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CRITERIA FOR THE QUANTITATIVE DETERMINATION OF SOIL DISPERSION

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LAWRENCE EUGENE ERBES

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Major Professor

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INTRODUCTION

Previous investigations at Kansas State University suggested that soil management problems would be severe in the proposed Wilson Irrigation Project subsequent to irrigation. Predicted salt and sodium levels were based upon extrapolation of soil and water data supplied by the Bureau of Reclamation.

Predictions on the expected salt and sodium levels occurring in the Wilson Project soils were based in part on the saturation percentage of the soil and the electrical conductivity of the irrigation water. A modified form of Gapon's equation was used to predict the exchangeable sodium percentage (ESP) that would develop subsequent to irrigation.

Based on reservoir operation studies by the Bureau of Reclamation, irrigation waters with three different salt levels were assumed as representative of a range of the irrigation water quality to be impounded in the Wilson reservoir at various times: (1) 32 me/liter total soluble cations (TSC) with a soluble sodium percentage (SSP) of 66 percent, (2) 20 me/liter TSC with a SSP of 57 percent and (3) 8 me/liter TSC with a SSP of 38 percent. Using water assumed to be intermediate in quality for the Wilson Reservoir, the predictions showed 33 of the 34 soil sites studied would have developed at least one saline horizon and 32 soil sites would have developed at least one alkali horizon subsequent to irrigation. These interpretations assume soil saturation extract electrical conductivity exceeding 4.0 mmhos/cm is saline and exchangeable sodium exceeding 15 percent is alkali.[1]

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[1] Predicted salt and sodium levels in 34 soils in the Wilson Project. Mimeo by Hyde S. Jacobs, Department of Agronomy, Kansas State University. 1963.

The United States Salinity Laboratory has outlined diagnostic criteria for evaluating saline and alkali conditions in soil and water quality (15). These criteria include the soil saturation extract electrical conductivity and exchangeable sodium percentage as an index for potential plant growth and adverse physical properties related to soil dispersion.

The common usage of exchangeable sodium percentage in saline and alkali investigations is subject to limitations. An exchangeable sodium level greater than 15 percent has been associated with poor physical properties relating to dispersion. Fifteen percent exchangeable sodium is only an arbitrary value selected for a wide scope of soils possessing dissimilar physical and chemical properties.

Therefore, the principal objectives of this investigation were threefold: (1) to develop a procedure for the quantitative determination of soil dispersion, (2) to estimate the critical ESP for specific soils from the Wilson Irrigation Project and (3) to determine the rate of dispersion at various ESP levels.

REVIEW OF LITERATURE

A description of dispersion has not been given as much attention as other aspects of salinity. The role of dispersion usually has been described qualitatively based on the presence or progress of dispersive activities. Hence, terminology used to estimate the degree of dispersion is somewhat inconsistent. Some attempt has been made by several workers to quantitatively characterize dispersion. However, an estimation of the critical exchangeable sodium percentage or rate of dispersion at various exchangeable sodium levels was not found in the literature.

Perhaps the first reported attempt to measure dispersion was made by Puri and Keen (14) in 1925. In their technique soil material direct from the field was suspended in water and allowed to stand for 24 hours. The amount of dispersion was determined by the concentration of clay in the top 8.5 cm of a one percent soil suspension. The clay concentration in the top 8.5 cm was expressed as a percentage of the total amount of soil used. This value was called the dispersion factor.

Several interesting facts evolved from Puri and Keen's work. Disintegration of soil aggregates proceeded continuously, rapidly at first and then more slowly, but dispersion continued to increase after shaking for 100 hours. The rate of change after the initial increase was related to the log of time (t). This may be expressed mathematically as follows:

$$d = a + K \log t \qquad (1)$$

where d is the dispersion factor and a and K are constants denoting the Y intercept and the slope of the regression line, respectively.

The co-workers found that dispersion was influenced by the concentration of soil in a soil-water suspension. They noted slight but systematic changes in dispersion at low soil concentrations where the suspension contained less than two percent soil. Moreover, flocculation usually increased concurrent with added soluble salts when the concentration of the soil suspension exceeded two percent. The effect of small increases in salt concentration upon dispersion was progressive and gradual with no sudden distinguishable flocculation or deflocculation.

The degree of dispersion differed dependent on initial moisture content of the soil sample. The clay fraction was found to decrease in dispersion as the initial moisture content decreased.

Harris (7) studied the effect of initial moisture content upon the dispersion obtained by shaking a soil sample in water. Similarly, he also found that soil dispersion increased as the initial moisture content increased.

Allison (1) has shown the modification of aggregation by plants during the growing season. The ease of dispersion increased throughout the growing season due to calcium cation removal and its subsequent replacement by sodium cations.

In 1931 Tiulin (18) reported a method for measuring soil tilth by using aggregates in their undisturbed state. Aggregates, although relatively permanent, became dispersed under cultivation and are replaced by temporary aggregates that are more vulnerable to dispersive activities. Tiulin differentiated between these two types of aggregates by passing soil through a series of sieves. He assumed that it was the temporary aggregates which dispersed upon being wet with water. After drying, comparison of the weight of permanent aggregates remaining on each sieve with that quantity obtained when sieving an air-dry sample without water, gave the relative proportion of resistant aggregates in each group.

Puri (12) later improved the method for quantitatively determining soil dispersion which he and Keen had originally developed. In Puri's method ten grams of soil were suspended in water in a one liter cylinder or bottle of uniform diameter. The suspension was mixed by turning the cylinder end over end a few times and the soil was then allowed to settle overnight. The suspension was then thoroughly mixed by gentle end over end motion and again allowed to settle. The clay (.002 mm in diameter) was determined as in the pipette method of mechanical analysis. The amount of clay remaining in suspension was termed the dispersion factor. The total clay fraction obtainable on complete dispersion of the soil was determined by Puri's method using NaCl-NaOH as the dispersing agent. The dispersion coefficient was obtained by dividing the dispersion factor by total clay content.

Taylor, Puri and Asghar (17) reported the variation in the dispersion coefficient among different soils. Maximum dispersion was noted in some instances when the exchangeable sodium was 60 percent. However, when an acid soil was neutralized by sodium hydroxide, the dispersion coefficient reached a maximum when the ESP reached 30 percent. The behavior of laterite soils was in marked contrast when studied under similar treatment. Maximum dispersion was not reached even when the soil was 100 percent saturated with sodium.

Puri (13) recognized that dispersion could occur without mechanical shaking. This phenomenon was termed auto-disintegration. Puri expressed the amount of dispersion resulting from auto-disintegration in terms of the dispersion coefficient.

The effect of sodium on the dispersion coefficient was determined by stepwise neutralization of acid soils with sodium hydroxide. Dispersion reached 100 percent at a pH of 10.8 whether auto-disintegration or a 24 hour shaking period was employed. In either case the dispersion increased sharply at pH values above 6.0.

Puri studied seventy-two soils to ascertain differences in dispersion which resulted from procedures employing both auto-disintegration and mechanical shaking. The results are shown in Table 1.

Table 1. Difference between the clay contents obtained by auto-disintegration and by mechanical shaking for 24 hours in 72 soils neutralized to pH 10.8 with NaOH after acid treatment

Difference in Percent Clay Between Auto-disintegration and Mechanical Shaking for 24 hours	Number of Soils Occurring in Group
6	1
3	7
2	11
1	18
less than 1	35

In every case maximum dispersion occurred at pH 10.8 and close agreement was found in the percent clay between auto-disintegration and mechanical shaking. Sixty-four soils (89%) had a difference of less than two percent clay between auto-disintegration and mechanical shaking.

Puri used ten different pH values ranging from 5.90 to 10.95 to determine the stability of the soil structure. Stability was judged by determining the percent of .005 mm clay in suspension at intervals over a 50 day period. In solutions where the pH ranged from 5.90 to 9.92 most of the dispersive activity occurred within two days and only increased slightly during the next three to five days. Complete dispersion, however, was essentially reached within the first four hours when the pH exceeded 10.52.

The structural status of soil particles at the different pH values represents a certain degree of stability which, if not permanent, is at least water-stable for considerable lengths of time according to Puri. Puri's statement is substantiated by comparing the percent of .005 mm clay particles in suspension at the lowest and highest pH values. The clay in suspension was 12.7 and 61.6 percent at pH 5.90 and 10.95 on the 50th day, respectively.

The effect of sodium on dispersion was also determined for other soil fractions to ascertain if aggregation is confined to the clay fraction. The amount of dispersion was studied for soil particles up to .06 mm in diameter. In this study two percent soil suspensions were neutralized to different pH values and then allowed to stand for three weeks. The results indicated that dispersion increased as pH was increased from 5.55 to 11.0. This relation between pH and dispersion was the same for all particle sizes studied, i.e. particles .002, .005, .008, .01, .02, or .06 mm in diameter.

The magnitude of dispersion increased as the soil particles increased from .002 to .06 mm in diameter. This characteristic increase in dispersion was demonstrated at all pH levels studied, e.g. at pH 5.5 the dispersion was 23.5 and 58.0 percent for particles at .002 and .06 mm in diameter, respectively. Likewise, at pH 11.0 the dispersion was 57.2 and 85.4 percent for particles at .002 and .06 mm in diameter, respectively.

The temperature of the soil-water suspension also influenced the rate of dispersion at all pH values studied by Puri. The effect of temperature was more pronounced under auto-disintegration than with mechanical shaking. For example, it took two weeks to achieve 61.7 percent dispersion (.005 mm particles at pH 11.0) at 12 degrees C using the auto-disintegration method, whereas using the same method, 64.2 percent dispersion was obtained within four hours at 35 degrees C.

Puri studied the effect of dilution on dispersion by treating 12-gram portions of a clay soil with NaOH to obtain variable pH levels. Soil samples representing pH values of 9.2, 9.8, 10.4, and 11.4 were kept in contact with 200, 400, 600, 800 and 1000 ml of water for ten days without mechanical shaking. After the ten-day period, the volume was made up to 1200 ml in every case to give a one percent suspension. Below pH 9.0 the dilution had no significant effect on dispersion. The diameter of the particles studied were .002, .005, .01, .02 and .06 mm. At pH values above 9.8 dispersion increased when dilutions of 600, 800, 1000 ml were used.

Puri attributed the increased dispersion which was due to dilution to the dissociation of soluble salts which increased the activity of electrolytes.

Black (2) measured dispersion using only the colloidal clay fraction. One gram of dry colloidal clay was suspended in 100 ml of water. The depth of the suspension was 10 cm. The amount of colloidal material remaining in suspension after 31 hours was designated as the dispersibility percentage.

PRELIMINARY INVESTIGATIONS

Methods

Preliminary studies were initiated in order to establish a laboratory procedure for bringing soil material to various levels of exchangeable sodium. A quantitative method was also needed to measure soil dispersion. The effect upon dispersion of exchangeable sodium percentage, time of shaking and aggregate size was investigated.

Leaching was the first method investigated for the purpose of obtaining different levels of exchangeable sodium. The leaching solutions each contained 100 me/liter of total soluble salts and were prepared by mixing

NaCl and $CaCl_2$ to give various sodium adsorption ratio (SAR) values. Solutions with the following SAR values were prepared: 0 (distilled water), 2, 8, 16, 24, 32 and 64. The solutions were leached through 1200 gm of air-dry soil which had been sieved through an 18 mesh sieve.

A constant head of one cm was maintained on each soil column to regulate the solution flow during the 10 day leaching period. The soil column was 10.0 cm high and 9.45 cm in diameter. Small samples (several grams) were removed from the bottom of each column after the first, third, fifth, seventh, and tenth day for chemical analysis to ascertain the time required for equilibrium.

Upon completion of the leaching period the soil cores were removed from their columns and allowed to air-dry while still containing soluble salts. The cores were then broken and crushed for sieving. Aggregates were obtained in three different size intervals: .25 to .5 mm, .5 to 1.0 mm and 1.0 to 2.0 mm in diameter.

Aggregate stability was measured by placing ten grams of aggregates representing a specific size range in a 1000 ml cylinder previously filled with about 990 ml of distilled water. The total volume was brought to 1000 ml after the aggregates were added to the cylinder. The cylinders were closed with rubber stoppers and shaken in a horizontal position at the rate of 120 cycles per minute. Different shaking periods were studied to evaluate dispersibility as a function of time. The time intervals included 0 (auto-disintegration), 1, 5, 10, 20 and 30 minutes. Each column was removed by tipping the top end to a standing position, allowing the soil mass to slide off the cylinder wall, and then inverting until most of soil moved to the corked end. Again the top end was raised to a standing position and swirled slightly to remove particles remaining on the rubber stoppers.

After six hours, the clay (.002 mm) in suspension was sampled in accordance with the pipette method of mechanical analysis.

The dispersibility of the soil was then calculated from the following equation:

$$DP = \frac{(DF_t - DF_{min})\ (100)}{(DF_{max} - DF_{min})} \qquad (2)$$

where DP is the dispersion percentage, DF_t, DF_{min} and DF_{max} are the treatment, minimum and maximum dispersion factors, respectively.

The grams clay in suspension after treatment is termed the treatment dispersion factor (DF_t), where t denotes a specific dispersion factor for a given treatment expressed as grams clay per liter.

The amount of clay which dispersed increased as the ESP increased. However, a portion of the clay will disperse from mechanical abrasion even if no sodium is present. The amount of clay which disperses under these conditions is termed the minimum dispersion factor (DF_{min}). The DF_{min} used in the preliminary investigation represented the amount of clay in suspension after the untreated soil sample had been shaken for 30 minutes.

