A STUDY OF WATER INFILTRATION

INTO THE SOIL

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INTRODUCTION

The infiltration of water into soil is important. The movement of water into and through the soil and its availability to plants are greatly influenced by the difference in the rate of water infiltration into the soil.

Infiltration is the only process by which precipitation enters the earth's surface and becomes available to plant and animal life. Whenever the rate of rainfall exceeds the rate of infiltration, surface runoff occurs. A relatively small increase in infiltration rate may eliminate runoff from a large number of rains.

Infiltration refers to the entrance of water into soils under field conditions. Infiltration rate presupposes an excess of water on the soil surface that tends to produce runoff or, if confined on an area so that runoff cannot occur, a head of water on the soil surface. The factors that govern the entrance of water into soil are complex.

There are many conditions that influence the infiltration rate of water into the soil. The system of managing the land, use of fertilizers, and the kind of topsoil and subsoil within each field determines the rate of water infiltration.

The management of the land makes the difference in the rate of water intake into the soil in a given length of time. It has long been known that water percolates into soils at different rates. Only recently has it been discovered that the cover, cropping and fertilizer systems make a great difference in the rate of water penetration into the soil.

There are many factors that influence water infiltration rates. Fortunately, the rate of infiltration can and has been changed by the management of the land.

The primary objective of this study is to relate some of the findings in a study of water infiltration into the soils on the Oklahoma Agricultural Experiment Station Agronomy Farm west of Stillwater, Oklahoma, and other locations.

REVIEW OF LITERATURE

According to Webster's Collegiate Dictionary (20),[1] the word "infiltration" means: "to enter, or cause to enter, by or as by penetrating the pores or interstices of a substance." Infiltration, as used in this manuscript, refers to the entrance of water into soils under field conditions.

Musgrave (43) claimed that the rate of infiltration is a variable rather than a constant factor, changing with changes in soil structure; the temperature of air, water and soil; the moisture content of soil; and the degree of biological activity within the soil profile. Some of the factors vary seasonally, and others vary during the course of a single storm. Despite these facts, it is recognized that the relative amount of infiltration of water into different soils is associated with their physical characteristics. Musgrave (43) indicated that farming practices modify infiltration rates. Either destructive or constructive practices may be in operation on a given land surface.

Among the destructive practices are: (1) intensive cultivation which results in destruction of aggregates as well as the organic matter that is effective in their formation; (2) undue compaction of the soil such as may be caused by excessive grazing, particularly when the soil is wet, or by inopportune plowing or tillage,

[1] Figure in parentheses refers to literature cited.

which puddles the soil; and (3) practices that permit the loss of the surface soil, which is usually more highly aggregated than the subsoil, is higher in organic-matter content, and is often of coarser texture.

Among the constructive practices are most of the items commonly recommended for wise soil management, particularly: (1) the incorporation and maintenance of organic matter through such practices as the use of good rotations, the return of crop residues, and the application of manure; (2) the use of cover on the land--particularly close-growing vegetation such as: grass, which is notable for its effect on aggregation; forests; winter cover crops; also, straw, stubble, or even stones which serve as a protection from the impact of rain and reduce the turbidity of surface water; (3) wise culture and tillage, such as the breaking of the surface crust after rains, fall plowing of heavy dense soils where conditions warrant, and manipulation of the soil under favorable moisture conditions and in a manner to improve tilth; and (4) practices which retard the rate of runoff, thereby reducing its velocity and turbidity and providing more time for the infiltration of surface waters.

According to Harper (22), data collected in Missouri by Duley and Miller, and in many other experimental studies, have shown that the highest runoff occurs on bare soil. A four-year study by Alderfer and Merkle indicates that protective cover, rather than change in soil structure, is responsible for the increased infiltration of rain. Several investigators have reported that silt and clay in runoff water fills the large pore spaces at the surface of the ground and retards the rate of infiltration (Hendrickson, Horton). Ellison has measured the kinetic energy of raindrops and their disintegrating effect on soil aggregates which makes the dispersed silt and clay particles more easily transported by runoff water. Uhland reported that soil aggregates taken from land cropped annually to corn were completely dispersed by approximately six raindrops falling on them from a height of thirty inches; whereas, the average number of raindrops required to disperse soil aggregates from land that had been in meadow one year was 37.7, in meadow two years, 41.2, and in alfalfa 13 years, 40.2.

Duley and Kelly (15) found a compact layer about 3 mm. thick on the surface soil where torrential rains fell on bare land. This layer retarded the absorption of the water although the macroscopic pore space in the soil immediately below this layer was favorable for rapid moisture movement. A straw mulch prevented the formation of a compact layer and increased the absorption of water from 0.24 inches per hour on bare soil to 0.74 inches per hour.

The differences in soils cause great differences in the rate of water infiltration into the soil. O'Neal (46) declared that permeability alone cannot be used to determine the speed of water penetration into the soil. Ordinarily, the structure of the soil is the most significant factor in determining the rate of water intake. Structure alone, however, must not be used as a basis for infiltration. Mottled soils usually are thought of as having a slow permeability. Soils which are mottled may be due to a seepage or a barrier which holds the water. Permeability of soil cannot be evaluated on one characteristic alone.

Bendixen, Hershberger and Slater (5) declared that descriptive terms of water movement in soil should be recognized in classifying permeability of soils. Their basis of definitions for descriptive classes of soil permeability in terms of water movement were made by a combination of measurements of the amount of pore space drained in one hour under 60 cm. of water tension and of percolation rates. Structure of soil had a great deal to do with pore-size distribution and continuity. Data, obtained on Coastal Plains soils, showed the general relationship between the amount of pore space drained and percolation rates. Pore-space classifications of permeability based on Coastal Plains soils were found to be in practical agreement with the field classification of the tests made of the Missouri soils. Kelley (26) claimed that sandy soils had a higher infiltration rate in using irrigation water than heavy clay soils. Soils which have a low water-infiltration rate must have the irrigation water held on the land longer in order to wet the soil.

Musgrave (43), in his study of infiltration, found that tests on a group of gravelly silt loams had an average infiltration rate of 2.57 inches per hour, compared to 0.23 inches on clay and clay loams. Uhland (55) claimed that soils vary widely in their property of transmitting water as well as retaining water for plant growth. This information is needed in the fields of irrigation drainage, flood control, erosion control and water conservation. Olmstead (45) found that infiltration rates were higher in soils having greater volume of pore space, providing that the surface condition was equal, or rather when the soil had not sealed over for some reason.

Frederick (18) claims that the State of New York has made use of infiltration information in handling sanitation conditions for the public health agencies. They were concerned about the rate of water intake for disposal of household sewage. The absorptive capacity of the soil is important for public health reasons. They measured absorption according to particle sizes of the soil. All soils were classified as to how long it took for one inch of water to drop one inch when poured into a one foot square hole dug in the soil. The work showed that clean, coarse sand has a drop of one inch of water into the sand in a matter of 13 seconds to one minute. Another example showed it required two to five hours for one inch of water to drop in heavy clayey soil. This indicates a difference in the speed of water infiltration as recognized by engineers and public health officials.

Frederick (18) described soil percolation tests with five different kinds of soil and the time required for water to drop one inch in the soil. The time required was as follows: 8.5 minutes in compact sand and some silt, 16 minutes for coarse sand, 35 minutes for compact cinders. At the end of 60 minutes, only slight percolation occurred in compact glacial till soil, and none had penetrated a stiff silty clay in 60 minutes. Harper's (22) review revealed that soil variations are quite likely to cause a difference in the rate and quantity of water absorbed within the same area as well as in different regions.

Musgrave (42) reported that Marshall silt loam, an important soil in western Iowa, absorbed rainfall from 7 to 10 times faster than Shelby silt loam which has a more dense subsoil. Musgrave (43) related that infiltration is primarily correlated with particles of large size and/or pores of large size.

The clay content of a soil makes a difference in the water intake. Jenny (24) claimed that if the clay content of soil exceeds 60 percent the material is practically impervious to water. He pointed out that the permeability of soil was slow when the clay content was 50 to 60 percent and the colloid content was 27 to 32 percent. He claimed it was moderate to slowly permeable when the clay content was 37 to 50 percent and the colloid content was 18 to 27 percent. The alterations in soil structure that bring about soil compaction hampers air and water circulation as well as tillage operations.

The downward movement of water is one of the prime factors in the transformation of a parent material into the soil with characteristic horizon differentiation. The rate of water permeability is one factor that determines the regional soil type. In a very coarse parent material, such as gravel, the water runs through too rapidly to allow chemical rock decomposition. In fine sandy and silty parent material the water percolation is neither too slow nor too fast, thus resulting in a rapid development of regional soil types.

Millar (38) indicated that the underlying soil horizon makes a difference in the amount of moisture that the soil will take and the extension of plant roots through the soil to reach moisture. If moisture and soil conditions are favorable, roots will grow and spread to great lengths. For example, studies by Dittmer (12) showed that the average daily increase in the length of the root system of a four-month-old rye plant was 3.1 miles. The lack of water in the soil has an ill effect upon the plant roots because most plant roots will not penetrate soil with a moisture content much below the wilting point. It is easy to understand why the study of infiltration of water into the soil is highly important, as it has to do with the growth and function of roots and their operation of efficiency in obtaining moisture for the plant.

Leeper (28) claimed that the smaller the pores in the soil, the more tightly it held water and the more resistance the soil had to water passing through the soil. Water will not move rapidly unless the soil contains channels at least one-twentieth of a millimeter in width, such as exist in sand. Water goes through heavier soils (clay) rapidly only as cracks develop during shrinkage or as space is left by decayed roots. After a few hours of rain, most of the channels close because of the swelling of the soil particles; and movement thereafter is relatively slow. Heavier soils, in addition to having slower water intake rates, have other marked characteristics such as having a higher field capacity, a higher wilting point percentage, and a greater difference between them. There is a correlation between water intake in soil and field capacity. For example, the sand that takes water easily and has a field capacity of only six percent is, in effect, as wet as clay with 34 percent field capacity. A Winkie sand, at 6.2 percent field capacity, has a wilting point of 2.4 percent; whereas the Niemer clay with 34.3 percent field capacity, has a wilting point of 16.5 percent. Some tough clays, at a six foot depth, have a field capacity of 64 percent water, a wilting point of 57.7 percent, and only seven percent useful water at field capacity. Soil with large pore space is well aerated in very wet spells. This is an indication of free and rapid passage of water through the soil. Some soils have mostly small pores which still hold water at field capacity, which is undesirable in wet weather. Many fine sandy loams have poor, single-grain structure, and belong to this class. Heavy soils are not necessarily bad in this respect, since they may be aggregated into a large structural unit.

Leeper (28) pointed out the comparison of walnut tree root growth in soils. He reported on a comparison of the percent of roots below a certain depth with aeration at field capacity, of two soils, on one of which the walnut tree roots made good growth and on the other where the tree roots did not make good growth. The first (Newberg silt loam) had 64 percent of the roots below a depth of three to four feet. This soil had 25.7 percent air at field capacity. The second (Sites clay loam) had only ten percent of the roots below three to four feet deep and only five percent air at field capacity. The rate of water infiltration evidently was correlated with the size of the soil pores. The larger the pores and the more pore space, the better the aeration and greater the water intake of the soil. The lack of oxygen and moisture, or a combination of the lack of the two, makes a difference in root growth and root penetration in soil.

The surface of the soil seals over, thus reducing water infiltration rates. Middleton (36), in his studies of the properties of soils which influence erosion, has compared the maximum water-holding capacity of seven erosive soils with that of four non-erosive soils. The average for the erosive soils was 42.9 percent, and for the non-erosive, 56.2 percent. He has recorded the pore space for these soils. The erosive ones average 32.5 percent, and the non-erosive, 45.1 percent. These comparisons undoubtedly indicate a higher infiltration capacity for the non-erosive than for the erosive soils.

Slater and Byers (50) made a laboratory study of the percolation rates of soil cores which were obtained in the field and forwarded to the laboratory without structural change. The Iredell silt loam, recognized as a highly erosive soil, showed a percolation rate of 0.30 inches per hour through open end cores of 14 cm. length; while the Davidson clay, recognized as a relatively non-erosive soil, gave a percolation rate of 1.02 inches per hour through open end cores of

20 cm. length. Auten (3) has compared the absorption rates of cultivated fields to old-growth forest soils. The forest soils were found to be more porous and had a higher absorption rate.

Page (47) pointed out that a thin surface layer of dispersed soil is all that is required to stop air circulation and slow the water penetration into the soil, regardless of what condition or what kind of soil (even a soil block) is in the profile below. The deficiency of oxygen and water in soils really show conditions on plants that are alike. In plants, water deficiency and oxygen deficiency manifest the same symptoms. Wilting oftentimes is due to lack of oxygen. Tillage is important in opening up the surface soil when it seals over, particularly if that soil is in cultivation. Fifty-seven percent of the roots of an alfalfa plant are in the top six to eight inches of soil. A total of 87 percent of the alfalfa plant's roots are found in the top ten inches of soil. When the physical conditions of soils are good, fertility will cause crop response. Water in the soil, plus a given amount of P_2O_5, produces alfalfa hay. The amount of the yield will be in proportion to the good or poor physical condition of the soil. The fertility does not increase yields satisfactorily unless the physical conditions of the soils are good.

Lowdermilk (30) concluded that the filling of the soil pores with fine sediment clogged the entrance and reduced the water intake into the soil. The bare soil resembles a sieve, and it can be stopped up and offer resistance to water entering the soil.

Slater and Byers (51) found that there was a variation of water intake when there were holes in the surface and other layers of soil, these holes being made by ants, insects, or roots that had finally decayed.

Zwerman (59) recognized that the absence of a crust on the surface and the lack of turbidity of the water made an increase in the rate of water penetration into the soil. The more soil crust and the greater the turbidity, the greater the water runoff. The water runoff on slopes of bare soil is greater when the intensity of rainfall is high, because it cannot enter the soil as fast as the water accumulates. Duley and Domingo (14) definitely decided that bare sand dunes took less water when exposed to rain, as compared to dunes which were covered with grass and exposed to rain.

Cover on the land increases the rate of water infiltration as compared to the same soil without cover. Zwerman (59) found that the second year following lespedeza, the rate of infiltration was 1.08 inches per hour, compared to 0.21 inches per hour where ordinary practices were applied (such as continuous row crops in the Coosa River area above Rome, Georgia.) Rates of infiltration under kudzu were 2.92 inches per hour, compared to 0.24 inches per hour on bare land. Properly managed forest land had an infiltration rate of 2.70 inches per hour, while poorly managed forest land had 1.12 inches per hour. A total of 101 tests were conducted.

Arend (2) made 588 tests in 28 areas in the Missouri Ozarks. His investigations definitely disclosed that removing the litter cover in forests decreased the rate of water infiltration. The rates of 294 unburned plots each year averaged 2.12 inches per hour, compared to those burned over each year which had a rate of 1.32 inches per hour. There was a total difference in all of his tests of 0.80 inches per hour (or 38 percent) which was highly significant statistically. On individual soil types, the difference ranged from 20 to 62 percent and was highly significant in all cases. This would indicate that the burning of cover affects the infiltration rates differently.

Arend (2) also conducted infiltration tests by removing the cover of litter mechanically instead of by burning. The average infiltration rate of the 168 plots with the leaf litter undisturbed was 2.36 inches per hour; that of the same plots after mechanical removal of the litter was only 1.94 inches per hour. The average reduction of 0.42 inches (or 18 percent) per hour, was highly significant statistically, in spite of the fact that 2 percent of the tests revealed higher infiltration rates without the litter. The apparent effect of the removal of forest litter on the rate of water intake varied less among soil types than that of the burned area. In fact, the reduction in infiltration following mechanical removal of the litter varied on different soils from 11 to 25 percent. It was significant for each of the soils.

