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SALINITY MANAGEMENT ALTERNATIVES FOR THE RECHNA DOAB, PUNJAB, PAKISTAN

Volume FOUR

Field Data Collection and Processing

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FOREWORD

This report is one of eight volumes under the umbrella title "Salinity Management Alternatives for the Rechna Doab, Punjab, Pakistan." The funding for this effort has been provided by the Government of The Netherlands through the Royal Netherlands Embassy in Islamabad under the Phase II project, "Managing Irrigation for Environmentally Sustainable Agriculture in Pakistan." Between 1989-93, IIMI operated three field stations in Rechna Doab using Dutch phase I funding; much of this field data has been incorporated into this study.

Rechna Doab, the ancient floodplain between the Ravi and Chenab rivers covering a gross area of 2.9 Mha, is one of the most intensively developed irrigated area within the country. With over a century of modern irrigation development, primarily by diversions from the Chenab River, agricultural productivity was continually bolstered. Then, some localities were beset with the threats of higher subsurface water levels and soil salinization. The public sector responded by implementing Salinity Control and Reclamation Projects (SCARPs) beginning in 1960. These projects, plus a huge increase in private tubewell development since 1980, have lowered subsurface water levels; however, the use of poor quality tubewell water, particularly in the center of the Doab, has resulted in secondary salinization. This study is an integrated attempt across both space and time to address the systems responsiveness to the abovementioned concerns.

Vast amounts of data have been collected by public agencies in this study area since 1960. There are a number of agriculture census reports (1960, 1972, 1980 and 1990). Also, the Water and Power Development Authority (WAPDA) has done extensive investigations; their data were made available to IIMI through the General Management (Planning) and the SCARPs Monitoring Organization (SMO). In addition, WAPDA deputed an engineer half-time to participate in these studies who is knowledgeable on the Indus Basin Model Revised (see Volume Eight), which was used primarily to study the effect of groundwater balance constraints on cropping patterns.

The planning for this study was done during January-March 1995. Then, spatial database manipulations using GIS tools were employed to provide the base stratifications leading to the selection of sample sites for IIMI's field campaigns during 1995, which were meant to corroborate, and in many instances update, the information already gathered from public sources. This included, in addition to structured farmer interviews, physical observations on the useable pumped water quality, soil salinity, surface soil texture, and cropping patterns.

This integrated approach involves a synthesis of spatial modeling comprising drainage, salinity, and groundwater use constraints with a calibrated groundwater salinity model, a root zone surface and groundwater balance model, and production function models appropriate to the agroecology of the area. The output provides both suggestive and predictive links to the sustainability of irrigated agriculture in the Rechna Doab.

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SALINITY MANAGEMENT ALTERNATIVES FOR THE RECHNA DOAB, PUNJAB, PAKISTAN.

Volume Four
FIELD DATA COLLECTION AND PROCESSING

I. INTRODUCTION TO DATA COLLECTION

The strategic linkages in the assimilation and processing of spatial and non-spatial information encompassing the web of modeled appropriations for the Rechna Doab have been described in a process flow chart under Section II (A) of Volume Three. These linkages, reproduced here as Figure 1, are sustained by the interactive mix of information within the geoinformation system framework whose deliverables are critical to the assessment of salinity management alternatives. Since time constraints inhibit quantitative links in information sharing within the GIS, the analysis sequence has been partitioned to represent inferential reporting at two distinct places of information flow within the flow chart. The first of these stages occurs about the time when the *Subdivisional Stratifications* of public sector thematic data are to be combined with the results of the *Field Sampling Component* that draws from the site selections under *Spatial Data Models* (see Section II (B) of Volume Three). The discussion in this volume focuses on the implementation of the *Field Sampling Component* and processing of information therein, for which the analytical linkages described under Section II (E) of Volume Three (pertinent to sample site selection) provide the primary reference to the *Spatial Data Models* mentioned above.

A. Spatial Appropriations for Sampling

The seven thematic models, described under numbered boxes 35, 36, 38, 47, 48, 49, & 50 in Figure 13 of Volume Three, provide the base stratifications leading to the selection of sample sites for IIMI's field campaigns. The field campaigns were meant to corroborate, and in many instances update, the information already gathered from public sources. This included, in addition to structured farmer interviews, physical observations on the useable pumped water quality, soil salinity, surface soil texture, and cropping pattern. Since many of the spatial models had subsets in time (e.g. comparisons of depth to water table or changes in groundwater quality), only the latest data sets were used for the extraction of sample sites. Digital overlay information from the Survey of Pakistan (SoP) 1:50,000 scale topographic sheets was used as the locational reference towards determining accessibility to the sites to be demarcated off of the seven thematic models set aside for this purpose. Figures 2-8 show these themes with the superimposed locational reference.

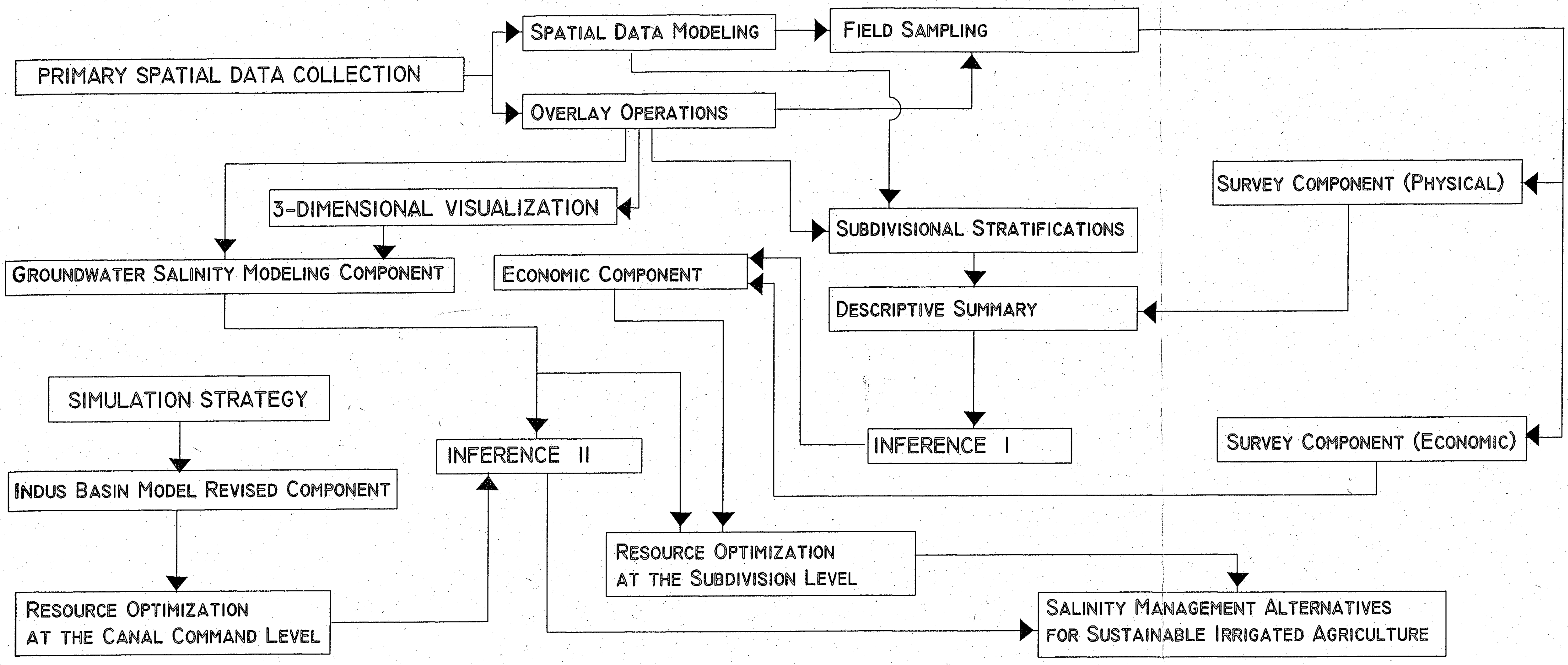

Figure 1. Process Flow Chart for the Study of Salinity Management Alternatives in the Rechna Doab, Punjab, Pakistan.

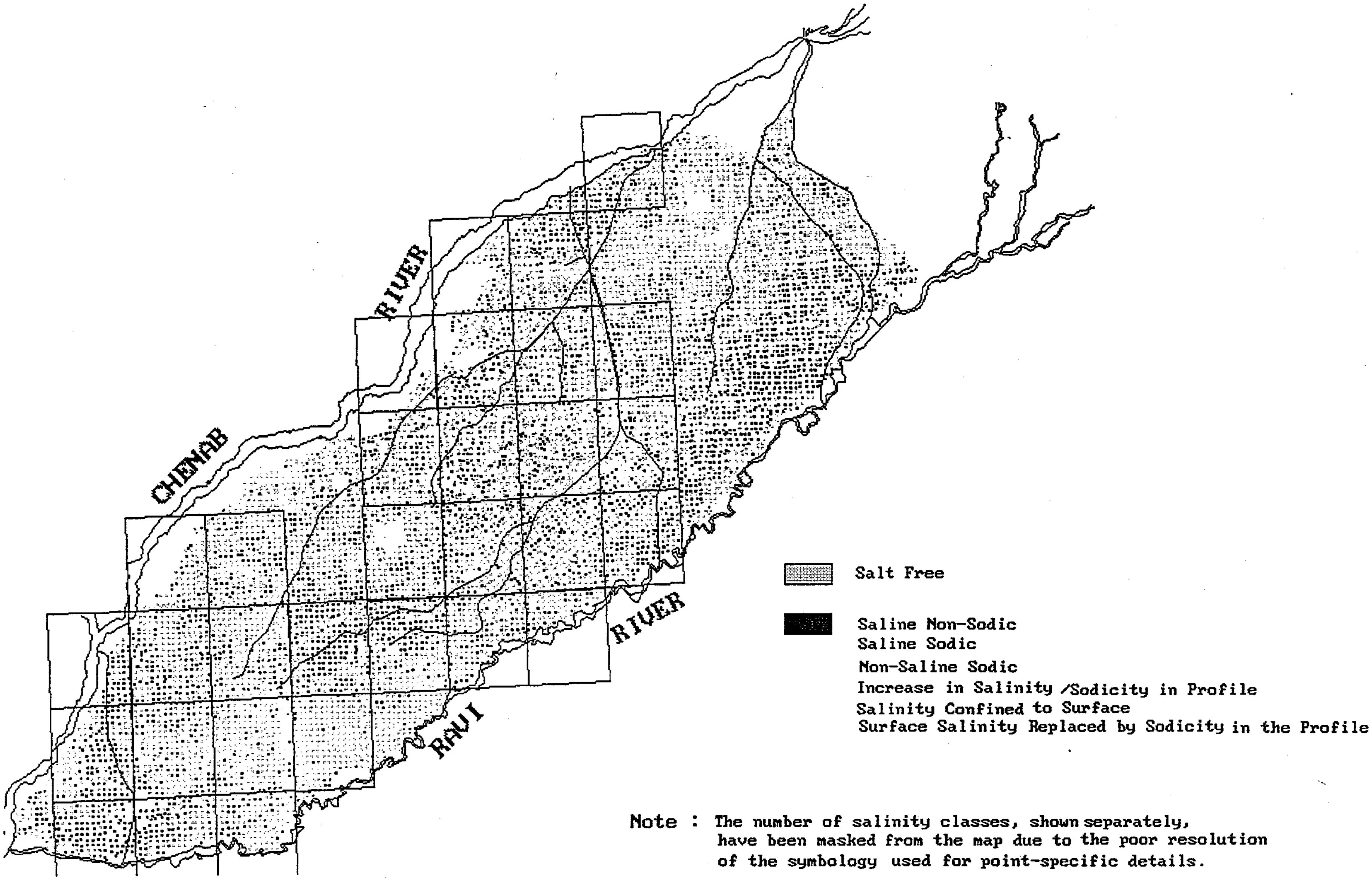

Figure 2 Comparison of Surface and Profile Salinity Assessment, WAPDA MPR Survey, 1979, Rechna Doab, Punjab, Pakistan.

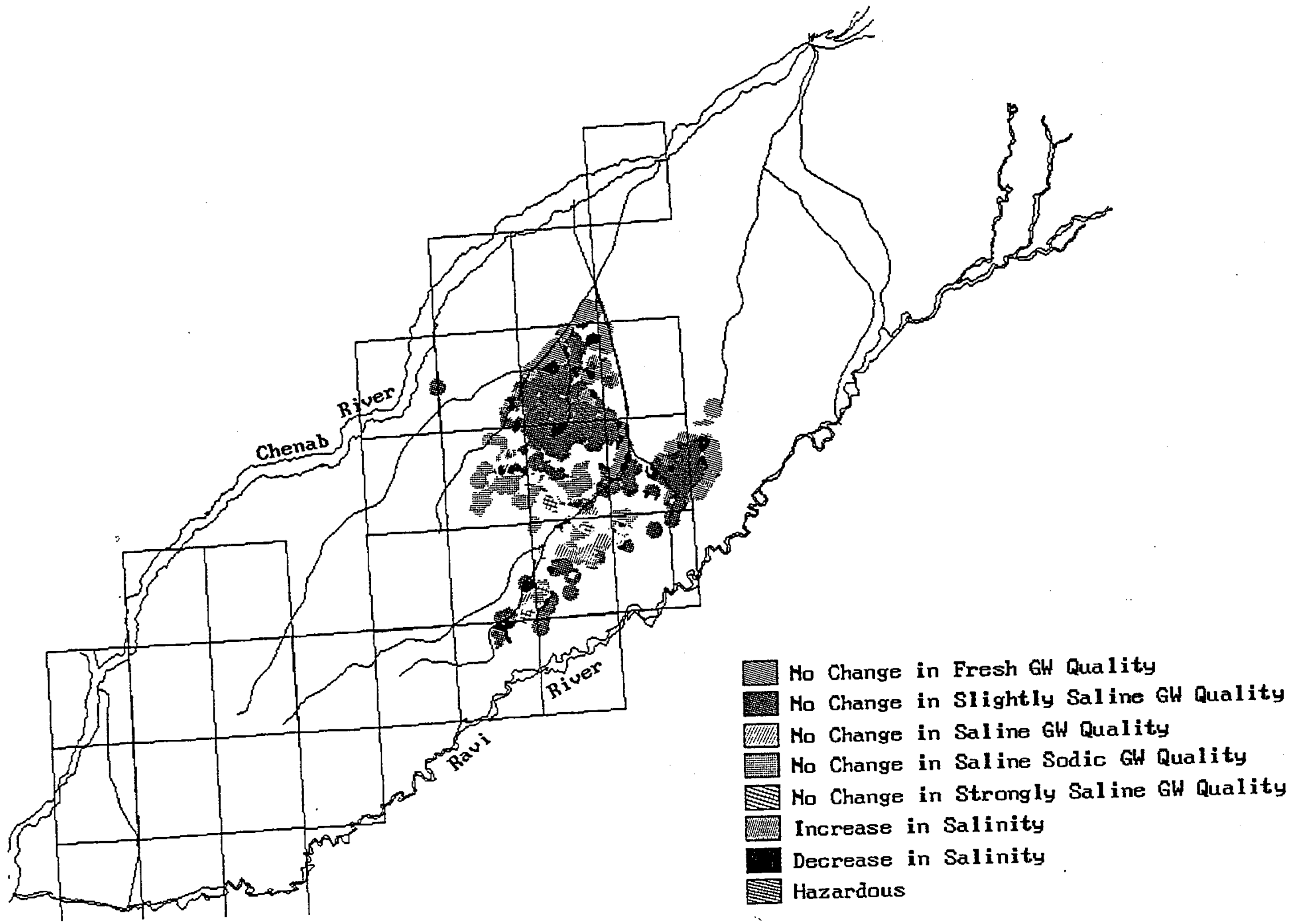

Figure 3 Temporal Comparison of Pumped Groundwater Quality for SCARP-I Tubewells, 1985-89, Rechna Doab, Pakistan.