The maximum dispersion factor (DF_{max}) represents the clay derived from totally dispersed aggregates. In the preliminary investigation the maximum dispersion factor was approximated as follows: 12 grams of aggregates were shaken with 400 ml of 1 N sodium acetate for five minutes. The treated soil was then filtered through a Buchner funnel and allowed to air-dry. Ten grams of the air-dry sodium acetate treated soil was then shaken for 30 minutes in a 1000 ml cylinder. The DF_{max} represented the amount of clay in suspension as determined by the pipette method of mechanical analysis.

The minimum dispersion factor is subtracted from both the maximum dispersion factor and the treatment dispersion factor so that the dispersion percentage obtained from equation (2) represents more nearly the dispersion due to exchangeable sodium.

Results and Discussion

The total leachate obtained during the ten day leaching period varied markedly depending on the SAR of the leaching solution. Since the total salt concentration (100 me/liter) was equal in all salt solutions, the total leachate obtained was associated with the relative quantity of sodium and calcium in the leaching solution. Figure 1 shows that the total filtrate was least for distilled water (2.6 liters). The total leachate increased sharply to 26.4 liters using a salt solution with a SAR of eight, but the total leachate decreased to 5.5 liters as the SAR increased to 64.

Table 2 shows the level of ESP which was obtained during the leaching period for each salt solution used. The ESP of the soil in the leaching column increased as the SAR values increased. Variations in ESP, however, were evident in every treatment throughout the ten day leaching period. The soil column leached with a salt solution having a SAR value of eight may be cited as an example of the fluctuation in ESP. The ESP at the bottom of the soil column was 5.7 after the first day of leaching. The ESP dropped to 4.2 and 4.4 on the third and fourth day, reached its highest level of 6.5 on the seventh day, but dropped again to 2.9 on the tenth day. The ESP obtained at the termination of the leaching period was

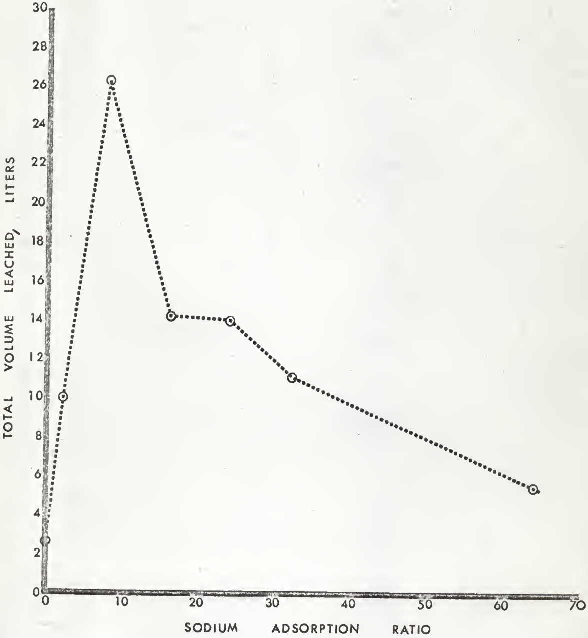

Fig. 1. The effect upon total volume leached through silty clay loam soil columns during 10 days leaching with distilled water and six salt solutions containing 100 me/liter of sodium and calcium chloride at different sodium adsorption ratios (SAR).

Table 2. Exchangeable sodium percentages obtained in a silty clay loam soil over a 10 day leaching period with salt solutions of varying sodium adsorption ratios. Each salt solution contained 100 me/liter of soluble calcium and sodium chloride.

SAR	Exchangeable Sodium Percentages at Various Time Intervals				
	Leaching Period, Days				
	1	3	5	7	10
0	1.0	0.8	0.5	1.6	0.5
2	1.8	1.6	1.6	2.1	1.3
8	5.7	4.2	4.4	6.5	2.9
16	9.1	7.5	9.1	8.6	8.0
24	13.5	13.0	13.5	13.5	12.5
32	15.6	18.2	17.1	16.4	18.2
64	16.1	25.2	32.2	26.5	34.8

about half of the SAR values of the leaching solution used, e.g. an ESP of 8.0 resulted when a leaching solution with a SAR of 16 was used.

The possibility exists that aggregate segregation may have occurred during preparation of the leaching columns and that solution channels developed in spite of dispersive activity within the soil cores subjected to leaching with a SAR value higher than eight. In any event it was concluded that leaching was not a satisfactory method for achieving the desired ESP levels because of the length of time required and the variation in ESP encountered.

Figure 2 shows the relationship between mean dispersion percentage and the logarithmic values of five shaking periods (1, 5, 10, 20 and 30 minutes) for three aggregate sizes of a silty clay loam soil. Dispersion

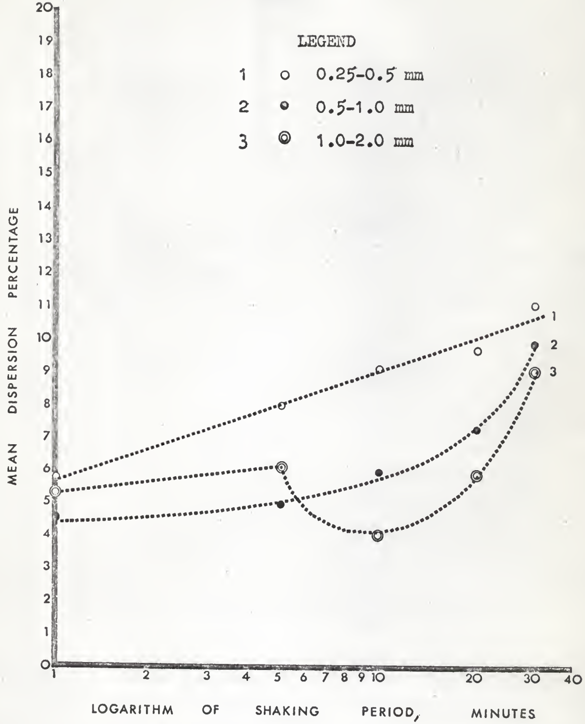

Fig. 2. The relationship between mean dispersion percentage and the logarithm of five shaking periods (1, 5, 10, 20 and 30 minutes) in three aggregate sizes for a silty clay loam soil.

percentages determined at each ESP level were used to calculate the mean dispersion percentage for a given shaking period. Although Puri observed the rate of dispersion as a function of the logarithmic value of the shaking period, he did not associate this relationship with a specific aggregate size.

The rate of dispersion in the .25 to .5 mm and the .5 to 1.0 mm aggregates was essentially linear when plotted as a function of the log of shaking time, Figure 2. However, dispersion did not increase regularly with time when the larger 1.0 to 2.0 mm aggregates were shaken. Figure 2 shows that the percentage dispersion for the .25 to .5 mm aggregates was higher at any given time than for the larger .5 to 1.0 or 1.0 to 2.0 mm aggregates.

Figure 3 shows the mean dispersion percentage as a function of the ESP of the silty clay loam soil samples. Dispersion percentages determined for each shaking period were used to calculate the mean dispersion percentage for a given ESP level. From Figure 3 it was apparent that the percentage dispersion increased gradually in each sized aggregate until the ESP reached approximately 18. At ESP values above 18 the percentage dispersion increased more rapidly indicating that a critical point had been reached. From this data it was concluded that a graph of the dispersion percentage vs. ESP would be a good criteria for determining the critical ESP level in soils.

A ten minute shaking period and an aggregate size range of 1.0 to 2.0 mm were selected on the basis of preliminary data as criteria for determining aggregate stability in future studies. Although these criteria generally represented the lowest levels of dispersion obtained, shown in

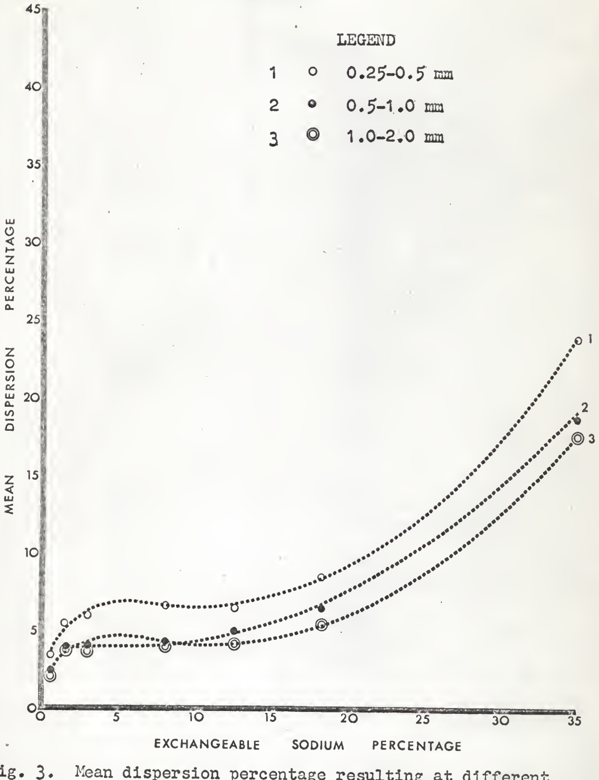

Fig. 3. Mean dispersion percentage resulting at different exchangeable sodium levels in three aggregate sizes obtained from leaching silty clay loam soil columns during 10 days leaching with distilled water and six salt solutions (100 me/liter of NaCl and $CaCl_2$).

Figures 2 and 3, a higher amount of dispersive activity would be required per gram of aggregates within the 1.0 to 2.0 mm than in .25 to .5 mm aggregates to achieve the same quantity of dispersed soil in suspension. Consequently, aggregates 1.0 to 2.0 mm in diameter would reflect a wider range of dispersive activity upon reaching 100 percent dispersion at a high ESP.

Auto-disintegration, a concept introduced by Puri, was not evident during the preliminary studies of this investigation. Puri, however, neutralized acid soils with NaOH to obtain variable pH and exchangeable sodium levels. Although he was able to demonstrate complete dispersion at pH 10.8 from either auto-disintegration or mechanical shaking, the method only demonstrated the occurrence of the dispersion associated with a predominately hydrogen-sodium system.

EXPERIMENTAL METHODS

Sampling. Soil samples were acquired from the proposed Wilson Irrigation Project in the Saline River valley in Lincoln, Ottawa and Saline Counties to evaluate their dispersibility hazard. Ten locations were used to represent a broad spectrum of soils occurring in the Wilson Irrigation Project. Each site was represented by three samples taken from different depths with a bucket auger. The depth increments sampled were selected from structural, textural and color changes. The location of the site was predetermined from data available through extensive studies made on 128 profiles by the Bureau of Reclamation. Although the soils in the Wilson Project are generally fine in texture, an effort was purposely made to acquire samples depicting texture differentiation.

Sample Preparation. Each sample containing about ten pounds of soil was spread out to air-dry for several days. The entire sample was then ground to pass a 1.5 mm sieve and mixed thoroughly to insure random sampling for later use.

Sodium Adsorption Ratio Solutions. Different SAR solutions were selected for this phase of the study than those used during preliminary work. The sodium adsorption ratios used were as follows: 7, 15, 19, 23, 27, 31, 35, 39, 47 and 55. This group of salt solutions include ten SAR values compared to seven SAR values formerly used and constitutes a smaller interval between each SAR value.

Each salt solution contained 200 me/liter of NaCl and $CaCl_2$. The concentration was increased from 100 me/liter to 200 me/liter of salts to help insure that the ESP obtained approximated an equilibrium between the soluble and exchangeable cations. Each soil sample was treated with the ten solutions of varying SAR.

To obtain different levels of exchangeable sodium 150 grams of soil were placed in 1000 ml of the previously prepared salt solutions in a two liter cylinder. Each cylinder was shaken horizontally for five minutes and then the sample was allowed to flocculate and settle. Within 30 minutes flocculation and settling was essentially complete and the supernatant salt solution was siphoned off using an aspirator. This treatment was repeated three times.

The soil was then decanted into a large Buchner funnel. Soluble salts were removed by washing with methyl alcohol. The first wash solution consisted of 500 ml of alcohol. Washing was continued using 50 ml aliquots of alcohol until the electrical conductivity of the filtrate was less than 40 mmhos/cm.

The salt free soil was oven-dried at 110 degrees C for two to three hours in large evaporating dishes to volatilize the alcohol. The soil sample was then saturated with water by capillarity. Since the alcohol wash virtually destroyed the soil structure, water was added to form artificial aggregates. The soil sample was then oven-dried at 60 degrees C. Ten to 15 hours drying time was required depending on the texture.

Aggregate Stability. The oven-dried soil was broken into large pieces and crushed with a large mortar and pestle. Only the aggregates ranging from one to two mm were saved for the study of aggregate stability.

The dispersibility of aggregates was determined similarly as in the preliminary investigation using a ten minute shaking period. Instead of using a DF_{max} value obtained from sodium acetate saturation, the DF_{max} value was based upon the percent clay calculated from mechanical analysis. One hundred percent sodium saturation with sodium acetate is difficult to obtain in the laboratory without detailed chemical analysis for verification. Likewise, the use of a SAR solution of 100 would have presented the same problem.

Since the Wilson Project soils studied had low exchangeable sodium percentages approximating one or two percent, the natural or untreated soil was used to determine the DF_{min} for each depth increment.

Chemical Analyses. The pH and percent organic matter of these soils were determined by methods used in the Kansas State Soil Testing Laboratory. The pH of the samples was determined on a 1:1 soil-water suspension with a glass electrode pH meter. The percent organic matter was determined colorimetrically from potassium dichromate-sulfuric acid treatment.