Judging from the facts revealed by Arend (2), the cover on the surface of any soil would increase the water intake nearly 20 percent. In a study of the effect of removing the litter on a cherty silt loam, Arend discovered a difference of 11 percent more water intake by leaving the litter on the soil than by removing it mechanically. The infiltration rates for the soil where the litter was removed mechanically were 2.8 inches per hour, compared to rates of 3.2 to 3.58 inches per hour where the litter was left on the soil surface. Other tests indicated that the minimum rate of intake on areas of unburned forest litter was 1.67 inches per hour. It was reduced to 1.37 inches per hour, or .30 inch per hour, by burning off the litter. The cherty silt loam, with its forest litter undisturbed, had the highest water intake--3.52 inches per hour. The intake was reduced to 2.58 inches per hour after the litter was burned. This was a reduction of 20 percent.

Duley and Domingo (14) found that the total amount of cover, including live grass associated with cover, showed a higher rate of water intake and was more important than the kind of grass or the type of soil. Tests made on a dune sand area showed that the grass present had a marked effect on infiltration. The intake on sandhill soil without either the grass or the grass roots on the surface was very much less than where the grass was present. This sandy land without native grass had infiltration rates similar to those obtained on a heavier cultivated soil which had been protected with a straw mulch.

Weaver (58) found that cover on the land increased the water intake over bare soil. He used a system of sprinkling water on the soil surfaces fast as it would take water. This was done for a 30-minute period and a 60-minute period. The amount of infiltration was measured by digging a trench through the watered soil immediately after the sprinkling period. The soil was very dry at the beginning of the test. It was a silt-loam topsoil, 12 inches in thickness. The water penetration was 9 inches on grassland and 2 inches on the bare land, in a 30-minute time period of sprinkling. Where sprinkling continued for 60 minutes, the respective average depths of moist soil were 20.5 and 11.5 inches. Big bluestem sod took the most water, 9 inches; blue grama, 7 inches; and western wheatgrass, 5.5 inches in 30 minutes.

According to Musgrave (40), on tests run on farms in Peoria County, Illinois, where cattle were grazed on bluegrass grown on

Muscatine silt loam, the bluegrass pasture had an infiltration rate of 0.61 inches per hour, compared to only 0.11 inches per hour on corn land. This was 0.50 inches per hour less than the bluegrass pasture.

Tigerman (54) pointed out in his tests that rangeland with good cover had a much higher intake of water than the range with a high percentage of bare ground. On protected enclosures where the vegetative cover was 29 percent and the bareground cover was 11 percent, the infiltration capacity was 4.25 inches per hour on a dry run, compared to 1.43 inches per hour dry run on a poor site where the vegetative cover was 21 percent and the bareground cover was 64 percent.

In browse plots, consisting of woody vegetation and shrubs on protected enclosures having 80 percent cover and 5 percent bare land, the infiltration rate on a dry run was 6.65 inches per hour, compared to only 5.00 inches per hour where the area was grazed in outside exclosures having only 50 percent vegetative cover and 15 percent bare ground cover. The soils were deep, heavy-textured soils, located in the Hoback Big Game Exclosure, Teton National Forest in Wyoming. The infiltration rate was high in all tests, due to cracks caused by dehydration.

Harper's (22) review disclosed that protective cover, rather than change in soil structure, is responsible for the increased infiltration of rain, as reported by Alderfer and Merkle in a four-year study. Moisture storage in the soil to a depth of six feet under plowed land was increased from 3.71 to 9.72 inches of water during a season of abundant rainfall, where two tons of straw per acre were placed on the surface after plowing. During two dry seasons (according to Duley and Russell), 1.96 inches more water was stored in the soil under the straw mulch, as compared with a plowed, mulched area. Duley and Domingo as reported by Harper (22) determined from infiltration studies on pasture land that the total cover of grass and litter was more important than the kind of grass. A slope of 5 percent covered with straw at the rate of 2 tons per acre for a period of nine weeks before artificial rain was applied, absorbed 97.5 percent of the water; whereas, unmulched plots absorbed 92 percent of the water. The difference was not great, but the bare soil lost 10 tons of soil per acre, compared to only a few pounds on the mulched plot.

A test by Nance (44) was conducted two miles north of Stroud, Oklahoma, in July, 1953, and revealed that virgin soil with a good cover of medium to tall native grasses took 2.10 inches of water the first hour. The adjacent formerly cultivated soil covered with triple-awn grass had a rate of 0.65 inches the first hour and a total of 1.57 inches at the end of six hours. The land covered with a much heavier growth of native grass had a rate of 4.90 inches for the total of six hours. In both cases the soil was wet, due to recent rains.

Van Doren and Klingebiel (56) reported that the addition of limestone and fertilizer increased the permeability rate of the soil as compared with the untreated plots. This response may be attributed to the increased growth of the plants. The percentage of large aggregates in the surface soil of cultivated areas was reduced from 20 to 4, as compared to virgin areas. Surface samples taken from plots farmed to a rotation of corn, oats, clover, and wheat (clover) were 16 times more permeable, and held 17 percent more available water than samples taken from plots farmed to a corn, corn, soybean rotation.

McCalla (33) reported that surface samples of soil which were treated with limestone, rock phosphate and potash, had higher permeability rates and higher percentage of pores drained than those from untreated plots.

Slater and Byers (51) discovered that the field percolation rate of a soil is governed more by the water passageways it contains (root channels or structural cleavage) than it is by the character or volume of the pore space of the soil mass.

Stanberry et al. (53) reported that phosphorus had a significant effect on crown and root weight, root diameter, amount and distribution of feeder roots of alfalfa. They found that phosphorus increased the size of the roots. The roots of plants that had been treated were longer, spread farther, and the amount of roots per plant was greater than those that were not treated. In all cases, this was correlated with moisture. The combination of moisture and phosphorus increased the total volume of the alfalfa roots in the soil. In addition, the yields of alfalfa were increased where the combination of water and phosphorus was available. The size of the roots and the total amount of roots would have some bearing on the percolation of water into the soil.

Fox and Lipps (17) made a study of roots of alfalfa and of sweet clover, as to how they were affected by the use of lime and phosphorus. During the first year of the alfalfa growth, the roots reached a depth of five feet in limed soil, compared to a depth of three feet on unlimed soil. The test was conducted on soil that was acid and needed lime. On calcareous soils, where no available phosphorus could be detected, plants failed to grow on untreated soil, compared to plots of the same soil which were treated with small amounts of phosphorus. The roots were abundant on the treated plots. Studies of the roots of alfalfa in the zone of 14 to 60 inches indicate that the lack of phosphorus at that depth reduced the branching of the roots and almost completely stopped nodulation.

Most investigators point out the same results about the effect of lime and phosphorus on the development, growth, branching and nodulation of alfalfa and sweet clover.

Kelley (26) pointed out a difference in the amount of water needed to produce alfalfa on dry and wet soil by irrigation on a soil of low fertility and one of high fertility. He found that it took 88 percent more water to produce a ton of hay on the dry, low-fertility plots, as compared to wet, high-fertility plots.

Here again the fertility evidently increased the root growth, thus prying the soil mass apart and making water infiltration faster and requiring a lesser volume of water, as more of it went into the soil in a given time.

Fireman, et al. (16) made a study to determine if sodium nitrate and ammonium nitrate fertilizers had any adverse effects on the permeability of western soils. They found that moderate rates did not decrease the permeability of the soil. Large amounts per acre did decrease the permeability of the soil. Sodium nitrate decreased the permeability much less than ammonium nitrate. When the nitrogen fertilizer was applied in bands on truck crops in extremely high amounts, the permeability was reduced 40 percent, and in some cases, 86 percent. The reduction was due to the increased dispersion of the finer fractions of the soil in the zone of fertilizer placement.

Gypsum has been tried as a means of increasing the infiltration of water into the soil. Bodman and Mazurak (7) have tried gypsum in California. They have had difficulty with slow water intake in the production of early potatoes and with cotton in the San Joaquin Valley of California, in the vicinity of Bakersfield. The soil where gypsum was used was a Hesperia sandy loam. It is a light gray-brown, micaceous soil developing upon the valley fill of granitic origin. It slopes to the southwest. They found that no consistently significant rapid increase in infiltration rates could be expected from the direct application of gypsum to the soil. They also claimed that more recently investigations by others, made elsewhere in the valley, where soil and water possessed very much lower Ca/Na ratios, indicated that gypsum may greatly increase infiltration rates, particularly when added to the irrigation water. In these experiments, it was discovered that the physical condition of the dense zone greatly affected the infiltration rate observed during the test.

Duley and Kelly (15) found that there was a tendency for the amount of water intake to decrease slightly with the increase in slope. The greatest intake was found on the more gentle slopes, particularly the 2 percent slopes or less. Infiltration rates on different slopes of the same soil series were recorded. Where the slope was 2 percent on Knox silt, the intake was 1.18 inches per hour. On a 4 percent slope, it was 0.98 inches per hour. The 6 percent slope had 0.79 inches per hour. The above readings were on the first day, the initial run. The second day the rate of intake on the 2 percent slope was 0.63 inches per hour; 4 percent slope, 0.51 inches per hour; 6 percent slopes at 0.25 inches per hour. The relative infiltration rates were as follows: 2 percent slope, 100; 4 percent slope, 56; and the 6 percent slope, 56.

Alderfer and Robinson (1) discovered that compaction affected the top one inch of soil. In their tests where water was applied at the rate of 1.4 inches per hour on plots having a sod of 40 percent blue grass cover and 60 percent ground mulch and which had not been grazed, there was no runoff. This was compared with plots of bluegrass having a poor sod and which had been heavily grazed. The runoff was 80 percent. The effective rainfall was equivalent to only 0.28 inches. Heavy grazing not only reduced the vegetative cover, but decreased noncapillary porosity and increased the volume weight of the top one-inch layer. In the 0 to 1 inch layer of soil, noncapillary porosity ranged from 3 to 10 percent for the heavily grazed plots, as compared to 15 to 33 percent for ungrazed and lightly grazed plots. Volume weights ranged from 1.54 to 1.91 on the heavily grazed sites, and from 1.09 to 1.51 on ungrazed and lightly grazed sites. It was interesting to note that layers of soil from 1 to 3 inches and others at 3 to 6 inches were not affected with regard to the volume weight and the intensity of grazing. Only the top one inch of soil was affected by compaction due to grazing.

The infiltration rates of heavily grazed bluegrass vegetative cover with 60 percent cover ranged from 0.35 inches per hour to 0.41 inches per hour. The same kind of pasture moderately grazed, with 90 percent cover, had a maximum infiltration rate of 1.13 inches per hour and a minimum of 1.11 inches per hour. In a bluegrass sod, ungrazed for five years, with a 100 percent cover, the maximum infiltration rate was 1.40 inches per hour and a minimum of 1.10 inches per hour. Clipping the grass to a height of one inch did not affect the intake rate.

Removing the mulch after clipping showed a maximum infiltration rate of 1.32 inches and a minimum of 1.25 inches per hour. This was a reduction of from .08 inches to .15 inches per hour by clipping and removing the mulch. Trampling by foot reduced the infiltration rate. The maximum rate was 0.90 inches per hour and the minimum rate was 0.63 inches per hour. The top one-inch layer of soil was affected most, as to compaction, and reduced the water infiltration, even though this layer showed the largest amount of organic matter.

Doneen and Henderson (13) related their findings in California with regard to decreased water penetration by grazing areas when wet and causing compaction. The plot studied was an old, irrigated pasture. Water percolation had been normal at planting time, but compaction was caused by cattle grazing while the soil was wet. The compaction was so severe that the water grass and other water-loving weeds crowded out pasture plants on the plot that had been grazed while the soil was wet. Duley and Kelly, in their studies (15) with mulches on cultivated soils, have shown that the clogging of the soil pores and the development of a condensed layer on the surface of cultivated, bare soil have a far greater effect on the intake of water than does the differences in soil type, degree of slope, previous moisture content of the soil, or the rate of rainfall. In fact, it seems to have a greater effect than all the other factors combined. Thus, conditions on the soil surface greatly influence water content of soil; and this, in turn, is a controlling factor in distribution of the roots of grasses and forbs.

Doneen and Henderson (13) pointed out that water penetration in

California is declining. The problem used to be with the "plow sole," which now extends from 18 to 24 inches in depth. This is attributed to the use of machinery. In many cases, water penetration has been adequate but is now becoming a problem. Soil samples were taken where implements had turned the soil many times. The rate of water infiltration into the soil before the soil was compacted by the use of machinery was three to four inches per hour. The rate of infiltration after the soil was compacted was 0.2 inches per hour. This was a reduction of 15 to 20 times after the compaction.

Locke and Mathews (29) and Bull (8) discovered that a compaction layer, or "plow sole," was located at depths of from 4 to 8 inches on a Pratt fine-sandy-loam soil. The infiltration rate was from 0.2 to 0.3 inches per hour. When the surface soil was removed and the infiltrometer was placed at a depth of 8 inches, the water penetration rate was about 9 inches per hour. Cultural practices which were applied when the soil was wet sometimes created a compacted layer. When the soil was worked in a wet condition, a crust was formed beneath the surface while drying, to the extent that root penetration was almost impossible. The field was formerly in native grass and was broken in 1914. Crops had been grown on it every year on uniformly prepared land.

Doneen and Henderson (13), determined that density alone is not a good criterion of soil compaction. In samples taken at 8 inches to 15 inches in depth, the bulk density was 1.73 and the water infiltration rate was 0.162 inches per hour. The second sample of soil was taken at a depth of 19 to 25 inches and had a bulk density of 1.62. This reduction of bulk density of 0.11 was accompanied by an increase in the infiltration rate of over 200 percent. The infiltration rate of the soil at the 19-25 inch depth was 0.499 inches per hour. Soil samples were taken where compaction was caused by farm implements. The density of the soil was high and the infiltration rate was low. In a barley field where a crawler-type tractor had been used, the water penetration was so poor that barley plants were nearly dead from lack of water. The bulk density of the two areas differed only slightly, being 1.73 on the compacted strips and 1.71 on the normal areas; but the infiltration rate on the noncompacted areas was $3\frac{1}{2}$ times that of the compacted strips.

Hunter and Kelley (23) found a very compact layer at 12 inches at Salinas, California. This layer was caused by tillage operations. The volume weight of this layer varied from 1.85 to 2.08, as compared to 1.60 for surface soil. Very few plant roots penetrated this zone; but once they did, and died, it became very difficult, if not impossible, to rewet the lower depths of this soil at the time of irrigation.

Duley and Domingo (14) found that a covering of straw on bare, cultivated land increased the infiltration rate nearly three times that of bare, cultivated land without straw. The land was an old alfalfa field of 15% slope on which the weeds had been removed and the soil had been spaded to a depth of six inches and then worked into a good seedbed. This plot was known as "Plot 14." The intake in the first $1\frac{1}{2}$ hours was 3.23 inches, compared to 8.36 inches on the same kind of soil and handled exactly like Plot 14, except that it was covered with 2.5 tons of straw per acre. This was just barely enough to cover the surface.

The use of manure has increased water infiltration rates. Bay and Hull (4) reported that surface application of barnyard manure decreased runoff by 0.66 inches and increased water percolation by 0.56 inches per hour. Their study showed that a mulch on the soil surface reduced runoff water, increased percolation, and reduced nitrogen losses, regardless of whether the residue was legume, straw, or barnyard manure.

Bennett (6) reported that in instances of bare ground (no crop), not manured, 14.16 inches of a total precipitation of 102.41 inches (14 percent) for the period passed below the root zone (3 feet below the surface), 58.78 inches (57.4 percent) evaporated, and 29.47 inches (28.8 percent) were lost as runoff. At the same time, only 5.77 inches passed below the root zone in the untreated area, 19.16 inches were lost immediately as runoff, and 77.48 inches disappeared through evaporation and transpiration. From corresponding manured areas, the runoff from bare ground was 8 inches less than from the unmanured bare area, and approximately 8 inches more passed below the root zone. The loss by evaporation remained substantially the same. At the same time, the manured corn land lost only 13.2 inches as runoff, and only 10.63 inches below the root zone. Evaporation and transpiration were about the same on both the manured and the unmanured corn land.

