

EFFECTS OF SODIUM, POTASSIUM, AMMONIUM  
ON DISPERSION OF CALCAREOUS SOILS

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by

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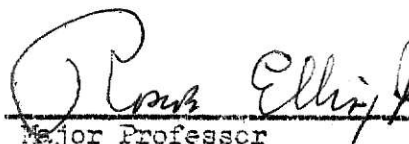
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## TABLE OF CONTENTS

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Page

ACKNOWLEDGEMENTS. . . . .	ii
LIST OF FIGURES . . . . .	iii
LIST OF TABLES. . . . .	viii
INTRODUCTION. . . . .	1
REVIEW OF LITERATURE. . . . .	2
MATERIALS AND METHODS . . . . .	17
Description of Soils Used in This Study. . . . .	17
Soil Properties. . . . .	17
Treatments . . . . .	20
Methods Used for Determination Soil Dispersion . . . . .	22
RESULTS AND DISCUSSION. . . . .	27
Keith silt loam soil . . . . .	28
Richfield silty clay loam soil . . . . .	51
Wakeen silt loam soil. . . . .	68
SUMMARY AND CONCLUSIONS . . . . .	90
REFERENCES CITED. . . . .	92
APPENDIX. . . . .	98

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## LIST OF FIGURES

Figure		Page
1.	Constant head apparatus. . . . .	26
2.	Hydraulic conductivity measurement for Keith soil treated with 10 me $\text{Na}^+$ /100 g soil and different levels of $\text{K}^+$ . . . . .	31
3.	Hydraulic conductivity measurement for Keith soil treated with 30 me $\text{Na}^+$ /100 g soil and different levels of $\text{K}^+$ . . . . .	32
4.	Hydraulic conductivity measurement for Keith soil treated with 50 me $\text{Na}^+$ /100 g soil and different levels of $\text{K}^+$ . . . . .	33
5.	Hydraulic conductivity measurement for Keith soil treated with 10 me $\text{Na}^+$ /100 g soil and different levels of $\text{NH}_4^+$ . . . . .	34
6.	Hydraulic conductivity measurement for Keith soil treated with 30 me $\text{Na}^+$ /100 g soil and different levels of $\text{NH}_4^+$ . . . . .	35
7.	Hydraulic conductivity measurement for Keith soil treated with 50 me $\text{Na}^+$ /100 g soil and different levels of $\text{NH}_4^+$ . . . . .	36
8.	Hydraulic conductivity measurement for Keith soil treated with 10 me $\text{K}^+$ /100 g soil and different levels of $\text{NH}_4^+$ . . . . .	37
9.	Hydraulic conductivity measurements for Keith soil treated with 30 me $\text{K}^+$ /100 g soil and different levels of $\text{NH}_4^+$ . . . . .	38
10.	Hydraulic conductivity measurement for Keith soil treated with 50 me $\text{K}^+$ /100 g soil and different levels of $\text{NH}_4^+$ . . . . .	39
11.	Hydraulic conductivity measurement for Keith soil treated with 10 me $\text{Na}^+$ /100 g soil and different levels of $\text{K}^+$ and $\text{NH}_4^+$ . . . . .	40
12.	Hydraulic conductivity measurement for Keith soil treated with 30 me $\text{Na}^+$ /100 g soil and different levels of $\text{K}^+$ and $\text{NH}_4^+$ . . . . .	41
13.	Hydraulic conductivity measurement for Keith soil treated with 50 me $\text{Na}^+$ /100 g soil and different levels of $\text{K}^+$ and $\text{NH}_4^+$ . . . . .	42



Figure	Page
14. Hydraulic conductivity measurement for Keith soil treated with different levels of $K^+$ and $NH_4^+$ . . . . .	43
15. SEM for Keith soil treated with 10 me $Na^+$ and 10 me $K^+$ /100 g soil . . . . .	44
16. SEM for Keith soil treated with 10 me $Na^+$ and 50 me $K^+$ /100 g soil . . . . .	44
17. SEM for Keith soil treated with 50 me $Na^+$ and 10 me $NH_4^+$ /100 g soil . . . . .	45
18. SEM for Keith soil treated with 50 me $Na^+$ and 50 me $NH_4^+$ /100 g soil . . . . .	45
19. SEM for Keith soil treated with 10 me $K^+$ and 10 me $NH_4^+$ /100 g soil . . . . .	46
20. SEM for Keith soil treated with 10 me $K^+$ and 30 me $NH_4^+$ /100 g soil . . . . .	46
21. SEM for Keith soil treated with 50 me $K^+$ and 30 me $NH_4^+$ /100 g soil . . . . .	47
22. SEM for Keith soil treated with 50 me $K^+$ and 50 me $NH_4^+$ /100 g soil . . . . .	47
23. SEM for Keith soil treated with 10 me $Na^+$ , 10 me $K^+$ , and 10 me $NH_4^+$ /100 g soil . . . . .	48
24. SEM for Keith soil treated with 10 me $Na^+$ , 50 me $K^+$ , and 30 me $NH_4^+$ /100 g soil . . . . .	48
25. SEM for Keith soil treated with 10 me $Na^+$ , 50 me $K^+$ , and 50 me $NH_4^+$ /100 g soil . . . . .	49
26. SEM for Keith soil treated with 30 me $Na^+$ , 50 me $K^+$ , and 50 me $NH_4^+$ /100 g soil . . . . .	49
27. SEM for Keith soil treated with 50 me $Na^+$ , 30 me $K^+$ , and 30 me $NH_4^+$ /100 g soil . . . . .	50
28. SEM for untreated Keith soil. . . . .	50
29. Hydraulic conductivity measurement for Richfield soil treated with 10 me $Na^+$ /100 g soil and different levels of $K^+$ . . . . .	52
30. Hydraulic conductivity measurement for Richfield soil treated with 30 me $Na^+$ /100 g soil and different levels of $K^+$ . . . . .	53

31. Hydraulic conductivity measurement for Richfield soil treated with 50 me $\text{Na}^+$ /100 g soil and different levels of $\text{K}^+$ . . . . .	54
32. Hydraulic conductivity measurement for Richfield soil treated with 10 me $\text{Na}^+$ /100 g soil and different levels of $\text{NH}_4^+$ . . . . .	55
33. Hydraulic conductivity measurement for Richfield soil treated with 30 me $\text{Na}^+$ /100 g soil and different levels of $\text{NH}_4^+$ . . . . .	56
34. Hydraulic conductivity measurement for Richfield soil treated with 50 me $\text{Na}^+$ /100 g soil and different levels of $\text{NH}_4^+$ . . . . .	57
35. Hydraulic conductivity measurement for Richfield soil treated with 10 me $\text{K}^+$ /100 g soil and different levels of $\text{NH}_4^+$ . . . . .	58
36. Hydraulic conductivity measurement for Richfield soil treated with 30 me $\text{K}^+$ /100 g soil and different levels of $\text{NH}_4^+$ . . . . .	59
37. Hydraulic conductivity measurement for Richfield soil treated with 50 me $\text{K}^+$ /100 g soil and different levels of $\text{NH}_4^+$ . . . . .	60
38. Hydraulic conductivity measurement for Richfield soil treated with 10 me $\text{Na}^+$ /100 g soil and different levels of $\text{K}^+$ and $\text{NH}_4^+$ . . . . .	61
39. Hydraulic conductivity measurement for Richfield soil treated with 30 me $\text{Na}^+$ /100 g soil and different levels of $\text{K}^+$ and $\text{NH}_4^+$ . . . . .	62
40. Hydraulic conductivity measurement for Richfield soil treated with 50 me $\text{Na}^+$ /100 g soil and different levels of $\text{K}^+$ and $\text{NH}_4^+$ . . . . .	63
41. Hydraulic conductivity measurement for Richfield soil treated with different levels of $\text{K}^+$ and $\text{NH}_4^+$ . . . . .	64
42. SEM for Richfield soil treated with 50 me $\text{Na}^+$ and 50 me $\text{K}^+$ /100 g soil. . . . .	65
43. SEM for Richfield soil treated with 10 me $\text{Na}^+$ and 10 me $\text{NH}_4^+$ /100 g soil. . . . .	65
44. SEM for Richfield soil treated with 50 me $\text{K}^+$ and 50 me $\text{NH}_4^+$ /100 g soil. . . . .	66

Figure	Page
45. SEM for Richfield soil treated with 50 me $\text{Na}^+$ , 50 me $\text{K}^+$ , and 50 me $\text{NH}_4^+$ /100 g soil. . . . .	66
46. SEM for untreated Richfield soil . . . . .	67
47. Hydraulic conductivity measurement for Wakeen soil treated with 10 me $\text{Na}^+$ /100 g soil and different levels of $\text{K}^+$ . . . . .	70
48. Hydraulic conductivity measurement for Wakeen soil treated with 30 me $\text{Na}^+$ /100 g soil and different levels of $\text{K}^+$ . . . . .	71
49. Hydraulic conductivity measurement for Wakeen soil treated with 50 me $\text{Na}^+$ /100 g soil and different levels of $\text{K}^+$ . . . . .	72
50. Hydraulic conductivity measurement for Wakeen soil treated with 10 me $\text{Na}^+$ /100 g soil and different levels of $\text{NH}_4^+$ . . . . .	73
51. Hydraulic conductivity measurement for Wakeen soil treated with 30 me $\text{Na}^+$ /100 g soil and different levels of $\text{NH}_4^+$ . . . . .	74
52. Hydraulic conductivity measurement for Wakeen soil treated with 50 me $\text{Na}^+$ /100 g soil and different levels of $\text{NH}_4^+$ . . . . .	75
53. Hydraulic conductivity measurement for Wakeen soil treated with 10 me $\text{K}^+$ /100 g soil and different levels of $\text{NH}_4^+$ . . . . .	76
54. Hydraulic conductivity measurement for Wakeen soil treated with 30 me $\text{K}^+$ /100 g soil and different levels of $\text{NH}_4^+$ . . . . .	77
55. Hydraulic conductivity measurement for Wakeen soil treated with 50 me $\text{K}^+$ /100 g soil and different levels of $\text{NH}_4^+$ . . . . .	78
56. Hydraulic conductivity measurement for Wakeen soil treated with 10 me $\text{Na}^+$ /100 g soil and different levels of $\text{K}^+$ and $\text{NH}_4^+$ . . . . .	79
57. Hydraulic conductivity measurement for Wakeen soil treated with 30 me $\text{Na}^+$ /100 g soil and different levels of $\text{K}^+$ and $\text{NH}_4^+$ . . . . .	80
58. Hydraulic conductivity measurement for Wakeen soil treated with 50 me $\text{Na}^+$ /100 g soil and different levels of $\text{K}^+$ and $\text{NH}_4^+$ . . . . .	81

Figure		Page
59.	Hydraulic conductivity measurement for Wakeen soil treated with different levels of $K^+$ and $NH_4^+$ . . . . .	82
60.	SEM for Wakeen soil treated with 10 me $Na^+$ and 10 me $K^+$ /100 g soil. . . . .	83
61.	SEM for Wakeen soil treated with 10 me $Na^+$ and 50 me $K^+$ /100 g soil. . . . .	83
62.	SEM for Wakeen soil treated with 50 me $Na^+$ and 50 me $K^+$ /100 g soil. . . . .	84
63.	SEM for Wakeen soil treated with 50 me $Na^+$ and 10 me $K^+$ /100 g soil. . . . .	84
64.	SEM for Wakeen soil treated with 30 me $Na^+$ and 10 me $NH_4^+$ /100 g soil. . . . .	85
65.	SEM for Wakeen soil treated with 50 me $Na^+$ and 10 me $NH_4^+$ /100 g soil. . . . .	85
66.	SEM for Wakeen soil treated with 10 me $K^+$ and 10 me $NH_4^+$ /100 g soil. . . . .	86
67.	SEM for Wakeen soil treated with 10 me $Na^+$ , 10 me $K^+$ , and 10 me $NH_4^+$ /100 g soil. . . . .	86
68.	SEM for Wakeen soil treated with 10 me $Na^+$ , 30 me $K^+$ , and 50 me $NH_4^+$ /100 g soil. . . . .	87
69.	SEM for Wakeen soil treated with 50 me $Na^+$ , 30 me $K^+$ , and 30 me $NH_4^+$ /100 g soil. . . . .	87
70.	SEM for Wakeen soil treated with 50 me $Na^+$ , 50 me $K^+$ , and 50 me $NH_4^+$ /100 g soil. . . . .	88
71.	SEM for untreated Wakeen soil. . . . .	88

## LIST OF TABLES

Table	Page
1. Chemical and physical properties of soils used in this study. . . . .	21
2. Treatments for study. . . . .	23
I. Clay minerals for Keith silt loam soil. . . . .	99
II. Clay minerals for Richfield silty clay loam soil. . . . .	100
III. Clay minerals for Wakeen silt loam soil . . . . .	101

## INTRODUCTION

The cations associated with the exchange complex have a marked effect on the soil physical and chemical properties. Soils which contain high amounts of exchangeable sodium are called alkali soils. Alkali soils have special properties such as high pH and weak structure. The effect of exchangeable sodium is pronounced on many irrigated alkali soils in dry regions having both chemical and physical effects.

The effect of exchangeable potassium is perhaps the least well understood of any of the cations (30). The effect of potassium is well defined in saline soils which have certain properties such as high salt content, and low pH.

The effect of exchangeable ammonium is different for different soils and sources of ammonium (29), but the effects of ammonium on the properties of soils have not been studied in detail.

The effects of exchangeable calcium and magnesium and other cations on soil are very important because calcium influences the behavior of other cations in soils. Dispersion and flocculation of soils are affected directly by exchangeable cations.

This study was initiated to study the effect of sodium, potassium, and ammonium on soil physical and chemical properties. Soil dispersion is very important in Iraq soils, with many calcareous soils. The objective of this study was to measure the dispersion of these soils.

## REVIEW OF LITERATURE

Effect of  $\text{Na}^+$  on Soil Dispersion

The sodium ion has great effects on physical condition of soils, Van Der Merwe and Burger (56) found extremely poor physical conditions in soils with high sodium contents as measured by permeability as an indicator for water movement. They concluded that effects of sodium may be related to swelling in soils especially at low sodium concentrations (50 me/l).

Ahmed, Swindale, and El-Swaify (2) studied tropical red earths and tropical black earths. They pointed out that the hydraulic conductivity was highest at twenty-four hours for Na-dominated soils but after that, Ca- and Mg-dominated soils had much higher hydraulic conductivities than K- and Na-dominated soils. Also aggregate stability was greater in Ca and Mg dominated soils.

Reeve et al. (46) measured the effect of sodium on permeability of air and water. They found that air permeability was different for different soil types. They explained that the differences were due to fragmentation and packing of the sample, but they found a decrease in water permeability when the sodium ion increased. They found that permeability ratio (air to water) increased with increasing exchangeable sodium but varied with soil type.

Quirk and Schofield (43) used a range of NaCl concentration and they noted a major decrease in soil permeability in sodium-saturated soils. Permeability decreased slowly with time which could be due to swelling and deflocculation.

Gardner et al. (24) used the weighted-mean diffusivity for the entry of water into a soil at a certain water content and related this to exchangeable-sodium percentage. They found when the exchangeable-sodium percentage

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was above 25, diffusivity was reduced and this reduction occurred mainly at higher water content.

Reeve and Tamaddoni (47) studied the effect of high-salt, high-sodium solutions on the permeability of a highly sodic soil in the field and laboratory. They reported a permeability-concentration relationship which depended markedly upon the initial solution concentration. If the initial solution concentration was low, the range of permeability values with varying solution concentration was lower than if the initial solution concentration was high. They obtained large differences for permeability between field and laboratory studies.

Quirk (42) observed a decrease in permeability for soils containing high amounts of sodium. He considered the concentration which causes a 10 to 15 percentage decrease in permeability as the threshold concentration. Infiltration measurements showed that for soils having appreciable cracking at the surface, the level of electrolyte does not cause differences in water entry since the main water entry in these soils is through the cracks.

McNeal and Coleman (37) found that decreases in hydraulic conductivity with decreasing electrolyte concentration and increasing sodium adsorption ratio (SAR) of the percolating solutions were related to clay mineralogy of soils. Decreases in hydraulic conductivities were noted for soils high in 2:1 layer clays while soils high in kaolinite and sesquioxides were not affected by variations in solution composition.

In Arizona, Nakayama (39) studied three pond soils using different sources of sodium ions. He used  $\text{NaCl}$ ,  $\text{Na}_2\text{SO}_4$ ,  $\text{Na}_2\text{CO}_3$ , and  $(\text{NaPO}_3)_6$ . He noticed that the dispersion of various soils was in the order of  $(\text{NaPO}_3)_6 \geq \text{NaCO}_3 > \text{Na}_2\text{SO}_4 = \text{NaCl}$ . When the Ca content in a soil is high,  $\text{NaCO}_3$  may be as effective a dispersing agent as  $(\text{NaPO}_3)_6$ .

Aldrich and Martin (3) studied the effect of exchangeable cations on soil aggregation from a chemical and biological standpoint. They found that when Na content increased aggregation is reduced. The kinds and numbers of microorganisms were not affected by cation composition but were influenced by organic matter content of soils. The only cations which affected the numbers of organisms in the soils were exchangeable sodium and hydrogen which increased the number of organisms. They reported addition of  $\text{CaCO}_3$  reduced the aggregation of soil.

Bakker et al. (8) found two types of flow rate-time curves. For the first type, after a period of constant flow, the flow rate slowly decreased with time. For the second type, again after a period of constant flow, the uppermost layers of aggregates were observed to start dispersing severely and the flow rate rapidly decreased to zero.

Bakker, Emerson, and Oades (7) pointed out that the relation between SAR and the ratio of amount of sodium to calcium or sodium to magnesium were nearly linear. This relation is true if exchange follows the Capon equation<sup>1/</sup>.

Rowell et al. (50) studied the effect of concentration and movement of solution on dispersion and swelling in saline and alkali soil. They measured porosity as an indicator for swelling and they used the following formula to find porosity.

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<sup>1/</sup> Capon equation

$$\text{Exch. Na\%} = \frac{100 \text{ kg Na}^+}{\sqrt{\frac{\text{Total soluble cations} - \text{Na}^+}{2} + \text{kg Na}^+}}$$

where kg = 0.01 - 0.02

$$E = \frac{V - ba}{100} - \frac{1}{p} \quad \text{where:}$$

$E$  = porosity in  $\text{cm}^3/\text{g}$  dry soil.

$V$  = volume of the soil pad in  $\text{cm}^3/100$  g dry soil.

$b$  = clay percentage in the soil.

$p$  = density of the solid particles of soil.

$a$  = swelling value, g water per g clay.

They stated that three aspects of these results need to be considered.

- (1) The application of mechanical stress to a clay has been shown to effect the electrolyte concentration at which dispersion occurs.
- (2) When the exchangeable sodium percentage is reduced in a soil, then not only is the magnitude of the clay swelling reduced, but also the amount of clay which disperses is also reduced.
- (3) The amount of clay which dispersed varied with the mechanical stress applied to the soil.

Rowell (49) gave three explanations for deflocculation when the amount of NaCl decreased. The explanations are:

- (1) The use of a  $< 2\mu$  fraction of clay may have given higher swelling values than a fine fraction.
- (2) Packing method.
- (3) Solution may have remained on the surface of the aggregates.

Some studies show that the use of high-salt water for reclamation of sodic soil is possible (Reeve and Bower (45)). They found a decreased exchangeable sodium percentage after adding a high-salt water for all treatment but differences were found for length of time and amount of water required for reclamation by the various treatments.

Martin and Richards (34) pointed out that increasing sodium reduced aggregation and conductivity, but increasing hydrogen at a given sodium

level increased aggregation and conductivity.

In Pakistan, Hausenbuiller, Hague, and Abdul Wahhab (27) studied the effect of irrigation water on the soil properties in the field and under controlled irrigation. They reported highly significant correlation between exchangeable sodium in the soil and residual  $\text{Na}_2\text{CO}_3$  content, soluble sodium percentage, and sodium adsorption ratios in the water.

Eaton and Horton (19) pointed out that the moisture equivalents<sup>2/</sup> of soil partially saturated with sodium were higher than those of the same soils treated with calcium.

Kelley (30) studied the effect of exchangeable sodium on both physical and chemical properties of soil. He found that a certain amount of exchangeable sodium produced a dispersed system and low permeability in that system.

In Egypt, Fathi, Milad, and Shehata (21) stated that the dispersion ratio and stable silt sized aggregates are positively and linearly related to both soluble and exchangeable sodium.

#### Effect of $\text{K}^+$ on Soil Dispersion

Ahmed, Swindale, and El-Swaify (2) reported that the hydraulic conductivity on the tropical red earth soils were less with potassium treatments than with calcium or magnesium treatments. They concluded that a heavy addition of potash fertilizers without a certain amount of lime could lead to a deterioration of soil structure.

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<sup>2/</sup> Moisture equivalent: Percentage of moisture remaining in 30 g sample of soil that had been saturated for 24 hours drained for 30 min. and then centrifuged for 30 min. in saturated cups in a standard moisture equivalent centrifuge drum operated at a rotational speed of 2440 rpm.

Reeve, Bower, Brooks, and Gschwend (46) studied the effect of exchangeable potassium on air and water permeability. They pointed out that a soil treated with potassium has less air permeability than a soil treated with sodium, but differed for soil type. They showed that potassium had little effect on soil stability.

Quirk and Schofield (43) found that exchangeable potassium decreased soil permeability when the solution of potassium is replaced by more dilute solutions. They concluded that potassium has a low threshold concentration<sup>3/</sup> for decreasing permeability.

Brooks, Bower, and Reeve (15) reported that increasing exchangeable potassium decreased the permeability ratio of some soils but not all soils. They concluded that addition of sodium and potassium both cause organic matter to be removed but the effect of sodium was greater.

Aldrich and Martin (3) said that a high percentage of exchangeable potassium may or may not reduce aggregation depending on soil type.

Martin and Richards (34) mentioned that increasing exchangeable potassium slightly reduced soil aggregation, but greatly reduced hydraulic conductivity.

Barshad (10) studied the fixation and replacement of potassium. He gave many factors which affect replaceability of potassium such as:

- (1) Magnitude of interlayer charge of crystal lattice.
- (2) The fixed potassium is replaced much more rapidly than the native potassium.
- (3) Replaceability of native potassium was affected by nature of

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<sup>3/</sup> Threshold concentration is the concentration of salt which causes 10 to 15 percentage decrease in soil permeability.

replacing cation.

(4) Replaceability of native potassium was affected by particle size.

Barshad (9) found that various amounts of interlayer  $Mg^{++}$ ,  $Ca^{++}$ ,  $Ba^{++}$ , or  $Na^{+}$  in vermiculite were trapped in the interior of the particles and rendered difficulty exchangeable upon replacement of the most accessible portion of these cations by  $NH_4^{+}$  or  $K^{+}$ . Variation in particle size of vermiculite strongly affected adsorption of  $NH_4^{+}$  and  $K^{+}$ .

Kelley (30) said, the physical properties of montmorillonite are affected by exchangeable potassium in that its degree of dispersion is increased, but not to as great an extent as is caused by exchangeable sodium.

Stanford and Pierre (53) pointed out that the calcareous soils have more capacity to fix potassium than acid soils, but that acid soils can fix potassium.

#### Effect of $NH_4^{+}$ on Soil Dispersion

Fox, Olson, and Mazurak (23) studied the effect of ammonium on soil properties. They reported that soil permeability decreased as the amount of ammonium applied increased. The degree of dispersion, soil structure breakdown, and visible crusting in the field was in proportion to the rate of ammonium applied. Nitrification of ammonium applied might promote a greater stability or flocculation in disturbed samples which in turn could increase permeability. They noticed a hard surface crust in the field caused by the ammonium.

Gifford and Strickling (25) studied the effect of anhydrous ammonia on water stability of soil aggregates from 1954 to 1957 in the field and laboratory. They found an increase in soil aggregate stability after they added ammonia in the field. The soil aggregate stability increased greatly in the laboratory when they added ammonia. However, Martin and Richards (34)

found a slight reduction in soil aggregation and a great reduction in hydraulic conductivity after they increased exchangeable ammonium.

Jenny, Ayers, and Hosking (29) studied the influence of the ammonium ion on water penetration in a laboratory study. They noted that no generalization was possible and the penetration varies with different soils, but increasing ammonium ion gives more water penetration than distilled water, and was different for different ammonium ion sources.

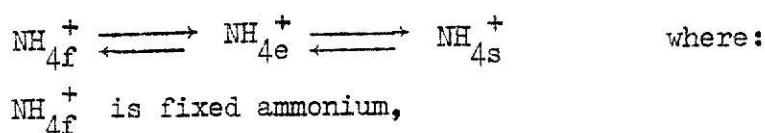
Barshad (10) pointed out that a decrease in particle size brings about a large increase in total adsorption as well as in the total fixation of ammonium ion. He explained that by increasing in the places for entry into the interior of the particle and therefore to a greater completion of the exchange reaction between the adsorbed cations in the interior of the particle and the replacing cations of the solution.

Fenn and Kissel (22) studied the effect of  $\text{CaCO}_3$  in soils on the volatilization of ammonium compounds. They found that ammonium nitrate reached a maximum  $\text{NH}_4^+$ -N loss at 1.3%  $\text{CaCO}_3$ , but they found some loss at 6.1%  $\text{CaCO}_3$ , but results were different for different sources of ammonium. This was emphasized by Steen and Stojanovic (54).

In Sweden, Hans Normik (40) did a very good study on fixation and de-fixation of ammonium in soil. He listed many factors affecting the fixation and release of ammonium in soil under moist conditions such as:

- (1) Effect of the concentration of the added ammonium solution.
- (2) Effect of temperature.
- (3) Effect of pH and different cations.

He reported the following equilibrium:



$\text{NH}_{4e}^{+}$  is exchangeable ammonium, and

$\text{NH}_{4s}^{+}$  is water soluble ammonium.

Chu and Knowles (18) said that 92.5% of added ammonium appeared in the exchangeable fraction while Singh, Agarwal, and Karchiro (52) point out that the release of ammonium depends on concentration in soil and the length of incubation. They found the order for effect of cations on ammonium release was:  $\text{Al} > \text{Fe} > \text{Ca} > \text{Mg} > \text{K} > \text{Na}$  in order of decreasing ammonium replacing power.

Brown and Hitchcock (16) stated that nitrification in alkali soils is increased by adding a small amount of  $\text{CaCO}_3$ , while  $\text{CaSO}_4$  has no effect. They stated that  $\text{CaCO}_3$  becomes toxic in alkali soil at 6.0 percent. The addition of  $\text{CaSO}_4$  with  $\text{Na}_2\text{CO}_3$  and  $\text{NaHCO}_3$  prevents any toxic effect from the largest amount used. Agarwal, Singh, and Kanchira (1) pointed out that the addition of  $\text{CaCl}_2 \cdot 2 \text{H}_2\text{O}$  results in the greatest  $\text{NH}_4^{+}$ -N release, followed by KCl and NaCl. The exchange reaction depends on, nature and valence of the cation concentration, length of reaction, and the anionic species associated with the cation. Broadbent and Nakashima (14) reported that nitrogen mineralization is increased by solution of KCl,  $\text{CaCl}_2$ , and  $\text{AlCl}_3$  but not for all soils.

Pathak and Jain (41) did a laboratory study to test the effect of alkali salts on nitrification. They found that increasing concentration of various salts in soils, nitrification was promoted by  $\text{CaCO}_3$  even in high concentration (up to 1.6%) and by  $\text{CaSO}_4$  and  $\text{MgSO}_4$  up to a certain concentration, and was inhibited even at low concentration by NaCl,  $\text{Na}_2\text{CO}_3$ ,  $\text{Na}_2\text{SO}_4$ , and  $\text{NaHCO}_3$ .

#### Effect of Salt Mixture on Soil Dispersion

Ahmed, Swindale, and El-Swaify (2) studied the effect of combinations



of Ca, Mg, K, and Na on hydraulic conductivity. They found that these cations produced intermediate effects with Ca saturated soils and were more susceptible to deterioration by K or Na than Mg saturated soil.

In South Africa, Van der Merwe and Burger (56) reported that the combination of Ca-Na and Mg-Na affected the physical properties of soils but that Mg-Na gave poorer physical properties than Ca-Na. The same results were reported by Quirk and Schofield (43).

McNeal, Layfield, Nerwell, and Rhoads (36) showed the effect of mixed salt solutions and soil texture on the hydraulic conductivity. They found when the same minerals were present but with different clay content that hydraulic conductivity in the presence of mixed-salt solutions decreased markedly with increasing clay content, particularly at the low salt concentration. The same thing was reported by McNeal (35). McNeal, and Coleman (37) reported that a high percentage of 2:1 layer clay in soil resulted in a decrease of hydraulic conductivity. McNeal, Norvell, and Coleman (38) showed that for soils containing expandible minerals, the swelling of extracted soil clays in mixed  $\text{NaCl-CaCl}_2$  solutions was well correlated with relative hydraulic conductivity of the soil in the same solutions.

Aldrich and Martin (3) reported that the combination of exchangeable Ca, Mg, and K with a constant exchangeable sodium percentage and increasing of exchangeable potassium did not influence aggregation, but increasing exchangeable sodium percentage decreased hydraulic conductivity.

Rowell, Payne, and Ahmad (50) reported that the threshold concentration was the electrolyte concentration at which the swelling values begin to increase above the value for the basic member of the series, and the concentration for aggregate dispersion is the maximum electrolyte concentration at which aggregates disperse.

Bakker, Emerson, and Oades (7) reported that calcium-sodium soil has to be increased to certain amount of these cations before it dispersed.

Rowell (49) pointed out that the uptake of solution by mixed Na-Ca montmorillonite clay depended on its activity ratio  $\frac{A_{Na}}{\sqrt{A_{Ca}}}$  and on the total electrolyte concentration. When the ratio decreased the swelling decreased.

Barshad (10) found little ammonium effect if  $NH_4^+$  replaced any inter-layered  $K^+$  and when  $MgCl_2$  was added to replace readily exchangeable  $K^+$ ,  $NH_4^+$  failed to replace any  $K^+$ .

Emerson and Bakker (20) pointed out that water uptake is more by Mg-Na aggregates for  $ESP > 3$  and for Ca-Na aggregates for  $ESP > 9$ . Ca-Na aggregates with an ESP of 7.0 wetted under suction, do not disperse when flooded with water.

Axley and Legg (6) stated that the addition of potassium with sodium has little effect on yields or nitrogen uptake, but with an ammonia source of nitrogen, similar potassium additions decreased yields and nitrogen uptake from soils. Raju and Mukhopadhyay (44) put the order of the effect of different cations on the fixation of  $NH_4^+$  as following:  $Ba^{++} > Na^+ > Ca^{++} > control > K^+$ , which shows ability of potassium to remove some of the  $NH_4^+$  fixed in the soil prior to sampling. Hanway, Scott, and Stanford (26) stated that if a solution has 2  $K^+$  ions per 100  $Na^+$  ions, there is no fixation of  $NH_4^+$  released from vermiculite. They found that with small amount of potassium present, the amount of fixed ammonium is decreased as the K/Na ratio is increased. On the other hand Agarwal, Singh, and Kanchiro (1) reported the order for the capacity of cations for release of ammonium decreasing as follows:  $Ca > K > Na$ , for the chloride series.

### Effect of $\text{Ca}^+$ and $\text{CaCO}_3$ on Soil Dispersion

Ahmed, Swindale, and El-Swaify (2) concluded that calcium gives high hydraulic conductivity in soils and the same thing was emphasized by Van der Merwe, and Burger (56). Quirke and Schofield (43) noted small decreases in soil permeability when the concentration of calcium was low. Bakker and Emerson (8) studied the effect of calcium on soil permeability. They found that permeability of aggregated soil does not decrease when washed with calcium. In Egypt, Fathi, Milad, and Shehata (21) studied the effect of water soluble and exchangeable calcium on aggregation of the Nile alluvial soils. They found a negative relationship between both dispersion ratio and the percentage stable silt sized aggregates with both soluble and exchangeable calcium.

Bower and Goertzen (13) studied the following reaction:

$2 \text{ Na adsorbed} + \text{CaCO}_3 + \text{H}_2\text{O} \rightleftharpoons \text{Ca adsorbed} + 2 \text{ Na} + \text{HCO}_3 + \text{OH}^-$ . This reaction happens in calcareous soil when the adsorbed sodium is replaced by calcium. The equilibrium of this reaction can be expressed by:

$$\text{Na}_{\text{ad}} = (K_1 K_2 \text{Na}^+) / (1 + K_1 \text{Na}^+), \text{ where,}$$

$K_1$  and  $K_2$  are constants,  $\text{Na}_{\text{ad}}$  and  $\text{Na}^+$  are the adsorbed and solution concentration of Na, respectively.

Hausenbuiller, Hague, and Wahhab (27) stated that changes in the  $\text{CaCO}_3$  equivalent are noted to parallel rather closely the changes in exchangeable Na.

Kaochkin and Molchanov (31) reported that increasing  $\text{CaCO}_3$  gives a decrease in nitrogen when the pH rises slightly and there is no relationship between amount of  $\text{CaCO}_3$  and the mobility of potassium. In general, the influence of high  $\text{CaCO}_3$  content in soil on its agrochemical properties is not always clear.

Rimmer and Greenland (48) studied the effect of  $\text{CaCO}_3$  on the swelling behavior of clay at different suctions. With Ca-saturated soil there is no difference in the swelling before and after removal of  $\text{CaCO}_3$  at high suction, but at low suction there is an increase in swelling especially when the soil  $\text{CaCO}_3$  content is high, but there is a decrease in swelling when the soil  $\text{CaCO}_3$  content is low. At intermediate suction there is a decrease in swelling with the removal of  $\text{CaCO}_3$ .

