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Role of Gypsum in Amelioration of Saline-Sodic and Sodic Soil

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ABSTRACT

Gypsum is the most commonly used amendment in Pakistan. It is relatively inexpensive and easily available. Large deposits of gypsum are known to exist in Mianwali, Khushab, Jehlum, D.G. Khan, Sibbi, Kohat and D.I. Khan. The deposits are estimated at well over 3.5 billion tons. In order to establish the usefulness of gypsum as an amendment for the reclamation of saline-sodic and sodic soils, various experiments have been conducted in the country. Besides, experiments have also been carried out to see the possibility of using gypsum as a preventive measure to sodicity if the soil is being irrigated with hazardous tubewell water. For this purpose, experiments have been carried out in various parts of the country by various agencies/departments. In Pakistan, soil salinity and sodicity have been recognized as one of the major constraints for agriculture production. Reclamation of saline-sodic and sodic soils, however, cannot be achieved by simple leaching. Reclamation of these soils is difficult, time consuming and more expensive than that of saline soils due to replacement of exchangeable sodium with calcium. Hence, it requires the addition of chemical amendments along with leaching. The results of studies have revealed that by the application of gypsum to saline-sodic and sodic soils, adsorbed sodium on the soil complex is being replaced by the calcium. The action of Ca salts is mainly through exchange reactions with sodium.

$$\text{Soil}\left\langle \begin{array}{l}\text{Na}\\ \text{Na}\end{array}\right. + CaSO_4 \longrightarrow \text{Ca Soil} + Na_2\,SO_4$$

$$Na_2CO3\ \text{(if present)} + Ca\,SO4 \longrightarrow \underset{\text{Precipitates}}{\underset{\downarrow}{Ca\,CO_3}} + \underset{\text{Leached}}{\underset{\downarrow}{Na_2\,SO_4}}$$

The effectiveness of gypsum depends upon (i) the degree of fineness (ii) the way in which it is incorporated in the soil and (iii) the efficiency of the drainage system. Regarding use of gypsum as a preventive measure against sodicity due to the use of hazardous tubewell waters, it has been concluded that potentially hazardous tube well water can be used to grow crops successfully without adversely affecting the soils, provided gypsum is applied to the soil. This paper gives an over view of the reclamation experiments carried out so far pertaining to the reclamation of sodic soils in various parts of the Pakistan. It is clear from the results that the use of gypsum increase infiltration rate of the soil. An application of gypsum remains effective for a period of about three years. Application of gypsum @ 50% requirement of the soils appears to be more economical than 100% application. It is recommended that reasonable facilities should be provided to farmers in Pakistan for using gypsum as amendment for the reclamation of their problematic soils to enable them to use this amendment on a large scale which will be highly profitable to both the Government and the farmers community through improvement of sodic soils and increase in over all agriculture production.

Key Words: Gypsum; Saline-sodic soils; Sodic soils; Irrigation water

INTRODUCTION

Accumulation of salts is a major retarding factor for the successful plant growth in irrigated areas of the arid region and in coastal areas of the tropics where the tidal flow of seawater had spread enough salts on the soils. Reclamation of soil with sodium is often a problem due to inadequate leaching facilities in such soils. Such soils are usually reclaimed by adding a fair source of soluble calcium. The application of calcium sources on the basis of gypsum requirement is likely to produce an undesirable salt concentration in the soil solution due to little leaching especially in heavy clay and submerged soil conditions. The sources of calcium for replacement of exchangeable sodium from sodic and saline-sodic soils are:

1. Irrigation water. If the irrigation water can pass through the soil, it will replace exchangeable sodium with calcium. Many saline-sodic soils are not easily permeable to good quality irrigation water. Anyhow, the amount of calcium in so called good quality irrigation water is so low that it will need a lot of water and time for reclamation.

2. Gypsum and calcium carbonate present in the soil. Gypsiferous saline-sodic soils containing enough gypsum for replacing exchange sodium are called self-reclaimed. Such soils can be reclaimed by simple leaching without the application of any amendment (WAPDA, 1972).

3. Chemical amendments. These are either a source of soluble calcium e.g. gypsum or convert calcium carbonate present in soil into calcium sulfate e.g. sulfur and sulfuric acid.

4. Biological or organic amendments. These help the reclamation through chemical, physical, and microbiological processes.