Mosier and Gustafson (39) claim that insects and worms penetrate the soil in all directions and furnish a ready means for movement of water laterally and vertically. The greatest amount of work done by earthworms was in heavy soils, where percolation is naturally slowest. Worms are not abundant in acid soils and those deficient in organic matter. Joffe(25) related that earthworms are practically nonexistent in the arid region between the Rocky Mountains and the immediate Pacific Coast from Manitoba to Texas; however, ants are found in areas from Texas to Montana. Openings made by ants increase water intake. Termites also have done considerable digging in the soil. Material in their passageways have been found which indicates excavation from considerable depths and they probably penetrate to the ground water. Cocannouer (10) declares that every particle of naturally productive land on our planet has at one time or another traveled the digestive system of an earthworm, because naturally fertile, dynamic land cannot exist without an earthworm population vigorously at work throughout the entire surface-soil mass. Every earthworm digests its own weight in soil every few hours. While prowling throughout the soil in search of food, they churn the soil as no manmade instrument could ever do it. Without this tunnel making, root growth in the lower soils would be seriously hampered for want of air. It has been proved that as many as eighteen tons of castings are deposited every year in every acre of land that is well-populated with earthworms, and that every portion of the ingredients which make up the castings is brought to the surface from the lower soil regions. There seems to be a very close affinity between earthworms and plant roots, and their relationship is not detrimental to plants. Earthworms work among dead, not live, roots to obtain organic materials. Carhart (9) indicated there are many burrowing, tiny, living things (earthworms, beetles, larvae of insects) constructing literally millions of pipes down into the soil through which water will percolate more readily. Slater and Byers (51) found that ant holes made a big variation in the water intake in soil. The infiltration rate was much higher where the ant holes were noticed.

Plant roots open up the soil and make a difference in the water intake. According to Mosier and Gustafson (39), roots of plants penetrate the soil, and later decay, leaving passageways through which water may pass quite readily. Joffe (25) disclosed that plant roots leave certain well-marked impressions in the soil profile. Especially is this true of the large roots which produce channels. Cocannouer (10) described situations where alfalfa roots have been found that were 81 feet from the plant. The root was obtaining water from a "swale." Tree roots have crossed under concrete highways into an irrigation reservoir. Duley and Domingo (14) reported that there is little indication that grass roots in themselves have much effect on water intake. The idea that water tends to follow roots into the soil at much faster rates than if the roots were not present does not seem to be borne out by results of their tests. This point needs further study, and the effect of old root channels should be considered. It seems that old, decayed roots rather than young roots are the ones that increase water intake.

Musgrave (40) claimed that the decay of plant roots is the important thing, in that it promotes aggregation and large soil pores. First-year alfalfa, growing on land previously intensively cropped, did not greatly affect infiltration; but after a few years, when roots had died and decayed, tests indicated that the intake was greater. In research on water movement into the soil, one of the problems is to separate the effects of dense vegetation or canopy interception of rain from those of infiltration. Young alfalfa, on previously intensively cropped land, will show a reduction in runoff because of its canopy interception (possibly as much as 0.50 inch) without in any way affecting infiltration. The best data probably comes from the large number of experiments showing the strong relation between soil organic matter, soil-genetic processes, aggregation, noncapillary porosity, and infiltration.

In addition to the surface effect of vegetation in restraining runoff and increasing infiltration, other benefits such as increased soil organic matter supply and channels opened by ramifying root penetration are of importance. Pavlychenko (48) finds, for example, that a single wild-oat plant, 80 days old, had a root system totaling 54 miles in length. He found one crown root from the main root system had a total length of 4.05 miles! The ground tunnel formed by the main stem of this crown root will probably be an effective water channel.

Zwerman (59) disclosed that low infiltration rates are associated with the presence of a soil crust and turbidity of runoff water. The higher rates are associated with the absence of soil crust and lack of turbidity of runoff. This conclusion was made after conducting 101 infiltration tests, made with an FA type infiltrometer. These tests were made on land suitable for cultivation and on land not suitable for cultivation.

Lowdermilk (30) showed that the infiltration rate of a soil is profoundly affected by the turbidity of surface water. Clear water penetrates a soil much more rapidly than turbid (muddy) water. This is because the suspended material of muddy water tends to filter out as surface water enters the soil openings, closing them and impeding downward movement. Those soils having a considerable proportion of their colloidal clay in a flocculated condition are much less subject to the sealing effect of muddy infiltration than those whose particles are deflocculated or separated as individual grains. Lowdermilk (30) found in the Berkeley experiment that a muddy suspension percolates through soil columns at about one-tenth the rate of clear water. He also found that after muddy water was applied to a soil column for a period of two weeks and the water was changed to a clear supply, the percolation rate did not increase under the reapplication of clear water. After the experiment, it was found that the soil in suspension had filtered out at the soil surface, to form a thin layer of fine-textured material, silt and clay, which determined the rate of intake or infiltration of water into the soil column, irrespective of the capacity of the material below the surface for percolation. This explains why the removal of cover creates a special hazard by decreasing water intake and increasing water runoff and soil erosion. Bennett (6) further pointed out results at the Clarinda, Iowa, Soil and Water Conservation Experiment Station to the effect that the water runoff from bluegrass and alfalfa land had less than 0.2 pounds of suspended soil per cubic foot, as against a turbidity of more than 4.0 pounds per cubic foot (or 20 times as much) in runoff from the same kind of land on which corn was grown continuously under the same amount of rainfall. These figures were taken over a period of three and one-half years.

Frevert, Schwab and Edminister (19) disclosed that the physical characteristics of the soil, including the infiltration capacity, can be changed by adding chemicals to it. In general, these additives are one of two types. The first type consists of materials that add to the permanency of the soil aggregate formations, and thereby generally improve the soil structure. This improved structure causes considerable increases in both the infiltration and percolation rates. The second type of additive is essentially a wetting agent, which does not change the soil but instead changes the angle of contact of the soil water with the soil surface and thereby the rate at which water can move through the soil. In general, it may be necessary to reapply these wetting agents periodically, as they leach out with continued water application.

Cracks in the soil increase the amount of water intake and the rate of water infiltration and percolation. Mosier and Gustafson (39) declared that the movement of water by percolation is aided greatly by the cracks that are produced in clayey soils by shrinkage during periods of drouth. These cracks do not fully close upon subsequent wetting, and may thus leave passageways for water. This is very important in heavy soils.

The trend in agricultural policies by the administration of the United States Department of Agriculture is to substitute grass for cash crops as one means of soil and water conservation and improvement in 1956. This movement will aid in the reduction of farm crop surpluses such as wheat, cotton, peanuts, tobacco, corn and some other cultivated crops. Planting land to grass helps to reduce water runoff and soil loss. Grass growing on the land increases water infiltration, according to Duley and Domingo (14). They have revealed much information in their tests. They have pointed out that grass cover protects the surface of the soil so that raindrops do not strike it directly, and a high infiltration rate may be maintained for a considerable time. When raindrops hit bare soil, they break the structural aggregates and cause a dense compact layer to form at the surface, thus reducing the rate of intake. When growing vegetation cannot be obtained, dead residue will have a marked effect in increasing infiltration and reducing runoff. Their tests were made with a sprinkler application of water to an infiltrometer. The open box used was inserted 6 inches into the soil, with a margin of 3 inches above the ground line. The tests were made during a 1.5 hour sprinkling period, and the rate at the end of the period was used. Tests were run a second time, 24 hours later, known as a "second run" or "wet test." The first test was to indicate what might be expected when rain falls after a period of dry weather. The second test was made with the idea that conditions would be similar to wet weather. These tests were conducted on a native grass meadow adjoining the Agronomy Farm at the University of Nebraska which had been mowed frequently. Information from the tests indicated that the soil absorbed over 2 inches of water during the first 1.5 hours, with an absorption rate of about 1.4 inches per hour at the end of the time.

Investigations showed that it made little difference whether the debris of dead grass was removed and the grass left for protection, or whether the grass was removed and the debris left. The intake rate depends largely on protection of the soil surface by some type of cover.

Sandy land with a good cover of native grass had water intake rates equal to forests. When the vegetation and roots in the top few inches of soil were removed, the infiltration rate was reduced noticeably. Grass on heavy clay or clay-loam soil may have high rates of infiltration wherever there is effective cover on the land. The amount of cover is more important than the type of soil. Tests were run to determine water intake on bare plowed land compared to the same land in the same condition covered with straw at the rate of 2.5 tons per acre. The water intake was 8.36 inches for the first 1.5 hours where the surface was covered with straw, compared to 3.23 inches per hour where the land was spaded 6 inches deep into a good seedbed. The second run, 24 hours later while the soil was wet, showed an intake rate of 3.44 inches on the straw-covered soil, and only 1.09 inches on the bare soil.

The organic matter content of the soil has an influence on the rate of water intake. Peterson (49) related that a field of sandy land that had been cropped for 35 years to milo and kaffir had lost 56 percent of its organic matter and took only 0.30 inches of water per hour. Musgrave (41) found in his tests on 68 sites that organic matter influenced the infiltration rates of water in soil. Soils with low organic matter content had a lower rate of infiltration. The organic matter content is associated with the size of aggregates. The high organic matter content of soils is in a way some measurement or indication of a higher percent of larger aggregates within a soil sample. Leeper (28) indicated that in a long cultivated orchard soil where the organic matter content was 4.2 percent, the percentage of aggregates above $\frac{1}{4}$ mm. in the soil was 92 percent. In long cultivated soils for cereals (sandy loam), where there was hard packing, it contained 1.00 percent organic matter and only 12 percent of the aggregates were above $\frac{1}{4}$ mm. in the soil. In a sandy land that had been cultivated 8 years after clover, the organic matter was 1.7 percent, and the percentage of aggregates above $\frac{1}{4}$ mm. was 53 percent. There was one exception where a high organic matter soil did not show a high rate of water infiltration.

Alderfer and Robinson (1) found that in badly trampled pastures, which were grazed by livestock, the top one inch of soil was decreased in water infiltration rate, even though the top one inch had a high organic matter content.

Smith, Brown, and Russell (52), discovered that the intake rate of water in Clarion loam was less than two inches in two hours where no organic matter was used; whereas, more than 3 inches of rainfall entered the soil in the same length of time under comparable conditions where eight tons of manure per acre were plowed in; $4\frac{1}{2}$ inches (twice as much) of rainfall entered the soil where 16 tons of manure per acre were applied.

Recreational uses of forests and parks change the soil. Due to the trampling of the soil, the density of the soil is increased and pore volume and air capacity are decreased. Due to the travelling and trampling by people in the forests, soils become firm and dense and finally form a hard, tough surface sheet which is more or less impermeable to air and sheds water readily. These findings were reported by Lutz (31) on Cheshire and Holyoke sandy loam. He further indicated that the soil below the trampled sheet becomes abnormal and offers unfavorable living conditions to the roots. The rate of infiltration of water in undisturbed soil was, on the average, five or six times that in the heavily trampled soil. He found that frost action during the winter months probably tended to loosen the compacted soils. Measurements in the spring would indicate less bad results. Investigations were made in Wharton Brook State Park and Sleeping Giant State Park, both of which are located near New Haven, Connecticut.

In the Wharton Brook State Park the average volume weight of the surface soil (0-10 cm. depth) in the used area was 1.37; in the non-used area, it was 1.008.

In the Sleeping Giant State Park, soils subjected to intense use by trampling had an air capacity of 20.4 percent on an average; soil not subjected to this influence averaged 38.3 percent. The difference of 17.9 percent was significant. The rate of infiltration in the Merrimac soil, which was subjected to trampling, was about one-sixth the rate in non-used areas.

Musgrave (41) found that the effect of temperature on infiltration is undoubtedly complex. There is a tendency toward an increase in rate of infiltration with an increase in soil temperature, and the correlation becomes significant for the wet run. Temperatures of the water on the soil surface were found to be similarly associated with infiltration rates; however, when temperature is included in a multiple correlation with other factors that have been demonstrated to be highly correlated with infiltration, such as noncapillary porosity, organic matter, and clay in the subsoil, the contribution of temperature seemed to be negligible. It can, therefore, be stated with a considerable degree of assurance that while temperature at the time of the run may have affected infiltration to some degree, it was not a dominant factor.

Mosier and Gustafson (39) reported that changes in temperature affect the viscosity or mobility of water to such an extent that it moves more readily at high temperature than at lower temperature. Water flowing through a one square centimeter of soil at 9° Centigrade was 9.15 grams per minute; and at 32.5° Centigrade, it was 10.54 grams. Water will percolate through soils faster in summer than winter. Water at 32° F. and at 70° F. was allowed to flow from a square millimeter opening under the same pressure in each case. Twice as much water flowed out at 70 degrees as at 32 degrees. Their data also showed that viscosity is frequently affected by substances dissolved in the water.

Almost all investigators indicate that wetness of soil reduces the infiltration rate. Lyon, Buckman and Brady (32) claimed that in clayey soils, collodial matter clogged small and large channels after the soil was wet. Such collodial matter may offer little obstruction at first; but as it swells, it may ultimately nearly close the smaller pores. Heavy soils that crack during dry weather at first allow rapid percolation of water. Later, however, these cracks may swell shut, thus reducing percolation to a minimum.

Bennett (6) claimed that tillage increased the rate of water infiltration at the start. Any cultivation increases the openness (combined cavity space) of a soil chiefly by increasing the size of the cavities.

Musgrave, Free and Stone (43) reported that measurements of infiltration rates of cultivated and uncultivated soil of the same kind have shown, for the types investigated, that the rate of intake on land plowed 4 inches deep averaged 0.99 inch an hour, and 1.20 inches where plowed 6 inches deep; as against an intake of only 0.77 inch where there was no cultivation. The effects last only until the soil settles back under the effect of subsequent rains to its former condition of density or even to a condition of increased density or until the openings are closed with fine particles filtered from influx of muddy surface water. In many cases, from 25 to 30 percent more soil is crammed into a cubic foot than was present in the virgin soil.

Harper (21) pointed out that breaking of the hardened or compact surface by cultivation will have some temporary effect toward increased intake of water. Subsoiling under certain conditions, particularly in soils having relatively impermeable sublayers susceptible to fracturing, also speeds up the rate of infiltration.

Land in continuous cultivation without a legume or grass rotation has a tendency to become compact. A plow pan may form at the bottom of the plow layer. The water infiltration rate has a tendency to be low after continuous cultivation for 50 years. These facts have been brought to light by Daniel, Cox and Elwell (11). They found the following infiltration rates:

TABLE I

RATES OF WATER INFILTRATION ON LAND IN CULTIVATION FOR 50 YEARS AT WHEATLAND CONSERVATION EXPERIMENT STATION, CHEROKEE, OKLAHOMA

Land Conditions	Rate of Infiltration in Inches Per Hour
Continuous Wheat	.168
Formerly Buffalograss for 5-Year Period	.920
Continuous Wheat on Friable Sandy Land	
Undisturbed Surface Soil	.102
Soil Below Plow Pan	1.330
Continuous Wheat on Friable Silt Loam	
Undisturbed Surface Soil	.040
Soil Below Plow Pan	6.600

These tests indicate that the entrance of water into the soil was limited by surface soil and plow pan conditions. These deleterious conditions were brought about by long continuous cultivation without a grass or legume rotation.

Bennett (6) related that the movement of water from the surface into the soil profile by way of openings (natural pores, cracks, root and animal holes, and cavities introduced by tillage) is known as infiltration. The importance of the differences in filtration characteristics is seen when it is considered that a rain falling at an intensity of one inch an hour would be entirely taken up over a three-hour period by Ruston sandy loam under conditions like those obtained where the foregoing measurements were made, whereas the same rain falling on Susquehanna clay loams under like conditions would produce an average runoff amounting to more than 0.90 inch an hour and would normally result in severe erosion on unprotected slopes. Such a rain on Davidson clay loam would, under the same conditions, cause a runoff of only about 0.2 inch an hour, whereas from Iredell clay loam the water lost as runoff would amount to 0.99 inch an hour.