Extractable sodium, exchangeable sodium and cation exchange capacity were determined in duplicate using modifications of method 18 and 19 in Agricultural Handbook 60 (15). The suggested quantities of extracting solutions were not used since the centrifuge head would not hold tubes large enough to accommodate the prescribed amount of solution. Consequently a smaller quantity of soil and extracting solution was used in the chemical analyses.

Extractable sodium was determined on the untreated soils using a two-gram soil sample with three washings of 20 ml each of 1N (pH 7.0) ammonium acetate. The same soil sample was used for cation-exchange capacity determinations. The soil was saturated with Na by washing the sample four times with 20 ml portions of 1N (pH 8.2) sodium acetate. Soluble salts were removed by washing with 25 ml aliquots of methyl alcohol until the electrical conductivity of the centrifuged supernatant was less than 40 mmhos/cm. The adsorbed sodium was replaced by extraction with three 20 ml portions of ammonium acetate.

Exchangeable sodium in those soil samples treated with salt (SAR) solutions, and then washed free of soluble salts with methyl alcohol, was determined in the same manner as extractable sodium previously mentioned. The sodium retained in the extraction solution depicts essentially exchangeable sodium since soluble salts had already been removed by alcohol. Sodium in the extracting solutions was determined on a Perkin-Elmer flame photometer.

Determining the Critical Exchangeable Sodium Percentage and Dispersion Percentage. The preliminary investigation showed that, upon reaching a certain level of exchangeable sodium, the rate of dispersion increased sharply over the remaining ESP range. Subsequently, it became necessary to ascertain more clearly where the dispersion rate changes using graphical methods. The dispersion percentages were plotted on the ordinate while ESP was plotted on the abscissa.

Regression analysis was used to fit linear curves to the data for each soil by the least squares method (16). In the majority of soils the graphical points formed two linear curves. The points associated with each curve were selected visually and then used in the regression analysis. The critical dispersion percentage and exchangeable sodium percentage occurs at a point created by the intersection of the two linear curves. This point is called the critical point (CP). The CP will be designated as CP (X, Y) where X is the ESP and Y is the DP at that point.

Specific Surface Area. Specific surface area of these soils was determined by ethylene glycol adsorption using Morin and Jacobs' modification (11) of the Sor and Kemper method. Organic matter was removed prior to determining surface area by hydrogen peroxide digestion.

EXPERIMENTAL RESULTS AND DISCUSSION

The soils investigated in the Wilson Project are moderately high in clay content. The textures ranged from loams and silt loams to silty clay loams and clays according to profile descriptions listed in Table 9 of the appendix. Table 9 also includes information regarding the profile number, legal descriptions, site location, surface drainage, parent material and a descriptive characterization of each depth increment. For the most part Wilson Project soils were calcareous and developed from alluvial parent material.

The ten profiles studied in this investigation will be denoted by their arabic number during the text of this thesis rather than the longer identification given by the Bureau of Reclamation. The soil profile numbers are as follows: 1, 41, 52, 55, 65, 78, 81, 85, 95 and 106.

According to the data given in Table 3, the pH values of Wilson Project soils were all greater than 7.0 except for profile number 81 and the topsoil of profile number 106. Profile 81 was acidic ranging from 6.15 at the surface to 6.65 at the 36 to 48 inch depth. The pH of 6.65 in the topsoil of profile 106 was the only other acid sample. The pH values of the remaining samples ranged between 7.0 and 8.2.

The Wilson Project soils were unusually high in organic matter (Table 3). For example, the organic matter in the topsoils ranged from 2.15 to 4.1 percent yet only 14 percent of the soils in this general area have more than 2.1 percent organic matter in the topsoil (10). The organic matter in the second depths ranged from 1.2 to 3.0 percent while that in the third depth ranged from .8 to 2.05 percent, respectively.

Information regarding soil depth, extractable sodium, cation-exchange capacity, percent clay, specific surface area and surface charge density are presented in Tables 3 and 4. Exchangeable sodium percentage, dispersion percentage and Gapon's proportionality factors are presented in Tables 10 through 19 in the appendix.

The stability of the aggregates formed during treatment, and expressed in terms of dispersion percentage, varied from zero to nearly 100 percent. This variation is expressed graphically in Figures 8 through 17 where DP is plotted against ESP for each soil and depth increment.

Table 3. Chemical properties of 10 selected soils in the Wilson Irrigation Project.

Soil Number	Depth of Sample (inches)	pH	Organic Matter (%)	Extractable Sodium me/100 g soil	Cation Exchange Capacity me/100 g soil
1	0-5	7.80	3.60	.72	22.6
	5-12	7.60	3.25	.75	24.0
	20-29	7.85	2.05	.67	30.3
41	0-5	7.80	3.40	.30	21.8
	5-8	7.75	2.95	.50	23.2
	19-23	8.00	1.50	.50	18.0
52	0-6	7.90	2.15	.40	16.2
	10-16	8.05	1.40	.40	11.6
	24-31	8.20	0.80	.40	9.3
55	0-3	7.80	3.40	.50	19.8
	3-7	7.95	3.30	.40	19.8
	7-31	7.60	1.75	.82	28.1
65	0-9	7.80	4.10	.60	21.2
	24-34	7.90	1.70	.50	25.9
	34-45	8.05	1.05	.62	21.0
78	0-6	7.85	2.50	.68	23.2
	28-38	7.75	2.45	.82	26.1
	38-46	8.05	1.50	.40	18.8
81	0-12	6.15	2.40	.35	16.4
	12-30	6.40	1.20	.50	11.7
	36-48	6.65	1.15	.60	14.6
85	0-12	7.75	3.45	.30	31.3
	12-24	7.70	3.20	.40	27.8
	24-40	8.00	1.25	.50	18.4
95	0-10	7.00	3.25	.45	27.2
	10-20	7.65	1.70	.62	30.6
	24-36	7.70	1.05	.92	26.1
106	0-9	6.65	2.80	.62	20.0
	12-24	7.05	1.90	.78	20.8
	24-36	7.40	1.40	.85	19.0

Table 4. Physical properties of 10 selected soils in the Wilson Irrigation Project.

Soil Number	Depth of Sample (inches)	Clay Content* (%)	Specific Surface Area m^2/g soil	Surface Charge Density 10^{-7} me/cm^2
1	0-5	56.4	257.4	0.88
	5-12	68.4	300.6	0.80
	20-29	63.2	280.6	1.08
41	0-5	27.4	107.4	2.03
	5-8	27.4	113.5	2.04
	19-23	32.4	103.9	1.73
52	0-6	24.6	82.6	1.96
	10-16	16.8	56.8	2.04
	24-31	15.2	51.6	1.80
55	0-3	53.6	249.0	0.80
	3-7	53.6	256.1	0.77
	7-31	54.6	274.2	1.02
65	0-9	53.0	244.5	0.87
	24-34	47.6	222.6	1.16
	34-45	42.5	188.4	1.11
78	0-6	34.8	128.1	1.81
	28-38	36.4	183.9	1.45
	38-46	32.8	143.9	1.31
81	0-12	22.0	67.7	2.42
	12-30	17.8	68.4	1.71
	36-48	37.3	72.2	2.02
85	0-12	42.2	191.3	1.64
	12-24	33.8	194.5	1.43
	24-40	17.2	105.8	1.76
95	0-10	23.6	133.5	2.04
	10-20	47.6	241.0	1.27
	24-36	40.6	207.4	1.29
106	0-9	52.0	235.5	0.84
	12-24	52.4	311.9	0.67
	24-36	52.8	289.0	0.66

*Data supplied by Bureau of Reclamation.

Nineteen of the 30 profile increments exhibited a critical point along the regression of dispersion percentage on exchangeable sodium percentage. The range of ESP and DP values at this critical point varied from 9.2 to 40.6 percent and .2 to 32.4 percent with a mean of 20.2 and 7.8 percent, respectively. Most profiles had either one, two or three depth increments that showed a constant rate of dispersion over the range of ESP obtained. Consequently, a critical point was not detectable in these horizons. Soil 41 was unique since in all horizons no critical point was reached at least for the ESP levels obtained. On the other hand, soils 78 and 95 had a critical point exhibited in every profile depth increment studied.

The slope of the regression curves can be used to compare the rate of dispersion among depth increments and between different profiles at a given ESP level. The slope values and critical points of the linear regression curves are listed in Table 5. The first slope is designated as the initial slope of the regression curve which terminates at the critical point. The second slope commences at the critical point. In soils which exhibited critical points the initial slopes ranged from -.013 to 1.928; the second slopes ranged from .376 to 6.175.

A study of Table 5 shows that the slope of the DP vs. ESP curves can be grouped into two categories. In the first group the slope is less than .4 while the slope of the second group is greater than .4. In most instances where the slope of the line is less than .4 the critical point has not yet been reached. In 18 out of the 19 horizons which exhibited a critical point, the slope of the line above the critical point was greater than .4.

Table 5. The slope values of the linear regression between dispersion percentage (DP) and exchangeable sodium percentage (ESP). Critical points, CP(X, Y), are included where an initial and second regression curve characterize the relationship between DP and ESP.

Soil Number	Depth of Sample (inches)	Initial Slope	Second Slope	Critical Points	
				X	Y
1	0-5	.194	.896	40.6	7.9
	5-12	.378	.908	34.5	11.0
	20-29	.753	---	---	---
41	0-5	.098	---	---	---
	5-8	.284	---	---	---
	19-23	.299	---	---	---
52	0-6	.098	---	---	---
	10-16	.296	---	---	---
	24-31	.445	5.968	22.4	8.2
55	0-3	.008	.497	30.0	2.3
	3-7	.397	---	---	---
	7-31	.024	1.410	14.5	0.5
65	0-9	.230	---	---	---
	24-34	.279	.775	17.0	4.5
	34-45	.185	1.016	20.2	4.2
78	0-6	-.013	.376	16.5	2.3
	28-38	.152	.820	21.8	5.6
	38-46	-.016	.404	20.4	2.3
81	0-12	.624	6.175	9.2	4.2
	12-30	-.116	4.699	10.6	0.2
	36-48	2.001	---	---	---
85	0-12	.227	1.205	14.0	5.5
	12-24	.257	.937	14.2	3.9
	24-40	.937	---	---	---
95	0-10	1.157	5.422	13.2	9.0
	10-20	1.594	4.508	13.0	13.4
	24-36	1.060	3.964	24.7	17.3
106	0-9	1.581	---	---	---
	12-24	1.928	4.804	26.4	32.4
	24-36	1.298	2.455	21.6	14.4

Thus it was concluded that the slope of the DP vs. ESP line is of value in determining the dispersion status of the soil. For example, in soils 95 and 106 the initial slopes are all greater than 1.0 and it is logical to conclude that the dispersion hazard in these soils is significant even at very low ESP values. This same type of hazard is exhibited in the lower horizons of soils 1, 81 and 85 even though the DP vs. ESP curves for these horizons contain no ordinary critical points.

Soils 81, 95 and 106 and the lowest depth increment in soil 52 were extremely susceptible to dispersion; the slope values of their regression equations supports this fact. The other soils were generally less susceptable to dispersion. Soil 41, for example, had no critical point even though the ESP values ranged up to 33. The slopes of the DP vs. ESP curves for the three horizons in soil 41 were all less than .3.

It is interesting to note that the mean slope (1.307) for the DP vs. ESP curves above the critical points for soils 1, 41, 52, 55, 65, 78 and 85 was just slightly greater than the initial mean slope (1.236) of soils 81, 95 and 106.

Hence, when the initial slopes of the DP vs. ESP is greater than .4, these soils should be recognized as potentially susceptable to dispersion. The intersection of this initial slope with the abscissa should then be regarded as the critical point for these soils.

The regression between specific surface area and percent clay is shown in Figure 4. Specific surface area increased from 51.6 m^2/g to 311.9 m^2/g as clay increased from 15.2 to 68.4 percent. The correlation coefficient of .931 was significant at the .001 level. The specific surface area vs. percent clay for representative bentonite, illite and

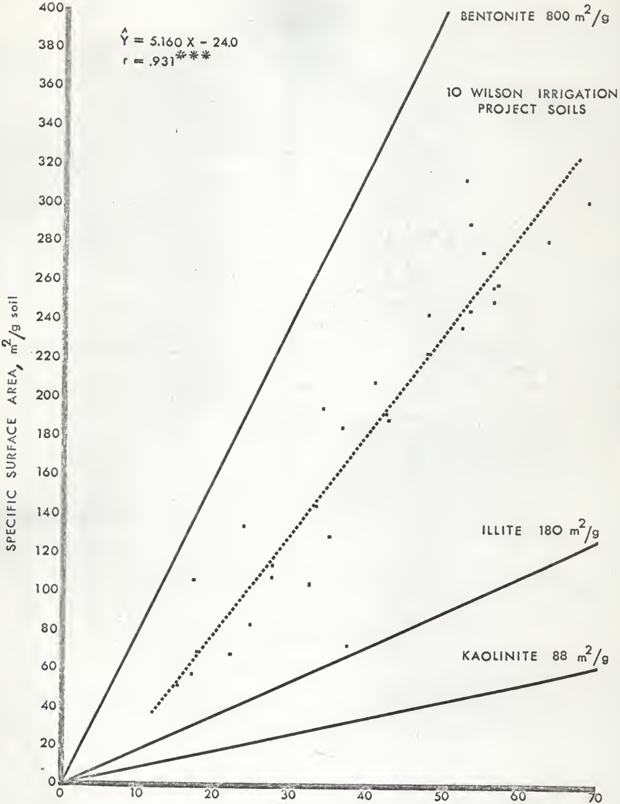

Fig. 4. The regression between specific surface area and percent clay for each depth increment of ten selected soils in the Wilson Irrigation Project. Theoretical regression curves are included for Bentonite, Illite and Kaolinite.

kaolinite clays are also shown in Figure 4 to show the relative position of Wilson Project soils with respect to these clays. It is evident that a mixture of clays is present in the soils. For example, the third depth in soil 52 contained 15.2 percent clay and exposed 51.6 m^2/g of surface area. Only 6.5 percent of a pure montmorillonite clay would expose the same quantity of surface area. The topsoil of soil 55 contained 53.6 percent clay and exposed 249 m^2/g surface area. Approximately 31 percent of pure montmorillonite would expose 249 m^2/g surface area. Therefore, appreciable quantities of clays other than montmorillonite must be present in these soils.

