total rainfall from June 1 to November 28 amounted to only 10.61 inches, and total rainfall for the six weeks preceding the time this dynamiting was done amounted to less than three-quarters of an inch. The field upon which the work was done grew corn during the summer of 1913. Certainly conditions could not have been much more favorable for work of this character.

It is the opinion of the writers that heavy plastic clay soils will seldom, if ever, be found dry enough under field conditions in humid climates to be shattered or cracked by explosions of dynamite, and that the physical condition of such soils will usually be injured rather than benefited by dynamiting.

Effect of Dynamite on Fruit Trees.

This work was done in cooperation with the horticultural department of this station. The dynamiting was done in the new horticultural orchard on the Marshall Silt Loam soil, which is practically the same as the Marshall Silt Loam previously described. The charges were placed at fifteen-foot intervals and at a depth of two and one-half feet. The soil was dynamited and the trees planted in the spring of 1911. The trees were planted without regard to the dynamiting; consequently, only two trees were planted in the cavities formed by the explosions, although a number of other trees were planted close to the dynamited holes.

Because of unfavorable weather conditions, many of the trees died on both dynamited and undynamited land during the first three years. Of the forty-two trees planted on the dynamited land, twenty-five, or 59.5 percent, had to be replaced in 1913, and there were fourteen dead trees on this area in 1914, while on the undynamited land thirteen, or 31 percent, of the forty-two trees were either dead or replaced in 1913, and eight were replaced in 1914.

Measurements of the average stem growth were taken during the summers of 1913 and 1914. Very little consistent variation was shown in the growth. Comparing the average stem growth of the Jonathan on the dynamited and undynamited plots, the trees on the undynamited plot averaged 5.5 inches greater stem growth for 1913 and 5.2 inches greater stem growth for 1914 than the trees on dynamited plots.

Measurements of stem growth were not made in 1915, but there was .no noticeable difference in the growth of the trees on the dynamited and.undynamited soil.

In summarizing the work for 1911 to 1915, M. F. Ahearn, associate professor of horticulture, stated that the effect of dynamite on fruit trees appears to be injurious rather than beneficial.

ACKNOWLEDGMENTS.

As indicated in the foreword, the work presented in this bulletin was made possible through the kindness of the E. I. Du Pont de Nemours Powder Co., who financed the work. The dynamiting was done in almost every instance by a representative of the powder company. Credit is due Chas. S. Myszka and P. E. McNall for the moisture, nitrate and bacteriological determinations, as well as many of the crop yields and other data presented. The work at the Fort Hays Branch Experiment Station was done in cooperation with the Office of Dryland Agriculture, Bureau of Plant Industry, and was under the immediate direction of A. L. Halstead, of that office, to whom much credit is due for the data presented from that station. The effect of dynamite on fruit trees was determined by the department of horticulture of this station, and credit is due Prof. Albert Dickens and Prof. M. F. Ahearn for their kindness in permitting the presentation, in this publication, of the results of their work. The authors also wish to thank the farmers with whom cooperative work was done for their assistance, without which much of the work presented could not have been accomplished.