5. Seawater or high-salt water

Among the above-mentioned sources of calcium, gypsum is an easily weatherable mineral. It is weathered out of soil similar to calcite. Chemically, it is calcium sulfate

($CaSO_4$ $2H_2O$). It supplies both calcium and sulfate to the soil. It is used as an amendment for reclaiming saline-sodic and sodic soils and is also used for the preparation of ammonium sulfate fertilizer.

Solubility of gypsum. The solubility of gypsum is very low, i.e., 0.04%. It is greatly lowered in the presence of soda due to formation of calcium carbonate and gets films on the surface of gypsum particles. Under waterlogged conditions, gypsum might be reduced to sulfate.

Experiments on reclamation of saline, saline-sodic and sodic soils:

Saline soil. It is also known as white kallar soil and thur soil by the engineers. It is mainly due to the presence of soluble salts, which alongwith the water, reach the surface where the water evaporates leaving behind the salts. Most of these salts (NaCl, Na_2SO_4) are water-soluble. The salinity may reduce crop yield by upsetting the water and nutritional balance of the plant. Salinity usually dominates where the land is fallow and where there is no crop over a long period of time. Saline soils are comparatively less detrimental for crops/plants as compared to the other two categories. During salinity, the plant has to spend more energy to sustain itself. However, in case of extreme salinity, the plant will suffer due to loss of water as a result of ex-osmosis. Saline soils are easy to reclaim simply by applying heavy irrigation, provided the soil has good drainage. The dissolved salts will move downwards due to percolation.

Sodic soils. On the basis of soil chemistry, all the salt affected soils can be classified into two main groups. In one group the soils have sodium carbonate, which has the dominant influence on soil properties and management requirements. This group is the most extensive. The use of gypsum is the most effective way to deal with the problem of these soils. The soils of the other group have gypsum, which has the dominating influence on soil properties. The sodic soils have ESP values equal to/greater than 15, EC_e less than 4 dSm^{-1} at 25°C and pH more than 8.5. These possess poor structure and a very low hydraulic conductivity due to their exchangeable sodium percentage. The dominant salt present in these soils is sodium carbonate. In Pakistan, these soils are termed as “bara”.

Saline-sodic soils. These soils have EC_e equal to or greater than 4 dSm^{-1} at 25°C and the ESP equal to or greater than 15. As long as excess salts are present, the properties of these soils in regards to appearance and permeability are similar to those of saline-soils. With the removal of excess salts, through leaching, these soils become sodic. The extent of these types of soils is given in Table I.

Effect on plants:

Too much sodicity and salinity affects plants in two ways.

1. In the presence of salts, the plants cannot get enough water because of the high osmotic pressure developed in the root zone. The growth becomes stunted and the colour of the plants is often blue-green. The yield may be reduced as much as 25%.

Table I. Frequency of various salts affected soils in Pakistan (Area 000 ha)

Types of Salt affected soil	Punjab	Sindh	NWFP/ FATA	Baluc-histan	Pakistan
Soil with surface/patch salinity & sodicity					
Irrigated	472.4	118.1	5.2	3.0	598.7
Un-irrigated	0	0	0	0	0
Gypsiferous saline/saline sodic soils					
Irrigated	152.1	743.4	0	76.6	972.1
Un-irrigated	124.5	536.3	0	160.1	820.9
Porous saline-sodic soils					
Irrigated	790.8	257.0	25.7	29.4	1102.9
Un-irrigated	501.0	150.1	7.8	364.0	1022.9
Dense saline-sodic					
Irrigated	96.7	32.5	0.9	0	130.1
Un-irrigated	530.0	379.7	8.9	714.8	1633.4
Total	**2667.1**	**2217.1**	**48.5**	**1347.9**	**6281.0**

Source: Daily (Article by Muhammad Zahid)

2. Salts have direct effect on plant growth. A characteristic leaf-burn develops. Leaves fall off. Trees may die when harmful amounts of sodium or chloride accumulate. Most of field, forage and truck crops may, however, accumulate large amounts of sodium or chloride in the leaves without developing visible symptoms of toxicity. Born and bicarbonate are toxic to all species of plants but the level of tolerance may vary from one crop to another.

Effect on soils:

Soils containing appreciable amounts of sodium are not flocculated. Water and air cannot move through the soil freely, even though there may be more openings. In some localities, the soil becomes swollen gelatinous mass that is impervious to air and water. Soils containing too much salt are generally flocculated. Water and air can move freely. But soluble salts reduce the rate at which plants absorb water.