Surface charge density was found to be negatively correlated with percent clay (Figure 5). The correlation coefficient of -.858 was significant at the .001 level. The graph indicates that soils with higher clay content, will have a lower surface charge per unit area. It should be noted that the organic matter was removed prior to the surface area determination but was not removed for the cation exchange capacity determination.

The dispersibility of colloidal clays has been related to the zeta potential. The higher the zeta potential the greater the tendency toward dispersion. According to Baver (2) the sodium cation is the most highly hydrated ion, except for lithium, and thus has a high zeta potential. Sodium has a hydrated radius of 7.90 A. A hydrated sodium ion would occupy about 250 A^2 of surface on the clay if the ion is assumed to occupy the same area as a square having one side equal to the hydrated diameter.

Grim (6) points out the fact that montmorillonite with a cation-exchange capacity of 100 me/100 g would have a total surface area of about 160 A^2 per exchange site. Obviously 160 A^2 per exchange site is short of

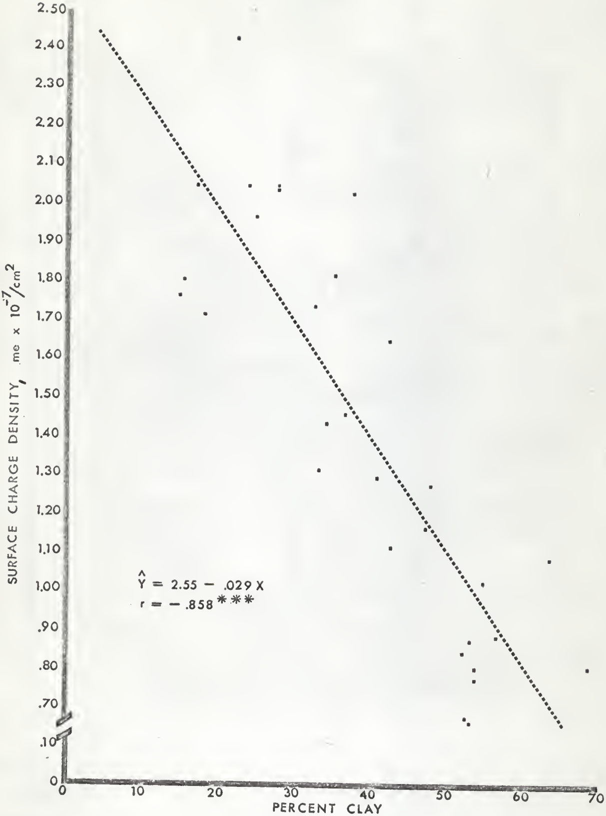

Fig. 5. The regression of surface charge density and percent clay for each depth increment of ten selected soils in the Wilson Irrigation Project.

the required area of 250 A^2 for one hydrated sodium cation. Thus, as more and more sodium is adsorbed, it might be expected that the sodium would be packed more and more loosely against the clay surface and that zeta potential and dispersion would increase.

If this concept is correct, soils occurring along the regression curve in Figure 5 at low clay content and high surface charge density, should have a higher zeta potential than soils where the surface charge density is lower. For example, the surface area per exchange site varied from 68.59 A^2 to 251.26 A^2 for a surface charge density of 2.42 and 0.66 me $\times 10^{-7}/cm^2$, respectively. These calculations are based upon the extreme values of surface charge density listed in Table 4. In the latter example slightly more surface area was present than the required area of 250 A^2 per hydrated sodium cation.

The experimental data, however, does not support the concept that dispersibility might be related to surface charge density. As noted previously, soils 81, 95 and 106 were extremely susceptable to dispersion even at low levels of exchangeable sodium. Soil 81, however, has a high surface charge density while soils 95 and 106 generally have a low surface charge density. Soil 41 and the first two depth increments in soil 52 have a high surface charge density but were among those soil samples showing the least amount of dispersion (Figures 9 and 10). Thus, severity of soil dispersion does not seem to be related to surface charge density alone.

Table 6 lists the DF_{min} and DF_{max} values used to calculate the DP for each profile depth increment. The DF_{max} values were calculated from the percent clay data supplied by the Bureau of Reclamation (4). The DF_{min} values ranged from .0640 to .8160. In seven out of ten profiles the DF_{min}

Table 6. The average minimum (DF_{min}) and maximum (DF_{max}) dispersion factors calculated for 10 selected soils in the Wilson Irrigation Project.

Soil Number	Soil Depth (inches)	Average DF_{min}	Average DF_{max}*
1	0-5	.2240	5.640
	5-12	.3160	6.840
	20-29	.3520	6.320
41	0-5	.1320	2.740
	5-8	.1520	2.740
	19-23	.2160	3.240
52	0-6	.1200	2.460
	10-16	.0880	1.680
	24-31	.1600	1.520
55	0-3	.3040	5.360
	3-7	.2560	5.360
	7-31	.8160	5.460
65	0-9	.2160	5.300
	24-34	.1760	4.760
	34-45	.2400	4.250
78	0-6	.1640	3.480
	28-38	.0640	3.640
	38-46	.1560	3.280
81	0-12	.1440	2.200
	12-30	.1400	1.780
	36-48	.1120	3.730
85	0-12	.1560	4.220
	12-24	.0880	3.380
	24-40	.1360	1.720
95	0-10	.1400	2.360
	10-20	.5280	4.760
	24-36	.4400	4.060
106	0-9	.2840	5.200
	12-24	.4400	5.240
	24-36	.5600	5.280

*Average DF_{max} is calculated from data supplied by the Bureau of Reclamation.

values in the deepest horizon exceeded that in the topsoil depth. This characteristic suggests that organic matter may help to minimize dispersive activity in the topsoil while it becomes less influential at lower depths.

The dispersion percentage calculated from equation (2) shows the net dispersion due to exchangeable sodium since the value of the DF_{min} is subtracted from both numerator and denominator.

Chemical analyses of extractable sodium occurring naturally in these ten profiles revealed very low levels of soluble and exchangeable sodium. The extractable sodium varied from .92 to .30 me/100 g as shown in Table 3. Since these constitute low values for extractable sodium, exchangeable sodium was not determined. Even if all extractable sodium present was assumed to be exchangeable sodium, the highest value (.92) would give an ESP of 3.5 while the lowest (.30) would yield an ESP of 1.4.

The cation-exchange capacity showed some degree of variation among the locations selected for investigation (Table 3). The cation-exchange capacity varied from 9.3 to 31.2 me/100 g soil and averaged 21.5 me/100 g soil.

It would be expected that different soils would adsorb different amounts of exchangeable sodium from a solution of a given SAR value. Moreover, the data show that this was true even within the horizons of the same profile. Figure 6 shows a comparison between the exchangeable sodium adsorbed by the topsoils of soils 81, 95 and 106 after treatment with solutions of various sodium adsorption ratios. The ESP vs. SAR curves in Figure 6 are typical of the range of ESP levels obtained for the entire set of soils. In the topsoil of soil 81 ESP increased from 4.6 to 13.4 as the SAR increased from 7 to 55; in the topsoil of 106

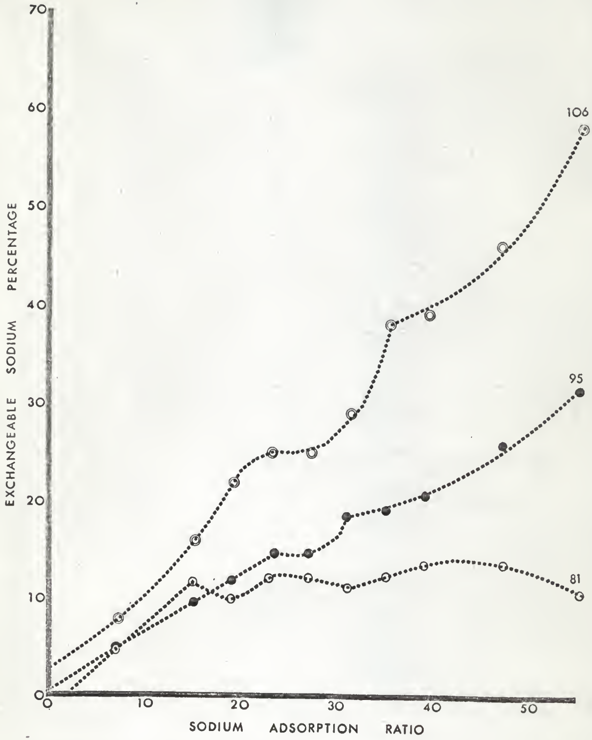

Fig. 6. Exchangeable sodium percentages obtained in the first depth increment of soils 81, 95 and 106 after three washings with 10 salt solutions containing 200 me/liter total soluble salts at different sodium adsorption ratios.

the ESP values exceeded the SAR value in several instances. Soils 81 and 106 represent the extremes in the adsorption of sodium by the soils whereas soil 95 more nearly represents the median conditions encountered.

A knowledge of chemical constituents in water has been used to predict ESP from an equilibrium between soluble and exchangeable cations (15). Gapon's equation is commonly used for this purpose. Since it is applicable to equilibria between mono and divalent cations, this equation is especially useful, particularly in predicting the amount of exchangeable sodium expected to accumulate in soils irrigated with water containing known concentrations of sodium, calcium and magnesium. The following form of Gapon's equation is often utilized in water quality studies (9):

$$ESP_g = \frac{100\ K_g\ Na}{\sqrt{\frac{TSC - Na}{2}} + K_g\ Na} \qquad (3)$$

where ESP_g is Gapon's estimate of ESP, TSC and Na are the total soluble cations and sodium concentration in irrigation water expressed in milliequivalents per liter and K_g is Gapon's proportionality factor. Since known quantities of sodium and calcium were present in the solutions used and since ESP can be determined through chemical analysis of treated soil samples, Gapon's proportionality factor can be calculated. The value of K_g was calculated from the following equation for the topsoils of each profile studied:

$$K_{gme} = \sqrt{\frac{50(100 - SSP)}{(SSP)^2\ (TSC)}}\ \frac{ESP}{(100 - ESP)} \qquad (4)$$

where SSP and TSC are soluble sodium percentage and total soluble cations and K_{gme} is Gapon's proportionality factor calculated from cation concentrations expressed in milliequivalents per liter.

Theoretically, the K_g values for a given soil or horizon should remain constant over the range of SAR values used. Nevertheless, calculations of K_{gme} using equation (4) indicate that a wide range of K_{gme} values characterize the topsoils. This attribute is illustrated in Table 14 of the appendix for soil 65. The K_g values vary from a high of .053 to a low of .012 for a SAR of 7 and 55, respectively, i.e. a low SAR gives a high K_g value while the converse is true at higher SAR values.

Gapon's K_g factor was also calculated by using the ionic activities of the cations concerned instead of the concentration in milliequivalents. Equation (3) can be rearranged and reduced to:

$$K_{ga} = \frac{ESP\sqrt{\frac{f_{Ca}\,[Ca]}{2}}}{(100 - ESP)\, f_{Na}\,[Na]} \qquad (5)$$

where f represents the activity coefficient of the respective cations. The activities (a) are calculated by multiplying the cation concentration $[Ca]$ or $[Na]$ in me/liter by the specific activity coefficient f_{Ca} or f_{Na}, respectively. Proportionality factors were calculated for each horizon and treatment using equation (5).

The activity coefficients were calculated using Debye and Huckel's second approximation (5):

$$-\log f = \frac{0.51\, z_i^2\sqrt{\mu}}{1 + 1.5\sqrt{\mu}} \qquad (6)$$

where z_i is the valence of a specific ion and μ is the ionic strength. Ionic strength was calculated from the following equation:

$$\mu = 1/2 \sum c_i z_i^2 \qquad (7)$$

where μ is equal to one half the sum of the products of the molar concentration (c_i) times the squared valence (z_i^2) of each ion species. The variations in calcium and sodium activity over the range of calcium and sodium concentrations used are given in Tables 7 and 8, respectively.

Proportionality factors K_{gme} and K_{ga} are listed in Tables 10 through 19 in the appendix. The K_{ga} values were much more constant than the K_{gme} values. Figure 7 illustrates the relative difference between K_{ga} and K_{gme} in the topsoils of 41 and 106. For example, in soil 41 K_{ga} values vary from .004 to .008, a twofold increase, whereas K_{gme} values extended from .009 to .034, nearly a fourfold increase. The K_{ga} in soil 106, although not as constant as in soil 41, ranged from .008 to .018 while K_{gme} counterparts extend over a wider scope, .020 to .042. The remainder of the topsoils depict similar differences between K_{ga} and K_{gme}.

Mean K_{ga} values ranged from .003 to .017 for all depth increments. Mean K_{ga} factors in soils 41, 52, 78, 81, 85 and 95 remained essentially constant throughout the profile. In no case did the mean K_{ga} values vary more than .003 in these six soils. However, the mean K_{ga} factors did not remain constant throughout a given profile for all soils. Soils 1, 55, 65, and 106 substantiate this characteristic deviation among mean K_{ga} values for the horizons sampled. For example, soil 1 has mean K_{ga} factors equal to .014 in the first two horizons while the mean K_{ga} decreased to .007 in the third horizon.

