石膏處理 및 用水管理方法에 依한 鹽害土壤의 除鹽實驗

A Laboratory Study for Reclamation of Salt-Affected Soils by Gypsum Amendment and Water Management Practices

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摘　要

石膏(改良劑)處理 및 用水管理方法에 依한 鹽害土壤의 除鹽效果를 分析하기 爲하여 浸出法 (leaching method), 水洗法(rinsing method), 湛水法(ponding method ; 石膏混合處理 및 石膏非混合處理)에 依해서 3處理 3反復 4回連續抽出實驗이 遂行되었다.

나트륨減少量과 總鹽分減少率은 浸出法이 水洗法이나 湛水法에 比하여 더욱 效果的이었다. 石膏處理區의 除鹽率이 石膏無處理區의 除鹽率보다 比較的 높았으며 石膏處理區(에이커當 2톤 石膏處理區 및 4톤 石膏處理區) 사이에는 別差異가 없었다.

除鹽實驗後 나트륨吸着度(SAR)는 浸出法과 水洗法을 使用한 石膏處理區에서 $10(\mathrm{meq}/l)^{1/2}$以下로 減少되었다. 連續抽出의 境遇 SAR은 水洗法을 使用한 石膏處理區에서 單位土壤깊이當 供給用水깊이의 比率(D_w/D_s)이 3.0以上으로 될때 $10(\mathrm{meq}/l)^{1/2}$以下로 減少되었고 浸出法을 使用한 石膏處理區에서는 D_w/D_s가 1.5以上일때 $10(\mathrm{meq}/l)^{1/2}$以下로 減少되었다.

除鹽實驗後 飽和抽出液의 電氣傳導度(EC)는 全實驗區에서 4mmhos/cm以下로 減少되었다. 連續抽出의 境遇 EC는 水洗法을 使用한 石膏處理區에서 D_w/D_s가 3.0以上일때 4mmhos/cm以下로 減少되었고 浸出法을 使用한 石膏處理區에서는 D_w/D_s가 1.5以上으로 될때 4mmhos/cm以下로 減少되었다.

排水가 比較的 良好한 土壤의 置換性나트륨百分率(ESP)은 除鹽實驗後 浸出法과 水洗法을 使用한 石膏處理區에서 15%以下로 減少되었고 排水가 不良한 土壤의 ESP는 水洗法을 使用한 石膏處理區에서 15%以下로 減少되었다.

나트륨吸着度, 電氣傳導度, 置換性나트륨百分率 等을 勘案하여 볼때 本鹽害土壤은 石膏處理浸出法 또는 石膏處理水洗法에 依하여 比較的 쉽게 改良될 수 있다고 判斷된다. 除鹽效果 및 改良劑費用等을 考慮하여 보면 排水가 比較的 良好한 鹽害土壤의 境遇 에이커當 2톤 石膏處理 浸出法이 效果的인 方法으로 보이며 排水가 不良한 鹽害土壤의 境遇에는 에이커當 2톤 石膏處理 水洗法이 比較的 效率的인 除鹽方法이라고 思料된다. 排水가 不良한 鹽害土壤의 浸透率을 增加시키고 除鹽을 促進시키기 爲해서는 石膏等과 같은 改良劑의 供給이 必要한 것으로 看做되며 現場條件下에서도 表土層土壤의 除鹽을 爲해서는 石膏處理浸出法과 石膏處理水洗法이 效率的인 方法으로 期待된다.

INTRODUCTION

Salt-affected soils are commonly classified into three main categories: Saline, saline-sodic, and nonsaline-sodic soils (U.S. Salinity Laboratory Staff, 1954). A saline soil is a nonsodic soil containing soluble salts in such quantities that they interfere with the growth of most crop plants. Saline soils are those for which the electrical conductivity of the saturation extract (ECe) is more than 4 mmhos/cm. at 25°C., the exchang-

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eable-sodium-percentage (ESP) is less than 15, and ordinarily the pH is less than 8.5. A saline-sodic soil contains sufficient exchangeable sodium to interfere with the growth of most crop plants and appreciable quantities of soluble salts. Saline-sodic is applied to soils for which the ECe is greater than 4 mmhos/cm. at 25°C., the ESP is is greater than 15, and the pH readings are seldom higher than 8.5. A nonsaline-sodic soil contains sufficient exchangeable sodium to interfere with the growth of most crop plants and does not contain appreciable quantities of soluble salts. Nonsaline-sodic is applied to soils for which the ECe is less than 4 mmhos/cm. at 25°C., the ESP is greater than 15, and the pH readings usually range between 8.5 and 10.