Extent: Such type of soil consist of about 6.00 million acres in the country. The category wise position is as under:

1. Dense saline alkali soils (2.2 m.a.)
2. Porous saline alkali soils (3.5 m.a.)
3. Porous saline soils with alkaline surface (0.3 m.a.)

Inspite of the fact that 65 to 80% of the salt affected soils of Pakistan are saline-sodic and sodic (Hussain, 1965a; Muhammad, 1975). In these soils, various methods for reclamation have been tried. According to Hussain (1965b), it takes 6-8 years for reclaiming a saline sodic-soil by rice culture, of course, the time for reclamation will vary with the texture, structure, clay mineralogy and sodicity of the soil. Application of gypsum to saline-sodic soils accelerates the rate of replacement of exchangeable sodium and thus shortens the period of reclamation. This is indicated by data of an experiment (Table II) conducted under controlled conditioned in specially made cement pipes of about 9-inch diameter (Muhammad, 1975). A sandy clay saline-sodic soils from Sahiwal district was used for reclamation. The soil had pH 9.0, EC_e 40.5 dS m^{-1}, SAR 143, ESP 70.9, CEC 11.1 me $100g^{-1}$, lime 5.59%, hydraulic conductivity 0.008

Table II. Analytical data of saline-sodic soil treated with gypsum on the basis of 50 to 125 % gypsum requirement and leached with three levels.

Gypsum added	Leaching water (Feet)	Depth of soils (inches)	pH	EC x 10^3	SAR	Det ESP	Lime (%)	Hydraulic conductivity (cm hr^{-1})
Nil	2	0-6	8.50	3.70	39.1	38.2	5.07	0.056
		6-12	8.53	3.90	44.0	42.3	5.16	0.042
G_1 (0%)	2	0-6	8.34	3.42	22.8	28.5	5.57	0.068
		6-12	8.43	3.50	29.6	31.4	5.56	0.092
	3	0-6	8.16	2.61	20.9	23.4	5.46	0.090
		6-12	8.23	2.71	22.7	24.9	5.48	0.089
	4	0-6	8.03	2.17	18.6	20.9	5.26	0.082
		6-12	8.04	2.21	19.7	21.9	5.28	0.081
G_2 (75%)	2	0-6	8.06	3.39	19.9	22.8	5.63	0.165
		6-12	8.19	3.45	22.5	25.0	5.59	0.161
	3	0-6	7.91	2.55	15.8	18.2	5.55	0.155
		6-12	7.99	2.68	18.2	20.2	5.59	0.152
	4	0-6	7.87	2.01	12.5	13.8	5.45	0.151
		6-12	7.92	2.13	13.3	14.2	5.46	0.148
G_3 (100%)	2	0-6	7.89	3.83	12.9	16.5	5.67	0.223
		6-12	7.98	3.88	15.2	18.1	5.64	0.221
	3	0-6	7.82	3.16	10.1	12.1	5.55	0.219
		6-12	7.82	3.21	11.1	14.0	5.59	0.217
	4	0-6	7.74	2.55	7.7	9.3	5.36	0.204
		6-12	7.78	2.60	8.0	11.0	5.40	0.203
G_4 (125%)	2	0-6	7.89	3.90	12.0	14.8	5.67	0.284
		6-12	7.99	-	14.7	15.9	5.62	0.284
	3	0-6	7.72	3.21	9.8	11.0	5.47	0.252
		6-12	7.77	3.24	11.0	12.4	5.48	0.250
	4	0-6	7.70	2.53	7.6	9.0	5.39	0.216
		6-12	7.78	2.54	8.4	10.5	5.48	0.215