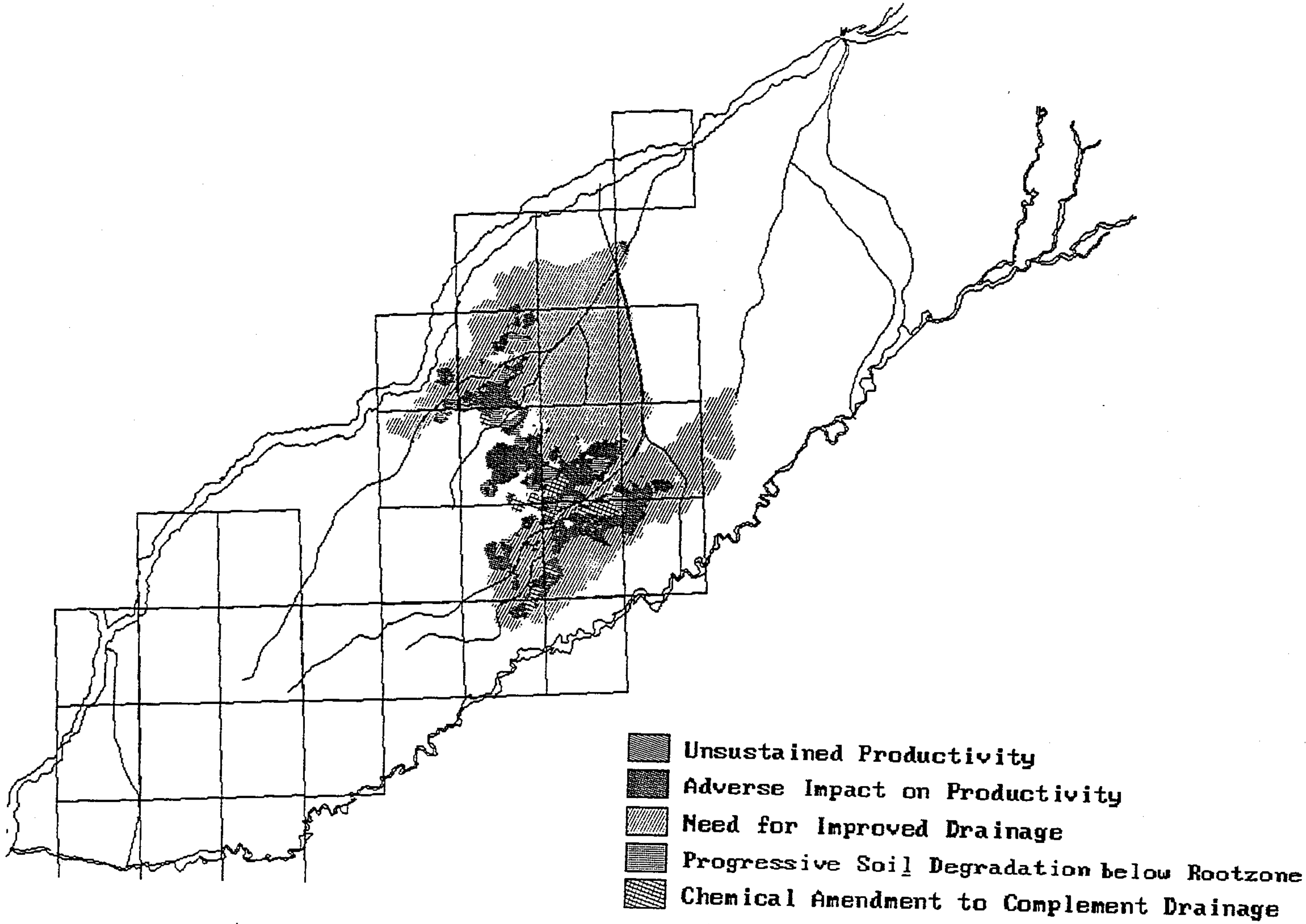

Figure 4 Comparison of Pumped Groundwater Quality to Seasonal Fluctuations in Depth to Water Table, SCARP-I, 1985, Rechna Doab, Pakistan.

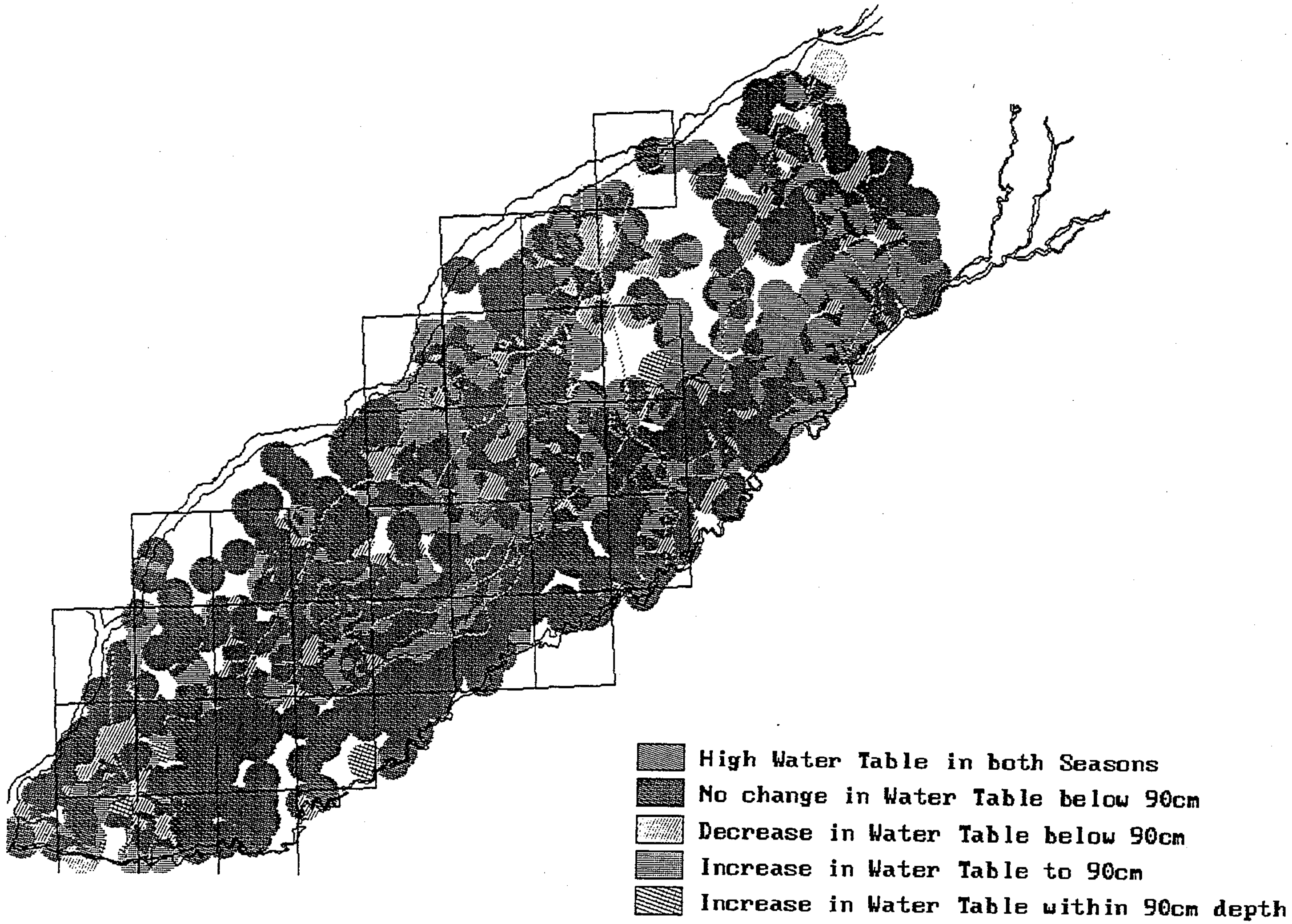

Figure 5 Seasonal Changes in Depth to Water Table, June-October 1993, Rechna Doab, Pakistan.

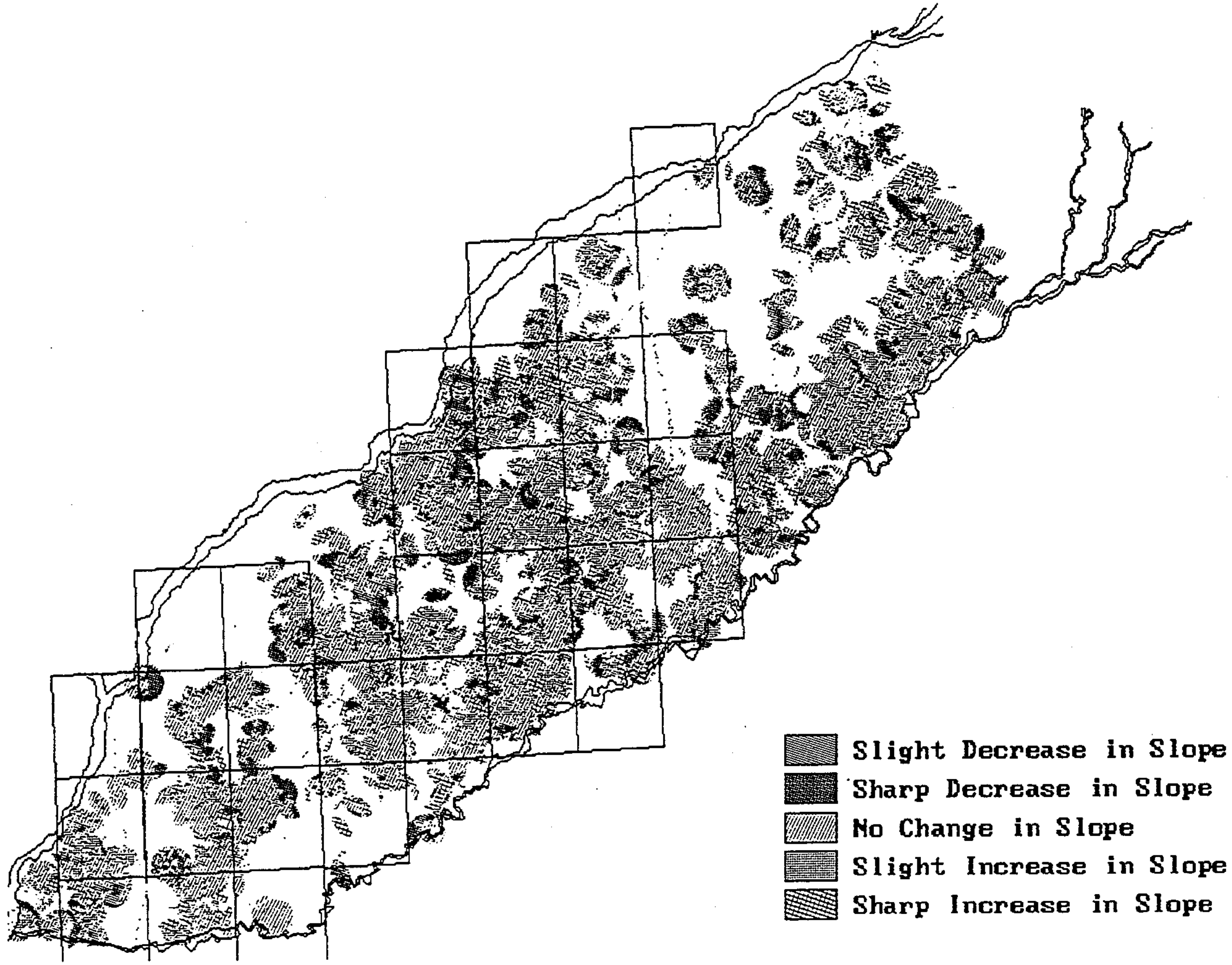

Figure 6 Seasonal Changes in the Water Table Slopes Between June-October, 1993. Rechna Doab, Pakistan.

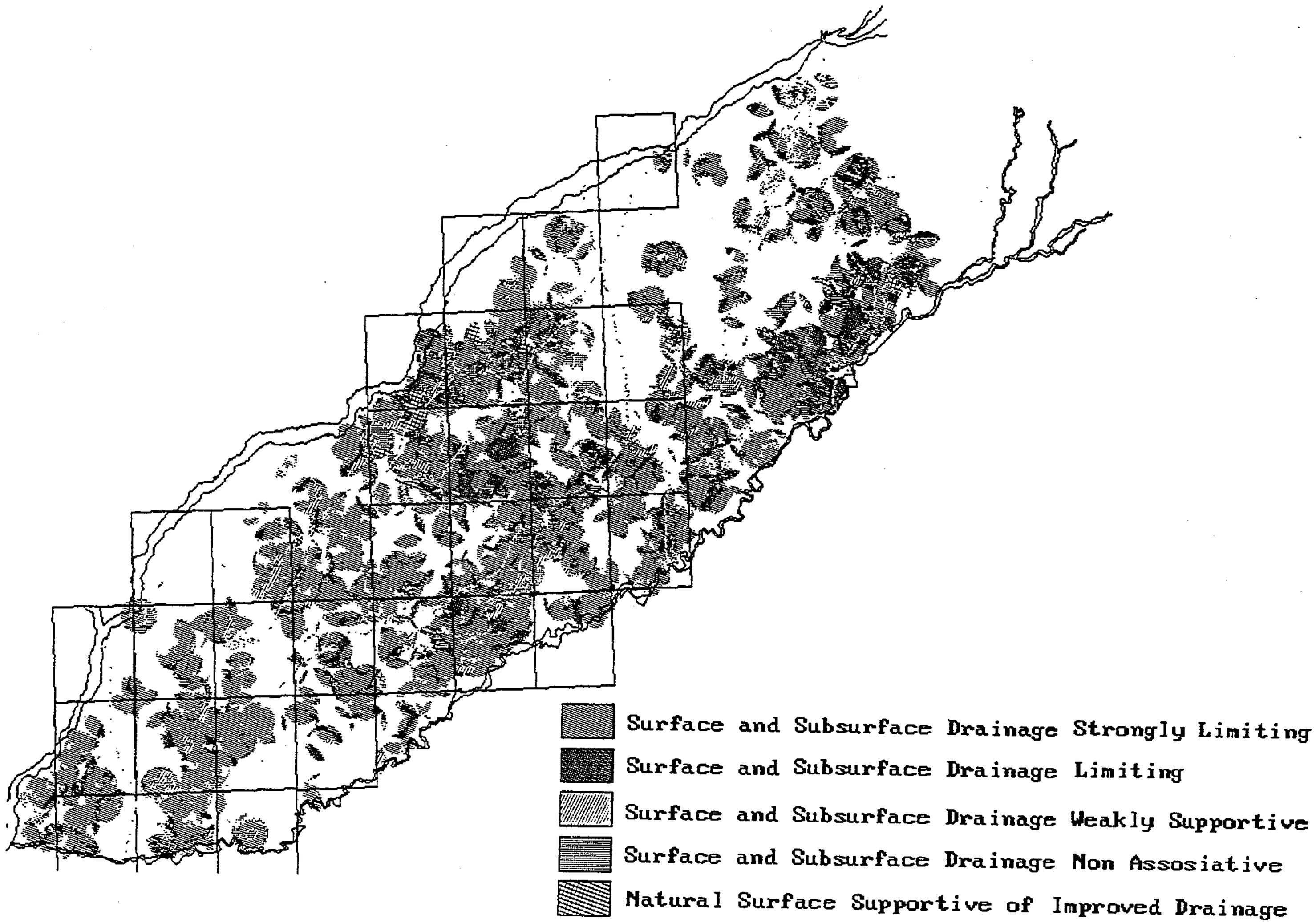

Figure 7 Association of Seasonal Changes in Water Table Slopes to Changes in Depth to Water Tables, June-October, 1993, Rechna Doab. Pakistan.