The only proven method of reclaiming salt-affected soils is by leaching accumulated salts to depths below the rootzone. The amount of water required to reclaim a saline soil depends on soil type, the initial soil salinity level, the irrigation water quality and irrigation method. Reeve, et al. (1948) showed that the amount of salt removed from the soil increased with the amount of water applied, and the equal depth of water added to soil depth (30 cm) reduced the salt content in the depth of soil but accomplished little leaching below the depth. Also, Reeve, et al. (1955) stated that about 80% of the soluble salts initially present in a soil profile can be removed by leaching with a depth of water equivalent to the soil depth to be reclaimed, providing that soil permeability and drainage are adequate. An experiment (Oster, et al., 1972) was conducted to compare continuous ponding, intermittent ponding and sprinkling for a saline soil. Hoffman (1980) found that for fine-textured soils about 70% of the initial salt present can be removed by continuous ponding if the depth of water leached through the profile equals the depth of soil reclaimed, but one-thired less water is required if application is by intermittent ponding or sprinkling.

Sodic soils are difficult and costly to reclaim, because soluble calcium is usually supplied to replace the excess exchangeable sodium. Reclamation usually proceeds slowly owing to the characteristic low permeability of sodic soils to water of relatively low electrolyte content (Reeve, et al., 1967). The reclamation of sodic soil may require that water penetration into and through the soil be improved by exchanging excess sodium with calcium so that leaching can proceed or initially leaching with saline water and then progressively decreasing the salinity of the applied water. For reclaiming sodic soils, an amendment or deep tillage may be required before leaching. The type and amount of amendment or deep tillage practice to be used depends on soil chacteristics, desired rate of sodium replacement, quality of leaching water, and economic considerations. Gypsum is the most commonly used amendment for sodic soil reclamation, primarily because of its low cost.

Greenhouse and laboratory studies (McNeal, et al., 1966) were undertaken to examine the effect of rice culture on the reclamation of sodic soils. Rice culture hastened the reclamation of coarse-textured sodic soils, but did not improve the reclamtion efficiency per unit of water leached through the soil. A laboratory column study of sodic soil reclamation (Prather, et al., 1978) was carried out using two soils high in exchangeable sodium percentage and three amendments. Hoffman (1980) presented guidelines for reclaiming saline, sodic, and boron-affected soils by leaching, provided drainage is adequate. In the guidelines sodic soils are considered fully reclaimed when the ESP is 10 or less. For reclaiming sodic soil, a graphical solution was proposed for estimating the amendment requirement. Sandy loam or clay loam soils in seven lysimeters were reclaimed by ponded or unsaturated leaching following a saline irrigation. The experiment was of 2.5 years duration and examined the relation between salinity, exchangeable sodium reductions, and the amount of applied water. Tests included several different soil conditions and different methods of reclamation (Jury, et al., 1979). A field-plot reclamation experiment was conducted on a virgin saline-sodic, sandy loam, permeable soil while growing rice with pre and post-planting leaching under conditions of continuous and intermittent submergence (Dahiya, et al., 1982). The data obtained showed that leaching efficiency was high under conditions of intermittent submergence and post-transplanting. Leaching under intermittent submergence alone progressively decreased salinity and sodicity throughout the top 100cm of the soil to levels safe for cultivation of relatively deep-rooted crops. The surface few centimeters of soil were reclaimed within a few hours after leaching so that young rice seedlings established and survived to give good yield.

Shainberg, et al. (1980) undertook studies to evaluate soil electrical conductivity over a wide range of salt concentration and to measure the dependence of the surface soil conductivity on: clay concentration; cation exchange capacity; and the ESP of the soil. The soil electrical conductivity increased nonlinearly with respect to the equilibrium solution electrical conductivity in the low range of salt concentration. In the higher salt concentration range, straight line relationships were obtained. The effect of the soil ESP on the electrical conductivity curve parameters was slight and was not significant when the electrical conductivity method was used to survey soil salinity.

The effect of gypsum, ground to varying fineness, on the properties of two soils, with exchangeable sodium percentage of 35 and 80 repectively, was studied in the laboratory(Chawla, et al., 1980). Treatments with the finest gypsum particles had the highest initial hydraulic conductivity. The hydraulic conductivity decreased sharply with time. On the other hand, treatments with coarser particles had a lower initial hydraulic conductivity and it was maintained or it increased with time. Hira, et al. (1980) conducted laboratory experiments with a sodic soil to ascertain the effect of exchangeable sodium percentage on the solubility of applied gypsum and to determine the amount of water required to dissolve gypsum and to leach the soluble salts from the surface soil. The increased ESP significantly increased the amount of gypsum dissolved per unit quantity of water. Keren, et al. (1982)carried out laboratory experiments to determine the effect of soil water velocity in soil on both gypsum dissolution rate and extent of reclamation of sodic soil.

Tide land reclamation has been carried forward and it has been planned to reclaim additional tide lands in Southwest Korea for expanding farm land because of the great shortage of arable land in Korea. About 600,000 ha of tide land has been reclaimed and the planning area amounts to 400,000 ha. The problem of high soluble salts and exchangeable sodium is serious in the beginning of reclaiming tide lands. It may take as long as 10 years to remove the excess salts after constructing the seawall, and during this period crops cannot be grown well. Therefore, it is important to reclaim these lands faster and more economically. Appreciable quantities of soluble salts are initially present in water used for irrigation from some wells in Louisiana. During the growing season, continued loss of water by evapotranspiration may result in a manifold increase in the soluble salts in soil. The increased concentration of soluble salts, especially sodium, may cause undesirable physical and chemical conditions in the soil resulting in decreased yield.