cm hr^{-1} and gypsum requirements 8.3 me $100g^{-1}$. For increasing the hydraulic conductivity ground gypsum was mixed with the upper half i.e. 6-inches of the soil column before leaching. Gypsum was applied at the rate of 50, 75, 100, and 125% of gypsum requirements, followed by leaching with canal water. Three columns of soil were leached with water alone (control soil column) to study the possibility of reclaiming such soils with out any amendment. A total of 15 soil columns were used. Although leaching with water alone reduced the ESP to some extent (this will be due to valence dilution, divalent cautions (Ca & Mg) supplied by water and $CaCO_3$ present in soil) yet the soil was not reclaimed even after one year. The hydraulic conductivity was so low that two feet of water passed through the soil in 247 days. The third foot of water did not pass through the soil eve after one year, when the experiment was discontinued. This agrees with the finding of U.S. Salinity Laboratory Staff (1954) who observed that leaching may present serious difficulties if the hydraulic conductivity of the soil is less than 0.1 cm hr^{-1}. Application of gypsum not only accelerated the replacement of exchangeable sodium with calcium but also increased the hydraulic conductivity, resulting in large reduction in the time required for reclamation. There was a gradual decrease in ESP with increasing either the depth of leaching water or the amount of gypsum applied. Application of gypsum at the rate of 75% of gypsum requirement (G_2) followed by leaching with four feet of water was as effective for reclaiming the saline-sodic soil as the combination of G_3 and three feet of water or G_4 and two feet of water. A field experiment to show the economic advantage of amendments for reclaiming saline- sodic soils was started near Shah Kot in SCARP-I by World Bank Consultants and later on taken up by WASID WAPDA. Three acres of barren saline-sodic soils were selected. The soil was silt loam to a depth of five feet underlain by silty clay loam to eight feet and fine sandy loam to 12 feet. The water table was below 12 feet. The area was divided into plots of one-fourth and one-eighth acre size. A partial flume, to measure the water supply to plots, was installed at the head of the channel constructed through the center of the area. Canal water, available on rotation basis, was applied to plots. Gypsum requirement, estimated from SAR, averaged about 5 tons per acre 6 inches of surface soil. The treatments existed of simple leaching, 2 and 5 tons of gypsum $acre^{-1}$, 20 tons of farm yard manure (manure) $acre^{-1}$ and 5 tons of gypsum plus 20 tons of manures $acre^{-1}$. After adding amendments, leaching of all plots was started in June 1965. After leaching with 15 inches of water, seedlings of Basmati rice were transplanted in plots 1 to 4 only. During Rabi 1965-66 berseem (*Trifolium alexandrium*) was planted in plots 1 to 4 and 1 to 11 and wheat in plots 5 to 8. A coarse variety rice (Jhonna) was transplanted in plots 1 to 11 during Kharif 1966. During Rabi 1966-67 wheat variety Panjamo was planted in plots 1 to 11. The crop yield was obtained by harvesting the crop from the entire plot. Soil samples for analysis were taken during May and November 1965, April and October 1966 and May 1967. Samples were composite from 10 bore holes in every plot for each foot to a depth of five feet. Nitrogen and phosphorus were applied to all crops. The amount of water (canal + rainfall) received by various plots and the effects of various treatments on reclamation are shown in Table III.

The results (Table III) show that excess soluble salts were leached from the surface two feet of most of the plots by the end of 1965 Kharif season. More soluble salts were leached from lower depths with the application of more water. The removal of exchangeable sodium (a measure of chemical reclamation of sodic and saline-sodic soils) was faster by the application of gypsum and gypsum + manure followed that of manure. The first crop of rice failed on plot No. 4, which did not receive any amendment. Increased salts in an area, which was not cropped at all but leached during 1965 Kharif season only is shown by the data of plot No. 12.

Haider and Ali (1975) conducted an experiment for the amelioration of medium texture, saline-alkali gypsiferous saline soil on four acres. The soil was lying barren and was never cultivated. After proper leveling, each one acre was divided into eight equal plots and eight