#### Scanning Electron Microscope Studies

Chen and Banin (17) using the direct scanning electron microscope (SEM) observed that a reduction in hydraulic conductivity of soils leached with mixed  $\text{NaCl-CaCl}_2$  solutions of low electrolyte concentration were related to fine particle dispersion and the formation of a more continuous network of these particles at higher SAR values.

Thien (55) using scanning electron microscope photos found more fine particles present in phosphoric acid treated aggregates than in untreated samples.

Sedgley (51) studied the difference in structure between flocculated and nonflocculated aggregates with an electron microscope. When flocculation occurred, the aggregates tended to maintain their identity and shape, and were separated from each other by pore space which lacks the characteristic shape of voids formed during shrinkage. In the unflocculated specimen, greater consolidation occurred, which resulted in the loss of structural pore space between aggregates.

#### THEORY

Colloidal particle of clay minerals and other soil colloids are usually charged electronegatively. Adsorption of cations are controlled by many factors such as, type of cations, ion concentration, nature of the anion

associated with the cation, and the nature of the colloidal particle.

The effect of type of cation has usually been studied from the replaceability in clays. The higher the valence of a cation the greater its replacing power and the more difficult its replacement from the clay surface by other cations.

The effect of ion concentration on the replacement of a cation follows the mass action law. When the ion concentration increases as charge of cations increase.

The nature of the anion associated with the cation has a great effect. When an anion is strongly adsorbed by clays, the cation adsorption will increase.

The type of clay and its effect on cation adsorption and replaceability have been studied by many investigators. The results show there is no one order of replaceability of cations that holds for all soil clays.

The effect of ion on Zeta potential is related to the ion charge, ion concentration, and its hydrated size. For equal size ions, when ion charge is increased, the Zeta potential is decreased.

Donnan gave the following relationship for the diffusible electrolyte AM:

$$(M^+)_{\text{i}} (A^-)_{\text{i}} = (M^+)_{\text{o}} (A^-)_{\text{o}}.$$

This constant ion product is usually known as the Donnan membrane equilibrium expression. A clay particle, may be considered as a micro-Donnan system. The surrounding diffuse double layer and the attractive electric forces between the particle surface and cations interior act, and that causes a non-uniform distribution of cations in the micellar solution (11,33).

Krishnamoorthy and Overstreet (32) considered two phases in clay suspensions which contain free electrolytes. These two phases are in equilibrium.

The first phase is the adsorbent phase and contains the adsorbed ions together with small but finite quantities of free electrolytes. The second phase contains the free electrolytes only but this layer does not contain appreciable amounts of the adsorbent particles because of the very low solubility of the adsorbent in water.

Helmy (28) stated that trivalent cations have more dominant adsorption when present in mixture of mono and di-valent cations but if the mixture has only mono and di-valent, cations in equal concentrations the divalent cation is adsorbed more.

Agresinger, Davidson, and Bonner (5) proposed the following relationship for activity coefficient, mole fraction and equilibrium concentrations:

$$K = \frac{N_a^v}{N_b^u} \cdot \frac{F_a^v}{F_b^u} \cdot \frac{C_b^u}{C_a^v} \cdot \frac{\gamma_b^u}{\gamma_a^v}$$

where  $N_a$  and  $N_b$  are the equilibrium mole fraction of the two components.

$F_a$  and  $F_b$  the corresponding activity coefficients.

$C_b$  and  $C_a$  the equilibrium concentration of ions b and a in solution phase.

and  $\gamma_b$  and  $\gamma_a$  the corresponding ionic activity coefficient.

## MATERIALS AND METHODS

## Description of Soils Used in This Study

The soils were collected from Western Kansas (Colby, Garden City, and Hays). The soil types are:

- |                              |             |
|------------------------------|-------------|
| 1. Keith silt loam           | Colby       |
| 2. Richfield silty clay loam | Garden City |
| 3. Wakeen silt loam          | Hays        |

These soils are calcareous (high amount of lime).

## Soil Properties

Analytical methods used for this study were:

1. pH, organic matter, CEC, EC, soluble  $\text{Na}^+$  and exchangeable cations ( $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{NH}_4^+$ ) as determined by Kansas State University Soil Testing Laboratory as:

- a. pH

Weigh 5 g soil, add 5 ml distilled-deionized water, stir approximately 1 minute with a glass stirring rod, allow to equilibrate for 30 minutes. Stir sample and read pH immediately on the standardized pH meter.

- b. Organic matter

Measure 1 g soil into a 250 ml flask, add 10 ml of normal potassium dichromate from 100 mm burette, add 20 ml of sulfuric acid rapidly, swirl to mix and allow to stand at least 30 minutes. Add 100 ml of distilled water, mix and allow to cool, filter to fill funnel tube half full. Set photometer with distilled water in tube, use wave length of 620 nm and read.

## c. CEC

Place 2 g of soil in a 100 ml centrifuge tube, treated 3 times with 50 ml of 1 N sodium acetate adjusted to pH 5.0 (because of calcareous soils), suspend the soil in 50 ml of 1 N calcium chloride, suspend the soil twice in 50 ml of 1 N calcium acetate, suspend the soil in 50 ml of 1 N calcium chloride. Centrifuge twice with 50 ml of ethyl alcohol, centrifuge as many additional times with methyl alcohol as are necessary so that no test for chlorides is obtained when  $\text{AgNO}_3$  is used as a test. Suspend soil 4 times in approximately 50 ml of 1 N ammonium acetate, save the supernatant liquid. Determine Ca in this solution by Perkin-Elmer Model 303 or 603.

## d. EC and soluble sodium

Weigh 300 g soil into a 800 ml beaker, add sufficient water to the soil to bring it to the saturation point, filter the saturated paste through a Buechner funnel with suction after allowing it to stand for at least 30 minutes. Measure the resistance of soil extract by electrical conductivity meter, and use the following equation to get EC.

$$\text{E.C.}_{25^\circ\text{C}} \times 10^3 = \frac{\text{Cell constant} \times 10^3}{\text{observed resistance in ohms at } 25^\circ\text{C}}$$

(millimhos/cm)

Determine the concentration of soluble sodium in soil extract by the atomic absorption 603.

## e. Exchangeable cations

Place 2 g of dry soil into a 100 ml centrifuge tube, suspend the soil in 50 ml of 1 N ammonium acetate (pH 7.0), repeat this step 4 times and save the supernatant liquid each time. Repeat the last step one additional time and save the supernatant liquid separately.



Evaporate the solution for the 5 centrifuge washings and the additional time solution nearly to dryness and then make a final volume of 100 ml. Determine the concentration of each cation separately by the atomic absorption 603.

f. Exchangeable ammonium

Add 20 ml of 2 M KCl to 2 g of soil, shake for 30 minutes, filter, and run  $\text{NH}_4^+$  on Technicon.

2. Determination of  $\text{CaCO}_3$  percentage

Acid neutralization method was used to determine  $\text{CaCO}_3$  percentage (57).

Place 5 g of soil in a 150 ml beaker, add 50 ml of hydrochloric acid (0.5 N) by means of a pipet, cover with a watch glass, and boil gently for 5 minutes. Cool, filter, and wash all the acid from the soil with water. Determine the amount of unused acid by adding 2 drops of phenolphthalein (1 percent in 60 percent ethanol) and back-titrating with sodium hydroxide (0.25 N). Determine  $\text{CaCO}_3$  percentage by the following equation:

$$\text{CaCO}_3\% = \frac{(\text{m.e. HCl added} - \text{m.e. NaOH used}) \times 5}{\text{Wt. of soil sample, g}}$$

3. Mechanical analysis

Hydrometer method was used to determine the mechanical analysis of soils (56).

Weigh 40 g of dry soil, add 100 ml of calgon solution, stir approximately 10 minutes with electrical stirring, allow to equilibrate for 24 hours. Place soil solution into a graduated cylinder, make a final volume of 1000 ml. Stir sample and take time as zero. Take the hydrometer readings for 1/2, 1, 3, 10, 30, 90, and 720 min. Calculations as following:

$$P = \frac{C}{C_0} \times 100$$

where

P = Summation percentage

C = Reading of hydrometer

C<sub>0</sub> = dry wt. of soil sample, g

$$\text{Corr. } \theta = \theta \sqrt{\frac{\eta_{\text{room temp.}}}{\eta_{30}}}$$

where

$\theta$  = Sedimentation parameter

$\eta$  = Viscosity of water

$$X = \frac{\text{Corr. } \theta}{\sqrt{T}}$$

where

X = Diameter of soil particles,  $\mu$

T = Time, min.

Plot X vs. P on semitogarithmetic paper, and then take X = 2 to get a percentage of clay, take X = 50 as percentage of silt and clay.

% Sand = (% 100) - (% silt + clay).

#### 4. X-ray diffraction

Clay was taken from soil by centrifuge method. The patterns of clay for untreated, KCl - treated, MgCl<sub>2</sub> - treated, and ethyl glycol treatments were prepared. The X-ray diffraction for soil samples were taken by Kansas State University - Geology Department.

The clay minerals of soils are listed in Appendix I.

The soil properties are shown in Table 1.

#### Treatments

The soils were dried, crushed, and passed through a 2.38 mm sieve. Two

Table 1. Chemical and physical properties of soils used in this study.

Property	Keith silt loam	Richfield silty clay loam	Wakeen silt loam
pH	7.80	7.80	7.90
CaCO <sub>3</sub> %	4.35	4.10	30.00
O.M.%	1.50	1.40	1.50
Exch. Ca <sup>2+</sup> , me	20.72	21.38	16.37
Exch. Mg <sup>2+</sup> , me	2.45	6.91	0.66
Exch. Na <sup>+</sup> , me	0.20	1.38	0.17
Exch. K <sup>+</sup> , me	2.29	1.47	0.57
Exch. NH <sub>4</sub> <sup>+</sup> , me	0.02	0.00	0.016
C.E.C., me/100 g soil	22.092	27.64	13.92
% sand	31	24	51
% silt	54	51	34
% clay	15	25	15
% exch. Na	0.91	3.61	1.34
Sol. Na me/100 g soil	0.033	0.60	0.033
E.C.	1.17	3.37	1.24

hundred grams of soil were used for each treatment, packed in the polyethylene tube (4.2 cm in diameter and 15 cm length), saturated by distilled water for 16 hours or more, the different salt solution (200 ml volume) for each treatment were added, and left over night (Table 2). There is no replication for this study.

#### Methods Used for Determination Soil Dispersion

Many methods have been used to measure soil dispersion. Hydraulic conductivity and scanning electron microscopy (SEM) were used to measure soil dispersion in this study.

##### 1. Hydraulic conductivity

A constant head method was used to measure hydraulic conductivity in this study (56). The equipment used is shown in Figure 1. The water as leaching solution was used. Collect the amount of flow (volume) and get the length of soil column and height of water over soil surface. Flow was collected at different times because the time factor is considered in Darcy's law. Darcy's law was used to calculate the hydraulic conductivity:

$$K = (Q/At)(L/\Delta H)$$

where

$K$  = hydraulic conductivity, cm/hr

$Q$  = volume of flow passing through column,  $\text{cm}^3$

$A$  = cross sectional area of the sample,  $\text{cm}^2$

$t$  = time, hr

$L$  = length of the soil sample, cm

$\Delta H$  = hydraulic head difference, cm

Table 2. Treatments for study.

Treatment No.	Na me/100 g soil	K me/100 g soil	NH <sub>4</sub> me/100 g soil
1	10	10	0
2	10	30	0
3	10	50	0
4	30	10	0
5	30	30	0
6	30	50	0
7	50	10	0
8	50	30	0
9	50	50	0
10	10	0	10
11	10	0	30
12	10	0	50
13	30	0	10
14	30	0	30
15	30	0	50
16	50	0	10
17	50	0	30
18	50	0	50
19	0	10	10
20	0	10	30
21	0	10	50
22	0	30	10
23	0	30	30
24	0	30	50
25	0	50	10
26	0	50	30
27	0	50	50
28	10	10	10
29	10	30	30
30	10	50	30
31	10	10	50
32	10	30	50
33	10	50	50
34	30	30	30
35	30	50	30
36	30	30	50
37	30	50	50
38	50	30	30
39	50	50	30
40	50	30	50
41	50	50	50

Table 2. Continued.

Treatment No.	Na	K	NH <sub>4</sub>
	me/100 g soil	me/100 g soil	me/100 g soil
42	0	10	0
43	0	50	0
44	0	0	10
45	0	0	50
46	0	0	0

## 2. Scanning Electron Microscopy (SEM)

After measuring the hydraulic conductivity by the previous method a sample was taken dried coated with SEM materials under vacuum. A scanning electron micrograph was taken for each sample using the proper magnification (500 times). The micrograph was taken at Kansas State University - Entomology Department. The distribution of particles was studied in the micrographs.

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WITH DIAGRAMS  
THAT ARE CROOKED  
COMPARED TO THE  
REST OF THE  
INFORMATION ON  
THE PAGE.**

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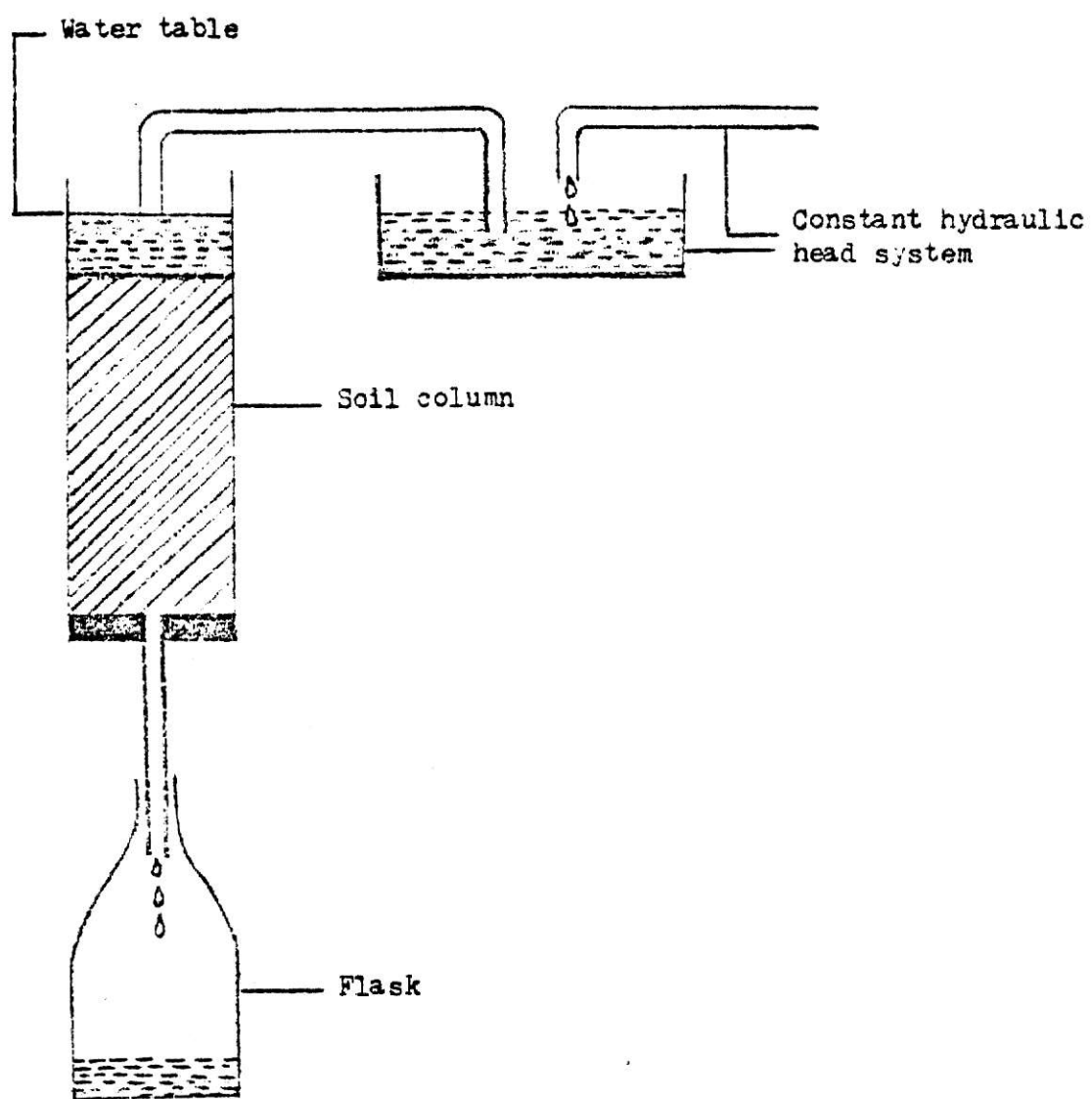


Fig. 1. Constant head apparatus.

## RESULTS AND DISCUSSION

Different concentrations and combinations of cations were compared for effect on soil dispersion, in these calcareous soils.

In general, application of potassium and ammonium ions increased hydraulic conductivity and soil flocculation in most treatments with Keith silt loam and Wakeen silt loam soils. On the other hand increasing amounts of sodium ion resulted in soil dispersion.

In this study hydraulic conductivity gave a more quantitative measurements of soil dispersion than examination with a scanning electron microscope.

Permeability begins to decrease at the same ion concentration as clay begins to swell. Changes in permeability are directly controlled by the swelling of clay until clay dispersion and movement begins. The concentration of a dispersive ion at which clay dispersion begins depends on the mechanical stress applied. When small mechanical stresses are applied, the proportion of the clay which swells and disperses depends directly on the exchangeable sodium percentage, but large mechanical stresses may disperse most of the clay even at low exchangeable sodium percentage (50).

The varying effects of the different cations are ascribed to differences in solubility and dissociation tendency of the colloid-cation combinations and to consequent differences in the density and diffusivity of the Helmholtz double layer of the colloidal micelles. The influence of a cation on a property seems to be in direct proportion to its percentage of complete replacement (4). The data do not indicate this with certainty.

Resistance to water flow through saturated soil pores generally develops with time due to microbiological activities, gradual mechanical breakdown of the exterior of soil granules, or the destruction of the granules

due to the chemical nature of soils and their interaction with percolating water (2).

The charge-density of the clay also has some effect on the relative amounts of adsorbed cations. A clay with higher surface-charge density has more trivalent and less monovalent adsorbed cations than the one with lower charge density. This effect increases as the concentration decreases (28).

In this study, the solutions which came from the soil columns were dark colored with sodium treated soils. The dark color is from dissolved organic matter (30).

The exchange rate constants  $K$ , although of the same order of magnitude, is larger when a soil is initially saturated with Ca or Mg than when initially saturated with Na. Moreover, under corresponding conditions of initial saturation, the constants are larger for coarse-textured than for the medium or fine-textured soils. While the factor that controls the exchange rate is not definitely known, the available data suggest a relation between the rate and the permeability of soil aggregates (12).

#### Keith silt loam soil

##### 1. Hydraulic Conductivity Method:

Increasing potassium levels resulted in greater hydraulic conductivities (Figure 2). The highest hydraulic conductivity, was obtained with the 10  $\text{Na}^+$  + 50  $\text{K}^+$  treatment. Increasing hydraulic conductivity with increasing potassium level is due to ion concentration and hydrated size, which effect zeta potential and soil dispersion (10, 33), also fixation of potassium between clay plates may be involved.

The highest concentration of potassium resulted in a high hydraulic conductivity while the two lower levels of potassium resulted in soil dispersion when sodium was added at 30 me/100 g soil (Figure 3). This is due to a large

amount of sodium present in the soil to cause dispersion.

At highest level of sodium (50 me/100 g soil), there was no effects of potassium addition on hydraulic conductivity because soil dispersion occurred (Figure 4) due to high sodium ion concentrations. Sodium removes more organic matter than potassium (15), which explains why the soil treated with sodium was more dispersed than when the soil was treated with potassium.

Soil dispersion occurred at the highest concentrations of ammonium at a constant 10 me/100 g soil of Na (Figure 5). The soil did not disperse at lower concentrations of ammonium.

The soil dispersed for all treatments when high concentrations (30 and 50 me/100 g soil) of sodium were present (Figures 6 and 7). The replacing power of sodium is much greater than ammonium (52). In this case the sodium replaced the ammonium in the soil and dispersion occurred. Ammonia loss by displacement is affected by sodium salts, it is increased with sodium and  $\text{CaCO}_3$  (16).

The effects of potassium and ammonium on soil dispersion in the absence of sodium is presented in Figure 8. Again good flocculation occurred with treatment B (30 me/100 g soil). Higher concentration resulted in lower hydraulic conductivity, while lower concentrations resulted in very low hydraulic conductivities. Ammonium ion readily displaces exchangeable potassium ions from clay particles. The extent of this reaction is greatly influenced, however, by the degree of potassium saturation of the clay (29).

The effect of concentrations on soil dispersion is shown in Figures 9 and 10. High concentration of potassium and ammonium resulted in good flocculation (treatment C). Treatment A resulted in lower hydraulic conductivity than treatment C but hydraulic conductivity remained higher than for the untreated soil. This is due to the high concentration of potassium (30 and

50 me/100 g soil).

The effects of sodium, potassium, and ammonium combinations on soil dispersion are presented in Figure 11. In general, low levels of sodium with increasing amounts of potassium and ammonium resulted in a flocculated soil, but the degree of flocculation varied for different amounts of potassium and ammonium. Again 30 me  $\text{NH}_4^+$ /100 g soil combined with high amounts of potassium resulted in good flocculation. Even with high concentration of sodium (30 and 50 me/100 g soil), various levels of potassium and ammonium resulted in a flocculated soil (Figures 12 and 13). High concentrations of sodium (50 me/100 g soil) with medium levels of potassium and ammonium (30 me/100 g soil) did not have a great effect on soil dispersion (treatment A, Figure 13). This is due to fixation of cations in the soil. In the soil solution,  $\text{NH}_4^+$  is more effective than  $\text{K}^+$  in blocking the release of fixed  $\text{NH}_4^+$ . The blocking effect of a given fixable/nonfixable ion ratio in neutral solutions increases as the amounts of salt extractant per gram of mineral is increased. This is due to the preferential adsorption of the fixable cations. Higher K/Na ratios are required to block the release of fixed  $\text{NH}_4$  in neutral solutions than in alkaline solutions (26).

The effect of potassium and ammonium concentrations on hydraulic conductivities are shown in Figure 14.

Low concentration of potassium or ammonium ions resulted in flocculation. High concentrations of ammonium or potassium resulted in soil dispersion.

## 2. Scanning Electron Microscopy Method:

Low sodium concentration resulted in some soil dispersion (Figures 15 and 16) as compared with untreated soil (Figure 28).

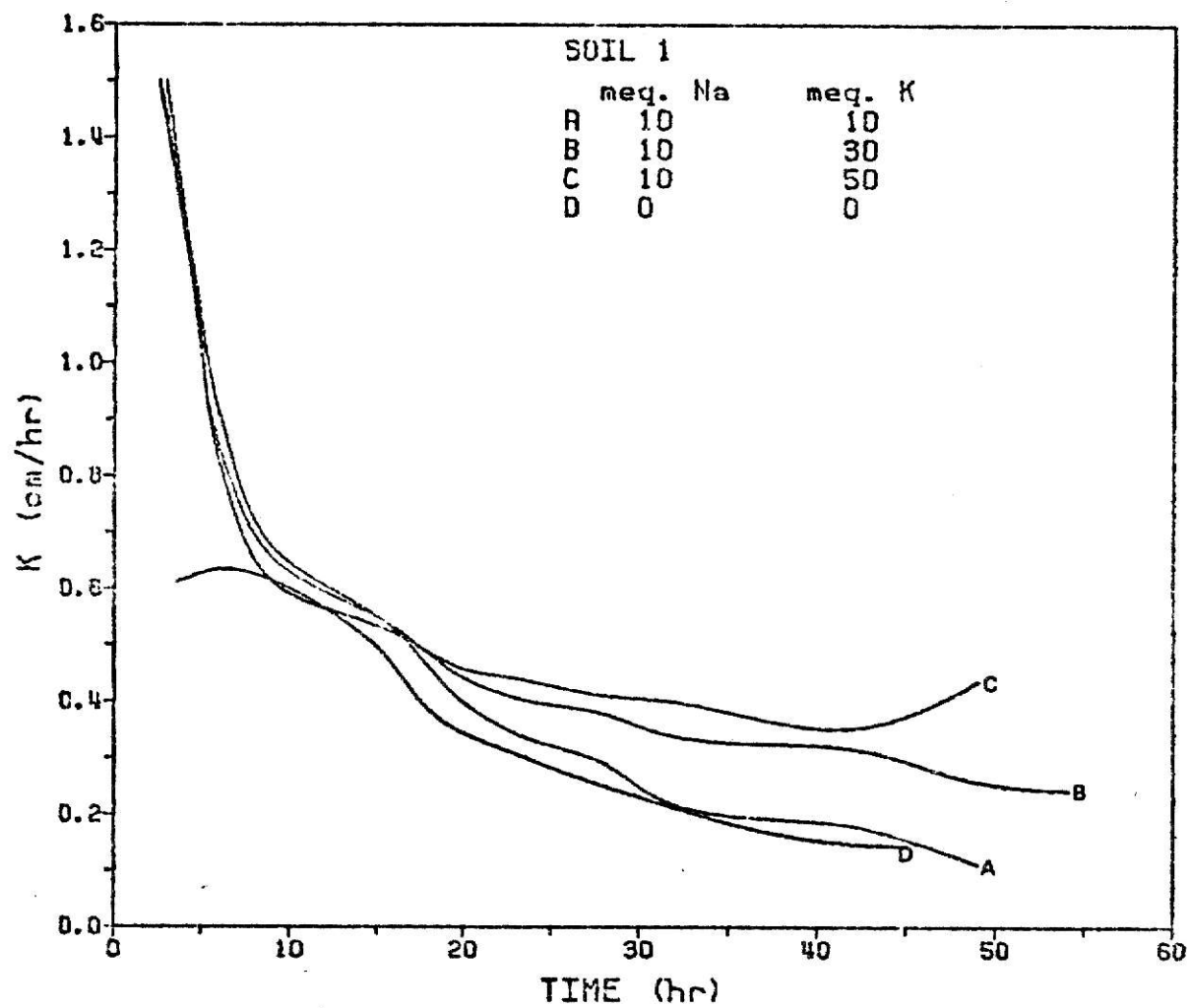


Fig. 2. Hydraulic conductivity measurement for Keith soil treated with 10 me  $\text{Na}^+$ /100 g soil and different levels of  $\text{K}^+$ .

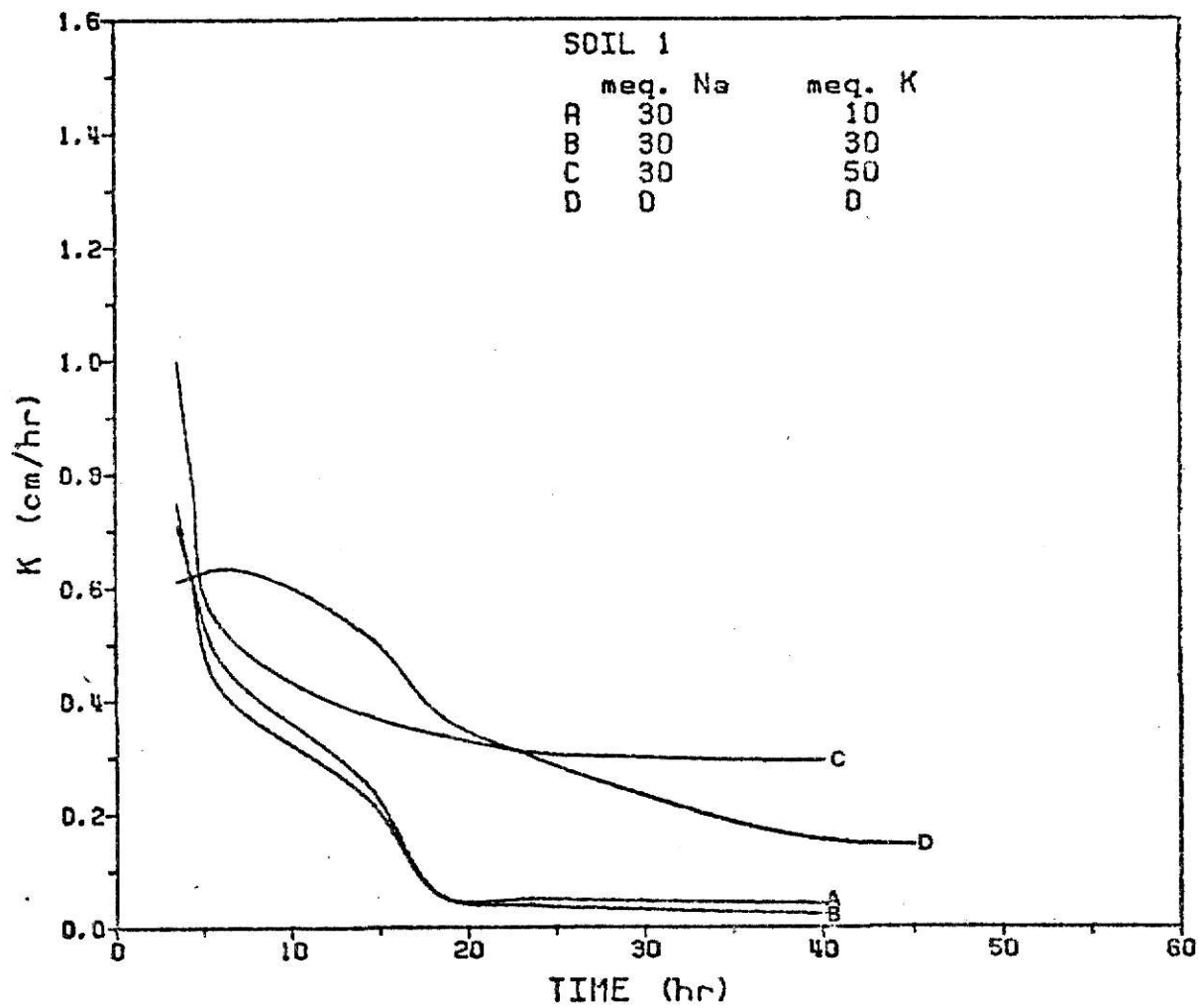


Fig. 3. Hydraulic conductivity measurement for Keith soil treated with 30 me  $\text{Na}^+$ /100 g soil and different levels of  $\text{K}^+$ .

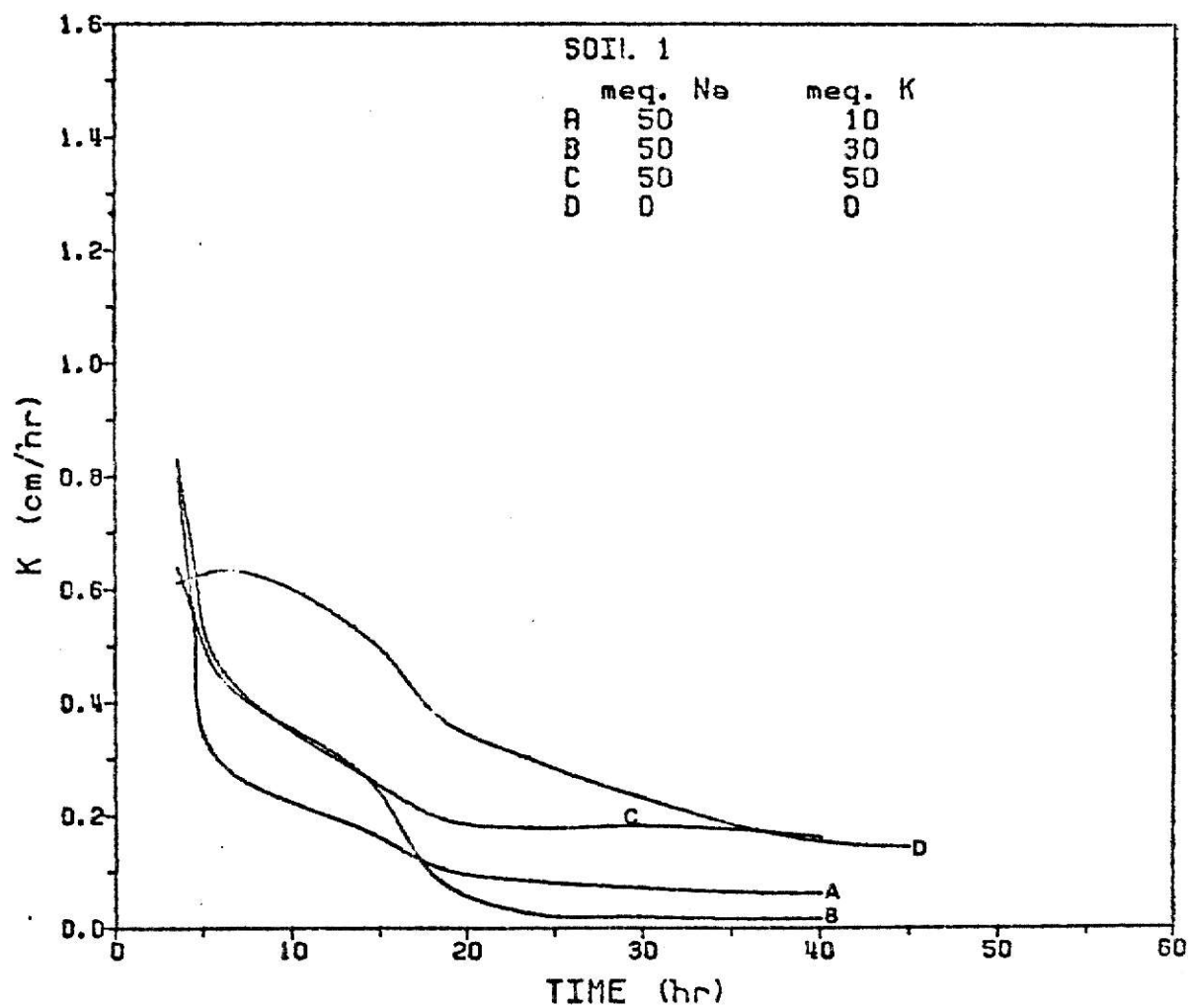


Fig. 4. Hydraulic conductivity measurement for Keith soil treated with 50 me  $\text{Na}^+$ /100 g soil and different levels of  $\text{K}^+$ .