Increased infiltration, aside from its powerful effect in reducing runoff and erosion, is important throughout the country generally because of the dependence of plants on soil water reserves in times of drouth. In general, then, it is important to increase the penetration of rainfall into the body of the soil by whatever practicable means available, for two reasons: (1) consequent reduction of runoff and erosion, and (2) increase of available water for plant growth.

In conclusion, the tests and information related in the literature on the subject of "Infiltration of Water into Soil" shows how infiltration depends on many factors and the rate of intake varies due to these factors.

EXPERIMENTAL METHODS AND RESULTS

The data included in this thesis is material gathered from a field study on the Oklahoma A. and M. College Experiment Station Agronomy Farm, located west of Stillwater, Oklahoma. The objective was to study the water infiltration rates of the soil.

Experiment I

To find the water infiltration rates of soil planted to alfalfa, tests were conducted on Series Number 2100.

These tests were started on October 8, 1954. Mature alfalfa was growing on the land at that time. The soil was very dry. The soil in this area has been mapped as 2B-1 Bethany silt loam, with slopes ranging from 1 to 3 percent. This soil occurs in areas transitional between the Norge loam, a deep, friable soil with only moderately clayey subsoil, and Kirkland silt loam, a dark soil with claypan horizon at 8 to 15 inches below the surface. Bethany has friable surface layers which are browner than those of Norge.[1]

Series No. 2100 has been used in a rotation of alfalfa and wheat for a total of 18 years, from 1937 through 1954. The rotation was four years of alfalfa, followed by eight years of wheat. Manure was applied at the rate of eight tons per acre in the preparation of the land for alfalfa; none was applied on the wheat. The east half of

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[1]A detailed description of these soils is listed in the Appendix, pp. 84-90.

the series was not limed; while the west half was limed. Lime application was made in accordance with the soil test at the beginning of the test. The pH was 6.5, according to the information listed in the profile description given in the appendix. The symbol "W" was added to the plot number, to indicate the west half which was limed. The symbol "E" was added to the plot number indicating the east one-half, which was not treated with lime. Plots in the series received the following treatments:

Plot 7E - No fertilizer treatment.

Plot 7W - Same as Plot 7E except that it was limed.

Plot 8E - 8 tons of manure per acre were applied at the time of seeding the alfalfa (once each 12 years). No lime treatment.

Plot 8W - Same as Plot 8E, except that 8W was limed.

Plot 9E - 8 tons of manure and 1600 lbs. of rock phosphate per acre were applied at the time of seeding alfalfa (once each 12 years). No lime treatment.

Plot 9W - Same as Plot 9E, except that 9W was limed.

Plot 10E- No fertilizer treatment.

Plot 10W- Same as 10E, except that 10W was limed.

Plot 11E- 8 tons of manure per acre were applied at the time of seeding alfalfa (once each 12 years). No lime treatment.

Plot 11W- Same as Plot 11E, except Plot 11W was limed.

Plot 12E- 8 tons of manure and 100 lbs. of superphosphate per acre were applied at the time of seeding the alfalfa. In addition, 100 lbs. of superphosphate were broadcast annually early in the spring for the other three years that the land was in alfalfa. No fertilizer was applied on the wheat, and it was not limed.

Plot 12W- Same as Plot 12E, except that 12W was limed.

The results of the yields of alfalfa and wheat are listed in the following table:

TABLE II

EIGHTEEN-YEAR (1937-1954) AVERAGE YIELDS FOR ROTATION OF FOUR YEARS OF ALFALFA AND EIGHT YEARS OF WHEAT AT OKLAHOMA A. & M. EXPERIMENT STATION AGRONOMY FARM

Treatment	Yield of Alfalfa lbs/acre	Yield of Wheat bu/acre	Continuous Wheat bu/acre
None	1684	16.13	16.18
Manure	3817	19.65	-
Manure + Rock Phosphate	4720	23.20	-
Manure + Super-Phosphate	4148	24.76	-

The water infiltration tests were started October 8, 1954. A patented, automatic-recording infiltrometer was used. This was the concentric ring cylinder type, U. S. Patent Number 2,540,096.

The water used came from the City of Stillwater's water system, which supplies the Oklahoma A. and M. College Agronomy Farm. The soil was very dry. The rainfall had been below normal in the summer and fall months, as indicated in the rainfall data in the appendix. The tests were completed between October 8, 1954, and November 1, 1954.

The tests were run on a three-hour time limit. The recordings were made during the third hour. This was used as the infiltration rate for any given area.

The outer rim of the concentric rings was 16 inches in diameter. The water for this ring made a barrier that kept the water in the inner ring from moving laterally. The inner ring was 8 inches in diameter. The water was maintained at a 2-inch depth above the soil surface in both rings, and the water put into the center ring was recorded automatically during the three-hour period.

The two concentric cylinders were driven into the soil to a depth of two inches. The alfalfa vegetation was disturbed very little. The full height of the alfalfa ranged from three to five inches after the last fall cutting. The vegetation was cut to a two-inch height, the same depth of the water level which was held at a two-inch level over the surface of the soil.

Care was taken when the two-inch head of water was released in both cylinders. A large sheet of oil paper was used to allow the water from the storage tank to run into the cylinders against the paper. This prevented the water from disturbing the soil, leaves, trash and litter on the surface of the soil. A system of this kind reduced the turbidity of the water to a minimum. In each case, a time of five minutes on the average was required to release a head of water two-inches deep on the surface before the recordings were started and the valves were adjusted and set for the release of water into both concentric rings.

Experiment II

Infiltration tests were conducted on Series 3100. The cropping system was a rotation of cotton, vetch, and wheat. The vetch followed the cotton each time cotton was planted. The vetch was planted in the fall after the cotton was harvested. The vetch was allowed to produce mature seed in the late spring and early summer following cotton grown the summer before. The wheat followed the vetch. The vetch matured in early summer and the residue remained until the land was prepared for wheat in the fall. The vetch was always seeded in the wheat stubble on the east half each fall and plowed under the following spring before cotton planting time. The vetch was plowed under during the latter part of April.

These tests were conducted in November, 1954. The soil was very dry. The soil in this area is described as Kirkland[2] silt loam, with slopes ranging from 0 to 2 percent.

Soil treatments are as follows: Manure was applied at the rate of five tons per acre every third year when the vetch was sowed. The plots run east and west and are labeled as "W" for west half and "E" for the east half. All plots on the east half had vetch plowed under, following wheat. It was plowed under in the spring before cotton-planting time. On the west half, the vetch was allowed to stand and produce mature seed. The plots were numbered from 1 through 9 from north to south in parallel strips running east and west. The plots

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[2] See Appendix for detailed description of Kirkland Silt Loam, p.89.

were divided in the middle with a line running north and south, thus making a west half and an east half.

Plots in the series had received the following treatments:

Plot 2W - Manuare, 5 tons per acre, applied every third year on the land.

Plot 2E - Same as 2W, except that treatment was applied on the vetch at seeding time and the vetch plowed under the following spring.

Plot 3W - Manure, 5 tons per acre, plus 300 pounds of rock phosphate applied every third year on the land.

Plot 3E - Same as 3W, except that treatment was applied on the vetch at seeding time and the vetch plowed under the following spring.

Plot 4W - Check plot; no fertilizer treatment.

Plot 4E - Same as 4W, except that the vetch was plowed under before cotton-planting time in the spring of the year.

Plot 5W - The residue of the stalks, straw and vetch was left on the land.

Plot 5E - Same as 5W, except that the vetch was plowed under before cotton-planting time in the spring.

Plot 6W - The residue of the stalks, straw and vetch was left on the land, and in addition, 300 pounds of rock phosphate per acre were applied every third year.

Plot 6E - Same as 6W, except that treatment was applied on the vetch at seeding time and the vetch plowed under the following spring.

Plot 7W - Check plot; no fertilizer treatment.

Plot 7E - Same as 7W, except that the vetch was plowed under before cotton-planting time in the spring of the year.

The water infiltration tests were conducted in November. A patented, automatic infiltrometer was used. The same equipment and the same methods were applied as described in the foregoing tests on alfalfa in Experiment Number I on plot 2100. The soil was very dry. The rainfall chart in the Appendix (p. 91) relates the rainfall data.

Experiment III

Infiltration tests were conducted on the west half of Number 4100 Series. This series had been growing cotton continually since 1916. The west half of 4100 was a test of fertilization of cotton planted continually.

The objective was to determine if the soil which was fertilized differed in water infiltration rate as compared to soil which had not been treated.

The soil in this area has been mapped as 6A-1, Kirkland silt loam, with slopes ranging from 0 to 2 percent. The soils are the same as in Experiment Number II.

Plots in the series had received the following treatments:

Plot 2W - An application of $7\frac{1}{2}$ tons of manure per acre was applied every third year.

Plot 3W - An application of $7\frac{1}{2}$ tons of manure per acre was applied every third year, and an addition of 450 pounds of rock phosphate per acre was applied at the same time.

Plot 4W - This was a check plot, and did not have any treatment.

Plot 5W - Crop residue plus 150 pounds of superphosphate per acre every year.

Plot 6W - Crop residue plus 450 pounds of rock phosphate per acre every third year.

Plot 7W - This was a check plot, and did not have any treatment.

These tests were conducted in November, 1954. The soil was very dry. The automatic recording infiltrometer was used in exactly the same way that was described in the preceding experiments number I and II.

Experiment IV

Infiltration tests were conducted on the east one-half of Series 4100. This study was a test of fertilizing cotton, growing a winter cover of vetch on the cotton land, and plowing under the vetch before cotton-planting time the following spring.

The objective of this experiment was to compare the rates of water infiltration in the soil on the check plots without any fertilizer treatment with the soil on plots which were fertilized.

The soil in this area has been mapped as 6A-1, Kirkland silt loam, with slopes ranging from 0 to 2 percent. The soils are the same as in Experiments II and III.

Plots in the series had received the following treatments:

Plot 2E - An application of $7\frac{1}{2}$ tons of manure per acre was applied every third year.

Plot 3E - An application of $7\frac{1}{2}$ tons of manure per acre was applied every third year, and an addition of 450 pounds of rock phosphate per acre was applied at the same time.

Plot 4E - This was a check plot, and did not have any treatment.

Plot 5E - Crop residue plus 150 pounds per acre of superphosphate every year.

Plot 6E - Crop residue plus 450 pounds of rock phosphate per acre every third year.

Plot 7E - This was a check plot. It did not have any treatment.

The tests were conducted in November, 1954. The soil was very dry. The automatic recording infiltrometer was used in exactly the same way that was described in the three preceding experiments I, II, and III.

Experiment V

Infiltration tests were run on 2E, 2W and 3E in Series 4100. The object of this experiment was (1) to determine what effect the compaction of the soil made by rubber-tired vehicles would have on the infiltration rates, compared to areas where the pressure or compaction was not present, and (2) to compare the difference in infiltration rates of soil when very dry and when saturated with water.

Plots in the series had received the following treatments:

Plot 2W - Manure applied at the rate of $7\frac{1}{2}$ tons per acre every third year. The infiltration test was run on a dry basis, where there was no compaction.

Plot 2W-1 This had the same fertilizer treatment as 2W, and the infiltration test was made three feet from 2W. The compaction was made by running a touring car up and down the middle of the cotton rows a total of 30 times. The soil was very dry.

Plot 2E - This had manure applied at the rate of $7\frac{1}{2}$ tons per acre every third year. This had the same fertilizer treatment as plot 2W, except that the vetch was plowed under in the spring just before planting time. The test was first run on a dry-soil basis. The rate was determined 24 hours later while the soil was still saturated. A period of 24 hours following this test elapsed before the third tests was made on a wet basis. This made a 48-hour period from the time the first dry run test was made.

Plot 3E - The manure was applied at the rate of $7\frac{1}{2}$ tons per acre plus 450 pounds of rock phosphate per acre each third year.

Plot 3E-1 The plot had the same fertilizer treatment as 3E, except that the compaction was made by driving a car over the area one time. The compaction was made while the soil was very dry.

The soil has been described in Experiment IV. The infiltration test was conducted the same as in Experiments I, II, III and IV. Comparisons were made of infiltration rates.

Experiment VI

Infiltration tests were run on Plots 2W, 3W, 4W, 5W, 6W, 7W, 8W, 9W, and 10W in the west half of Series 5100. The objective of this experiment was to compare the rates of water infiltration in the soil on the check plots without any fertilizer treatment with the soil on the plots which had been fertilized. The west half of Series 5100 was one-fourth of an area which had been planted to sweet clover every fourth year. The west half of Series 5100 was growing legumes in 1954. The rotation was grain sorghum in 1951, cotton in 1952, oats and first-year sweet clover in 1953, and second-year clover in 1954.

The soil in this area has been mapped as 6A-1, Kirkland silt loam, with slopes ranging from 0 to 2 percent. The soils are the same as in Experiments II, III, IV and V. The soil was very dry at the time of the test in late November and early December of 1954. The automatic recording infiltrometer was used in exactly the same way as described in the five preceding experiments.

Plots in the west half of Series 5100 had received the following treatments:

Plot 2W - An application of 5 tons of manure per acre every fourth year when the legume was planted.

Plot 3W - Five tons of manure per acre were applied every fourth year when the legume was planted. The land was limed.

Plot 4W - A check plot - no treatment.

Plot 5W - The land was limed, and 5 tons of manure and 500 pounds of rock phosphate per acre were applied once each fourth year when the legume was planted.

Plot 6W - The land was limed, and 5 tons of manure and 150 pounds of superphosphate per acre were applied once every fourth year when the legume was planted.

Plot 7W - A check plot - no treatment.

Plot 8W - The crop residue only was returned to the soil.

Plot 9W - The crop residue only was returned to the soil, and the land was limed.

Plot 10W- A check plot - no treatment.

Experiment VII

Infiltration tests were run on plots no. 1 through 30 in Series 4400. This is a virgin, native grass area located southeast of the Agronomy Farm Headquarters adjacent to Highway 51. Fertilizer tests had been conducted on this native grass series for a period of 18 years, from 1928 through 1946. The objective of this experiment was to compare the water infiltration rates on fertilized plots with those on check plots which were not fertilized. In addition, a single cylinder infiltrometer was designed for practical and economical use by laymen, as a means of comparing infiltration rates in fields. The plots were numbered from south to north, one through thirty. There were two columns of plots, the east group being numbered from one to fifteen and the west group from sixteen through thirty.

The tests were started in June, 1955. Native grass was growing on the land at that time. The soil was moist. The soil in this area has been mapped as 1C-2, Norge loam, with slopes ranging from 3 to 5 percent.[3]

The extreme south end and the southwest corner of the area are bordering on 6A-1, Kirkland silt loam, a dark soil with claypan horizon at eight to fifteen inches below the surface. The soil profile is described in the Appendix.

Plots in the series received the following treatments:

Plot 1 - Check plot--no treatment.

Plot 2 - Application of 137 pounds of sodium nitrate per acre.

Plot 3 - Application of 100 pounds of ammonium nitrate per acre.

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[3]Detailed description of Norge in Appendix, p. 84.

Plot 4 - Check plot--no treatment.

Plot 5 - Application of 137 pounds of sodium nitrate, 100 pounds of 0-20-0, 25 pounds of 0-0-50 per acre.

Plot 6 - Application of 100 pounds of ammonium nitrate, 100 pounds of 0-20-0, 25 pounds of 0-0-50 per acre.

Plot 7 - Check plot--no treatment.

Plot 8 - Application of 274 pounds of sodium nitrate per acre.

Plot 9 - Application of 200 pounds of ammonium nitrate per acre.

Plot 10- Check plot--no treatment.

Plot 11- Application of 274 pounds of sodium nitrate, 100 pounds of 0-20-0, 25 pounds of 0-0-50 per acre.

Plot 12- Application of 200 pounds of ammonium nitrate, 100 pounds of 0-20-0, 25 pounds of 0-0-50 per acre.