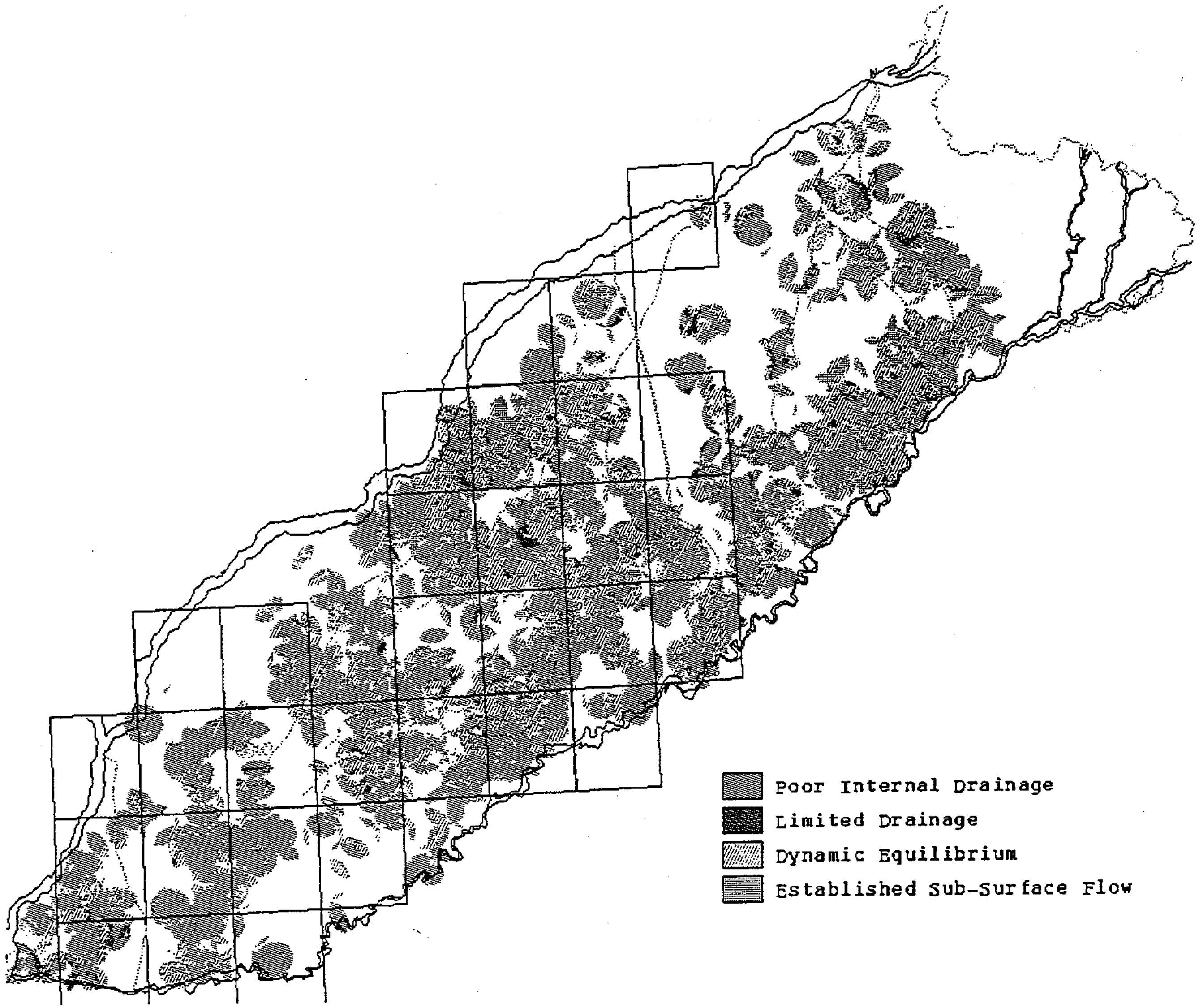

Figure 8 Comparison of Topographic Slopes to Seasonal Changes in Water Levels and Subsurface Slopes, June-October, 1993, Rechna Doab, Pakistan.

A total of 219 sample site delimitations were transferred from the spatial models to the SoP sheets. Homogeneous with respect to the legend-specific details in each of the spatial models, these areas were 8-12 km^2 in extent and were subsequently coded for reference in terms of an **XXXX** numeric scheme. The first digit in the code corresponded to the Spatial model, followed by the legend information, and the last two digits corresponded to the number of polygons or closed areas under the preceding sequence. In hindsight, due to unintended remissions in equal distribution of these sample regimes and the overestimation of coverage actually possible during the surveys, there were gaps in sampling, as is evident from Figures 9(a), (b), & (c). Accordingly, comparative details on the deviation from the targeted coverage are presented in Table 1.

Three separate field campaigns were made between June-November, 1995 for data collection across the sample polygons. The first of these was just ahead of the monsoons and about the time when rice and cotton plantations could be observed on the fields. During this visit, staff from the Soil Survey of Pakistan (SSoP) also accompanied for field specific interpretation of soil texture. The second survey, in the month of September, permitted observations wherein the crop stands could be assessed for vigor in the context of prevailing salinity. The last survey period, extending into the 3rd week of November, coincided with the harvest of the principal kharif crops whereby a majority of the land under cultivation was observed to be bare. The end-of-season observations on salinity were useful with respect to assessment of salts remaining in the root zone since the last applied irrigation.

B. Pumped Groundwater Quality

1) Primary Aggregation

Towards simulation and prediction of the long-term trends in salinity variations of pumped water through the HST3D groundwater salinity model, data on salinity of tubewell water constituted an essential input. The data on groundwater salinity of public tubewells were collected from the records of SCARPs Monitoring Organization (SMO) of the Water And Power Development Authority (WAPDA). The information on private tubewells was obtained from IIMI's own records of past research on tubewell irrigation carried out during the 1988-1992 period in the Lower Chenab Canal (LCC) command (Table 2).

For ***SCARP-I***, groundwater quality data for 2074 tubewells were available for a period of 30 years (1960-1989); however, there were inconsistencies in the yearly reporting. Out of 2074 tubewells, only 500 tubewells have consistent groundwater quality data for the periods 1960, 1965, and 1985. These tubewells have a salinity range of 1000 to 4000 μS/cm, whereas 53 out of 500 tubewells have an electrical conductivity (EC) range of 1500-4000 μS/cm, showing a deteriorating trend in groundwater quality with time.

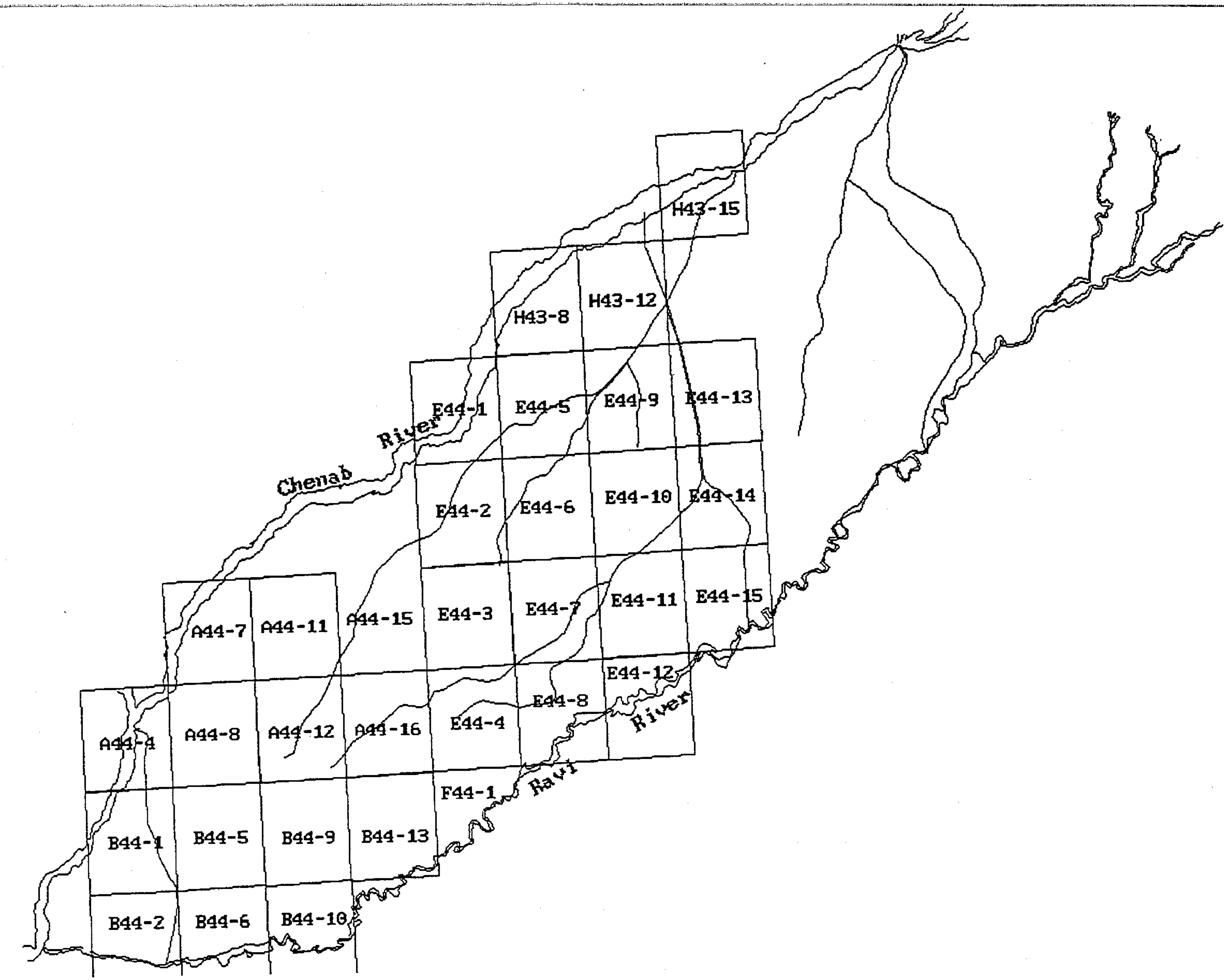

Figure 9(a) Survey of Pakistan Topographic Sheet Coverage at 1:50,000 Scale for the Rechna Doab, Pakistan.

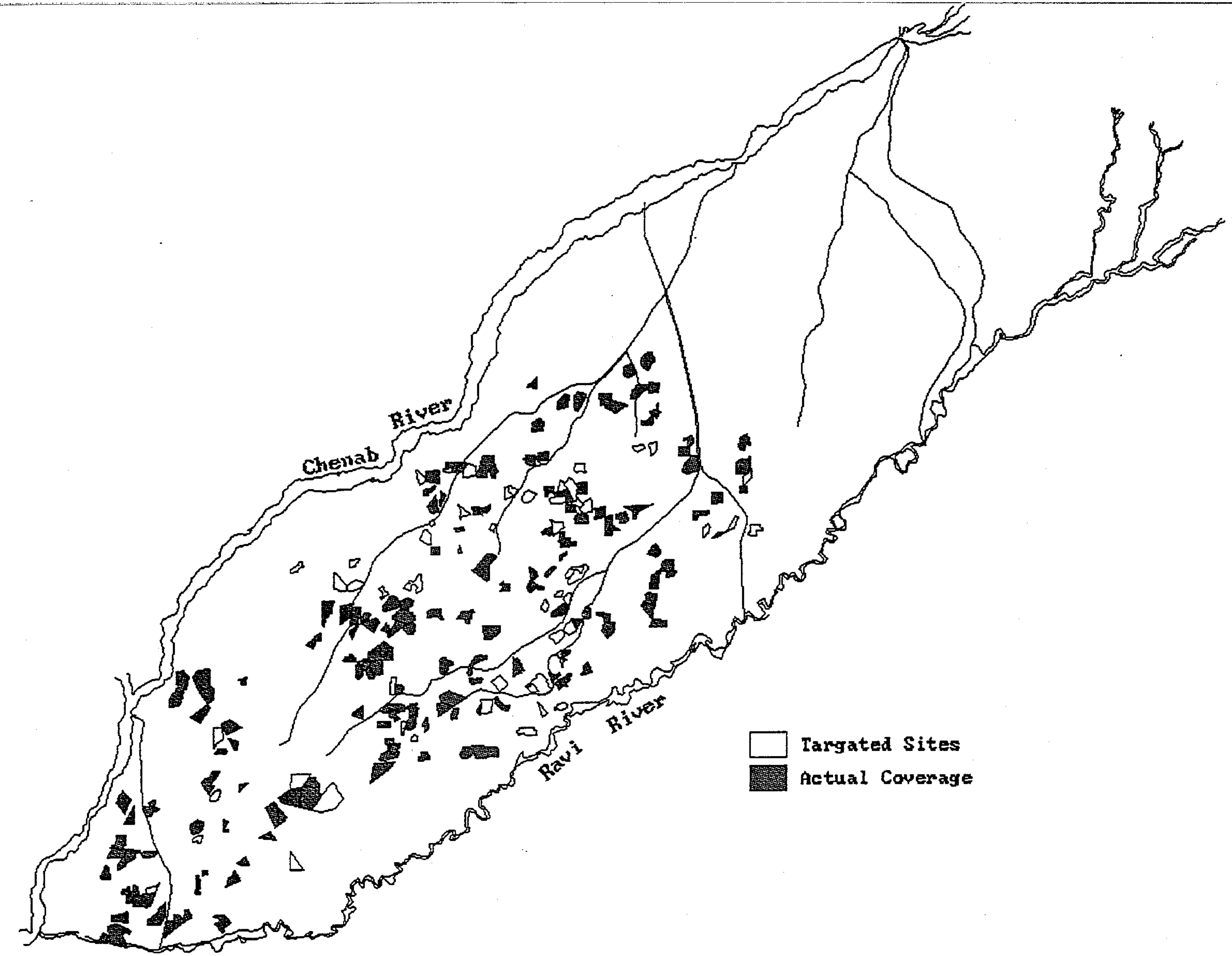

Figure 9(b) Target versus Actual Coverage of the IIMI Sample Sites for the Collection of Physical Data, Rechna Doab, Pakistan.

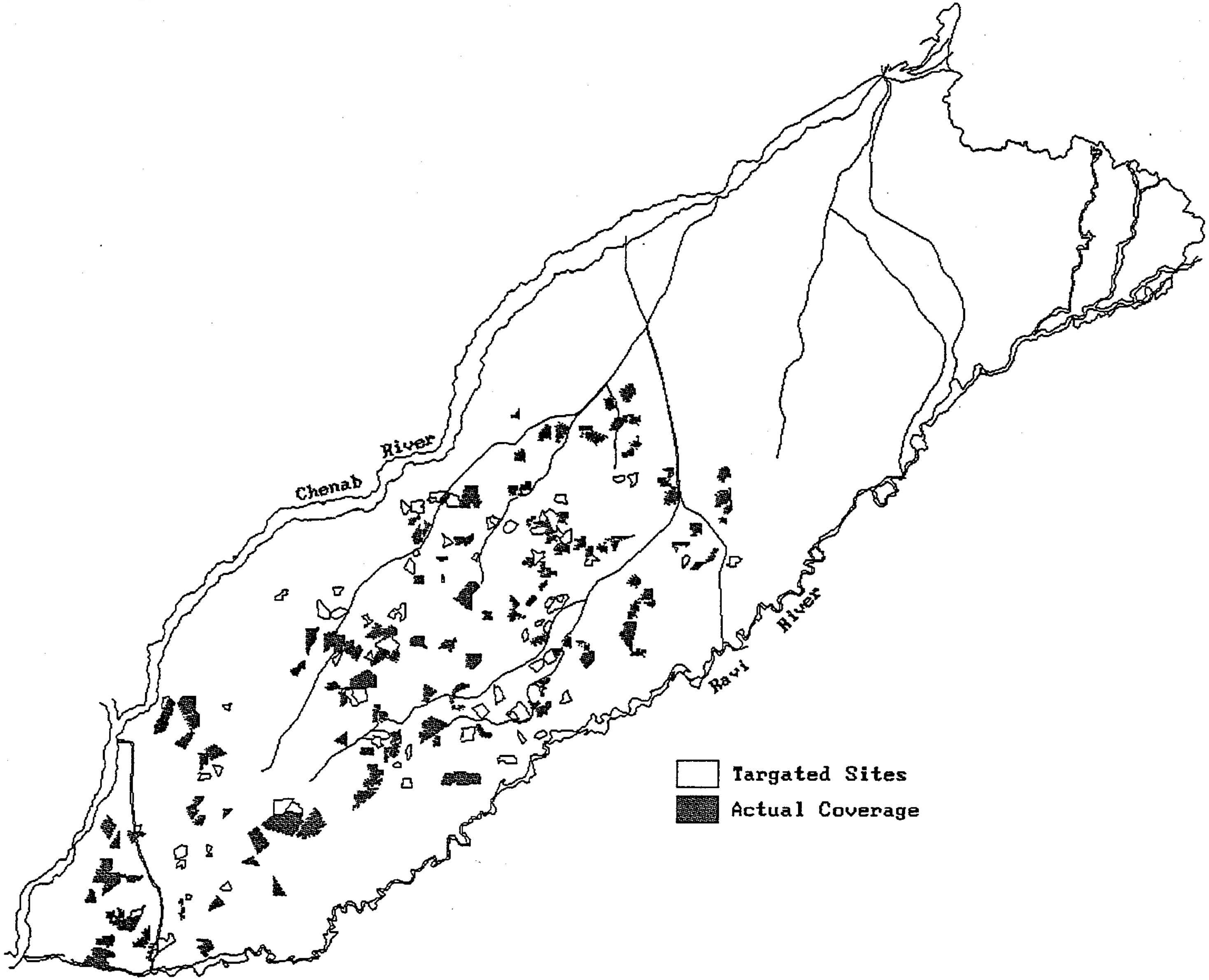

Figure 9(c) Target versus Actual Coverage of the IIMI Sample Sites for the Collection of Farm Level Data, Rechna Doab, Pakistan.