Research is needed to evaluate interrelationships among quantity and quality of irrigation water, water management practices, and soil characteristics to investigate possible ways of reducing high levels of soluble salts and improving undesirable conditions in salt-affected soils. The objective of this study is to evaluate possible water management techniques of removing excess salts and exchangeable sodium in salt-affected soils, especially sodic soil, as fast as possible, economically, through laboratory experiments. Emphasis is on short term reclamation to shallow depths to shorten time required to initiate rice production in reclaimed tide lands. Traditional leaching methods are envisioned for long term reclamation of these soils where lower salt content is desired. In parts of Louisiana, the sodium accumulation occurs only in surface horizons due to the low soil permeability together with factors already described. information obtained from this research will also provide basic information for future studies planned to determine probable extent of sodium accumulation of development of other characteristics over long-term periods of time and evaluate pumping and water management cost in salt-affected soils.

MATERIALS AND METHODS

Three soils (A,B, and C) from Southwest Korea and three soils (D,E, and F) from Louisiana were collected for laboratory experiments. The soils were air-dried, ground to pass a 2 mm sieve, mixed to provide homogeneous samples, and each soil was stored in an air-tight container. The physical and chemical properties of the soils used were analyzed by standard methods (U.S. Salinity Laboratory Staff, 1954) before carrying out reclamation experiments. The initial properties of the soils are given in Table 1.

Table-1. Physical and chemical properties of the soils

Soil sample	Soluble cations in saturation extract(meq/l)					SAR $(meq/l)^{1/2}$	ECe (mmhos/cm)	pH
	Ca	Mg	Na	K	S			
Soil A	9.44	37.96	269.04	4.33	29.73	55.3	16.4	7.6
Soil B	0.41	1.28	19.38	0.66	3.56	21.1	1.9	7.9
Soil C	15.41	56.70	289.13	4.70	42.91	48.2	18.5	6.7
Soil D	0.88	1.14	3.83	0.03	0.64	3.8	0.5	6.8
Soil E	1.17	0.32	61.35	0.05	0.83	71.1	4.8	6.9
Soil F	0.31	0.25	4.35	0.18	0.41	8.2	0.4	7.5

Soil sample	Exchangeable cations (meq/100g)				ESP (%)	Mechanical composition(%)			Texture class
	Ca	Mg	Na	K		Sand	Silt	Clay	
Soil A	1.11	3.48	7.86	0.78	46.8	70.1	25.7	4.2	Sandy loam
Soil B	1.07	2.56	1.80	0.57	27.5	79.5	16.3	4.2	Loamy sand
Soil C	1.44	4.08	7.80	0.71	41.4	78.3	16.6	5.1	Loamy sand
Soil D	7.94	7.82	0.80	0.12	4.7	1.9	69.8	28.3	Silty Clay loam
Soil E	2.97	0.60	4.61	0.06	54.6	17.4	64.6	18.0	Silt loam
Soil F	5.53	3.94	0.99	0.12	9.1	16.0	63.8	20.2	Silt loam

SAR: Sodium-adsorption-ratio. ECe: Electrical conductivity of the saturation extract.
ESP: Exchangeable-sodium-percentage.

The following laboratory reclamation experiments were performed. Four different reclamation experiments (four management systems) were carried out as outlined in the sections that follow (see Table 2). Three treatments (0, 2, and 4 tons/acre of gypsum) for each management system and three replications for each treatment were done on this study. Gypsum

Table-2. Management systems and treatments

Soil	Management system	Treatment	Replication	Remark
3 Soils from Korea: Soil A Soil B Soil C 3 Soils from Louisiana: Soil D Soil E Soil F	No.1 : Mix Soil and gypsum. Place in cylinder and wet. Mix mixture and water. Let stand and decant. Repeat adding water. No.2 : Same as No. 1 above, without mixing mixture and water. No.3 : Same as No.2 above, without mixing gypsum with soil. No. 4 : Mix soil and gypsum. Place in cylinder and flood. Collect leachate, if any. Repeat adding water.	No.1 : No gypsum added. No.2 : Add gypsum at the rate of 2 tons/acre. No.3 : Add gypsum at the rate of 4 tons/acre.	3 Replications for each treatment. 4 sequential extractions for each management system.	Code for keeping track of samples: (Ex) A1234 Letter: Soil 1st No.: Management system. 2nd No.: Treatment. 3rd No.: Treatment replication. 4th No.: Sequential extraction.

was added to the soil and throughly mixed before the experiment was conducted for all but one experiment(management system system 3). Throughout the experiment, volumes of water added and volumes of supernatant or leachate removed from the soil were recorded. Bottom-sealed glass cylinders (4.2 cm in diameter by 60 cm in length) were used for management system 1, 2, and 3. The glass cylinders attached to a 115 ml sterilization filter unit were used for management system 4. The following procedures were used for the respective management systems.