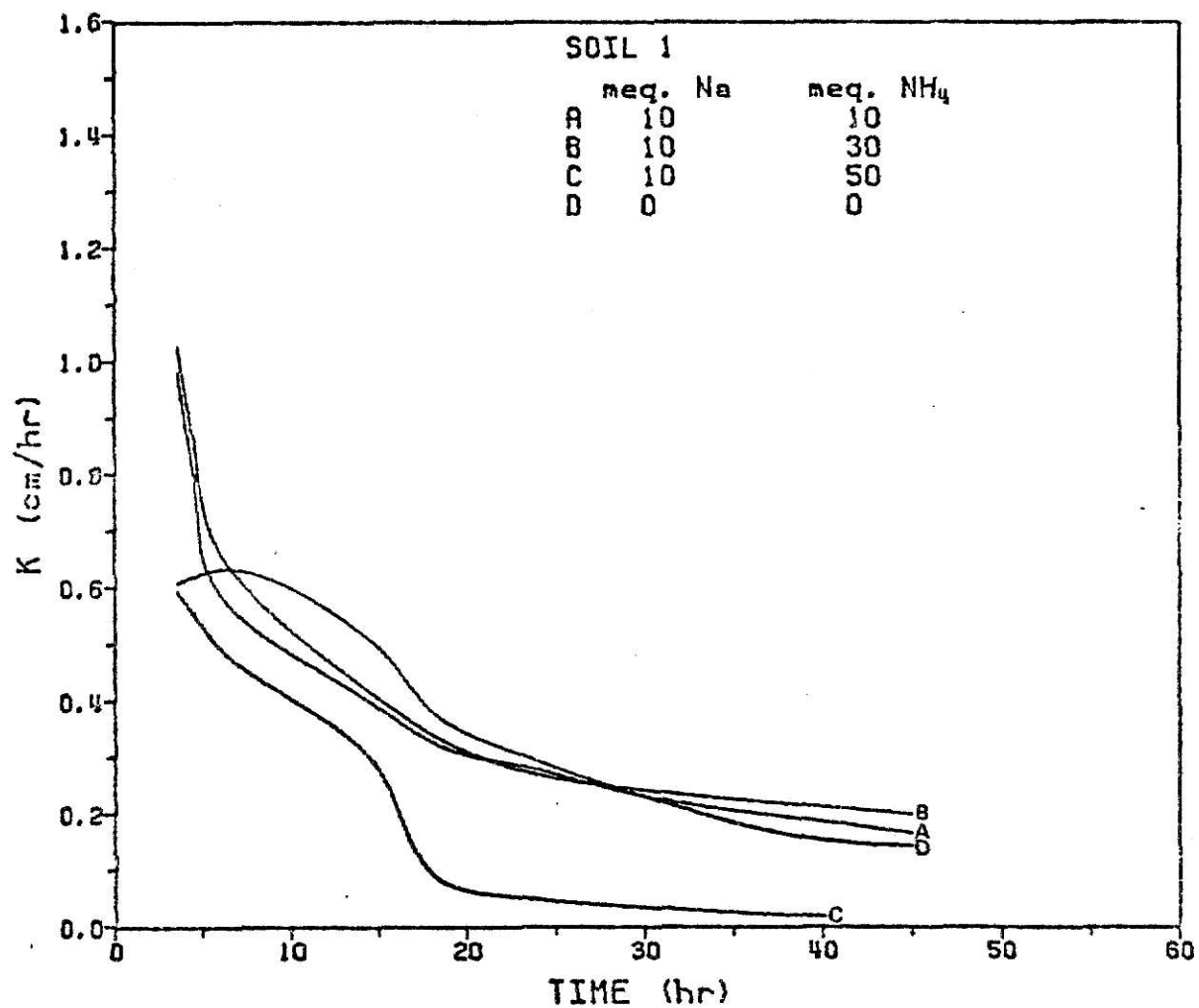


Fig. 5. Hydraulic conductivity measurement for Keith soil treated with 10 me  $\text{Na}^+$ /100 g soil and different levels of  $\text{NH}_4^+$ .

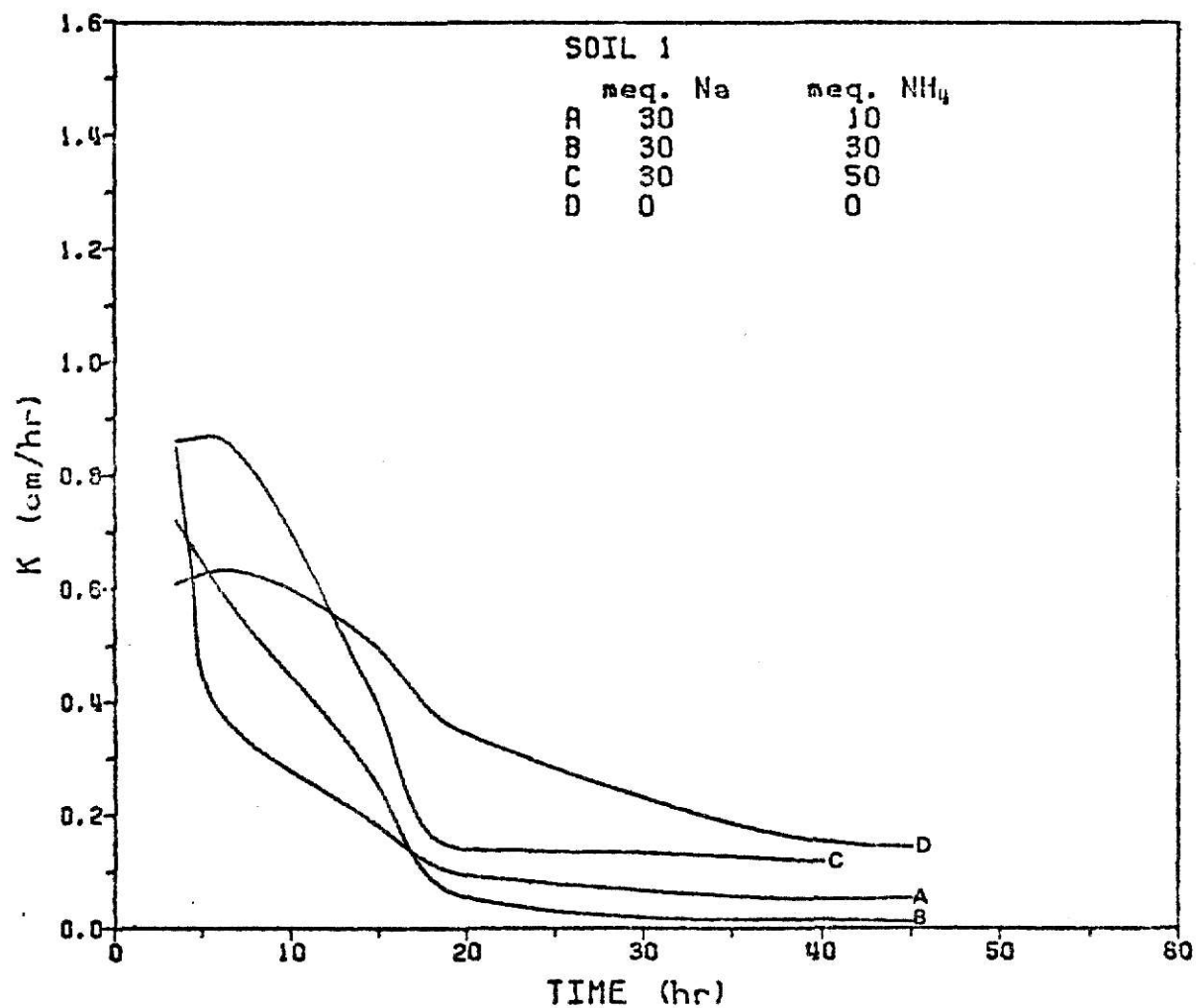


Fig. 6. Hydraulic conductivity measurement for Keith soil treated with 30 me  $\text{Na}^+$ /100 g soil and different levels of  $\text{NH}_4^+$ .

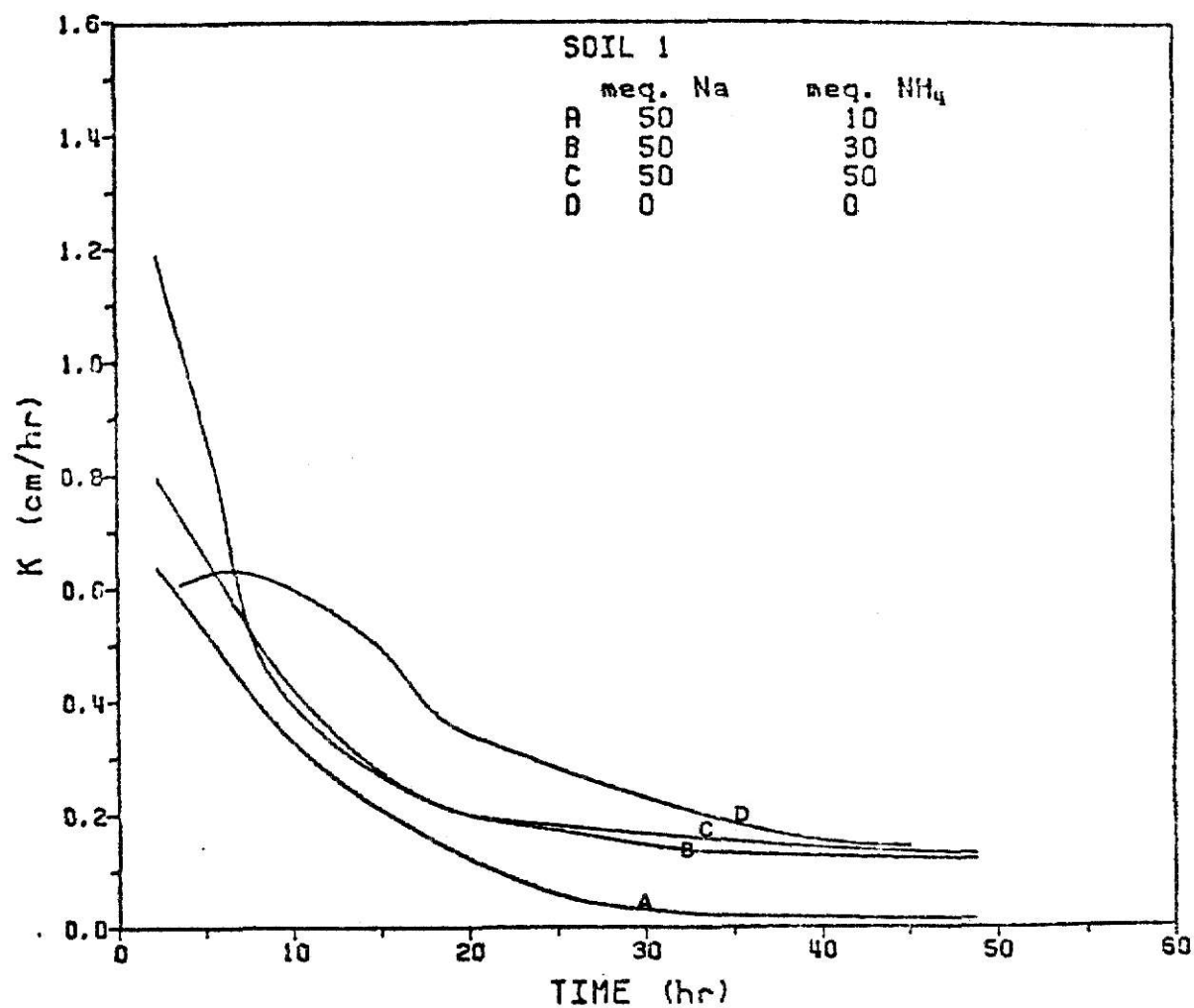


Fig. 7. Hydraulic conductivity measurement for Keith soil treated with 50 me  $\text{Na}^+$ /100 g soil and different levels of  $\text{NH}_4^+$ .

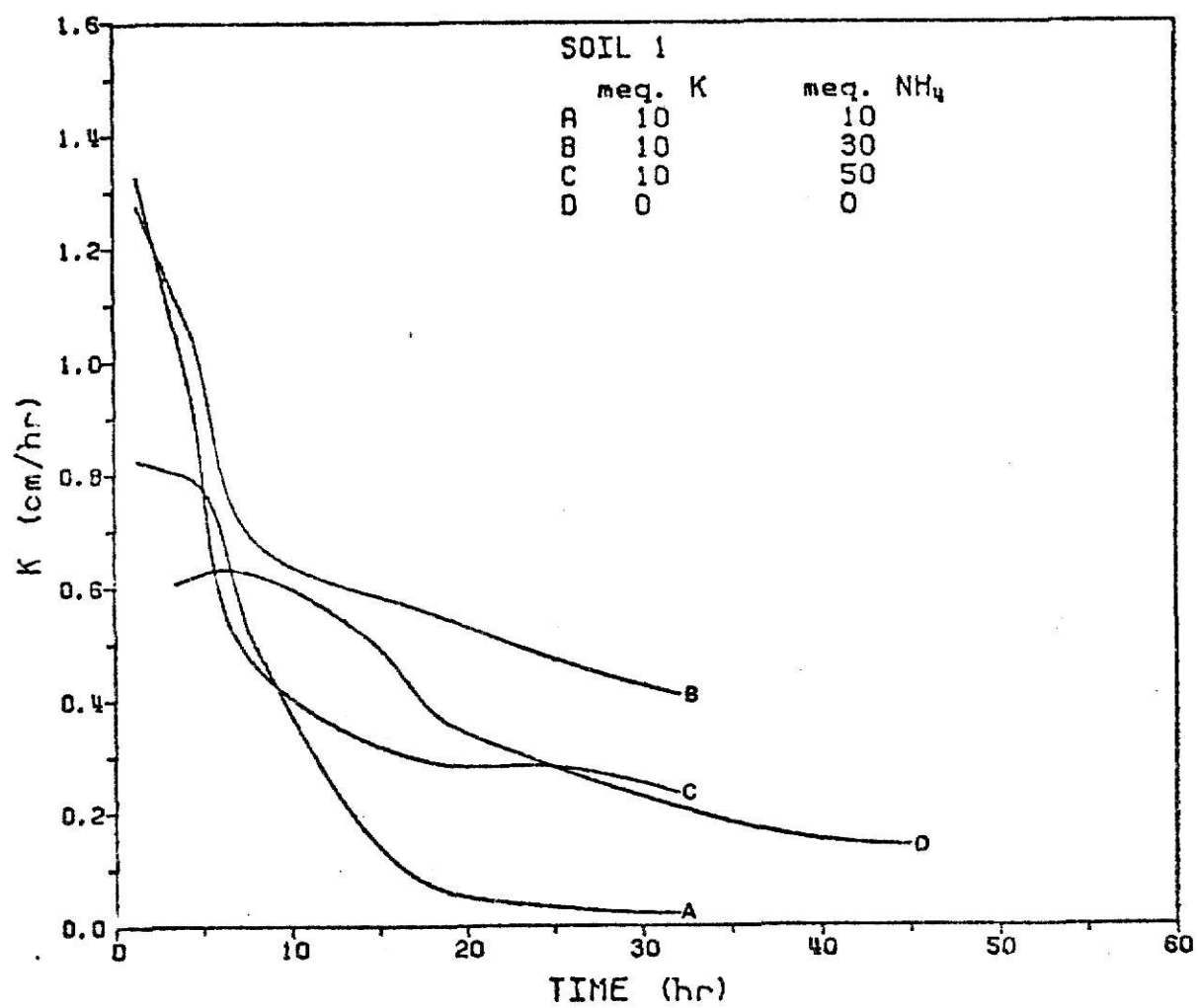


Fig. 8. Hydraulic conductivity measurement for Keith soil treated with 10 me  $\text{K}^+$ /100 g soil and different levels of  $\text{NH}_4^+$ .

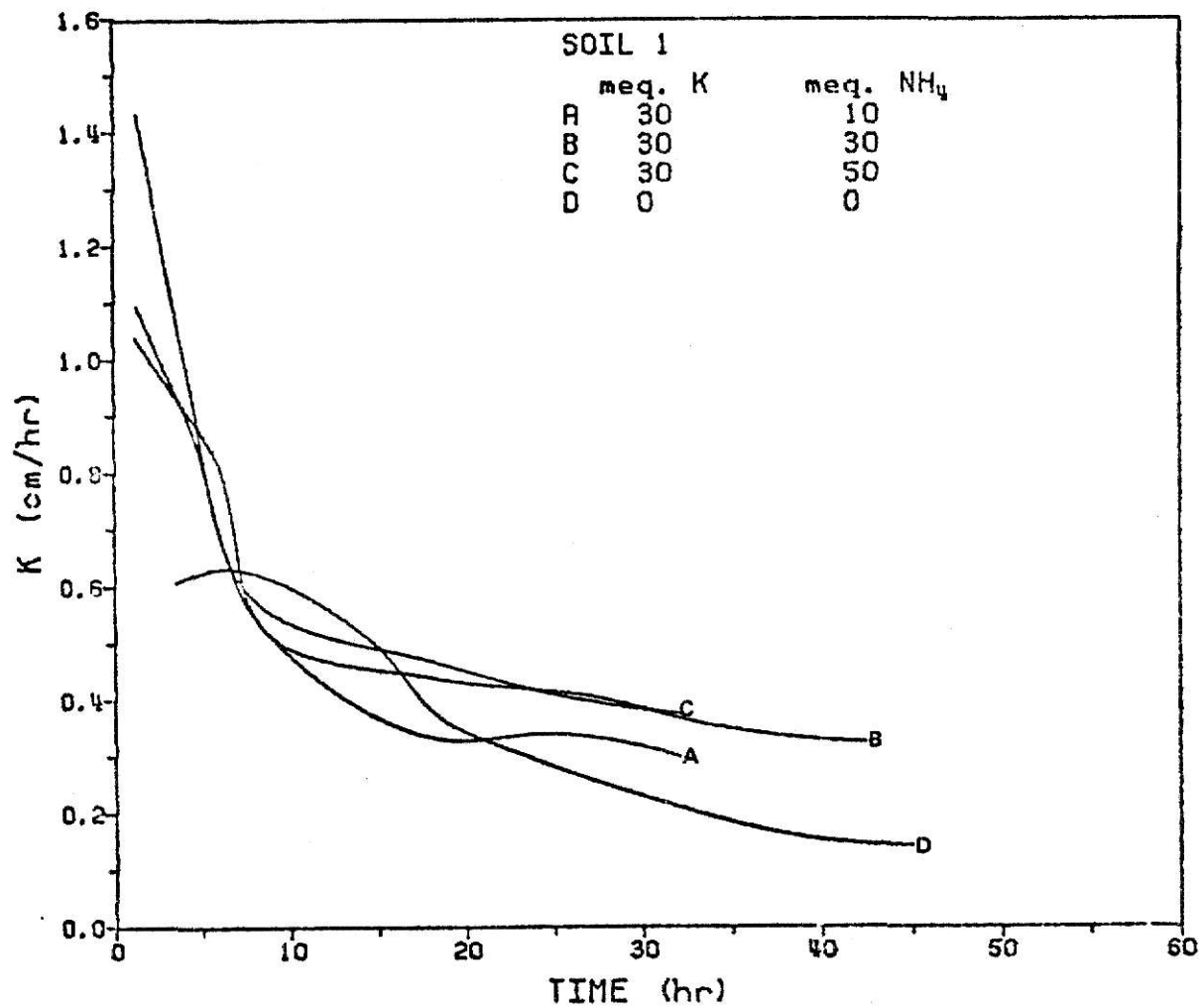


Fig. 9. Hydraulic conductivity measurements for Keith soil treated with 30 me  $\text{K}^+$ /100 g soil and different levels of  $\text{NH}_4^+$ .

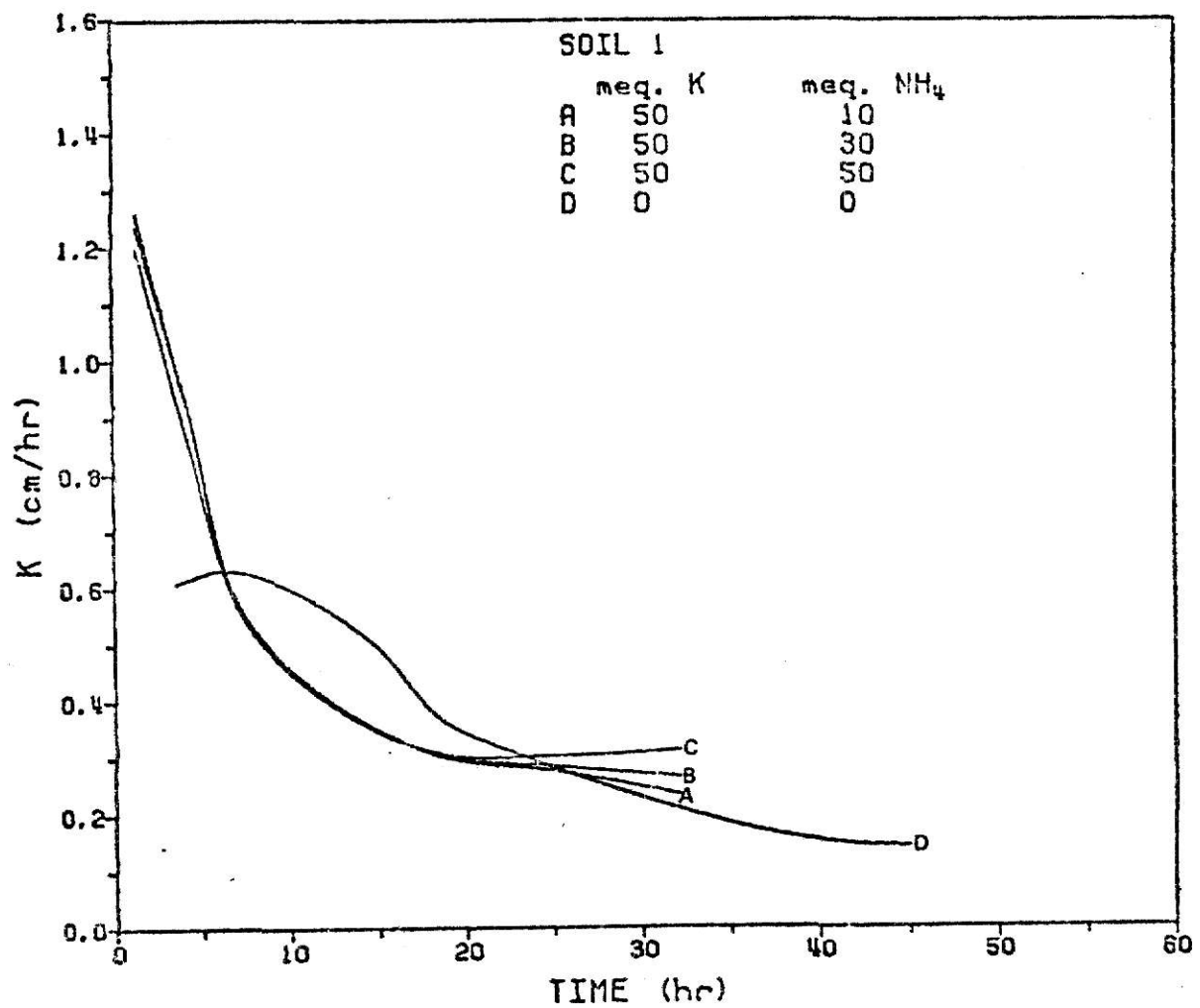


Fig. 10. Hydraulic conductivity measurement for Keith soil treated with 50 me  $\text{K}^+$ /100 g soil and different levels of  $\text{NH}_4^+$ .

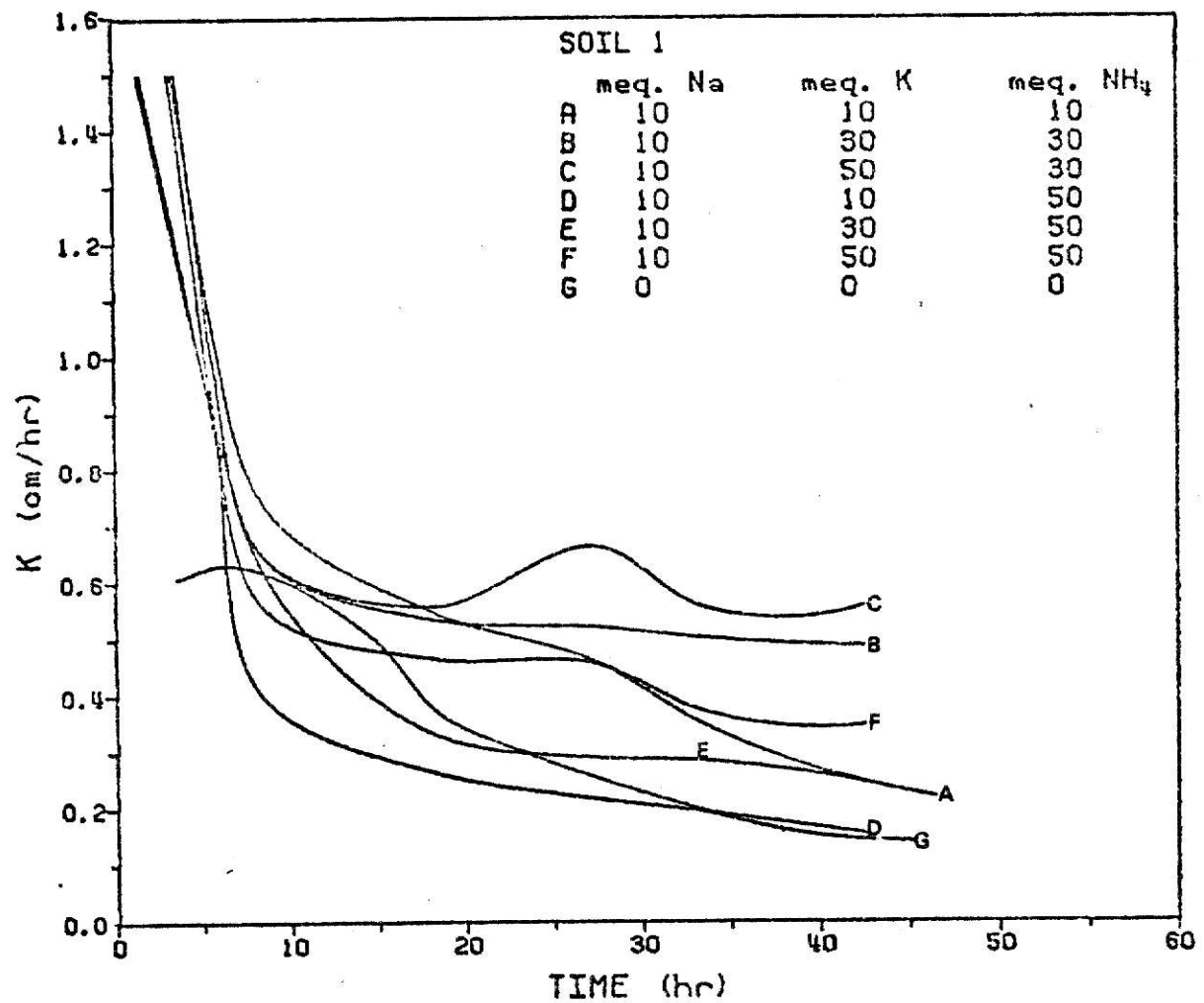


Fig. 11. Hydraulic conductivity measurement for Keith soil treated with 10 me  $\text{Na}^+$ /100 g soil and different levels of  $\text{K}^+$  and  $\text{NH}_4^+$ .

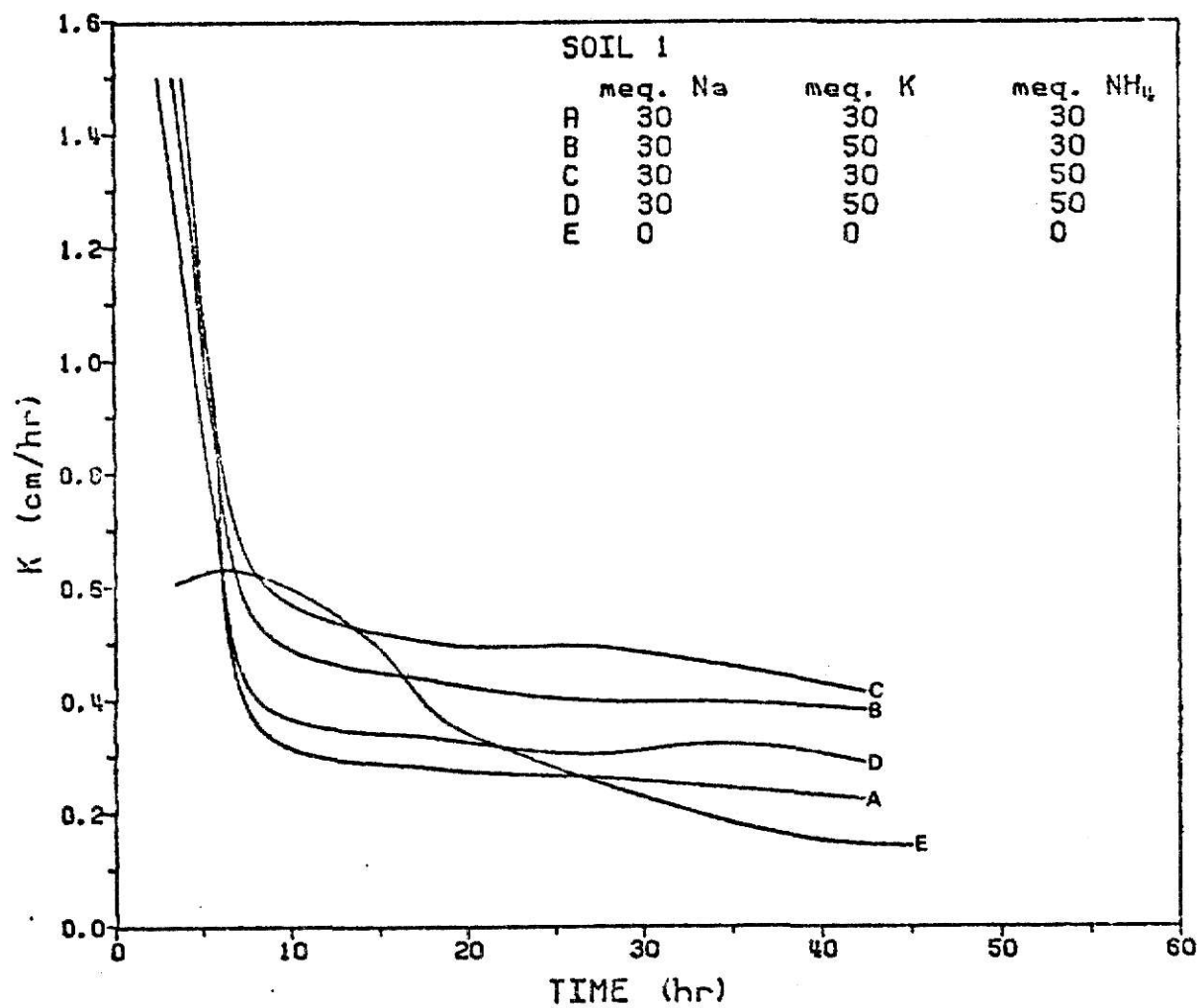


Fig. 12. Hydraulic conductivity measurement for Keith soil treated with 30 me  $\text{Na}^+$ /100 g soil and different levels of  $\text{K}^+$  and  $\text{NH}_4^+$ .



