COMPARATIVE PHYSICAL AND CHEMICAL PROPERTIES OF A "SLICK SPOT" AND AN ADJOINING NORMAL SOIL OF THE REDDISH PRAIRIE SOIL AREA

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CHAPTER I

INTRODUCTION

Liebig said, "Agriculture is, of all industrial pursuits, the richest in facts and the poorest in comprehension." To a large degree this statement is still true in spite of our advances in agricultural science. Many unsolved problems in agriculture, old and new, still await the answer. In most of the agricultural problems the study of the soil is of primary importance.

The soils that support us are the products of different combinations of rocks, climate, slope, vegetation, and time. Nature has had to make many types of combinations of the soil forming factors to produce all the different types of soils in the world. Even the good soils are significantly different.

Besides these forces of nature, soils are also influenced by the action of man when he cultivates the land and grazes his herds upon it. On good soils production can be maintained or improved by proper use, or it may be decreased through careless use or abuse of the land. When the soils become less productive whether as a result of natural or artificial causes, it is a matter of deep concern to us because upon this depends the prosperity of a nation and the welfare of society. Someone has rightly said, "The base of the social pyramid rests today where it has always rested—upon the land. Upon the land man makes his first application of productive effort—to extract from it food to sustain his life and give him energy, fiber for clothes to protect his body and conserve its vital warmth, wood to build shelter against the elements and one from which to furnish tools." Therefore, to maintain a high productive capacity in soils, both those which are normally productive and in those which have been impaired for one reason or another, is clearly a matter of the highest order of national importance. It is possible to get the largest returns from lands by using the best cultural methods and most improved breeds of plants and animals only when it is uniformly productive. The occurrence of "slick spots" in some of the normal productive soil areas reported from Illinois, Idaho, Kansas, Colorado, California, and Oklahoma creates a hazard in the treatment and maintenance of such normal soils.

"Slick Spots"

The term "slick spot" has been commonly used to designate certain small barren spots, which are found in many places in sub-humid climates. They give the appearance on a field similar to the face of a man affected with small-pox. This name has been given to them because when they are wet, they appear slick and shiny, whereas the soil adjacent to them has the dull lustre, characteristic of most soils. In certain parts of the country they are also known as "gumbo spots."

These spots vary greatly in size and number and consequently in the percentage of the land which they cover. They vary in size from a wagon wheel to an acre. They are usually of extremely irregular outline and are promiscuously scattered in a field. They vary also in the intensity of the characteristics which render the soil unproductive. The location of these spots has no particular reference to the topography of the land (21). The presence of "slick spots" was recognized in Illinois in more humid parts of the prairie belt (20). The "slick spots" have been found in Nebraska on the first-bottom lands, particularly in association with Minatare, Laurel, and Lamoure soils, but occasionally they occur on low bench land mapped as Tripp (13). In Kansas (1) these spots have been reported to develop chiefly on slopes, in depressions, or at the sides or heads of draws. In Idaho (31) they have been reported to occur on the lower bench lands. Such spots have frequently been observed in central and eastern Oklahoma (16) on freshly ploughed land following a period of heavy rainfall. They occur more frequently on upland than on bottomland (17). These spots can be recognized easily on a field by having sparce vegetation.

Object of Research

The "slick spots" are an "eye-sore" on the field and they not only reduce the economic value of the land but also affect production and increase erosion hazard. Although to begin with they may not seem very important if the percentage of the land occupied is small, but with their increase in number not only does it become a serious problem from a production point of view but it also entails a heavy expenditure in reclaiming them. This problem has attracted the attention of a few workers from different states; but the work done is not of an elaborate nature nor have all the workers agreed to their characteristics and nature of development probably because of their varied nature. It was therefore desired to take up the study of a "slick spot" soil, an intrazonal soil caused by local factors; and compare it with neighboring normal soil, a Reddish Prairie, in order to compare the important differences in some of their physical and chemical characteristics and from which, if possible, to throw some light on its development and cure.

CHAPTER II

REVIEW OF LITERATURE

To understand the nature of "slick spot," it is necessary to know the morphology, genesis, and some of the physical and chemical properties of the profile and its comparison with neighboring normal soil. The findings of other workers in the field have been briefly summarized. As this problem is more or less closely allied to alkali soils, applicable references have also been included concerning similar work done on alkali soils.

Morphology

Studies made through soil surveys and other field work have disclosed a number of soils in California having the morphology of Solonetz. Storie (41) found the presence of "slick spots" on flat poorly drained plains associated with the Solano series. The 'A' horizon, 0-12", was brownish gray structureless fine sandy loam, distinctly acid in reaction. The layer was highly siliceous and the lower part of the horizon had ashy gray color. The B_1 horizon, 12"-26", was dull brownish gray clay. This horizon was compact, resistant to penetration of water and was distinctly basic. The B_2 horizon, 26"-38", light grayish brown clay, contained lime carbonate in seams and nodular form and highly colloidal clay, and was more basic. The C_1 horizon, 38"-72", was of light brownish gray, moderately compact massive material of heavy texture which contained considerable lime carbonate and sulphate and was highly alkaline.

In North Dakota large areas in the Great Plains are characterized by a spotted appearance of the surface. Kellogg (27) described normal Scobey-loam soil and several soil profiles from Solonchok to Solodi Stages existing in the western part of North Dakota. The profile description of solodised-solonetz was as follows:

A_1	0 - 1"	Brownish gray loam with a soft crumb structure.
A_2	1"- 3"	Grayish brown loam with a platy structure
B_1	3" - 5"	Dull grayish brown silt loam
B_2	5" - 8"	Dark brown clay with a well developed, hard columnar structure.
B_3	8"-12"	Olive brown clay with irregular prismatic structure.
B_{31}	12"-22"	Olive brown clay similar to above except that carbonates are present.
C_1	22"-26"	Olive gray sandy clay, highly mottled with white.
C	26"——	Olive gray sandy clay till, mottled with white.

The normal soil had the same horizons as above. The soils in all horizons were friable and mostly on the acidic side.

The soil of one such "slick spot" located about 70 miles east of the established boundary between the prairie soils and the chernozems had been studied at Manhattan by Ahi and Metzer (1). The normal soil belonged to the Derby series.

The 'A' horizon of normal soil, 0 - 9", was a dark brown silt loam with no pronounced structural development although there was a tendency towards granulation. The B_1 horizon, 10" - 21", was light brown to reddish brown, silty clay loam with a soft crumb structure. The B_2 horizon, 22" - 36", was reddish brown and less compact than B_1. It was silty loam and contained small concretions of lime. The parent material, occurring below 36", was a fairly uniform calcareous wind blown deposit of silt loam texture. The horizon was friable and contained small concretions of lime.

The 'A' horizon of the "slick spot" soil resembled the 'B' horizon of the normal soil. It was only 6" in depth, sandy clay loam with irregular structure and mild effervescence with HCl. The 'B' horizon, 7" - 24", was an exceedingly, heavy, sticky and nearly impervious layer. The texture was clay loam and the color was steel gray. It was devoid of structural development and effervesced strongly with HCl. The 'C' horizon was relatively loose, very friable, light gray clay loam with a sharp line of demarcation from the 'B' horizon. It gave strong effervescence with HCl.

Genesis

It was established by Joffe and McLean (23) that base exchange is the corner stone of the research on the origin of alkali soils, and for understanding their behavior and reclamation.

