PHYSICAL, SALINITY, AND FERTILITY ANALYSES OF SELECTED PAKISTAN SOILS

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by

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ABSTRACT

Textural, moisture retention, and salinity-related analyses are reported for 58 soil samples representing profiles from 11 sites in the Punjab. These alluvial soils contain more than 45% salt in surface layers at 9 sites and as much as 80% salt in subsoil layers. Thus, the high-silt soils are expected to be subject to weak aggregate stability, compaction, and low permeabilities. Soil moisture retention values can be estimated from textural analyses using the following regression equations: (1) Log 1/3-Bar Moisture % = 0.836 Log C + Si(<50μ)% - 0.179, (2) 15-Bar Moisture % = 0.48 C + FSi(<5μ) % + 0.3. Improved exchangeable sodium percentage (ESP) estimates from sodium-adsorption-ratio (SAR) measurements of saturation extracts can be obtained with the following regression equations: (1) ESP = 0.90 SAR + 1.94, or (2) $ESP = \frac{100\ (.0124\ SAR + .0063)}{1 + (.0124\ SAR + .0063)}$. The fertility status of 110 soil samples from 4 Pakistani Provinces was assessed. The low organic matter content (<1%) in the alluvial soils explains the large N response found for non-leguminous crops. Available P is deficient (<10 ppm) in most soil surface layers. Available K is generally adequate (>100 ppm) to very high. Available Zn may be inadequate (<1 ppm) for Zn-sensitive crops at about one-third of the sites tested. Iron, Mn, and Cu were generally adequate for the large majority of the samples.

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INTRODUCTION

Laboratory studies were initiated at Colorado State University at the same time cooperative relationships with several Pakistani agencies and workers were being established to undertake on-the-farm water management research in Pakistan. The on-campus studies were conducted to supply background information for the Pakistan research studies. A total of 58 soil samples representing 11 profiles were obtained from sites in the Punjab Province at Lahore, Lyallpur, and in SCARP I and II. The locations of the sample sites are shown graphically in Figure 1 and descriptively in Table 1. Fifty-one additional samples were obtained from the Punjab, Northwest Frontier, Baluchistan, and Sind Provinces for soil fertility analyses. The site locations are listed in Table 1.

The immediate objectives for obtaining the Punjab soil samples were to determine the sand, silt, and clay mineralogy. However, additional physical, salinity, and fertility analyses were made to further characterize the soils to aid in selecting desirable sites for field experiments. This report contains the basic data and interpretations of the physical, salinity, and fertility analyses. Empirical relations developed from the data are presented, also.

PHYSICAL ANALYSES

Mechanical analyses of the Punjab soil samples were performed by sedimentation and sieving techniques after organic matter and lime were removed (Kittrick and Hope, 1963). The textural analyses of the samples are given in Table 2. These alluvial soils contain large proportions of silt. Nine of the 11 profiles contain more than 45% silt in surface layers and silt is as high as 80% in subsoil layers. Aggregates in high-silt soils are generally

Table 1. Description of soil sample locations.

Soil Designation	Location
Punjab Samples[1/]	
LRD	Land Reclamation Directorate, Mughalpura, Lahore
PAU	Pakistan Agricultural University, Lyallpur
A	Square 13, E ¼ of Block 20, Soils Research Farm
B	Square 13, Center of Block 30, Soils Research Farm
C	Square 13, E ¼ of Block 10, Soils Research Farm
TW 149	SCARP II, TW* 149 SO, near Mandi Bahauddin
TW 161	SCARP II, TW* 161 BS, near Mandi Bahauddin
TW 14	SCARP I, TW* 14 FAQ, near Chuharkana
TW 85	SCARP II, TW* 85 Khadir, near Rabwah
TW 7A	SCARP II, TW* 7A Khadir, near Lalian
TW 178	SCARP II, TW* 178 Khadir, near Ghausewala
TW Rahawali	SCARP I, TW* in Rahawali Area (Mirza Majid)
Punjab, Northwest Frontier, and Baluchistan Samples[2/]	
PARI-1-3	Punjab Agricultural Research Institute, Lyallpur, Agronomy Section
PARI-4-16	Surface samples from Peshawar (4), Rawalpindi (5), Murree (6), Sialkot (7), Lyallpur (8), Multan (9), Khan Pur (10), Bhakhar (11), Dundi Estate (12), Campbellpur (13), Quetta (14), Kala Shah Kaku (15), Harrappa (16)
Sind Samples[3/]	
S-TJ	Soil profile from Tandojam Atomic Energy Research Center
S-WF	Soil profile, wheat field - Tandojam Atomic Energy Research Center
S-CF	Soil profile, cotton field - Tandojam Agricultural Research Institute
S-SC	Soil profile, sugar cane field - near T. M. Khan, Hyderabad District

* Soil under command of specified tubewell (TW)

1/ Soil samples collected by Ch. Nur-ud-Din Ahmad, Land Reclamation Directorate, Lahore, and Dr. S. H. Krashevski, USAID Soils Advisor, formerly at Lahore

2/ Soil samples collected by M. Hyatt Bhatti, Punjab Agricultural Research Institute, Lyallpur

3/ Soil samples from the Sind Province were collected by Dr. M. Bashir Malik

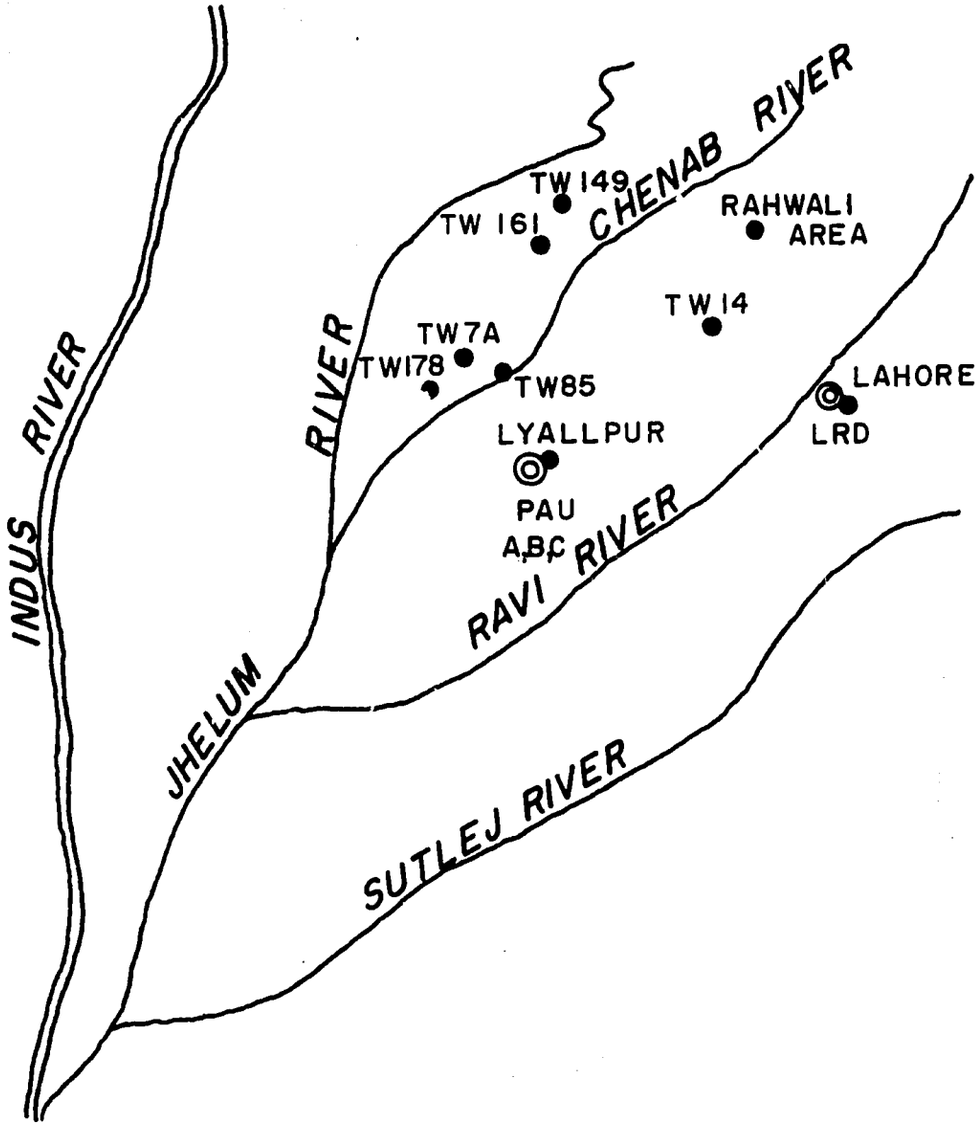

Figure 1. Location of the soil sample sites in the Punjab region of Pakistan.