Management System No.1-Rinsing Practice: (a) Place known amount (about 20 cm depth) of soil into each cylinder. (b) Add known quantity (about 20 cm depth) of distilled water, making sure entire soil is wetted. (c) Completely mix soil and water and allow suspension to stand 48 hours. (d) Withdraw a 25 to 50 ml of supernatant and store in a refrigerator for later analyses Ca, Mg, K, Na, S, Fe, Al and Mn. (e) Measure and discard the excess supernatant. (f) Repeat steps "b" through "e" four times. (g) Remove soil and air-dry for final analyses.

Management System No.2 - Ponding Practice: (a) Put 20 cm of soil into each cylinder. (b) Add 20 cm of distilled water, making sure entire soil is wetted and allow ponded soil to stand 48 hours. (c) Withdraw a 25 to 50 ml of supernatant and store in a refrigerator for later analyses of Ca, Mg, K, Na, S, Fe, Al, and Mn. (d) Measure and discard the excess supernatant. (e) Repeat steps "b" through "d" four times. (f) Remove soil and air-dry for final analyses.

Management System No.3 - Ponding Practice: This experiment is identical to No. 2 except that the gypsum is not mixed into the soil. Instead it is applied to the surface after the dry soil is added to the cylinder.

Management System No.4 - Leaching Practice: (a) For this experiment assume the soil to have 50% pore space, thus one pore volume of water is equal to one-half the volume of soil used. (b) Put 20 cm of soil into each cylinder. (c) Initially, flood the soil with two pore volume equivalents of distilled water. (d) Allow the soil to drain (assuming it drains) and trap leachate through the soil (see "j" that follows). (e) Measure the volume of leachate and store a 25 to 50 ml subsample in a refrigerator for later analyses of Ca, Mg, K, Na, S, Fe, Al, and Mn.

(f) Measure and discard the excess leachate from the preceding step. (9) Add one pore volume equivalent of distilled water to the soil. (h) Repeat steps "d" through "g" three more times. (i) Remove soil and air-dry for final analyses. (j) If soil doesn't drain freely, apply vacuum and proceed. If vacuum doesn't extract water, abandon the experiment.

Each sample of each soil carried through the different reclamation experiments was air-dried, ground to pass a 2 mm sieve, and stored in an air-tight container. Exchangeable cations were determined by ammonium acetate method. Soluble and extractable cations in saturation paste extract were determined by inductively coupled argon plasma spectrophotometer. Electrical conductivities were measured by a conductivity bridge and pH values were measured in 1 : 1 soil water suspension. Exchangeable sodium percentage (ESP) and sodium adsorption ratio (SAR) were determiined by standard methods (U.S. Salinity Laboratory Staff, 1954). The effect of sodic soil reclamation was mainly analyzed for rinsing and leaching practies using the three sodic soils (A,C, and E) with high SAR, ESP, and EC. Accumulative sodium removed, the fraction of sodium concentration remaining and the fraction of total salt concentration remaining during reclamation, and the SAR and EC values of sequential extract were measured with increasing the depth of water applied per unit depth of soil. The SAR, ESP, and EC values of the soils before and after reclamation were determined for various treatments.

RESULTS AND DISCUSSION

The results of chemical analyses of six soils carried through reclamation experiments are summarized in Table 3. Initially, three soils(A, C, and E) were sodic with high sodium adsorption ratio (SAR), exchangeable sodium percentage (ESP), and electrical conductivity of saturation extract (ECe). The other three soils (B,D, and F) were not sodic. Drainage through the soil columns was poor in the soil A,B, and C, and very poor in the soil D,E, and F. Leaching practices couldn't be carried out in the soil D,E,and F. Rinsing (management 1) and leaching (management 4) were effective in reducing the values of SAR,ESP, and ECe in most of soils, but ponding(management 2 and 3) were not effective. The treatment identification numbers used in tables and figures are given in Table 2.

Table-3. Some characteristics of the soils carried through the reclamation experiments.