According to Hilgard (19) the alkali soils are characterized by the presence of sodium carbonate which is formed in the soil as a result of the complex of the sodium compounds and calcium carbonate existing in soil solution.

It has been claimed by Gedroiz (15) that whenever there is an abundance of chlorides and sulphates there is no sodium carbonate. His theory demanded that the soda formation was the second stage in the process of alkali formation while the first process was the salinizing process (solontzhak in Russian), then came the third de-salinizing stage followed by the appearance of the zeolite sodium and formation of soda (solonetz in Russian). He also postulated that the zeolitic portion in order to react with cations of the soluble salts does not go into the solution stage but the reaction is a surface phenomenon. Since the reactions in the zeolitic portion are of surface character it is understood that the degree of dispersion of the particles has an important bearing, especially in the alkali soil where the colloidal content is high. And from this viewpoint the study of the behavior of the alkali soil extract is of extreme interest.

The theory of Dominicis (10) is in agreement with that of Gedroiz except as to the necessity of calcium carbonate for the accumulation of sodium carbonate. He states that the hydrolysis of the sodium complex results in the formation of sodium hydroxide which reacts with carbon-dioxide to form sodium carbonate.

The genesis of solonchak and solonetz soils of western North Dakota was studied by Kellogg (27). He found that normal soil, solonchak, solonetz, and soloth do not represent exclusive categories, either of morphology or genesis. Such a soil as the solonchak-complex may show some characteristics of both solonetz and soloth; and nearly every solonetz shows some properties of solonchak or soloth. The general cycle of the genesis of these soils from the normal soil, and back again to the normal soil, both for complex types and the flood types has been shown.

DeSigmond (9) believes that when sodium occupies not less than 10-15 per cent of the exchange complex and the total soluble salts are down to 0.1-0.15 per cent, the exchangeable sodium disperses the soil colloids and reduces percolation. Hydrolysis of sodium from the exchange complex gives the soil an alkaline reaction with removal of soluble salts. This leads to the formation of solonetz. Solodization then starts, which results in the eluviation of 'A' horizon and deposition of clay and colloidal matter in the 'B.' Under the peptising influence of sodium, organic matter from 'A' horizon moves into the 'B' horizon. Such a soil is called a solodized-solonetz. With further hydrolysis of sodium from the exchange complex sesquioxides are also eluviated into the 'B' from 'A.' The process of hydrolysis and leaching continues until the profile loses its solonetz characteristics and becomes friable to a considerable depth with more of 'A' horizon than 'B.' Such a soil is called a soloth.

Harper and Stout (17) from Oklahoma conclude that a "slick spot" is the alkaline phase of soil development (solonetz soil) which develops after soluble salts, principally chlorides and sulphates, have been removed by leaching. The unfavorable physical structure which developed under the influence of sodium still remains after the sodium and other bases are removed by leaching and replaced by hydrogen.

The formation and occurrence of white and black alkali soils have been reported by Burgess (5) from Arizona. He has concluded that the "slick spots" are formed in fields where fine textured soils predominate. At one time these areas carried sufficient white alkali to transform a considerable portion of their clay zeolites into the sodium clay. Subsequently the white alkali salts were leached out of the surface soils, either by natural rainfall or artificial means, thus reducing the salt content sufficiently to permit the formation of small quantities of black alkali. This alkalinity has so deflocculated and cemented the soil particles as to render penetration nearly impossible.

Norton and Bray (30) have discussed the "slick spot" soils of Illinois and have attributed their presence to the interruption of leaching of a shallow loess by an underlying impervious till. This slightly pervious buried soil has interferred with the drainage and leaching of the overlying calcareous material, resulting in accumulation of the products of weathering as secondary minerals. The secondary accumulation includes unusually high amounts of replaceable sodium and calcium, and calcium carbonate is found precipitated in some of the horizons in the upper or super-imposed profile.

While working with "slick spots" in Idaho, Peterson (31) found that calcium carbonate was the cause of these "slick spots" and it was probably due, in large measure, to the cementing action which took place when the calcium was deposited from solutions in the soil.

According to Murphy and Daniel (29) the presence of these so called "alkali spots" is probably due to the accumulation of sodium salts in the sediments laid down by the receding sea, as the water in the deeper surface reservoirs evaporated as a result of arid conditions. The lateral extent of an individual alkali spot is usually quite distinct, indicating definite abrupt surface conditions at the time of deposition, accumulation and formation of solonchak soil. As the soluble sodium salts reacted with the base exchange complex, sodium clay was formed. As the sodium salts were leached out of the surface soil by rain water, hydrolysis of the sodium clay occurred and sodium hydroxide, its soluble product, caused the soil to become alkaline and highly deflocculated. This retarded further leaching, and with this retardation and under the existing climatic conditions, morphological features characteristic of solonetz developed.

Ahi and Metzer (1) from Kansas while discussing the genesis of "slick spot" soils attribute the presence of such soils to ground water seepage.

"Slick spots" have never been found in soils with good internal drainage at Illinois, and Smith (38) consequently proposed that the salts carrying the sodium which were primarily responsible for the formation of the "slick spots" were moved laterally by ground water, or that in some instances "slick spots" may have developed as a result of capillary action due to a high water table.

During the discussion of alkali soil formation, Kelley (26) has pointed out that even if soluble salts and exchangeable sodium are removed by leaching it does not necessarily follow that the normal physical characteristics of the soil will be restored. Probably the profound physical alterations pointed out gradually develop over a long period of time and these physical changes may not be completely overcome by the mere replacement of sodium by calcium. This appears to be the case in many small spots in Western United States known locally as "slick spots." Certain so called "slick-spots" are found to contain but little exchangeable sodium—or else they lose it by moderate leaching—and yet water penetrates these soils with extreme slowness.

Thorne and Peterson (42) described "slick spots" as small areas of alkali soils. Such spots are often underlain by dense plastic clay horizons that seriously impede leaching operations.

Stauffer and Smith (39) at Illinois found only 1.8 inches of percolate from a 38 inch Putnam soil column, out of the total precipitation over an eighteen month period. If weathering liberated a high proportion of sodium as compared to the other bases, the interruption in percolation could result in "slick spot" formation.

It has been shown that the majority of the "slick spot" soils in Colorado are high in adsorbed sodium at normal moisture, but nearly become saturated with calcium and magnesium when washed. Gardner, Whitney and Kezer (14) have shown that sodium saturated clay may swell to occupy a much larger volume than calcium saturated clay, even when the sodium clay was coagulated with a large excess of salts. It was concluded that many of the "slick spots" in western Colorado owe their impervious condition to adsorbed sodium, even in the presence of an excess of calcium sulphate and sodium salts, and that reclamation depends upon removal of the excess of sodium salts.

Plice and Emerson (32) believe that "slick spot" soils are not caused by the "present" sodium ions contained therein, but, instead, by the past "presence" of it. In other words sodium was the actual cause of "slick spot" soil formation, whether any of it still remains in the soil or not. In fact, their data indicate very strongly that most of the soluble sodium must leave the soil before the extremely bad physical condition can result.

Physical and Chemical Properties

In view of the varied nature of "slick spots" reported from different places, their physical and chemical properties also show wide differences.