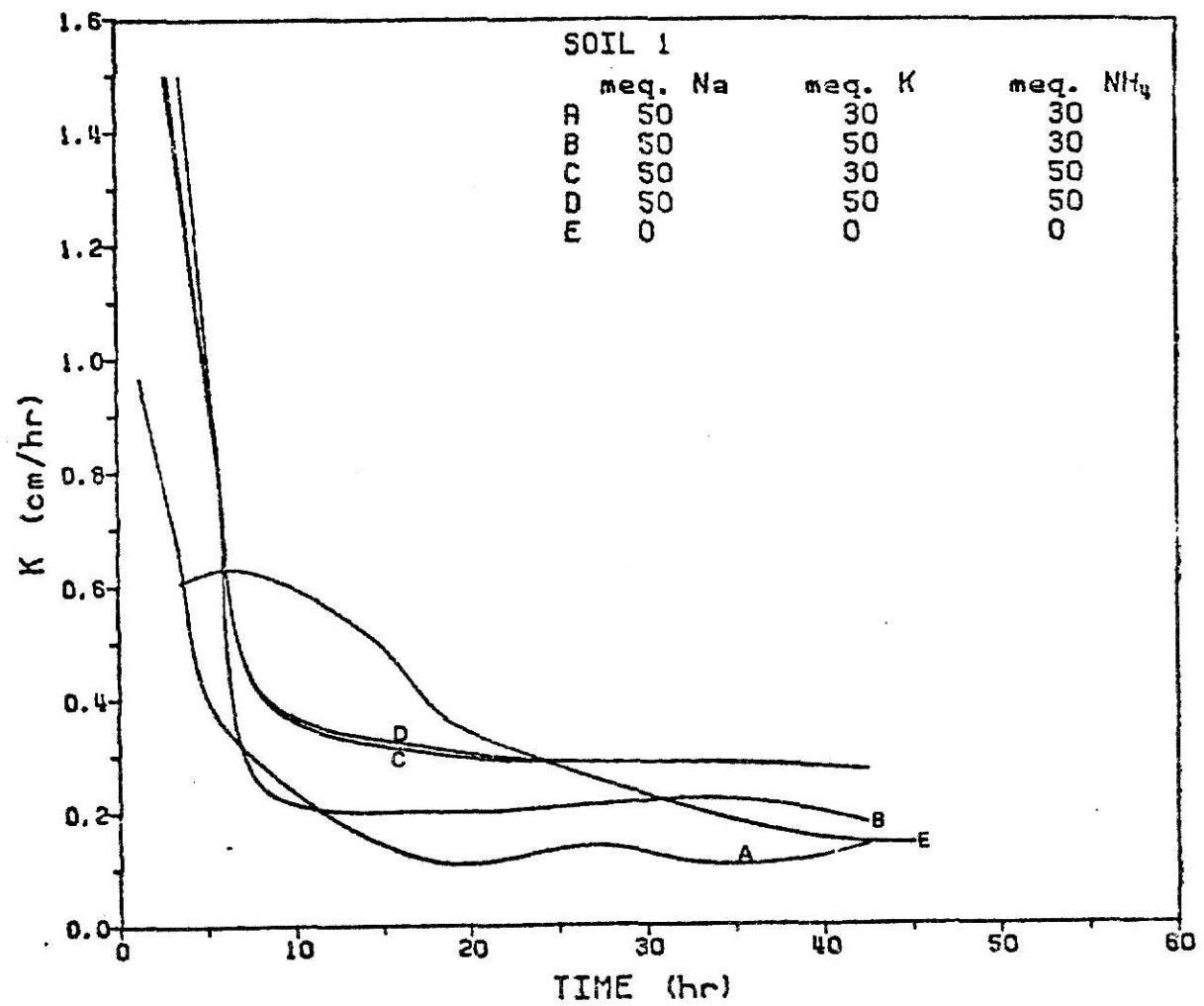


Fig. 13. Hydraulic conductivity measurement for Keith soil treated with 50 me  $\text{Na}^+$ /100 g soil and different levels of  $\text{K}^+$  and  $\text{NH}_4^+$ .

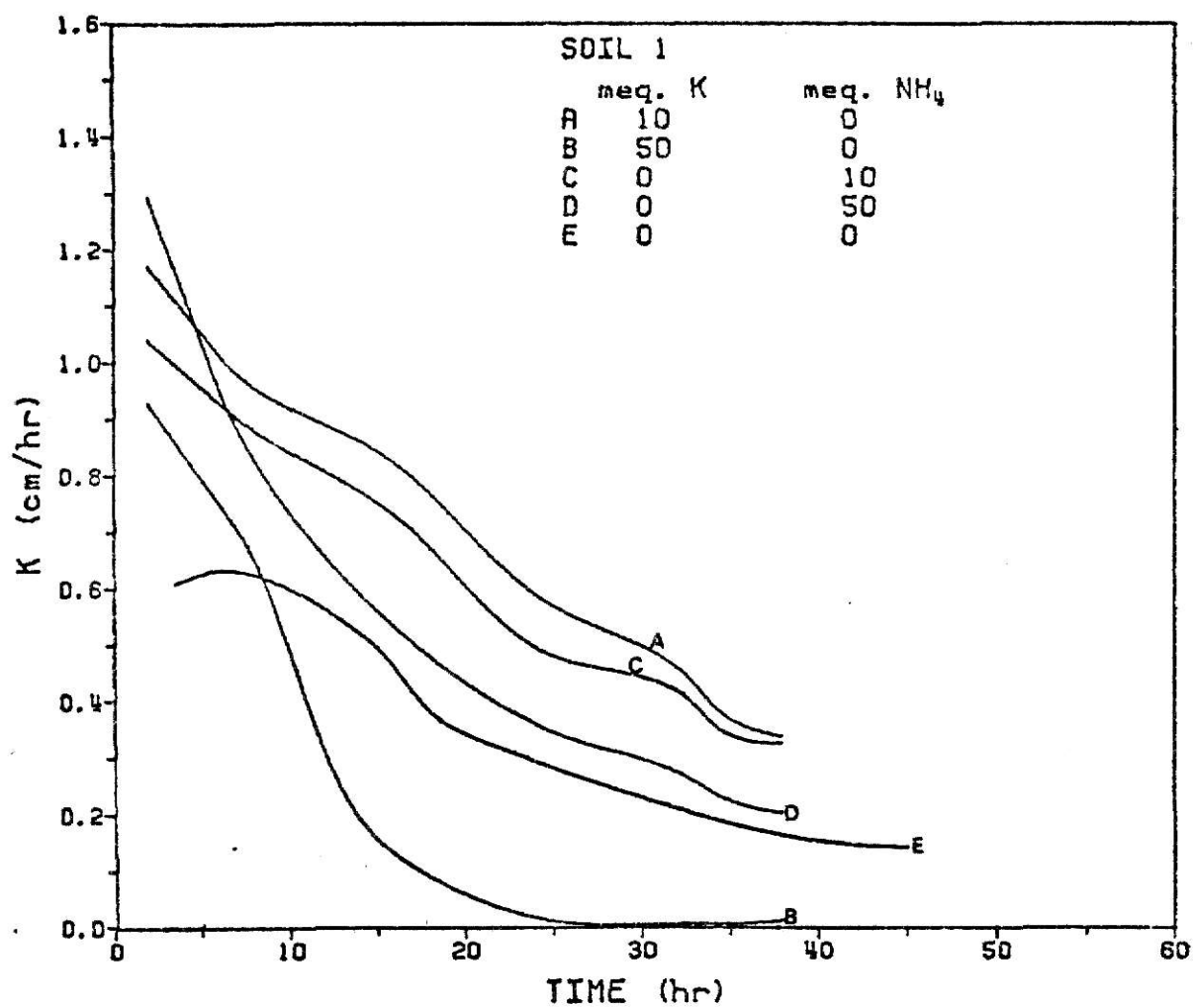


Fig. 14. Hydraulic conductivity measurement for Keith soil treated with different levels of  $\text{K}^+$  and  $\text{NH}_4^+$ .

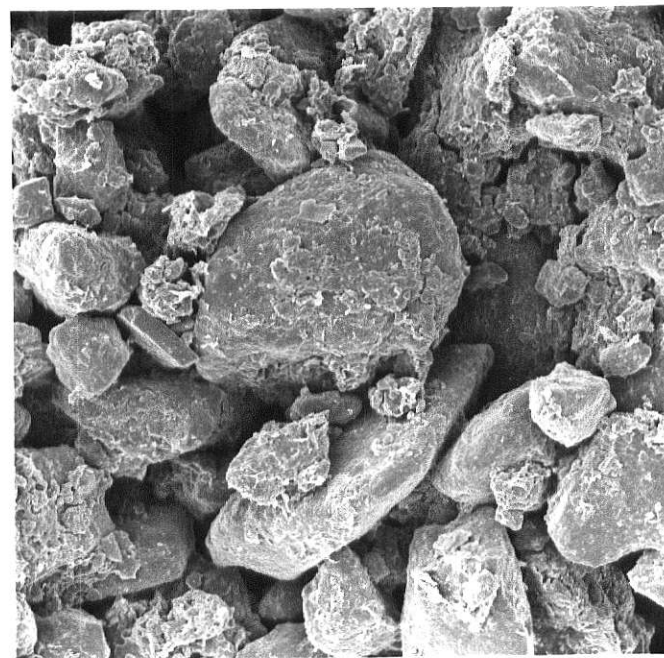


Fig. 15. SEM for Keith soil treated with 10 me Na<sup>+</sup> and 10 me K<sup>+</sup>/100 g soil.

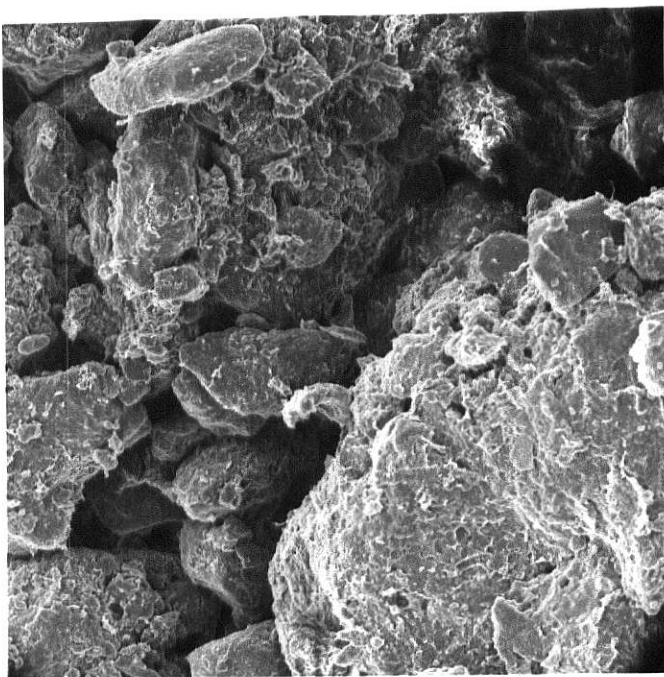


Fig. 16. SEM for Keith soil treated with 10 me Na<sup>+</sup> and 50 me K<sup>+</sup>/100 g soil.

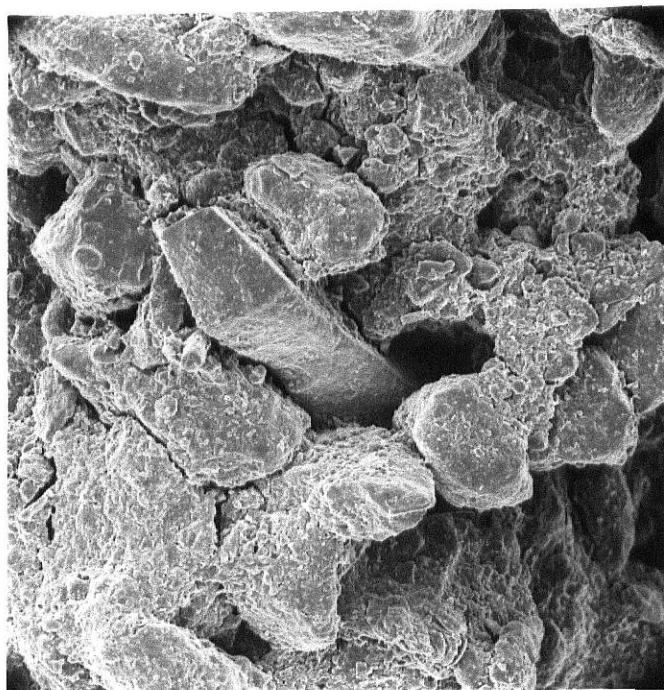


Fig. 17. SEM for Keith soil treated with 50 me Na<sup>+</sup> and 10 me NH<sub>4</sub><sup>+</sup>/100 g soil.

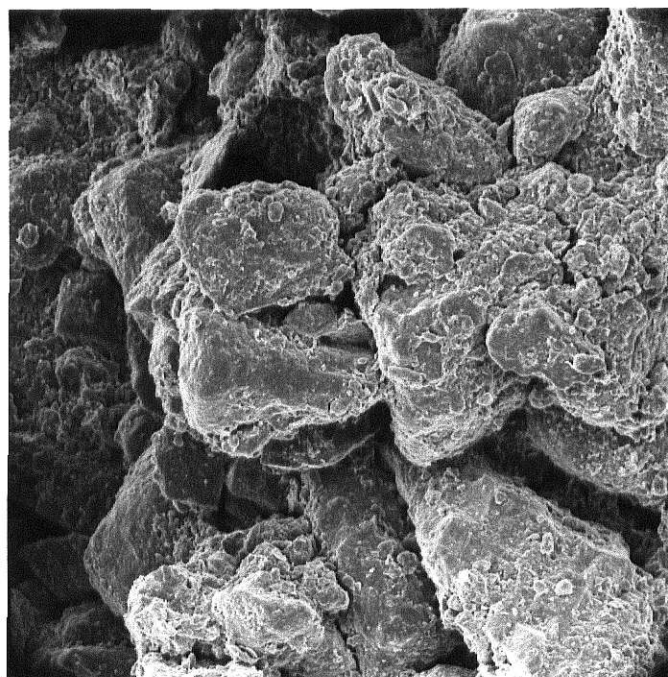


Fig. 18. SEM for Keith soil treated with 50 me Na<sup>+</sup> and 50 me NH<sub>4</sub><sup>+</sup>/100 g soil.

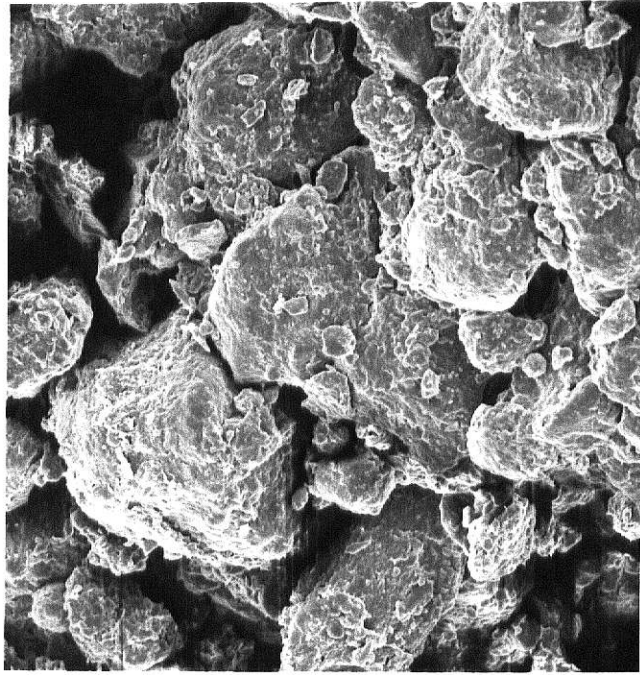


Fig. 19. SEM for Keith soil treated with 10 me  $K^+$  and 10 me  $NH_4^+$ /100 g soil.

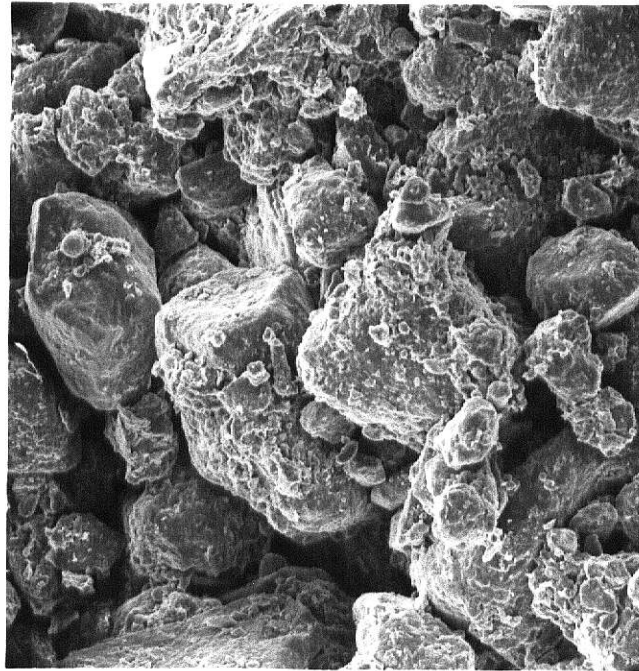


Fig. 20. SEM for Keith soil treated with 10 me  $K^+$  and 30 me  $NH_4^+$ /100 g soil.



Fig. 21. SEM for Keith soil treated with 50 me  $K^+$  and 30 me  $NH_4^+$ /100 g soil.

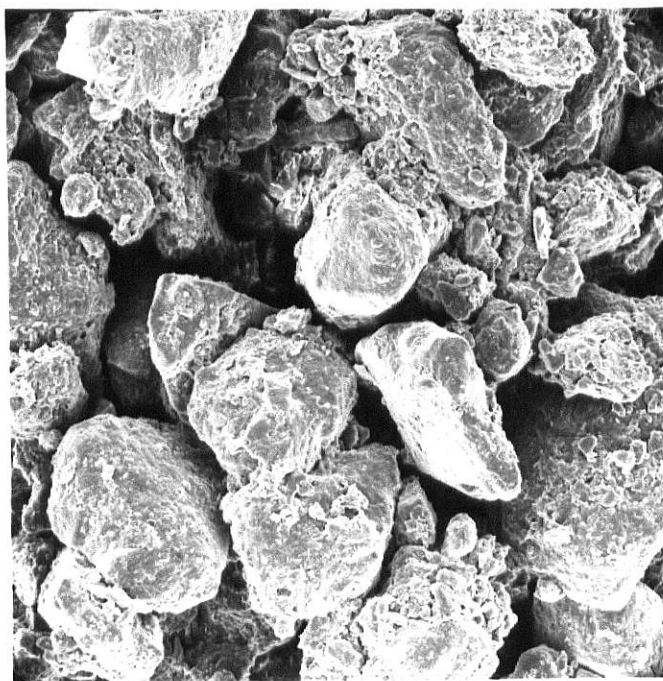


Fig. 22. SEM for Keith soil treated with 50 me  $K^+$  and 50 me  $NH_4^+$ /100 g soil.



Fig. 24. SEM for Keith soil treated with 10 me Na<sup>+</sup>, 50 me K<sup>+</sup>, and 30 me NH<sub>4</sub><sup>+</sup>/100 g soil.

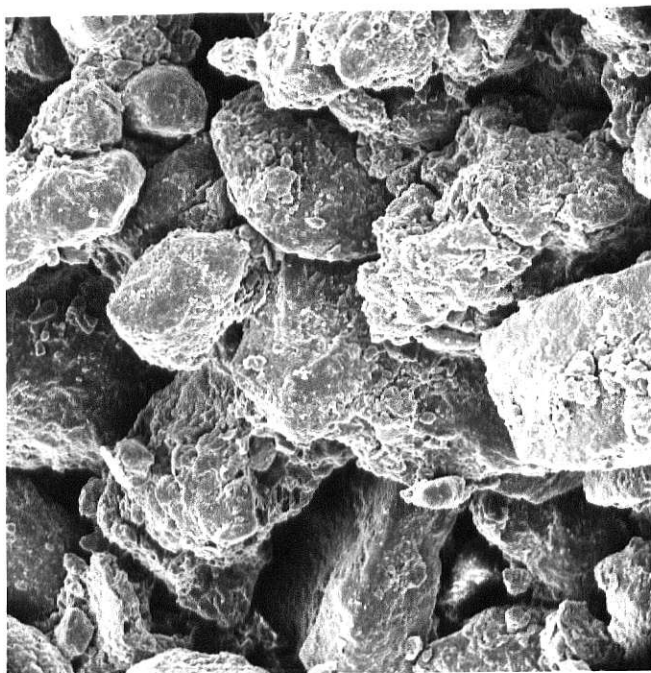


Fig. 23. SEM for Keith soil treated with 10 me Na<sup>+</sup>, 10 me K<sup>+</sup>, and 10 me NH<sub>4</sub><sup>+</sup>/100 g soil.



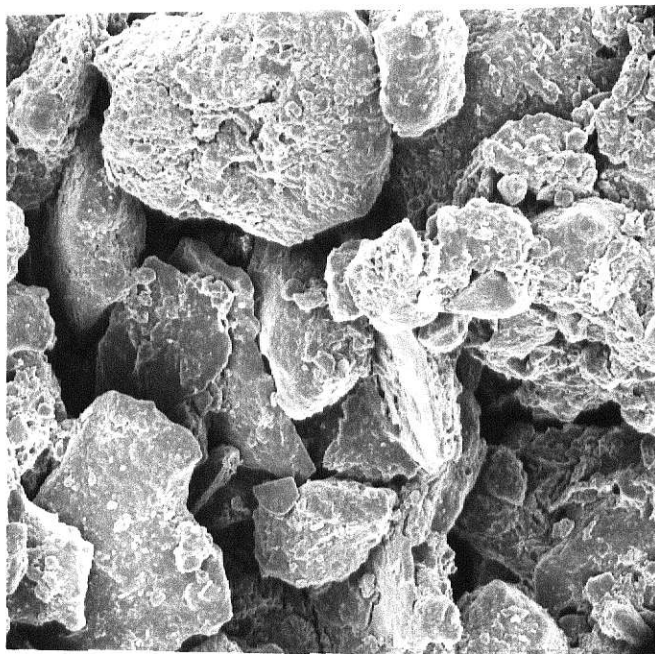


Fig. 25. SEM for Keith soil treated with 10 me  $\text{Na}^+$ , 50 me  $\text{K}^+$ , and 50 me  $\text{NH}_4^+$ /100 g soil.

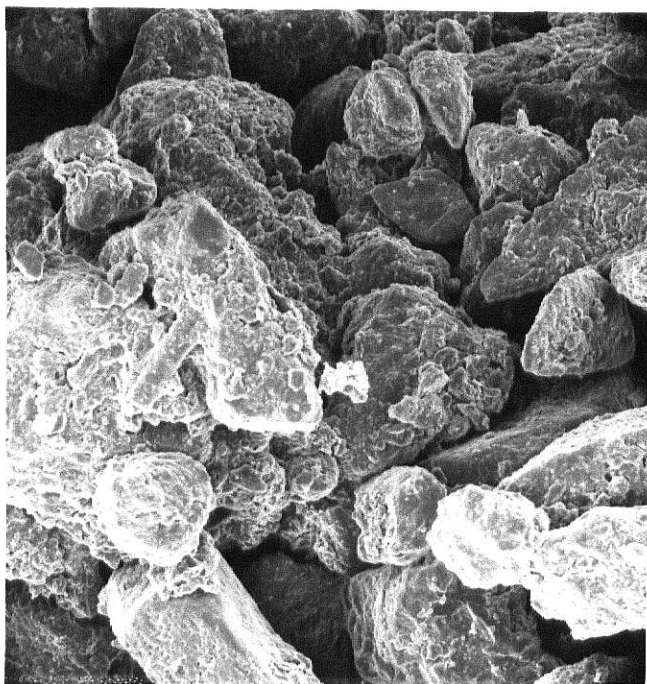


Fig. 26. SEM for Keith soil treated with 30 me  $\text{Na}^+$ , 50 me  $\text{K}^+$ , and 50 me  $\text{NH}_4^+$ /100 g soil.



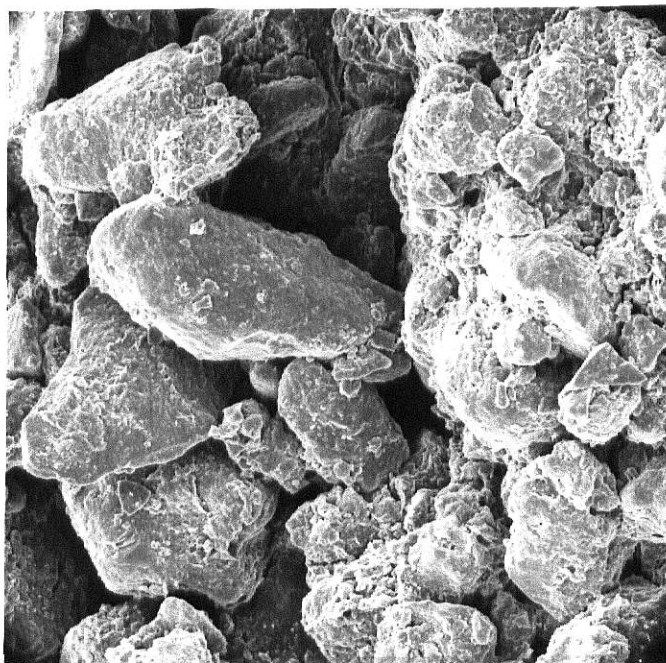


Fig. 27. SEM for Keith soil treated with 50 me Na<sup>+</sup>, 30 me K<sup>+</sup>, and 30 me NH<sub>4</sub><sup>+</sup>/100 g soil.

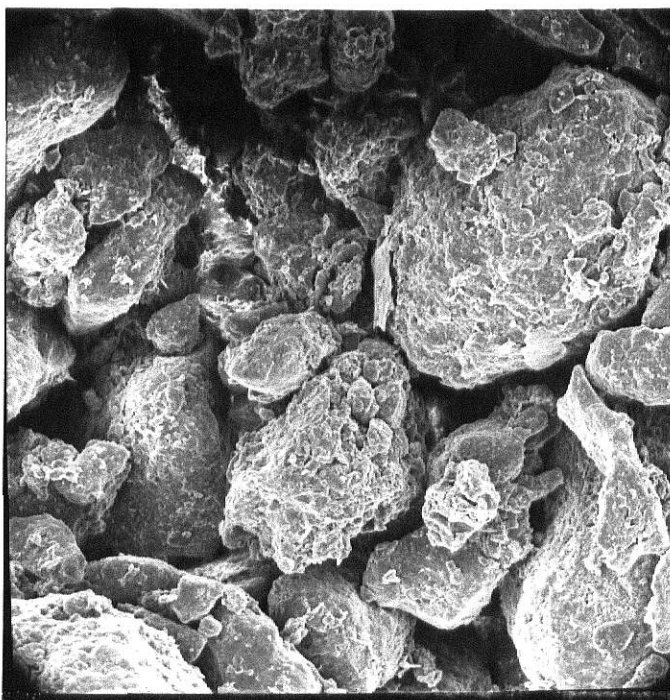


Fig. 28. SEM for untreated Keith soil.

Soil dispersion increased when the concentrations of sodium increased (Figures 17 and 27). As the concentrations of ammonium ions increased at the same level of sodium (Figure 18), soil structure improved somewhat.

Soil structure changed with levels of sodium (Figures 23, 24, 25, 26 and 27). More dispersion occurred with high level of sodium (Figure 27). Some dispersion occurred at low levels of sodium (Figures 23, 24 and 25) compared with untreated soil (Figure 28).

No dispersion occurred with potassium and ammonium at the zero level of sodium (Figures 19, 20, 21 and 22) compared with the untreated soil (Figure 28).

#### Richfield silty clay loam soil

The type of soil is a very important factor in soil dispersion. The results for this soil were very different than for the two other soils. This soil originally contained more sodium and had high clay content which could influence dispersion.

##### 1. Hydraulic Conductivity Method:

All treatments resulted in lower hydraulic conductivities compared with untreated soil (Figures 29-41), but there were some differences between treatments, for example, Figure 29, treatment C (10 me/100 g soil  $\text{Na}^+$  + 50 me/100 g soil  $\text{K}^+$ ) resulted in less dispersion than treatments A and B.

Increasing concentrations of sodium increased dispersion (Figures 29, 30 and 31). The hydraulic conductivity went to zero (Figure 31) with high level of sodium (50 me/100 g soil) at all K levels. Dispersion of soil occurred with all sodium and ammonium treatments (Figures 32, 33 and 34).

Quicker dispersion occurred with high sodium treatments, 30 me/100 g soil (Figures 33 and 34).

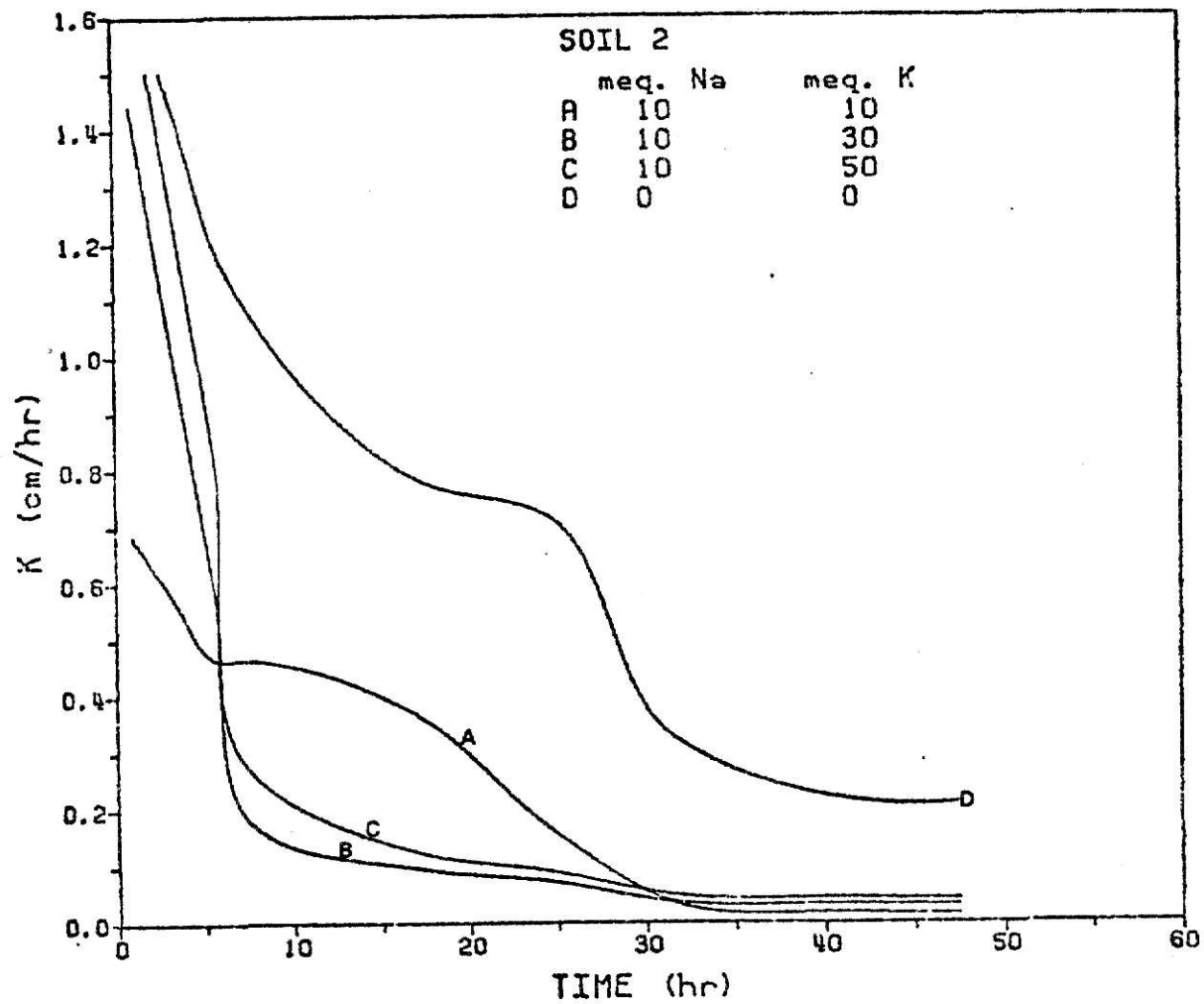


Fig. 29. Hydraulic conductivity measurement for Richfield soil treated with 10 me  $\text{Na}^+$ /100 g soil and different levels of  $\text{K}^+$ .

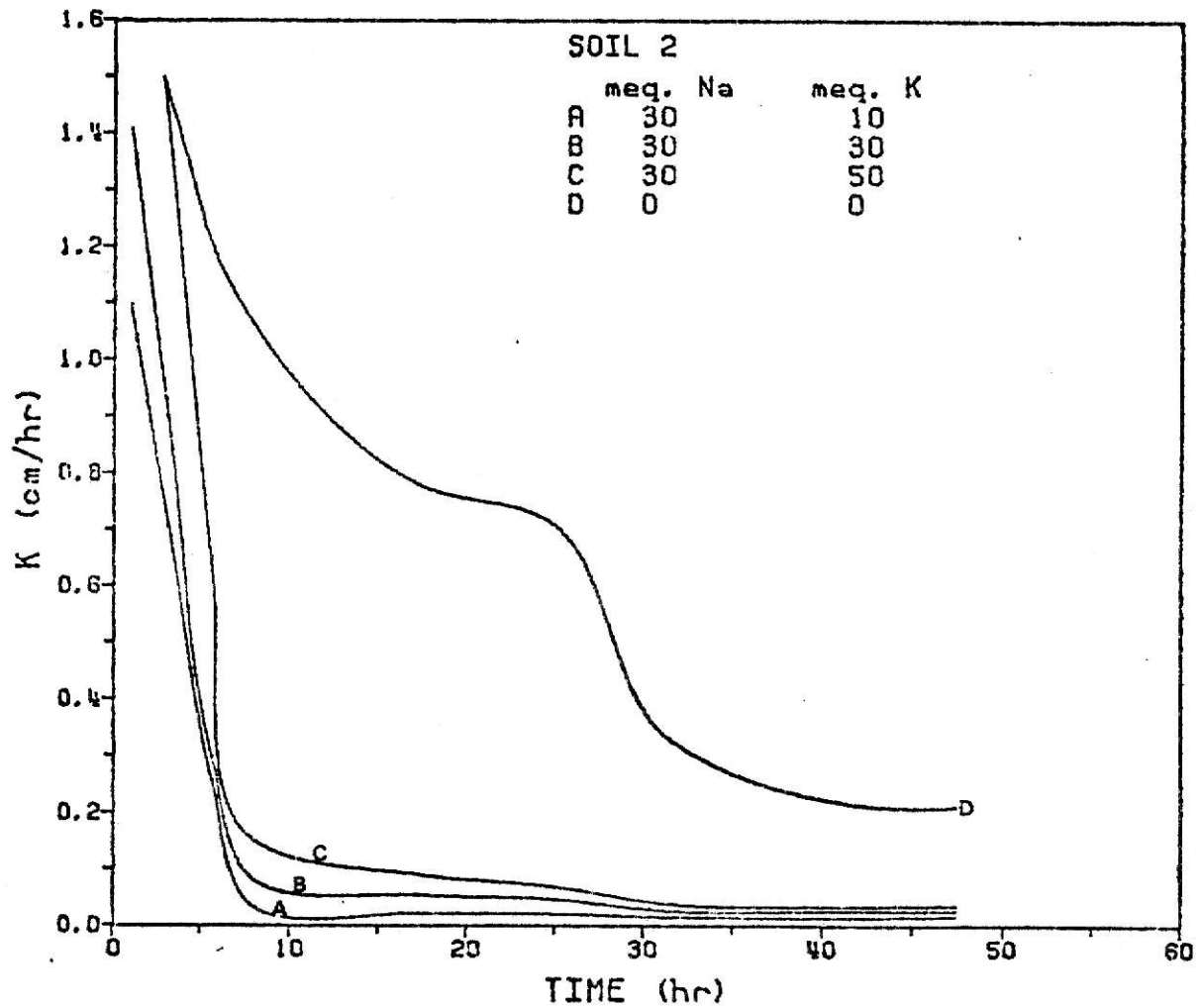


Fig. 30. Hydraulic conductivity measurement for Richfield soil treated with 30 me  $\text{Na}^+$ /100 g soil and different levels of  $\text{K}^+$ .