Table 1. Difference Between Targeted and Surveyed Sites in the IIMI's Sample Surveys (1995) of the Rechna Doab, Pakistan.

Spatial Model	Model Code	Target sites		Surveyed sites			
		# of polygons	Area (ha)	Physical observations		Farmers interviews	
				# of polygons	Area (ha)	# of polygons	Area (ha)
Comparison of Surface vs. Profile Salinity/Sodicity	1	32	30927.94	23	21833.02	24	23842.17
Temporal Comparison of Pumped Groundwater Quality	2	19	14549.25	17	13640.53	17	13640.53
Comparison of Groundwater Quality to Seasonal Changes in Depth to Watertable	3	18	13103.13	17	12486.99	18	13103.13
Comparison of Seasonal Changes in Depth to Water	4	30	28443.18	21	20408.1	19	19593.65
Seasonal Changes In Subsurface	5	47	31851.44	31	22504.64	25	17236.93
Association of Subsurface Drainage Impediments	8	30	23618.48	21	17433.32	21	19055.32
Comparison of Surface and Subsurface Drainage	9	43	33147.22	31	25605.33	21	21164.75

Table 2. Groundwater Salinity Information of Public and Private Tubewells within Rechna Doab, Pakistan.

Public Tubewells Data (from SMO)	
SCARP-I:	
Total number of tubewells (1960 - 1989)	= 2074
No. of tubewells (1960, 1965, & 1985)[1]	= 500 (EC[2]: 1000 - 4000 μ S/cm[3])
No. of tubewells (1960, 1965, & 1985)[4]	= 53 (EC: 1500 - 4000 μ S/cm)
SCARP-IV:	
Total number of tubewells (1975 - 1989)	= 952 (EC: 650 - 1600 μ S/cm)
Satiana Pilot Project:	
Total number of tubewells	= 71
No. of tubewells (1981 & 1986)	= 40 (EC: 1600 - 6190 μ S/cm)
No. of tubewells (1981 & 1986)[4]	= 18 (EC: 1600 - 6190 μ S/cm)
Shorkot-Kamalia Pilot Project	= 101
No. of tubewells (1975)	= 11 (EC: 350-1070 μ S/cm)
Private Tubewells Data (from IIMI)	
Lagar Distributary Command:	
Total number of tubewells (1988)	= 202 (EC: 480 - 3000 μ S/cm)
No. of tubewells	= 72 (EC: 1500 - 3000 μ S/cm)
Mananwala Distributary Command:	
Total number of tubewells (1990)	= 168 (EC: 350 - 3000 μ S/cm)
No. of tubewells	= 75 (EC: 1500 - 3000 μ S/cm)
Pir Mahal Distributary Command:	
Total no. of tubewells (1992)	= 37 (EC: 270 - 1500 μ S/cm)
Total no. of tubewells in Junejwala Minor (1992)	= 68 (EC: 760 - 3000 μ S/cm)
No. of tubewells in Junejwala Minor	= 21 (EC: 1500 - 3000 μ S/cm)

1 = For these tubewells data are available consistently for years 1960, 1965, & 1985.
2 = Electrical Conductivity.
3 = MicroSiemens per centimeter.
4 = For these tubewells data showed deterioration in tubewell water quality with time.

The groundwater quality profile for ***SCARP-IV*** (1975-1989) indicates the EC ranging from 650-1600 μS/cm across the 952 tubewells monitored for this purpose. Despite a gradual deterioration in quality, the pumpage is still within useable limits, largely because of its proximity to the Ravi river.

For the ***Satiana Pilot Project***, groundwater quality information were available for 40 tubewells out of a total of 71 tubewells installed under this project. The salinity of pumped water of these tubewells varied from 1600 to 6200 μS/cm. Out of 40 tubewells, 18 show a deteriorating trend during the period of 1981-1986. For the ***Shorkot-Kamalia Pilot Project***, data were available only for 1975, and limited to just 11 tubewells (from amongst 101 locations). The range of EC values is between 350 to 1100 μS/cm.

For ***private*** tubewells, data on groundwater quality sampling were available for Lagar (1988), Mananwala (1990) and Pir Mahal (1992) distributary commands in the LCC system. According to the WAPDA groundwater quality criteria for irrigation use (Table 3), about 72 tubewells in Lagar Distributary Command, 75 in Mananwala Distributary Command and more than 21 in Pir Mahal Distributary Command pump groundwater of marginal quality that requires mixing with canal water to be used for irrigation purposes. On comparison with the Directorate of Land Reclamation (DLR) standards, a majority of these wells pump marginal to hazardous quality groundwater unsuitable for irrigation purposes.

IIMI's own survey of the pumped groundwater quality in 1995 across sample areas, predominantly within the LCC system, encompassed information on tubewell location, type of tubewell, and groundwater salinity of pumped water (Table 4). In this reconnaissance level exercise, only the operational wells were targeted in the field. Figure 10 shows the location of these numerous sampling sites in the context of prevailing WAPDA standards for discrimination of water quality with respect to EC.

Antecedent to this survey, about 13 previously known well sites were visited in the Command of Lagar Distributary for comparison with information on pumped water quality sampled in 1988. Table 5 presents the change in the EC values in what could be termed as a sensitizing exercise to assess the possible trends in the quality of pumpage.

2) Three-Dimensional Visualization

Figure 1 had shown one of the *Overlay Operations* inputs to the Groundwater Salinity Modeling Component through a three-dimensional visualization process. This aspect of information portrayal is aimed at capturing the depth related aspects of variations in the aquifer water quality towards a critical assessment of concentration zones across the lower two-thirds of the Rechna Doab. Inputs for this purpose have come from the earliest Water and Soils Investigation Division (WASID) test hole-based investigations and from the Project Planning Organization's special test holes and wells. Additionally, the pumped water

Table 3. Groundwater Quality Classification Criteria for Irrigation Use.

Water and Power Development Authority (WAPDA) Criteria:			
Useable	EC	= 0-1500	micromhos/cm
	RSC	= 0-2.5	meq/l
	SAR	= 0-10	
Marginal	EC	= 1500-3000	micromhos/cm
	RSC	= 2.5-5	meq/l
	SAR	= 10-18	
Hazardous	EC	= more than 3000	micromhos/cm
	RSC	= more than 5	meq/l
	SAR	= more than 18	
Directorate of Land Reclamation (DLR) Criteria:			
Useable	EC	= less than 1000	micromhos/cm
	RSC	= less than 1.25	meq/l
	SAR	= less than 10	
Marginal	EC	= 1000-1500	micromhos/cm
	RSC	= 1.25-2.5	meq/l
	SAR	= 10-15	
Hazardous	EC	= more than 1500	micromhos/cm
	RSC	= more than 2.5	meq/l
	SAR	= more than 15	

Table 4. Groundwater Quality Sampling by IIMI in 1995 within the Irrigation Subdivisions of the Rechna Doab, Pakistan.

S.No.	Tubewell location	Type of tubewell	EC (μS/cm)
1	Aminpur subdivision	Private	2590
2	"	"	380
3	"	"	1600
4	Buchiana subdivision	"	521
5	"	"	1420
6	Chuharkana subdivision	"	660
7	"	"	540
8	"	"	1200
9	"	"	1300
10	"	"	860
11	"	Public	900
12	"	Private	2100
13	"	"	2200
14	"	"	1250
15	"	"	1790
16	"	"	1750
17	"	"	860
18	Dhaular subdivision	"	820
19	"	"	1000
20	"	"	740
21	"	"	1150
22	"	"	1495
23	"	"	2400
24	"	"	1030
25	"	"	1200
26	"	"	2600
27	"	"	2400
28	"	"	2200
29	"	"	1200

Table 4. Continued

S.no.	Tubewell location	Type of tubewell	EC (μ S/cm)
30	"	Private	1560
31	"	"	480
32	"	"	1200
33	"	"	4030
34	Haveli	Public	541
35	"	Private	1450
36	"	"	2190
37	"	"	470
38	"	"	6600
39	"	"	510
40	"	"	320
41	"	"	360
42	"	"	440
43	"	"	900
44	"	"	890
45	"	"	690
46	Kanya subdivision	"	1700
47	Kot Khuda Yar subdivision	"	860
48	"	"	1290
49	"	"	900
50	"	"	2190
51	"	"	440
52	"	"	1200
53	"	"	1120
54	"	"	630
55	"	"	730
56	"	"	1350
57	"	"	990

Table 4. Continued

S.no.	Tubewell location	Type of tubewell	EC (μ S/cm)
58	Mohlan subdivision	Private	27020
59	"	"	2990
60	"	"	3010
61	"	"	2890
62	"	"	1600
63	"	"	1305
64	"	"	2480
65	"	"	4050
66	"	"	1500
67	"	"	970
68	"	"	1000
69	Paccadala subdivision	"	1410
70	"	"	1000
71	"	"	1500
72	Sagar subdivision	"	940
73	"	"	920
74	"	"	1090
75	"	"	1200
76	"	"	1300
77	Sangla subdivision	"	2000
78	"	"	2100
79	"	Public	1800
80	"	Private	1900
81	Tandlianwala subdivision	"	3200
82	"	"	1550
83	"	"	1400
84	"	"	1890
85	"	"	1300

Table 4. Completed

S.no.	Tubewell location	Type of tubewell	EvC (μ S/cm)
86	Tandlianwala subdivision	Private	1690
87	"	"	2400
88	"	"	2680
89	Uqbana subdivision	"	4000
90	Veryam subdivision	"	1840
91	"	"	1400
92	"	"	1500
93	"	"	2200
94	"	"	1800
95	"	"	1150
96	"	"	1120
97	"	"	1280
98	"	"	1240
99	"	"	480
100	"	"	1800
101	"	"	1680
102	"	"	1240

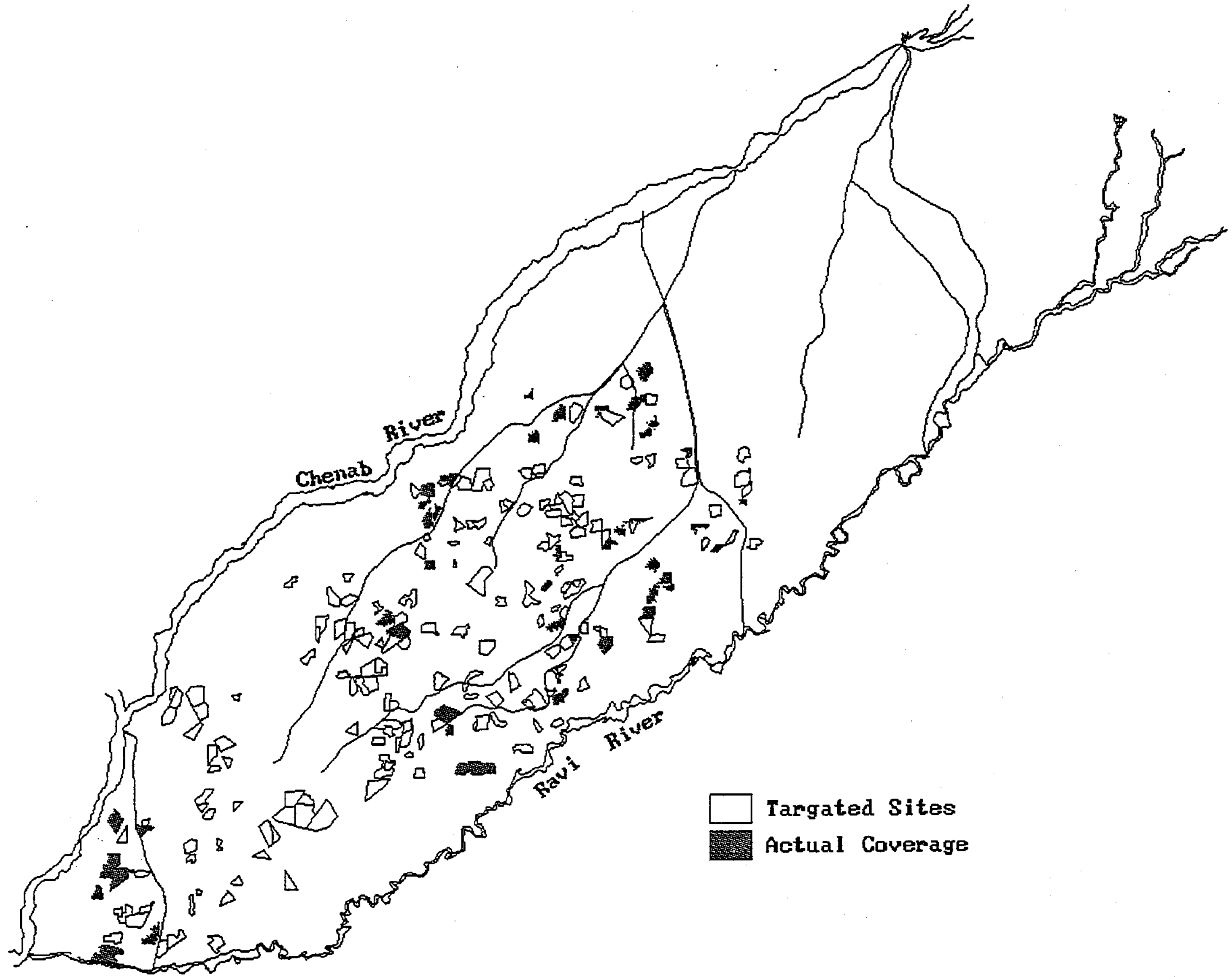

Figure 10 Distribution of IIMI Groundwater Quality Sampling Sites in the Rechna Doab, Pakistan.

Table 5. **Temporal Comparison of Pumped Groundwater Quality of Private Tubewells in Lagar Distributary Command, Lower Chenab Canal System, Rechna Doab, Pakistan.**

S.no.	Tubewell location/ owner's name	EC (μS/cm)	
		1988	1995
1	10R Imdad	-	950
2	FAO 14	1000	780
3	JIL Abdul Rehman	1240	1190
4	2R Anwar	1160	1260
5	2R Faqir	800	690
6	10R M. Hussain Shah	1050	795
7	10R Hanif Qurreshi	1500	1310
8	10R Sardar	1270	1300
9	J3L Siddiq Dogar	1200	1190
10	J3L Ashraf	1460	1410
11	J2L Santa Cheema	1000	810
12	J2L M. Mansha	1040	820
13	21TL F.Fakhar	-	1910

quality of the SCARP-I tubewells in Harse Shaikh, Shahkot, Beranwala, Sangla Hill, Jaranwala, and Zafarwal schemes (see Figure 34, Vol. II) has also been included in the selections cumulatively shown under Figure 11.

The three-dimensional picture of the aquifer (interpolated to a depth of 330 meters) is sliced at regular intervals to constitute the input for the groundwater salinity modeling, subsampled at the subdivision level. The predictions to the year 2010 constitute part of the resource optimization strategy at this level. Multiple subdivision-level predictions are combined to form the information essential for resource optimization at the canal command level.

Figure 12 provides some examples of the three-dimensional partitioning of space wherein EC and DS values have been used to expose the aquifer water quality above the bedrock. The flexibility of the software used for this visualization is such that the phenomenon could be restricted to, and constructed anew, for any part of the aquifer for detailed study.

C. Salinity Measurements

For each of the above campaigns, there were three independent survey teams of which two were assigned towards the collection of physical data while the remaining group concentrated on farm level interviews. For *in situ* salinity measurements, an EM 38 device was used that translates the conductance of electromagnetic signals across the soil between two fixed length dipoles into digital readings for both horizontal and vertical readouts on the *apparent* levels of salinity. The horizontal readings (EM_h) correspond to the apparent salinity in the top few centimeters of the soil surface, while the vertical readings (EM_v) indicate the aggregate status to a depth of 1.5 meters (optimum at 0.75 meters). The paired observations on salinity, collected somewhat recessed from the four corners of a field and its center, were coincident with the land use and the soil texture (aggregate sample to a depth of 30 cms, observed through the touch and feel method).