Striking differences in growth between the plants of alfalfa grown on normal soil and "slick spots" in the same field have been reported by Peterson (31) from Idaho. He found that the most consistent difference in the two kinds of soils is in the content of lime. The normal soil is remarkably low in its content of calcium carbonate, considering the large amount in the sub-soil. The percentage of clay in "slick spot" soils and normal soils was the same. However, there is a difference in the ratio of very fine sand to silt which was much narrower in the non-slick soils varying between 2:3 and 3:2. The pore space does not differ widely in the two classes of soils.

Kelley (25) at California has shown that the amount of one or more of the soluble salts in soil samples taken from a very small area varied enormously. The distribution of chlorides and sulphates was more variable than that of the alkali carbonate.

The pH of the "slick spot" profile has been shown by Norton and Bray (30) at Illinois to have a good correlation with the texture, structure, and consistence characteristics as observed in the field and with replaceable sodium as determined in the laboratory.

Bray (2) at Illinois observed that wherever the characteristics of "slick-spots" were found, that the pH was high as was the content of replaceable sodium, but of the soils examined having a pH of 7 or more, only those showing "slick spot" characteristics in the field contained appreciable amounts of replaceable sodium, even though carbonates were abundant. Some of the sodium here reported as replaceable was probably soluble in water.

It has been shown by Brown, Rice, and Byers (4) that the average sodium content of the first 30 inches of a mature loess-derived Illinois prairie soil was about 0.77 per cent. The replaceable sodium content of a well developed "slick spot" was seldom over 0.1 per cent for the same depth. The replaceable sodium was therefore only about 13.0 per cent of the total sodium.

"Slick spots" have been observed in the soils of the Solano series of California by Storie (41). He found a close relationship between pH, replaceable sodium, moisture equivalent, and structure.

Isack (21) at Idaho obtained very little difference between chemical analysis and pH of normal soils and "slick spot" soils. They were low in water soluble salts. There was a marked difference in the Ca:Na ratio in the exchange complex of the soils--the ratio for slick soils was low, 1.71; and for the normal soils, very high, 48.4. The mechanical analysis of the soils showed that the colloidal portion of a "slick soil" was about three times as great as that of a normal soil. The amount of water required to produce one gram of plant dry matter from the "slick soils" was about three times that for the normal soils. Low crop producing power of the "slick spot" soil was attributed to the physical condition of this soil, which in turn was influenced by a relatively high exchangeable sodium content.

The physical and chemical properties of the surface layer of normal soils and the 'B' horizons of solonetz soils in Oklahoma had been compared by Murphy and Daniel (29). They found more water soluble sodium in the 'B' horizon of the solonetz than in the 'A' horizon of the normal soils. They found the average ratio of exchangeable calcium to sodium was 11.0 to 1.0 in the normal soils and 0.58 to 1.0 in the solonetz. Only one out of nineteen paired samples had a pH lower than 7.0 and eight were above 8.0.

The influence of exchangeable sodium upon certain physical properties of soils even when there were relatively small amounts of exchangeable sodium in the soil has been established by Ratner (34). The influence of exchangeable sodium in chernozem soil on plant growth begins to be deleterious under the conditions imposed by pot tests only when it amounted to about 50 per cent of the total exchangeable bases. The unfavorable influence of exchangeable sodium upon the physical properties of soil, as well as its harmfulness to plant growth, when there was a considerable amount of organic matter present in the soil, was more marked in soils rich in organic matter than in poorer soils.

Ahi and Metzer (1) at Kansas have observed that in general the "slick spot" profile contained somewhat less total sands and slightly more fine particles than the normal soils. The only marked difference, however, was in the content of the total sands and silt in the 'B' horizon of the two soils. The "slick spot" soils contained considerably less colloidal material than the normal soil.

Though the soluble salts were higher in "slick spot" profiles than normal ones, they were not excessive. Among the exchangeable bases in the two profiless the marked difference was in the relative amounts of exchangeable sodium—about eight times more in slick spot profile. The C:N ratio of "slick spots" was low as compared to the normal profile. Silica:sesquioxide ratio and base exchange capacities of the colloidal fraction from the "slick spot" profile was higher than in normal soils. Jarusov (22) observed that the mobility of exchangeable cations depends not only on the kind of soil, and on the degree of saturation of the complex by them, but also on the kind of exchangeable cations in the soil.

That the surface horizons of the "slick spot" soils have a lower colloidal content than the adjacent soils has been shown by Smith (38) at Illinois. The horizon of accumulation was found at a much shallower depth in the "slick-spot" soils. The most important difference between the "slick soil" and the adjacent prairie soil was in the content of exchangeable sodium.

Fitts, Rhoades and Lyons (13) found at Nebraska that the "slick spots" were consistently higher than the normal soils in percentage of saturation with sodium and potassium and poor physical properties was attributed to this. A close relationship has also been shown between the pH of the "slick spot" soils and normal soils and their respective percentages of exchangeable monovalent ions and calcium carbonate.

Fitts, Lyons and Rhoades (12) at Nebraska also studied the influence of sulphur, gypsum and calcium chloride on some physical and chemical properties of calcareous "slick spots" and found that all treatments reduced the percentage of clods larger than 1/4 inch and increased the rate of water intake by them.

Plice and Emerson (32) at Oklahoma observed little difference between "normal" and "slick spot" soils in texture but found noted differences between them in permeability and plasticity. The reason for the poor physical condition of "slick spot" soils was mostly ascribed to their high degree of dispersion which was due to the presence of certain salts, particularly those containing sodium. "Slick spots" were reported to be quite variable having traces to considerable water soluble salts present and also in the proportion of exchangeable sodium. Most of the soils had their pH value higher than 7.0, ranging between 6.0 to 8.9. When soils were leached with solutions of basic salts or when the basic soils are leached with water, organic matter and nitrogen were lost. The organic matter and nitrogen content of normal soils were double those of "slick spot" soils. It was believed that much of the poor physical condition and general sterility of the "slick spot" soils was due to loss of organic matter from those soils caused by the action of excessive salt concentration.

It was observed by Harper and Stout (17) that "slick spot" soils were usually high in clay content and the aggregates were usually more dispersed in water. They found that these soils were usually more alkaline than normal soils due to a physical structure which retarded leaching and that most of the "slick spots" did not contain sufficient soluble salts to retard normal plant growth. Organic matter in the"slick spots"was usually low. These soils were low in total and water soluble phosphorus but all were adequately supplied with exchangeable calcium and potassium. Exchangeable sodium was higher in most of the "slick spot" profiles than the normal ones.

Certain recommendations for reclaiming slick spot soils with gypsum, organic matter and sulphur have been made by Harper and Plice (18). They also reported that since "slick spot" soils were very much varied with regard to their structure and chemical composition it was difficult to make accurate recommendations for improvement that would apply to all areas. The "slick spots" from central and eastern Oklahoma have been reported by Harper (16) to be deficient chemically in a number of ways. Sodium has been reported to be one of the important factors in developing an unfavorable structure. The "slick spots" were reported to be low in organic matter and available phosphorus but may or may not be alkaline though often they were.

Loughridge (28) at California observed that the salts found impregnating alkali soils consisted of varying portions of sodium sulphate, sodium chloride and sodium carbonate and that they were concentrated in the surface four-foot layer of soil. Joffe and Zimmerman (24) have shown that magnesium was present in high concentration, its effects were harmful and that in the same manner as sodium. Calcium on the other hand antagonized magnesium and sodium.