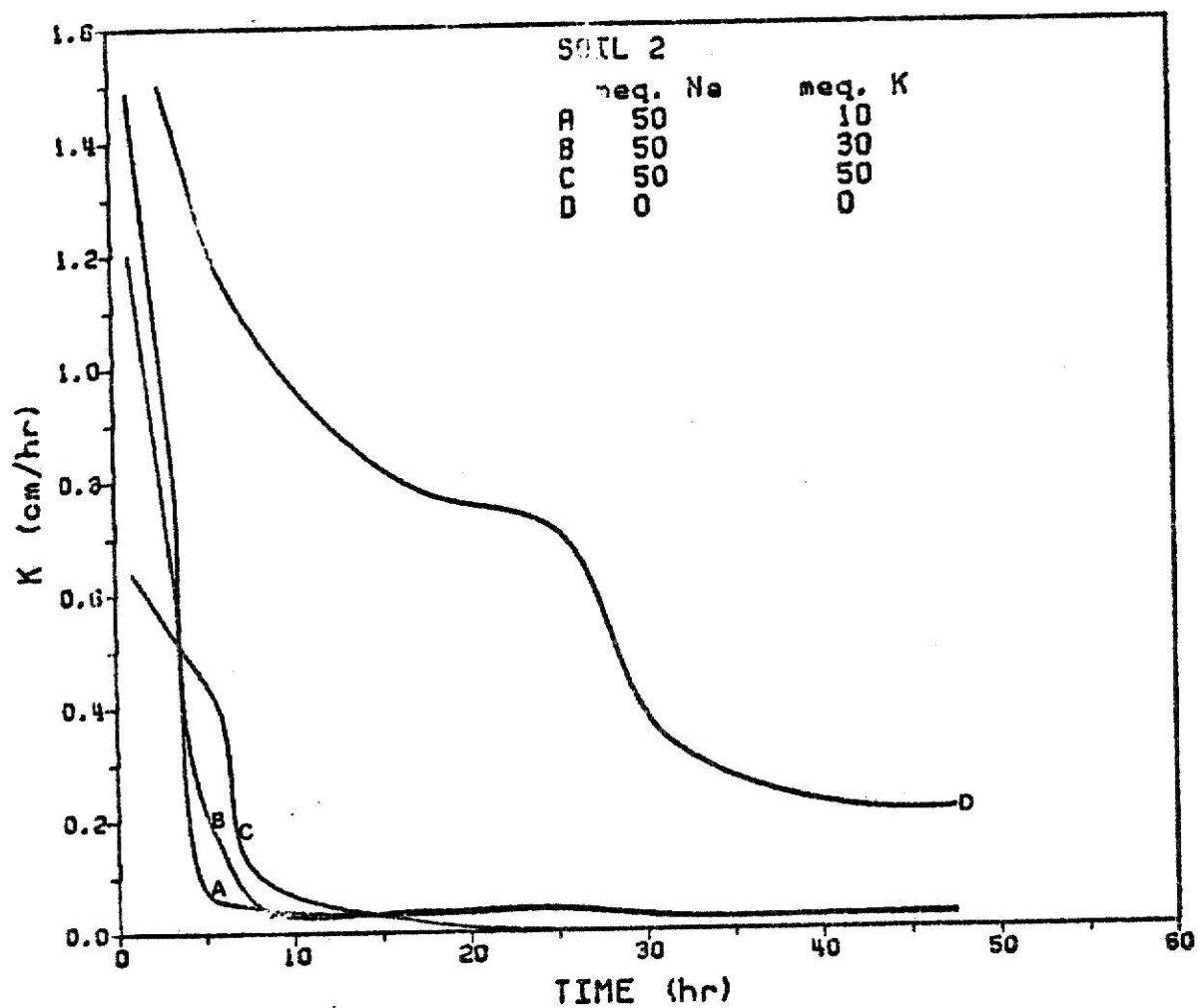


Fig. 31. Hydraulic conductivity measurement for Richfield soil treated with 50 me  $\text{Na}^+$ /100 g soil and different levels of  $\text{K}^+$ .

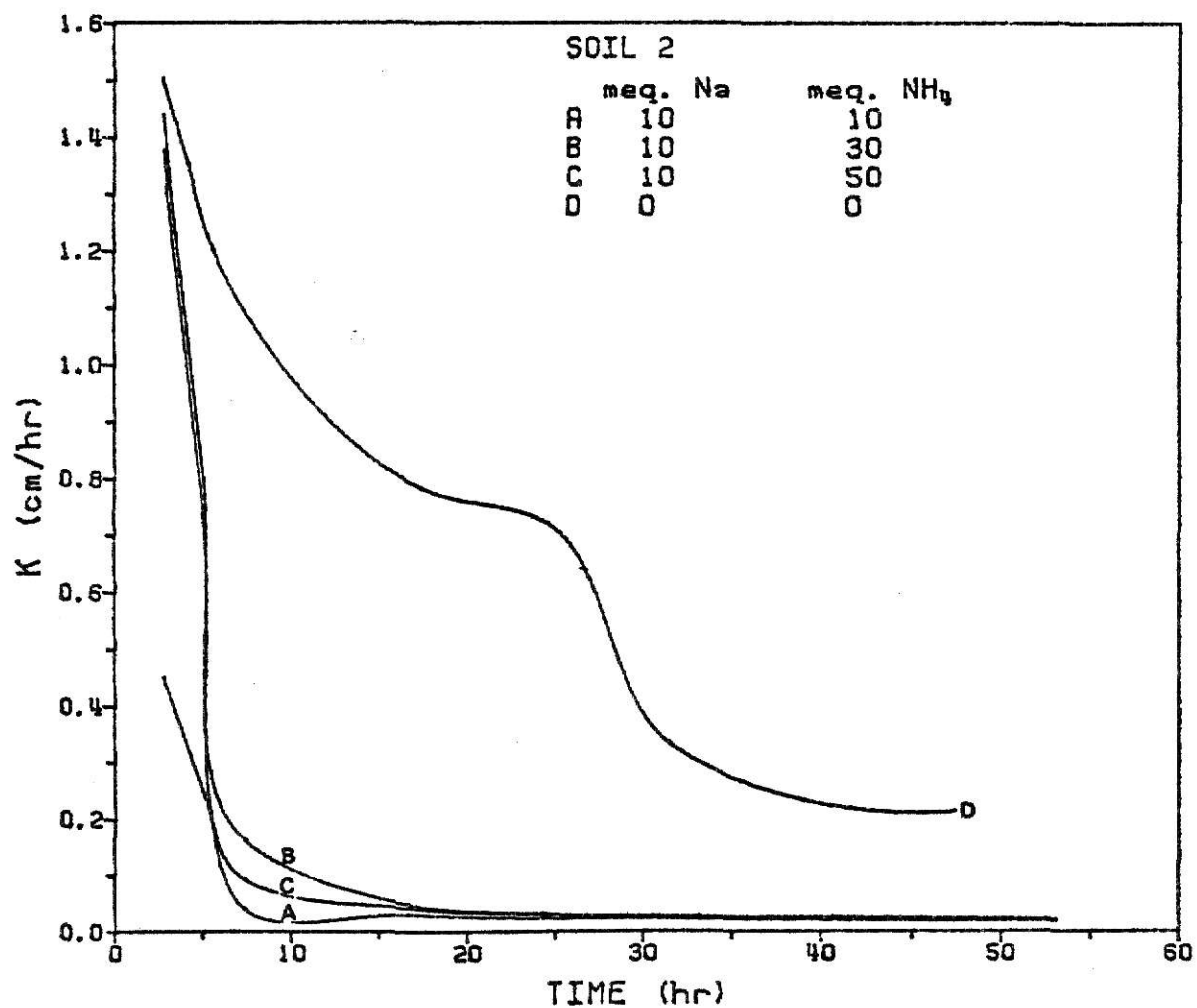


Fig. 32. Hydraulic conductivity measurement for Richfield soil treated with 10 me  $\text{Na}^+$ /100 g soil and different levels of  $\text{NH}_4^+$ .

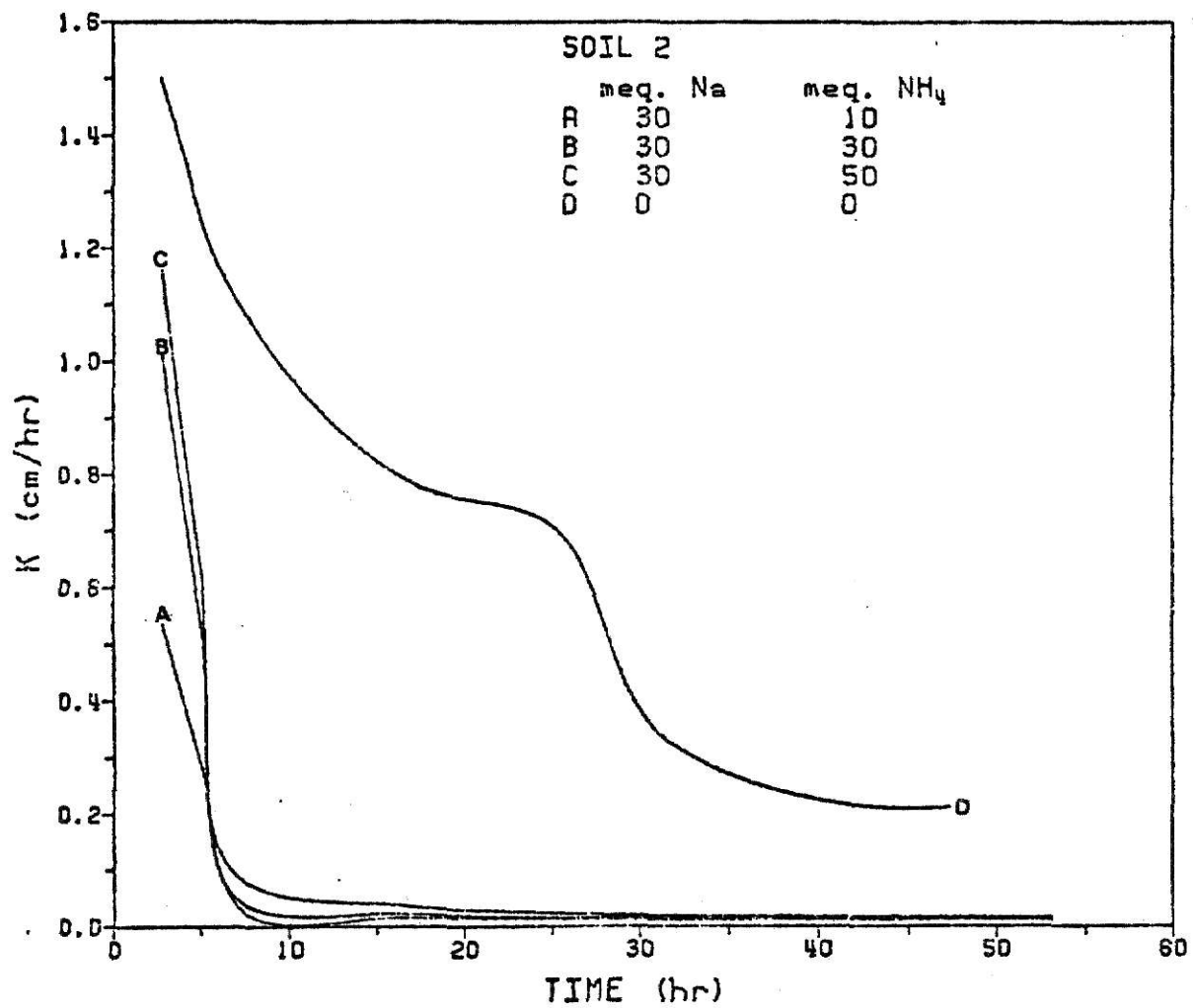


Fig. 33. Hydraulic conductivity measurement for Richfield soil treated with 30 me  $\text{Na}^+$ /100 g soil and different levels of  $\text{NH}_4^+$ .

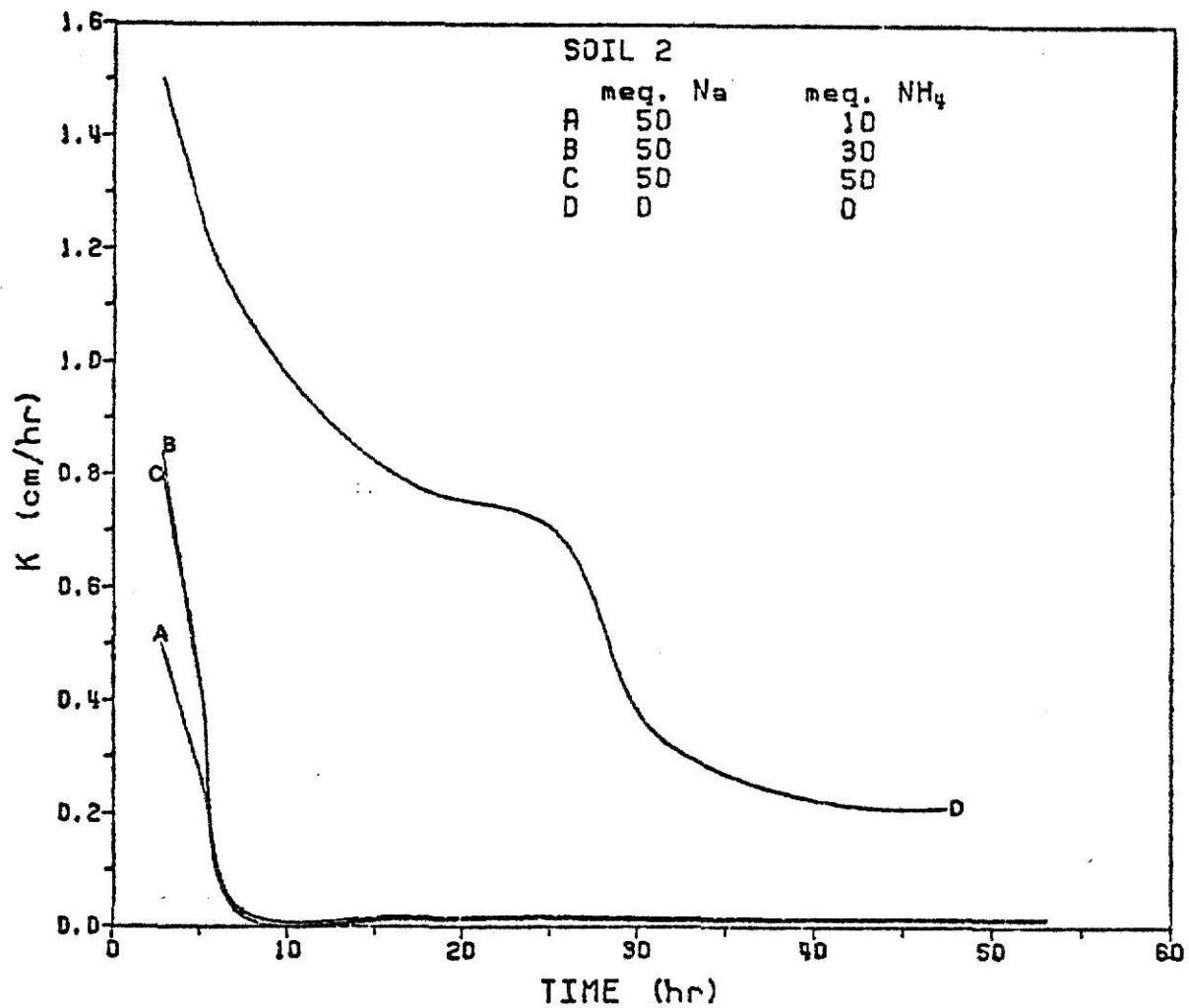


Fig. 34. Hydraulic conductivity measurement for Richfield soil treated with 50 me  $\text{Na}^+$ /100 g soil and different levels of  $\text{NH}_4^+$ .



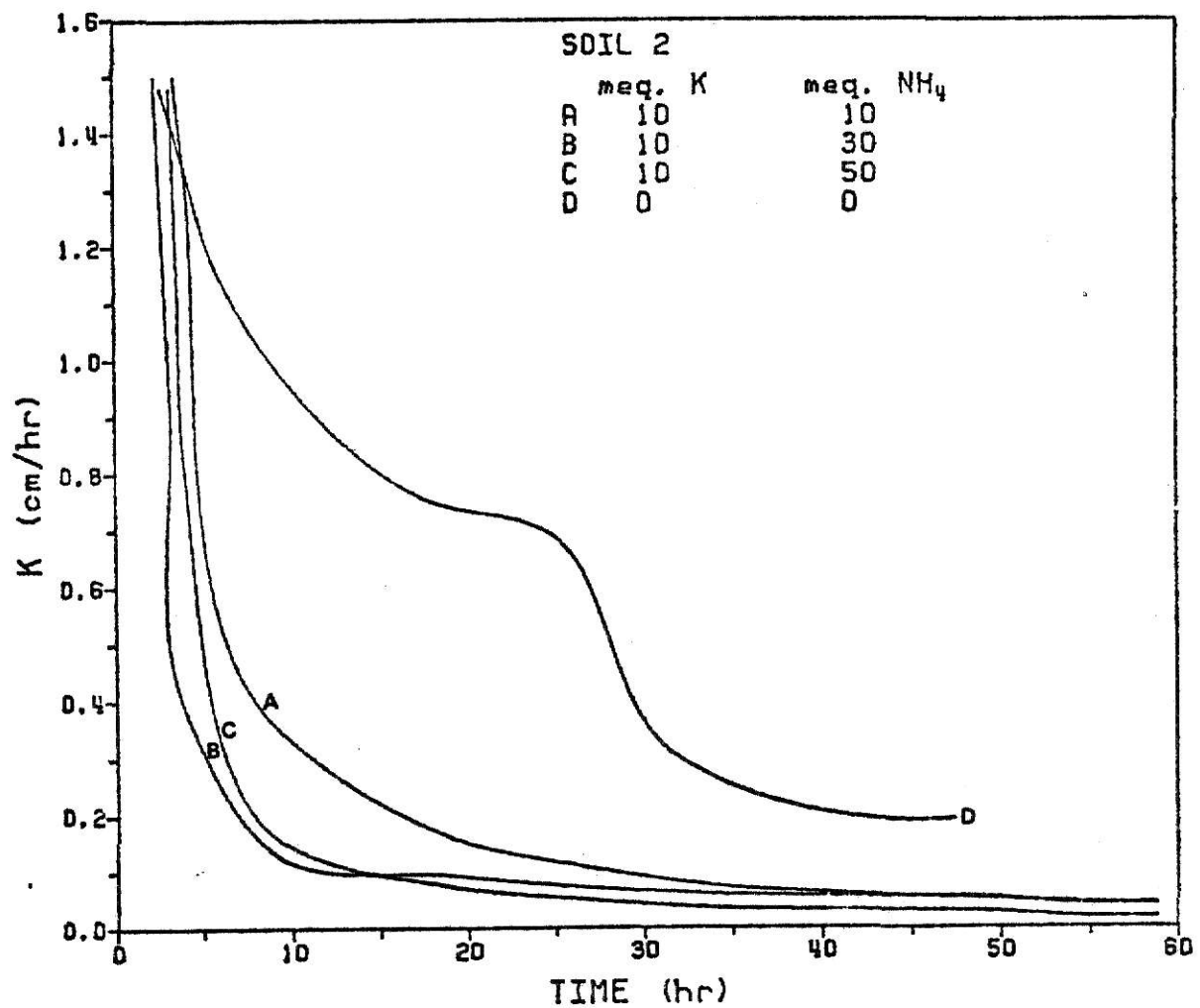


Fig. 35. Hydraulic conductivity measurement for Richfield soil treated with 10 me  $\text{K}^+$ /100 g soil and different levels of  $\text{NH}_4^+$ .

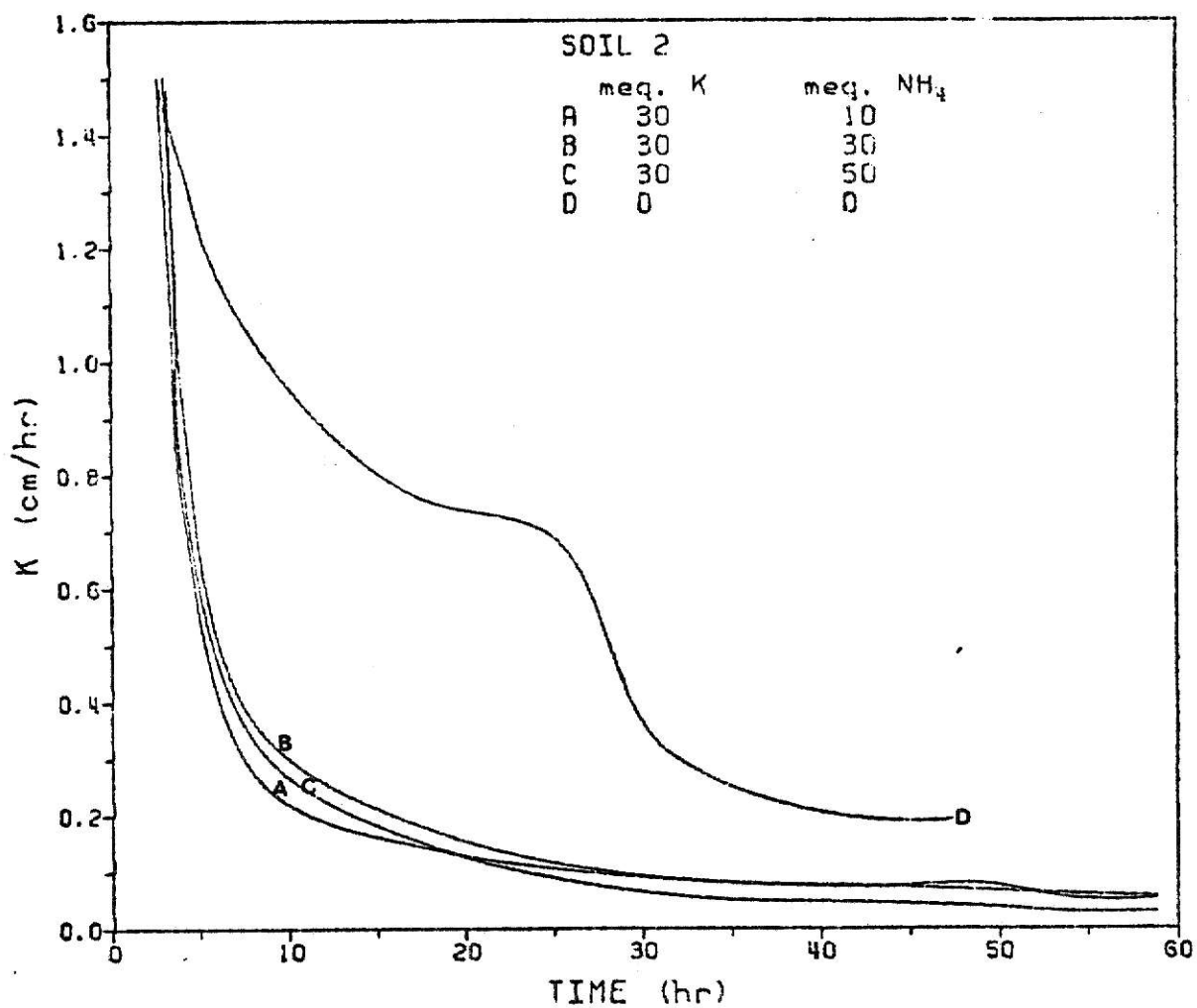


Fig. 36. Hydraulic conductivity measurement for Richfield soil treated with 30 me  $\text{K}^+$ /100 g soil and different levels of  $\text{NH}_4^+$ .

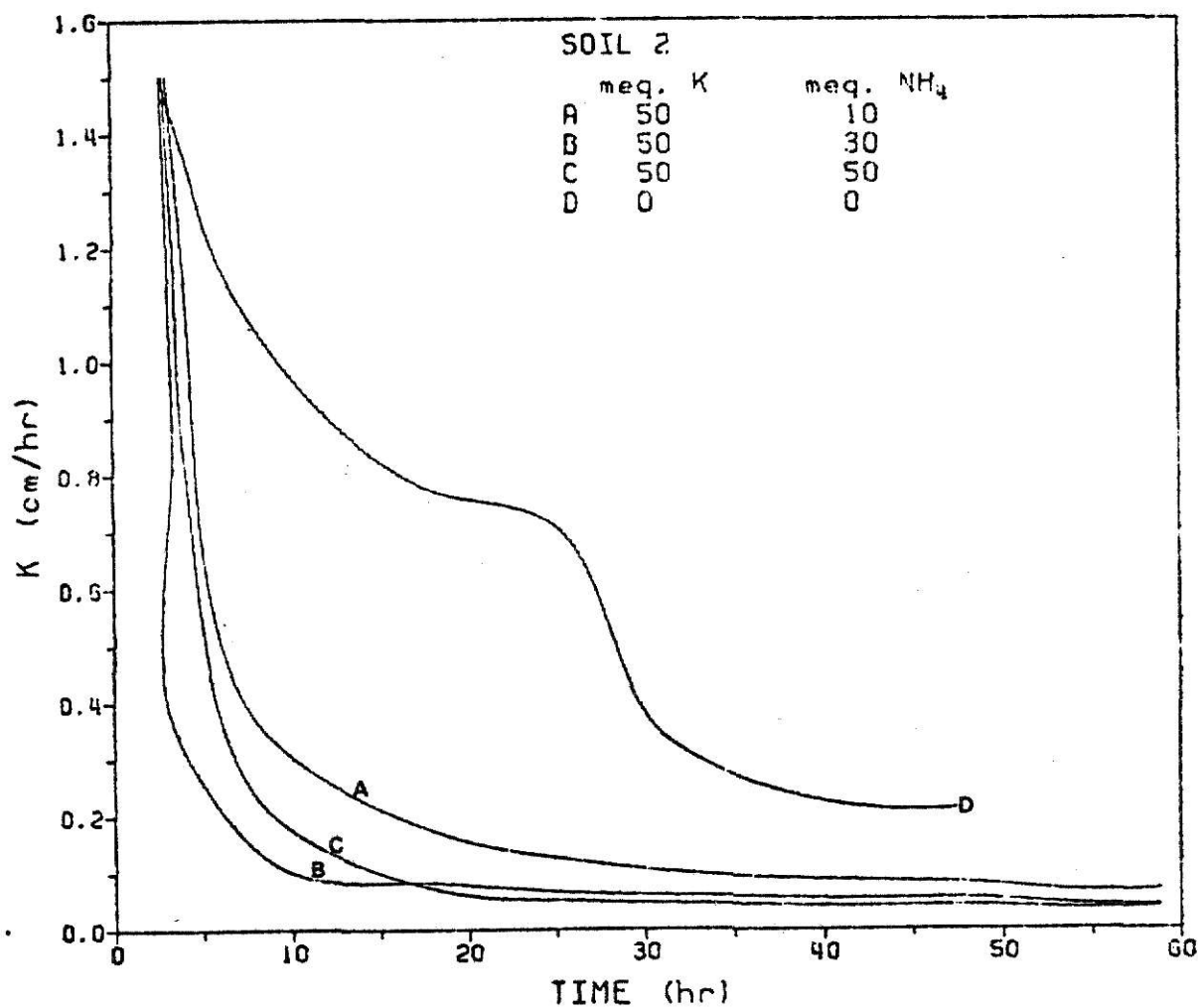


Fig. 37. Hydraulic conductivity measurement for Richfield soil treated with 50 me  $\text{K}^+$ /100 g soil and different levels of  $\text{NH}_4^+$ .

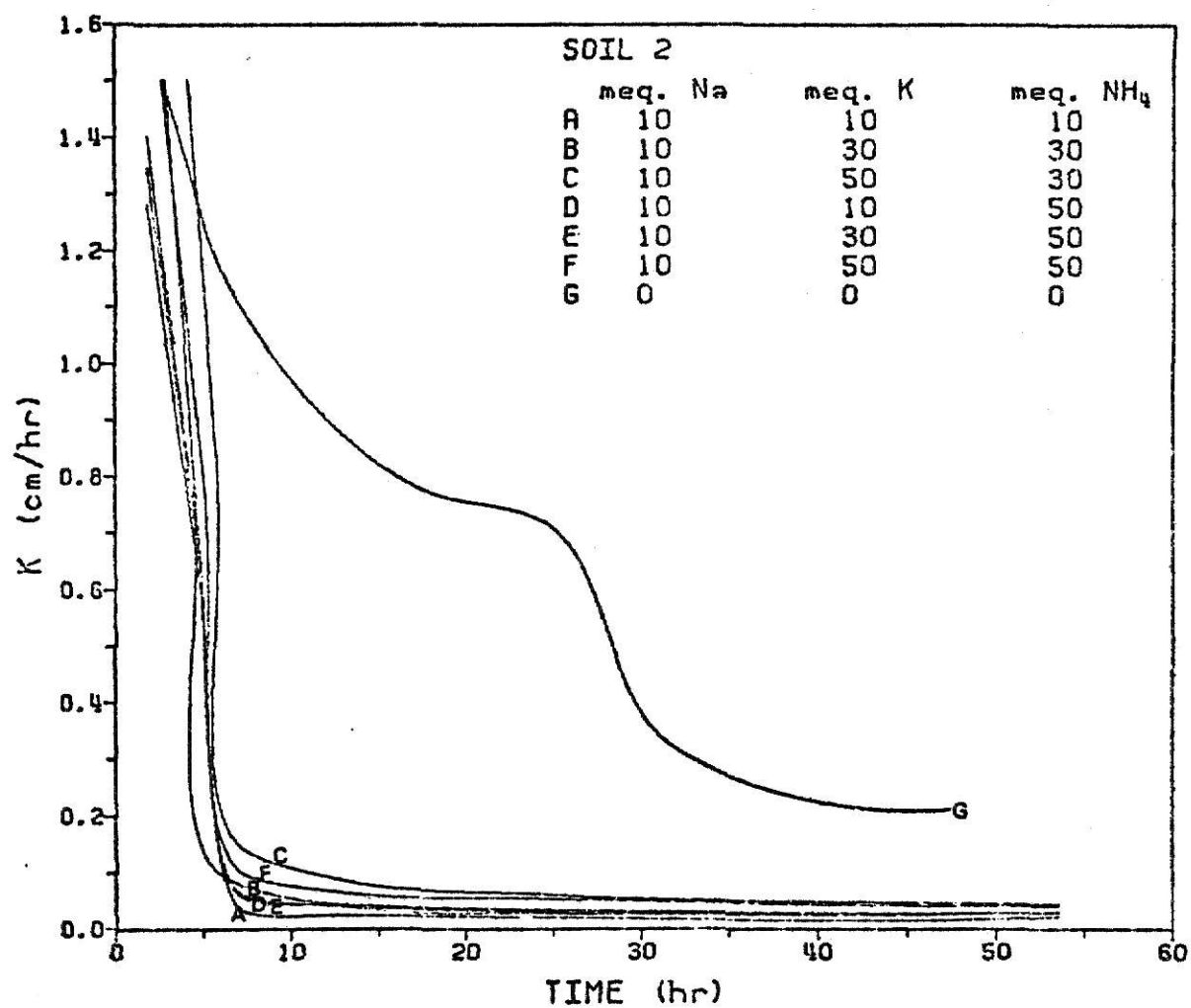


Fig. 38. Hydraulic conductivity measurement for Richfield soil treated with 10 me Na<sup>+</sup>/100 g soil and different levels of K<sup>+</sup> and NH<sub>4</sub><sup>+</sup>.