Treatment No.	SAR (meq/1)$^{1/2}$	ECe (mmhos/cm)	pH	ESP (meq/100g)
Initial value	55.3	16.4	7.6	46.8
A11	15.5	0.8	8.5	19.9
A12	4.7	1.3	7.9	10.6
A13	2.5	2.7	7.7	6.0
A21	30.9	14.3	7.5	53.5
A22	24.5	17.7	7.5	36.7
A23	23.0	17.3	7.5	27.2
A31	33.1	18.0	7.5	53.0
A32	24.6	18.8	7.4	40.5
A33	23.6	18.2	7.4	32.2
A41	8.3	0.3	8.6	26.6
A42	2.4	0.3	8.0	4.1
A43	1.1	0.3	7.9	2.1
Initial value	21.1	1.9	7.9	27.5
B11	10.3	0.2	8.4	16.9
B12	1.3	0.5	7.6	3.3
B13	0.6	1.7	7.4	1.8
B21	21.2	1.9	8.1	27.8
B22	7.3	5.0	7.5	13.8
B23	6.9	5.3	7.5	9.0
B31	19.0	2.1	8.0	27.9
B32	7.8	4.7	7.6	16.5
B33	7.0	5.2	7.5	11.3
B41	14.5	0.5	8.3	19.2
B42	1.0	0.2	7.5	1.4

B43	0.4	0.3	7.6	0.9
Initial value	48.2	18.5	6.7	41.4
C11	12.0	0.9	7.3	16.8
C12	4.8	1.3	7.1	10.0
C13	2.4	2.8	6.8	6.2
C21	27.0	18.2	6.6	49.5
C22	24.1	20.4	6.6	34.8
C23	22.6	20.0	6.6	26.6
C31	26.8	17.8	6.6	49.5
C32	23.0	19.3	6.6	38.2
C33	23.0	19.3	6.6	29.5
C41	15.1	0.7	7.5	23.0
C42	2.2	0.3	7.1	3.5
C43	0.6	0.2	7.0	1.2
Initial value	3.8	0.5	6.8	4.7
D11	0.6	0.2	7.0	3.1
D12	0.8	0.5	7.1	1.3
D13	0.5	0.9	7.0	1.0
D21	1.5	0.4	7.6	4.1
D22	1.3	2.3	7.2	2.8
D23	1.1	2.8	7.2	2.2
Initial value	71.1	4.8	6.9	54.6
E11	13.6	0.3	7.5	46.7
E12	9.1	0.6	7.2	16.2
E13	2.9	1.6	6.7	7.6
E21	42.6	2.6	7.2	56.8
E22	14.0	4.6	6.6	28.0
E23	11.8	5.4	6.5	19.3
Initial value	8.2	0.4	7.5	9.1
F11	1.6	0.1	7.6	7.2
F12	1.2	0.4	7.4	2.2
F13	0.6	1.3	7.2	1.5
F21	1.2	0.2	7.8	9.1
F22	2.2	2.7	7.2	5.2
F23	2.0	3.1	7.2	3.7

Exchangeable Sodium Removal: The relationship between the depth of water applied per unit depth of soil (Dw/Ds, where Dw is the depth of water applied and Ds is the depth of given soil) and the amount of accumulative sodium leached (meq/100g), and the fraction of sodium concentration remaining (Na/Na_0 where Na_0 is the initial sodium concentration and Na is the sodium concentration during reclamation) are shown in Figures 1 and 2, respectively. On the whole, the amount of accumulaive sodium leached and he fraction of sodium concentration removal were considerably greater with leaching (management 4) when compared to rinsing (management 1). Sodium removed by leaching increased with the rate of gypsum in the treatments. The difference in total sodium removal between Tmt.2 and Tmt.3 was not appreciable. Total sodium removal increased with amounts of water applied to the soil in Mgt.1, but did not increase appreciably in Mgt.4. Total sodium removal increased sharply, at first, as water was rinsed from the soil E. In contrast, there was a small rate of increased sodium removal with water rinsed from the soil A and C.

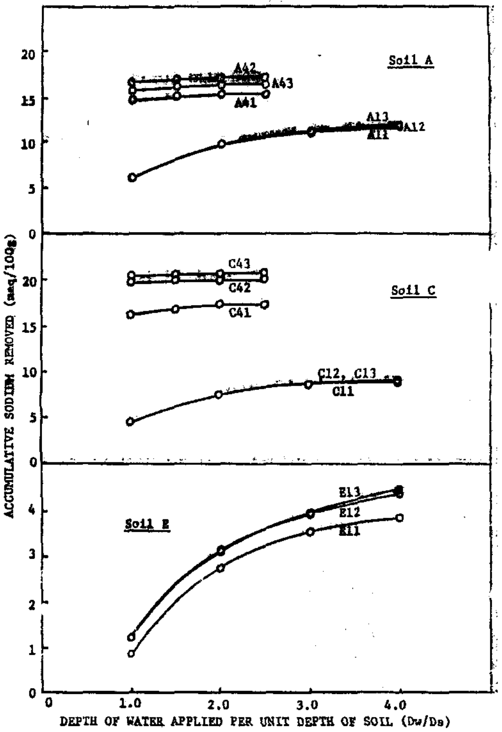

Fig. 1. Depth of water applied per unit depth of soil versus accumulative sodium removed for various treatments.