Outstanding differences between alkali and productive soil in exchangeable sodium, exchangeable sodium per cent, pH of saturation paste and soluble salts have been reported by Chang (7) from New Mexico. Analysis of water soluble ions revealed that: (1) higher quantities of sodium in saline-alkali soils than normal soils; (2) low concentration of available calcium in spite of calcareous nature of soil; (3) variations of potassium and magnesium ions were small; (4) high ratio of sulphates to chlorides were found in nearly all soils; (5) higher salt content and greater proportions of sodium ions were present in lower horizons than in surface soils; (6) the soluble carbonates were low in alkali soils and were entirely absent in productive soils. Ratios of exchangeable calcium to sodium for non-alkaline soils were noticeably lower than those for productive soils. Exchangeable potassium was high for all soils. Except for saline-alkali soils, the quantity of exchangeable magnesium was roughly similar to potassium. The actual and relative amounts of exchangeable magnesium in the lower horizons of a saline-alkali soil were usually low. A close relation between pH and exchangeable sodium has been established. Fireman, Morgen, and Baker (11) at Idaho have shown that the problem soils of the Emmett valley area generally were characterized by high water table conditions, low salinity, high pH, high sodium and exchangeable percentages, and low rates of infiltration and permeability. The irrigation, drainage, and ground waters were relatively low in total salts, but were high in bi-carbonates, which may be related to the development of high sodium soils. A close relationship has been found by Russel (37) between moisture equivalent and base exchange capacity of soils. Coutts (8) concluded that the moisture equivalent of alkaline and saline soils of Sind gives valuable information to their physical condition while it added little information to the data obtained by other methods for Natal soils. Robinson and Holmes (36) and Steinkoenig (40) found the percentage of titanium oxide to be highest in the finer fractions of the soil. Robinson (35) has shown that usually the titanium content increases in the sub-soil.

CHAPTER III

METHODS AND MATERIALS

The normal reddish prairie soil selected for the study belonged to the Brewer Series and the neighboring "slick spot" was of the Drummond Series. The geographical location of the soils was: on land adjoining the first bottom land of Camp Creek six miles southeast of the city of Pawnee in Pawnee County. The morphological characteristics of the two profiles is as follows:

Normal Profile

A (0 - 9") - Brewer clay loam, very dark grayish brown, 10YR 3/2 (Dry), 2/2 (moist), heavy silt loam, strongly medium granular, friable, permeable, pH-6.3.

B_2 (9" - 20") - Dark reddish brown, 5YR 4/3 (dry), 3/3 (moist), clay or heavy silty clay, compound weak medium blocky and sub-angular, crushes rather easily to medium granules in moist stage, permeable, firm, pH-6.7.

B_3 (20" - 36") - Reddish brown 5Y 5/4 (dry), 5Y 4/4 (moist) clay, weak medium blocky, crushes to moderate sub-angular blocky in moist stage, very firm when dry, contains a number of fine and moderate size white concretions of calcium carbonate and a few fine black pellets, slowly permeable, pH-7.85.

C (36" - 62") - Reddish brown (same as above), silty clay or clay, a few scattered calcium carbonate concretions present. A few narrow streaks of light brown clay loam and a few fine black concretions. Structure less pronounced, slowly permeable, pH-8.15.

"Slick Spot" Profile

A (0 - 5") - Pale brown, 10YR 6.5/3 (dry), 5/3 (moist), very fine sandy loam to silt loam layered with very pale brown (10YR 7/3 when moist); strongly platy and vesicular, very powdery when dry, slowly absorptive, mildly alkaline, pH-7.6, grades at about one inch into brown, weak granular silt loam, rests abruptly on the layer below.

B_2 (5" - 18") - Dark brown, 7.5YR 3/2 (dry); 2/2 (moist) silty clay, coarse blocky, compact, plastic when wet, slight evidence of columnar structure, grades to the layer below, pH-7.8.

B_3 (18" - 48") - Dark brown, 7.5 YR (dry), 3/3 (moist), silty clay, moderate medium sub-angular blocky, firm, slowly permeable, grades to the lower layer below, pH-8.1.

C (48" - 72") - Reddish brown, 5YR 5/4 (dry), 4/4 (moist) silty clay, similar to above layer, pH-8.2.

Hydrogen Ion Concentration: The pH values were determined by the Beckman pH meter, using a glass electrode and a soil suspension containing one part of soil to two and a half parts of water.

Mechanical Analysis: Fifty grams of air dry twenty mesh soil was placed in a beaker and covered with water. Five c.c. of normal sodium hydroxide and five c.c. of saturated solution of sodium oxalate was added to it and then the soil dispersed for ten minutes and readings taken after forty seconds and one hour with the hydrometer as described by Bouyoucos (6).

Moisture Equivalent: Thirty grams of air dry soil was placed in cups, kept overnight in water and centrifuged for forty minutes at 2440 r.p.m. and the percentage of moisture retained was determined as described by Briggs and McLane (3).

Soluble Salts: The total soluble salts, carbonates, bi-carbonates, sulphates, chlorides, calcium and magnesium were determined in an extract from one part of soil to five parts of water, as outlined by Wright (43).

Sodium and potassium were determined in the same extract by the Perkins-Elmer Flame Photometer.

Exchangeable Bases:

(a) Exchangeable calcium and magnesium. Twenty-five grams of air dry soil was leached with N-Na Cl till the leachate was one liter. The same soil was then leached with another liter of N-Na Cl. Calcium and magnesium were determined by the usual methods in both leachates, and the difference between the two gave the exchangeable calcium and magnesium as described by Wright (44).

(b) Exchangeable Potash and Sodium. Twenty grams of air dry soil was shaken for thirty minutes with sixty c.c. of neutral normal ammonium acetate and the sodium and potassium in the filtrate was determined by the Perkins-Elmer flame photometer. The sodium and potassium obtained in the soluble salts was deducted from the figures obtained under this section to give the true values of exchangeable potassium and sodium.

Total Nitrogen: Determination of nitrogen was made by the Kjeldahl method as described by Wright (45).

Organic Matter: One gram of one hundred mesh soil was treated with ten c.c. of 0.4 normal potassium-di-chromate solution and fifteen c.c. of concentrated sulphuric acid. The excess dichromate was titrated with 0.2 normal ferrous ammonium sulphate, using ortho-phenanthroline as the indicator, as described by Walkley and Black (48).

Calcium Carbonate: Five grams of air dry soil was treated with one hundred c.c. of normal hydrochloric acid, stirred vigorously several times for one hour and a portion of the aliquot titrated with normal sodium hydroxide, as described by Piper (33).

Total Phosphorus: One tenth of a gram of one hundred mesh soil was fused with about two grams of sodium carbonate and the fused mass dissolved and made up to two hundred c.c. with water. A portion was taken, neutralized with sulphuric acid and the phosphorus determined colorimetrically after development of the blue color with ammonium molybdate and stannous chloride, as described by Wright (46).

Other Chemical Constituents (Sodium carbonate fusion): One gram of one hundred mesh soil was fused with five grams of sodium carbonate. The fused mass dissolved in hydrochloric acid and silica, iron, aluminium, titanium, calcium, and magnesium determined as described by Wright (47).