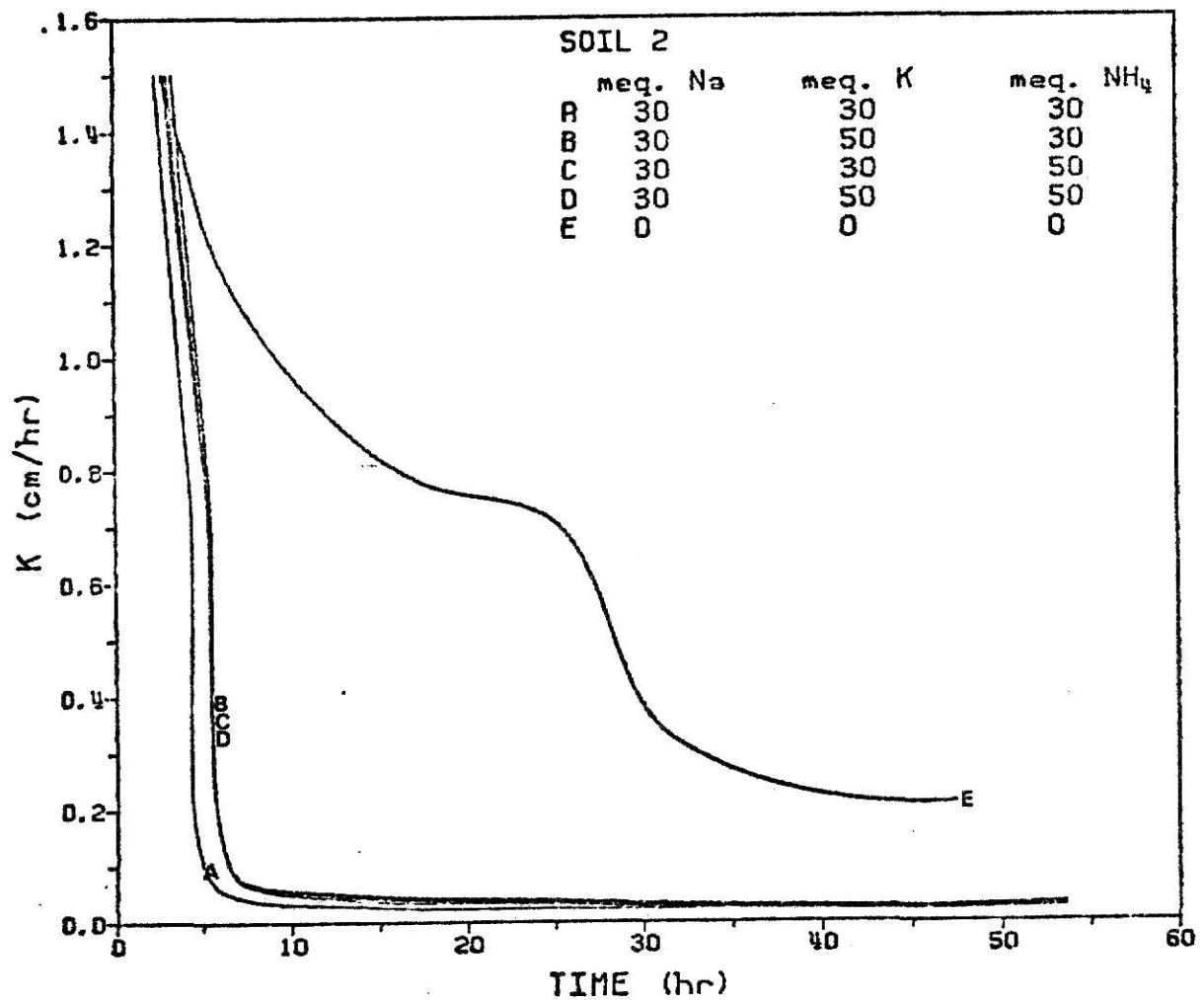


Fig. 39. Hydraulic conductivity measurement for Richfield soil treated with 30 me  $\text{Na}^+$ /100 g soil and different levels of  $\text{K}^+$  and  $\text{NH}_4^+$ .

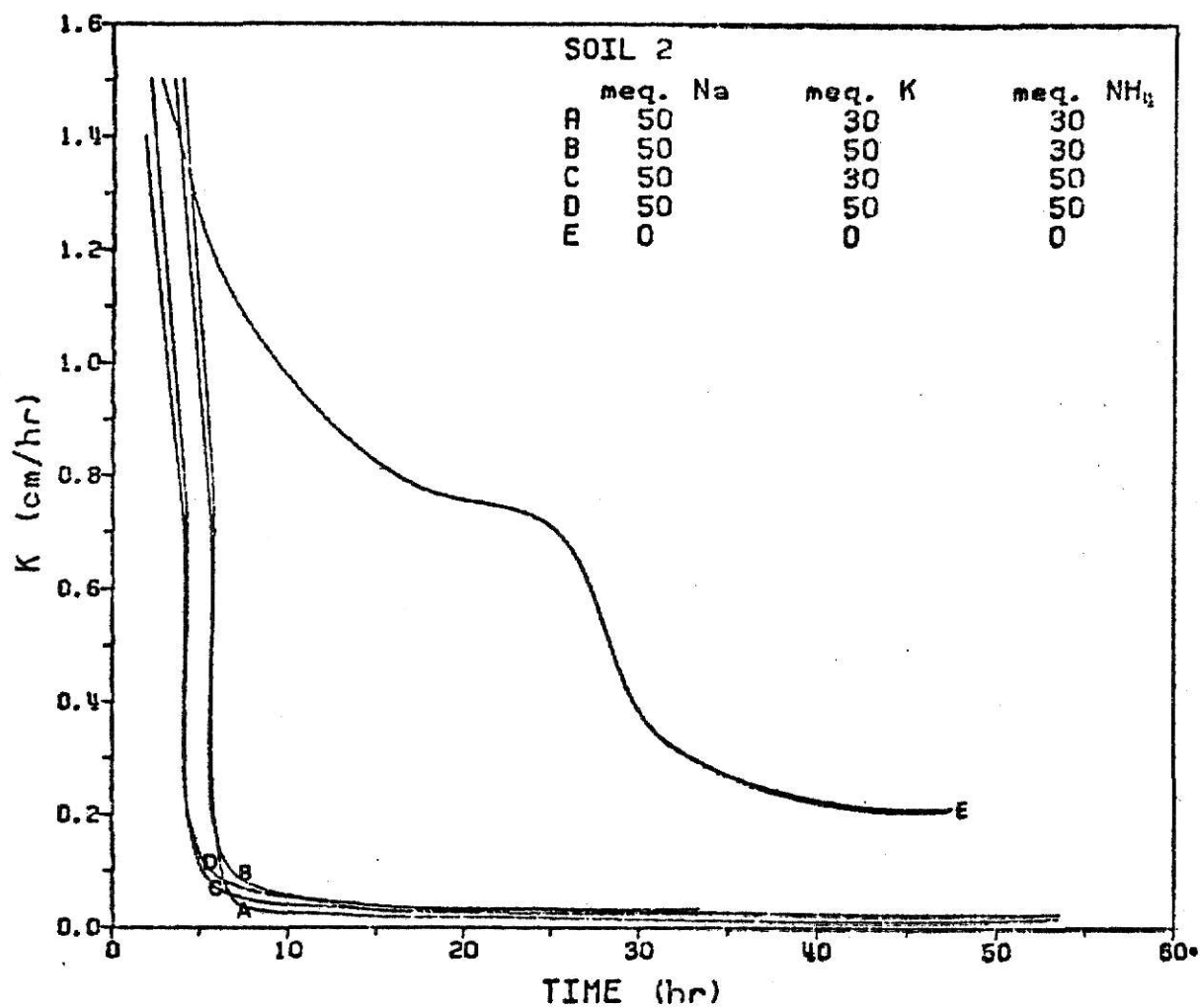


Fig. 40. Hydraulic conductivity measurement for Richfield soil treated with 50 me  $\text{Na}^+$ /100 g soil and different levels of  $\text{K}^+$  and  $\text{NH}_4^+$ .

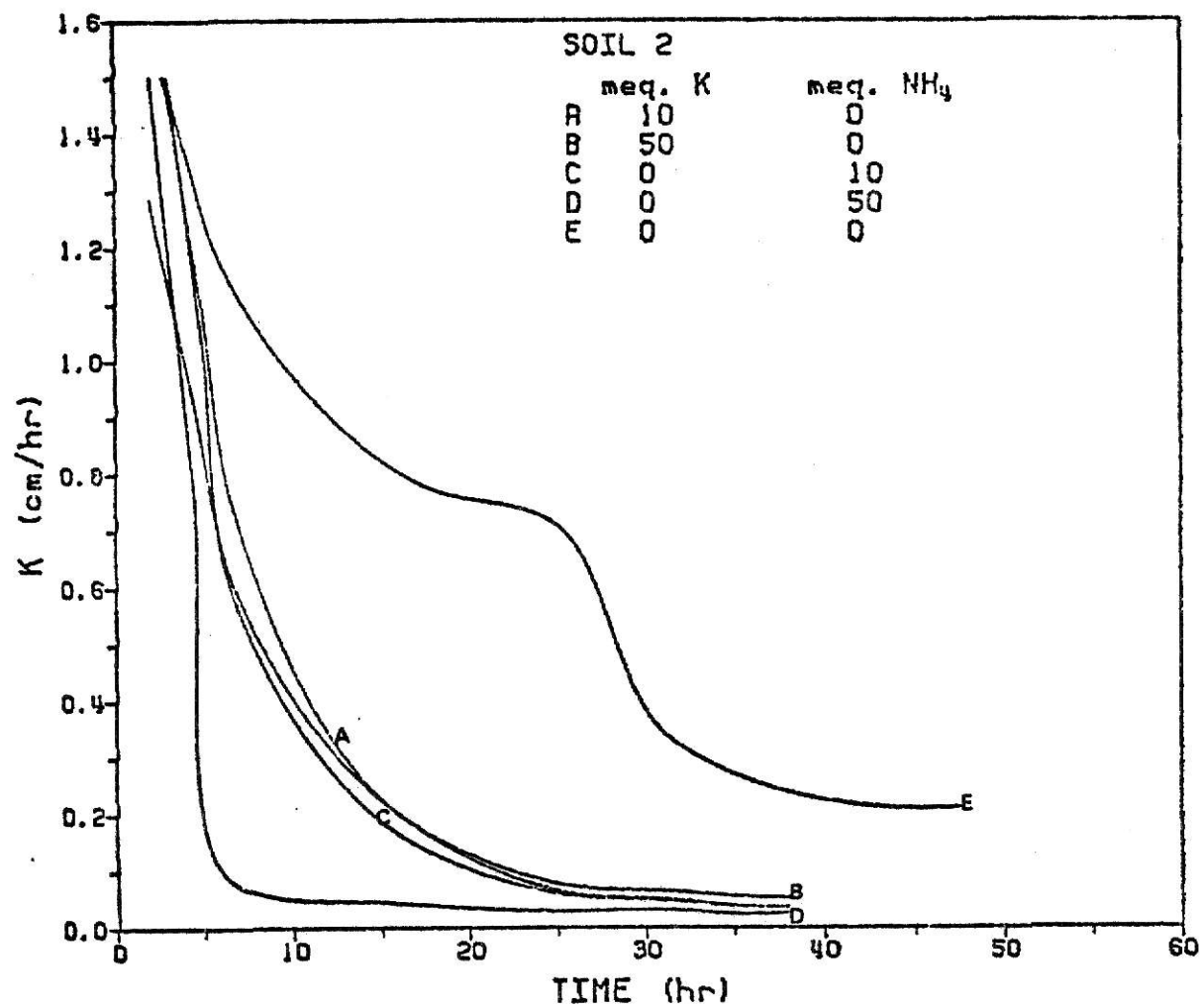


Fig. 41. Hydraulic conductivity measurement for Richfield soil treated with different levels of  $\text{K}^+$  and  $\text{NH}_4^+$ .

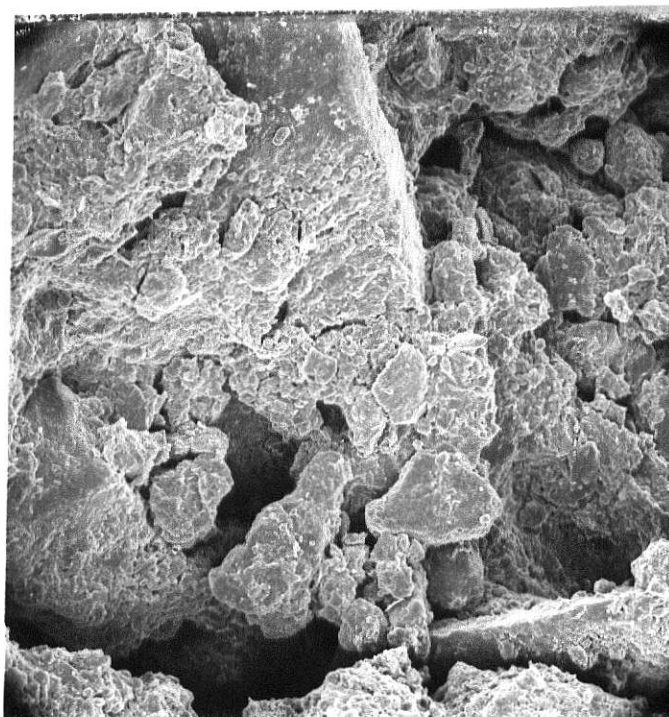


Fig. 42. SEM for Richfield soil treated with 50 me Na<sup>+</sup> and 50 me K<sup>+</sup>/100 g soil.

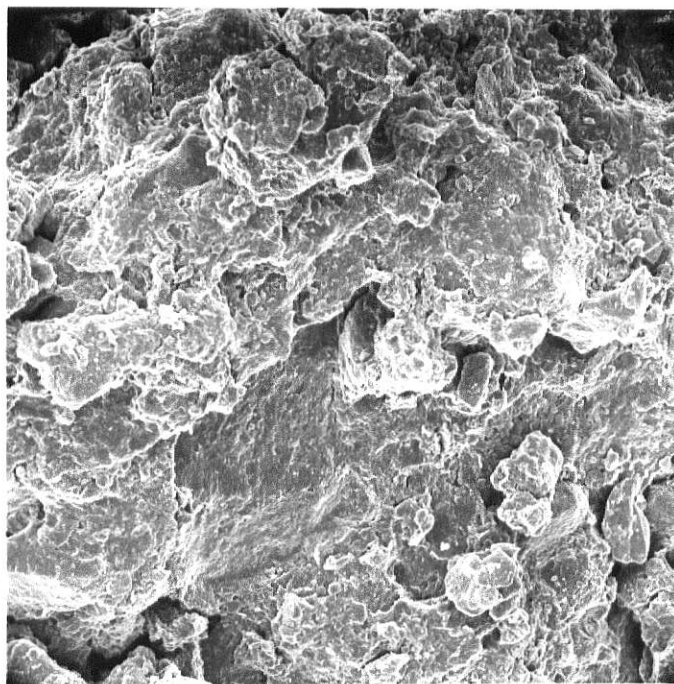


Fig. 43. SEM for Richfield soil treated with 10 me Na<sup>+</sup> and 10 me NH<sub>4</sub><sup>+</sup>/100 g soil.



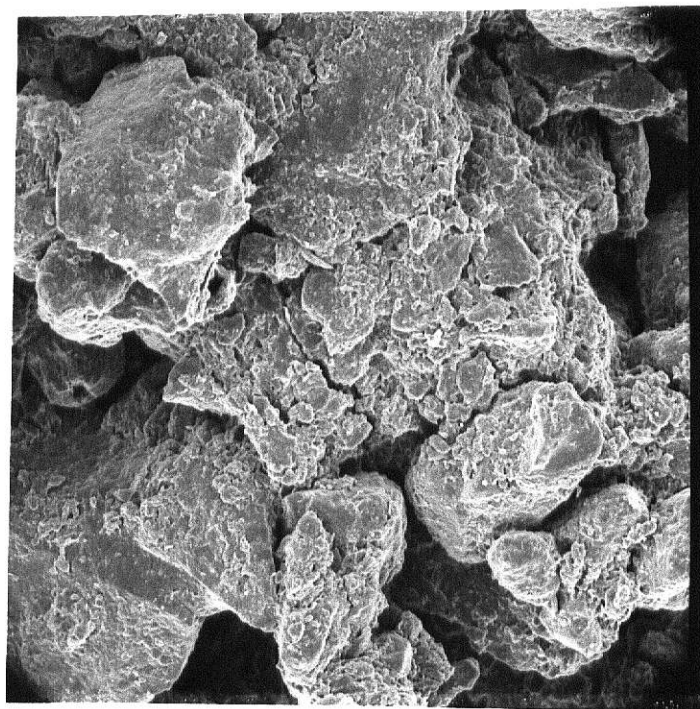


Fig. 44. SEM for Richfield soil treated with 50 me K<sup>+</sup> and 50 me NH<sub>4</sub><sup>+</sup>/100 g soil.

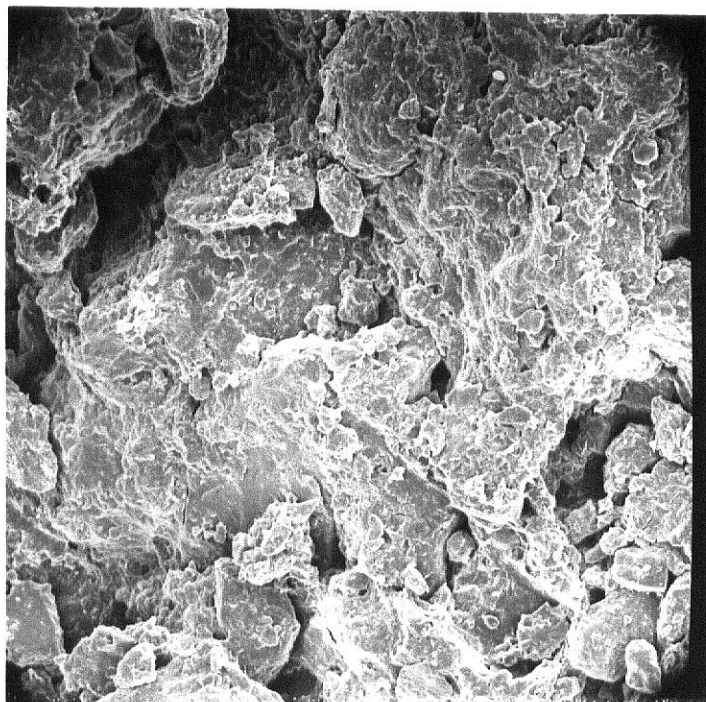


Fig. 45. SEM for Richfield soil treated with 50 me Na<sup>+</sup>, 50 me K<sup>+</sup>, and 50 me NH<sub>4</sub><sup>+</sup>/100 g soil.

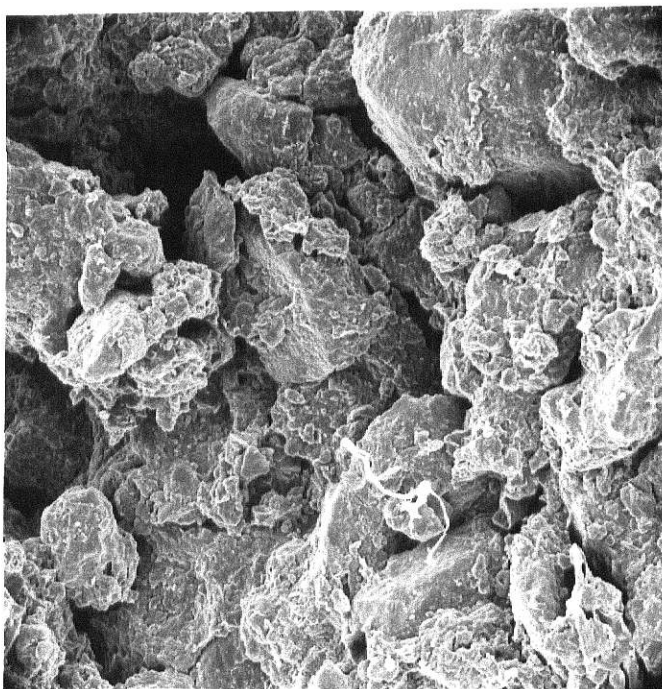


Fig. 46. SEM for untreated Richfield soil.

Treatments involving potassium and ammonium without sodium decreased hydraulic conductivities (Figures 35, 36 and 37).

Potassium and ammonium treatments at low levels of sodium, resulted in better flocculation (Figure 38). High sodium levels (30 and 50 me/100 g soil) resulted in dispersion even with high levels of potassium and ammonium (Figures 39 and 40).

The effects of potassium and ammonium additions without sodium on soil dispersion are shown in Figure 41. Application of potassium gave less dispersion than addition of ammonium at 50 me/100 g soil, but all treatments resulted in more dispersion than in the untreated soil.

## 2. Scanning Electron Microscopy Method:

Dispersion occurred with this soil for all treatments (Figures 42, 43, 44 and 45) as compared with untreated soil (Figure 46). High concentrations of potassium and ammonium did not improve the structure of this soil (Figure 45). These results are due to high sodium concentrations originally present in untreated soil and high clay content.

### Wakeen silt loam soil

This soil contains approximately 30 percent  $\text{CaCO}_3$ . The high  $\text{CaCO}_3$  content affects ammonium losses by volatilization, pH, fixation of cations, solubility of compounds, and activity of ions (16).

## 1. Hydraulic Conductivity Method:

The changes in hydraulic conductivity with time as influenced by the various treatments are presented in Figures 47 through 59. Treatments involving low sodium with either low potassium or ammonium (10 me/100 g soil) resulted in low hydraulic conductivities (Figures 47 and 50). Increasing

the level of sodium at the low levels of potassium or ammonium resulted in severe dispersion and low hydraulic conductivities (Figures 48, 49, 51 and 52). Increasing the potassium and ammonium levels resulted in less dispersion with ammonium being more effective in preventing dispersion than was potassium. Some dispersion occurred with all treatments at the high level of sodium (50 me Na/100 g soil).

All combinations of potassium and ammonium without sodium resulted in increases in hydraulic conductivity (Figures 53, 54 and 55) compared with untreated soil. Treatments involving all three cations ( $\text{Na}^+$ ,  $\text{K}^+$  and  $\text{NH}_4^+$ ) resulted in increases in hydraulic conductivities at the low sodium level (Figure 56). Increasing the sodium level decreased hydraulic conductivity (Figures 57 and 58). Increasing potassium and ammonium levels improved hydraulic conductivity to some extent (Figure 59).

## 2. Scanning Electron Microscopy Method:

High concentrations of potassium (50 me/100 g soil) with low level of sodium (10 me/100 g soil) (Figure 61) resulted in less dispersion compared with untreated soil (Figure 71), but low concentration of potassium with low level of sodium (Figure 60) resulted in some dispersion.

High concentration of sodium with low and high concentrations of potassium resulted in weak soil structure (Figures 62 and 63).

Medium concentrations of sodium (30 me/100 g soil) with low concentrations of ammonium (10 me/100 g soil) as shown in Figure 64, resulted in less dispersion than high concentrations of sodium (Figure 65).

High concentrations of sodium with low level of ammonium (Figure 65), and high sodium with potassium and ammonium (Figure 69) resulted in a deterioration of soil structure compared with untreated soil (Figure 71).

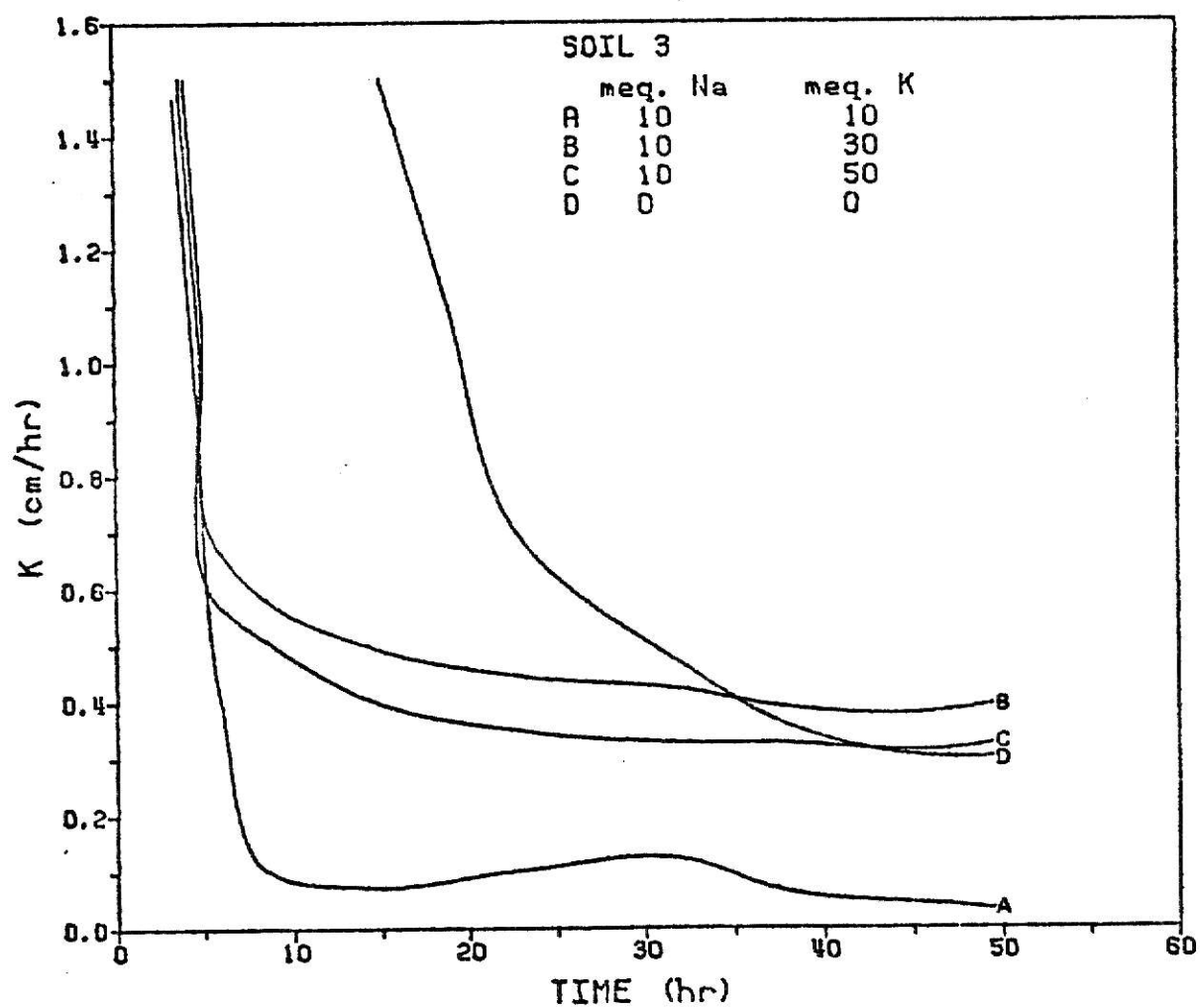


Fig. 47. Hydraulic conductivity measurement for Wakeen soil treated with 10 me  $\text{Na}^+$ /100 g soil and different levels of  $\text{K}^+$ .

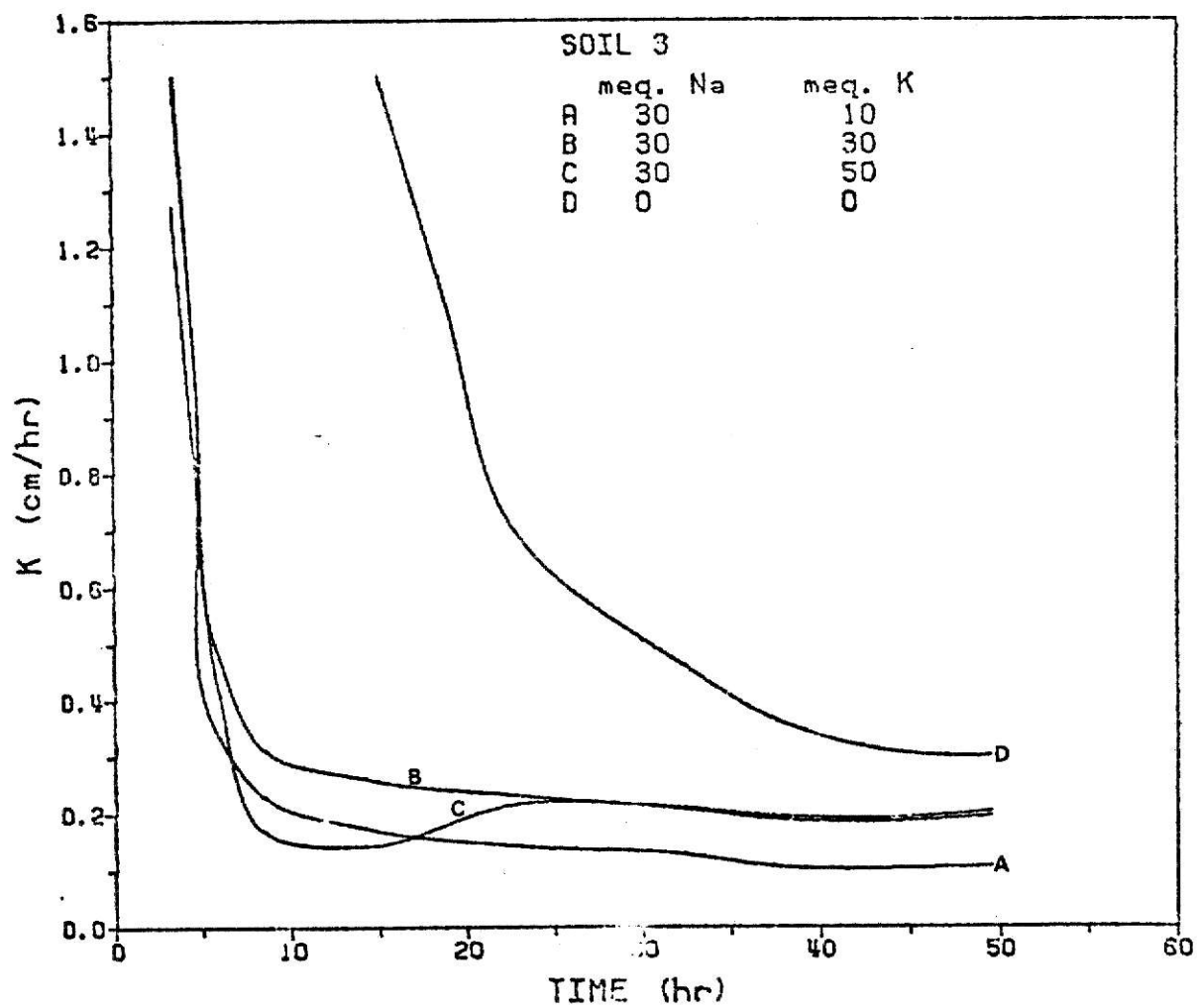


Fig. 48. Hydraulic conductivity measurement for Wakeen soil treated with 30 me  $\text{Na}^+$ /100 g soil and different levels of  $\text{K}^+$ .

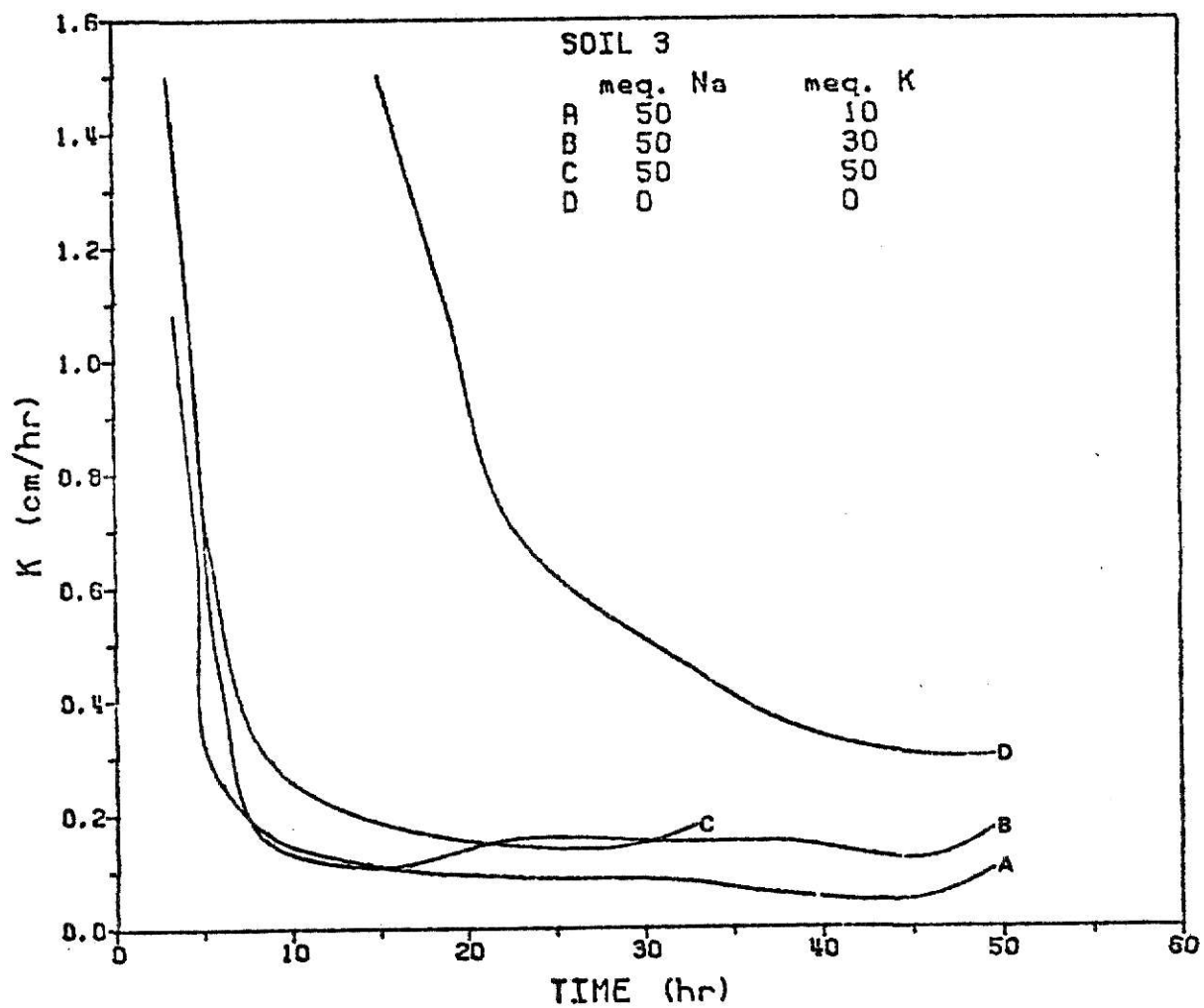


Fig. 49. Hydraulic conductivity measurement for Wakeen soil treated with 50 me  $\text{Na}^+$ /100 g soil and different levels of  $\text{K}^+$ .