Table 2. Organic matter-and-lime-free separates of Pakistan soils.

Soil Location and Depth (ft.)	% Clay		% Silt			% Sand					Total			Texture
	<.2μ	.2-2μ	2-5μ	5-20μ	20-50μ	.05-.1 mm	.1-.25 mm	.25-.5 mm	.5-1 mm	1-2 mm	Clay	Silt	Sand	
LRD*														
0-1	4.9	6.5	4.4	28.2	34.0	16.3	4.3	0.6	0.6	0.2	11.4	66.6	22.0	SiL
1-2	4.8	5.4	3.3	27.4	34.8	18.2	4.0	0.5	0.9	0.7	10.2	65.5	24.3	SiL
2-3	4.5	5.3	1.9	29.9	35.1	18.3	2.6	0.7	1.0	0.7	9.8	66.9	23.3	SiL
3-4	5.1	5.7	2.1	33.2	35.1	14.4	2.3	0.5	1.0	0.6	10.8	70.4	18.8	SiL
4-5	5.1	6.3	2.4	26.9	36.6	19.4	2.1	0.3	0.5	0.4	11.4	65.9	22.7	SiL
PAU** A														
0-.5	6.3	8.9	3.5	28.4	18.0	10.8	21.2	2.3	0.4	0.1	15.2	49.9	34.9	L
.5-1	7.9	11.9	4.9	38.4	14.0	7.5	13.6	1.5	0.3	0.0	19.8	57.3	22.9	SiL
1-2	7.3	11.0	5.1	45.5	16.8	5.2	7.9	0.9	0.2	0.1	18.3	67.4	14.3	SiL
2-3	8.2	10.3	6.3	40.2	26.9	3.2	4.5	0.3	0.1	0.0	18.5	73.4	8.1	SiL
3-5	6.0	6.8	4.1	34.5	26.6	9.0	11.9	0.5	0.5	0.1	12.8	65.2	22.0	SiL
4-5	3.3	3.3	1.6	14.3	14.0	15.3	47.6	0.5	0.1	0.0	6.6	29.9	63.5	SL
PAU B														
0-.5	8.1	9.3	4.5	24.6	17.5	10.7	22.7	2.3	0.3	0.0	17.4	46.6	36.0	L
.5-1	8.0	13.3	7.5	40.6	13.8	5.6	9.7	1.3	0.2	0.0	21.3	61.9	16.8	SiL
1-2	8.4	10.8	5.3	28.6	12.9	9.3	22.1	2.3	0.3	0.0	19.2	46.8	34.0	L
2-3	8.0	10.8	5.7	43.3	18.5	5.6	7.4	0.6	0.1	0.0	18.8	67.5	13.7	SiL
3-4	5.3	6.1	4.8	29.8	14.7	10.7	25.3	2.6	0.6	0.1	11.4	49.3	39.3	L
4-5	2.2	1.9	1.5	7.6	8.0	15.3	63.0	0.4	0.1	0.0	4.1	17.1	78.8	LS
PAU C														
0-.5	5.8	9.3	4.2	18.6	23.3	15.2	21.2	2.1	0.3	0.0	15.1	46.1	38.8	L
.5-1	6.0	9.5	4.1	17.2	20.4	15.6	24.3	2.6	0.3	0.0	15.5	41.5	43.0	L
1-2	7.4	10.6	4.2	17.6	20.5	16.5	21.0	1.8	0.4	0.0	18.0	42.3	39.7	L
2-3	7.3	10.4	3.8	13.4	18.0	16.5	28.1	2.3	0.2	0.0	17.7	35.2	47.1	L
3-4	7.1	9.3	3.5	14.6	18.4	16.6	27.5	2.7	0.3	0.0	16.4	36.5	47.1	L
4-5	7.2	10.1	3.2	13.7	18.5	16.0	28.1	2.9	0.3	0.0	17.3	35.4	47.3	L

(Continued)

Table 2. Organic matter-and-lime-free separates of Pakistan soils. (continued)

Soil Location and Depth (ft.)	% Clay		% Silt			% Sand					Total			Texture
	<.2μ	.2-2μ	2-5μ	5-20μ	20-50μ	.05-.1 mm	.1-.25 mm	.25-.5 mm	.5-1 mm	1-2 mm	Clay	Silt	Sand	
TW149														
0-1	8.5	10.8	7.5	29.8	25.3	7.4	6.7	3.3	0.7	0.0	19.3	62.6	18.1	SiL
1-2	10.8	14.2	5.6	32.6	23.0	6.4	4.7	2.3	0.4	0.0	25.0	61.2	13.8	SiL
2-3	13.3	14.9	5.8	34.7	21.0	4.8	3.7	1.5	0.3	0.0	28.2	61.5	10.3	SiCL
3-4	13.7	16.3	6.3	32.2	22.1	5.6	2.6	1.0	0.2	0.0	30.0	60.6	9.4	SiCL
4-5	10.7	17.3	5.6	36.1	21.7	5.5	2.2	0.7	0.2	0.0	28.0	63.4	8.6	SiCL
TW161														
0-1	4.1	7.1	2.5	15.1	20.4	15.3	21.9	12.0	1.6	0.0	11.2	38.0	50.8	L
1-2	5.8	7.0	2.5	16.7	15.4	8.4	26.1	15.7	2.4	0.0	12.8	34.6	52.6	L
2-3	6.5	9.3	3.0	14.3	17.5	8.6	22.4	15.8	2.3	0.3	15.8	34.8	49.4	L
3-4	7.3	8.5	3.1	19.3	17.9	6.8	19.6	14.7	2.4	0.0	16.2	40.3	43.5	L
4-5	6.7	8.6	3.3	19.5	18.2	7.9	19.1	14.4	2.3	0.0	15.3	41.0	43.7	L
TW14 FAO														
0-1	3.2	5.9	2.7	13.7	15.0	9.4	37.9	10.8	1.4	0.0	9.1	31.4	59.5	SL
1-2	4.9	11.3	4.8	27.2	14.5	7.6	19.5	7.3	1.2	1.7	16.2	45.5	37.3	L
2-3	8.9	10.4	4.3	17.6	13.7	8.3	26.2	9.3	1.3	0.0	19.3	35.6	45.1	L
3-4	6.7	7.5	2.7	13.0	13.6	11.1	32.9	11.1	1.4	0.0	14.2	29.3	56.5	SL
4-5	6.6	6.8	2.1	13.6	14.3	10.3	33.5	11.3	1.5	0.0	13.2	30.0	56.6	SL
TW85 Khadir														
0-1	6.3	12.0	6.2	28.4	26.2	14.2	6.1	0.5	0.1	0.0	18.3	60.8	20.9	SiL
1-2	8.1	16.1	8.5	38.1	19.9	5.9	3.1	0.3	0.0	0.0	24.2	66.5	9.3	SiL
2-3	6.6	24.0	14.3	37.0	13.0	3.3	1.3	0.2	0.1	0.0	30.6	64.4	5.0	SiCL
3-4	6.5	34.4	6.7	21.2	22.4	5.0	3.2	0.4	0.2	0.0	40.9	50.3	8.8	SiC
4-5	7.3	13.5	7.8	36.3	19.8	11.1	3.6	0.3	0.1	0.2	20.8	63.9	15.3	SiL

(Continued)

Table 2. Organic matter-and-lime-free separates of Pakistan soils. (continued)