Plot 13- Check plot--no treatment.

Plot 14- Application of 100 pounds of 0-20-0 per acre.

Plot 15- Application of 100 pounds of 0-20-0, 25 pounds of 0-0-50 per acre.

Plot 16- Check plot--no treatment.

Plot 17- Application of 137 pounds of sodium nitrate, 100 pounds of 0-20-0, 25 pounds of 0-0-50 per acre.

Plot 18- Application of 100 pounds of ammonium nitrate, 100 pounds of 0-20-0, 25 pounds of 0-0-50 per acre.

Plot 19- Check plot--no treatment.

Plot 20- Application of 274 pounds of sodium nitrate per acre.

Plot 21- Application of 200 pounds of ammonium nitrate per acre.

Plot 22- Check plot--no treatment.

Plot 23- Application of 274 pounds of sodium nitrate, 100 pounds of 0-20-0, 25 pounds of 0-0-50 per acre.

Plot 24- Application of 200 pounds of ammonium nitrate, 100 pounds of 0-20-0, 25 pounds of 0-0-50 per acre.

Plot 25- Check plot--no treatment.

Plot 26- Application of 100 pounds of 0-20-0 per acre.

Plot 27- Application of 100 pounds of 0-20-0, 25 pounds of 0-0-50 per acre.

Plot 28- Check plot--no treatment.

Plot 29- Application of 137 pounds of sodium nitrate per acre.

Plot 30- Application of 100 pounds of ammonium nitrate per acre.

A single ring cylinder type of infiltrometer was used to conduct the infiltration test. This type of machine is practical and economical for comparison work. The cylinder was made of 16-gauge galvanized tin. The diameter was 6 inches inside measurement, and 12 inches in length. A tank 6 inches in diameter inside and 14 inches in length was used for a water supply. The water was released from the bottom of the tank supply through an outlet and a rubber hose one-fourth inch in diameter. The end of the hose, where the water was released into the 6-inch cylinder, was connected to an eye dropper. The water was regulated through the eye dropper with a hose clamp which was adjustable. The water tank supply was supported on a device which was at least one inch higher than the 6-inch cylinder inserted in the soil. This made it possible for a gravity flow of water into the cylinder.

The water was measured with a wooden scale by inserting it into the supply tank at the beginning of the test and measuring the amount of water remaining in the supply tank at the end of a given period of time. The 6-inch-diameter cylinder was strong enough to be driven into the soil to a depth of six inches.

The tests were run on a three-hour time limit. The recordings were made during the third hour. This was used as the infiltration rate for any given area. The water in the cylinder, which was inserted into the soil, was maintained at a two-inch depth above the soil surface in the ring. In each test, a time of five minutes on the average was required to release a head of water two-inches deep on the surface before the water was released from the supply tank for the infiltration time test.

The techniques used were exactly the same as the other six tests previously described.

RESULTS AND DISCUSSION

Weather conditions were extremely dry when most of the infiltration tests were run from October through December in 1954 (See Appendix, p. 91). This was the driest year in 44 years in Oklahoma. The total rainfall was 17.58 inches in 1954 which was 59 percent of normal. There were 45 days when the temperature was above 100° Fahrenheit, and 107 days when the temperature was 90° Fahrenheit, or higher.

The total rainfall was 1.70 inches during October. The largest amount was on October 12, 1954 (.54 inches), and again on October 22 (.60 inches). The total rainfall in November, 1954, was .17 inches on November 2. The total rainfall in December was 2.44 inches, of which 1.11 inches fell on December 26.

The cotton crop was considered a complete failure at the Experiment Station due to the drouth in 1954.

Effect of Fertilizer on Alfalfa in Relation to Water Infiltration Rates

The application of a combination of eight tons of manure per acre and 1600 pounds of rock phosphate per acre once each 12 years at planting time on alfalfa gave one of the highest water infiltration rates found. It was 5.60 inches per hour. The land was growing alfalfa at the time of the test. This was in Series 2100.

The infiltration test was the same, 5.6 inches per hour, on growing alfalfa, where an application of eight tons of manure and

100 pounds of superphosphate per acre was applied once each 12 years at seeding time of alfalfa. A total of 100 pounds of superphosphate per acre was applied annually the remainder of the time. The crop rotation was four years of alfalfa, followed by eight years of wheat in Series 2100. The average of the two replicates where no treatment was applied had an infiltration rate of 1.6 inches per hour. The two different kinds of treatment, which had the same infiltration rate, showed a tremendous increase in water infiltration rates over the check plots. The increase was 250 percent. The increase in infiltration rates must have been due to the increased size of roots and the total number of roots. An examination of the roots showed they were much larger and longer from the treated plots and the total mass of root volume was much greater. Reference is made to the comparison in the accompanying photographs in the Appendix, Figures 4 and 5, pp. 79 and 80.

The application of eight tons of manure per acre, once each 12 years at alfalfa seeding time, caused some increase in water infiltration rate. In fact, the difference in Plot 8W (one of the low rates) was 0.20 inches per hour over the average of all four check plots. The four check plots averaged 1.60 inches per hour. The average of four replicates of land treated with manure at the rate of eight tons per acre once each 12 years, at seeding time of alfalfa, was 2.15 inches per hour. This was an increase of 34.3 percent in water intake. In Plot 11W, the infiltration rate was only 1.60 inches per hour, which was the same as the average of all check plots. All check plots had 1.60 inches intake of water per hour.

There were large variations in water infiltration rates in the treated areas all over the different plots. There were no variations in rates of infiltration in the check plots.

The application of lime with fertilizers did not increase the water infiltration rates. The west side of Series 2100 had lost some topsoil by erosion due to slope. In general, the infiltration rates on treated plots were less on the west side of Series 2100. Some topsoil probably had been lost all the way along the west side. Reference is made to Table III (p. 55) which shows the results of infiltration tests.

The average infiltration rate for all the treated plots on the east side (Plots 8E, 9E, 11E and 12E) was 4.1 inches per hour. The average infiltration rate of the two check plots on the east side (7E and 10E) was 1.6 inches per hour. The average rate of infiltration on all four treated plots was 156.25 percent greater than the average of the two check plots.

The average infiltration rate of all the treated plots on the west side (8W, 9W, 11W, 12W) was 2.25 inches per hour; while the average rate on the two check plots (7W and 10W) was 1.6 inches per hour. The average rate of infiltration on all four treated plots was 40.63 percent greater than the average on the two check plots.

The average infiltration rate for all eight treated plots (8W, 9W, 11W, 12W, 8E, 9E, 11E and 12E) was 3.17 inches per hour. The average infiltration rate for all four check plots (7W, 10W, 7E and 10E) was 1.6 inches per hour. The average infiltration rate for all eight treated plots showed an increase of 98.13 percent over the four check plots.

TABLE III

THE EFFECT OF FERTILIZING ALFALFA ON THE INFILTRATION RATES IN SOIL. ROTATION WAS FOUR YEARS OF ALFALFA FOLLOWED BY EIGHT YEARS OF WHEAT

Infiltration Rate in Inches per Hour			Infiltration Rate in Inches per Hour		
Limed			Not Limed		
		Plot No.			Plot No.
1.6"	Check--no treatment	7W	1.6"	Check--no treatment	7E
1.8"	8 tons manure /1 per acre, once in 12 years	8W	3.2"	8 tons manure /1 per acre, once in 12 years	8E
3.2"	8 tons manure /1, 1600 lbs. rock phosphate per acre, once in 12 years	9W	5.6"	8 tons manure /1 1600 lbs. rock phosphate per acre, once in 12 years	9E
1.6"	Check--no treatment	10W	1.6"	Check--no treatment	10E
1.6"	8 tons manure /1 per acre, once each 12 years	11W	2.0"	8 tons manure /1 per acre, once each 12 years	11E
2.4"	8 tons manure /1, 100 lbs. superphosphate once each 12 years, plus 100 lbs. superphosphate /2 per acre, annually	12W	5.6"	8 tons manure /1, 100 lbs. superphosphate once each 12 years, plus 100 lbs. superphosphate /2 per acre, annually	12E

/1 All manure and fertilizer applied only at seeding time on alfalfa.

/2 100 lbs. of superphosphate applied every year on plots 12W and 12E.

Effect of Fertilizer on Infiltration Rates in a Crop Rotation of Cotton, Vetch and Wheat

Water infiltration rates were increased by fertilizer treatments in a three-year rotation of cotton, vetch and wheat, as indicated in Experiment II on Series 3100. The highest rate was 2.40 inches per hour on Plot 3E, where five tons of manure and 300 pounds of rock phosphate per acre were applied every third year when the vetch was seeded. In this case, the vetch was plowed under preceding cotton planting in the spring of the year. The minimum rate on the check plots was 0.50 inches per hour, while the maximum rate was 0.90 inches per hour. The average infiltration rate for the four check plots was 0.73 inches per hour. The average for all the plots treated was 1.56 inches per hour. This is an increase of 116.67 percent. In all tests, the treated plots had a higher infiltration rate than the check plot did. Table IV (p.57) gives the details of the fertilizer treatment and the infiltration rate tests.

Effect of Fertilizer Applied Every Third Year on Cotton Grown Continuously, Relative to the Water Infiltration Rate of the Soil

The highest infiltration rate per hour was 1.6 inches where the continuous cotton had been treated with $7\frac{1}{2}$ tons of manure per acre. The average infiltration rate of the two fertilized plots was 1.4 inches per hour. The average of the two check plots with no treatment was 1.0 inch per hour. The treated plots showed an increase of 40 percent infiltration rate over the areas not treated. Reference is made to Table V (p. 58) which gives the details.

TABLE IV

THE EFFECT OF FERTILIZER APPLIED AT SEEDING TIME ON VETCH EVERY THIRD YEAR IN A 3-YEAR CROP ROTATION OF COTTON, VETCH AND WHEAT, AS RELATED TO WATER INFILTRATION RATES. EXPERIMENT CONDUCTED ON SERIES 3100

Infiltration Rate in Inches per Hour			Infiltration Rate in Inches per Hour		
	/2 Treatment	Plot No.		/1 Treatment	Plot No.
2.4"	Manure--5 tons per acre, applied every 3rd year.	2W	1.6"	Manure--5 tons per acre, applied every 3rd year on vetch at seeding time	2E
1.6"	Manure--5 tons plus 300 lbs. rock phosphate per acre, applied every 3rd year.	3W	2.4"	Manure--5 tons, plus 300 lbs. rock phosphate per acre, applied on vetch every 3rd year at planting time.	3E
0.8"	Check--no treatment	4W	0.9"	Check--no treatment	4E
0.9"	Residue--Straw and vetch residue	5W	1.6"	Residue--Straw and vetch residue	5E
1.0"	Residue, plus rock phosphate (300 lbs. per acre) applied every 3rd year.	6W	1.0"	Residue, plus rock phosphate (300 lbs. per acre) on the vetch at planting time every 3rd year.	6E
0.5"	Check--no treatment	7W	0.7"	Check--no treatment	7E

/1 The vetch in Plots 2E, 3E, 4E, 5E, 6E, 7E, were plowed under each spring before cotton-planting time.

/2 The vetch was allowed to make seed and remain on the land until seedbed preparation for wheat on 2W, 3W, 4W, 5W, 6W and 7W.

TABLE V

EFFECT OF FERTILIZER APPLIED ON COTTON GROWN CONTINUALLY, AND ON COTTON AND VETCH GROWN CONTINUALLY, AS RELATED TO WATER INFILTRATION RATES. EXPERIMENT CONDUCTED ON SERIES 4100

/1 Continuous Cotton			/2 Cotton and Vetch		
Infiltration Rate in Inches per Hour			Infiltration Rate in Inches per Hour		
Rate		Plot No.	Rate		Plot No.
1.6"	Manure ($7\frac{1}{2}$ tons per acre) applied every 3rd year on cotton	2W	1.1"	Manure ($7\frac{1}{2}$ tons per acre) applied on vetch at seeding time every 3rd year	2E
1.2"	Manure ($7\frac{1}{2}$ tons plus 450 lbs. rock phosphate per acre) applied every 3rd year.	3W	1.8"	Manure ($7\frac{1}{2}$ tons plus 450 lbs. rock phosphate per acre) applied on vetch every 3rd year.	3E
1.0"	Check--no treatment	4W	0.8"	Check--no treatment	4E
	Infilt. test not run	5W		Infilt. test not run	5E
	" " " "	6W		" " " "	6E
1.0"	Check--no treatment	7W	0.65"	Check--no treatment	7E

/1 The cotton was grown continually.

/2 The cotton was grown continually and vetch was planted each fall between the cotton rows. The vetch was plowed under each spring just before cotton-planting time.

Effect of Fertilizer Applied Every Third Year on Cotton Grown Continuously with Vetch, Planted on the Cotton Land in the Fall and Plowed Under Before Cotton-Planting Time in the Spring

The use of fertilizer applied on the vetch at planting time every third year, when cotton was grown continuously with vetch planted between rows in the fall and plowed under before cotton-planting time, increased the infiltration rate. The highest infiltration rate was 1.8 inches per hour on Plot 3E. The treatment was 7½ tons of manure plus 450 pounds of rock phosphate per acre, applied on the vetch every third year. The average infiltration rate on the fertilized plots was 1.45 inches per hour, compared to .73 of an inch on the plots not treated with fertilizer. Reference is made to Table V (p. 58) which gives the details. The treated plots showed an increase of 98.63 percent infiltration rate over the plots not treated.

Results of Compaction of Soil Made in the Field by Pressure of a Rubber-Tired Vehicle, as Related to the Water Infiltration Rate into the Soil

The infiltration rate on Plot 2W, with no compaction and under dry soil conditions, was 1.60 inches per hour. The infiltration rate of the compacted area in the same plot was 0.45 inches per hour under dry-soil conditions. The compaction was made with a touring car driven over dry soil 30 times. The noncompacted area had 255.56 percent greater water infiltration rate than the compacted area in Plot 2W. Reference is made to Table VI (p. 60) which gives the details.

TABLE VI

WATER INFILTRATION RATES AS AFFECTED BY HEAVY COMPACTION AND WETTING OF SOIL AS COMPARED WITH DRY SOIL THAT HAD NOT BEEN COMPACTED
SERIES 4100

Infiltration Rate in Inches Per Hour Continuous Cotton /1			Infiltration Rate in Inches Per Hour Continuous Cotton with Vetch /2		
Rate	Treatment	Plot No.	Rate	Treatment	Plot No.
	Manure applied at rate of $7\frac{1}{2}$ tons per acre every 3rd year			Manure applied at rate of $7\frac{1}{2}$ tons per acre every 3rd year	
1.60"	(1) Infiltration rate on dry soil (no compaction)	2W	1.80"	(1) Infiltration rate on dry soil (no compaction	2E
0.45"	(2) Infiltration rate after being packed by car driven over same area 30 times on dry soil.	2W	.42"	(2) Infiltration rate on wet soil same as above, (1), 24 hours after being thoroughly wet.	2E
0.30"	(3) Infiltration rate on above (2) after 24 hours from time soil was thoroughly wet.	2W	.25"	(3) Infiltration rate on soil wet twice at 24-hour intervals, totaling 48 hours, after soil was originally very dry.	2E

/1 Cotton planted continuously every year and fertilized every third year.

/2 Cotton planted every year and vetch planted in the fall and plowed under in the spring. Fertilized every third year on vetch.

Effect of Wet Compacted Soil on Water Infiltration Rates

On Plot 2W, the infiltration rate was .30 inches per hour on the compacted area after it was thoroughly wet and a time of 24 hours had lapsed before the test was made. The two infiltration rates on the compacted area were (1) dry soil rate, 0.45 inches per hour, and (2) wet soil rate, 0.30 inches per hour. The infiltration rate on compacted soil that was dry was 50 percent greater than when the soil was thoroughly wet. Reference is made to Table VI (p. 60).