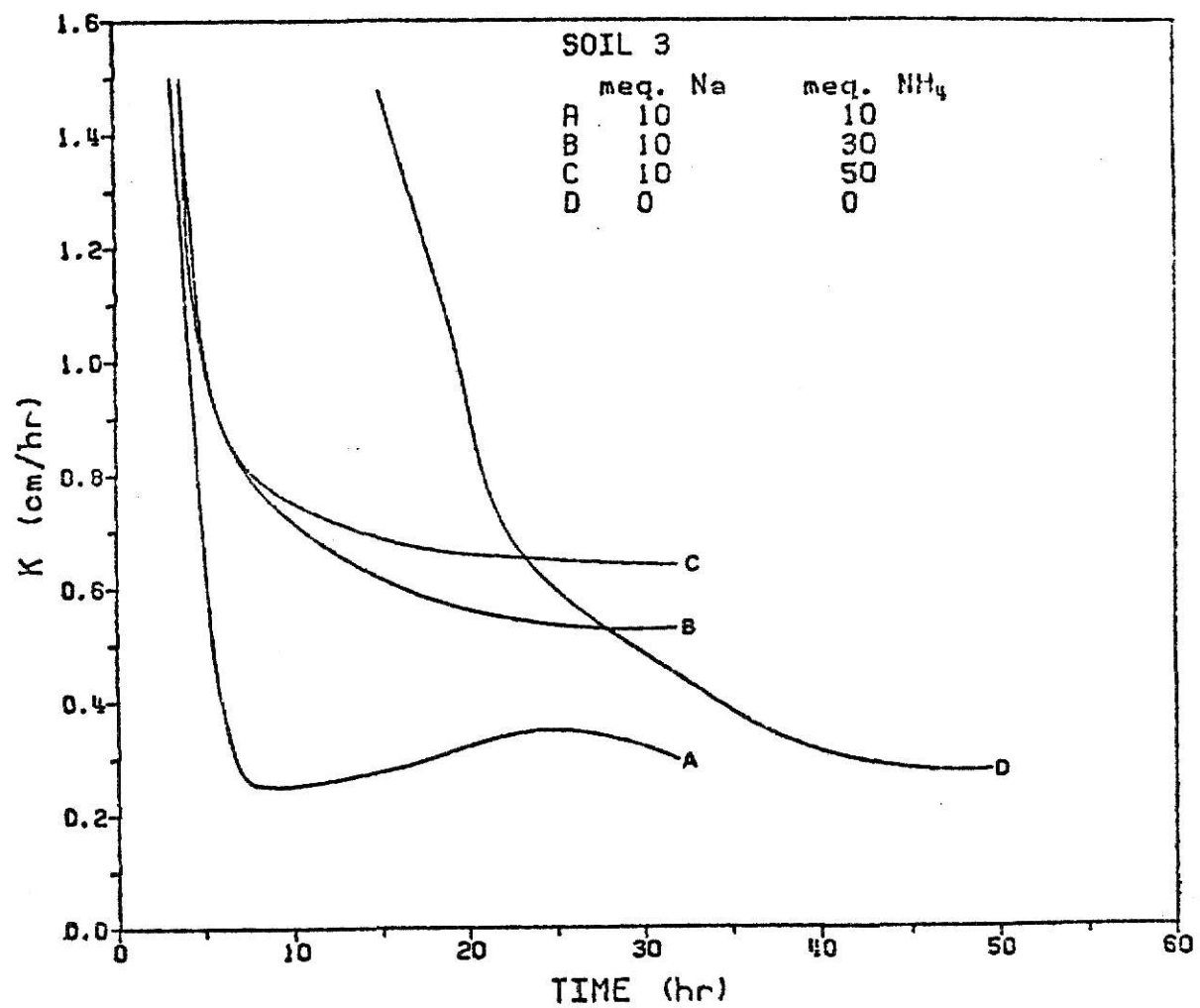


Fig. 50. Hydraulic conductivity measurement for Wakeen soil treated with 10 me  $\text{Na}^+$ /100 g soil and different levels of  $\text{NH}_4^+$ .



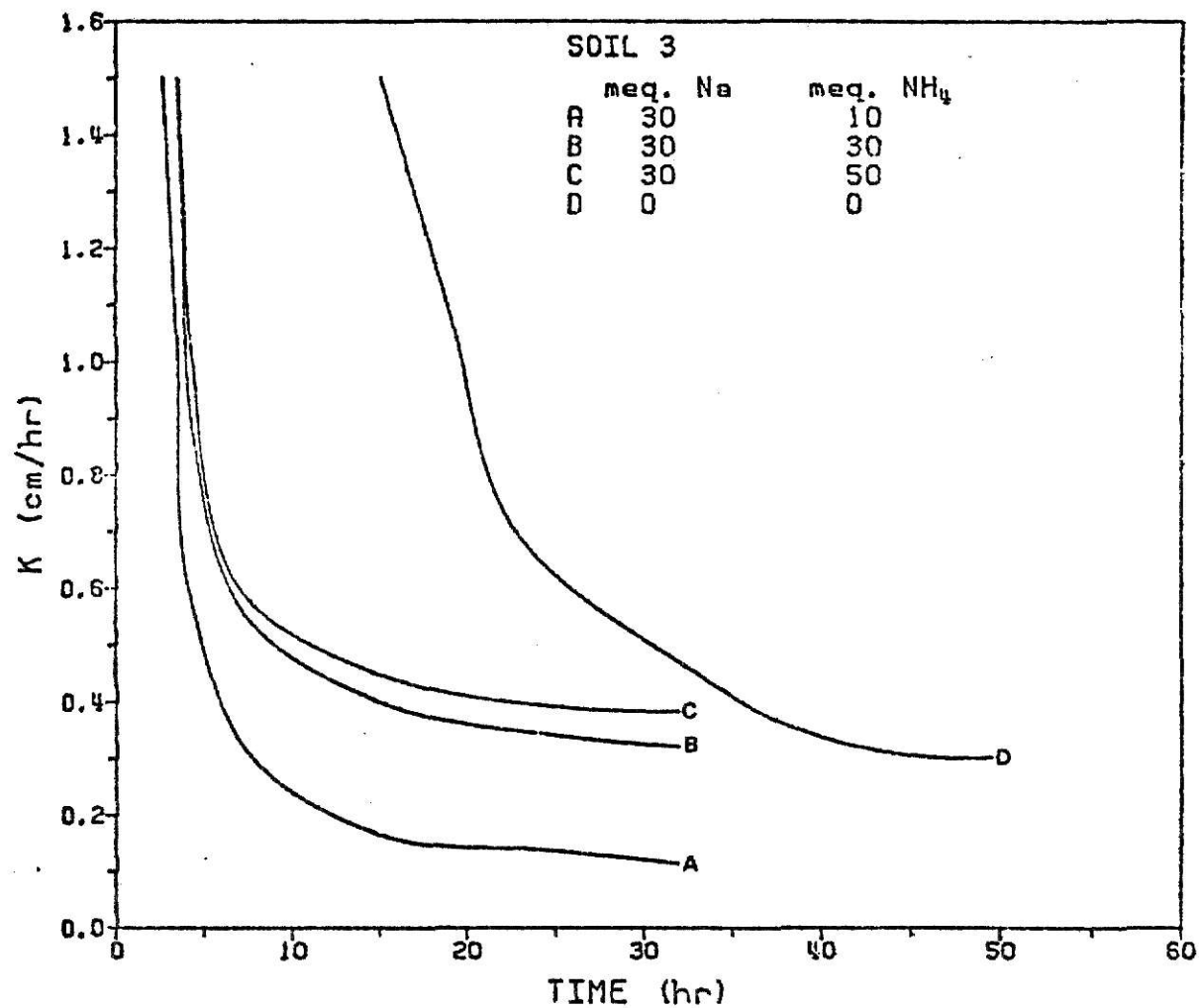


Fig. 51. Hydraulic conductivity measurement for Wakeen soil treated with 30 me  $\text{Na}^+$ /100 g soil and different levels of  $\text{NH}_4^+$ .

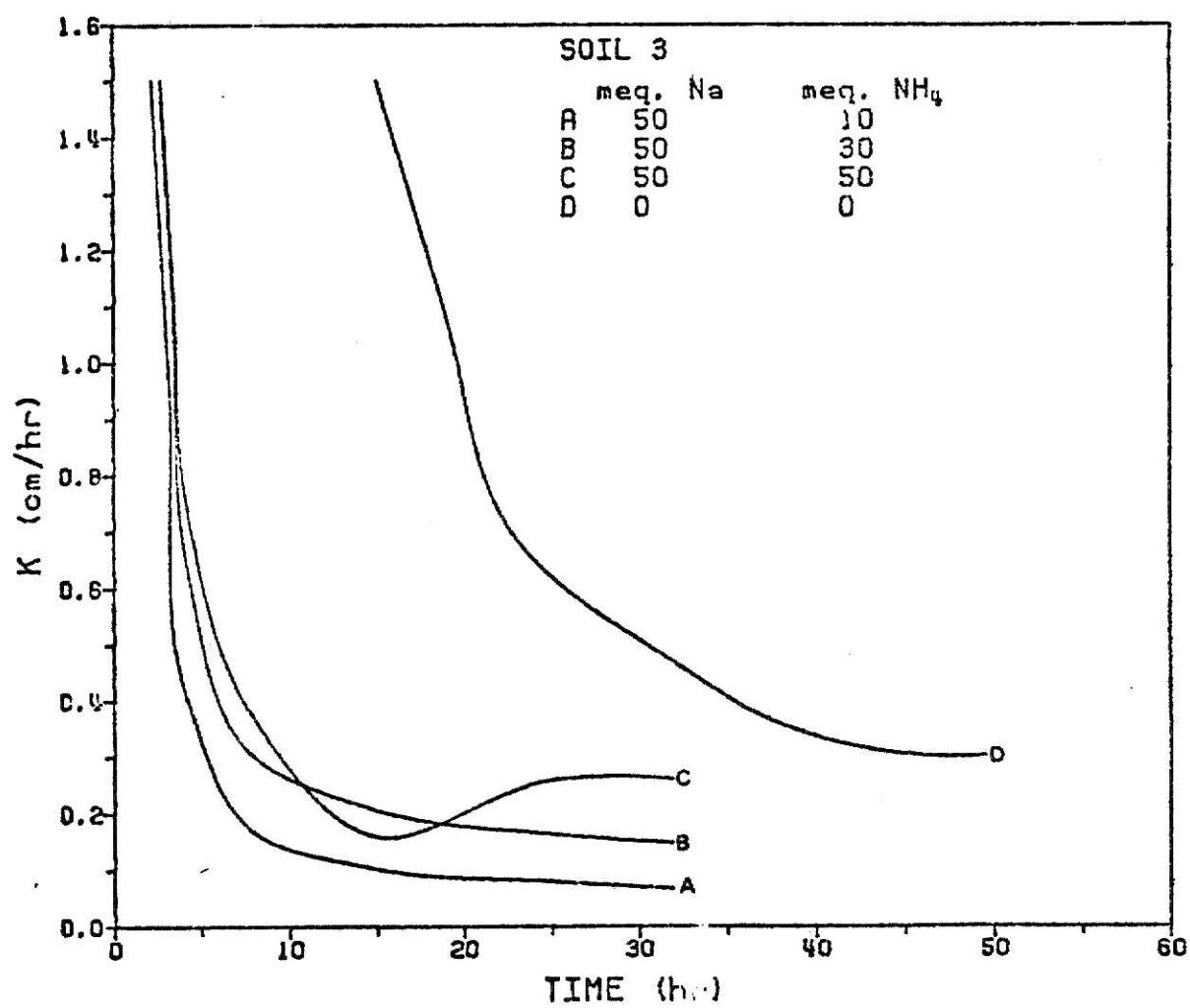


Fig. 52. Hydraulic conductivity measurement for Wakeen soil treated with 50 me Na<sup>+</sup>/100 g soil and different levels of NH<sub>4</sub><sup>+</sup>.

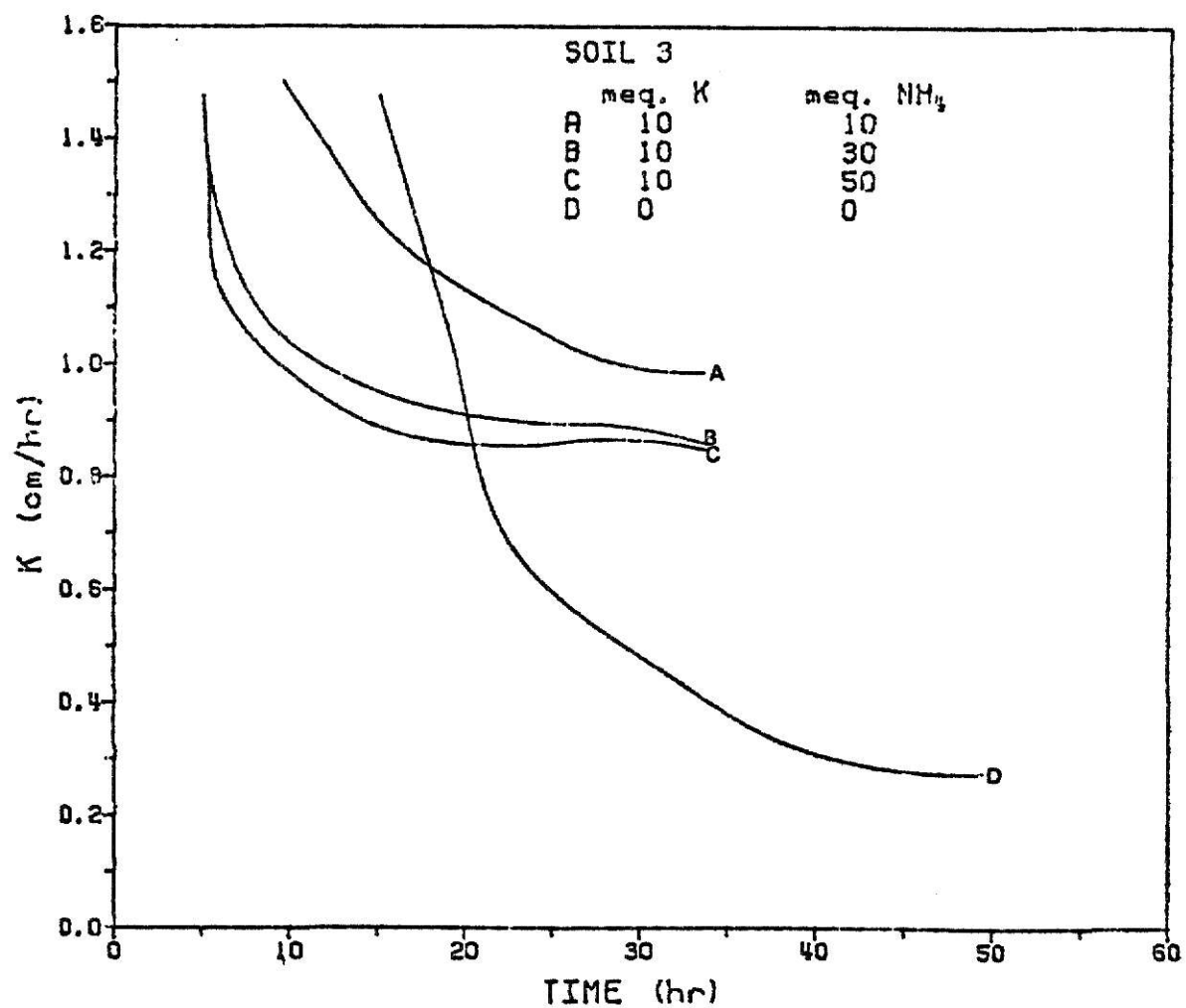


Fig. 53. Hydraulic conductivity measurement for Wakeen soil treated with 10 me  $\text{K}^+$ /100 g soil and different levels of  $\text{NH}_4^+$ .

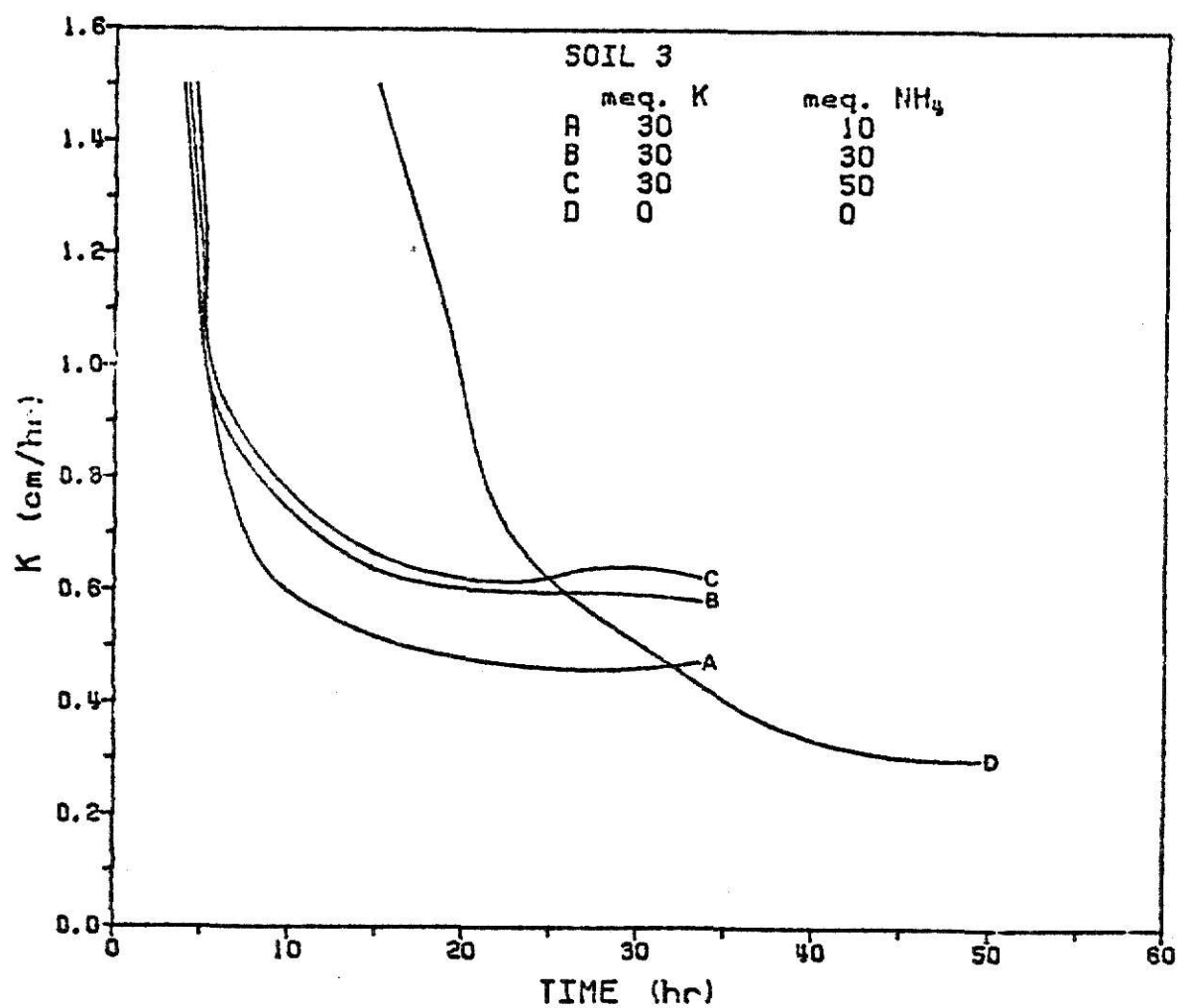


Fig. 54. Hydraulic conductivity measurement for Wakeen soil treated with 30 me K<sup>+</sup>/100 g soil and different levels of NH<sub>4</sub><sup>+</sup>.

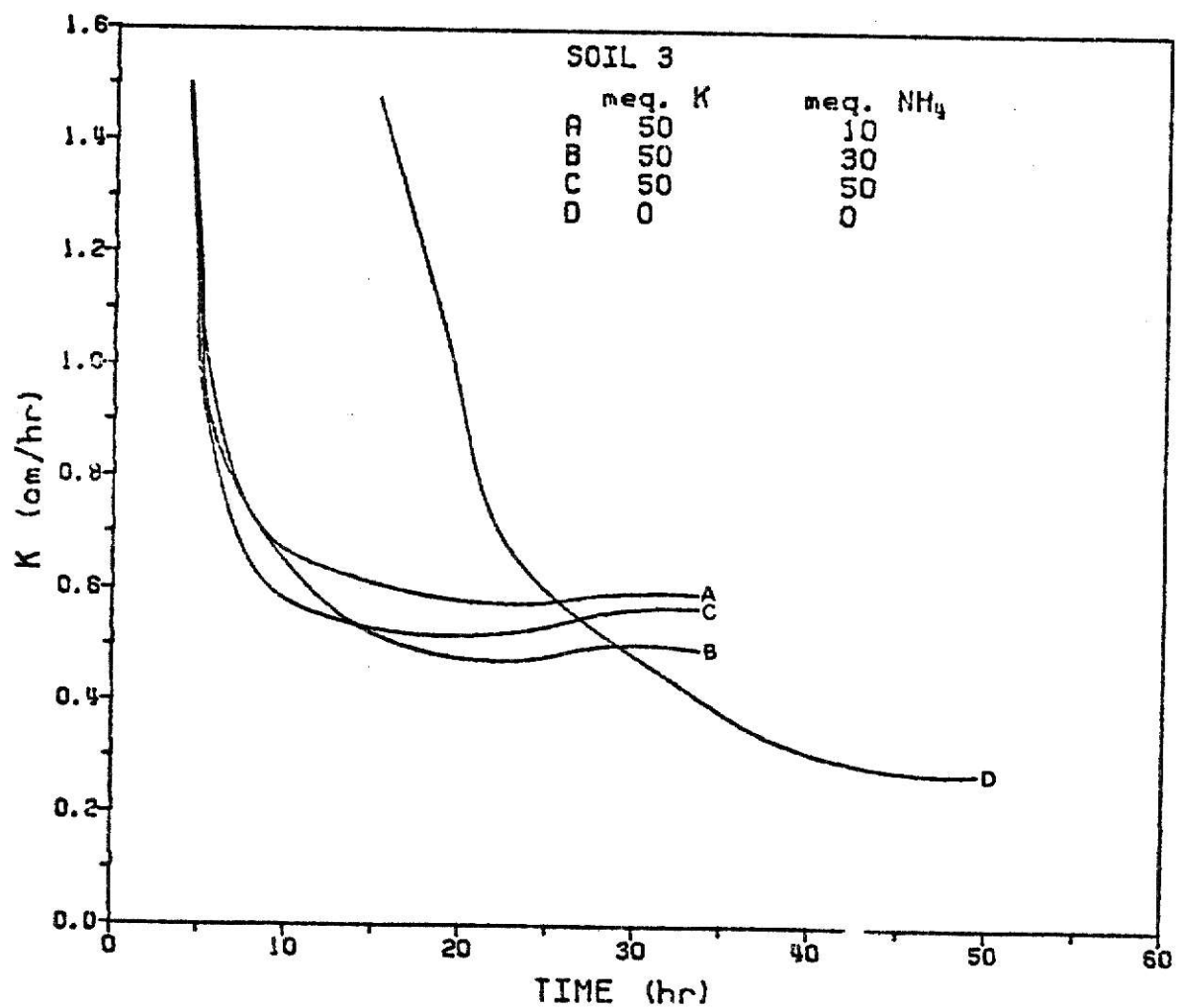


Fig. 55. Hydraulic conductivity measurement for Wakeen soil treated with 50 me  $\text{K}^+$ /100 g soil and different levels of  $\text{NH}_4^+$ .

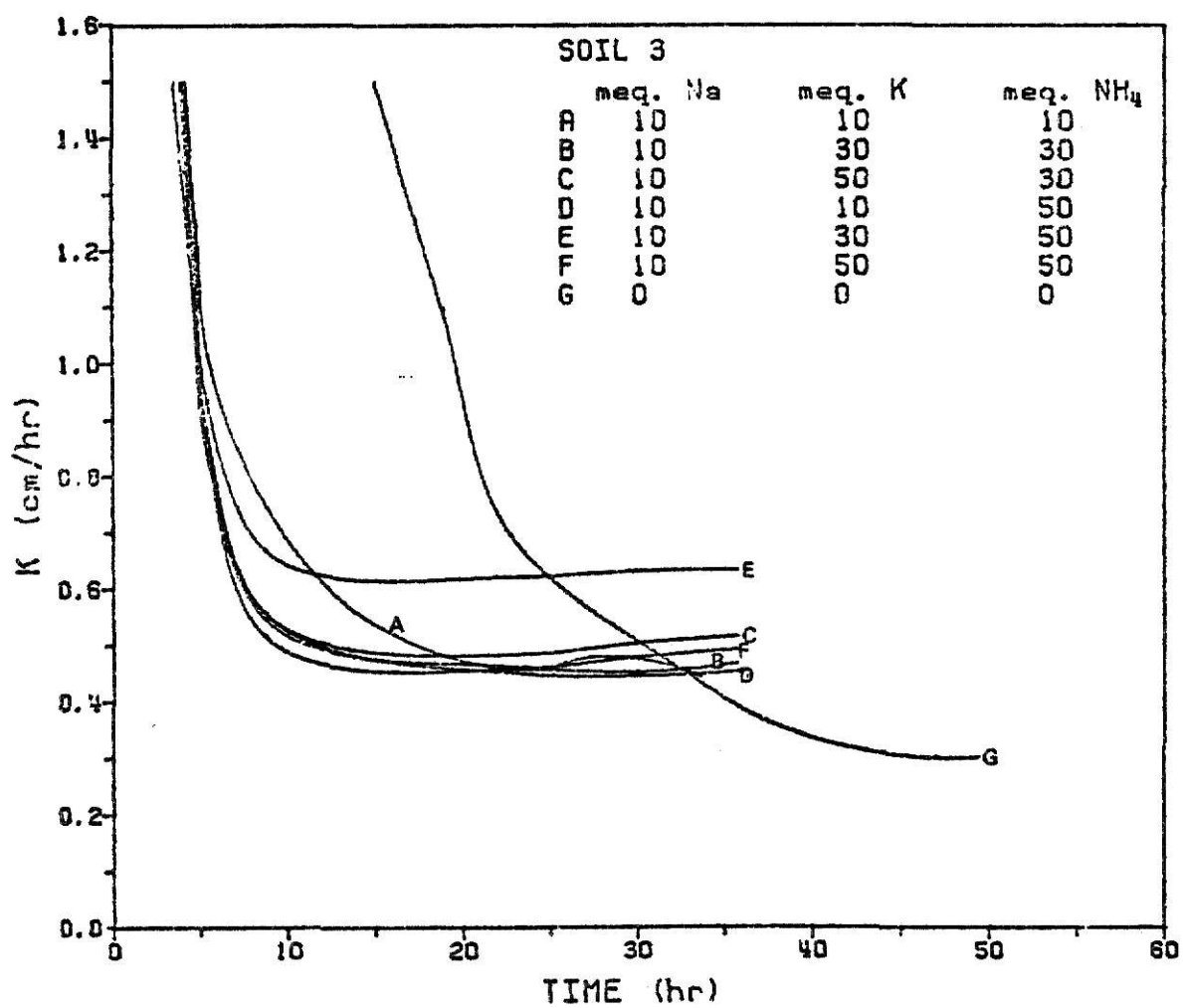


Fig. 56. Hydraulic conductivity measurement for Wakeen soil treated with 10 me  $\text{Na}^+$ /100 g soil and different levels of  $\text{K}^+$  and  $\text{NH}_4^+$ .

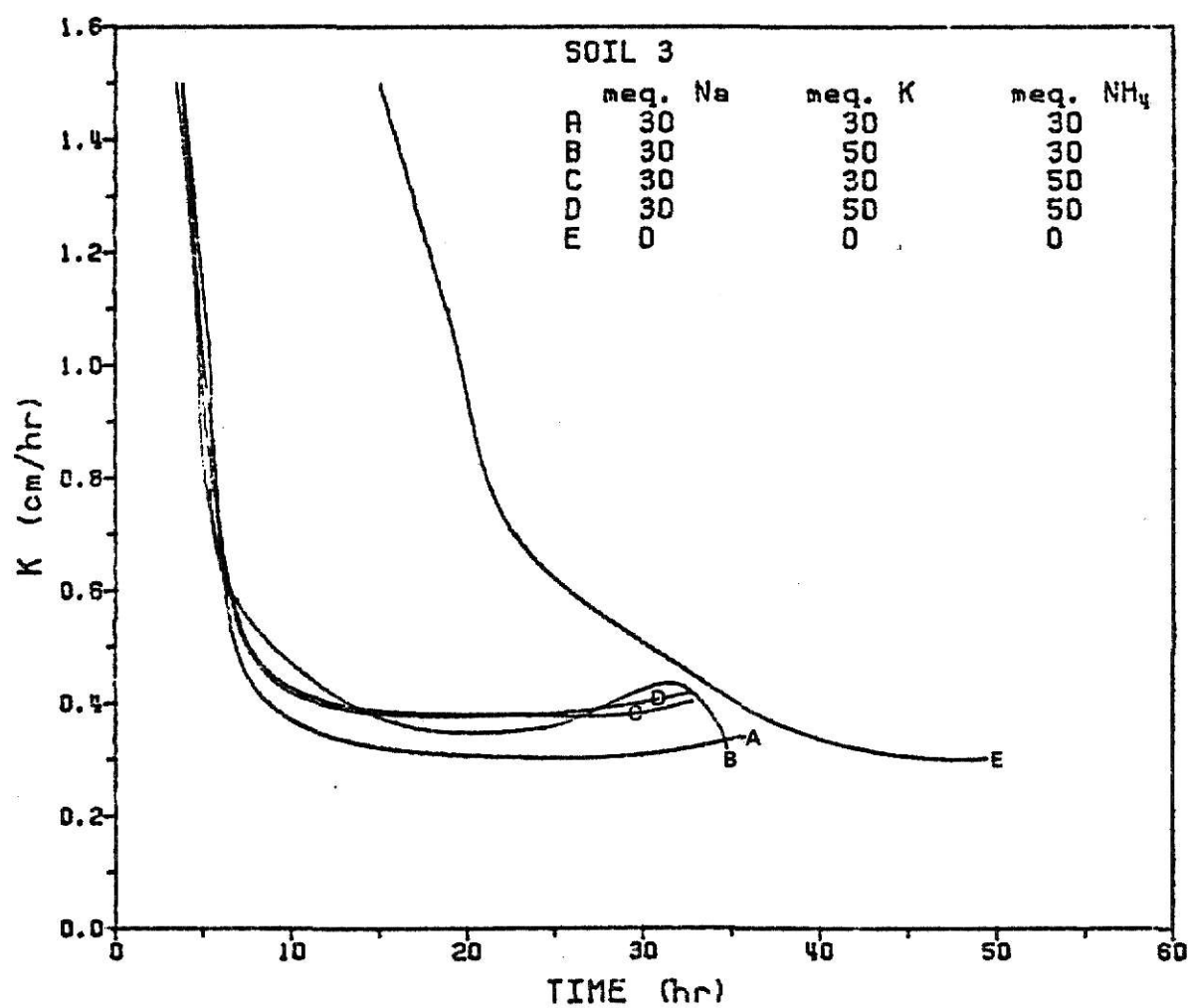


Fig. 57. Hydraulic conductivity measurement for Wakeen soil treated with 30 me  $\text{Na}^+$ /100 g soil and different levels of  $\text{K}^+$  and  $\text{NH}_4^+$ .