Soil Location and Depth (ft.)	% Clay		% Silt			% Sand					Total			Texture
	<.2μ	.2-2μ	2-5μ	5-20μ	20-50μ	.05-.1 mm	.1-.25 mm	.25-.5 mm	.5-1 mm	1-2 mm	Clay	Silt	Sand	
TW7A Khadir														
0-1	5.7	9.3	5.3	26.6	26.4	12.2	13.3	1.1	0.1	0.0	15.0	58.3	26.7	SiL
1-2	5.7	10.8	3.6	22.2	25.5	17.4	13.7	1.0	0.1	0.0	16.5	51.3	32.2	SiL
2-3	6.7	11.2	3.8	22.0	25.7	16.0	13.8	0.8	0.0	0.0	17.9	51.5	30.6	SiL
3-4	7.4	12.3	3.5	25.8	22.8	16.5	10.9	0.8	0.0	0.0	19.7	52.1	28.2	SiL
4-5	7.1	10.8	3.2	28.8	28.0	12.2	8.2	0.5	0.2	1.0	17.9	60.0	22.1	SiL
TW178 Khadir														
0-1	4.1	8.6	3.9	23.7	27.6	22.8	8.5	0.7	0.1	0.0	12.7	55.2	32.1	SiL
1-2	3.7	16.1	1.4	32.3	31.3	8.1	6.3	0.6	0.1	0.1	19.8	65.1	15.1	SiL
2-3	6.0	14.9	7.1	45.4	22.8	2.4	1.2	0.1	0.0	0.1	20.9	75.3	3.8	SiL
3-4	7.3	15.2	9.8	42.5	19.6	0.0	5.3	0.3	0.0	0.0	22.5	71.9	5.6	SiL
4-5	5.0	10.3	5.6	43.3	31.2	3.1	1.4	0.1	0.0	0.0	15.3	80.1	4.6	SiL
Rahawali Area Mirza Majid														
0-1	7.2	17.5	9.3	30.6	23.3	8.2	3.8	0.1	0.0	0.0	24.7	63.2	12.1	SiL
1-2	3.2	23.3	15.8	36.6	14.9	2.6	3.1	0.3	0.2	0.0	26.5	67.3	6.2	SiL
2-3	6.2	8.1	9.9	23.0	32.1	10.3	9.4	0.7	0.3	0.1	14.2	65.0	20.8	SiL
3-4	4.8	11.2	5.2	32.7	35.4	7.6	2.5	0.6	0.0	0.0	16.0	73.3	10.7	SiL
4-5	6.4	8.7	8.6	31.7	30.9	6.9	6.2	0.5	0.1	0.0	15.1	71.2	13.7	SiL

* - Land Reclamation Directorate

** - Pakistan Agricultural University

weak and unstable in water. Compacted slowly, permeable surface soils constitute a widespread problem for efficient irrigation and crop growth in Pakistan soils.

One-third and 15-bar moisture retention values were run on standard pressure membrane equipment. The moisture retention data, including saturated paste percentages, for the samples are given in Table 3.

In non-scheduled irrigation systems, timing of irrigation has been made on the basis of percent of "available moisture" depleted and when "moisture tension" reaches an arbitrarily selected value. Equipment to determine moisture retention versus tension curves is extremely scarce in Pakistan. Thus, the "available moisture" concept is an expedient approach for applying experimental irrigation timing variables. However, the concept of "available moisture", "field capacity", and "wilting point" do not conform to rigid definitions and measurement. Both saturation percentage and tension values have been used to estimate available moisture from "field capacity" to "permanent wilting point". As a "thumb-rule", field capacity has been considered as being one-half of the saturation percentage and wilting point as one-fourth of the saturation percentage. Also, the 1/3-bar moisture content has been used to represent field capacity and the 15-bar moisture percentage used to represent wilting point. However, none of these approximations are completely valid or precise over a wide range of soil textural conditions. To examine how the two different methods for approximating field capacity and wilting point relate to textural class, the range and average ratios of 1/3-bar to ½-saturation percentage and 15-bar to ¼-saturation percentage are shown in Table 4. A ratio of 1.0 indicates the two independent measures are the same.

Table 3. Moisture retention properties of Punjab soils.

Soil[1/]	Depth	Saturation	1/3-Bar	15-Bar
	ft.	%	%	%
LRD	0-1	34.6	22.5	7.5
	1-2	33.7	22.4	6.3
	2-3	32.5	24.8	6.1
	3-4	35.3	26.0	7.0
	4-5	35.4	25.8	7.8
PAU A	0-.5	30.9	20.6	10.6
	.5-1	34.9	22.0	13.5
	1-2	38.4	25.6	12.7
	2-3	41.9	32.5	13.0
	3-4	39.4	26.7	9.8
	4-5	27.0	14.8	4.3
PAU B	0-.5	31.2	21.3	10.0
	.5-1	33.4	23.5	12.3
	1-2	37.1	26.0	12.0
	2-3	43.2	31.0	11.5
	3-4	32.5	22.2	6.8
	4-5	26.5	8.6	2.4
PAU C	0-.5	29.3	20.3	9.5
	.5-1	29.1	18.5	9.1
	1-2	30.4	17.7	9.3
	2-3	30.8	18.7	9.7
	3-4	31.0	19.1	9.8
	4-5	29.7	19.2	9.1
TW 149	0-1	35.3	22.2	11.5
	1-2	36.7	24.3	14.7
	2-3	42.0	25.0	15.4
	3-4	42.2	29.3	16.6
	4-5	45.1	27.2	16.5
TW 161	0-1	25.5	15.3	6.5
	1-2	23.9	14.6	6.7
	2-3	26.5	17.1	9.0
	3-4	28.7	20.0	9.4
	4-5	27.4	18.6	9.1
TW 14	0-1	24.0	13.9	6.6
	1-2	36.4	23.4	12.2
	2-3	34.2	21.2	10.4
	3-4	28.2	18.0	8.1
	4-5	29.0	17.9	8.0

(continued)

Table 3. (continued)

Soil 1/	Depth	Saturation	1/3-Bar	15-Bar
	ft.	%	%	%
TW 85	0-1	38.2	23.1	12.1
	1-2	45.3	27.1	15.1
	2-3	42.0	34.2	23.8
	3-4	54.2	32.8	20.8
	4-5	48.2	26.5	14.2
TW 7A	0-1	36.7	23.2	9.0
	1-2	33.5	20.0	9.5
	2-3	34.7	20.5	9.8
	3-4	36.9	21.7	10.5
	4-5	37.1	22.3	10.3
TW 178	0-1	25.9	23.2	9.1
	1-2	41.9	29.7	13.0
	2-3	52.9	28.5	12.7
	3-4	52.4	35.2	16.7
	4-5	47.9	37.0	11.1
Rahawali Area	0-1	42.4	27.4	16.7
	1-2	56.5	35.6	23.2
	2-3	38.5	26.2	11.7
	3-4	41.4	30.3	9.0
	4-5	45.2	28.0	12.6

LRD - Land Reclamation Directorate. PAU - Pakistan Agricultural University. TW - Tubewell.

Table 4. Relations of ratios of 1/3-bar to 1/2-saturation and 15-bar to 1/4-saturation percentage and textural class of Punjab soils.

No. Samples	Texture	1/3-bar/½-saturation Range	1/3-bar/½-saturation Average	15-bar/¼-saturation Range	15-bar/¼-saturation Average
1	LS	-	0.65	-	0.36
4	SL	1.10-1.28	1.17	0.64-1.15	1.00
17	L	1.16-1.40	1.30	0.84-1.37	1.23
31	SiL	1.10-1.79	1.33	0.75-1.64	1.16
4	SiCL	1.19-1.62	1.35	1.46-2.26	1.69
1	SiC	-	1.21	-	1.54

In general, 1/3-bar and 15-bar moisture percentages are significantly lower than field capacities and wilting points determined in the field on coarse-textured sandy soils. The 1/3-bar and 15-bar moisture percentages give closer estimates of field capacity and wilting point percentages in the finer-textured soils, whereas ½-saturation and ¼-saturation give close estimates for sandy soils. Therefore, estimates of field capacity or wilting points based upon saturation percentages are recommended only for the coarser-textured sandy soils.

Where more precise results are needed in irrigation experiments determining consumptive use or evapotranspiration demands, for example, field capacity measurements should be made at the study sites throughout the season because of the uncertainties involved in the empirically derived values. However, wilting point percentages are generally not as critical and, thus, the empirically derived values are usually satisfactory.