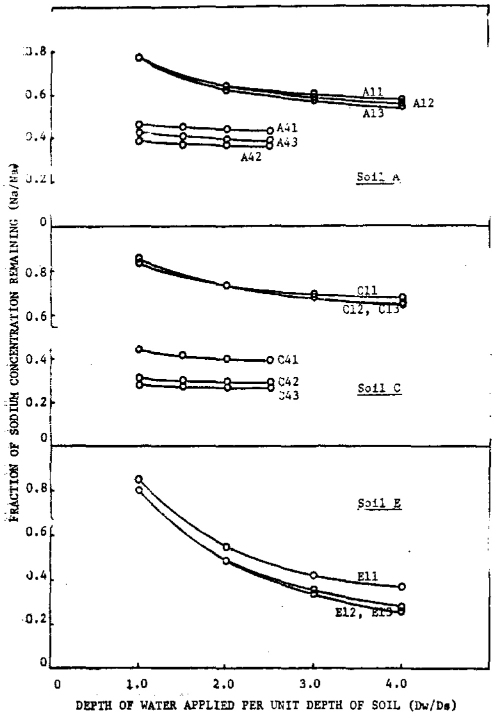

Fig. 2. Fraction of sodium concentration remaining during reclamation versus depth of water applied per unit depth of soil.

The fraction of sodium concentration removal, $(Na_0-Na)/Na_0$, increased from 23 to 42% in soil A, 16 to 32% in soil C, and 15 to 63% in soil E, respectively as Dw/Ds increased from 1.0 to 4.0 in Mgt.1 - Tmt.1. It increased from 23 to 44% in soil A, 16 to 33% in soil C, and 20 to 73% in soil E, respectively as Dw/Ds increased from 1.0 to 4.0 in Mgt.1 - Tmt.2 and 3. It increased from 54 to 57% in soil A and 56 to 60% in soil C, respectively as Dw/Ds increased from 1.0 to 2.5 in Mgt.4 - Tmt.1. It increased from approximately 60 to 62% in soil A and 70 to 72% in soil C, respectively as Dw/Ds increased from 1.0 to 2.5 in Mgt.4 - Tmt.2 and 3. More than 1.0 depth of water applied per unit depth of soil was required to reduce the fraction of sodium concentration remaining to less than 40% of its initial value in Mgt.4 - Tmt.2 and 3 in soil A and C, and more than 3.0 was required in Mgt.1 - Tmt.2 and 3 in soil E.

Total Salt Romoval: Figure 3 shows the relationship between the depth of water applied per unit depth of soil (Dw/Ds) and the fraction of salt concentration remaining (C/C_0, where C_0 is the initial salt concentration and C is the salt concentration during reclamation). As similar to the fraction of sodium concentration removal, the fraction of total salt concentration removal, $(C_0-C)/C_0$, was considerably higher in Mgt.4 than Mgt.1, and it was greater in Tmt.2 and 3 as compared with Tmt.1 except in soil E. The most efficient treatment for total salt removal in soil A and C was Mgt.4 - Tmt.2 and 3. More than 1.5 Dw/Ds was required to reduce C/C_0 to less than 30% of its initial value in soil A and more than 1.0 Dw/Ds was required to reduce C/C_0 to less than 20% of its initial value in soil C. Unlike soil A and C, $(C_0-C)/C_0$ was greater in Tmt.1 as compared with Tmt.2 and

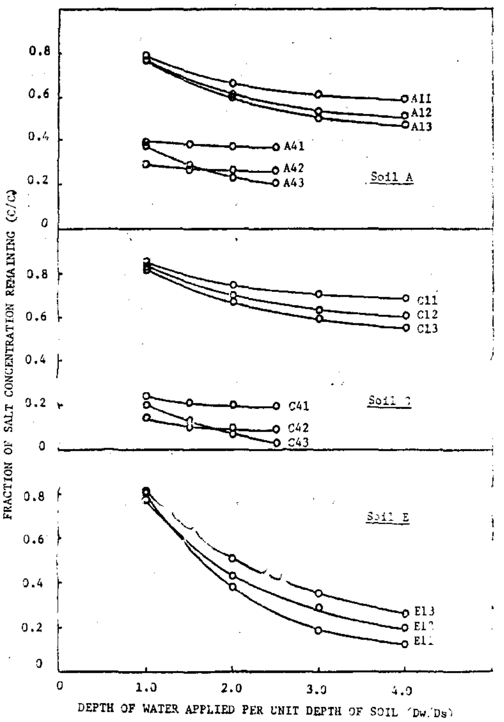

Fig. 3. Fraction of salt concentration remaining during reclamation versus depih of water applied per unit depih of soil.

3. The most effective treatment for increasing total salt removal in soil E was Mgt.1 - Tmt.1, more than 3.0 Dw/Ds was required to reduce C/Co to less than 20% of its initial value.