Correct evaluation of soil and water quality is essential to a permanent, productive irrigation agriculture. Since the balance between

Table 7. Values of ionic strength (μ), activity coefficient of calcium (f_{Ca}) and calcium activity (f_{Ca} [Ca]) calculated from molar concentrations of calcium chloride at each sodium adsorption ratio (SAR) level.

SAR	me Ca/l	M $CaCl_2$	Ionic Strength μ	f_{Ca}	f_{Ca} [Ca]
7	141.0	.0705	.2705	.2555	36.0255
15	96.0	.0480	.2480	.2613	25.0848
19	80.0	.0400	.2400	.2652	21.2160
23	67.0	.0335	.2335	.2696	18.0632
27	57.0	.0285	.2285	.2696	15.3672
31	48.0	.0240	.2240	.2739	13.1472
35	41.3	.0206	.2205	.2739	11.3121
39	36.0	.0180	.2180	.2739	9.8604
47	27.1	.0136	.2137	.2784	7.5446
55	21.2	.0106	.2107	.2784	5.9021

Table 8. Values of ionic strength (μ), activity coefficient of sodium (f_{Na}) and sodium activity ($f_{Na}[Na]$) calculated from molar concentrations of sodium chloride at each sodium adsorption ratio (SAR) level.

SAR	me Na/l	M NaCl	Ionic Strength μ	f_{Na}	$f_{Na}[Na]$
7	59.0	.0590	.2705	.8109	47.8431
15	104.0	.1040	.2480	.7150	74.3824
19	120.0	.1200	.2400	.7178	86.1360
23	133.0	.1330	.2335	.7206	95.8398
27	143.0	.1430	.2285	.7206	103.8180
31	152.0	.1520	.2240	.7235	109.9720
35	158.7	.1587	.2205	.7235	114.8194
39	164.0	.1640	.2180	.7235	118.6540
47	172.9	.1729	.2137	.7264	125.5946
55	178.9	.1789	.2107	.7264	129.9530

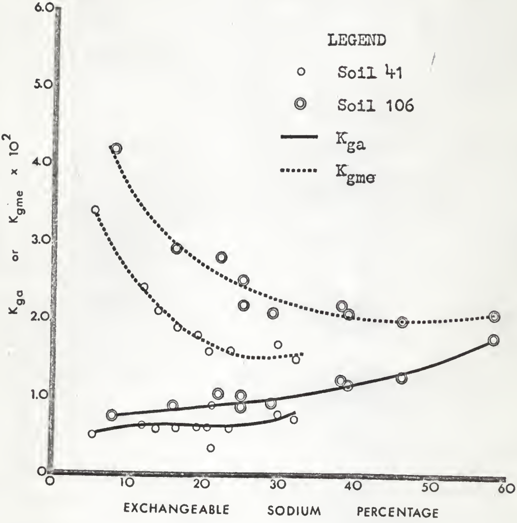

Fig. 7. A comparison between two methods of calculating Gapon's proportionality factors K_{ga} and K_{gme} using ionic activities (a) and milliequivalent concentrations (me) at different levels of exchangeable sodium in the topsoil of soils 41 and 106.

exchangeable calcium and sodium play the dominate role in the maintenance of adequate permeability, it is important to be able to predict the ESP which will result from a given irrigation water. Based on the above data, predictions of ESP would be much more reliable using K_{ga} than by using K_{gme} values in Gapon's equation.

In the preliminary work of this study the aggregates formed from the air-dry cores still retained soluble salts. The aggregates from the Wilson Project soils were washed free of salts with alcohol. In either case the electrical conductivity of the soil suspensions in the shaking cylinder was less than 20 mmhos/cm. Although the suspensions in the first case were low in soluble salts, the salt level within the aggregates themselves may have been sufficient to suppress dispersion. Diffusion, however, probably brought the aggregates to a salt free or alkali state. Therefore, the dispersion results obtained in both the preliminary study and for the Wilson Project soils represent a non-saline condition. Where the ESP was high, a non-saline-alkali condition was created.

The three levels of water quality assumed for the Wilson reservoir, e.g. 32 me/liter TSC with a SSP of 66 percent, 20 me/liter TSC with a SSP of 57 percent, and 8 me/liter TSC with a SSP of 38 percent, would have SAR values of 9.06, 5.51 and 1.94 for high, intermediate and low contents of total soluble salts, respectively. The use of water qualities of these SAR values for some soils in the Wilson Irrigation Project appears to be questionable.

Using Figure 6 it appears that the maximum ESP, which would result after applying irrigation waters of the lowest quality, approximate

6, 6 and 10 percent for soils 81, 95 and 106, respectively. These ESP values are not normally thought of as being hazardous. However, the DP vs. ESP curves for these soils shown in Figures 14, 16 and 17 indicate that dispersion increases rapidly with increasing ESP. Consequently, once dispersive activity commences, the rate of dispersion increases rapidly with just a small increase in exchangeable sodium.

Although the third horizon in soil 52 showed severe dispersion after reaching its critical point, dispersion is not expected to be serious when exchangeable sodium is low. The maximum exchangeable sodium percentage and dispersion percentage, which would result in this horizon subsequent to irrigation with water of the highest salt content assumed for the Wilson reservoir, approximate 8.5 and 3.0 percent, respectively.

Based on this study soils 1, 41, 55, 65, 78 and 85 and their respective horizons are not expected to develop serious dispersion problems subsequent to irrigation with water from the Wilson reservoir. In any event the exchangeable sodium and the dispersion percentage would not likely be greater than 18 and 8 percent, respectively.

SUMMARY AND CONCLUSIONS

The principal objectives of this investigation were to develop a procedure for the quantitative determination of soil dispersion, to estimate the critical exchangeable sodium percentage for specific soils in the Wilson Irrigation Project and to predict the rate of dispersion at various exchangeable sodium percentage levels.

Three profile depth increments were acquired from ten locations in the Wilson Irrigation Project. The soils developed from alluvial parent materials in the Saline River valley in Lincoln, Ottawa and Saline counties. The soils investigated were generally high in clay content varying in textures from loams to clays.

Each soil sample was washed with ten salt solutions containing 200 me/liter of soluble sodium and calcium chloride. The sodium adsorption ratio of the wash solutions was varied from 7 to 55 in order to obtain soil samples with varying levels of exchangeable sodium.

The net effect of exchangeable sodium on dispersion was determined using the pipette method of mechanical analysis to measure the amount of clay dispersed from artificial aggregates. The aggregates were prepared by drying and crushing the soil after it had been treated with a salt solution of a given sodium adsorption ratio. Dispersion was accomplished by shaking ten grams of 1.0 to 2.0 mm aggregates in 1000 ml of water for ten minutes. Under these conditions dispersion percentages ranged from 0 to nearly 100.

A plot of dispersion percentage vs. exchangeable sodium percentage revealed definite critical points for some soils as evidenced by a break in the curve. The amount of dispersion occurring increased rapidly above the critical point. The exchangeable sodium percentage ranged from 9.2

to 40.6 and the dispersion percentages ranged from .2 to 32.4 percent at the critical point. The exchangeable sodium percent was 20.2 and the dispersion percentage was 7.8 at the mean of the critical points. However, in over one-third of the horizons a distinguishable critical point was not encountered.

The rate of dispersion at various ESP levels can be compared between soils by evaluating the slope value occurring in the linear regression equations. Soils 81, 95 and 106 were very susceptable to dispersion as indicated by the slope of the regression curves. The initial regression curves in these three soils have a mean slope of 1.236. For the other soils with a definite critical point the mean slope of that portion of the curve above the critical point was only 1.307. Hence the initial rate of dispersion in soils 81, 95 and 106 almost equalled the rate of dispersion in soils which had already reached the critical point in the regression curves.

The mean proportionality factors calculated from ionic activities varied from .003 in the topsoil of soil 81 to .016 in the topsoil of soil 55. The maximum variation encountered among proportionality factors based upon ionic activities for all exchangeable sodium levels in any one horizon was .0140.

The mean proportionality factor for the topsoils based upon milliequivalent concentration varied from .015 to .030. As a result these proportionality factors are nearly twice those calculated from ionic activities. The maximum variation encountered among proportionality factors based upon milliequivalent concentrations for all exchangeable sodium levels in any one horizon was .041. This variation is much greater than the variation encountered when ionic activities were used to compute the proportionality factor. Consequently, predictions of exchangeable sodium percentage would be much more reliable using ionic activities rather than milliequivalent concentrations in Gapon's equation.

Chemical analysis for extractable sodium in the untreated samples indicated that very low levels of soluble and exchangeable sodium were present.

The regressions between specific surface area vs. percent clay and surface charge density vs. percent clay were determined. The correlation coefficients were .931 and -.858, respectively, and both were significant at the .001 level.

Calculations based on the size of the hydrated sodium ion and the surface area per exchange site suggested that dispersion might be high where the surface charge density was high. The experimental data did not support this conclusion, however. The surface area per exchange site varied from 68.6 to 251.3 A^2, yet there was no clear-cut effect on dispersion.

The three levels of water quality assumed for the Wilson reservoir would have sodium adsorption ratios of 1.94, 5.51 and 9.06 for low, intermediate and high contents of total soluble salts, respectively. The use of waters high and intermediate in salt content is questionable for some Wilson Irrigation Project soils. Soils 81, 95 and 106 portrayed significant dispersion hazards even when exchangeable sodium was less than ten percent. Therefore, from laboratory data obtained in this investigation and water quality assumed for the Wilson reservoir, soils 81, 95 and 106 definitely should not be managed under irrigation agriculture.

Although the third horizon in soil 52 showed severe dispersion after reaching its critical point, dispersion is not expected to be serious at low exchangeable sodium. The maximum exchangeable sodium percentage and dispersion percentage, which would result in this horizon subsequent to irrigation with the highest salt content assumed for water from the Wilson reservoir, approximate 8.5 and 3.0 percent, respectively.

Based on the critical points found in this study, soils 1, 41, 55, 65, 78 and 85 would not be expected to develop serious dispersion problems subsequent to irrigation using water from the Wilson reservoir. In any event the dispersion percentage in these soils would not be expected to be greater than 8 percent and the exchangeable sodium greater than 18 percent.

The limitations of the data should be recognized since interpretations herein are based only on laboratory investigations. It was assumed that the critical points and the slopes of the lines in the dispersion vs. exchangeable sodium curves are important in assessing the hazard due to using high sodium waters. However, the effect of a given degree of dispersion upon permeability, aeration or other physical properties of the soil was not investigated. Likewise, it was not verified that exchangeable sodium percentages obtained represent a true equilibrium between exchangeable and soluble ions. In addition artificial, salt-free aggregates were used in measuring dispersion. These limitations should be kept in mind in using and interpreting the data presented.

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APPENDIX

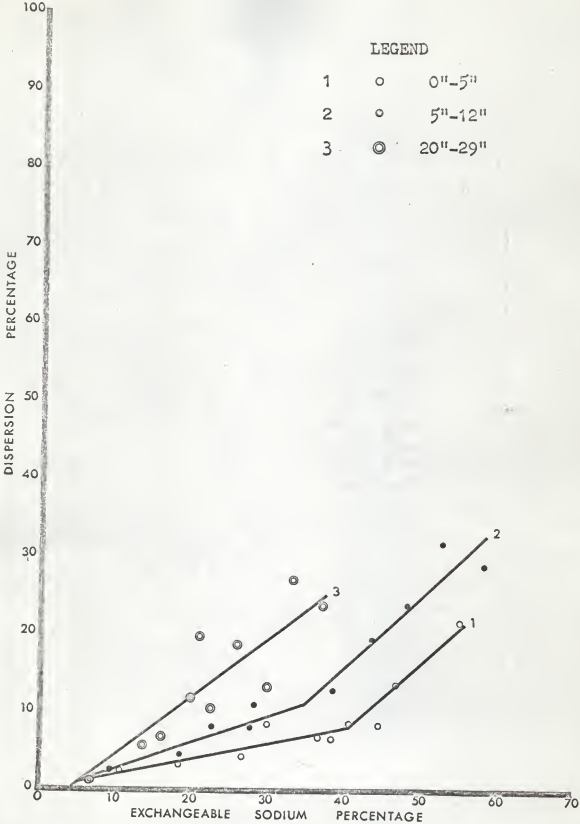

Fig. 8. The regression between dispersion percentage and exchangeable sodium percentage in soil number I at three different depth increments.

Fig. 9. The regression between dispersion percentage and exchangeable sodium percentage in soil number 41 at three different depth increments.

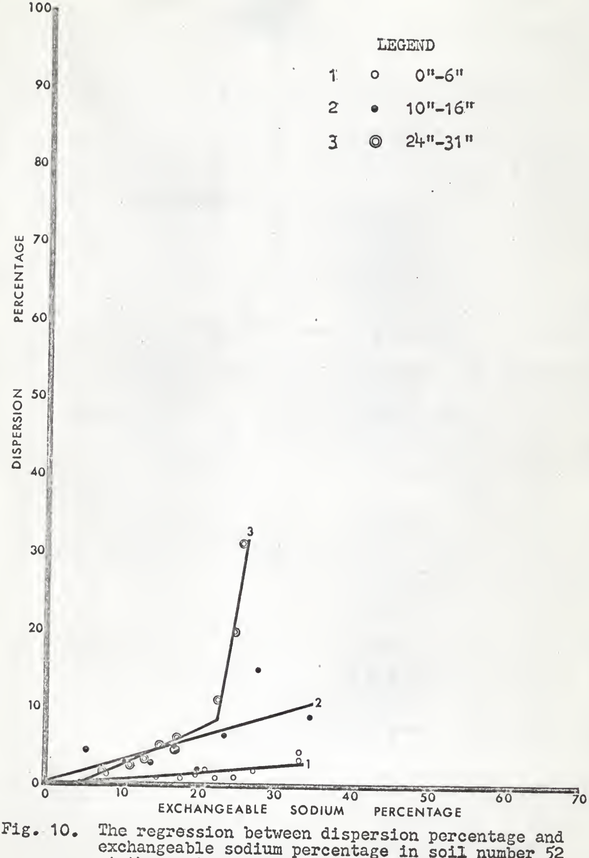

Fig. 10. The regression between dispersion percentage and exchangeable sodium percentage in soil number 52 at three different depth increments.