Table III. Effect of various treatments on soil properties

Plot No	Amendment acre^{-1}	Depth (feet)	EC$_e$ (dS m^{-1})					SAR					pH				
			Date of Sampling					Date of Sampling					Date of Sampling				
			5/65	11/65	4/66	10/66	5/67	5/65	11/65	4/66	10/66	5/67	5/65	11/65	4/66	10/66	5/67
1	5 tons Gypsum	0-1	2.1	2.0	1.4	0.8	1.1	42	5	8	9	10	8.8	8.1	8.2	8.4	8.5
		1-2	4.4	1.4	1.7	1.4	1.6	60	28	11	28	14	9.2	8.9	8.5	9.1	9.1
		2-3	5.3	1.8	1.4	1.4	2.0	120	35	9	17	33	9.2	9.2	8.8	9.2	9.2
		3-4	6.8	2.0	1.8	1.9	2.4	151	40	13	25	43	9.2	9.5	9.2	9.4	9.6
		4-5	6.4	2.3	2.4	1.6	1.7	151	45	21	31	23	8.0	9.2	9.2	9.4	9.3
2	5 tons Gypsum + 20 tons manure	0-1	4.5	2.0	1.6	1.0	1.1	88	5	5	6	10	8.8	8.1	8.2	8.6	8.4
		1-2	7.4	1.9	1.8	1.3	1.2	153	37	10	25	20	9.1	9.0	8.8	8.9	8.7
		2-3	0.6	2.5	2.4	1.8	1.5	254	50	31	36	24	9.2	9.4	9.1	9.3	9.1
		3-4	7.0	4.5	2.9	1.8	1.9	150	88	31	35	27	9.3	9.4	9.4	9.4	9.4
		4-5	7.9	7.3	-	1.8	2.8	162	156	-	24	35	9.3	9.4	-	9.1	9.3
3	20 tons manure	0-1	0.0	1.2	1.3	0.8	1.5	63	15	9	13	13	8.2	8.7	8.6	8.7	8.6
		1-2	8.6	1.2	1.3	0.8	1.2	59	24	12	16	1	8.1	9.1	9.1	9.4	9.1
		2-3	8.0	1.3	1.3	1.2	1.2	97	26	12	23	25	8.3	9.4	9.4	9.2	9.1
		3-4	6.9	2.3	1.5	1.6	1.4	06	46	11	21	22	8.7	9.5	9.3	9.4	9.1
		4-5	1.8	4.2	3.4	2.3	2.6	36	83	38	43	36	9.5	9.4	9.2	9.3	9.3
4	Nil	0-1	5.9	2.2	1.7	1.0	1.3	123	42	15	19	16	9.4	9.0	8.9	9.2	8.9
		1-2	7.4	1.5	1.5	1.8	1.5	159	28	1	25	23	9.1	9.4	8.8	8.7	9.3
		2-3	6.3	3.8	1.5	2.8	1.8	140	78	16	55	29	9.0	9.5	8.9	9.3	9.4
		3-4	4.6	5.8	5.8	2.8	2.6	95	18	87	40	48	9.1	9.4	9.6	9.4	9.3
		4-5	1.8	4.2	3.4	2.3	2.6	36	83	38	43	36	9.5	9.4	9.2	9.3	9.3
5	5 tons Gypsum	0-1	13.6	1.7	2.1	0.9	1.3	213	15	18	6	82	8.6	8.6	8.6	8.4	8.5
		1-2	12.7	1.7	1.8	1.3	1.5	221	27	23	13	20	9.0	9.3	9.0	9.0	8.8
		2-3	11.2	2.4	1.7	2.0	2.2	122	39	18	18	28	8.9	9.4	9.1	9.0	8.9
		3-4	6.5	3.4	3.0	2.1	2.5	130	64	31	21	26	9.2	9.4	9.2	9.2	8.9
		4-5	10.2	4.4	3.6	3.2	3.0	220	65	44	41	38	9.5	9.2	9.1	9.2	9.0
6	5 tons Gypsum + 20 ton manure	0-1	16.0	3.5	2.4	1.0	1.2	242	12	21	9	11	8.8	8.5	8.5	8.7	8.3
		1-2	10.3	1.9	1.3	1.4	1.4	193	30	17	14	17	8.9	9.3	8.8	9.1	8.8
		2-3	6.9	3.5	1.9	1.9	2.1	130	61	25	19	24	9.2	9.4	9.2	9.2	9.0
		3-4	5.0	7.9	1.9	3.0	3.1	82	81	24	29	32	9.6	9.4	9.2	9.5	9.1
		4-5	3.4	3.2	2.4	2.8	3.2	68	68	32	26	36	9.7	9.6	9.3	9.2	9.1

Table III Continued….