CHAPTER IV

EXPERIMENTAL RESULTS

The data presented here are for one "slick spot" profile of the Drummond series and one neighboring profile of the normal Brewer series. The data indicate many characteristics in which the "slick spot" profile differs from the normal one. Of course in the "slick spot" profile especially in the B_2 and B_3 horizons there was a high amount and percentage of exchangeable sodium, low Ca/Na ratio and high percentage of fine fractions which has been commonly found in all such soils.

pH Values: The A and B_2 horizon of the normal soil are acidic in nature while B_3 and C horizons are basic. The pH values of C horizons of both the profiles were more or less the same as shown in Table I. All the horizons of the "slick spot" soil were basic in character. The pH value gradually increased from 7.6 to 8.2.

TABLE I

pH AND CALCIUM CARBONATE CONTENT OF THE VARIOUS HORIZONS
OF THE NORMAL SOIL AND THE "SLICK SPOT" SOIL (AIR DRY)

Constituents	Normal Soil				"Slick Spot" Soil			
	A	B_2	B_3	C	A	B_2	B_3	C
pH	6.3	6.7	7.8	8.2	7.6	7.8	8.1	8.2
Calcium Carbonate p.c.	1.3	1.8	2.0	2.0	0.8	1.8	3.0	2.0

Lime: The percentage of calcium carbonate in both the profiles increased with depth up to B_3 horizon and then it decreased in the "slick spot" profile but remained constant in the normal profile. The highest percentage was in the B_3 horizon of the "slick spot" profile. There was no close relation between pH and calcium carbonate as shown in Table I.

Mechanical Composition and Moisture Equivalent: The A horizon of the "slick spot" profile was very characteristic in that it contained a high percentage of sand and only about fifty per cent of silt and clay, as shown in Table II. This had a distinct difference with the A horizon of the normal soil which was seventy-five per cent silt and clay and about twenty-five per cent sand. In the normal profile the percentage of sand gradually decreased with depth, and the finer fractions especially clay increased in a regular manner. This was also worked out by the various ratios of the three fractions, ($\frac{Sand}{Silt}$, $\frac{Sand}{Clay}$, and $\frac{Sand}{Silt + Clay}$), in most cases the ratios decreased with depth. The ratio of $\frac{Silt}{Clay}$ for the normal soil also followed the same pattern. The relationship in the "slick-spot" profile was not so regular. After the siliceous A horizon, B_2 and B_3 horizons had eighty to eighty-two per cent of the soil fraction as silt and clay, while the C horizon had about seventy-five per cent of these fractions. Leaving aside the A horizon, it could be observed that except for $\frac{Silt}{Clay}$ ratio which followed the same trend as for the normal soil, the other three ratios of the "slick spot" soil tended to increase from B_2 to C horizon. Except for the A horizon of the "slick spot" profile, it can be generally said that the three ratios of sand to fine fractions of the "slick spot" soil horizons were numerically lower when compared to the ratio for the same horizons of the normal soil.

Moisture equivalent in the normal and the "slick spot" soil followed

TABLE II

MECHANICAL COMPOSITION, THEIR RATIOS AND MOISTURE EQUIVALENT OF THE NORMAL SOIL AND "SLICK SPOT" SOIL (AIR DRY BASIS)

Constituents	Normal Soil A	Normal Soil B_2	Normal Soil B_3	Normal Soil C	"Slick Spot" Soil A	"Slick Spot" Soil B_2	"Slick Spot" Soil B_3	"Slick Spot" Soil C
Mechanical Composition								
Sand %	25.5	24.5	22.5	17.5	48.5	17.5	19.5	25.5
Silt %	46.0	39.0	39.0	40.0	33.5	45.5	38.5	36.5
Clay %	28.5	36.5	38.5	42.5	18.0	37.0	42.0	38.0
Ratios								
Sand / Silt	0.55	0.63	0.57	0.43	1.45	0.38	0.50	0.70
Sand / Clay	0.89	0.67	0.58	0.41	2.70	0.48	0.46	0.67
Sand / Silt + Clay	0.34	0.32	0.29	0.21	0.94	0.21	0.24	0.34
Silt / Clay	1.61	1.07	1.01	0.94	1.86	1.23	0.90	0.96
Moisture Equivalent								
Moisture Equivalent	23.0	23.6	24.2	28.4	16.9	29.2	29.9	27.1

the same trend as the amount of fine fractions, especially clay. The moisture equivalent in the C horizons was about the same. The highest figure for the normal soil was obtained for the C horizon while the highest for the "slick spot" soil was obtained for the B_3 horizon. These values are of great importance in soil-moisture relationship.

Soluble Salts

The differences in the soluble salts between the two profiles were very marked---the "slick spot" profile having higher amounts for each horizon when compared to the normal ones as shown in Table III.

TABLE III

SOLUBLE CATIONS, THEIR RATIOS AND SOLUBLE ANIONS OF THE VARIOUS HORIZONS OF THE NORMAL SOIL AND THE "SLICK SPOT" SOIL (AIR DRY BASIS)

Soluble Cations and Anions

Constituents	Normal Soil				"Slick Spot" Soil			
	A	B_2	B_3	C	A	B_2	B_3	C
	PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM
Calcium (Ca)	46.5	60.4	55.8	37.2	18.6	37.2	37.2	37.2
Magnesium (Mg)	52.4	50.2	41.5	43.6	32.7	39.3	39.3	54.6
Potassium (K)	13.2	13.2	19.8	19.8	6.6	6.6	6.6	6.6
Sodium (Na)	90.0	150.0	190.0	310.0	310.0	620.0	880.0	375.0
Carbonates (Co_3)	Abs.	Abs.	Abs.	Abs.	Abs.	Abs.	Abs.	Abs.
Bi-carbonates (HCo_3)	122.0	183.0	366.0	549.0	275.0	490.0	830.0	610.0
Sulphates (So_4)	238.0	321.0	123.0	180.0	190.0	460.0	650.0	180.0
Chlorides (Cl)	123.0	164.0	232.0	369.0	340.0	500.0	657.0	383.0
Total Soluble Salts	770.0	930.0	990.0	1440.0	1160.0	2250.0	2950.0	1530.0

Ratios

$\frac{Ca}{Na}$	0.51	0.40	0.29	0.12	.06	.06	.04	.09
$\frac{Ca + Mg}{Na}$	1.10	0.73	0.51	0.26	0.16	0.12	0.08	0.24
$\frac{Ca + Mg}{Na + K}$	0.96	0.68	0.46	0.25	0.16	0.12	0.08	0.24
Na as percentage of total cations	44.50	54.70	61.80	75.60	84.20	87.20	90.30	77.50

The amounts gradually increased with depth except in the case of "slick spot" profile where the highest concentration was in the B_3 horizon. Calcium, magnesium, and potash were low while sodium was high for each horizon of the "slick spot" when compared to the normal soil. Bi-carbonates, sulphates, and chlorides were also high in all horizons of the "slick spot" soil when compared to the normal. Of course in both the C horizons there was a close similarity regarding the amounts of cations and anions.

$\frac{Ca}{Na}$ ratio was very high in the normal soil as compared to the "slick spot" soil, especially in the A, B_2, and B_3 horizons. The ratio decreased with depth of soil in both cases. $\frac{Ca + Mg}{Na}$ and $\frac{Ca + Mg}{Na + K}$ ratios in both the soils also followed the same trend as $\frac{Ca}{Na}$ ratio except that the numerical figures were higher than the $\frac{Ca}{Na}$ ratio. Sodium as a percentage of total cations was eighty-five to ninety per cent in the case of A, B_2, and B_3 horizons of the "slick spot" profile while it was only forty-five to sixty per cent in the case of equivalent horizons of the normal soil. C horizons of both profiles had sodium percentages of about seventy-six.