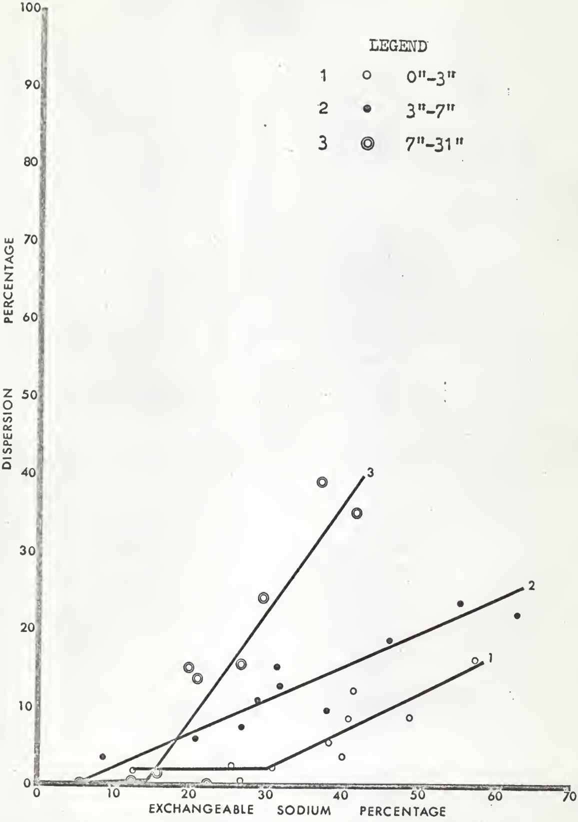

Fig. 11. The regression between dispersion percentage and exchangeable sodium percentage in soil number 55 at three different depth increments.

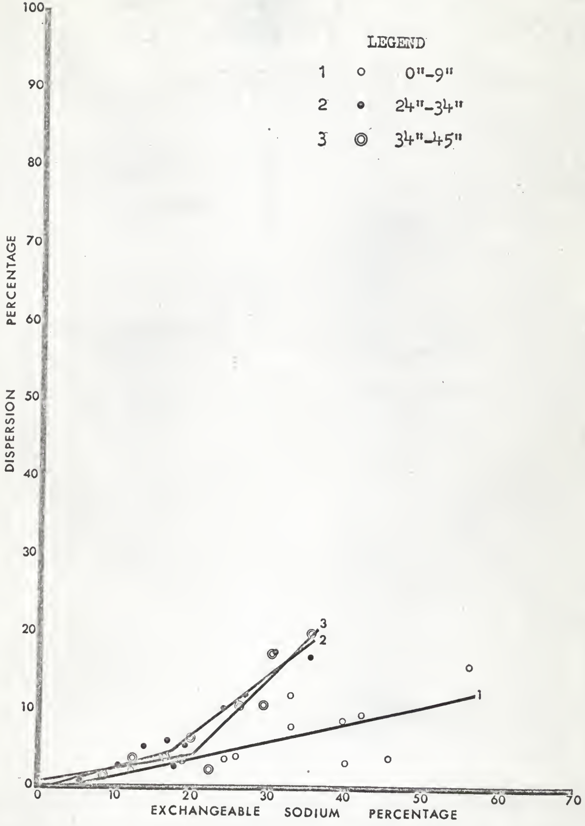

Fig. 12. The regression between dispersion percentage and exchangeable sodium percentage in soil number 65 at three different depth increments.

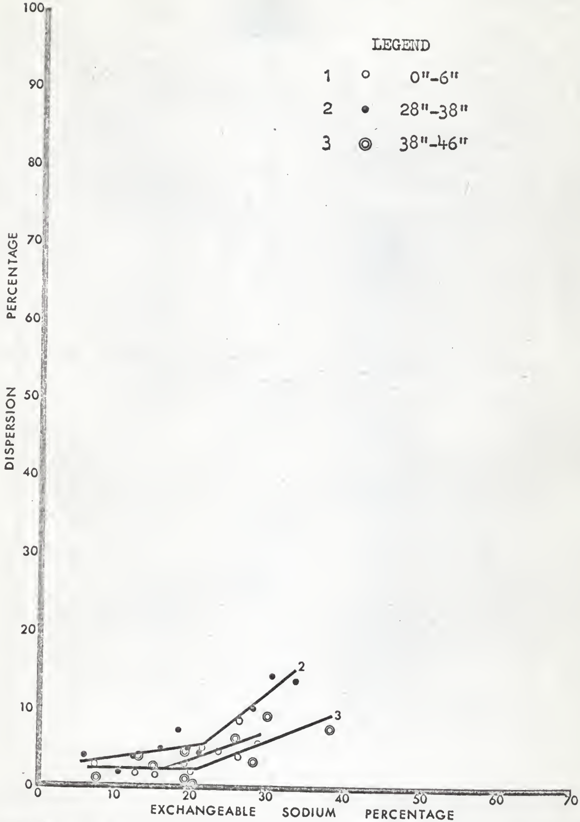

Fig. 13. The regression between dispersion percentage and exchangeable sodium percentage in soil number 78 at three different depth increments.

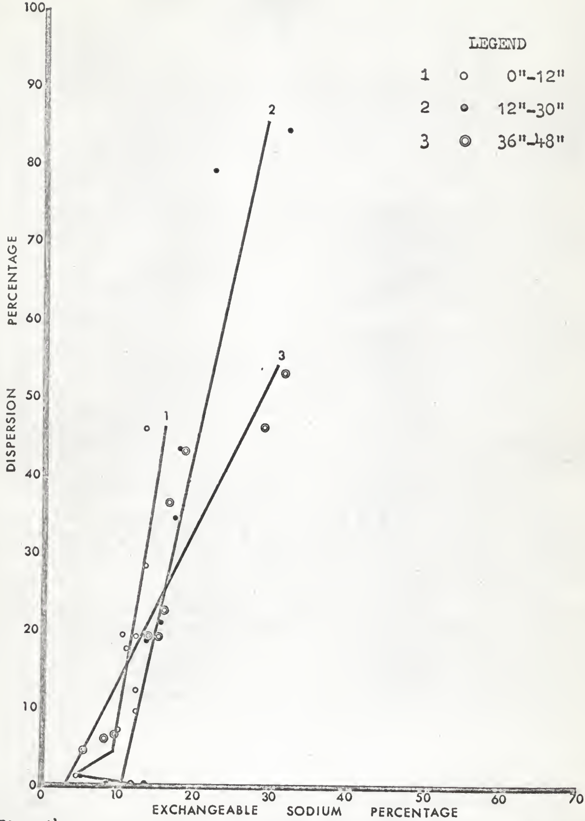

Fig. 14. The regression between dispersion percentage and exchangeable sodium percentage in soil number 81 at three different depth increments.

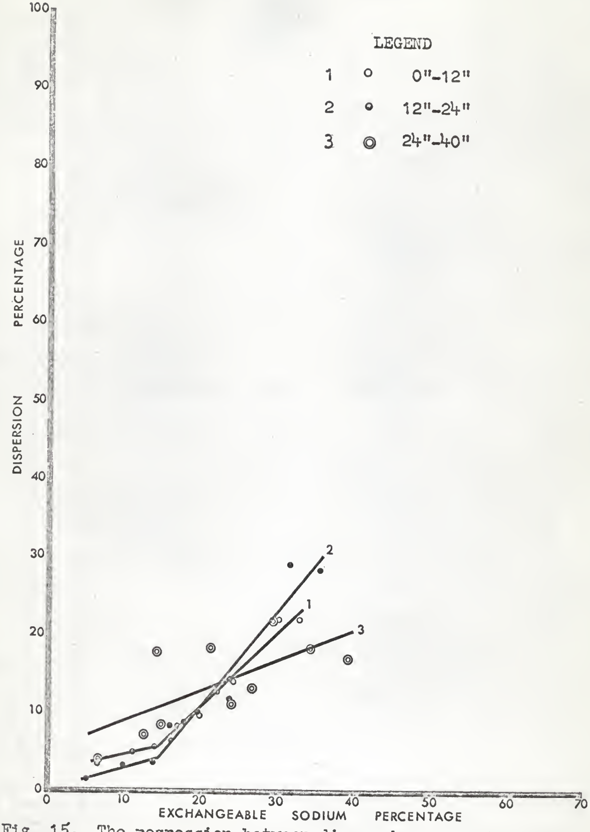

Fig. 15. The regression between dispersion percentage and exchangeable sodium percentage in soil number 85 at three different depth increments.

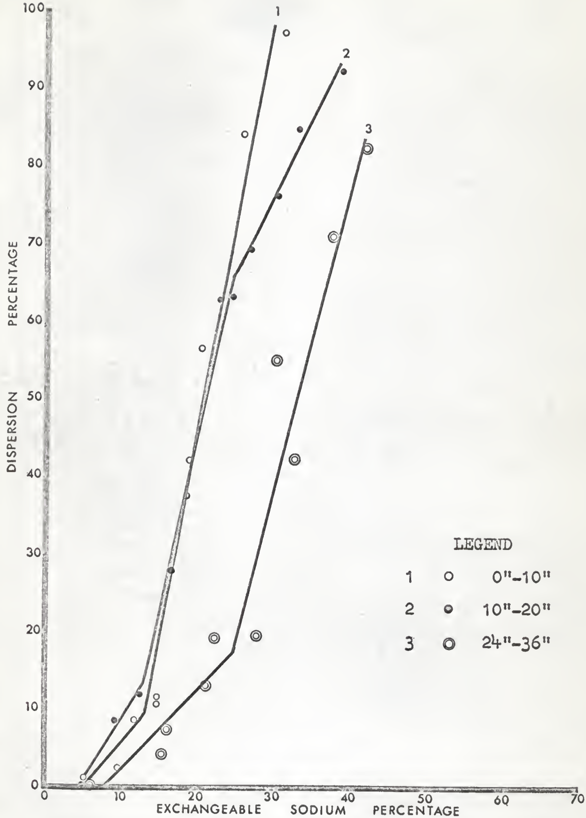

Fig. 16. The regression between dispersion percentage and exchangeable sodium percentage in soil number 95 at three different depth increments.

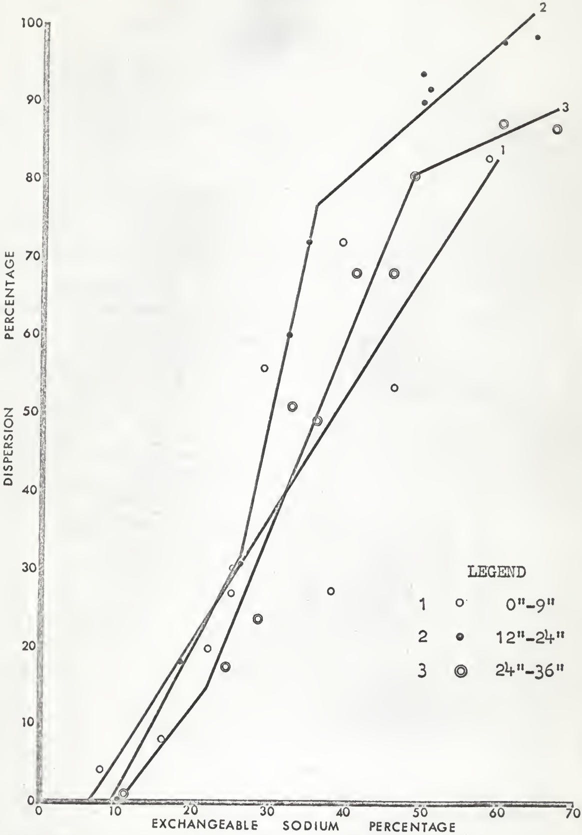

Fig. 17. The regression between dispersion percentage and exchangeable sodium percentage in soil number 106 at three different depth increments.

The legal descriptions of the soil sites sampled in the Wilson Irrigation Project are abbreviated as follows: the first number is the township, the second gives the range, the third the section, and the letters give the quarter section (160 acres), quarter quarter section (40 acres) and quarter quarter quarter section (10 acres), respectively. For example the legal description for soil number K2WL1 is designated as 12-6-19 abb, i.e. township 12, range 6, section 19 and quarter section a, quarter quarter section b and quarter quarter quarter section b, respectively.

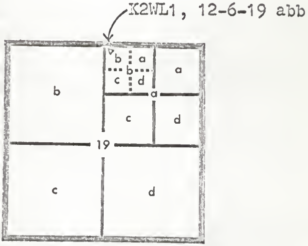

Fig. 18. The legal description for soil number K2WL1 is the NW¼, NW¼, NE¼ Sec. 19, T12S, R6W. This legal description is abbreviated in the text as follows: 12-6-19 abb.

Table 9. Profile descriptions of 10 selected soils in the Wilson Irrigation Project*.