Soil moisture retention is a function of soil texture. Good correlations were obtained between 15-bar moisture and <5μ particle size (Figure 2) and

1/3-bar moisture and <50μ particle size percentages (Figure 3). If pressure membrane equipment is not available, reasonably good moisture retention values can be estimated from textural analyses and the regression equations.

SALINITY ANALYSES

Electrical conductivities of saturated extracts, water soluble cations (Ca, Mg, Na, K) and anions (CO_3, HCO_3, Cl, SO_4), ammonium acetate soluble Na, cation exchange capacity, and exchangeable Na percentages were determined on each sample by basic U. S. Salinity Laboratory methods (U. S. Salinity Laboratory Staff, 1954). These results are given in Tables 5 and 6.

It was noted in examining 1100 tubewell waters from SCARP I and II analyzed by the Land Reclamation Directorate that about half of the waters contained more Mg than Ca. It is possible that a part of the growth-depressing effects of waters with high bicarbonate concentrations may be due to Mg toxicity or Ca deficiency. Calcium precipitates to a greater degree than Mg during the evapotranspiration process, and unfavorable Ca/Mg ratios may develop. Some experimental evidence indicates unfavorable Ca/Mg ratios may be in the range of <.1-.2. No adverse Ca/Mg ratios were noted in the saturation extracts of the soil samples analyzed, however. Only 4 of the 11 Punjab profiles contained saline and sodic layers.

Sodium-adsorption-ratio (SAR) and exchangeable-sodium-percentage (ESP) relationships developed by the U. S. Salinity Laboratory workers are frequently used by agronomists and other workers to estimate ESP from the SAR of saturated paste extracts. Correlations of SAR of extracts from the Punjab soils were made with analytically determined ESP. The correlation coefficient for this relationship (Figure 4) is r = 0.96. The U. S. Salinity Laboratory regression equation was calculated from exchangeable-sodium-ratio ($ESR = \frac{ES}{CEC-ES}$) and SAR

Table 5. Water soluble cations and anions of Punjab soils.

Soil[1/]	Depth	Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4
	ft.				me/l				
LRD	0-1	22.5	8.9	85.0	1.3		4.0	123.8	23.8
	1-2	2.9	1.3	10.0	0.1		5.7	4.2	6.8
	2-3	1.4	0.4	11.0	0.1	1.7	2.7	1.4	6.9
	3-4	2.1	0.8	22.0	0.1	0.7	4.0	7.5	13.1
	4-5	2.4	1.1	24.5	0.2	0.4	3.9	8.5	18.2
PAU A	0-.5	34.3	9.3	155.0	2.0		4.5	64.8	130.0
	.5-1	4.1	2.7	38.5	0.6		4.7	8.5	37.6
	1-2	1.6	1.7	20.0	0.2		4.0	3.9	15.6
	2-3	0.9	1.2	9.0	0.2		3.7	2.3	4.8
	3-4	3.8	3.9	7.0	0.5		4.0	2.1	8.0
	4-5	5.0	4.5	4.0	0.6	0.7	3.3	3.4	8.5
PAU B	0-.5	11.5	5.6	42.5	1.3		4.3	11.3	42.5
	.5-1	10.0	3.9	51.5	0.7		4.0	16.9	46.0
	1-2	13.7	8.2	45.0	0.5		3.0	14.1	50.0
	2-3	12.2	5.4	21.5	0.4		2.8	14.1	28.8
	3-4	6.9	4.5	7.0	0.4		4.3	11.3	9.5
	4-5	4.1	1.8	6.0	0.4		4.0	5.6	4.8
PAU C	0-.5	7.9	1.8	12.5	1.2		3.9	9.0	9.0
	.5-1	11.9	2.4	7.0	0.6		3.5	6.8	9.8
	1-2	11.9	2.5	6.0	0.3		2.8	3.9	12.4
	2-3	11.9	2.2	4.5	0.2		3.1	2.8	12.0
	3-4	9.9	1.8	5.0	0.3		3.5	4.2	10.0
	4-5	8.0	1.1	4.0	0.3		3.8	4.2	[illegible].5

(Continued)

Table 5. (Continued)

Soil[1/]	Depth	Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4
	ft.				me/l				
TW 149	0-1	3.3	0.8	8.1	0.2	0.2	3.5	4.7	4.2
	1-2	1.5	0.3	7.8	0.1		6.0	2.8	2.4
	2-3	2.7	0.7	7.0	0.1		4.7	3.7	4.4
	3-4	7.1	1.9	7.0	0.1		3.3	4.7	8.5
	4-5	12.5	3.4	7.6	0.2		2.0	9.5	11.6
TW 161	0-1	4.1	0.9	6.8	0.3	0.2	5.5	2.8	3.9
	1-2	4.5	0.9	5.3	0.2		3.8	4.0	3.6
	2-3	3.2	0.5	4.8	0.1		4.0	3.7	3.1
	3-4	3.3	0.5	5.0	0.1		3.8	3.3	2.2
	4-5	3.9	0.7	4.8	0.1		3.7	3.7	2.2
TW 14	0-1	2.0	1.8	11.0	0.4	1.0	4.5	4.3	5.1
	1-2	1.3	0.9	10.8	0.3		4.3	2.8	4.4
	2-3	1.2	0.7	9.1	0.1		4.9	2.8	4.4
	3-4	1.0	0.6	8.4	0.1	0.3	5.5	3.5	3.8
	4-5	0.8	0.6	9.6	0.1	0.5	5.0	2.8	3.8
TW 85	0-1	7.0	4.1	14.0	0.4		5.0	8.4	8.5
	1-2	4.4	2.7	8.8	0.4		4.0	5.7	6.0
	2-3	3.6	1.9	6.8	0.2		3.7	3.8	4.4
	3-4	3.6	1.7	6.6	0.2		3.4	4.3	4.0
	4-5	4.1	0.6	6.8	0.2		2.9	4.5	4.0
TW 7A	0-1	22.2	7.0	32.5	0.6	2.0	1.0	42.3	16.0
	1-2	51.5	10.3	52.5	1.1		3.0	83.2	32.3
	2-3	36.9	20.3	53.5	0.6		3.3	60.6	47.0
	3-4	28.4	17.5	30.0	0.5		4.0	33.8	47.5
	4-5	29.4	16.7	29.3	0.6	0.4	3.0	20.7	53.1

(Continued)

Table 5. (Continued)

Soil[1/]	Depth	Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4
	ft.				me/l				
TW 178	0-1	12.0	3.7	18.2	0.8		5.0	11.3	6.3
	1-2	5.5	1.6	8.4	0.4		3.7	5.6	5.0
	2-3	5.2	1.9	7.4	0.3		3.0	4.7	3.3
	3-4	4.7	1.4	6.8	0.3		3.0	3.7	3.3
	4-5	4.7	2.1	6.4	0.3		4.0	4.2	4.0
Rahwali Area	0-1	6.2	3.1	14.6	0.4		3.4	6.2	11.8
	1-2	3.5	1.3	7.0	0.3		2.4	2.8	4.4
	2-3	3.5	1.1	5.8	0.3		2.8	3.4	4.0
	3-4	2.9	0.9	6.8	0.2		3.2	2.8	3.5
	4-5	3.3	1.1	5.4	0.2		3.2	3.4	3.2

1/ LRD - Land Reclamation Directorate, PAU - Pakistan Agricultural University. TW - Tubewell.

Table 6. Salt and exchangeable sodium, and cation exchange capacity analyses of Punjab soils.