Data as to the nature of soluble salts present in the different horizons of the two profiles are presented by Table IV. It must however be mentioned that these are hypothetical calculations and that the amounts of salts are approximate but it does give a fairly good idea of the comparative amounts of the various types of salts present. The most striking feature was the high percentage of sodium bi-carbonate present in the B_2 and B_3 horizons of "slick spot" and to a smaller extent in the case of C horizons of both the profiles. The A, B_2, and B_3 horizons of the normal soil did not contain any sodium bi-carbonate. Calcium bi-carbonate in the A, B_2, and B_3 horizons of the normal soil was present in higher amounts

TABLE IV

PROBABLE COMBINATIONS OF SOLUBLE SALTS IN P.P.M. IN THE VARIOUS HORIZONS OF THE NORMAL SOIL AND "SLICK SPOT" SOIL

	Normal Soil				"Slick Spot" Soil			
Nature of Salt	A	B_2	B_3	C	A	B_2	B_3	C
Calcium Bi-carbonate	189.	242.	223.	149.	74	151	151	151
Magnesium Bi-carbonate	16	—	251	262	197	239	239	327
Potassium Bi-carbonate	—	—	—	49	15	17	17	17
Sodium Bi-carbonate	—	—	—	240	21	230	694	304
Magnesium Sulphate	252	251	—	—	—	—	—	—
Potassium Sulphate	30	30	45	—	—	—	—	—
Sodium Sulphate	36	153	150	270	285	695	960	270
Sodium Chloride	200	260	360	537	540	816	976	511

than the "slick spot" horizons. The "slick spot" profile was, however, richer in sodium chloride and sodium sulphate than the normal profile.

Exchangeable Bases: The most marked difference in the two profiles, as shown in Table V, was in the relative amounts of exchangeable sodium. The difference in the A horizons was only about two times, but in the case of B_2 and B_3 horizons the "slick spot" soil contained about twenty to twenty-five times more exchangeable sodium than the corresponding horizons of the normal soil. This was the zone of highest sodium accumulation in the "slick spot" soil, however, it decreased in the C horizon. The C horizons of both

TABLE V

AMOUNT OF EXCHANGEABLE BASES, THEIR RATIOS AND PERCENTAGE OF SODIUM IN THE VARIOUS HORIZONS OF THE NORMAL SOIL AND THE "SLICK SPOT" SOIL (AIR DRY BASIS)

			Exchangeable Bases					
Nature of Cations in M.E./100 grams of Soil	Normal Soil				"Slick Spot" Soil			
	A	B_2	B_3	C	A	B_2	B_3	C
Calcium (Ca)	13.0	16.1	15.0	13.7	6.6	10.5	10.4	14.3
Magnesium (Mg)	2.6	4.0	4.1	4.3	2.0	2.6	3.0	4.1
Potassium (K)	0.5	0.4	0.3	0.3	0.3	0.4	0.4	0.4
Sodium (Na)	0.3	0.4	0.6	2.6	0.5	8.9	9.6	3.3
			Ratios					
$\frac{Ca + Mg}{K + Na}$	21.3	26.2	21.5	6.1	10.2	1.4	1.3	4.9
$\frac{Ca}{Na}$	46.0	38.0	27.0	5.0	13.0	1.2	1.1	4.3
$\frac{Ca + Mg}{Na}$	56.0	48.0	34.0	7.0	17.0	1.5	1.4	5.6
			% of Sodium					
Sodium as % of Exchangeable Bases	1.7	2.0	2.8	12.5	5.3	39.0	41.0	15.0

profiles had nearly the same amount of exchangeable sodium. The amount of exchangeable potash in different horizons of the profiles did not show marked differences. The amount of exchangeable calcium and magnesium was higher in A, B_2, and B_3 horizons of the normal soil. There was a close resemblance between the C horizons of the two profiles for exchangeable calcium and magnesium.

$\frac{Ca}{Na}$ ratio was higher in the normal soils than in the "slick soil"—the ratio was about four for the A horizon, twenty-five to thirty for B_2 and B_3 horizons, and less than one and a half for the C horizon. This difference between $\frac{Ca}{Na}$ ratio being wide for normal soils and narrow for "slick spot" soils has been universally found—the ratios, however, vary from place to place, depending upon the soil. $\frac{Ca + Mg}{Na}$ ratio followed the same trend as $\frac{Ca}{Na}$ ratio for all horizons except that the ratios in this case were numerically higher. $\frac{Ca + Mg}{Na + K}$ ratio also followed the same trend as $\frac{Ca}{Na}$ except that the ratios were numerically lower. Sodium as a percentage of total cations was only about two to three per cent in the case of A, B_2, and B_3 horizons of the normal soil while in the B_2 and B_3 horizons of the "slick spot" profile it was about forty per cent. The high percentage of sodium as twelve per cent of total cations in the C horizon of the normal soil warrants special attention. The C horizon of the "slick spot" profile had also about the same percentage of exchangeable sodium.

Other Chemical Constituents: The percentage of organic matter and nitrogen was higher in A, B_2, and B_3 horizons of the normal soil when compared to "slick spot" horizons. The C horizons of both have about the same organic matter and nitrogen. The highest percentage of organic matter and nitrogen was in the A horizon of the normal soil and it decreased with depth. In the case of the "slick spot" profile the highest amount of organic matter and nitrogen was in the B_2 horizon, as shown in Table VI. It may however be mentioned that no account has been taken of the effect of any reduced compounds in the lower horizons of the soil, if present, which might influence the values of organic matter by this method.

TABLE VI

AMOUNT OF SOME CHEMICAL CONSTITUENTS OF THE VARIOUS HORIZONS OF THE NORMAL SOIL AND THE "SLICK SPOT" SOIL (AIR DRY BASIS)

	Normal Soil %				"Slick Spot" Soil %			
Constituents	A	B_2	B_3	C	A	B_2	B_3	C
Silica (SiO_2)	74.5	74.0	71.0	73.0	85.4	75.5	72.9	72.4
Iron oxide (Fe_2O_3)	2.8	4.5	4.0	4.5	2.4	3.8	4.8	3.5
Aluminium oxide (Al_2O_3)	9.0	10.0	11.1	11.5	7.2	11.3	11.3	12.7
Titanium oxide (TiO_2)	0.4	0.5	0.5	0.6	0.3	0.4	0.3	0.3
Phosphoric Acid (P_2O_5)	0.16	0.09	0.05	0.046	0.015	0.07	0.04	0.04
Calcium oxide (CaO)	1.08	1.45	1.66	1.70	0.54	1.56	1.86	1.65
Magnesium oxide (MgO)	0.88	1.39	1.54	1.54	0.92	1.35	1.48	1.70
Organic Matter	2.37	1.10	0.70	0.60	0.50	1.08	0.58	0.65
Total Nitrogen	0.104	0.052	0.033	0.032	0.024	.05	0.031	0.032

Except for the A horizon of "slick spot" profile which contained about eighty-five per cent of silica, the B_2, B_3, and C horizons contained decreasing amounts of silica with depth; viz., seventy-five, seventy-three, and seventy-two per cent, respectively. The percentage of silica in the normal profile also decreased with depth but there was a slight increase in the C horizon when compared to the B_3 horizon. Except for the C horizons of the two profiles where the silica percentage was more or less the same, the silica percentage in the A, B_2, and B_3 horizons of the "slick spot" was higher when compared to equivalent horizons of the normal soil and more pronounced in the A horizon.