Sodium Adsorption Ratio: The sodium adsorption ratio (SAR) values before and after reclamation, and the relationship between the SAR values of sequential extract and the depth of water applied per unit depth of soil (Dw/Ds) are presented in Figures 4 and 5, respectively. The initial SAR values of soils A,C, and E before reclamation were very high, 55.3, 48.2, and 71.1, respectively. The final SAR values of soils A,C, and E after reclamation decreased to less than 10 in Mgt.1 and 4 - Tmt.2 and 3. Considering the reduction of SAR values (Hoffman, 1980), the sodic soils may be considered to be reclaimed by Mgt.1 and 4 - Tmt.2 and 3. The SAR values of sequential extract decreased to less than 10 in Mgt.1 - Tmt.2 and 3 when Dw/Ds was more than 3.0 in soils A,C, and E. It decreased to less than 10 in Mgt.4 - Tmt.2 and 3 when Dw/Ds was more than 1.5 in soils A and C.

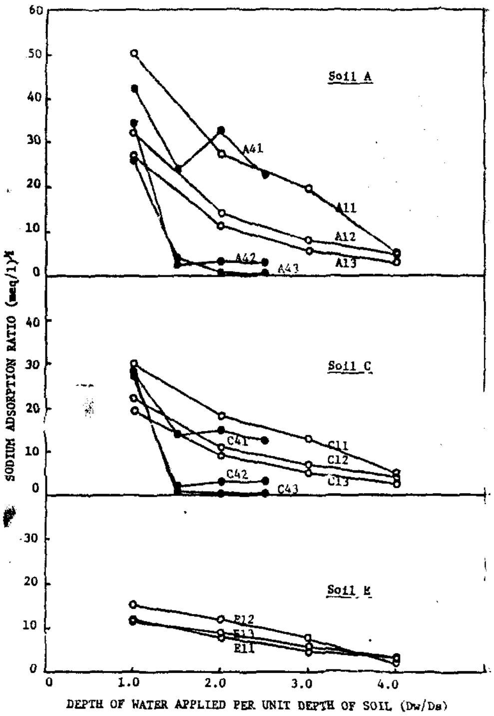

Fig. 5. The relationship between the SAR values of sequential extract and depth of water applied per unit depth of soil.

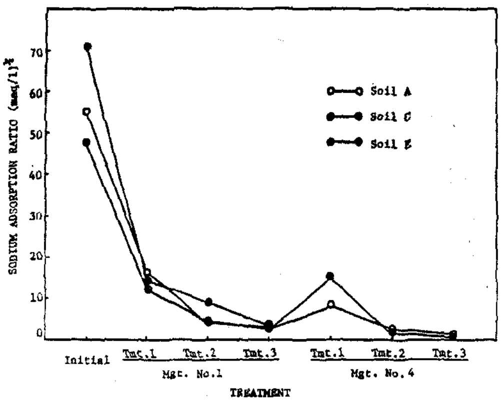

Fig. 4. Sodium adsorption ratio values before and after reclamation for various treatments.

Electrical Conductivity: Figures 6 and 7 presents the electrical conductivity of saturation extract(ECe) before and after reclamation, and the relationship between the electrical conductivity values of sequential extract and the depth of water applied per unit depth of soil (Dw/Ds), respectively. The initial ECe values of soils A, C, and E before reclamation were 16.4, 18.5, and 4.8 mmhos/cm. at 25.°C, respectively.

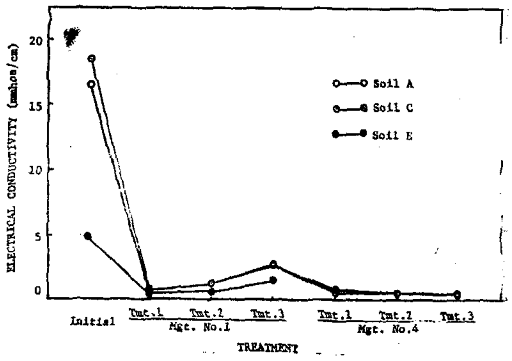

Fig. 6. Electrical conductivity values before and after reclamation for various treatments.

In all cases, the final ECe values after reclamation decreased to less than 4.0 mmhos/cm. at 25°C. The ECe values of sequential extract decreased to less than 4.0 mmhos/cm. at 25°C in Mgt.1 - Tmt.2 and 3 when Dw/Ds was more than 3.0 in soils A and C, and when Dw/Ds was more than 2.0 in Soil E. It decreased to less than 4.0 mmhos/cm. in Mgt. 4—Tmt.2 and 3 when Dw/Ds was more than 1.5 in soils A and C.