Soil[1/]	Depth	$EC \times 10^3$	SAR	Exch. Na	CEC	ESP
	ft.	mmhos/cm		me/100 g.		
LRD	0-1	12.9	21.3	1.00	8.2	26.8
	1-2	1.6	7.0	0.70	7.4	9.4
	2-3	1.6	11.5	1.00	7.2	13.9
	3-4	2.3	18.2	1.30	7.2	18.1
	4-5	3.0	18.5	1.53	7.8	19.6
PAU A	0-.5	14.7	33.2	2.57	8.6	30.0
	.5-1	4.3	21.0	1.90	9.4	20.2
	1-2	2.4	15.7	1.35	9.0	15.0
	2-3	1.2	9.8	0.70	8.2	8.5
	3-4	1.5	3.6	0.36	7.4	4.9
	4-5	1.5	1.8	0.23	4.8	4.8
PAU B	0-.5	5.5	14.5	1.11	8.6	12.9
	.5-1	6.1	19.6	1.68	9.0	18.7
	1-2	5.8	13.6	1.46	9.6	15.2
	2-3	4.0	6.3	0.67	9.6	7.0
	3-4	1.9	7.2	0.37	5.0	7.4
	4-5	1.3	3.5	0.22	3.8	5.8
PAU C	0-.5	2.2	5.7	0.63	10.4	6.0
	.5-1	2.0	2.6	0.32	10.0	3.2
	1-2	1.7	2.2	0.26	10.4	2.5
	2-3	1.7	1.7	0.30	11.4	2.6
	3-4	1.5	2.1	0.26	10.4	2.5
	4-5	1.3	1.9	0.24	10.4	2.3
TW 149	0-1	1.3	5.6	0.76	11.4	6.7
	1-2	1.1	8.1	1.35	14.6	9.3
	2-3	1.1	5.4	1.15	17.8	6.5
	3-4	1.7	3.3	0.74	16.8	4.4
	4-5	2.4	2.7	0.62	15.8	3.9
TW 161	0-1	1.3	4.3	0.39	6.2	6.3
	1-2	1.1	3.2	0.31	7.4	4.2
	2-3	0.9	3.5	0.47	9.6	4.9
	3-4	0.9	3.7	0.50	10.0	5.0
	4-5	1.0	3.2	0.42	9.0	4.7
TW 14	0-1	1.4	7.9	0.54	7.8	6.9
	1-2	1.1	10.5	1.05	14.0	7.5
	2-3	1.1	9.6	1.38	13.0	10.6
	3-4	1.2	9.4	1.28	11.0	11.7
	4-5	1.2	11.4	1.21	7.4	16.4

(Continued)

Table 6. (Continued)

Soil[1/]	Depth	ECx10^3	SAR	Exch. Na	CEC	ESP
	ft.	mmhos/cm		me/100 g.		
TW 85	0-1	2.5	6.0	0.62	7.8	8.0
	1-2	1.6	4.7	0.60	9.4	6.4
	2-3	1.3	4.1	0.95	14.6	6.5
	3-4	1.2	4.1	0.60	16.4	4.1
	4-5	1.3	4.4	0.50	9.4	5.3
TW 7A	0-1	5.1	8.5	1.07	11.4	9.4
	1-2	10.4	9.4	1.08	10.8	10.0
	2-3	9.9	10.0	0.94	11.8	8.0
	3-4	7.8	6.3	1.03	11.8	8.7
	4-5	7.3	6.1	0.91	10.8	8.4
TW 178	0-1	3.6	6.5	0.69	6.2	11.1
	1-2	1.7	4.5	0.49	7.4	6.6
	2-3	1.7	3.9	0.49	7.8	6.3
	3-4	1.4	3.9	0.52	6.6	7.9
	4-5	1.4	3.5	0.41	7.4	5.6
Rahawali Area	0-1	2.3	6.8	0.82	9.4	8.7
	1-2	1.3	4.5	0.72	11.4	6.3
	2-3	1.1	3.8	0.50	7.4	6.8
	3-4	1.3	5.0	0.44	6.4	6.9
	4-5	1.1	3.6	0.56	8.2	6.8

1/ LRD - Land Reclamation Directorate. PAU - Pakistan Agricultural University. TW - Tubewell.

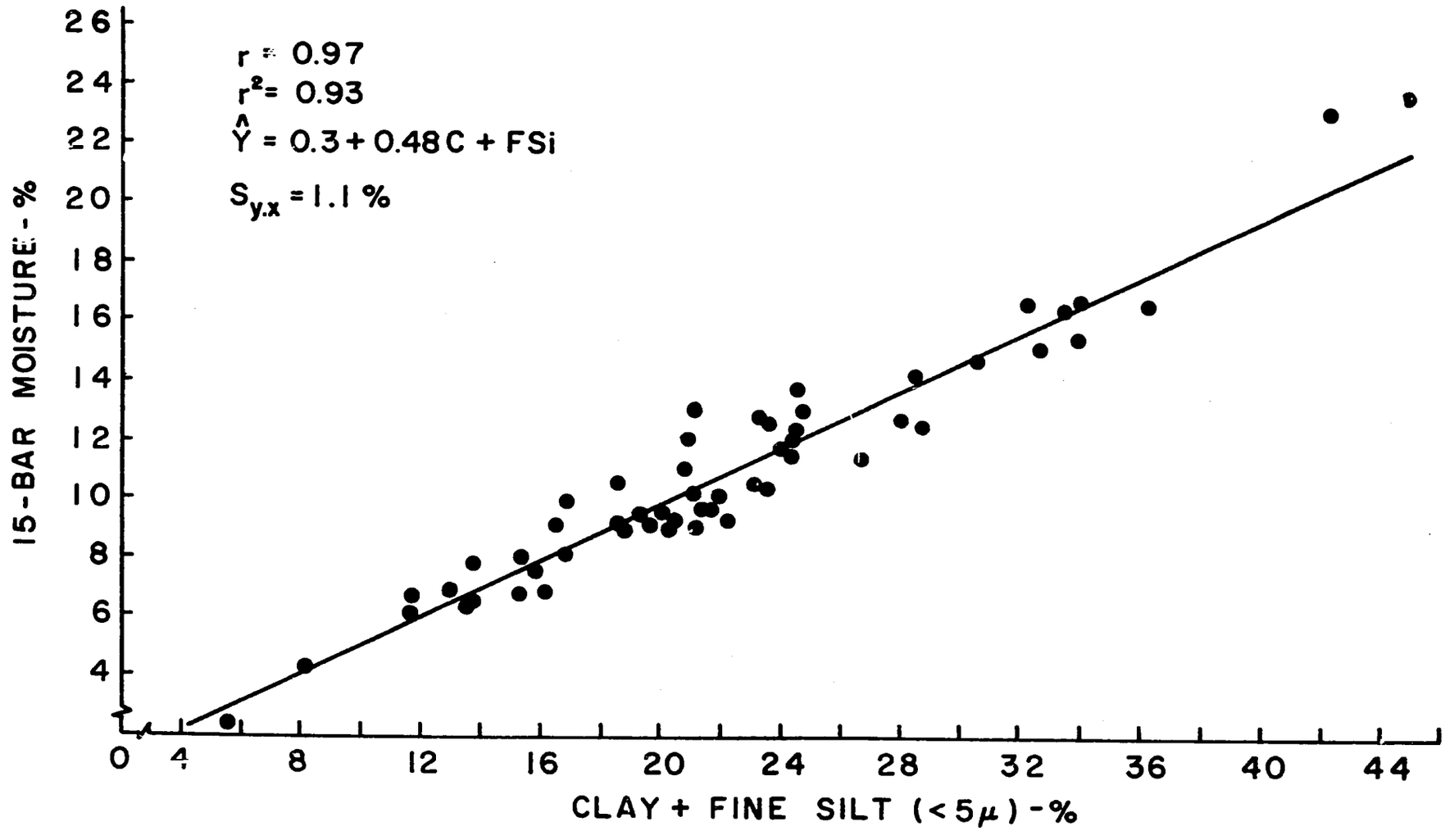

Figure 2. The relationship between the <5μ particle size and 15-bar moisture of the Punjab soil samples.