In both the profiles the total amount of iron and aluminium increased with depth. The increase was more prominent from A to B_2 than in the other horizons. Though the differences between the B_2, B_3, and C horizons of the two profiles regarding the total amount of iron and aluminium was not very marked, the trend was higher in the case of the "slick spot" profile when compared to the normal. The differences in the total iron and aluminium content, especially the latter, was quite marked in the A horizons of the two profiles.

The amount of titanium was higher in the normal profile than the "slick spot" profile for all the horizons--the differences were more marked in the lower horizons.

The total phosphorus was high in all the horizons of the normal soil compared to similar horizons of the "slick spot" soil. The most marked difference was in the A and B_2 horizon of the "slick spot" and the normal soil. The quantity of P_2O_5 gradually decreased with depth in the normal profile, while, in the case of the "slick spot" profile the highest amount of P_2O_5 was in B_2 horizon and lowest in A horizon.

The quantity of calcium except for the A horizon of the "slick spot" and the normal profile was more or less the same in both the profiles in the B_2, B_3, and C horizons--the quantity of lime increasing with depth in both cases. Magnesium more or less follows the same trend as calcium except that the "slick spot" A horizon contained magnesium similar to the A horizon of the normal soil.

CHAPTER V

DISCUSSION

"Slick spot" soils have been classified as belonging to the white alkali group of soils or to saline soils, mostly the former. However, since some of them are not alkaline and contain very little or no soluble salts, they could be considered, more properly, to be degraded alkali or degraded saline soils. There is such a heterogeneity in the nature of these soils, that considerable difficulty arises in defining even wide distinctions among them. For example, some of them contain considerable water soluble salts while a few contain only traces of salts. Great variations exist in the proportions of the various ions in these salts. Of course sodium--particularly exchangeable sodium--is generally considered to be the sine que non of "slick spot" soils.

The morphological features of the "slick spot" profile and the normal profile resemble very closely those described by Ahi and Metzer (1) and Storie (41). The "slick spot" profile very much resembles a solodised-solonetz from its morphology which is also corroborated by its physical and chemical characteristics.

Several theories have been propounded regarding the genesis of "slick spots" but all the workers have agreed that "slick spot" develops due to an interruption in leaching. Peterson (31) ascribes the interruption in leaching to the formation of a hard layer on account of the cementing action of lime (calcium carbonate) resulting in "slick spot" formation. Since both the normal as well as the "slick spot" profile do not contain large quantities of lime, this does not seem to be the likely cause of "slick spot" formation under question.

On account of the presence of large amounts of soluble salts and exchangeable sodium in the "slick spot" profile as compared to the normal one, coupled with other characteristics, it was assumed that the starting point of such "slick spot" was the preponderance of soluble salts. These soluble salts could have come from irrigation water, decomposition of parent material, receding sea, blowing wind, or from underground water by capillarity or seepage. The soil has not been under irrigation and so this possibility as a source of soluble salts is ruled out. Since the normal soil from 0" - 36" contains very little soluble salts and exchangeable sodium, as compared to "slick spot" ones, it was presumed that the source of soluble salts is not from parent material or blowing wind or receding sea. The only likely source of soluble salts in the soil seems to be due to some underground water which gave rise to soluble salts by capillary action or seepage. The question now arises, why do "slick spots" develop only on particular spots and not on the whole area? The answer seems to be that the underground flowing water at one time or the other moved in streams with ups and downs and wherever the soils were touched at high levels, it affected those places much more than the rest and the salts gradually rose up and concentrated in the upper horizons. The high amount of soluble salts in the 36" - 62" layer of the normal soil could be explained in two ways. According to one, the flowing underground water which touched "slick spots" at high places also touched this place at lower levels such that the soluble salts could accumulate at that depth only and were not enough to rise up. The second possibility why sodium percentage and soluble salts are high in

36" - 62" of the normal soil may be due to the lateral percolation of soil solution rich in sodium from the horizons of a neighboring "slick spot" profile. Harper and Stout (17) found high exchangeable sodium in some of the dense clay sub-soils of normal soils. They explained this condition by a gradual movement of the sodium, which caused the development of "slick spot" soils out of the surface soil into the sub-soil.

Having established the presence of soluble salts in the soil it was presumed that on account of leaching taking place and in several stages (salinization, solonization, and solodization) after a good length of time a "slick spot" profile having the characteristics of a solodised-solonetz developed. In the development of this profile the high exchangeable sodium, especially in the B_2 and B_3 horizons, coupled with high amounts of clay resulted in poor nutrient balance, nutrient availability, poor soil tilth and poor water penetration and movement. The theory of development of the "slick spot" soil profile as mentioned above has also been subscribed to by Gedroiz (15), Harper and Stout (17), Murphy and Daniel (29), de Sigmond (9), and Kellogg (27).

This view is further supported by its physical and chemical characteristics. The A horizon of the "slick spot" soil is shallow and siliceous, as shown in Table VII, because it has been elluviated of organic matter and colloidal matter. Another reason for shallowness may be due to a part of it being eroded as observed by Murphy and Daniel (29). Though the surface A horizon contains little soluble salts and exchangeable sodium to affect plant growth, it does not exhibit good physical behavior and this together with low quantity nutrients makes the A horizon responsible for poor plant growth. It has been shown by Kelley (26) that even when much of the sodium has left the soil that it is not necessarily so that it will show good

TABLE VII

COMPARISON OF THE DIFFERENT HORIZONS OF THE NORMAL SOIL WITH EQUIVALENT HORIZONS OF THE "SLICK SPOT" SOIL FOR ORGANIC MATTER, SILICA AND TOTAL PHOSPHORIC ACID

	Organic Matter %				Silica %				Total Phosphoric Acid %			
	A	B_2	B_3	C	A	B_2	B_3	C	A	B_2	B_3	C
Normal Soil	2.4	1.1	0.7	0.6	74.5	74.0	71.1	73.0	0.16	0.09	0.03	0.05
"Slick Spot" Soil	0.5	1.0	0.6	0.7	85.4	75.5	72.9	72.4	0.01	0.07	0.04	0.04

physical behavior because once the physical structure becomes impaired it takes a long time to bring it to its original state, even though the condition which created it is removed. The B_2 and B_3 are horizons of illuviation, these horizons are rich in organic matter, nitrogen, iron, aluminium, phosphorus, lime and magnesium. This must have been due to the dispersion of colloids, dissolving of organic matter, and their moving down by leaching. This also accounts for the higher amounts of iron and aluminium in the B_2 and B_3 horizons of "slick spot" soils when compared to normal. Harper and Stout (17) obtained higher amounts of organic matter and phosphorus in 6" - 12" layers of "slick spots" when compared to 0 - 6" horizons. Of course the values for these were very high in equivalent horizons of normal soil. The higher percentage of titanium in normal soil in all horizons compared to "slick spot" profile could not be explained. Of course the lower layers which contain more silt and clay, in both cases, contained more titanium; and this has also been observed by Robinson and Holmes (36) and Robinson (35).