7	20 tons manure	0-1	15.6	2.1	1.8	1.2	2.0	249	27	22	84	30	9.0	8.8	8.8	9.0	8.7
		1-2	12.0	1.5	1.7	1.6	228	228	28	20	24	31	9.3	9.4	9.1	9.4	9.0
		2-3	7.8	2.0	1.8	2.1	147	147	38	26	31	33	9.4	9.6	9.3	9.5	9.0
		3-4	6.6	3.1	2.5	3.1	1	1	55	28	54	41	9.6	9.5	9.1	9.5	9.3
		4-5	4.7	4.3	3.3	3.4	84	84	85	40	53	49	9.6	9.5	9.3	9.7	9.4
8	Nil	0-1	15.7	2.6	2.7	1.5	339	339	27	33	20	35	9.4	9.5	9.2	9.2	8.9
		1-2	11.8	4.5	4.4	3.1	283	283	98	61	44	59	9.3	9.2	9.2	9.3	9.0
		2-3	6.3	6.6	3.9	5.2	136	136	114	49	66	125	9.4	9.4	9.2	9.1	9.1
		3-4	4.2	4.5	4.6	5.4	76	76	58	57	72	84	9.7	9.2	9.2	9.4	9.0
		4-5	3.9	5.8	3.7	5.1	72	72	106	51	82	80	9.6	9.3	9.3	9.4	9.2
9	5 tons Gypsum	0-1	16.1	2.4	2.8	1.1	224	224	11	11	9	7	9.2	8.4	8.3	8.6	8.7
		1-2	8.9	2.7	2.9	2.1	147	147	41	27	27	37	9.4	9.3	8.8	9.3	9.2
		2-3	3.7	3.2	2.0	2.9	66	66	65	24	37	54	9.8	9.5	9.2	9.4	9.6
		3-4	2.5	6.5	3.5	3.6	40	40	128	43	37	48	9.6	9.3	9.1	9.6	9.3
		4-5	3.1	5.3	3.8	4.0	54	54	97	49	47	55	9.4	9.3	9.4	9.3	9.4
10	2 tons Gypsum	0-1	29.1	2.0	1.6	1.8	404	404	21	19	19	33	8.8	8.9	8.9	9.2	8.6
		1-2	7.0	2.4	3.5	1.7	132	132	42	48	14	19	9.6	9.3	9.2	8.9	9.0
		2-3	3.2	4.6	2.2	2.9	63	63	92	24	26	47	9.7	9.8	9.2	9.0	9.0
		3-4	2.6	8.8	3.4	3.2	51	51	126	43	33	53	9.8	9.5	9.3	9.0	9.0
		4-5	3.7	5.3	3.5	4.2	74	74	83	53	42	76	9.6	9.4	9.5	9.0	9.0
11	Nil	0-1	30.5	2.9	3.1	1.7	593	593	50	34	21	35	9.4	9.4	9.0	9.1	8.7
		1-2	11.9	4.6	3.8	2.8	238	238	94	42	32	51	9.6	9.5	9.4	9.2	8.8
		2-3	4.1	8.3	6.5	3.8	72	72	178	81	49	59	9.8	9.5	9.3	9.2	9.2
		3-4	2.9	8.1	2.1	2.1	56	56	183	102	47	63	9.7	9.3	9.4	9.3	9.1
		4-5	3.9	2.8	4.7	3.8	21	21	254	52	53	69	9.7	9.3	9.4	9.4	9.2
12	Nil and no cropping	0-1	31.3	2.5	2.4	6.0	256	256	50	30	37	92	9.2	9.0	8.8	9.0	8.7
		1-2	10.4	3.5	3.0	4.7	146	146	64	40	56	78	9.5	9.4	9.3	9.1	9.1
		2-3	3.4	5.6	4.2	5.1	60	60	121	53	64	64	9.4	9.5	9.3	9.1	9.1
		3-4	2.8	7.4	6.2	4.1	56	56	142	70	52	60	9.6	9.4	9.2	9.1	9.1
		4-5	3.3	7.0	3.4	4.0	60	60	157	40	46	62	9.5	9.3	9.4	9.1	9.1

different methods of reclamation were tested. Rice-Berseem and Rice-Wheat crop rotation was followed during reclamation operation. The results revealed that saline alkali gypsiferous soil can be reclaimed by simple leaching and application of any amendment did not help much. Treatment farm yard manure + crops proved most economic followed in order by treatment crop, Australian grass, 50% gypsum + crops, leaching + crops, 100% gypsum + crops 50% gypsum + leaching + crops and 100% gypsum + leaching + crops. However, infiltration rates of soils due to treatment leaching + crops, Australian grass and crops was significantly lower compared to other treatments.