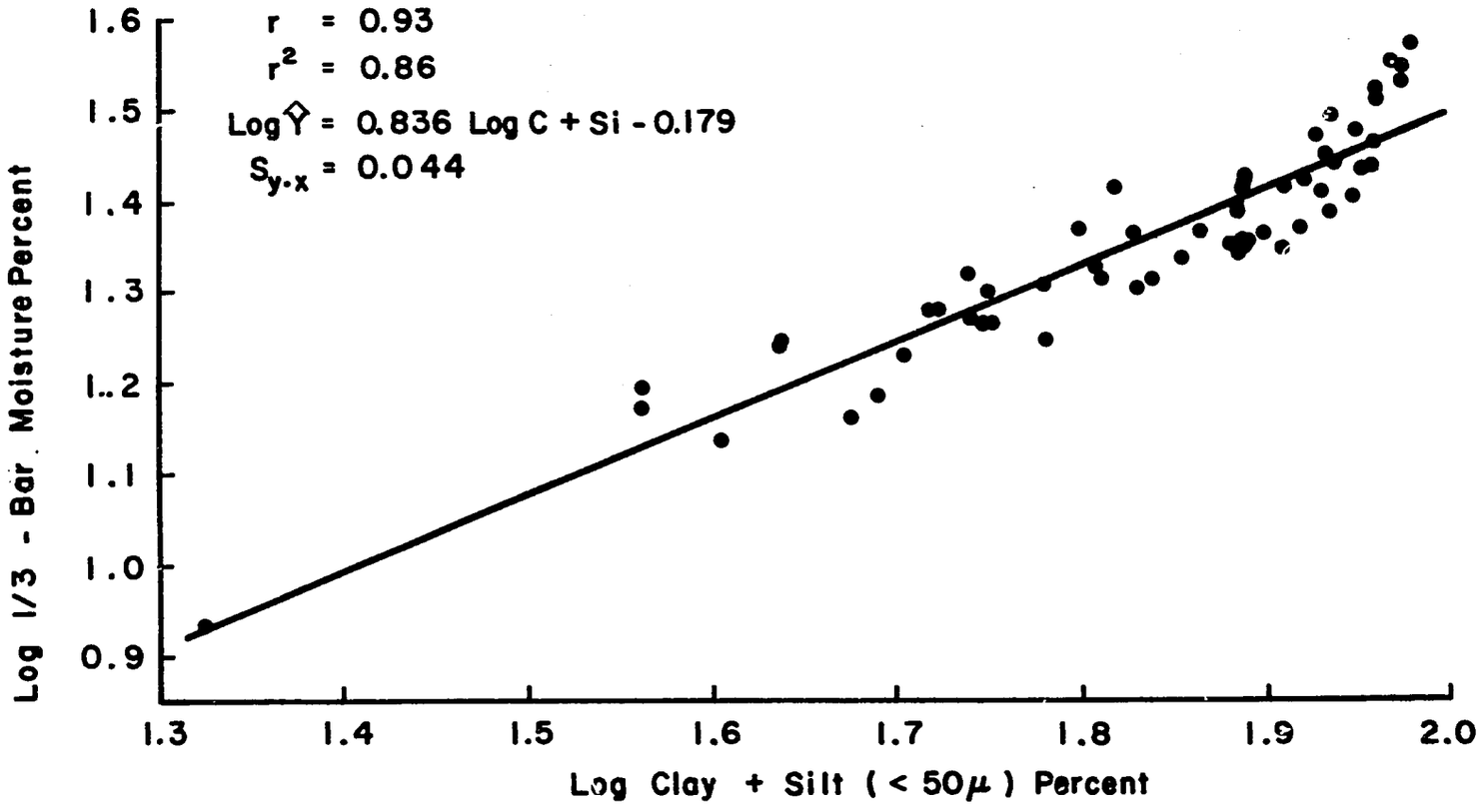

Figure 3. The relationship between the <50μ particle size and 1/3-bar moisture of the Punjab soil samples.

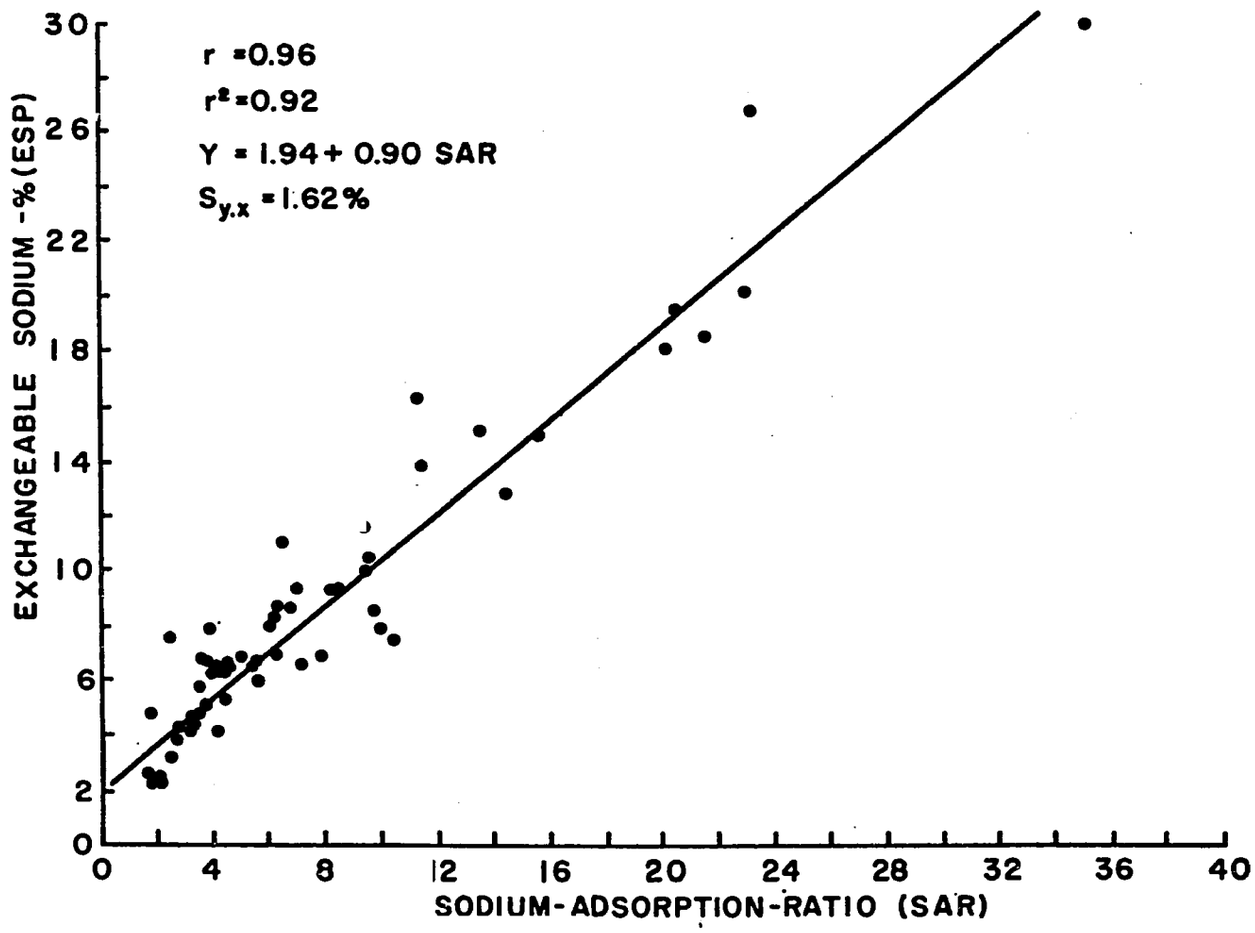

Figure 4. The relationship between SAR and ESP for the Punjab soil samples.

correlations (U. S. Salinity Laboratory Staff, 1954).

A correlation was made between SAR and ESP of the Punjab soils. Also, a correlation was made between SAR and the Gapon-type equation used by Bower (1959), $\frac{Na_{(ad)}}{(Ca + Mg)_{(ad)}} = \frac{ES}{CEC-ES-EP}$. The linear regression equations for these relationships are summarized in Table 7.

Table 7. Linear correlations of SAR of saturated extracts with ESR and Gapon-type absorbed ion ratios.

X	Y	Correlation Coefficient (r)	Regression Equation	
SAR	ESR	.959	.0063 + .01240X	Punjab soils
SAR	ESR	.923	-.0126 + .01475X	USSL (1954)
SAR	$\frac{Na}{Ca + Mg}$	.962	.0106 + .01237X	Punjab soils
SAR	$\frac{Na}{Ca + Mg}$	.91	.0057 + .0173X	Bower (1959)

The correlation coefficients obtained between SAR of the Punjab soil extracts and both methods of expressing adsorbed ion ratios are higher than for the U. S. soils. The intercepts in the linear regression equations are slightly higher for the Punjab soils than for the U. S. soils but the slopes are lower. The lower slopes indicate less Na adsorption as the SAR increases for the Punjab soils in which mica (illite) and chlorite clays predominate.