The apparent electrical conductivity (EC_a) of a soil of given texture increases as the soluble salt content and the soil moisture contents increase. Heavy textured soils have higher EC_a values than light textured soils with the same soil water EC. The texture effect is partly a moisture content effect (i.e. heavy soils hold more water and salt than light soils and have more pathways for current flow) and partly due to clay content itself. Clay particles are negatively charged and therefore can conduct a current across their surface whilst many soil minerals (e.g. $CaCO_3$, $CaSO_4$) have no surface charge and, therefore, act as insulators reducing current flow.

The conversion of the paired EM 38 measurements of apparent electrical conductivity to a single saturation extract value was made using the calibration relationships provided for soils of different saturation percentage at *field capacity* (Slavich, 1990). The EC_e calculation to a depth of 0.6m is per equation;

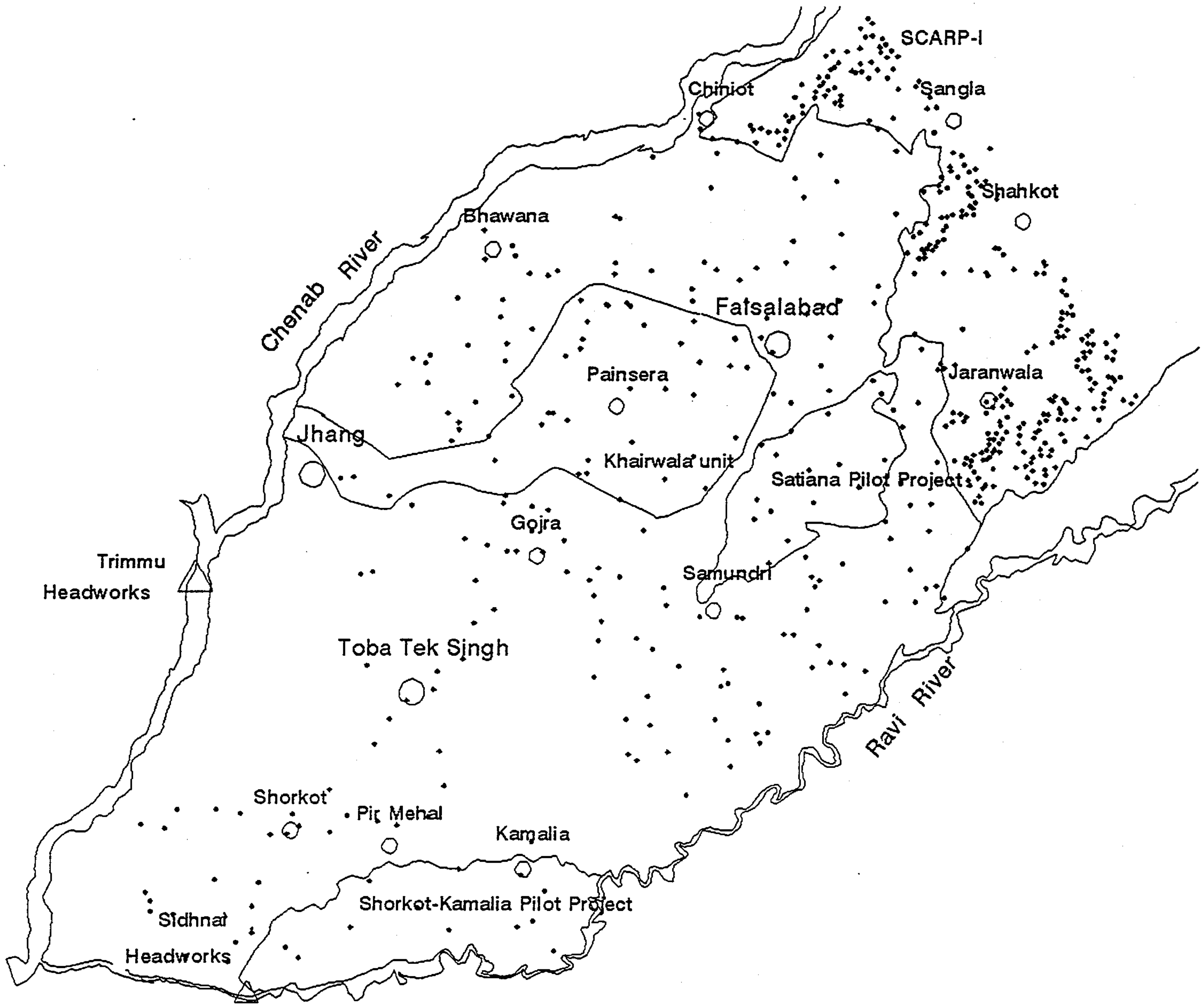

Figure 11 Location of Sampling Sites for the Three-Dimensional Visualization of Aquifer Water Quality in the Rechna Doab, Pakistan.

$$EC_e = b_vEM_v + b_hEM_h + C$$

where b_v and b_h are constant terms that vary with the saturation percentage specific to a soil texture and C is the intercept term that increases with the saturation percentage. Comparative values of b_h, b_v, and C are provided in Table 6 for reference towards either of two possibilities, i.e. $EM_v > EM_h$, and vice versa. The first of the two possibilities indicates increasing salt concentration with depth of soil, whereas the latter indicates higher levels of salinity near the surface.

A total of 15,235 paired observations of salinity were made across 161 sample polygons for a cumulative coverage of 135,000 ha, or roughly 77% of the targeted coverage. In comparison to the 2.975 Mha gross area of the Rechna Doab, this is approximately 4.54 %. Appendix-A provides a breakup of all sample area salinity measurements into four principal classifications of non-saline (S1), slightly saline (S2), moderately saline (S3), and strongly saline (S4) soils. In aggregate terms, the class-wise constitution of these measurements is as follows:

Non-saline	13261
Slightly Saline	1001
Moderately Saline	576
Strongly Saline	397

The significance of these observations, in comparison to the past public sector observations, is explained in the next section.

II. PROCESSING OF EM38 MEASUREMENTS

A. Soil Salinity for the Aggregate Sample Domain

IIMI's reconnaissance-level assessment of soil salinity within sample sites shows over 87% of the cultivated regime to be salt free (Figure 13). This is based on direct EM 38 observations on approx. 1250 ha that were selected from traverse-led visual observation across 7500 ha. This non-saline incidence constitutes a 3% improvement over the nationally reported figures by WAPDA in 1979 (see Table 6(a), Volume Two). There has, however, been no significant change in the areal distribution of salinity across all classes. Probably much of this increase in the non-saline coverage is because of the extensive augmentation of the groundwater supplies for irrigation whereby higher consumptive use crops have positively impacted on land reclamation. It may be mentioned that IIMI's observations on salinity are limited to the top root zone (30 cms soil depth) and do not reflect the conditions in the stratum below. Hence, comparisons elsewhere, like the over 9000 profile sampling pits used by WAPDA for the MPR Survey in 1976-79 period, must be limited accordingly.

Table 6. Values of Parameters Specific to the Soil Saturation Percentage for Conversion of EC_a Values to EC_e

$$EC_e = B_v * EM_v + B_h * EM_h + C$$

NO.	$EM_v > EM_h$				$EM_h > EM_v$		
	Soil Saturation percentage	B_v	B_h	C	B_v	B_h	C
1	15	-5.87	15.66	-0.40	-0.42	10.34	-0.40
2	20	-5.45	14.55	-0.60	-0.39	9.65	-0.60
3	25	-5.04	13.45	-0.80	-0.36	8.96	-0.80
4	30	-4.80	12.90	-0.90	-0.35	8.60	-0.90
5	35	-4.21	11.24	-1.20	-0.30	7.56	-1.20
6	40	-3.60	9.50	-1.50	-0.26	6.20	-1.50
7	45	-3.38	9.03	-1.60	-0.25	6.17	-1.60
8	50	-2.80	7.50	-1.90	-0.20	5.80	-1.90
9	55	-2.55	6.81	-2.00	-0.19	4.79	-2.00
10	60	-2.30	6.20	-2.10	-0.17	4.10	-2.10
11	65	-1.72	4.60	-2.40	-0.13	3.40	-2.40

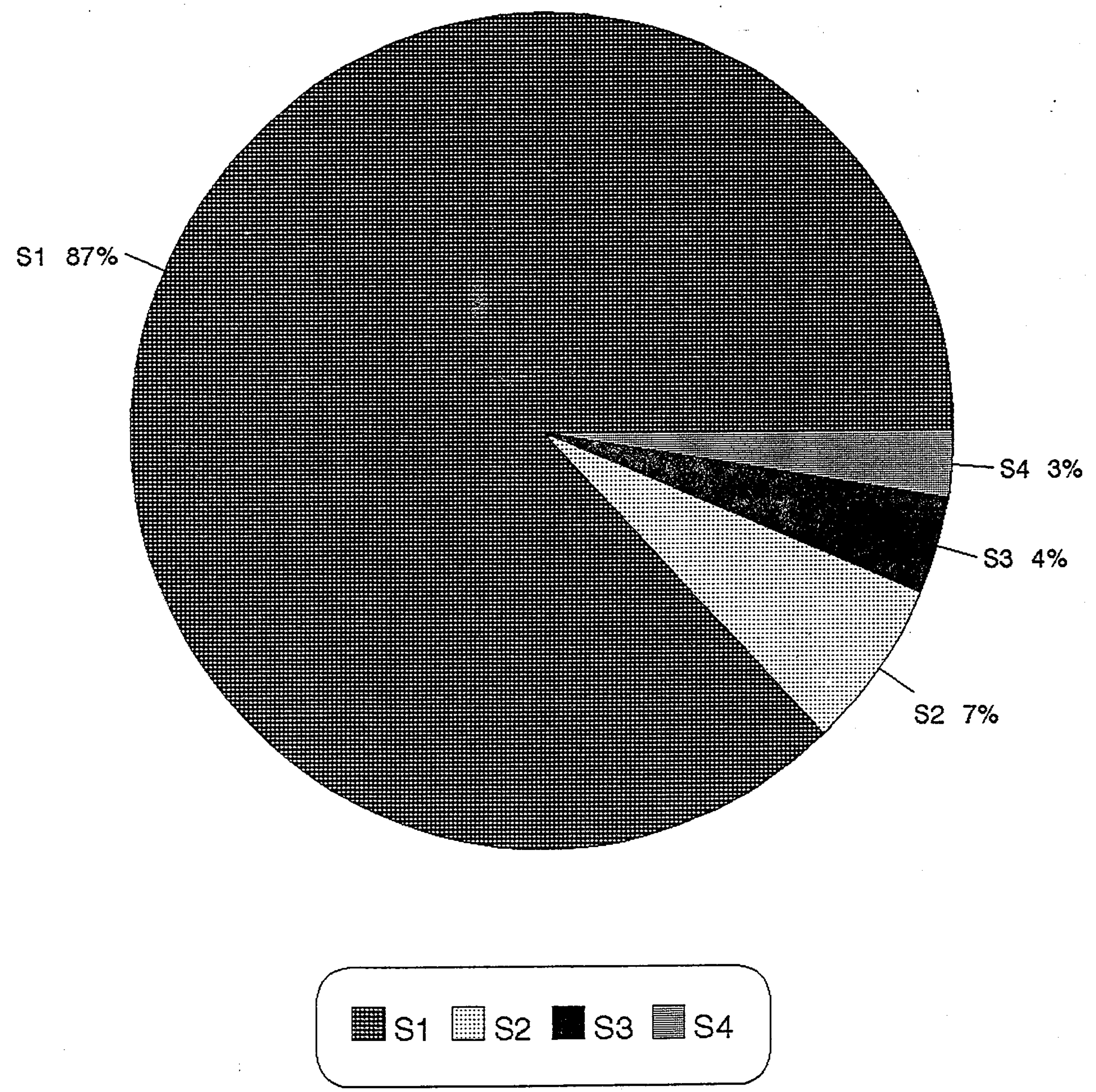

Figure 13 Class Differentiation of Salinity from IIMI's Sample Field Measurements in the Rechna Doab, Pakistan.

Assuming the 3% improvement in non-saline land is proportionately distributed in space, the interrelationships amongst WAPDA's soil series data (textural definition to a depth of 185 cms, see Figure 8 in Volume Two) and the spatial model developed for the incidence of both surface and profile salinity, as reported by WAPDA in 1979 (Figure 2 above), may be shown to represent the threat of secondary salinization in reference to the coarseness of the soils. Figure 14 shows the salinity constitutions for the five major soil series described under Section VI. B of Volume Two. If legend items corresponding to sodic or saline-sodic status are combined together for each of the series, then the incremental trend in soil degradation is clearly evident with increasing fineness in the texture. For the Nokhar series, representing clayey fractions, the overall sodicity-related percentage is somewhat less due to the suitability of these soils for high delta crops and also because these soils are mostly limited to the fresh groundwater regime in the upper reaches of the Rechna Doab.

The field-specific determination of the soil texture, as an essential input towards conversion of apparent salinity values to the saturation extract values, has yielded valuable insights into the dominant pattern of a soil's susceptibility to salinization. For example, the salinity-texture correspondence in Figure 15 shows that, aside from the differences in magnitude of the observations, the proportion of the silt loam and clay categories increases towards higher salinity classifications. This is characteristic of the Khurrianwala and Jhakkar soil series (and their respective undifferentiated groups) and the spatially limited clayey phases of the Eminabad, Firoz, Dungi and Gajiana soils. Sandy loam and Loam soils continue to be the most dominant combination across all classes of salinity, the mutual gap amongst them reducing in favor of the coarser sandy loam towards higher levels of salinity. Overall, the salinity-texture transitions are subtle in proportion but may be broadly partitioned into S1 & S2 combinations versus the higher salinity classes of S3 & S4.

The polygon delimitations, realized as a result of the spatial modeling, had to be homogeneous extents in order to preserve the integrity of the sample domain. Accordingly, the large areal extent of these delimitations (8-12 km^2) was unlikely to be covered from the traverse-based surveys intended for salinity assessment. While the preceding paragraph has dwelled on the spatial concordance between measurements of salinity and the soil texture, a similar assessment is also facilitated given WAPDA's 1976-79 surface salinity survey coverage and the surface texture map prepared since the WASID surveys of the early sixties. In the context of the <u>IIMI sample sites</u>, the *proportionate* interaction of the public sector data on salinity and texture reveals deviations from the situation in Figure 15. Figure 16 shows these deviations to be predominantly fine sandy loams across all salinity classes; this contrasts with the loams observed by IIMI in the field. The influence (and the incidence) of finer soils beyond loam is negligible, which also conflicts with IIMI's observations made with the assistance of the SSoP staff. In general, except for the distribution of the sandy loam textures, there are little to none similarities in the texture-wise constitution of salinity, as asessed by IIMI and WAPDA, within the 135,000 ha of the IIMI sample domain.