Results of Infiltration Test Rates on the Soil When Thoroughly Wet and Tests Made at 24-Hour and 48-Hour Intervals Following Wetting of the Soil

The infiltration test was conducted on Plot 2E of Series 4100. The rate on dry soil was 1.80 inches per hour. The soil was thoroughly wet and the test was made 24 hours later on exactly the same spot. The infiltrometer was left remaining on the same location. The infiltration rate on the wet soil was 0.42 inches per hour, or a reduction of 1.38 inches per hour, which was a 76.67 percent decrease. The infiltrometer was left in place for another 24 hours. This made a period of 48 hours from the time the first test was made on very dry soil. When the 48-hour test was run, the rate was 0.25 inches per hour (or 0.17 inches less, which was a reduction of 40.48 percent).

The rate of water infiltration decreased from a soil that was very dry, wet at intervals, allowed to dry for a short time, and then thoroughly wet again. The decrease in water infiltration from the very dry condition of the soil being thoroughly wet twice at two 24-hour intervals, to a wet condition, was 86.11 percent.

Reference is made to Table VI (p. 60) which gives the detailed figures, the tests made, and the results.

In the latter part of Experiment V, a compacted-soil area was produced by running a car over the soil one time while the soil was very dry, and the reduction of the water intake was compared at the same time within three feet of the same test area on dry soil that had not had any soil compaction. The soil was then thoroughly wet and the infiltration test was run 24 hours after being thoroughly wet, in order to compare the reduction in the infiltration rate caused by wetting the soil. The rate of infiltration on the dry soil without any compaction was 2.00 inches per hour, on Plot 3E (1), compared to only 1.35 inches per hour where the soil was compacted lightly by driving a car one time over the dry soil area on Plot 3E (2). There was a difference of 0.65 of an inch less intake on the compacted area. This was a reduction of 32.5 percent. The soil was thoroughly wet on the dry non-compacted area and a test was made 24 hours later. This is referred to as 3E (3). The intake rate was reduced to 0.90 inches per hour, or a reduction of 1.10 inches per hour (55 percent). Reference is made to Table VII (p. 63).

Effects of Fertilizing Legumes Every Fourth Year in a Four-Year Rotation of Oats and First-Year Sweet Clover, Followed by Second-Year Sweet Clover, then Darso, and lastly, Cotton in the Fourth Year, Relative to the Infiltration Rates in Soil, when the Legumes were Growing in 1954

The average of the three check plots with no treatment in Experiment VI showed an average infiltration rate of 1.47 inches per hour, compared to the infiltration rate average of 2.47 inches per hour on the fertilized plots on the west side of Series 5100.

TABLE VII

EFFECT OF LIGHT COMPACTION AND WETTING OF SOIL IN COMPARISON TO DRY SOIL WITH NO COMPACTION--REGARDING WATER INFILTRATION RATES - SERIES 4100

Infiltration Rate in Inches per Hour

Continuous Cotton with Vetch

Rate	Treatment	Plot No.
	Manure applied at the rate of $7\frac{1}{2}$ tons per acre plus 450 lbs. of rock phosphate per acre on the vetch every third year.	
1.35"	The car was used to compact the soil lightly by passing over the area one time only	3E (1)
2.00"	The same treatment was applied as in 3E (1) except that the compaction was not made on the soil by the pressure of the car. The test was run 3 feet from the test in 3E (1)	3E (2)
0.90"	The soil was treated the same as in 3E (1) and 3E (2), except that it was thoroughly wet and an infiltration test was made 24 hours after being thoroughly wet.	3E (3)

TABLE VIII

WATER INFILTRATION TESTS IN THE SOIL ON PLOTS IN SERIES 5100, WHERE FERTILIZER WAS APPLIED EVERY FOURTH YEAR ON THE LEGUME IN A FOUR-YEAR ROTATION OF OATS AND FIRST-YEAR SWEET CLOVER, FOLLOWED BY SECOND-YEAR SWEET CLOVER, THEN DARSO, AND, LASTLY, COTTON

Planted to a Legume in 1954

Infiltration Rate in Inches Per Hour

Rate	Treatment /1	Plot No.
2.4"	5 Tons manure per acre	2W
2.0"	5 Tons manure per acre and limed	3W
1.2"	Check plot--no treatment	4W
2.4"	5 Tons manure, plus 500 lbs. rock phosphate per acre and limed	5W
2.4"	5 Tons manure, plus 150 lbs. superphosphate per acre and limed	6W
2.3"	Check plot--no treatment	7W
2.4"	Residue	8W
3.2"	Residue and limed	9W
0.9"	Check plot--no treatment	10W

/1 Fertilized every fourth year on the first-year sweet clover.

TABLE IX

COMPARISON OF WATER INFILTRATION RATES OF FERTILIZED AND NON-FERTILIZED NATIVE GRASSLANDS, TREATED ANNUALLY ON SERIES 4400

Infiltration Rate in Inches per Hour

Rate	Treatment	Plot No.
1.00"	Check--no treatment	1
5.50"	Sodium nitrate, 137 lbs. per acre	2
5.50"	Ammonium nitrate, 100 lbs. per acre	3
3.75"	Check--no treatment	4
6.25"	Sodium nitrate--137 lbs. per acre 0-20-0 100 lbs. per acre 0-0-50 25 lbs. per acre	5
7.37"	Ammonium nitrate--100 lbs. per acre 0-20-0 100 lbs. per acre 0-0-50 25 lbs. per acre	6
5.42"	Check--no treatment	7
7.00"	Sodium nitrate--274 lbs. per acre	8
7.75"	Ammonium nitrate--200 lbs. per acre	9
5.12"	Check--no treatment	10
7.50"	Sodium nitrate--274 lbs. per acre 0-20-0 100 lbs. per acre 0-0-50 25 lbs. per acre	11
5.12"	Ammonium nitrate--200 lbs. per acre 0-20-0 100 lbs. per acre 0-0-50 25 lbs. per acre	12
5.00"	Check--no treatment	13
6.00"	0-20-0 100 lbs. per acre	14
5.37"	0-20-0 100 lbs. per acre 0-0-50 25 lbs. per acre	15

TABLE IX (Continued)

Infiltration Rate in Inches per Hour

Rate	Treatment	Plot No.
4.25"	Check--no treatment	16
5.37"	Sodium nitrate--137 lbs. per acre 0-20-0 100 lbs. per acre 0-0-50 25 lbs. per acre	17
7.12"	Ammonium nitrate--100 lbs. per acre 0-20-0 100 lbs. per acre 0-0-50 25 lbs. per acre	18
4.50"	Check--no treatment	19
8.25"	Sodium nitrate--274 lbs. per acre	20
5.37"	Ammonium nitrate--200 lbs. per acre	21
1.50"	Check--no treatment	22
5.50"	Sodium nitrate--274 lbs. per acre 0-20-0 100 lbs. per acre 0-0-50 25 lbs. per acre	23
6.40"	Ammonium nitrate--200 lbs. per acre 0-20-0 100 lbs. per acre 0-0-50 25 lbs. per acre	24
5.25"	Check--no treatment	25
7.00"	0-20-0 100 lbs. per acre	26
7.87"	0-20-0 100 lbs. per acre 0-0-50 25 lbs. per acre	27
4.12"	Check--no treatment	28
5.62"	Sodium nitrate--137 lbs. per acre	29
8.00"	Ammonium nitrate--100 lbs. per acre	30

There was a difference of one inch per hour, or an increase of 68.03 percent in water infiltration rates. Reference is made to Table VIII (p. 64) which gives the details. The test was made in the late fall of 1954.

The conclusion is that fertilized legumes every fourth year in a rotation with row crops increased the infiltration rate over the untreated legumes.

Effects of Fertilization of Native Grasses in Relation to Water Infiltration Tests in the Soil

The average infiltration rate of all 10 check plots was 3.99 inches of water per hour. The average of all 20 treated plots was 6.49 inches per hour. The difference in infiltration rates of the fertilized plots was 2.50 inches per hour, or an increase of 62.66 percent from fertilization. Reference is made to Table IX (pp. 65-66) which gives the details and the results.

SUMMARY AND CONCLUSIONS

The infiltration rates of water into the soil were studied on seven experiments on the Agronomy Farm of the Oklahoma A. and M. College Experiment Station, from October, 1954, through June, 1956. The following conclusions were made:

1. Fertilizing crops increased the infiltration rates of water into the soil.

2. The infiltration rates were much greater in the first 30 minutes on dry soil than any period following.

3. The infiltration rate was much greater on dry soil than soil which was saturated with water.

4. The infiltration rates were much greater on native grasses than on cultivated crops.

5. The packing of soil by implement wheels reduced the rate of water intake considerably.

6. Fertilized alfalfa land, treated once each twelve years in a rotation of 4 years of alfalfa and 8 years of wheat, increased the water infiltration rate on a loam topsoil with a slowly to very slowly permeable subsoil.

7. The infiltration rate was reduced very much when the soil was thoroughly wet at intervals of 24 hours and 48 hours following a dry soil condition.

8. The fertilization of continuous cotton increased the water infiltration rates very noticeably.

9. The infiltration rate of land growing alfalfa was considerably greater than land growing continuous cotton, on soil which was similar in all properties and characteristics.

10. The fertilization of vetch every third year at seeding time increased the water infiltration rate in a three-year rotation of cotton followed by vetch, followed by wheat.

11. Land on which there was a cover, such as native grass, had a much greater infiltration rate than did bare cultivated cropland.

12. The fertilization of native grassland increased the water intake over the untreated native grassland to a noticeable extent.

13. In correlating the water infiltration rates on Series 2100, on four years of alfalfa and eight years of wheat, with the records of the Agronomy Department, Oklahoma A. and M. College Experiment Station, it was found that the increased water infiltration rates in the soil were associated with increases of yields of wheat from 3.52 bushels per acre to a maximum of 8.63 bushels per acre per year, over an 18-year period, from 1937-1954 inclusive.

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APPENDIX

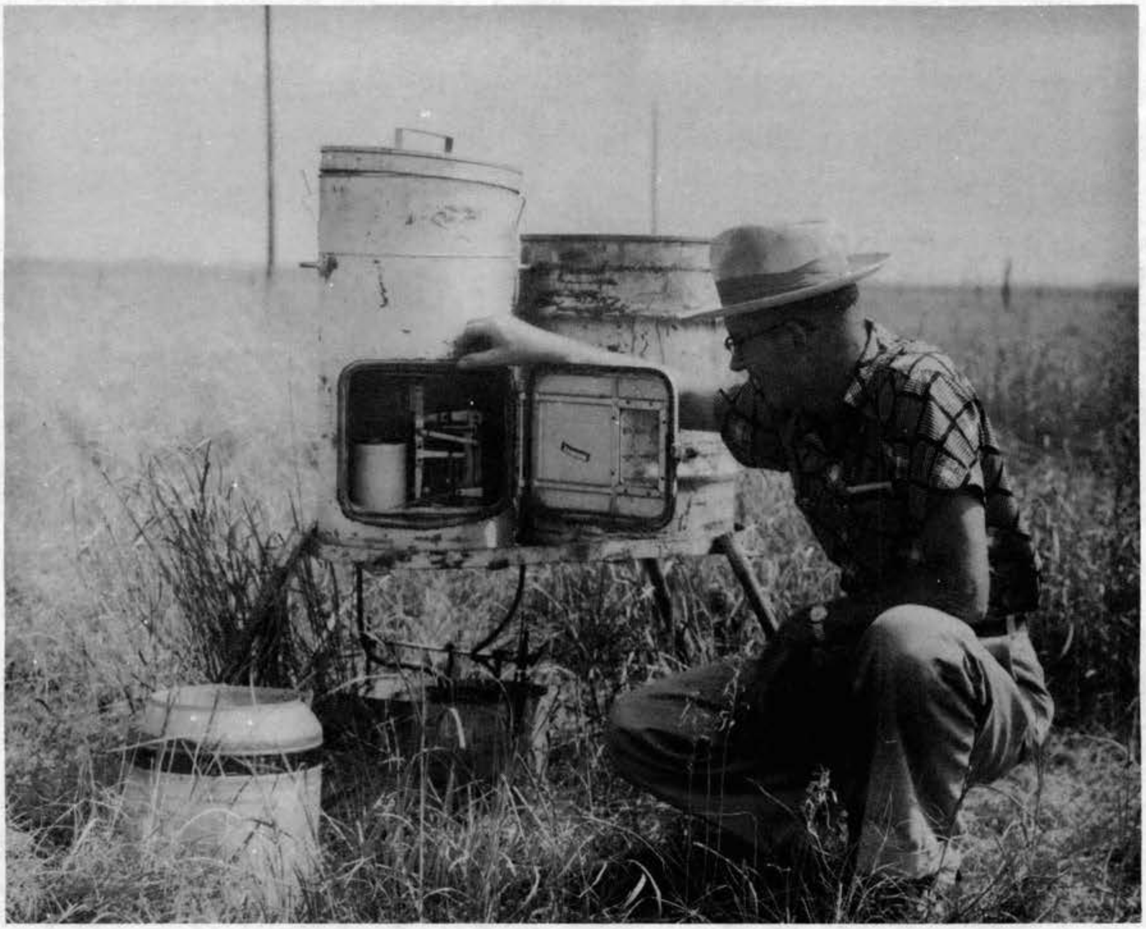

Figure 1.
The automatic recording infiltrometer, patent number 2,540,096. It was patented February 6, 1951, by A. D. Bull, Soil Scientist, Soil Conservation Service, at Chickasha, Oklahoma. This is the infiltrometer used on all plots except the native grass plot number 4400.

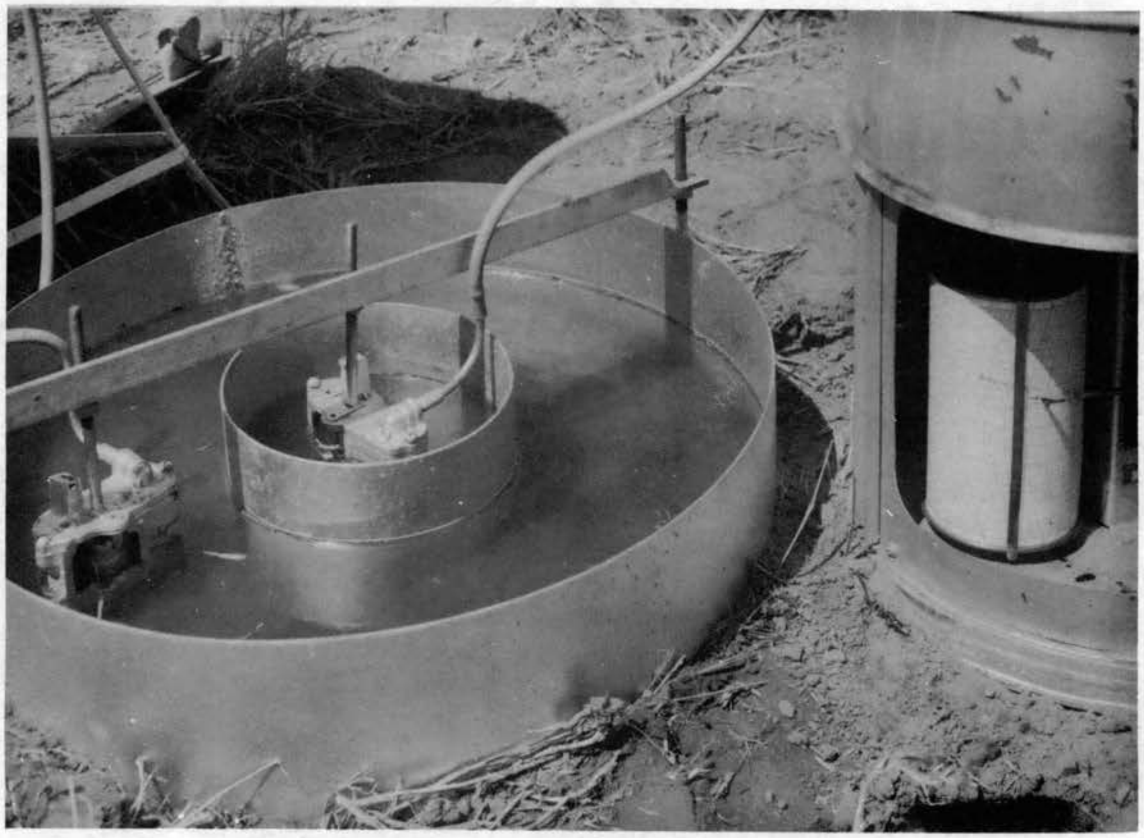

Figure 2.
A close-up view of the concentric ring cylinders which were driven into the soil, in connection with the infiltration tests conducted with the automatic recording infiltrometer. Note the level of the water is the same in the outside and the inside ring.