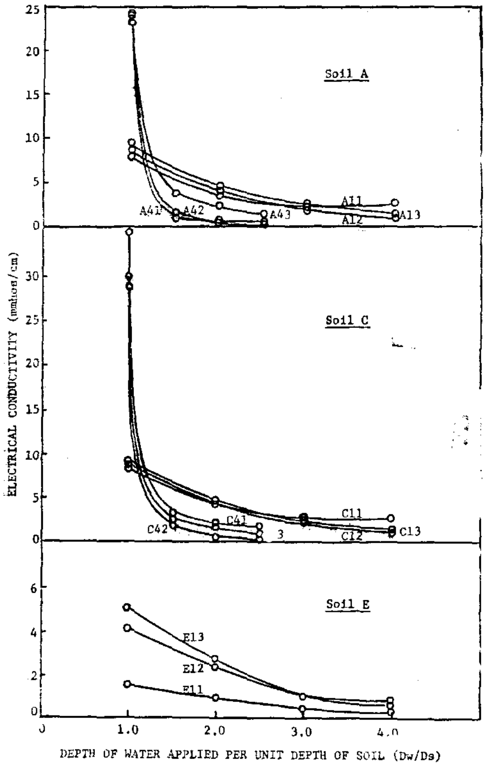

Fig. 7. **Depth of water applied per unit depth of soil versus electrical conductivity of sequential extract.**

Exchangeable Sodium Percentage: The exchangeable sodium percentage (ESP) values before and after reclamation are given in Figure 8. The initial ESP values of soils A,C, and E before reclamation were high, 46.8, 41.4, and 54.6%, respectively. The final ESP values of soils A and C decreased to less than 15% in Mgt.1 and 4 - Tmt.2 and 3, and the values of soil E decreased to less than 15% in Mgt.1 - Tmt.2 and 3. In consideration of the reduction of ESP values, the sodic soils were considered reclaimed by Mgt.1 and 4 - Tmt.2 and 3. The exception is with soil E in Mgt.4 - Tmt.2 and 3.

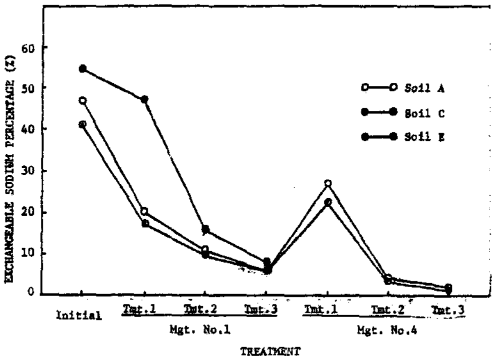

Fig. 8. **Exchangeable sodium percentage values before and after reclamation for various treatments.**

CONCLUSIONS

In this laboratory study, four different reclamation experiments, namely, leaching, rinsing, ponding with mixing gypsum and soil, and ponding without mixing gypsum and soil, were carried out to evaluate the effect of sodic soil reclamation by gypsum amendment and water management practices. Three treatments for each reclamation experiment and three replications for each treatment were carried out and four sequential extractions were repeated for each reclamation experiment.

The cumulative amount of sodium removed, the fraction of sodium removed, and the fraction of total salt removal were greater with leaching compared to rinsing. Reclamation was greater with the 2 and 4 tons/acre of gypsum treatments as compared with the treatment without gypsum. The difference in the values between 2 and 4 tons/acre of gypsum treatmment was not appreciable. The sodium adsorption ratio (SAR) values after reclamation decreased to less than 10 in the 2 and 4 tons/acre of gypsum treatments involving leaching and rinsing practices. The SAR values of sequential extract decreased to less than 10 in the 2 and 4 tons/acre of gypsum treatments of the rinsing practice when the depth of water applied per unit depth of soil (Dw/Ds) was more than 3.0. The SAR values decreased to less than 10 in the 2 and 4 tons/acre of gypsum treatments of the leaching practice when Dw/Ds was more than 1.5. In all treatments, the electrical conductivity of saturation extract (ECe) after reclamation decreased to less than 4.0 mmhos/cm. at 25°C. In the 2 and 4 tons/acre of gypsum treatments of rinsing practice, the EC values of sequential extract decreased to less than 4.0 mmhos/cm. when Dw/Ds was more than 3.0, and in the 2 and 4 tons/acre of gypsum treatments of leaching practice, the values decreased to less than 4.0 mmhos/cm. when Dw/Ds was more than 1.5. The exchangeable sodium percentage (ESP) of soil A and C after reclamation decreased to less than15% in the 2 and 4 tons/acre of gypsum treatments of leaching and rinsing practices, and the ESP of soil E decreased to less than 15% in the 2 and 4 tons/acre of gypsum treatments of rinsing practice. Considering the reduction of SAR, ECe, and ESP values, the sodic soils were considered comparatively reclaimed by the 2 and 4 tons/acre of gypsum treatments using either leaching or rinsing practices.

In consideration of the reclamation effects and amendment costs, the most efficient treatment for reclaiming sodic soil seems to be the 2 ton/acre of gypsum treatment of leaching practice, if drainage is adequate. Where drainage is poor, the 2 tons/acre of gypsum treatment of rinsing practice is considered as a effective reclamation method. The application of an amendment such as gypsum may be desirable to improve the infiltration rate of the soils and hasten the reclamation process in sodic soils and where such soils do not drain well. The results indicate that either rinsing or leaching in combination with 2 or 4 tons/acre of gypsum could be expected to effectively reclaim surface horizons of soils such as those studied under field conditions.

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