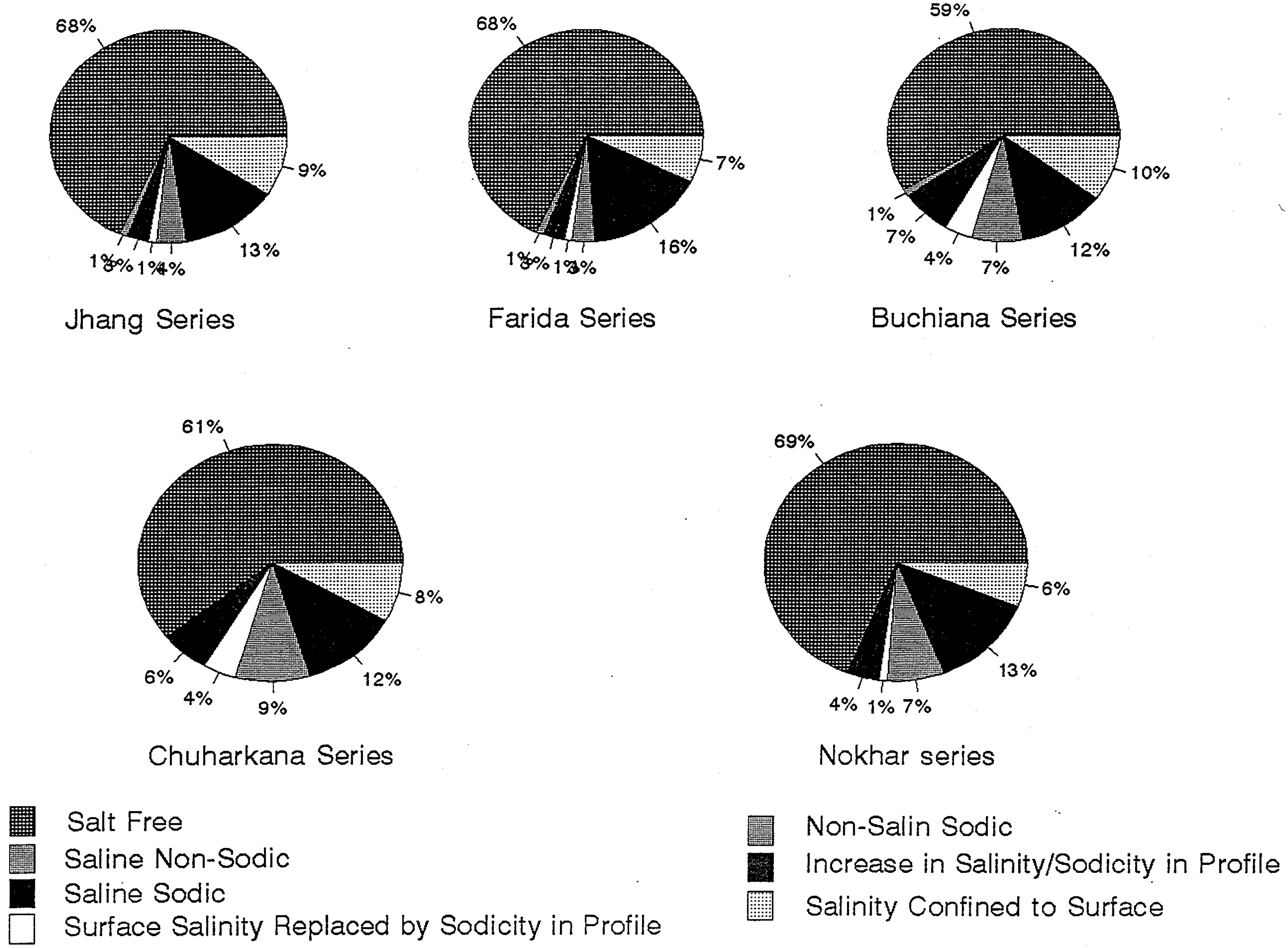

Figure 14 Constitution of Surface and Profile Salinity (WAPDA MPR Survey, 1976-79) within the Dominant Soil Series (as defined by WASID, 1960).

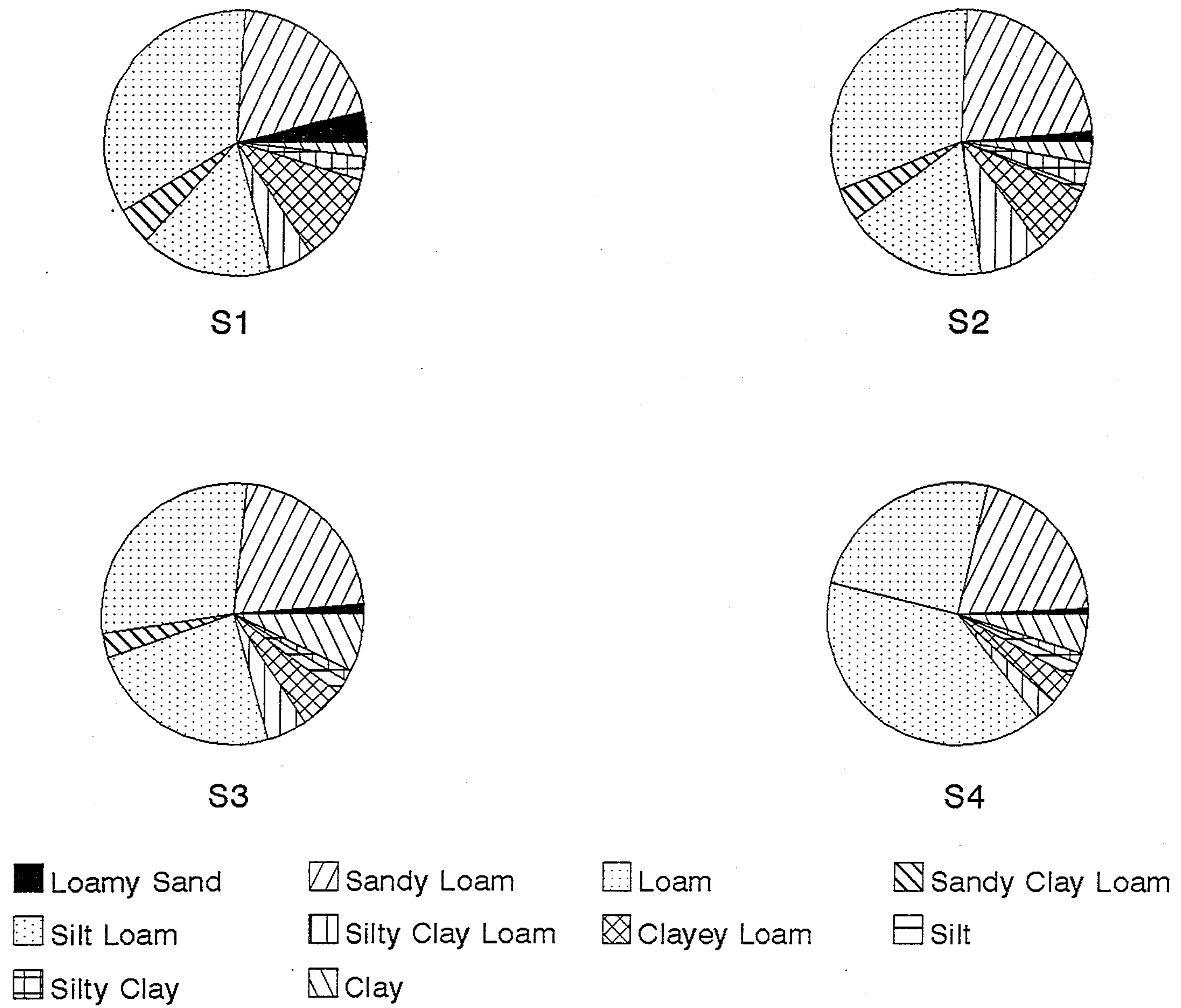

Figure 15 Root Zone Soil Textural Differentiation of Salinity Classifications based on IIMI Sample Field Measurements, Rechna Doab, Pakistan.

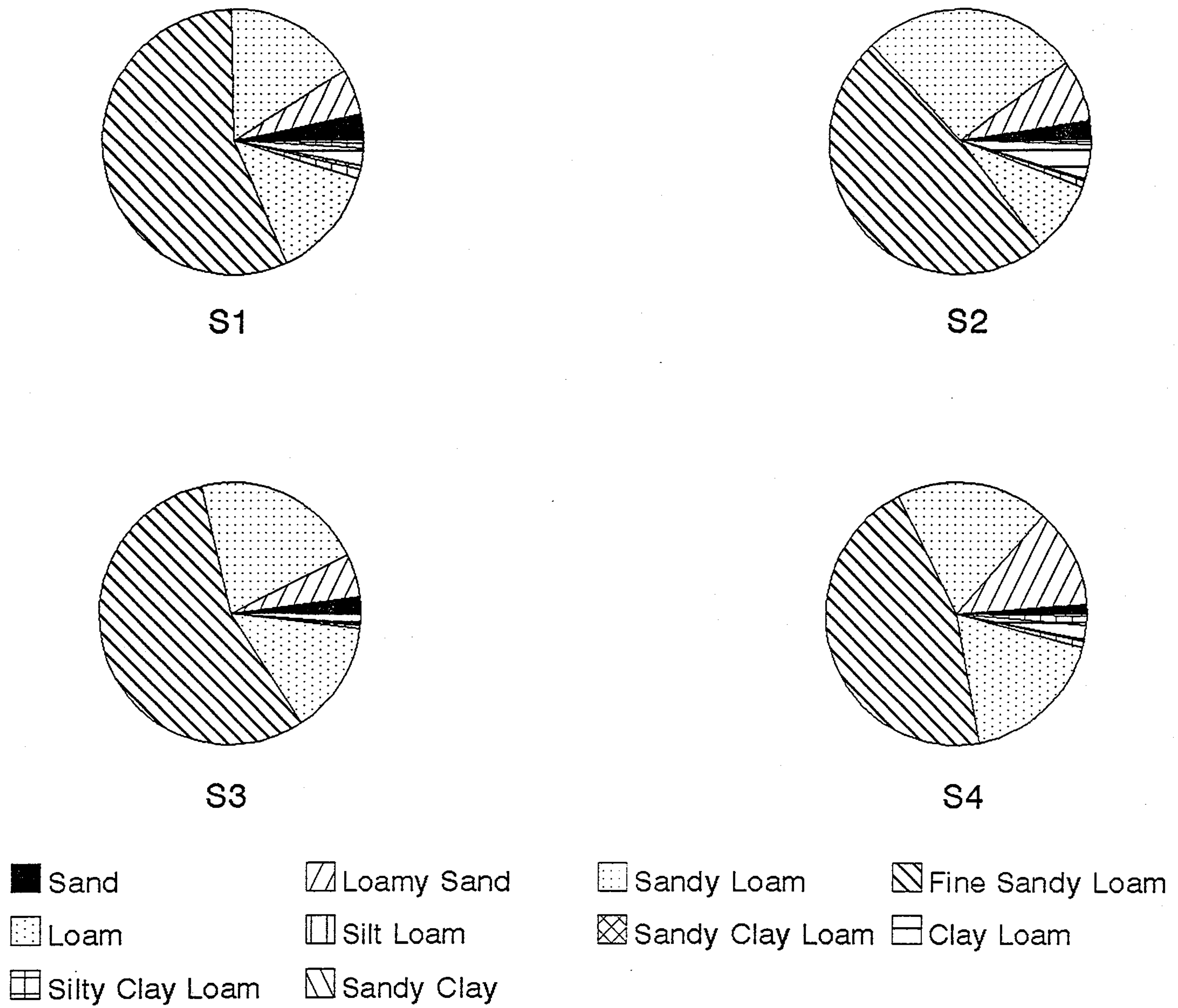

Figure 16 Proportions of Surface Soil Textures Corresponding to Surface Salinity Classification (WAPDA MPR Survey, 1976-79) within IIMI Sample Sites, Rechna Doab, Pakistan.

B. Aggregation at Subdivision Level

Corresponding to the flow of information in the Process Flow Chart of Figure 1, the proportionate distribution of nearly 15,000 EM 38 measurements in space has been subsampled at the irrigation subdivision level. This was a prerequisite to the contextual analysis of the data with the three tiered coincidence of salinity, soil texture, and land use information gathered from the field. Table 7 shows the number of polygons or sample sites falling within each subdivision, their cumulative area, and the incidence of non-saline land. This subsampling essentially prevails on two succeedingly detailed levels of analyses that are explained below.

1) Soil Salinity in Comparison to Soil Texture

Table 6 provides values of the saturation percentage corresponding to increasingly fine textured soils that are needed for conversion of the apparent EC measurements to the saturation extract values. The EC_e so computed is sorted according to the salinity classification criteria adopted by WAPDA, wherein the four principal classes are non-saline (EC_e < 4 mmhos/cm), slightly saline (EC_e 4-8), moderately saline (EC_e 8-16), and strongly saline (EC_e > 16). Owing to the dependence of the computed value of EC_e on the soil texture, a further desegregation was performed on each of the salinity classes for this contextual differentiation. The results of this desegregation, achieved at the irrigation subdivision level, are provided in Appendix-B. Independent discussion on the significance of this information is provided in Volume Seven of this report.

2) Soil Salinity Differentiated for Texture and Crop Type

Appendix-B shows the variations in soil texture across class separtions of salinity. These variations are further explained in the context of land use information coincident with the apparent EC values measured in the field. For the major land use categories like ploughed/fallow land, and cultivations of fodder, sugarcane, rice, cotton, and vegetables, frequency separations for texture-salinity mixes were shown to indicate the predominant pattern of crop growth conditions at the subdivision level. In some cases, in contrast to non-saline land use, comparative figures on texture-salinity admixtures are also provided for the barren or salinized tracts. The graphical output of this exercise appears under Appendix-C and, similar to Appendix-B, its connotations are discussed in conjunction with other aspects of spatial information in Volume Seven.

Table 7. Distribution of IIMI Sample Survey (1995) of Soil Salinity Measurements Across the Irrigation Subdivisions of Lower Rechna Doab, Pakistan.

Sr. #	Subdivision	# of samples regimes	Area (ha)	# of salinity observations	Non-saline observations (%)
1	Aminpur	11	10945	834	85.809
2	Bhagat	12	8872	883	94.177
3	Butchiana	8	7550	620	77.770
4	Chuharkana	13	9882	1544	95.888
5	Dhular	11	9844	891	82.035
6	Haveli	12	13574	958	62.537
7	Kanya	9	7592	792	79.353
8	Kot Khuda Yar	11	7658	1325	93.334
9	Mohlan	15	11115	1470	94.121
10	Pacca Dala	16	12198	2078	90.472
11	Sagar	1	424	116	100.000
12	Sangla	4	3322	508	90.607
13	Sultanpur	3	3166	222	79.770
14	Tandlianwala	6	5550	556	84.440
15	Tarkhani	11	10741	1009	81.584
16	Uqbana	14	13153	1198	79.594
17	Veryam	13	8265	1050	84.105
18	Wer	1	954	87	90.805

III. PROCESSING OF THE AGROECONOMIC DATA

A. District Level Aggregates for Public Sector Archives

The public sector data used in this study are taken from the four Agricultural Census reports of Pakistan published in 1963, 1975, 1983, and 1994. One main advantage of these data sets is that they cover not only the pre-Green Revolution/Pre-SCARPS period (1960), and the initial Green Revolution/SCARPS period (1972 & 1980), but also the matured Green Revolution/SCARPS period (1990).

The public sector data sets pertaining to all of the administrative districts were integrated, for all census years, for areas comprising the Rechna Doab. This data set comprises 36 cases based on the multiplicative mix of nine farm categories[1] across four census years. All of the farms in each category, across all of the districts, were added to arrive at the total number of farms and area and other relevant variables for the entire Rechna Doab. The first level of integration involved using the nine farm categories' data for the three census periods, i.e. 1960-90. This produced a data set of 189 cases of time-series and cross-sectional observations (i.e., an average of nine farm categories for each of the census periods between 1960 and 1980 (nine farm categories x five districts x three census periods = 135, and another 54 cases from six districts listed in the 1990 census). This entire aggregation was intended to be revealing on the pre- and post-SCARPS differences in the land use intensity and cropping intensity native to the data set.

The data set was devoid of farm-level details as these are not encumbered in the census reports. Even if the farm level data were available, often the hypotheses with respect to the demand for labor, or for any other variable, are stated in terms of average group behavior. Small farms, on an average, are expected to employ more labor and larger farms are expected to employ less family labor and more hired labor; hence, the hypotheses are stated for average behavior pertaining to a particular farm-size group. In such cases, the best way to represent the relationship in the regression equation will be to define it in terms of averages for each group and use the averages in the estimation of the regression parameters (Rao and Miller, 1972). Since most of the hypotheses stated in the literature pertain to grouped behavior, rather than individual farm behavior, using the grouped data at the farm-size level would be preferable than using the individual farm-size data.

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1 The nine operational farm-size categories are:

1:	< 1.0 acre	4:	5.0 - 7.5 acres	7:	25.0 - 50.0 acres
2:	1.0 -2.5 acres	5:	7.5 -12.5 acres	8:	50.0 - 150.0 acres
3:	2.5 -5.0 acres	6:	12.5 -25.0 acres	9:	150.0 and above.