The pH of the "slick spot" profile was alkaline and it increased with depth. This has also been noticed by Ahi and Metzer (1), Harper (16), Plice and Emerson (32) and Bray (2). The low pH values for B_2 and B_3 horizons compared to the amount of exchangeable sodium present was probably due to the absence of sodium carbonate. Sodium bi-carbonate was present in the C horizons of both the profiles and in B_2 and B_3 horizons of the "slick spot" profile and probably this is one of the factors responsible for pH values on the alkaline side. The lower layers of the "slick spot" profiles have been found to be rich in the fine fractions, as shown in Table VIII. Ahi and Metzer (1), Harper (16), and Isaak (21) reported similar results while Peterson (31) did not find any such difference. Moisture equivalent which closely follows the finer fractions of the soil, especially clay, has been found to be higher in B_2 and B_3 horizons of the "slick spot" horizon when compared to normal soil. There was some parallelism between moisture equivalent and exchangeable sodium. Storie (41), Russell (37), and Coutts (8) also made such observations.

TABLE VIII

COMPARISON OF THE DIFFERENT HORIZONS OF THE NORMAL SOIL WITH EQUIVALENT HORIZONS OF THE "SLICK SPOT" SOIL FOR SILT, CLAY AND MOISTURE EQUIVALENT

	Silt %				Clay %				Moisture Equivalent			
	A	B_2	B_3	C	A	B_2	B_3	C	A	B_2	B_3	C
Normal Soil	46.0	39.0	39.0	40.0	28.5	36.5	38.5	42.5	23.0	23.6	24.2	28.4
"Slick Spot" Soil	33.5	45.5	38.5	36.5	18.0	37.0	42.0	38.0	16.9	29.0	29.9	27.1

The soluble salts were higher in "slick spot" soils than normal soils, especially in the B_2 and B_3 horizons, as shown in Table IX. Though this amount was not enough to stop plant growth it does adversely affect plant growth. The presence of sodium in the form of bi-carbonates in higher amounts is very deleterious to plant growth. The high ratios ($\frac{Ca}{Na}$, $\frac{Ca + Mg}{Na}$, $\frac{Ca + Mg}{K}$) and low percentage of sodium as a total of cations obtained for normal soil when compared to "slick spot" soil has also been recorded by Murphy and Daniel (29) and Chang (7).

TABLE IX

COMPARISON OF THE DIFFERENT HORIZONS OF THE NORMAL SOIL WITH EQUIVALENT HORIZONS OF THE "SLICK SPOT" SOIL FOR TOTAL SOLUBLE SALTS, $\frac{Ca}{Na}$ RATIO AND SODIUM AS A PER CENT OF TOTAL CATIONS

	Total Soluble Salts P.P.M.				$\frac{Ca}{Na}$ Ratio				Sodium as Per Cent of Total Cations			
	A	B_2	B_3	C	A	B_2	B_3	C	A	B_2	B_3	C
Normal Soil	770	930	990	1440	0.50	0.40	0.29	0.12	45	55	61	76
"Slick Spot" Soil	1160	2250	2950	1530	0.06	0.06	0.04	0.09	84	87	90	78

The high exchangeable sodium, especially in B_2 and B_3 horizons of "slick spot" profile, as shown in Table X, was very charactoristic as this seems to be the cause of most of the trouble. The high $\frac{Ca}{Na}$, $\frac{Ca + Mg}{Na}$, and $\frac{Ca + Mg}{K + Na}$ ratios and low sodium as a percentage of total cations as obtained for normal soils and reverse of it for "slick spot" profiles has been observed by Isaak (21), Bray (2), Ratner (34), Ahi and Metzer (1), Fitts (13), Harper (17), and Chang (7). There is the largest agreement among different workers on this property of "slick spot" soils.

TABLE X

COMPARISON OF THE DIFFERENT HORIZONS OF THE NORMAL SOIL WITH EQUIVALENT HORIZONS OF THE "SLICK SPOT" SOIL FOR EXCHANGEABLE SODIUM, $\frac{Ca}{Na}$ RATIO AND EXCHANGEABLE SODIUM AS PER CENT OF TOTAL EXCHANGEABLE BASES

	Exchangeable Sodium (M.E.)				$\frac{Ca}{Na}$ Ratio				Exchangeable Sodium as Per Cent of Total Exchangeable Bases			
	A	B_2	B_3	C	A	B_2	B_3	C	A	B_2	B_3	C
Normal Soil	0.3	0.4	0.6	2.6	46.0	38.0	27.0	5.0	1.7	2.0	2.8	12.5
"Slick Spot" Soil	0.5	8.9	9.6	3.3	13.0	1.2	1.1	4.3	5.3	39.4	41.2	15.0

CHAPTER VI

SUMMARY AND CONCLUSIONS

The "slick spots" as reported by various workers from Idaho, Illinois, Colorado, New Mexico, Kansas, Nebraska, and Oklahoma are of varied nature. Though the total area of "slick spots" in this state is not great, they are important because they are a foci of erosion and a hazard in the proper management of soils. For this reason a study was made of one "slick spot" profile and one neighboring normal profile, Brewer Series, in the Reddish Prairie soils area for its morphological, physical, and chemical characteristics.

The "slick spot" profile has the characteristics of a solodised-solonetz.

It is inferred that the "slick spot" profile developed on account of interference in leaching brought about by exchangeable sodium and soluble salts. The presence of soluble salts is ascribed to be due to some underground source of water. The high percentage of soluble salts and exchangeable sodium in the C horizon of the normal profile is attributed to underground water or from lateral movement of the soil solution from a neighboring "slick spot" profile.

The "slick spot" profile was alkaline in nature and in the normal soil A and B_2 horizons were acidic while B_3 and C were alkaline. The amount of calcium carbonate for both profiles was low and largest amount was found in B_3 and C horizons.

The A horizon of "slick spot" profile was rich in sand, which the other horizons especially B_2 and B_3 contained about 80-85% of silt and clay. The B_2 and B_3 horizons of the normal soil contained less than this amount. The moisture equivalent was very high in B_2 and B_3 horizons of "slick spot" profile and C horizons of both profiles. It follows the percentage of fine fractions very closely.

The total soluble salts were high for all horizons of "slick spot" soil compared to normal ones. $\frac{Ca}{Na}$, $\frac{Ca + Mg}{Na}$ and $\frac{Ca + Mg}{Na + K}$ was high and sodium as percentage of cations was low in the normal profile compared to "slick spot" profile. The exchangeable sodium was high in "slick spot" profile especially in B_2 and B_3 horizons and the above ratios for exchangeable bases also followed the same pattern as those of soluble cations.

Organic matter and total phosphorus was higher in the normal soil than "slick spot" soil, while the B_2 and B_3 horizons of "slick spot" were richer in these than A horizon. There was not much difference in the total iron and aluminium amount of the two profiles except in the A horizon.

The above results especially obtained for C horizon of the normal soil give food for thought. If this is the result of the effect of neighboring "slick spots" we might expect several areas to be affected like that and this might result in more land getting into adverse physical state and thus will require proper management to see that the underlying sodium is not allowed to come up and turn our good land into additional "slick spots." Of course, more data from a number of places would be desirable to confirm the above theme.

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