The major conclusions drawn form this study are:

- Saline-alkali gypsiferous soils can be reclaimed by simple leaching or growing of high delta crops. Application of any amendment does not help much.
- All the treatments proved equally effective in reclaiming the saline-alkali gypsiferous soils.
- Irrespective of treatment, the removal of salts and stages, slowed down quickly afterwards.
- Different treatments did not affect any significant change in soil pH.
- In general, the yield of crops from farm-yard manure treatments were higher compared with other treatments.
- Infiltration rate of the soil due to treatment involving leaching + crops, Australian grass, and crops, was significantly lower compared to other treatments.
- The difference in infiltration rate of the soil in other treatments was non- significant.
- Farmyard manure treatment proved most economical followed in order by treatment crops, Australian grass, 50% gypsum +crops, leaching + crops, 100% gypsum + crops, 90% gypsum +leaching +crops and 100% gypsum +

leaching +crops. Gypsum, the most economical amendment, which is needed on a large scale, is mixed in the soil with two or three ploughing so that it may complete its chemical action with every soil particle. Gypsum contains calcium, which converts exchangeable sodium into sodium sulfate. Sodium sulfate is soluble in water and is leached down to the lower horizons. The chemical reaction, which takes place, is as under:

$CaSO_4 + Na = Na_2SO_4 + Ca$

or

$2Na X + CaSO_4 = CaX_2 + Na_2SO_4$

The amount of gypsum required to replace indicated amount of exchangeable sodium has been given in Table IV.

The action of salts is mainly through exchangeable reaction with sodium.

$Soil\ Na + CaSO_4 \rightarrow Soil\ Ca + Na_2SO_4$

Na_2CO_3 (If present) $+CaSO_4 \rightarrow CaCO_3 + Na_2SO_4$

↓ ↓

Precipitates Leached

The quantity of gypsum depends upon the amounts of exchangeable sodium and Na_2CO_3 in the soil. On an average, 10-15 tons produced gypsum of 100 mesh is required for one acre. Since it is slightly soluble in water, considerable quantity of water is required for its full effect. Gypsum also tends to react with free Na_2CO_3 in the soil converting it into $CaCO_3$ and Na_2SO_4.

Table IV. Amount of gypsum required to replace indicated amount of exchangeable sodium

Exch. Sodium me 100 g^{-1} of soil	Gypsum ($CaSO_4.2H_2O$) Tons/acre foot	Gypsum ($CaSO_4.2H_2O$) Tons/ acre-6 inches
1	1.7	0.9
2	3.4	1.7
3	5.2	2.6
4	6.9	3.4
5	8.6	9.3
6	10.3	5.2
7	12.0	6.0
8	13.7	6.9
9	15.5	7.7
10	17.2	8.6

The amounts of gypsum are given to the nearest 0.1 ton.; 1 acre- foot of soil weighs approximately 4, 000,000 pounds; 1 acre- 6 inches of soil weighs approximately 2, 000,000 pounds.

If the soil contains excessive soluble sulfates it may be necessary to leach out greater part of the SO_4 otherwise the solubility of gypsum may be too low. It would be desirable to organize gypsum supply in the public sector on a subsidized basis in the beginning and at no profit basis later on. It may be pointed out that the gypsum is the most effective means of reclaiming alkali soils and is the only potential means of improving the quality of your tubewell water.

The effectiveness of gypsum depends upon (i) the degree of fineness i.e. the specific surface area; (ii) The way in which it is incorporated into the soil and; (iii) The efficiency of the drainage system. As regard to fineness almost 80% of the gypsum should pass through 1mm sieve. The determined gypsum requirements + 24% are usually required under farm conditions. This is because that reaction between gypsum and exchangeable sodium is an equilibrium reaction and therefore does not go entirely to completion. The effect of gypsum might last for ever if no upward movement of mineralized water takes place. However, in the presence of upward movement, frequent addition of gypsum are needed.

Experience has shown that use of some marginal/poor quality tubewell water has adversely affected the soil conditions and crop growth therefore such water requires special soil and water management practices and use of soil amendments for successful crop production. The presence of gypsum delays the accumulation of exchangeable sodium in the soil. The application of gypsum is recommended at the rate of 0.1 tons acre-foot^{-1} of tubewell for every increase in RSC by 1.0 meL^{-1} beyond RSC 2.5 meL^{-1} to neutralize the deterious effects of high RSC tubewell water.