B. Net Benefits of Producing Major Crops in the Rechna Doab

The cost of producing wheat, cotton, rice, and sugarcane crops in each of the irrigation subdivisions were estimated to evaluate the net benefits accruing from different crops in different areas of the Rechna Doab. To calculate the cost of production of the major crops, all of the variable costs incurred (i.e. cost of land preparation, cost of seed bed preparation, cost of seed, irrigation cost, fertilizer cost, labor cost and other chemical and herbicide costs, excluding the land rent), were added together to calculate the total cost of production for each specific crop on each farm. To estimate the gross income, the total farm crop production for the specific crop is measured in value terms. Crop output is defined as the sum of the money value of the total specific crop produced on the farm during the survey year. The value of the by-product was also added to arrive at the gross income estimates. In order to calculate the net benefits per farm from each of the crops, the total variable costs for each specific crop were deducted from the gross revenue per farm for that specific crop.

C. Description of the Variables

Given the theoretical principles and availability of data, the variables used in the economic analysis are described below.

1) Total Farm Crop Production

Total farm crop production is measured in terms of value. Crop output will be defined as the sum of the money value of the total specific crop produced on the farm during the survey year. In this study, only the wheat, rice, sugarcane and cotton crops have been taken for detailed investigation. Farmers were asked to give their best estimates about the production of the major crops on their farms. The gross return of each crop per farm consisted of the value of the crop output. To measure the total farm crop output in value terms, the price per 40 kg of crop output, received by the farmers at the farm gate, was used.

2) Amount of Labor

The farm labor performs different routine activities in crop production management. The participation of the family's adult (male), women and children, as well as any hired labor contribution, has been systematically computed for cost accounting.

3) Irrigation Cost

Irrigation cost includes tubewell cost (either diesel or electric) and charges for canal water. The tubewell cost includes:

(i) the fixed cost, incurred at the time of tubewell installation;
(ii) the variable costs such as fuel, cost of engine lubrication and electricity charges of motor; and
(iii) the depreciation and interest on the irrigation structure (engine, electric motors, building, fittings, etc.).

The per hour operational cost of tubewells for each of the major crops is estimated by using the procedure adopted from Chaudhry et al. (1985). To estimate the irrigation cost for a specific crop, the tubewell's per-hour operational cost was multiplied by the number of hours the tubewell was used for irrigating each of the major crops at the farm. The charges for the canal water and the amount paid for water hired from other people for each of the major crops, if any, were included in this expenditure. Manual labor required for irrigation was not included.

4) Fertilizer Cost

Fertilizer has become the key component in crop production. The physical quantities of fertilizers containing nitrogen, phosphorus and potash for each of the major crops and zinc used for the rice crop were taken into account. The farmers were asked about the type and quantity of fertilizer used for each of the major crops. The total fertilizer applied to each of the major crops on the farm was estimated in terms of nutrient[2] kilograms and multiplied with their respective market price to quantify this variable in the value term.

5) Dry Land Preparation

In contrast to the cotton and sugarcane crops, the roots of rice and wheat plants are superficial in nature and require good preparation of the top soil. The number of dry ploughings and the number of plankings used for dry land preparation was used at each farm in the analysis.

6) Wet Land Preparation

Wet-land preparation for the rice crop is required to reduce the water percolation through

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[2]actual active ingredients.

the soil pores; it also reduces the germination of weeds and increases the soil's water retention capacity. This is achieved through ploughing of the puddled soils. The cost of the number of wet ploughings per farm were added to the cost of land preparation for the case of the rice crop.

7) Land

Expressed in acres, land includes only the area used by the respondents to cultivate the major crops.

8) Average Culturable Waste Area Per Farm (ACWA)

The culturable waste area is defined as "that uncultivated farm area which was fit for cultivation but was not cropped during the survey year, nor in the previous year; it also consists of saline/waterlogged patches of the land." In order to calculate the average culturable waste area per farm from the census reports, the total culturable waste area available in each farm category was divided by the total number of farms as follows:

$$ACWA = \frac{CWA}{FNO} \tag{1}$$

where:

ACWA = Average Culturable Waste Area per farm category;
CWA = Total Culturable Waste Area on each farm category; and
FNO = Total Number of Farms in each farm category.

9) Average Size of Land Holding Per Farm (AFAT)

The total farm size represents the ownership size of the farm and it includes culturable and unculturable areas contained in the farm. In order to compute the average size of land holding per farm from the census data, the total farm area in each farm category was divided by the total number of farms in each farm category as follows:

$$AFAT = \frac{FAT}{FNO} \tag{2}$$

Where:

AFAT = Average Farm Size in each farm category;
FAT = Total Farm Area on each farm category; and
FNO = As already defined.

10) Proportion of Irrigated to Total Farm Area (PIFAT)

In order to compute the proportion of irrigated to total cultivated area, the total *irrigated* cultivated area (CAI) in each farm category was divided by the total farm area (FAT) in each farm category.

$$PIFAT = \frac{CAI}{FAT} \qquad (3)$$

11) Gross Cropped Area (GCA)

This is defined as the aggregate area of crops raised on a farm during one year, including the area under fruit crops. It measures the intensive use of land.

12) Net Sown Area (NSA)

This is defined as the cultivated farm area which is actually cropped during one year, regardless of number of crops raised (includes the area under orchards for the same year).

13) Cropping Intensity (CI)

Cropping intensity indicates the extent to which the cultivated area is used for cropping. It is computed as follows:

$$CI = \frac{GCA}{NSA} \qquad (4)$$

Where:

CI = Cropping Intensity for each farm category;
GCA = Gross cropped area for each farm category (as already defined);
NSA = Net Sown Area for each farm category (as already defined).

14) Index of Inefficiency in Cropping Intensity (IICI)

Inefficiency in cropping intensity is an easy concept but difficult to operationalize. At the conceptual level, it is the difference between the number of times a cultivated area is cropped in a year and the number of times the area could have been potentially cropped, the latter being difficult to measure. This requires certain assumptions considered reasonable within the limitations of the available data. For measuring the inefficiency in cropping intensity, irrigated areas are assumed to a have potential for two crops and unirrigated areas have a potential for at least one crop. As such, the minimum number of times a unit area of land is croppable is equal to twice the net-irrigated area added to the unirrigated area. The index of inefficiency can be defined as:

$$\textbf{IICI} = \left(\frac{NSA + CAI - GCA}{NSA + CAI} \right) \tag{5}$$

Where:

NSA = Net Sown Area in each farm category;
CAI = Cultivated area irrigated in each farm category; and
GCA = Gross cropped area in each farm category.

There is a possibility for a negative number in certain cases because the unirrigated area may be cropped more than once and/or the irrigated areas may be cropped more than two times a year, thereby making GCA greater than the sum of NSA and CAI.

15) Index of Inefficiency in Total Use of Land (IITLU)

Inefficiency in total utilization of land rests on the concept of potential gross cropped area, which is defined as the sum of unused land, unirrigated cropped area and twice the net irrigated area. Subtracting GCA from this, a figure is obtained which indicates the gross area lost due to inefficiency in cropping intensity and non-utilization of certain cultivable land. Thus, the index for measuring the inefficiency in total utilization of land is calculated as follows:

$$IITLU = \left(\frac{NSA + CAI + CWA - GCA}{NSA + CAI + CWA} \right) \tag{6}$$

Where:

CWA = Culturable waste area in each farm category; and
GCA = Gross cropped area in each farm category.

IV. SPECIFICATION OF THE MODELS

A. Trends in Area and Production of Major Crops in the Rechna Doab

The following model is used for testing the relationship between production, yield per hectare, area under major crops and the effects of the Green Revolution/SCARPS on the production of the major crops. The econometric criteria, used to select the best fit, is described in the ensuing section. The dependent and independent variables, which are included in the model, are defined as:

$$Y_{it} = A_{i1} + A_{i2} + A_{i3} + b_{i1}W_{i1} + b_{i2}W_{i2} + b_{i3}W_{i3} + b_{i4}P_{i1} + b_{i5}P_{i2} + b_{i6}P_{i3} + e \quad (7)$$

Where:

Y_{it} = Production of i crop in year t;
b_{1-6} = Estimated Coefficients;
W_{i1} = Area of crop i, in year t;
W_{i2} = Post-1980s Dummy for area of crop i;
W_{i3} = Post-1990s Dummy for area under crop i;
P_{i1} = Per unit Production of crop i, in year t (kg/ha);
P_{i2} = Post 1980 dummy for the Per unit Production of crop i, (kg/ha);
P_{i3} = Post-1990s Dummy for the Per unit Production of crop i, (kg/ha);
A_{i1} = Constant term in year t for crop i;
A_{i2} = Intercept dummy for post-1980s period for crop i;
A_{i3} = Intercept dummy for post-1990s period for crop i; and
e = Random error term.

According to Equation 7, if the area and productivity of the crops increases with the passage of time, then the value of the beta coefficient (b_{is}) would be positive, which means that, with the passage of time, there was an increasing trend in area under cultivation and productivity. In order to find how this relationship has been affected by the SCARP schemes, the slope coefficients for area and productivity are summed to see whether this relationship is strengthened or weakened, depending upon the sum of ($b_1+b_2+b_3$) and sum of ($b_4+b_5+b_6$); whether it is greater than, or less than, b_1 and b_4, respectively. To see the spatial differences in the area under different crops and its productivity over time, the relationship in Equation 7 for all of the districts in the Rechna Doab for the major four crops were estimated. A negative relationship between the increase in area and productivity is anticipated during the post-1980s time period that may partly be attributed to salinity. Equation 7 was used to study the relationship between area and productivity of different crops, both before and after the SCARP schemes/Green Revolution. The variation in the constant term will indicate the temporal variation in the intercept due to the impact of the SCARPS/Green Revolution.

B. Trends in Cropping Intensity and Culturable Waste Area in the Rechna Doab

There are two aspects of the problem of underutilization of lands, viz. the proportion of cultivable area actually cultivated, and how intensively the cultivated area is cropped in a year. Assuming a multiplicative relationship and using the econometric criteria suggested by Fuss, Mcfadden and Mundlak (1978); Maddala (1988); and Ramanathan (1992), the following log-linear models were found to be the best fit for testing the relationship between farm size, proportion of irrigation and their effects after the Green Revolution/SCARPS on culturable waste areas and cropping intensity. The dependent and independent variables, which are included in the models, are defined in the following:

$$\ln CWA = \ln a + \ln D_{72} + \ln D_{80} + \ln D_{90} + B_1 \ln FAT + B_2 \ln FAT_{72} + B_3 \ln FAT_{80} + B_4 \ln FAT_{90} + e. \quad (8)$$

$$\ln CWA = \ln a + \ln D_{72} + \ln D_{80} + \ln D_{90} + B_1 \ln FAT + B_2 \ln FAT_{72} + B_3 \ln FAT_{80} + B_4 \ln FAT_{90} + B_5 \ln (CAI/FAT) + B_6 \ln (CAI/FAT)_{72} + B_7 \ln (CAI/FAT)_{80} + B_8 \ln (CAI/FAT)_{90} + e. \quad (9)$$

$$\ln CI = \ln a + \ln D_{72} + \ln D_{80} + \ln D_{90} + B_1 \ln FAT + B_2 \ln FAT_{72} + B_3 \ln FAT_{80} + B_4 \ln FAT_{90} + e \quad (10)$$

$$\ln CI = \ln a + \ln D_{72} + \ln D_{80} + \ln D_{90} + B_1 \ln FAT + B_2 \ln FAT_{72} + B_3 \ln FAT_{80} + B_4 \ln FAT_{90} + B_5 \ln (CAI/FAT) + B_6 \ln (CAI/FAT)_{72} + B_7 \ln (CAI/FAT)_{80} + B_8 \ln (CAI/FAT)_{90} + e. \quad (11)$$

Where:

CWA = Culturable Waste Area in each farm category;
CI = Cropping intensity in each farm category;
a = Constant term;
B_{1-8} = Estimated Coefficients;
D_{72-90} = Intercept Dummies for year 1972, 1980 and 1990, respectively;
FAT = Average size of holding per farm in each farm category;
FAT_{72} = 1972 dummy for average size of holding per farm on each farm category;
FAT_{80} = 1980 dummy for average size of holding per farm on each farm category;
FAT_{90} = 1990 dummy for average size of holding per farm on each farm category;
(CAI/FAT) = Proportion of irrigated area per farm on each farm category;
$(CAI/FAT)_{72}$ = 1972 dummy for proportion of irrigated area per farm on each farm category;
$(CAI/FAT)_{80}$ = 1980 dummy for proportion of irrigated area per farm on each farm category;
$(CAI/FAT)_{90}$ = 1990 dummy for proportion of irrigated area per farm on each farm category; and
e = Random error term.

From Equation 8, if the proportion of culturable wasteland increases with the size of holding, the value of the beta coefficient (B_1) would be greater than one which means that as the farm size increases, there would be an increase in the amount of culturable waste area (CWA) more than the proportion before the Green Revolution/SCARPS projects. In order to find how this relationship has been affected by the Green Revolution/SCARPS projects, the slope coefficients are summed together to see whether this relationship is strengthened or weakened, depending upon the sum of B_1+B_2, B_1+B_3, and B_1+B_4. A negative relationship between the increase in proportionate area under irrigation and the effect of irrigation on CWA was anticipated. The intercept term would capture the impact of the technological development, i.e. an inverse relationship vis a vis the CWA.

The equations (10) and (11) were estimated to study the relationship between cropping intensity (CI) and other variables, such as the farm size and level of irrigation, both before, during, and after the Green Revolution. The results are reported in the following section. A negative relationship between farm size and CI and a positive relationship between the proportionate area under irrigation and the CI was expected. It is also anticipated that the technological development led to an increase in the CI and a positive sign for the intercept term was expected. The intercept dummies provided the information about the temporal changes in the impact of technological development on the CWA and CI.

C. Econometric Production and Profit Function Modeling

Econometric modeling will provide the basis for estimating the efficiency of resource allocation in the Rechna Doab. The input response will be analyzed through the econometric estimation of the production function. The use of the production function will provide information needed in determining or specifying the use of resources and the pattern of outputs which maximize farm profits.

Economic theory rarely provides precise mathematical forms of econometric relationships. There is a wide variety of production functions to choose from in order to represent any economic function (e.g. linear, quadratic, translog and Cobb-Douglas forms). The widely accepted procedure is to choose the function that best explains the variation in the dependent variable. This study will analyze the relationship between crop productivity/ profitability as it relates to farm size, gross cropped area, cropping pattern, agronomic inputs (seed, fertilizer, manure, irrigation, etc), salinity, groundwater quality, and cultural practices along with spatial and temporal dummy variables.

1) Functional Form

For the present study, four functional forms (linear, quadratic, semi-log, and log linear forms, and most probably some other appropriate functional forms along with dummy variables) will be applied and the results of the selected equations will be discussed. The widely accepted procedure is to choose the function that best explains the variation in the dependent variable. Equations having the highest R^2 and least residual sum of squares are used to select the best fit (Madala, 1988; Koutsiyiannis, 1977). This study will analyze the resource use efficiency based on the variables included in the model as defined below:

$$Y_i = a + \sum_{j}^{7} B_j X_{ij} + e \tag{12}$$

i = 1, 2, ...n farm households.
j = 1, 2, ...n determinant variables.

Where:

Y_i = Total output from major crops per farm (40 kg bags);
X_1 = Distance of the farm from the outlet (blocks of 25 acres);
X_2 = Total cost of the land preparation per farm for major crops (Rs);
X_3 = Total number of canal irrigations for major crops per farm;
X_4 = Total number of tubewell irrigations for major crops per farm;
X_5 = Total cost of fertilizer applied to major crops per farm (Rs);
X_6 = Total cost of insecticide/herbicide applied to the major crops per farm;
X_7 = Total cost of farm yard manure applied to major crops per farm (Rs.);
a = Constant;
e = Random error term; and
$B_{i's}$ = Parameters to be estimated.

2) ECONOMETRIC CRITERIA

Regarding the econometric criteria in selecting the best equation among the wide variety of compatible functional forms, Fuss, Mcfadden and Mundlak (1978) have suggested the following:

Parsimony in Parameters: The functional form should contain only those parameters which are necessary for consistency with the maintained hypotheses. Excess of parameters escalate the problem of multicollinearity, brought about by market substitution, which causes prices, and hence the quantities, to be highly correlated.

Ease of Interpretation: Excessively complex or parameter-rich functional forms may contain implausible implications which are hidden from easy detection. Further complex transformations may make it laborious to compute and assess the economic effects of interest (for example, elasticity of substitution). Therefore, ceteris paribus, it is better to choose functional forms in which the parameters have an intrinsic and intuitive economic interpretation, and in which functional structure is clear.