Either the equation ESP = 1.94 + 0.903 SAR or $ESP = \frac{100\ (.0063 + .01240\ SAR)}{1 + (.0063 + .01240\ SAR)}$ should give improved estimates of ESP for Pakistan soils.

FERTILITY ANALYSES

Organic matter (Allison, 1965), pH, lime (Allison and Moodie, 1965), available P (Olsen, et al., 1954; Watanabe and Olsen, 1965), available K (Pratt, 1965),

DTPA extractable Fe and Zn (Lindsay and Norvell, 1968) were run on the Punjab soils originally obtained primarily for mineralogical studies. Additional analyses run on part of the soil samples obtained at later dates were: DTPA extractable Mn and Cu (Norvell and Lindsay, 1969; Follett and Lindsay, 1971); and NO_3-N (Bremmer, 1965). These results are given in Tables 8 and 9.

Organic Matter and NO_3-N

Organic matter was 1% or less in the surface soil in all but five sites. One sample site, at Murree, elevation about 6000 ft.(PARI-6), was exceptionally high in O.M. (3.5%). Other surface samples above 1% O.M. were found in the Tandojam and Hyderabad areas of the Sind (S-TJ and S-SC) at Sialkot (PARI-6), at Dundi Estate (PARI-8) and at Kala Shah Kaku (PARI-15). Exceptionally low O.M. contents (<0.1 and 0.2%) were found in two sandy soils at Bhakhar (PARI-11) and Campbellpur (PARI-11). The low O.M. content of the majority of the soils confirms the generally large N response found for non-leguminous crops in the irrigated region of Pakistan.

Nitrate-N was determined on samples taken from experimental sites in all cases except one, S-SC, a farmer's sugar cane field near Hyderabad. High NO_3-N levels (>10 ppm) reflect N-fertilizer applications in most cases. Exceptionally high NO_3-N levels (PARI-9, Multan; PARI-16, Harrappa) appear to be related to high soil salinity levels (EC_e = 11 and 90 mmhos/cm, respectively).

Phosphorus

General guidelines for interpreting the 0.5 M $NaHCO_3$-extractable P levels are: 0-7 ppm - low, crop response expected for all crops; 7-15 ppm - medium, crop response possible for many crops; >15 ppm - high, crop response not usually expected. Available P was deficient (<10 ppm) in 20 of the 27 soil surface layers sampled. Higher P levels (>10 ppm) were mainly at soil fertility ex-

Table 8. Fertility analyses of Punjab soils.

Soil[1/]	Depth (ft.)	Texture	pH (1:5)	O.M. (%)	Lime (%)	P (ppm)	K (ppm)	Zn (ppm)	Fe (ppm)
LRD	0-1	SiL	8.4	0.6	7.1	24.2	99	1.55	4.2
	1-2	SiL	8.9	0.2	7.8	4.6	40	0.54	3.9
	2-3	SiL	9.1	0.1	8.6	3.5	40	0.48	4.0
	3-4	SiL	9.2	0.2	9.5	2.4	40	0.42	4.1
	4-5	SiL	9.2	0.1	12.2	1.5	40	0.52	4.6
PAU	0-.5	L	8.5	0.5	9.8	8.9	218	10.00+	5.1
	.5-1	SiL	9.3	0.2	15.5	2.0	137	3.66	4.1
A	1-2	SiL	9.3	0.2	14.2	1.5	81	2.40	3.6
	2-3	SiL	9.1	0.2	12.6	3.7	81	6.30	3.8
	3-4	SiL	9.7	0.1	9.2	0.9	79	5.30	4.1
	4-5	SL	8.8	0.2	6.2	1.1	50	5.80	5.8
PAU	0-.5	L	8.8	0.5	8.2	3.7	191	10.00+	4.6
	.5-1	SiL	9.0	0.2	15.0	1.1	149	10.00+	3.4
B	1-2	L	8.8	0.1	12.8	0.7	85	3.30	3.4
	2-3	SiL	8.6	0.1	13.8	0.7	67	.55	3.5
	3-4	L	8.7	0.2	8.6	1.7	48	6.10	4.7
	4-5	LS	8.8	0.1	5.6	1.1	26	6.00	7.3
PAU	0-.5	L	8.6	0.8	2.0	5.9	292	6.00	6.4
	.5-1	L	8.4	0.3	1.0	7.2	183	1.47	6.1
C	1-2	L	8.3	0.4	0.8	4.1	121	0.64	6.9
	2-3	L	8.3	0.1	0.7	6.8	117	6.90	8.8
	3-4	L	8.3	0.1	0.5	8.1	121	2.16	8.7
	4-5	L	8.4	0.2	0.5	6.5	125	4.40	8.3
TW 149	0-1	SiL	8.7	1.0	0.9	1.1	133	1.06	7.7
	1-2	SiL	8.8	0.5	0.7	0.9	129	0.52	8.0
	2-3	SiCL	8.7	0.7	1.3	1.3	121	0.59	8.5
	3-4	SiCL	8.4	0.6	2.1	2.0	117	0.42	8.0
	4-5	SiCL	8.3	0.5	2.0	3.9	117	0.58	7.4
TW 161	0-1	L	8.7	0.4	3.7	1.1	81	0.92	6.7
	1-2	L	8.6	0.4	2.1	0.9	56	0.47	5.5
	2-3	L	8.6	0.4	3.1	0.9	54	0.51	5.3
	3-4	L	8.6	0.4	4.4	0.9	56	0.52	5.9
	4-5	L	8.6	0.1	6.7	1.1	48	0.54	5.3
TW 14	0-1	SL	9.0	0.6	1.3	1.1	111	0.65	12.7
	1-2	L	9.1	0.1	5.9	0.7	141	0.39	4.6
	2-3	L	9.3	0.1	3.7	0.7	111	0.48	6.2
	3-4	SL	9.3	0.1	2.0	1.3	107	0.50	5.5
	4-5	SL	9.4	0.1	2.0	1.7	93	0.53	4.9

(continued)

Table 8. (continued)

Soil[1/]	Depth (ft.)	Texture	pH (1:5)	O.M. (%)	Lime (%)	P (ppm)	K (ppm)	Zn (ppm)	Fe (ppm)
TW 85	0-1	SiL	8.7	0.5	7.6	1.1	149	0.65	9.6
	1-2	SiL	8.7	0.5	0.4	0.9	149	0.60	8.0
	2-3	SiCL	8.5	0.5	2.0	2.2	200	0.78	15.7
	3-4	SiC	8.5	0.1	2.0	0.7	171	0.55	14.7
	4-5	SiL	8.6	0.4	6.4	1.1	97	0.44	5.2
TW 7A	0-1	SiL	8.3	0.2	6.9	0.9	111	0.55	5.6
	1-2	SiL	8.5	0.2	6.0	0.9	137	0.56	3.4
	2-3	SiL	8.4	0.2	5.2	1.1	129	0.46	3.2
	3-4	SiL	8.5	0.1	8.3	2.2	149	0.54	3.0
	4-5	SiL	8.5	0.1	13.8	2.2	121	0.55	3.2
TW 178	0-1	SiL	8.6	0.3	5.0	1.1	117	0.68	5.6
	1-2	SiL	8.6	0.5	5.8	0.9	121	0.60	7.0
	2-3	SiL	8.5	0.2	7.6	0.4	93	0.51	6.8
	3-4	SiL	8.6	0.2	6.8	0.7	121	0.41	7.2
	4-5	SiL	8.6	0.1	5.4	0.2	73	0.51	7.4
Rahawali Area	0-1	SiL	8.7	0.6	4.4	2.6	163	0.54	28.8
	1-2	SiL	8.6	0.4	1.3	1.1	179	0.50	10.6
	2-3	SiL	8.7	0.1	3.8	0.7	97	0.48	4.9
	3-4	SiL	8.7	0.1	5.8	0.4	67	0.53	3.6
	4-5	SiL	8.7	0.3	6.9	0.4	97	0.59	4.2

1/ LRD - Land Reclamation Directorate, PAU - Pakistan Agricultural University, TW - Tube Well.