Figure 3.
The infiltration test was conducted on compacted soil, made by running a touring car over the area thirty times in Experiment V.

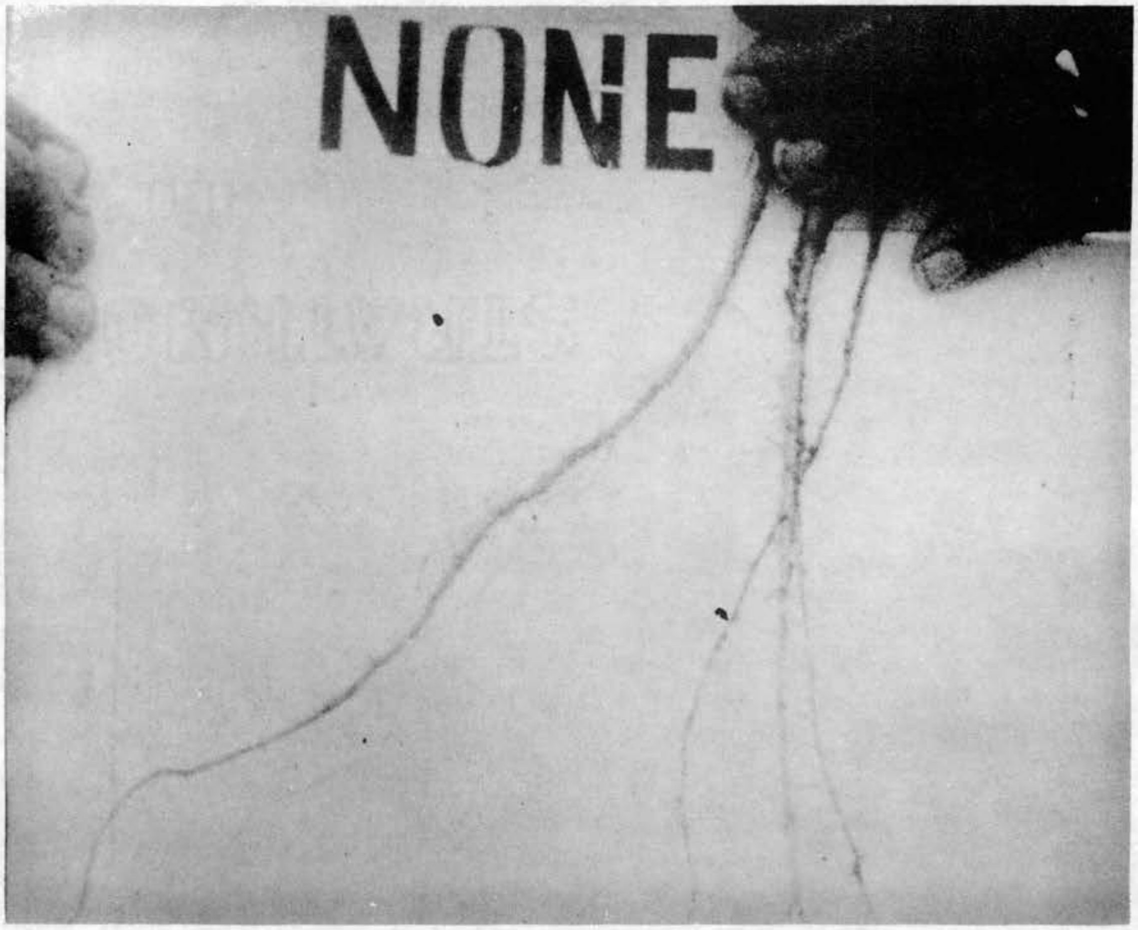

Figure 4.
Compare the size of alfalfa roots on nonfertilized alfalfa plots in Experiment I with those on the fertilized plots. The roots are much smaller in this photogragh taken of non-fertilized plants. The water infiltration rate was much less than on the fertilized alfalfa plots.

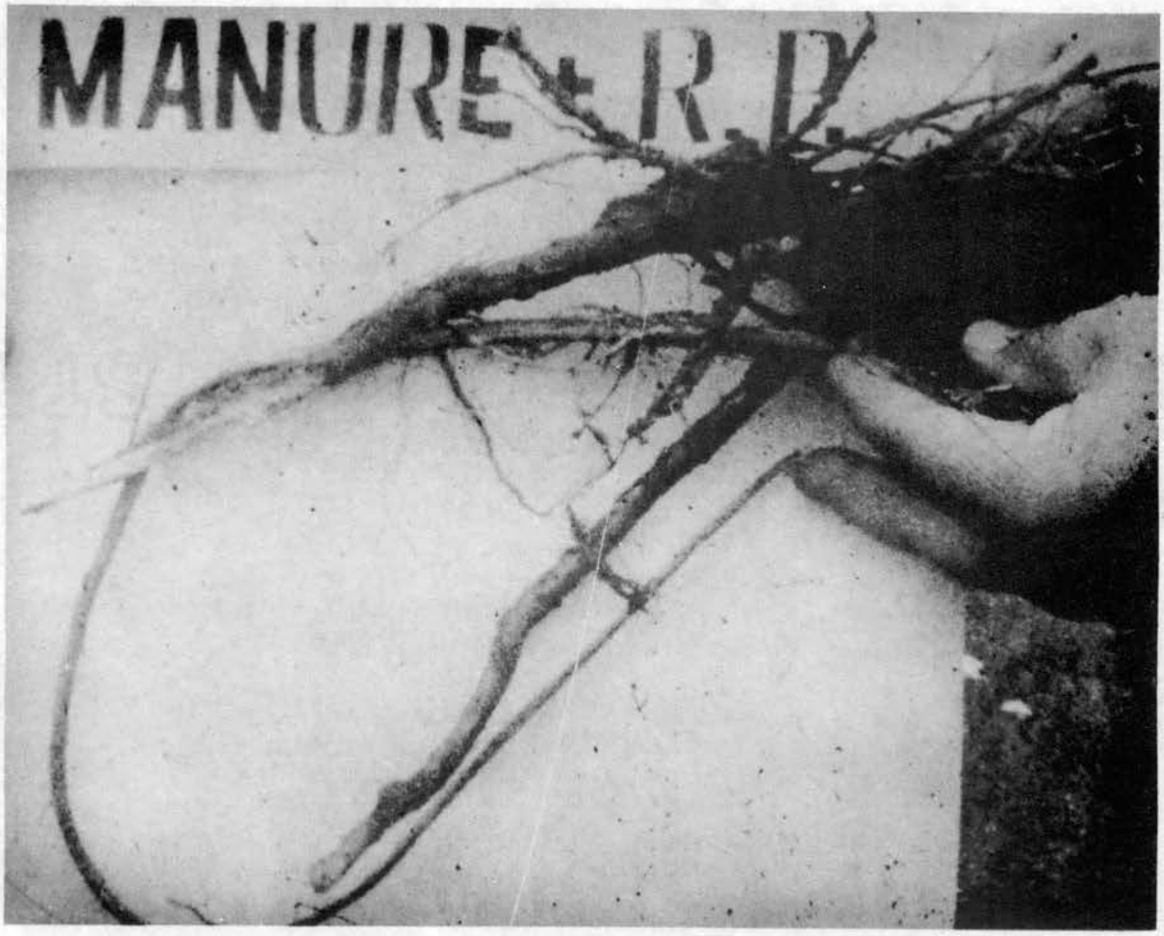

Figure 5.
A photograph of the roots of alfalfa on fertilized plots in Experiment I. The roots were much larger than on the non-fertilized plots and the water infiltration rate was much greater.

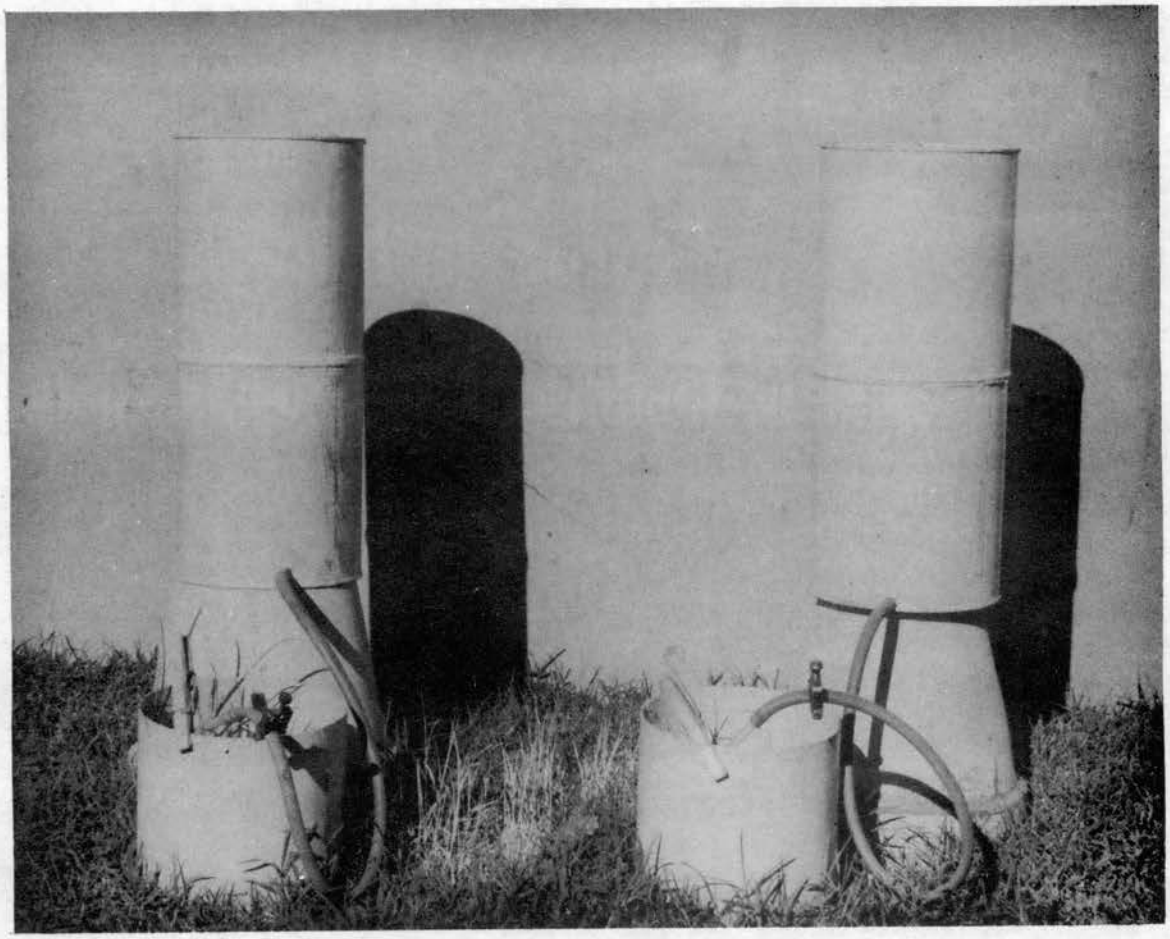

Figure 6.
The single-cylinder infiltrometers used in Experiment VII to test the water infiltration rate in native grassland. This is a rapid, low-cost method of infiltration measurement for use in determining water intake rates of soils.

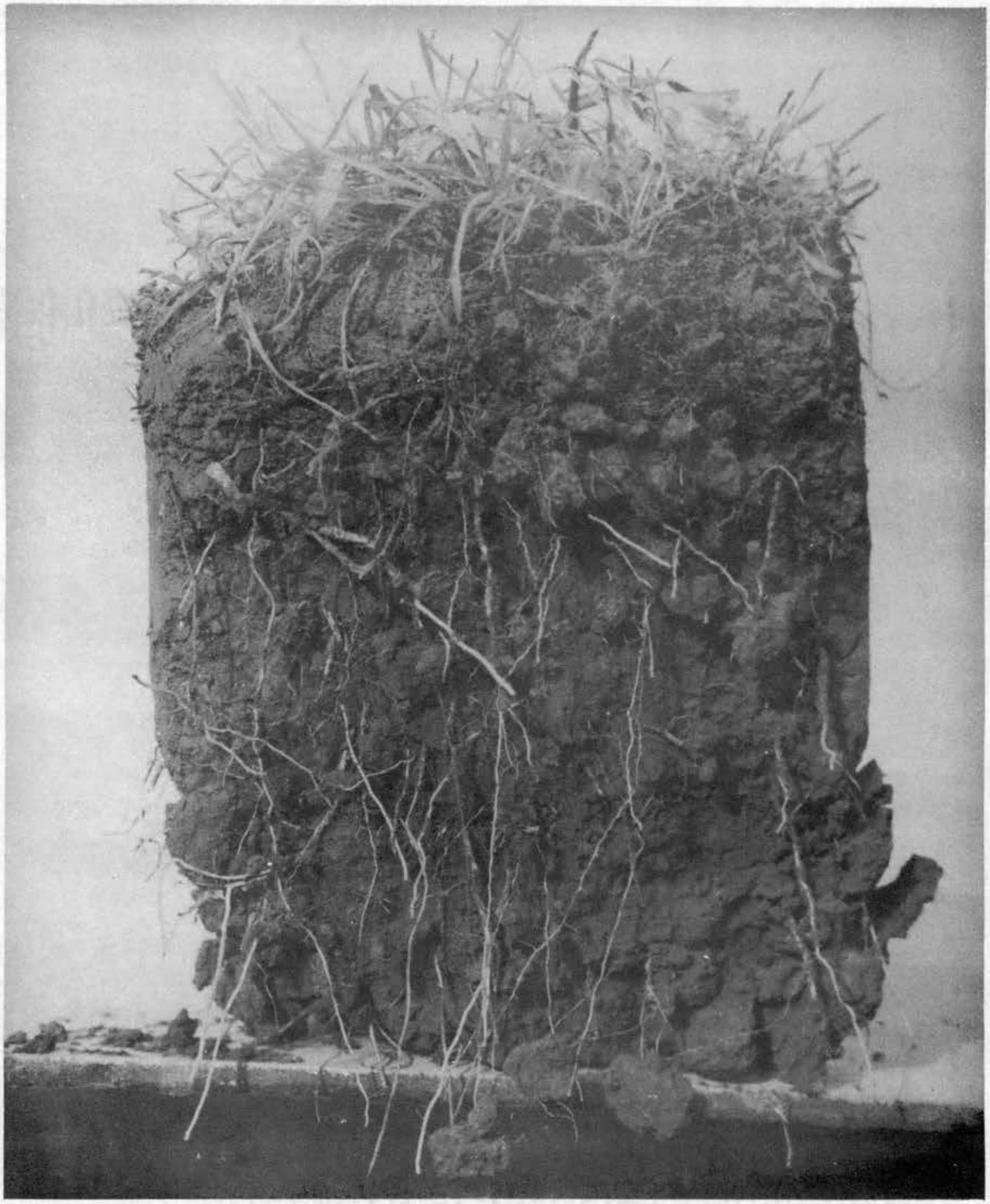

Figure 7.
This is a six-inch profile of soil removed from the six-inch diameter cylinder used in making infiltration measurements in native grassland. This was taken from Plot 23. Note the enormous grass roots that fill the mass of soil volume. The infiltration rate was high.