Profile No. K2WL1 Lincoln County

Legal Description: 12-6-19 abb
Site Location: 163 ft. south of sec. road and 50 ft. east of half sec. boundry.
Surface Drainage: inadequate

0"-5"	Heavy silty clay loam, very dark gray, weak sub-angular blocky-fine, calcareous, organic, many small roots, free drainage (2-4).
5"-12"	Silty clay, very dark gray brown, weak sub-angular blocky-fine, calcareous, organic, few small roots, imperfect drainage (10-12).
20"-29"	Silty clay, dark brown, weak sub-angular blocky-fine, calcareous, organic, few small roots, imperfect drainage (24-26).

Note: Lime concretions occur at about 36 inches.

Profile No. K3WL41 Lincoln County

Legal Description: 12-9-9 ccb
Site Location: level 3, 375 ft. north and 115 ft. east of railroad tract.
Surface Drainage: adequate
Parent Material: alluvium

0"-10"	Clay loam, very dark gray brown, weakly granular fine, friable, calcareous, few small roots, free drainage (5-7).
19"-32"	Silty clay loam, yellowish brown, weakly granular, friable, calcareous, few small roots, free drainage (25-37).

Profile No. K3WL52 Lincoln County

Legal Description: 12-8-6 dad
Site Location: level 3, 50 ft. west of sec. line and 100 ft. south of Union Pacific railroad, or 50 ft. south of observation well.
Surface Drainage: adequate
Parent Material: alluvium

Table 9. Continued

0"-11" Silt loam, dark gray brown, weakly granular fine, friable, calcareous, few small roots, free drainage (6-8).

11"-50" Silt loam, brown, weakly granular fine, calcareous, few small roots, free drainage (31-33).

Note: Worm casts were present.

Profile No. K3WL55 Lincoln County

Legal Description: 12-8-2 bbc
Site Location: level 3, 1300 ft. south of sec. cor. and 130 ft. east of county road.
Surface Drainage: inadequate
Parent Material: alluvium

0"-20" Clay, very dark brown, weakly granular to subangular blocky fine, calcareous, few small roots, free drainage (9-11).

20"-45" Clay, dark gray brown, stable subangular blocky medium, calcareous, few small roots, imperfect drainage, moderate mottling iron stain (34-36).

Profile No. K3WL65 Lincoln County

Legal Description: 12-7-13 dad
Site Location: level 3, 130 ft. west of north-south road and 500 ft. north of stone bridge.
Surface Drainage: inadequate
Parent Material: alluvium

0"-22" Clay-silty clay, very dark brown, weakly granular blocky to subangular blocky stable fine, firm, calcareous, many medium roots, free drainage (12-14).

22"-36" Silty clay, very dark gray brown, stable subangular blocky coarse, firm, calcareous, many small roots, free drainage, slight reddish mottling (28-30).

36"-45" Silty clay, yellowish brown, stable blocky medium, firm, calcareous, many small roots, imperfect drainage, moderate reddish mottling (40-42).

Note: The land use is in native grass pasture.

Table 9. Continued

Profile No. K3WL78 Ottawa County

Legal Description: 12-5-21 aad
Site Location: level 3, directly across road from irrigation well, 80 ft. west centerline of road and 20 ft. north of 1/4 line.
Surface Drainage: adequate
Parent Material: alluvium

0"-20"	Silty clay loam, dark brown, weakly granular fine, friable, calcareous, few small roots, free drainage (9-11).
20"-34"	Silty clay loam, stable sub-ang. blocky fine, friable, calcareous, few small roots, free drainage (26-28).
34"-48"	Silty clay loam, yellowish brown, weakly sub-ang. blocky to granular fine, friable, calcareous, few small roots, free drainage (40-42).

Profile No. K3WL81 Ottawa County

Legal Description: 12-4-20 cbc
Site Location: level 4, 100 ft. east of north-south section line county road, 1,600 ft. north of section corner.
Surface Drainage: adequate
Parent Material: alluvium

0"-12"	Loam, very dark gray brown, weakly sub-ang. blocky fine, friable, non-calcareous, few small roots, free drainage (6-8).
12"-30"	Silt loam, dark yellowish brown, weakly sub-ang. blocky to granular fine, friable, non-calcareous, few small roots, free drainage (20-22).
30"-45"	Silty clay loam, very dark brown, weakly sub-ang. blocky medium, friable, non-calcareous, few small roots, free drainage (38-40).
45"-68"	Silty clay, dark yellowish brown, weakly to sub-ang. blocky coarse, friable plastic, non-calcareous, few small roots, free drainage (56-58).

Note: A buried soil occurs from 30"-45" depth.

Table 9. Continued

Profile No. K3WL85 Ottawa County

Legal Description: 12-4-30 dad
Site Location: level 3, 150 ft. west of section line and 50 ft. north of county road.
Surface Drainage: adequate
Parent Material: alluvium

0"-20" Silty clay, very dark gray brown, stable sub-ang. blocky medium, calcareous, few small roots, free drainage (9-11).

20"-60" Silt loam, yellowish brown, weakly granular fine, calcareous, free small roots, free drainage (39-41).

Profile No. K3WL95 Saline County

Legal Description: 13-4-12 baa
Site Location: level 3, 50 ft. west of observation well.

Surface Drainage: adequate
Parent Material: local alluvium

Soil Type: Berg silt loam, 0-2% slope, (Bm--Saline Co. Soil Survey).

0"-10" Silt loam, very dark gray brown, weakly sub-ang. blocky fine, non-calcareous, few small roots, free drainage (5-7).

10"-24" Silty clay, very dark gray brown, stable sub-ang. blocky medium, non-calcareous, few small roots, free drainage, slight reddish brown mottling (20-22).

24"-40" Silty clay, dark gray brown, stable sub-ang. blocky coarse, firm, calcareous, few small roots, free drainage, slight reddish brown mottling (31-33).

Profile No. K3WL106 Saline County

Legal Description: 13-3-21 cbb
Site Location: level 3, 100 ft. south of centerline county road directly south of observation well.

Table 9. Concluded.

Surface Drainage: adequate
Parent Material: alluvium

Soil Type: Sutphen silty clay, 0-2% slope, (Sx--Saline Co. Soil Survey).

0"-18" Clay, black, weakly sub-ang. blocky fine, non-calcareous, few small roots, free drainage (9-11).

18"-36" Clay, very dark gray brown, weakly sub-ang. blocky medium, non-calcareous, few small roots, free drainage, moderate reddish brown mottling (26-28).

Note: Lime concretions occur at 48 inches depth.
The auger hole permeability was 0.25 inches/hour and the water table was 13.55 ft. on 5/8/63.
A platy layer occurs at 12 inches depth.

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*Information supplied by Bureau of Reclamation.

Table 10. Dispersion percentage, exchangeable sodium percentage and Gapon's proportionality factors, K_{gme} and K_{ga}, calculated for soil number 1 after washing with 10 solutions differing in sodium adsorption ratios (SAR).

Depth of Sample (inches)	SAR	Dispersion Percentage	Exchangeable Sodium Percentage	Gapon's Proportionality Factors			
				K_{gme}	mean	K_{ga}	mean
0-5	7	2.1	10.6	.049		.0105	
	15	3.1	18.1	.031		.0105	
	19	4.3	26.5	.032		.0136	
	23	8.4	29.6	.028		.0132	
	27	6.8	36.3	.028		.0154	
	31	6.6	38.0	.025		.0142	
	35	8.4	44.2	.025		.0164	
	39	13.6	46.5	.024		.0162	
	47	21.6	54.9	.023		.0188	
	55	8.6	40.3	.015	.028	.0089	.014
5-12	7	2.4	9.2			.0089	
	15	4.3	18.3			.0106	
	19	8.0	22.5			.0109	
	23	8.0	27.5			.0119	
	27	10.9	27.9			.0103	
	31	12.8	38.5			.0145	
	35	19.3	43.3			.0158	
	39	23.8	47.9			.0171	
	47	31.7	52.5			.0170	
	55	28.8	57.9			.0182	.014
20-29	7	1.2	6.6			.0062	
	15	5.6	13.5			.0074	
	19	6.7	15.8			.0071	
	23	11.8	19.8			.0077	
	27	10.4	22.4			.0076	
	31	13.3	29.7			.0098	
	35	18.5	25.7			.0071	
	39	19.6	20.8			.0049	
	47	26.9	33.0			.0076	
	55	23.7	37.0			.0077	.007

Table 11. Dispersion percentage, exchangeable sodium percentage and Gapon's proportionality factors, K_{gme} and K_{ga}, calculated for soil number 41 after washing with 10 solutions differing in sodium adsorption ratios (SAR).

Depth of Sample (inches)	SAR	Dispersion Percentage	Exchangeable Sodium Percentage	Gapon's Proportionality Factors			
				K_{gme}	mean	K_{ga}	mean
0-5	7	0.8	5.5	.034		.0051	
	15	0.8	11.9	.024		.0064	
	19	0.8	13.8	.021		.0060	
	23	0.6	16.5	.019		.0062	
	27	0.0	19.3	.018		.0063	
	31	2.6	20.6	.016		.0060	
	35	0.8	23.4	.016		.0063	
	39	2.0	29.8	.017		.0079	
	47	3.8	32.1	.015		.0073	
	55	2.9	21.1	.009	.019	.0035	.006
5-8	7	1.2	4.3			.0039	
	15	0.3	7.8			.0040	
	19	0.3	9.9			.0041	
	23	1.5	9.5			.0032	
	27	2.0	15.1			.0047	
	31	3.1	18.1			.0051	
	35	3.7	18.1			.0045	
	39	4.0	21.1			.0050	
	47	8.3	25.9			.0053	
	55	5.6	28.4			.0052	.004
19-23	7	1.3	5.6			.0052	
	15	1.9	10.0			.0052	
	19	2.1	13.3			.0058	
	23	2.6	12.8			.0046	
	27	3.4	15.6			.0049	
	31	2.6	16.7			.0046	
	35	5.8	22.8			.0061	
	39	7.0	23.3			.0056	
	47	7.1	27.8			.0059	
	55	8.7	33.3			.0066	.005

Table 12. Dispersion percentage, exchangeable sodium percentage and Gapon's proportionality factors, K_{gme} and K_{ga}, calculated for soil number 52 after washing with 10 solutions differing in sodium adsorption ratios (SAR).

Depth of Sample (inches)	SAR	Dispersion Percentage	Exchangeable Sodium Percentage	Gapon's Proportionality Factors			
				K_{gme}	mean	K_{ga}	mean
0-6	7	1.5	8.0	.042		.0077	
	15	1.2	14.8	.028		.0082	
	19	1.0	22.2	.028		.0108	
	23	1.2	17.6	.020		.0067	
	27	1.5	19.8	.018		.0065	
	31	1.3	24.7	.018		.0076	
	35	2.0	27.2	.017		.0077	
	39	3.2	33.3	.018		.0093	
	47	4.3	33.3	.015		.0077	
	55	2.0	21.0	.009	.021	.0035	.008
10-16	7	4.5	5.2			.0048	
	15	3.3	10.3			.0054	
	19	3.0	13.8			.0060	
	23	4.8	17.2			.0065	
	27	5.0	17.2			.0055	
	31	2.0	19.8			.0057	
	35	5.5	17.2			.0043	
	39	6.5	23.3			.0056	
	47	15.1	27.6			.0058	
	55	9.0	34.5			.0069	.006
24-31	7	1.8	7.5			.0071	
	15	2.9	10.8			.0057	
	19	3.5	12.9			.0055	
	23	5.3	15.0			.0055	
	27	6.5	17.2			.0055	
	31	4.7	17.2			.0048	
	35	6.5	17.2			.0043	
	39	11.2	22.6			.0054	
	47	20.0	24.7			.0050	
	55	31.2	25.8			.0046	.005

Table 13. Dispersion percentage, exchangeable sodium percentage and Gapon's proportionality factors, K_{gme} and K_{ga}, calculated for soil number 55 after washing with 10 solutions differing in sodium adsorption ratios (SAR).

Depth of Sample (inches)	SAR	Dispersion Percentage	Exchangeable Sodium Percentage	Gapon's Proportionality Factors			
				K_{gme}	mean	K_{ga}	mean
0-3	7	2.1	13.1	.052		.0133	
	15	1.0	27.3	.041		.0178	
	19	3.0	26.0	.031		.0133	
	23	2.6	30.6	.029		.0138	
	27	4.1	40.4	.031		.0180	
	31	9.0	41.2	.027		.0163	
	35	9.3	49.2	.028		.0200	
	39	12.6	41.9	.022		.0134	
	47	16.8	57.6	.025		.0209	
	55	6.0	38.6	.014	.030	.0083	.016
3-7	7	3.8	9.1			.0088	
	15	6.4	21.2			.0127	
	19	7.7	27.3			.0142	
	23	11.4	29.3			.0130	
	27	13.2	32.3			.0127	
	31	10.0	38.4			.0145	
	35	15.8	31.8			.0096	
	39	19.0	46.5			.0162	
	47	24.0	55.6			.0193	
	55	22.6	63.1			.0226	.014
7-31	7	0.0	6.4			.0060	
	15	0.0	12.8			.0069	
	19	1.9	16.4			.0074	
	23	15.6	20.3			.0079	
	27	14.0	21.4			.0072	
	31	0.0	22.8			.0068	
	35	15.8	27.0			.0076	
	39	24.5	29.9			.0079	
	47	39.4	37.4			.0092	
	55	35.5	42.0			.0095	.008

Table 14. Dispersion percentage, exchangeable sodium percentage and Gapon's proportionality factors, K_{gme} and K_{ga}, calculated for soil number 65 after washing with 10 solutions differing in sodium adsorption ratios (SAR).