Table 9. Fertility analyses of Punjab, Northwest Frontier, Baluchistan, and Sind soils.

Soil	Depth (in.)	O.M. %	P (ppm)	K (ppm)	Zn (ppm)	Fe (ppm)	Cu (ppm)	Mn (ppm)	NO_3-N (ppm)	pH	Lime	Texture
PARI-1	0-6	0.9	7.8	198	2.35	4.7	1.13	7.9	6.4	8.4	Med.	SiL
	6-12	0.8	4.3	170	0.91	4.1	1.38	6.1	5.8	8.2	Med.	SiL
	12-24	0.5	1.0	110	0.50	3.3	1.66	4.5	4.6	7.6	Med.	SiL
	24-36	0.8	3.5	102	1.27	3.5	0.85	5.0	7.9	8.2	Med.	SiL
PARI-2	0-6	0.9	4.8	298	1.29	3.9	1.54	6.3	9.4	8.2	Med.	SiL
	6-12	0.6	3.8	200	1.35	3.4	2.70	5.9	7.7	8.1	Med.	SiL
	12-24	0.4	6.5	170	0.91	2.7	1.26	6.0	5.4	8.2	Med.	SiL
	24-36	0.3	2.8	115	1.40	2.3	3.04	4.3	5.6	8.1	Med.	SiL
PARI-3	0-6	0.9	5.0	165	6.45	4.5	1.13	7.0	7.7	8.2	Med.	SiL
	6-12	0.7	2.0	148	2.05	4.4	1.13	7.5	9.4	8.0	Med.	SiL
	12-24	0.5	2.8	115	1.03	3.5	0.96	5.7	4.0	8.2	Med.	SiL
	24-36	0.4	3.5	110	2.86	3.6	0.98	6.7	2.2	8.2	Med.	SiL
PARI-4	0-6	1.0	8.3	182	3.25	4.4	4.46	6.8	2.6	7.9	Med.	SiL
5	0-6	0.9	6.0	115	3.85	3.8	0.67	21.2	10.7	7.9	Low	SiL
6	0-6	3.5	-	130	10.50	21.0	2.50	53.0	15.0	7.3	Low	SiL
7	0-6	1.4	25.5	215	3.55	4.8	4.90	14.3	30.0	7.7	Low	SiL
8	0-6	0.9	8.3	200	1.83	4.7	1.20	7.7	7.3	8.3	Low	SiL
9	0-6	0.9	14.3	250	3.75	3.3	2.66	12.7	157.0	7.4	Med.	SiL
10	0-6	0.9	3.5	142	0.66	7.4	1.97	3.5	7.5	7.8	Med.	SiL
11	0-6	<0.1	5.3	68	0.96	5.2	0.17	2.3	3.3	8.2	Med.	S
12	0-6	1.4	13.8	425	1.72	8.1	2.64	4.6	3.8	7.9	Hi	SiL
13	0-6	0.2	6.0	40	0.87	6.4	0.35	9.5	1.6	7.6	Low	S
14	0-6	0.9	31.5	315	5.20	3.2	1.07	9.9	7.9	8.0	Med.	SiL
15	0-6	1.5	6.5	140	1.71	16.9	4.00	10.0	5.5	7.8	Med.	SiL
16	0-6	0.5	16.3	262	1.04	7.4	1.38	3.3	96.5	10.1	Med.	SiL
S-TJ	0-6	1.8	18.5	370	0.38	20.8	-	-	8.8	7.4	-	SiC
	6-12	1.9	5.0	345	0.36	25.0	-	-	4.8	7.5	-	SiC
	12-24	1.9	1.0	215	0.18	10.2	-	-	1.5	7.5	-	SiC
	24-36	1.4	1.0	168	0.16	9.6	-	-	0.0	7.7	-	SiC
	36-48	1.3	3.3	215	0.20	20.0	-	-	0.3	7.7	-	SiC
	48-60	1.4	1.0	290	0.24	24.4	-	-	2.1	7.7	-	SiC

Table 9. (continued)

Soil	Depth (in.)	O.M. %	P (ppm)	K (ppm)	Zn (ppm)	Fe (ppm)	Cu (ppm)	Mn (ppm)	NO_3-N (ppm)	pH	Lime	Texture
S-WF	0-6	0.9	15.5	398	0.41	7.7	2.30	6.8	0.6	7.8	Hi	SiCl
	6-12	0.6	9.3	317	0.32	6.3	1.90	7.7	3.3	8.0	Hi	SiCl
	12-18	0.4	4.8	223	0.33	4.9	1.00	5.1	1.2	8.1	Hi	SiCl
	18-24	0.4	3.5	177	0.77	5.8	0.92	5.6	10.7	8.2	Hi	SiCl
	24-36	0.5	6.5	213	0.34	6.2	0.98	5.2	10.1	8.1	Hi	SiCl
S-CF	0-6	0.7	3.5	203	0.28	6.2	1.78	6.3	3.3	8.0	Hi	SiCl
	6-12	0.6	4.8	213	0.19	5.3	1.38	5.8	0.0	8.1	Hi	SiCl
	12-18	0.5	4.8	278	0.20	6.4	1.24	6.5	0.0	8.3	Hi	SiCl
	18-24	0.5	2.0	253	0.22	6.6	0.98	5.7	0.0	8.0	Hi	SiCl
	24-36	0.8	5.3	249	0.30	6.6	1.72	6.5	0.0	8.0	Hi	SiCl
S-SC	0-6	1.2	8.3	187	0.35	10.3	2.72	7.8	2.0	8.1	Hi	SiCl
	6-12	1.2	7.8	185	0.26	11.3	2.44	7.8	4.6	8.1	Hi	SiCl
	12-18	0.9	6.5	208	0.19	7.8	2.00	5.8	3.3	8.1	Hi	SiCl
	18-24	0.8	7.8	133	0.19	6.3	1.30	5.9	1.4	8.2	Hi	SiCl
	24-36	0.4	4.0	143	0.16	5.9	1.00	3.8	0.0	8.3	Hi	SiCl

perimental sites where P fertilizers were applied. Available P levels were very low (<2.6 ppm) in all SCARP-I and SCARP-II samples (TW 149 - Rahwali Area, Table 9). These low P levels appear to be typical of irrigated soils in the Punjab where farmers have not adopted P fertilization.

Potassium

General guidelines for interpreting available K levels in soils are: 0-60 ppm, low; 60-120 ppm, medium; 121-180 ppm, high; >180 ppm very high. Available K was adequate (>100 ppm) in 24 of 27 surface soil samples. Thus, response to K fertilizers on field crops would be expected to occur rarely and any response would not be large. Mica, which appears to be the predominant clay mineral in the soils of the Indus Plain, accounts for the adequate K supply in most soils.

Zinc

General guidelines for interpreting available Zn and Fe analyses (DTPA extractable) are: 0-0.25 ppm - very low; 0.26-.50 ppm - low; 0.51-1.0 ppm - marginal; >1 ppm - adequate. The soil tests show that Zn deficiency (< 1 ppm) may be expected for sensitive crops, such as maize, sorghum, potatoes, and beans, on 11 of the 27 surface soil samples. Zinc deficiency may develop more frequently on paddy rice. Samples from the Tandojam-Hyderabad areas of the Sind all show low available Zn levels (<0.5 ppm).

Iron

General guidelines for interpreting available Fe (DPTA-extractable) are: 0-2.5 ppm - low; 2.6-4.5 ppm - marginal; >4.5 ppm - adequate. Iron availability is marginal to borderline in only five of the 27 surface soil samples. Marginal Fe levels were found in samples from Rawalpindi (PARI-5), Multan PARI-9), and Quetta (PARI-14). Crops sensitive to Zn deficiency are frequently sensitive to Fe deficiency, also.

Manganese and Copper

General guidelines for interpreting available Mn (DPTA-extractable) are: 0-1 ppm - low; >1 ppm - adequate. Guidelines for available Cu (DPTA-extractable) are: 0-0.2 ppm - low; >0.2 ppm - adequate. The analyses indicate the Mn and Cu are adequate in all soil samples except the sandy soil sample from Bakhar (PARI-11) which has borderline Cu availability.

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