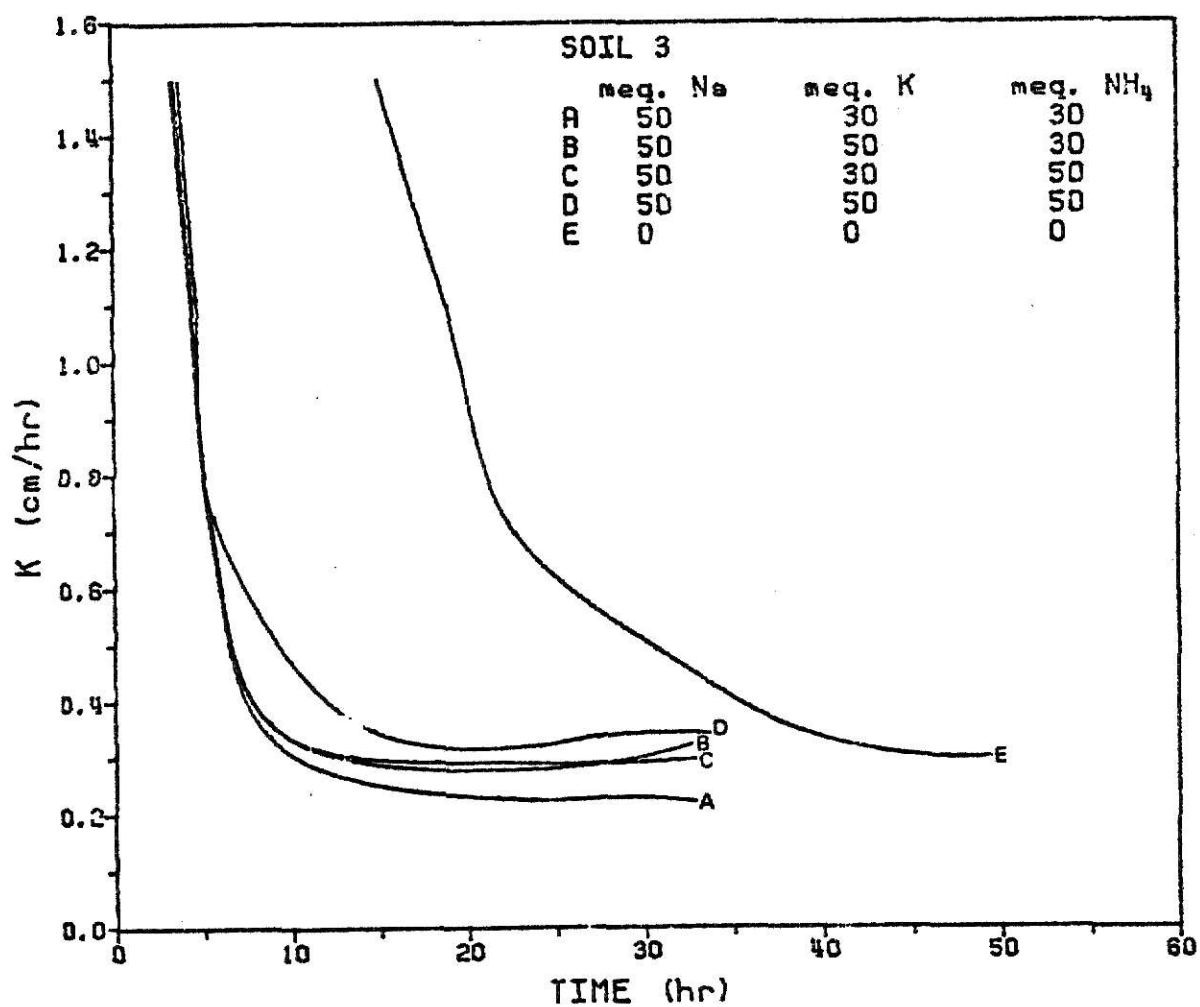


Fig. 58. Hydraulic conductivity measurement for Wakeen soil treated with 50 me Na<sup>+</sup>/100 g soil and different levels of K<sup>+</sup> and NH<sub>4</sub><sup>+</sup>.



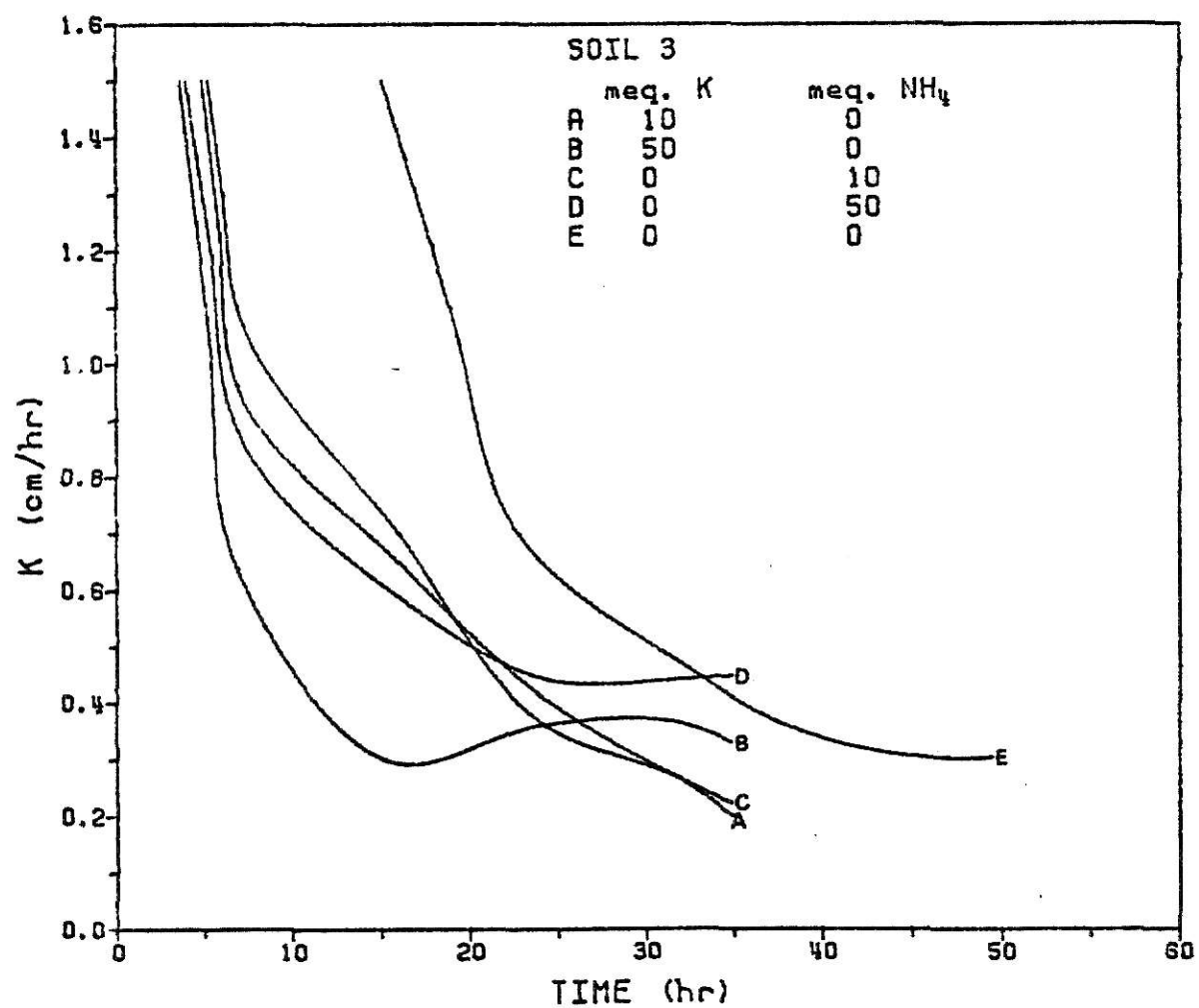


Fig. 59. Hydraulic conductivity measurement for Wakeen soil treated with different levels of  $\text{K}^+$  and  $\text{NH}_4^+$ .

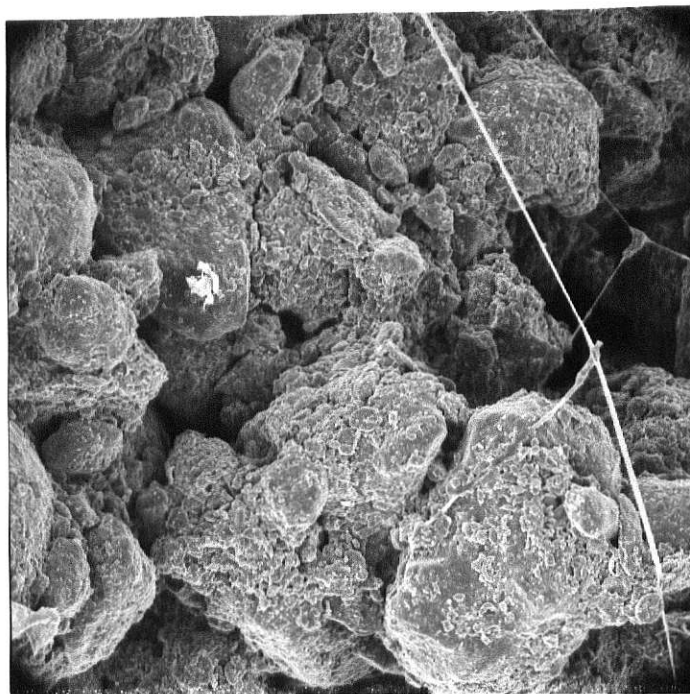


Fig. 60. SEM for Wakeen soil treated with 10 me Na<sup>+</sup> and 10 me K<sup>+</sup>/100 g soil.

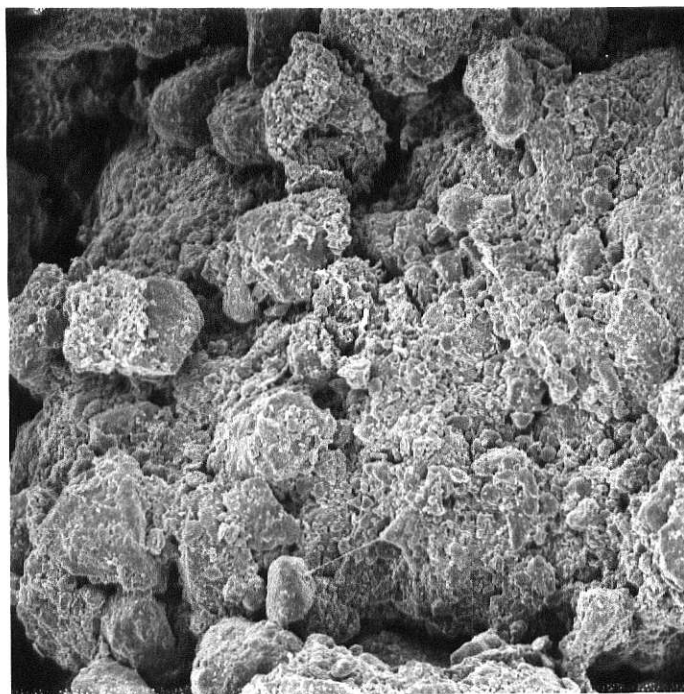


Fig. 61. SEM for Wakeen soil treated with 10 me Na<sup>+</sup> and 50 me K<sup>+</sup>/100 g soil.

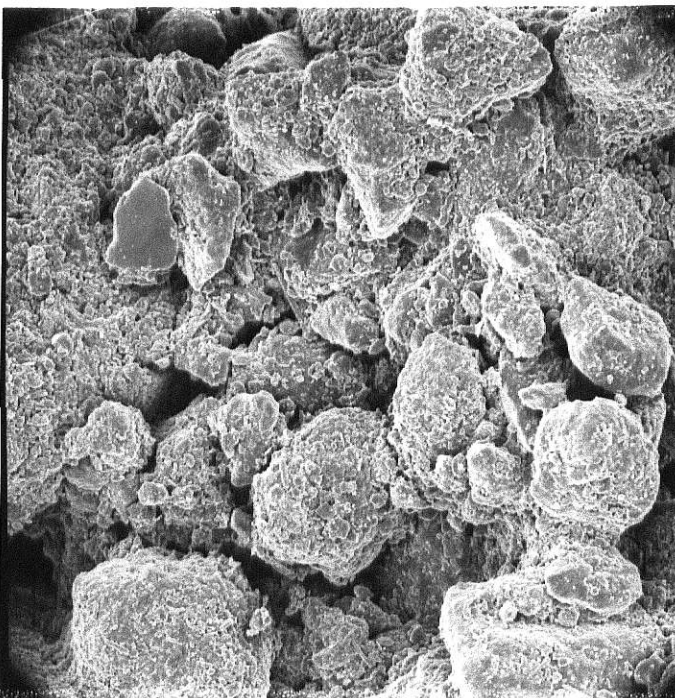


Fig. 63. SEM for Wakeen soil treated with 50 me Na<sup>+</sup> and 10 me K<sup>+</sup>/100 g soil.

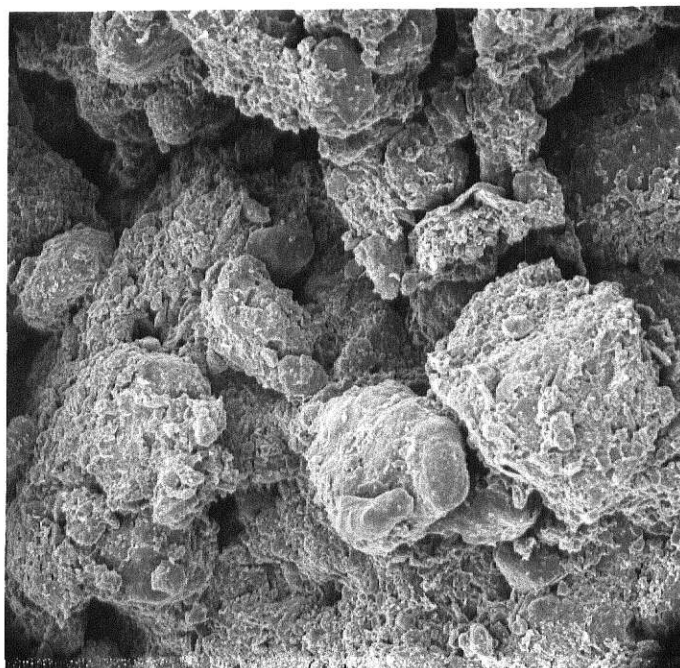


Fig. 62. SEM for Wakeen soil treated with 50 me Na<sup>+</sup> and 50 me K<sup>+</sup>/100 g soil.

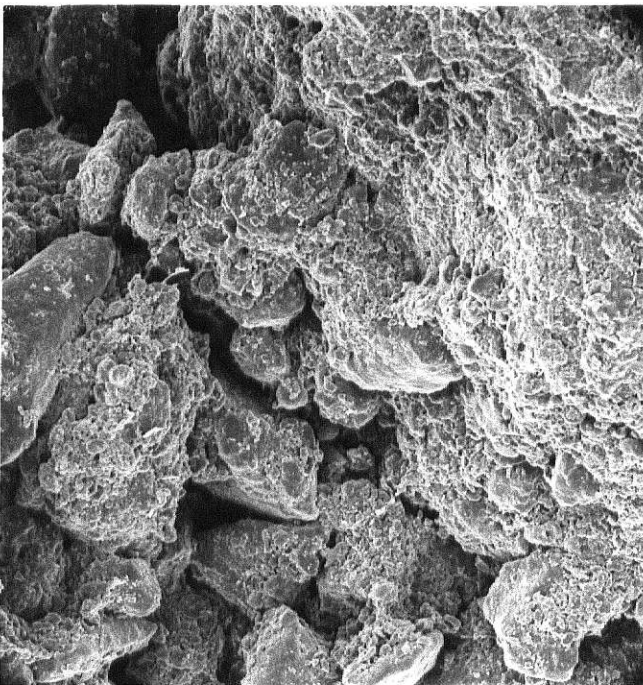


Fig. 65. SEM for Wakeen soil treated with 50 me Na<sup>+</sup> and 10 me NH<sub>4</sub><sup>+</sup>/100 g soil.

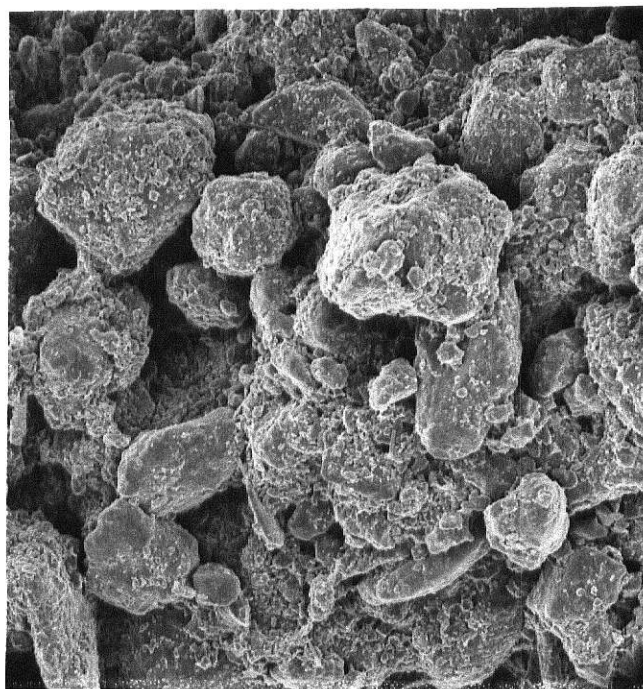


Fig. 64. SEM for Wakeen soil treated with 30 me Na<sup>+</sup> and 10 me NH<sub>4</sub><sup>+</sup>/100 g soil.

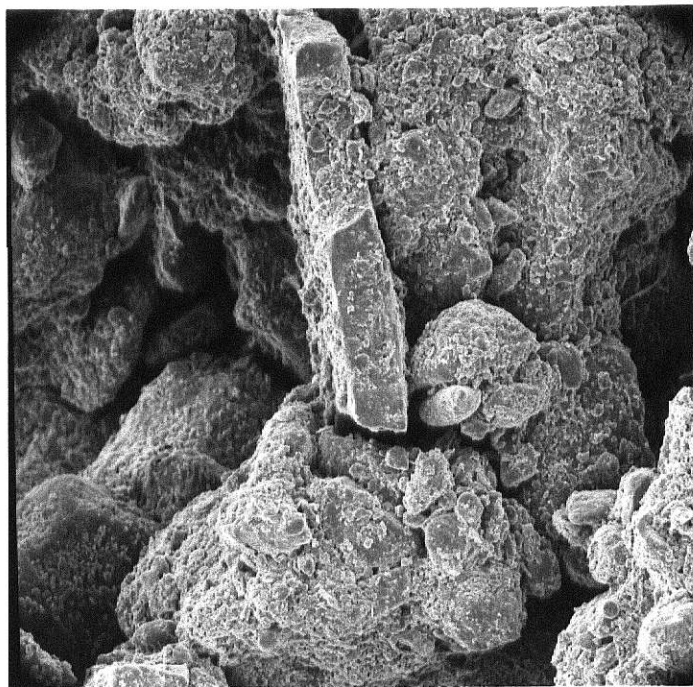


Fig. 66. SEM for Wakeen soil treated with 10 me K<sup>+</sup> and 10 me NH<sub>4</sub><sup>+</sup>/100 g soil.

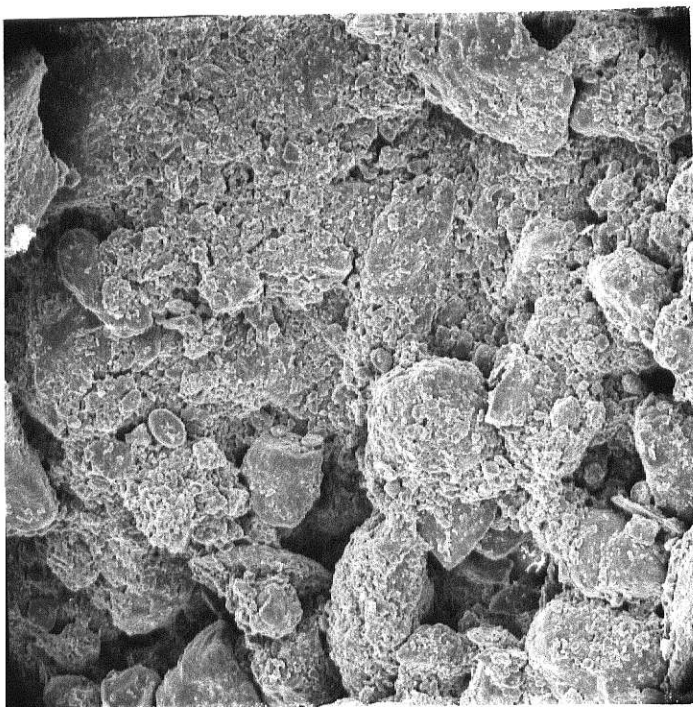


Fig. 67. SEM for Wakeen soil treated with 10 me Na<sup>+</sup>, 10 me K<sup>+</sup>, and 10 me NH<sub>4</sub><sup>+</sup>/100 g soil.

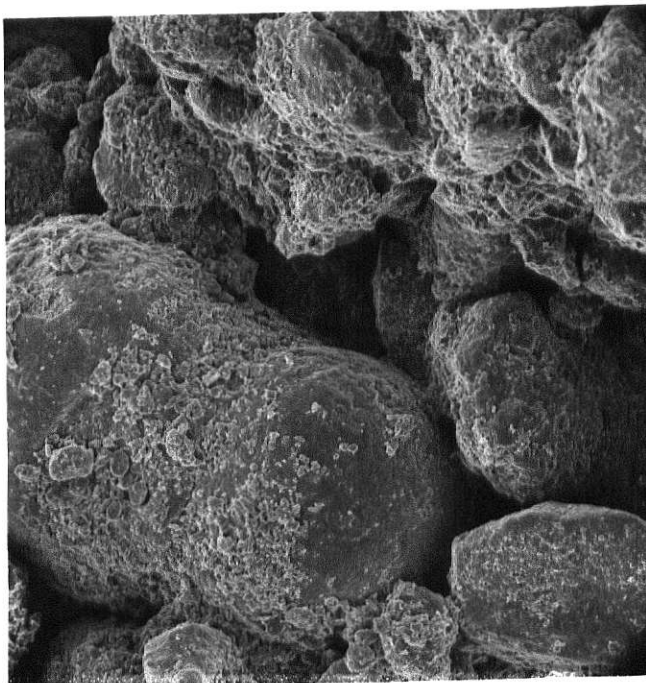


Fig. 68. SEM for Wakeen soil treated with 10 me Na<sup>+</sup>, 30 me K<sup>+</sup>, and 50 me NH<sub>4</sub><sup>+</sup>/100 g soil.

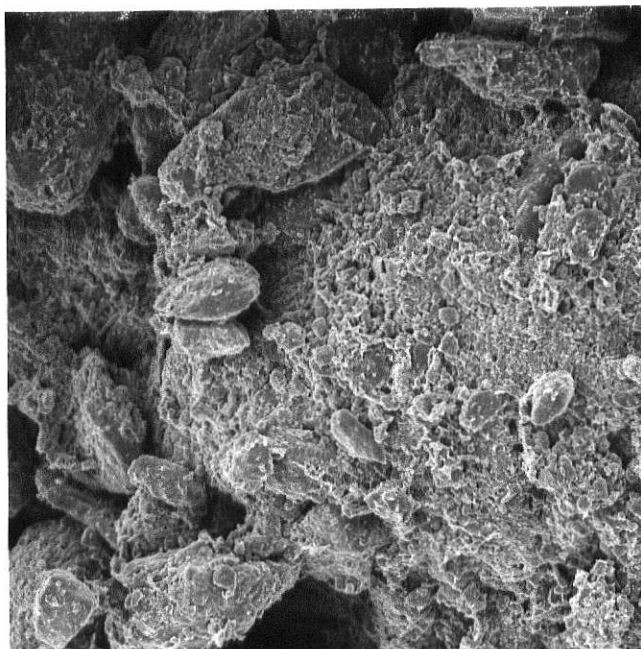


Fig. 69. SEM for Wakeen soil treated with 50 me Na<sup>+</sup>, 30 me K<sup>+</sup>, and 30 me NH<sub>4</sub><sup>+</sup>/100 g soil.



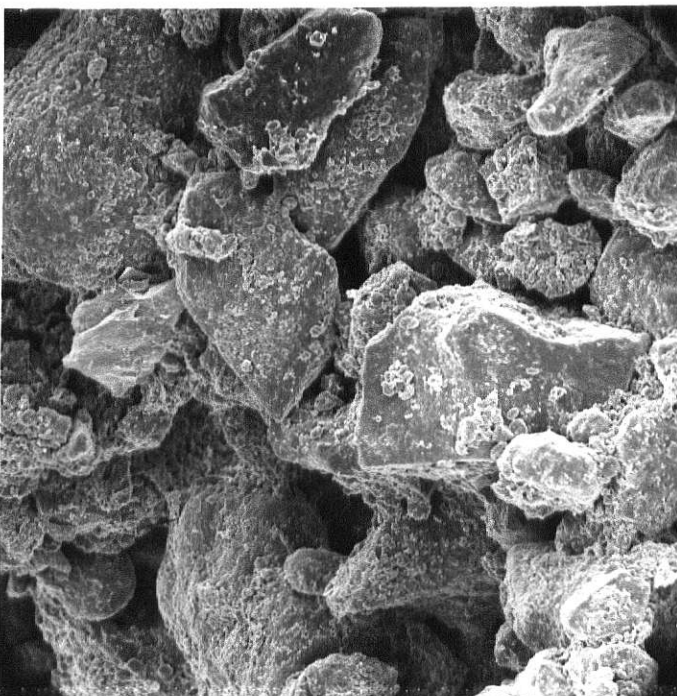


Fig. 71. SEM for untreated Wakeen soil.

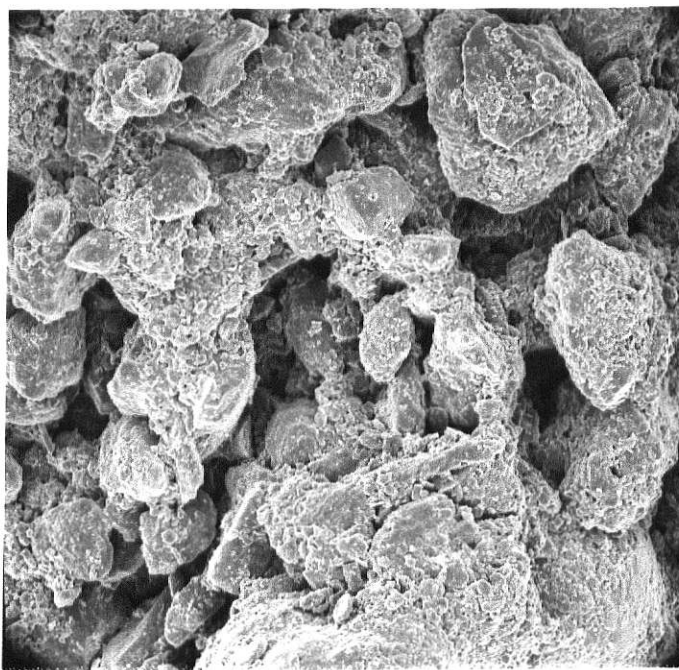


Fig. 70. SEM for Wakeen soil treated with 50 me  $\text{Na}^+$ , 50 me  $\text{K}^+$ , and 50 me  $\text{NH}_4^+$ /100 g soil.

Treatments without sodium (only potassium and ammonium) resulted in better soil structure (Figure 66), than sodium treated soil (Figures 65 and 69).

Low level of sodium with low levels of potassium and ammonium produced some dispersion (Figure 67), while low level of sodium with high concentrations of potassium and ammonium (Figure 68) resulted in improvement in soil structure.

High concentrations of sodium with high concentration of potassium and ammonium (50 me/100 g soil) resulted in some dispersion (Figure 70).



## SUMMARY AND CONCLUSIONS

Soil dispersion was measured by two methods, hydraulic conductivity and scanning electron microscopy. There were differences between the two methods. Scanning electron microscopy is a quick method for observation of soil dispersion, but it is not sensitive for measuring small differences in soil structure. The hydraulic conductivity method is more sensitive for measuring small differences between treatments, but it requires more time.

## Hydraulic Conductivity Method

Applications of potassium and ammonium alone or in combinations increased hydraulic conductivity in most treatments of Keith silt loam and Wakeen silt loam soils compared with untreated soils. High sodium (50 me/100 g soil) at all levels of potassium and ammonium resulted in dispersion of these calcareous soils. Low levels of sodium (10 me/100 g soil) with different levels of potassium and ammonium resulted in some increase in hydraulic conductivities, for most treatments with Keith silt loam and Wakeen silt loam soils compared with untreated soils. Richfield silty clay loam showed dispersion for all treatments because of high sodium concentrations present originally in this soil and because of the fine texture of this soil (silty clay loam). Keith silt loam and Wakeen silt loam soils showed varied hydraulic conductivities after applied ammonium. This shows the influence of ammonium on hydraulic conductivity in artificially prepared soil columns varies with different soils.

From this study, the differences between treatments depend upon: cation type and concentration, soil type, and soil minerals.

### Scanning Electron Microscopy Method

High sodium at all levels of potassium and ammonium resulted in soil dispersion in all three soils as shown by SEM observations. Low sodium with high levels of a potassium and ammonium did not produce soil dispersion with the Keith silt loam and Wakeen silt loam soils. Dispersion occurred with Richfield silty clay loam soil for all treatments.

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## APPENDIX

Table I. Clay minerals for Keith silt loam soil.

Treatment	A°	Minerals
Untreated	3.35	Quartz
	3.57	Kaolinite, chlorites
	4.98	Micas, chlorites
	7.14	Kaolinite, chlorites
	10.06	Illite
	11.21	Mont.
	13.84	Chlorite
	15.43	Mont.
Mg Cl <sub>2</sub>	1.99	Chlorites, illite
	3.34	Quartz
	3.57	Kaolinite, chlorite
	4.26	Illite
	4.97	Illite
	7.20	Kaolinite, chlorites
	10.20	Illite
	13.22	Chlorites
K Cl	1.99	Chlorites, illite
	3.02	Calcite
	3.13	Illite
	3.55	Kaolinite, chlorites
	4.97	Micas, chlorites
	7.08	Kaolinite, chlorites
	10.08	Illite
	13.14	Chlorites
E. glycol	3.33	Quartz, illite
	3.55	Kaolinite, chlorites
	7.12	Kaolinite, chlorites
	10.04	Micas, illite
	13.18	Chlorites
	17.65	Mont.
	20.43	Mont.

Table II. Clay minerals for Richfield silty clay loam soil

Treatment	$\Delta^{\circ}$	Minerals
Untreated	3.34	Quartz
	3.58	Kaolinite
	5.00	Muscovite
	7.20	Kaolinite
	10.06	Mica, illite
	12.58	Mont.
	14.28	Mont.
Mg Cl <sub>2</sub>	1.99	Kaolinite
	3.33	Quartz
	3.57	Kaolinite
	4.24	Quartz
	4.97	Illite
	7.13	Kaolinite
	10.04	Illite
	11.94	Mont.
K Cl	1.80	Quartz
	1.99	Kaolinite
	2.22	Illite
	2.82	Illite
	3.13	Micas
	3.34	Quartz
	3.58	Kaolinite
	4.26	Quartz
	5.00	Muscovite
	7.16	Kaolinite
	10.04	Illite, micas
E. glycol	3.33	Quartz
	3.57	Illite
	4.24	Quartz
	4.97	Illite, micas
	7.14	Kaolinite
	10.01	Illite
	18.78	Mont.

Table III. Clay minerals for Wakeen silt loam soil.

Treatment	$\lambda^{\circ}$	Minerals
Untreated	3.05	Calcite
	3.34	Quartz
	3.58	Kaolinite
	7.17	Kaolinite
	10.24	Illite
	13.54	Mont.
Mg $\text{Cl}_2$	1.60	Quartz
	1.62	Quartz
	1.87	Calcite
	1.91	Calcite
	2.09	Calcite
	2.28	Calcite
	2.49	Kaolinite
	3.02	Calcite
	3.33	Illite, muscovite, quartz
	3.57	Chlorite, kaolinite
	3.84	Kaolinite
	4.25	Quartz
	5.00	Muscovite
	7.14	Kaolinite
K Cl	10.08	Illite
	12.37	Mont.
	1.91	Calcite
	2.09	Calcite
	2.27	Calcite
	2.48	Kaolinite
	3.02	Calcite
	3.13	Mica
	3.33	Illite, muscovite, quartz
	3.56	Kaolinite
E. glycol	3.83	Kaolinite, calcite
	4.25	Illite
	7.13	Kaolinite
	10.04	Illite
	3.02	Calcite
	3.34	Quartz, illite, muscovite
	3.57	Kaolinite
	3.85	Calcite
	4.26	Illite
	4.98	Illite

Table III. Continued.

Treatment	$A^{\circ}$	Minerals
	7.16	Kaolinite
	9.92	Micas and illite
	17.58	Mont.
	20.82	Mont.

EFFECTS OF SODIUM, POTASSIUM, AMMONIUM  
ON DISPERSION OF CALCAREOUS SOILS

by

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Soil dispersion is very important in Iraq with many calcareous soils. The objective of this study was to measure effects of monovalent cations on dispersion of calcareous soils. Calcareous loess soils were collected from three different locations in western Kansas -- Colby, Garden City, and Hays. The soil types are Keith silt loam, Richfield silty clay loam, and Wakeen silt loam, respectively. Treatments of sodium, potassium, and ammonium at different levels and combinations were used. Two hundred grams of soil were saturated with water for at least 16 hours and then treated with solutions containing the monovalent cations. Soil dispersion was measured by hydraulic conductivity (constant head method). Soils were dried after measuring hydraulic conductivity and the scanning electron microscope was used to observe soil dispersion.

Different results were obtained with the different soils. Soil dispersion occurred with high concentrations of sodium (50 me/100 g soil) and low concentrations of potassium and ammonium (10 me/100 g soil) for all treatments with the three soils. Low levels of sodium (10 me/100 g soil) with low levels of potassium and ammonium (10 me/100 g soil) resulted in lower hydraulic conductivities and weak soil structure for the Keith silt loam soil and Wakeen silt loam soil, and very low hydraulic conductivities and severe dispersion occurred with Richfield silty clay loam soil. Low concentrations of sodium (10 me/100 g soil) with high concentrations of potassium and ammonium (50 me/100 g soil) increased hydraulic conductivities for Keith and Wakeen soils and good structure was observed on the scanning electron micrographs. The Richfield soil was dispersed with the combination of high concentration of sodium (50 me/100 g soil) and low concentrations of potassium and ammonium (10 me/100 g soil). The Richfield soil had low hydraulic

conductivities and weak soil structures for all treatments. This soil contained appreciable quantities of sodium and clay in the untreated soil.

The hydraulic conductivity method was more sensitive for measuring small differences between treatments than was the scanning electron microscopy method.

This study shows that cation, cation concentration, soil type, and soil minerals influenced dispersion of these soils.