Haider and Farooqi (1972) reported that the effects of 50 and 100% gypsum treatment on chemical and physical characteristics of soil is similar. They have recommended that gypsum should be added to the soil at the rate of 50% of gypsum requirement as a preventive measure to check the increase in alkali of soil being irrigated with potentially hazardous tubewell water. This application of gypsum remains effective for a period of three years. They have further shown that the average SAR of 0-6 inches soils in 50% gypsum treated plots decreased from 17.97 to 10.02 after gypsum as against non-gypsum plots where it increased from 18.02 to 20.27. The average SAR of the soil in the 100% gypsum treated soils first increased from 7.52 to 14.72 in the subsequent three sampling. The SAR of the non-gypsum plots however, increased from 12.23 to 24.20 during the same period. The difference in SAR value of the soil in the gypsum and non-gypsum plots is significant at all the stages of soil sampling. The SAR of the gypsum plots remained significantly lower than that of non-gypsum plots throughout the course of the experiment. However, at the lower depths, the application of gypsum had little or no effect. The SAR of the soil starts rising again.

The reduction in SAR of the soil in gypsum plots is due to the reason that application of gypsum increased Ca^{2+} + Mg concentration in the soil solution and thereby reduced SAR of soil. Consequently as long as the gypsum remained in the soil, the SAR of the soil remained low and as soon as the quantity of gypsum depletes, on account of exchangeable reaction and leaching, the SAR of the soil starts rising again.

Addition of gypsum initially increases the EC_e of the soil. Therefore, it is recommended that either extra irrigation should be applied or high delta crops should be grown. The application of gypsum increased the infiltration rates of the soil by improving soil structure by flocculating soil particles and consequently increases the infiltration rate of soil.

Following the reclamation of top foot of the soil, growing of alkali tolerant grasses, i.e. Burmuda grass, Rhodes grass and Sweet clover is recommended. Growing of alkali and waterlogging tolerant crops i.e. Samar is practiced in Egypt. These produce CO_2 which enhance solution of $CaCO_3$ and thus reclamation. Frequent deep ploughing and profile inversion increases the physical conditions of the soil. After these, crops have been harvested. Alfalfa can be grown for few years following a more varied cropping pattern.

RECOMMENDATIONS

- It is high time that the gypsum is introduced on large scale for improving productivity of sodic and saline-sodic soils. The use of gypsum becomes more attractive and economical if the farmers are educated and convinced about its usefulness. Large scale popularization of gypsum requires reduction in prices and easy supply at the door step of users. Credit facilities linked with its supply may accertain long spread use.
- The use of gypsum may be subsidized to the extent of 50% of the cost. The subsidy should be planned gradually as the farmers start accepting the efficiency of gypsum in relating saline-sodic soils. Gypsum can be publicized as a fertilizer for salt-affected soils and its economic advantages projected which will encourage farmers to take up its use.
- The royalty from mining of gypsum realized by the government should be discontinued to reduce its cost of production. A formula can also be worked out with Railway Authorities for conditional freight charges in line with the charge rates frequently applied for the transport of essential fruits.
- Small rock crushing units be established in the heart of areas of potential consumption. Preferably at or near Mandi towns. Farmers can use their own conveyance for haulage of crushed gypsum from there. This will greatly reduce the handling charges and eliminate even the usual bagging cost.
- It is worth mentioning that across the border in Indian Punjab, the slow process of reclamation with green manure has been largely replaced by gypsum application for quick results. The Indian Punjab Government allows:

i. 75% subsidy on gypsum cost to small farmers and 30% to others.

ii. Easy power connection for tubewells in salt-affected areas.

With the above facilities the quantity of gypsum use has jumped from 600 tons in 1972-73 to 2,18,000 tons in 1979-80. Concomitantly, the area reclaimed has increased from 450 acres in1972-73 to 74,000 acres in 1979-80.

Similar or comparable facilities if provided to farmers in Pakistan may result in tremendous boost to popularizing the use of gypsum, which in time will be highly profitable to both the Government and the farming community through improvement of sodic soils and increase in agriculture production.

It may, however, be mentioned that the suitable size of gypsum particles is between 8-30 mash. The particle should pass through a 2 mm sieve but 50% of it must pass through a 0.5 mm (30 mesh) sieve also. This is more economical than the micro fined gypsum publicized by the gypsum corporation.

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