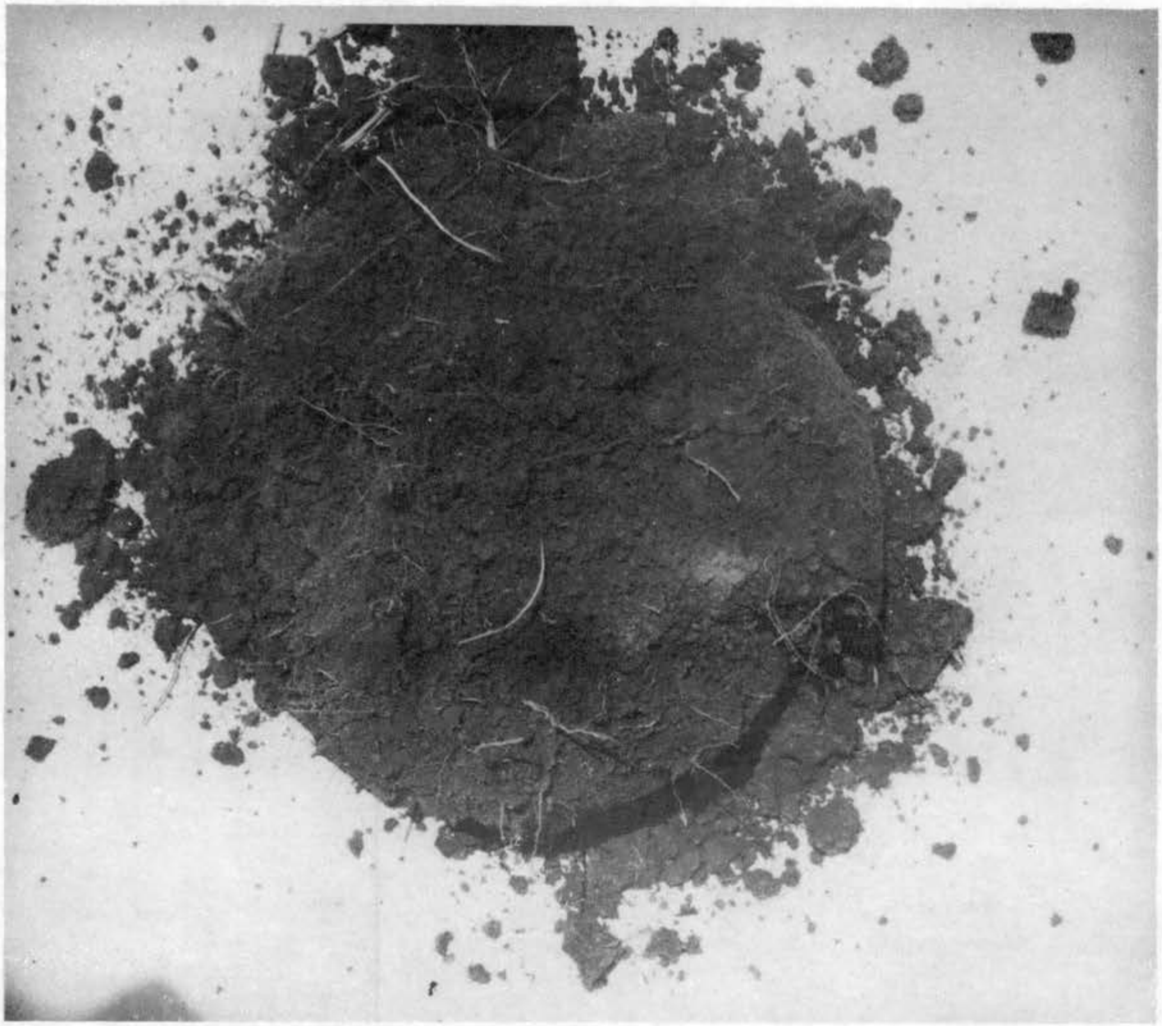

Figure 8.
This is the bottom side of the soil profile at four inches depth, in the native grassland in Experiment VII. The soil profile was removed from the six-inch-diameter cylinder in Plot 23. Note the number of roots and the openings made in the soil. The water infiltration rate was high.

TABLE X

A DESCRIPTION OF THE PROFILE OF 1C-2 NORGE LOAM

A sample of this soil was collected from Plot 6400, 30 feet south of the east-west roadway and 40 feet east of the center. This profile is representative of the soil as mapped here and occurs on a gentle slope with a convex surface and gradient of about $2\frac{1}{2}$%.

Profile*

Sample 54-OK-60-32-1

A_{1p} 0- 7" Reddish-brown (5 YR 5/4; 4/4, when moist) loam; weak medium granular; friable; pH 5.8; grades shortly to layer below.

Sample 54-OK-60-32-2

A_1 7-11" Reddish-brown (5 YR 5/4; 4/4, when moist) coarse silt loam with occasional light-reddish-brown spots or splotches; moderate medium granular; friable; permeable; pH 5.8; many pores, fine tubes and wormholes; grades to layer below.

Sample 54-OK-60-32-3

B_1 11-18" Reddish-brown (5 YR 4/4; 3/4, when moist) light clay loam slightly specked with yellowish-red (5 YR 5/6) compound moderate medium granular and weak fine subangular blocky; friable moist; slightly hard when dry; pH 6.2; many pores and fine tubes; occasional worm casts; grades to layer below.

Sample 54-OK-60-32-4

B_{2-1} 18-30" Red (2.5 YR 4/6; 3/6, when moist) silty clay loam finely and faintly mottled with 20% of reddish-brown (5 YR 5/4); compound moderate fine subangular blocky and medium granular; firm; hard when dry; many fine vertical tubes and pores; pH 6.5; grades to layer below.

*Color notations following color names are based on the standard Munsell system of color designation and refer to the dry soil unless stated otherwise.

TABLE X (Continued)

Sample 54-OK-60-32-5

B_{2-2} 30-46" Faintly mottled, red (2.5 YR 4/6) and light reddish-brown (5 YR 6/4) light silty clay; weak fine subangular blocky; firm; slowly permeable; pH 6.5; a few fine black concretions and black ferruginous films; a few fine pores; grades to layer below.

Sample 54-OK-60-32-6

B_1C 46-58" Red (2.5 YR 4/8) silty clay streaked and mottled with 20% light-reddish-brown (5 YR 6/4) weak medium subangular blocky; firm; slowly permeable; pH 7.0; a few fine pores, black concretions, and ferruginous films; the very fine sand is visible in this material; it grades to the layer below.

Sample 54-OK-60-32-7

C_{u-1} 58-72" Reddish-brown (2.5 YR 5/4; 4/4, when moist) silty clay; weak medium blocky; firm; sides of peds have a faint shine; a few black pellets and ferruginous films; occasional fine pores and darkened, filled root channels; pH 7.0; grades to layer below.

Sample 54-OK-60-32-8**

C_{u-2} 72-84" Much like layer above but contains a number of coarse $CaCO_3$ concretions; pH 7.5; non-calcareous in the mass; this is blocky, shiny and compact clay which is probably of Permian clay beds.

Variations: The B_2 horizons vary from light silty clay or sandy clay to clay loam or silty clay loam. Materials below about $4\frac{1}{2}$ feet are more clayey and have had little influence on profile development. Mottling is usually in the more clayey subsoils but profiles with somewhat more sandy materials below are usually unmottled. Substrata vary from clay loams to silty clays. Pebbles occur in some areas where the solum overlies plastic red clays within 2 to 3 feet of the surface and the soil is gradational toward Renfrow silt loam. In gradations toward Bethany, upper subsoils are dark-brown silty clay loams and overlie dark-brown clay or silty clay at 16 or 18 inches.

**Deepest soil horizon sampled in this profile.

TABLE XI

A DESCRIPTION OF THE PROFILE OF 2 B-1 BETHANY SILT LOAM

A representative area of this soil was found and a sample was collected in plot 7200 at a point 20 feet east and 220 feet north of the southwest corner. The site has a weak convex surface and gradient of $1\frac{1}{4}$%. It was in wheat in 1954. The profile is described as follows:

Profile*

Sample 54-CK-60-33-1

A_{1p} 0- 8" Brown (7.5 YR 5/2; 4/2, when moist) silt loam; weak medium granular; friable; permeable; pH 6.5; rests with a shear face on the layer below.

Sample 54-OK-60-33-2

A_1 8-14" Dark-brown (7.5 YR 4/2; 3/2, when moist) heavy silt loam; compound moderate medium granular and weak medium sub-angular blocky; friable; pH 6.5; many pin holes, pores and worm casts. There is a tendency for this material to cleave on horizontal faces and primary breakage is into rough cubes about 3/4 to $1\frac{1}{2}$ inches on a side. It grades to the layer below.

Sample 54-OK-60-33-3

B_1 14-21" Brown (7.5 YR 4/3; 3/3, when moist) heavy silty clay loam specked with strong-brown around the fine root holes and pores; moderate medium subangular blocky; firm; crumbly when moist; pH 6.5; weak shine on peds; many pores and worm casts; grades shortly to layer below.

Sample 54-OK-60-33-4

B_{2-1} 21-33" Brown (7.5 YR 5/3; 4/3, when moist) clay; weak medium blocky; very firm; slowly permeable; pH 7.0; peds have a weak shine and are coated with dark-brown (7.5 YR 4/2); occasional brown and strong-brown specks about the pores; most fine roots grow between faces of the peds; grades to the layer below.

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*Color notations following color names are based on the standard Munsell system of color designation and refer to the dry soil unless stated otherwise.

TABLE XI (Continued)

Sample 54-OK-60-33-5

B_{2-2} 33-46" Reddish-brown (5 YR 5/5; 4/4, when moist) light clay; weak medium blocky; firm; slowly permeable; pH 7.0; occasional pores and old root channels; sides of peds are stained dark-reddish-brown; slightly crumbly when moist and less compact than the layer above; grades to layer below.

Sample 54-OK-60-33-6

BC 46-56" Reddish-brown silty clay loam much like the layer above but has occasional light-gray streaks and strong-brown splotches; pH 7.0; becomes more crumbly and appears more permeable in the lower part; grades to the layer below.

Sample 54-OK-60-33-7

C_1 56-70" Red (2.5 YR 4/7; 3/6, when moist) silty clay loam with a number of thin light-brown and pink horizontal streaks; weak medium blocky; firm; crumbly when moist; permeable; pH 7.0; grades through a broad transition to the layer below.

Sample 54-OK-60-33-8

C_2 70-92" Red (10 R 5/8; 4/8, when moist) clay loam with occasional pink silt loam streaks; weak subangular blocky; permeable; pH 7.0+; sides of peds have weak-red (10R 4/4) coatings; occasional fine black concretions; black ferruginous films line old root holes and pores; grades to layer below. This layer appears to be of old alluvium.

Sample 54-OK-60-33-9

C_u 92-128"+ Red fine sandy loam stratified with silt loam and sandy clay loam; many pores and fine root channels; occasional black concretions and ferruginous films; pH 7.5. This is sandier than layers above and differs in that respect from the material in which the solum was developed. It appears to be alluvium and is probably of Pleistocene age.

Variations: Surface soils vary in texture from silt loam to light clay loam and in thickness from 7 to 14 inches. They average about 12 inches thick. The B_1 layers range from 3 to 8 inches thick

TABLE XI (Continued)

and are usually silty clay loams. B_2 layers are silty clays or clays of firm to very firm consistence. They vary from slowly to very slowly permeable. Substrata are usually clay loams but in places may be silty clays or clays.

It is probable that this soil developed in clay loam alluvium which may be loess-mantled. In the layers below about 6 feet, evidence of alluvium is rather plain, but the material above could be partly loessial origin with all materials derived locally from the flood-plain of Stillwater and Cow Creeks.

TABLE XII

A DESCRIPTION OF THE PROFILE OF 6 A-1 KIRKLAND SILT LOAM

A typical profile of the soil was studied in Plot 6100 from a point about 50 feet east of the center of this plot. This area occurs on a plane slope with a gradient of about 3/4%. It was in sorghum during 1953. The profile is described as follows:

Profile*

Sample 54-OK-60-37-1

A_{1p} 0- 8" Grayish-brown (10 YR 4.5/2; 3.5/2, when moist) heavy silt loam; weak medium granular; friable; permeable; pH 6.5; a few fine pores; rests abruptly on the layer below.

Sample 54-OK-60-37-2

B_{2-1} 8-22" Dark-grayish-brown (9 YR 4/2; 3/2, when moist) clay; moderate fine blocky; very firm; sticky and plastic when wet; very slowly permeable; pH 7.0; sides of peds are varnished and have strong clay films; occasional fine black concretions; grades through a 4" transition to the layer below.

Sample 54-OK-60-37-3

B_{2-2} 22-32" Dark-grayish-brown (10 YR 4/2; 3/2, when moist) clay; weak angular blocky; very firm and compact; very slowly permeable; pH 7.5; occasional fine black pellets; a few strong-brown specks about the tiny root holes; many fine $CaCO_3$ concretions below 24 or 26 inches; peds have a weak shine when moist; grades through a 3" transition to the layer below.

Sample 54-OK-60-37-4

B_3 32-42" Brown (7.5 YR 5/4; 4/3, when moist) light clay; weak medium blocky; firm or very firm; very hard when dry; pH 7.5; occasional black pellets and $CaCO_3$ concretions; sides of peds have weak coatings of dark-brown (7.5 YR 4/2, when moist); grades to the layer below.

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*Color notations following color names are based on the standard Munsell system of color designation and refer to the dry soil unless stated otherwise.

TABLE XII (Continued)

Sample 54-OK-60-37-5

C_1 42-52" Reddish-brown (5 YR 5/4; 4/4, when moist) heavy silty clay loam or light silty clay much like the layer above; pH 7.5 +; occasional large $CaCO_3$ concretions and black ferruginous films; grades to the layer below.

Sample 54-OK-60-37-6

C_2 52-64" Reddish-brown (3.5 YR 5/4; 4/4, when moist) silty clay loam splotched with 10% of red (2.5 YR 4/6) has occasional light-gray streaks; weak irregular blocky; firm; slowly permeable; pH 7.5; occasional fine black pellets and fine concretions of $CaCO_3$; grades to the layer below.

Sample 54-OK-60-37-7

C_3 64-84"+ Red (2.5 YR 4/6; 3/6, when moist) silty clay with occasional light-gray streaks and splotches; weak medium blocky; firm but not compact; pH 7.5 +; many fine pores; changes little to greatest depth sampled.

No pebble line is found here nor is there definite evidence of lower layers being in old alluvium as under the Bethany silt loam samples some 600 feet southeast of here. It is likely, though, that this substratum is in old alluvium, but of material nearly like the normal "red beds" strata found in this vicinity.

Variations: In a few spots where surface soils are about 12 inches thick, there are thin light-gray A_2 horizons above the claypan. Other spots along drainage sides have very-dark-gray plastic clay subsoils which have olive-brown mottling below 20 inches. One of these is found near the east center of Plot 5200. Another in the northeast of Plot 6100 occurs toward the head of a shallow drainageway and has a clay loam surface soil over a plastic dark-gray clay. A similar situation occurs along the east side of Plot 3200 due to surface erosion adjacent to the natural drainageway.

Kirkland is best adapted to small grains which mature early or to drought-resistant summer crops such as grain sorghums and cotton. It is not well suited for irrigation, due to slow permeability and the resultant loss of excess water.

TABLE XIII

RAINFALL DATA DURING 1954-1955 AT STILLWATER, OKLAHOMA

Total for January through December, 1954

January	0.33	inches
February	0.71	"
March	0.17	"
April	2.24	"
May	5.41	"
June	2.49	"
July	0.03	"
August	1.93	"
September	0.96	"
October	1.70	"
November	0.17	"
December	2.44	"
Total for the year	18.58	inches

Total for January through July, 1955

January	0.81	inches
February	1.31	"
March	2.01	"
April	0.53	"
May	9.73	"
June	3.42	"
July	1.36	"

VITA

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Master of Science

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Date of Final Examination: July, 1956