Depth of Sample (inches)	SAR	Dispersion Percentage	Exchangeable Sodium Percentage	Gapon's Proportionality Factors			
				K_{gme}	mean	K_{ga}	mean
0-9	7	2.4	12.3	.053		.0124	
	15	3.8	24.3	.036		.0152	
	19	4.2	25.9	.031		.0132	
	23	8.3	33.0	.035		.0154	
	27	9.6	42.2	.032		.0194	
	31	8.8	39.8	.026		.0153	
	35	3.5	40.1	.023		.0138	
	39	4.1	45.8	.024		.0158	
	47	16.0	56.1	.024		.0197	
	55	12.3	33.0	.012	.030	.0065	.015
24-34	7	1.2	5.4			.0050	
	15	2.9	10.4			.0055	
	19	5.4	13.9			.0061	
	23	5.6	19.3			.0075	
	27	6.3	17.0			.0054	
	31	2.8	17.8			.0050	
	35	10.5	24.3			.0066	
	39	12.2	27.0			.0069	
	47	17.8	30.9			.0069	
	55	17.2	35.5			.0072	.006
34-45	7	1.6	8.6			.0083	
	15	4.0	16.7			.0095	
	19	3.8	12.4			.0053	
	23	6.7	20.0			.0078	
	27	3.6	19.0			.0062	
	31	2.5	22.4			.0067	
	35	10.8	26.2			.0073	
	39	11.0	29.5			.0078	
	47	17.6	30.5			.0067	
	55	20.2	35.7			.0073	.007

Table 15. Dispersion percentage, exchangeable sodium percentage and Gapon's proportionality factors, K_{gme} and K_{ga}, calculated for soil number 78 after washing with 10 solutions differing in sodium adsorption ratios (SAR).

Depth of Sample (inches)	SAR	Dispersion Percentage	Exchangeable Sodium Percentage	Gapon's Proportionality Factors			
				K_{gme}	mean	K_{ga}	mean
0-6	7	3.0	7.3	.040		.0069	
	15	1.8	12.5	.025		.0067	
	19	1.6	15.1	.022		.0067	
	23	3.0	19.0	.021		.0073	
	27	2.3	19.8	.018		.0065	
	31	4.8	23.3	.018		.0070	
	35	4.1	25.8	.017		.0072	
	39	5.7	28.5	.016		.0074	
	47	8.6	26.1	.017		.0054	
	55	5.1	21.2	.009	.020	.0035	.006
28-38	7	4.2	5.7			.0053	
	15	2.2	10.3			.0054	
	19	4.2	12.3			.0053	
	23	4.9	15.7			.0058	
	27	5.1	19.2			.0063	
	31	4.5	20.7			.0060	
	35	7.4	18.0			.0045	
	39	10.2	27.6			.0071	
	47	14.5	30.3			.0067	
	55	13.9	33.3			.0066	.006
38-46	7	1.3	7.4			.0070	
	15	4.0	12.8			.0069	
	19	2.7	14.9			.0066	
	23	4.7	19.1			.0074	
	27	0.2	20.2			.0067	
	31	1.2	19.1			.0054	
	35	6.4	25.5			.0070	
	39	3.4	27.7			.0071	
	47	9.3	29.8			.0065	
	55	7.6	37.8			.0080	.007

Table 16. Dispersion percentage, exchangeable sodium percentage and Gapon's proportionality factors, K_{gme} and K_{ga}, calculated for soil number 81 after washing with 10 solutions differing in sodium adsorption ratios (SAR).

Depth of Sample (inches)	SAR	Dispersion Percentage	Exchangeable Sodium Percentage	Gapon's Proportionality Factors			
				K_{gme}	mean	K_{ga}	mean
0-12	7	1.2	4.6	.038		.0042	
	15	0.4	11.6	.024		.0062	
	19	7.0	9.8	.017		.0041	
	23	9.7	12.2	.016		.0043	
	27	12.4	12.2	.014		.0037	
	31	17.7	11.0	.015		.0028	
	35	19.4	12.2	.013		.0028	
	39	28.4	13.4	.012		.0028	
	47	46.1	13.4	.003		.0023	
	55	19.4	10.4	.002	.015	.0015	.003
12-30	7	1.2	5.1			.0047	
	15	0.0	8.5			.0044	
	19	0.0	13.7			.0060	
	23	0.0	13.7			.0049	
	27	19.0	13.7			.0042	
	31	21.2	15.4			.0042	
	35	34.6	17.1			.0042	
	39	43.6	17.9			.0040	
	47	79.3	22.2			.0044	
	55	84.4	31.8			.0061	.005
36-48	7	4.6	5.5			.0051	
	15	6.2	8.2			.0042	
	19	6.8	9.6			.0040	
	23	19.4	15.1			.0055	
	27	19.3	13.7			.0042	
	31	22.6	15.8			.0043	
	35	43.2	18.5			.0038	
	39	37.1	16.4			.0036	
	47	46.4	28.8			.0062	
	55	53.3	31.5			.0060	.005

Table 17. Dispersion percentage, exchangeable sodium percentage and Gapon's proportionality factors, K_{gme} and K_{ga}, calculated for soil number 85 after washing with 10 solutions differing in sodium adsorption ratios (SAR).

Depth of Sample (inches)	SAR	Dispersion Percentage	Exchangeable Sodium Percentage	Gapon's Proportionality Factors			
				K_{gme}	mean	K_{ga}	mean
0-12	7	3.7	6.4	.037		.0060	
	15	4.9	10.9	.023		.0058	
	19	5.4	14.0	.021		.0061	
	23	8.7	17.7	.020		.0067	
	27	8.2	16.8	.017		.0053	
	31	9.6	19.8	.016		.0057	
	35	12.7	22.0	.015		.0058	
	39	13.7	24.3	.015		.0060	
	47	21.8	30.0	.014		.0066	
	55	21.8	32.6	.013	.019	.0064	.006
12-24	7	1.4	5.0			.0046	
	15	3.2	9.7			.0051	
	19	3.6	13.7			.0060	
	23	6.4	16.2			.0060	
	27	8.3	15.8			.0050	
	31	9.8	19.4			.0056	
	35	11.7	23.7			.0064	
	39	14.3	23.7			.0058	
	47	28.9	31.3			.0070	
	55	28.2	35.3			.0072	.006
24-40	7	3.8	6.5			.0061	
	15	7.1	12.5			.0067	
	19	8.3	14.7			.0065	
	23	17.7	14.1			.0051	
	27	18.2	21.2			.0071	
	31	11.1	23.9			.0073	
	35	13.1	26.6			.0075	
	39	21.7	29.3			.0077	
	47	18.2	34.2			.0080	
	55	16.9	39.1			.0084	.007

Table 18. Dispersion percentage, exchangeable sodium percentage and Gapon's proportionality factors, K_{gme} and K_{ga}, calculated for soil number 95 after washing with 10 solutions differing in sodium adsorption ratios (SAR).

Depth of Sample (inches)	SAR	Dispersion Percentage	Exchangeable Sodium Percentage	Gapon's Proportionality Factors			
				K_{gme}	mean	K_{ga}	mean
0-10	7	0.9	5.1	.033		.0047	
	15	2.3	9.6	.022		.0050	
	19	8.6	11.8	.019		.0050	
	23	10.6	14.7	.018		.0054	
	27	11.7	14.7	.015		.0045	
	31	37.5	18.4	.015		.0052	
	35	42.0	18.9	.014		.0048	
	39	56.4	20.4	.013		.0047	
	47	83.8	25.7	.012		.0053	
	55	97.1	31.2	.012	.017	.0060	.005
10-20	7	0.0	4.9			.0045	
	15	8.4	9.2			.0048	
	19	11.8	12.4			.0053	
	23	27.8	16.3			.0061	
	27	62.6	22.9			.0079	
	31	63.1	24.5			.0075	
	35	69.2	26.8			.0075	
	39	76.1	30.1			.0080	
	47	84.5	33.0			.0076	
	55	92.2	38.6			.0083	.007
24-36	7	0.0	6.9			.0065	
	15	4.2	15.3			.0086	
	19	7.3	16.1			.0072	
	23	13.0	21.1			.0084	
	27	19.0	22.2			.0076	
	31	19.4	27.6			.0089	
	35	54.8	30.3			.0090	
	39	42.2	32.6			.0090	
	47	70.9	37.5			.0092	
	55	82.2	41.8			.0095	.008

Table 19. Dispersion percentage, exchangeable sodium percentage and Gapon's proportionality factors, K_{gme} and K_{ga}, calculated for soil number 106 after washing with 10 solutions differing in sodium adsorption ratios (SAR).

Depth of Sample (inches)	SAR	Dispersion Percentage	Exchangeable Sodium Percentage	Gapon's Proportionality Factors			
				K_{gme}	mean	K_{ga}	mean
0-9	7	4.1	8.0	.042		.0076	
	15	7.8	16.0	.029		.0089	
	19	19.9	22.0	.028		.0105	
	23	26.9	25.0	.025		.0103	
	27	30.3	25.0	.022		.0088	
	31	55.9	29.0	.021		.0094	
	35	27.4	38.0	.022		.0125	
	39	72.2	39.0	.021		.0118	
	47	53.5	46.0	.020		.0129	
	55	83.2	58.0	.021	.025	.0179	.011
12-24	7	0.0	10.1			.0099	
	15	18.2	18.3			.0106	
	19	30.6	26.0			.0133	
	23	60.2	32.2			.0149	
	27	72.0	34.6			.0141	
	31	94.0	49.5			.0228	
	35	92.0	50.5			.0211	
	39	90.2	49.5			.0183	
	47	98.0	60.1			.0232	
	55	98.7	64.4			.0239	.017
24-36	7	0.8	11.0			.0109	
	15	17.4	24.2			.0151	
	19	23.6	28.4			.0150	
	23	51.0	32.6			.0151	
	27	49.2	35.8			.0148	
	31	68.3	41.0			.0161	
	35	68.3	45.8			.0175	
	39	80.8	48.4			.0175	
	47	87.6	60.0			.0231	
	55	87.1	64.7			.0242	.017

CRITERIA FOR THE QUANTITATIVE DETERMINATION OF SOIL DISPERSION

by

LAWRENCE EUGENE ERBES

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The principal objectives of this investigation were to develop a procedure for the quantitative determination of soil dispersion, to estimate the critical exchangeable sodium percentage for specific soils in the Wilson Irrigation Project and to predict the rate of dispersion at various exchangeable sodium percentage levels.

Three profile depth increments were acquired from ten soils in the Saline River valley in Lincoln, Ottawa and Saline counties. The soils developed from alluvial parent material.

Each soil sample was washed with ten salt solutions containing sodium and calcium chloride at different sodium adsorption ratios to obtain soil aggregates varying from low to high levels of exchangeable sodium.

The dispersibility of soil aggregates 1.0 to 2.0 mm in diameter was based on the suspended clay content which was present after shaking ten grams of aggregates in a 1000 ml cylinder for ten minutes. The quantity of dispersion occurring at various exchangeable sodium levels was expressed as the dispersion percentage. The dispersion percentages ranged from 0 to nearly 100 percent.

The regression of dispersion percentage on exchangeable sodium percentage revealed a definite critical point for 19 of the 30 soil horizons as evidenced by the breaks in the curves. However, 11 horizons exhibited no distinguishable critical point over the range of exchangeable sodium obtained. The rate of dispersion at various exchangeable sodium percentage levels can be compared between soils by evaluating the slope of the lines.

Gapon's proportionality factor was calculated for each treatment by two methods. In one instance the concentration was expressed in milliequivalents. In the second method ionic activities were substituted for

concentrations. Gapon's proportionality factor was more constant when ionic activities rather than concentrations were used.

The regressions between specific surface area vs. percent clay and surface charge density vs. percent clay were determined. The correlation coefficients were .931 and -.858, respectively, and both were significant at the .001 level.

Calculations based on the size of the hydrated sodium ion and the surface area per exchange site suggested that dispersion might be high where the surface charge density was high and where there was a relatively small area upon which each large hydrated sodium ion could be adsorbed. However, this was not borne out by the experimental data. Soils 81, 95 and 106 were extremely susceptable to dispersion. Soil 81 was high in surface charge density and low in area per exchange site. Soils 95 and 106 were low in surface charge density and had more area per exchange site. Although the surface area per exchange site varied from 68.6 to 251.3 A^2 in these three soils, there was no clear-cut effect on dispersion.

The three levels of water quality assumed for the Wilson reservoir would have sodium adsorption ratios of 1.94, 5.51 and 9.06 for low, intermediate and high contents of total soluble salts, respectively. The use of water high and intermediate in soluble salts is questionable for some Wilson Irrigation Project soils. Soils 81, 95 and 106 portrayed a high dispersion hazard even when exchangeable sodium was low. If the water of high and intermediate salt content assumed for the Wilson reservoir were used to irrigate these three soils, it is expected that the soils would be subject to severe dispersion.

Soils 1, 41, 52, 55, 65, 78 and 85 would not be expected to develop serious dispersion problems subsequent to irrigation under the highest sodium adsorption ratio assumed for water from the Wilson reservoir. The dispersion percentage in these seven soils would not be greater than 8.0 while the exchangeable sodium is not expected to be greater than 18 percent.

The limitations of the data should be recognized since interpretations were based only on laboratory investigations. Artificial rather than natural aggregates were used in measuring dispersion. Moreover, the effect of a given degree of dispersion upon permeability, aeration or other physical properties of the soil under field conditions was not investigated.