Computational Ease: Historically, systematic multivariate empirical analysis has been confined to linear (parameters) for computational ease. While current computational technology makes direct estimation of non-linear forms feasible, linear parameter systems have a computation cost advantage, and have, in addition, the advantage of more fully developed statistical theory. The tradeoff between the computational requirements of a functional form and thoroughness of empirical analysis should be weighed carefully in the choice of a model.

Interpolative Robustness: Within the range of the observed data, the chosen functional form should be well behaved, displaying consistency with maintained hypotheses such as positive marginal products or convexity. If these properties must be checked numerically, then the form should admit convenient computational procedures for this purpose.

Extrapolative Robustness: The functional form should be compatible with maintained hypotheses outside the range of observed data. This is a particularly important criterion for forecasting applications.

3) Summary

In the light of the above five criteria, the most appropriate functional form will be selected. The analysis will examine geographic differentiation of the resource use based on the physical and qualitative variations of sampled farms. At the policy level, this study will attempt a rational assessment of the investment priorities in distribution of additional resources to different geographic locales within the Rechna Doab.

V. IIMI SAMPLE COVERAGE

A. Processing of Farm Level Data

The primary data were collected on a well designed pre-tested questionnaire (Appendix-D) from 443 farms located in 144 different sampling sites defined through GIS modeling (Figure 9(c)). The irrigation subdivision and district-wise distribution of these farms is given in Figure 17. The questionnaire information was subsequently organized into a matrix whereby for each farm appearing as a row, there was a column-wise separation of the variables that were suitably coded. For the 443 farming locales, the coded matrix, which served as the principal source for data analysis, appears in Appendix-E. The major results derived from this master matrix are discussed in Section II of Volume Six. Additionally, this master matrix has been resampled for the four major crops under Appendix-F that shows crop-specific investments and returns from amongst the sampled farms.

The questionnaire, besides including information on farm size, location, land use pattern, incidence of salinity, inputs, costs, etc., also gathered the perception of the farming community with respect to the privatization of the SCARP tubewells, the available groundwater quality, drainage conditions, and any significant changes in production during the last ten years and the reasons. To arrive at the total farm revenue, the farmers were also asked about the earnings received for the specific crop output and about the value of the by-products for the four major crops of wheat, cotton, rice, and sugarcane.

The Questionnaire also included subjective details on farmer tendencies for laboratory analysis of soil and water samples, information about purchase and sale of irrigation water, and rule-of-thumb practices about managing salinity/sodicity and the resultant expectations from the government.

B. The Aggregate Sample Domain

The interview data across 443 farms of the Rechna Doab affords many useful insights into the general pattern of resource utilization and the pattern of constraints affecting sustainable agriculture. Concommitantly, information on cropping pattern, adaptive land use, farm inputs, and returns has been systematically organized to reveal strategies about sustainable land use. Since no spatial sensitivity has been invoked for this initial insight into the farming regime, the inference represents the dominant pattern of the variants in the cultivation practices presently in vogue. Appendix-G contains the salient features of the aggregations performed on the interview data that provides convenient reference to comparisons available elsewhere. This graphic compendium contrasts with the questionnaire data, where the emphasis is on the spatially sensitive physical aspects of the system. As a supplement to the questionnaire information, the graphic stratification of information so achieved is invaluable to the identification of farm level inefficiencies and their extrapolation to the larger description of the physical regime (afforded by the spatial information system).

C. Generation of Spatial Themes

The connotations of the information in Appendix-G could be further strengthened in the context of a spatial discretization whereby, for each subdivision comprising the sample areas, an aggeragate picture of land use and constraints to irrigated agriculture could be identified. This is accomplished on the basis of the tabulations H1-H5 given in Appendix-H, where a highly revealing set of thematics is presented towards spatial variability of salient farm level aggregates. Figures H1 to H5 specifically cater to Table H1 wherein constraints (reported as numbers of farms) is contrasted with the prevailing land use and cropping pattern.

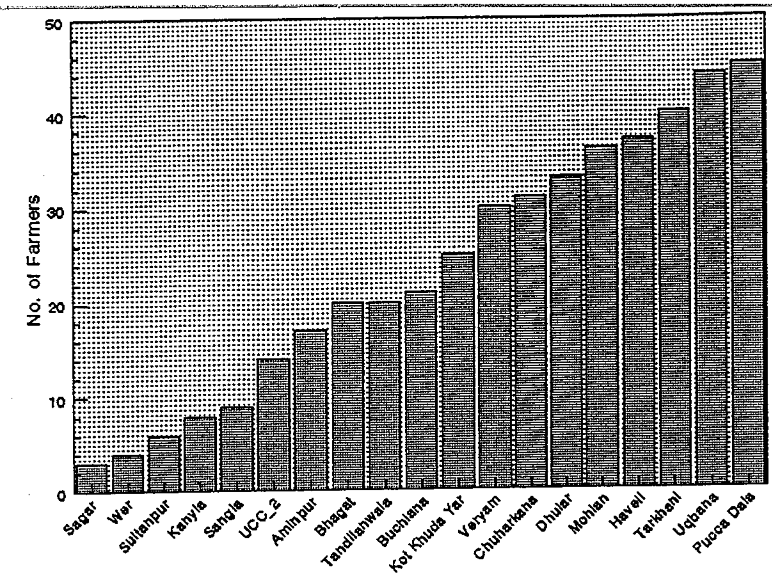


Figure 17(a) Distribution of IIMI Sample Farmers in the Irrigation Subdivisions of the Lower Rechna Doab, Pakistan.

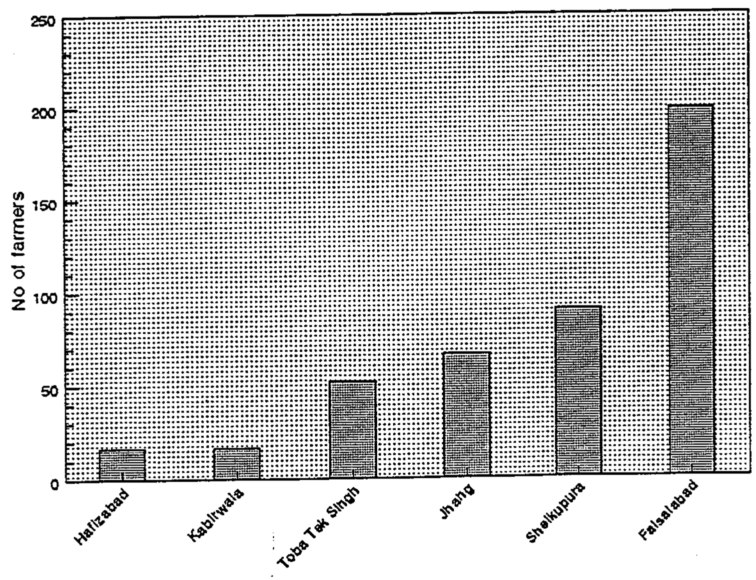


Figure 17(b) Distribution of IIMI Sample Farmers in the Civil Administrative Districts of Rechna Doab, Pakistan.

Onwards, for each of the remaining four tables in the Appendix, there are two sets of crop-specific themes pertaining to *macro level indicators of farm economics* and *cost distribution of gross farm inputs*. There are gaps in the information portrayal because of inadequate sample coverage of farm holdings specific to the crop; however, even with these remissions, it is not difficult to identify the significant trends across average levels of investment and returns from the cultivation of major crops.

D. Subsampling for Production Function Modeling

1) Appendage of Spatially Defined Constraints to Farm Level Stratifications

Figure 17(a) shows the non-uniform distribution of the farming locales across the irrigation subdivisions of the Rechna Doab that were visited during IIMI survey campaigns. This 'gap' in information was unavoidable in lieu of the immense size of the sampling regime and the limited amount of time set aside for this purpose. Since this deficiency in data collection would have been difficult to overcome towards statistically sound results, the generation of the yield-constraint relationships had to rely on the entire population of the farmers differentiated on the basis of the four major crop types of wheat, cotton, rice, and sugarcane. Appendix-E served as the primary input to the crop-wise differentiation of the database appearing under Appendix-F.

To ensure uniformity in the selection of constraints to production function modeling, only those farm characteristics were chosen from Appendix-E that could be universally applied across all the four crop databases. It was also important that these characteristics were adequately representative of the performance assessment strategy in vogue within the public sector. Hence, factors like farm size, cropping and land use intensity, and farmers' flexibility to avail alternate sources of irrigation were chosen over several other constraints like farm location, revenue, inputs, shareholding, cultivation practices, etc.

The general description of the farm level constraints specific to soil and salinity conditions (as appearing under Appendix-G) was inadequate for extrapolation purposes given the large heterogeneity in cultural and irrigation practices. Without identification of comparable soil and salinity conditions exclusive to the sampling domain, it would not be possible to 'fit' the results of the regression modeling to specific parts of the irrigation system within the Rechna Doab. The Process Flow Chart of Figure 1 shows this level of resource optimization to be achieved at the subdivision level.

For acquisition of soil and salinity information local to the sampling regime (defined in terms of the polygons), the maps produced from public sector investigations were relied upon. For each sample site or polygon, the information on soil salinity was obtained by its corresponding geographical match with the salinity/sodicity differentiation provided by the SSoP map given in Figure 11 of Volume Two. This differentiation, comprising scientific discrimination of the soils, was more reliable in comparison to the subjective reporting by the farmers.

Similarly, for soil textural differentiation, WAPDA data (Figures 8 & 9 of Volume Two) was used for polygons containing sample farmers. This data, representing the dominant surface and profile textural conditions, could be selectively aggregated to correspond with the porous and dense saline sodic conditions identified by the SSoP.

2) Crop-Specific Attributes for Constraints to Productivity

Based on the constraints defined above for the selective retrieval of information from the individual crop databases, an interactive two-dimensional matrix was prepared that comparedthe combinatorial mix of constraints (appearing as rows) to the individual searches planned for this purpose (in columns). Tables 8(a) through (d) provide details on these constraint-led selections that are tallied, for every succeeding search, at the bottom of the table as number of hits. These searches are not random but correspond to a plausible mix of physical and farming factors that are deemed to affect productivity. Since by themselves, these searches or simulations are neither all encompassing towards a definitive farming profile nor produce a statistically significant number of 'hits' for regression analysis, it is desirable that multiples of these simulations are grouped towards an aggregate farm description, hereonwards referred to as 'Cases.' A complete description of the constitution of individual Cases is provided under Appendix-I; however, for brevity's sake, the crop-specific Tables 9(a) through (d) provide the cumulative number of sample farmers falling under each Case, alongwith the salient features of the farm inputs, outputs, and incomes.

3) The Production Functions

Towards production function modeling, the crop-specific files prepared under Table 9 were regressed for yield as the dependent variable and all farm level inputs as the independent variables. This procedure, applied on a case-by-case basis, was further expanded to reveal the intra-Case farm size differentiations affecting inclusion of significant variables in the production function. The results of this analysis are presented in Tables 10(a) through (d), wherein only those Cases are included from Table 9 that had a significant number of farms to be viable confidence in reporting. Resultantly, there is a discrepancy in the number of Cases reported under Table 9 versus the actual number of Cases processed under Table 10.

The above functional forms will provide the primary reference for the estimation of resource productivity at the subdivision level, for which information on the physical environment of each of the subdivisions will be detailed in Volume Seven. Since no single functional form can be explanatory for all of the land use constraints within a subdivision, the emphasis would be on the selection of the appropriate forms that collectively underscore the gaps in efficient utilization of the resources within a given area. Hence, figures on cropping intensity, soil type, incidence of salinity, and prevailing groundwater quality, specific to a subdivision, will need to be considered in the context of the prevailing farm incomes and the potential derivatives rendered by the combination of production functions considered for this purpose.

Table 8(a) Matrix for the Selection of Constraints to the Wheat Crop, IIMI Sample Survey (1995), Rechna Doab, Pakistan.

	Constraints	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
Profile	Mod. Coarse																																			
	Medium				x	x	x	x						x	x	x	x	x	x	x	x			x	x	x	x	x	x	x	x					
	Mod. Fine	x	x	x							x	x	x										x									x	x			
	Fine	x	x	x							x	x	x										x									x	x			
Surface	Sand																																			
	Loamy Sand																																			
	Sandy Loam																							x	x	x	x	x	x	x	x					
	F. Sandy Loam																							x	x	x	x	x	x	x	x					
	Loam																						x										x			
	Silt Loam																						x										x			
	Silt																						x										x			
	Sandy Clay Loam								x	x	x							x	x	x	x											x				
	Clay Loam								x	x	x							x	x	x	x											x				
	Silty Clay Loam								x	x	x							x	x	x	x											x				
	Sandy Clay								x	x	x							x	x	x	x											x				
	Silty Clay								x	x	x							x	x	x	x											x				
	Clay								x	x	x							x	x	x	x											x				
GWQ	Good		x		x	x			x							x	x			x	x			x				x				x				
	Medium	x							x			x								x	x			x				x				x				
	Poor			x			x	x		x	x		x	x	x			x	x				x		x	x	x		x	x	x					
Salinity	Non-saline Non-Sodic	x	x		x	x			x	x		x	x											x	x			x								
	Mod. Fine to Fine Saline			x							x												x													
	Medium Saline Sodic						x	x						x	x	x	x	x	x	x	x					x	x			x	x					
Farm Size	< 10	x	x	x	x			x									x				x			x	x	x	x									
	> 10					x	x							x		x		x		x								x	x	x	x					
Cropping Intensity	> 60	x	x	x					x	x		x		x				x		x	x															
	> 70				x	x	x	x								x	x							x	x	x		x	x	x						
Land Use Intensity	> 80								x	x		x																								
	> 90	x	x		x	x																		x	x	x		x	x	x						
No. of Hits		6	10	0	29	32	8	5	53	24	3	6	14	8	20	17	9	2	7	10	5		3	6	3	0	0	10	6	2	10	35	57	0	0	0

Table 8(b) Matrix for the Selection of Constraints to the Cotton Crop, IIMI Sample Survey (1995), Rechna Doab, Pakistan.

	Constraints	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Profile	Mod. Coarse																								
	Medium	x	x	x	x	x	x	x	x																
	Mod. Fine									x	x					x	x	x						x	x
	Fine									x	x					x	x	x							
Surface	Sand																								
	Loamy Sand																								
	Sandy Loam																								
	F. Sandy Loam																								
	Loam											x	x						x					x	
	Silt Loam											x	x						x					x	
	Silt											x	x						x					x	
	Sandy Clay Loam													x	x										x
	Clay Loam													x	x										x
	Silty Clay Loam													x	x										x
	Sandy Clay													x	x										x
	Silty Clay													x	x										x
	Clay													x	x										x
GWQ	Good	x	x				x		x																
	Medium	x	x				x		x																
	Poor			x	x	x		x																	
Salinity	Non-saline Non-Sodic		x				x			x		x		x	x	x	x		x						
	Mod. Fine to Fine Saline										x							x						x	x
	Medium Saline Sodic	x			x	x			x				x												
Farm Size	< 10	x	x	x	x									x					x						
	> 10					x	x	x	x			x	x		x										
Cropping Intensity	> 60			x				x		x	x					x									
	> 70																							x	x
Land Use Intensity	> 80			x				x		x	x						x								
	> 90																							x	x
No. of Hits		4	18	7	5	5	30	6	13	8	2	59	1	14	21	11	17	4	38					5	6

Table 8(c) Matrix for the Selection of Constraints to the Rice Crop, IIMI Sample Survey (1995), Rechna Doab, Pakistan.

	Constraints	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
Profile	Mod. Coarse																			x	x	x	x	x	x	x										
	Medium	x	x	x	x	x							x	x	x	x																				
	Mod. Fine						x	x	x	x							x	x	x								x									
	Fine						x	x	x	x							x	x	x								x									
Surface	Sand																																			
	Loamy Sand																																			
	Sandy Loam																									x										
	F. Sandy Loam																									x										
	Loam												x	x	x	x	x	x	x				x													
	Silt Loam												x	x	x	x	x	x	x				x													
	Silt												x	x	x	x	x	x	x				x													
	Sandy Clay Loam									x	x	x												x	x		x									
	Clay Loam									x	x	x												x	x		x									
	Silty Clay Loam									x	x	x												x	x		x									
	Sandy Clay									x	x	x												x	x		x									
	Silty Clay									x	x	x												x	x		x									
	Clay									x	x	x												x	x		x									
GWQ	Good	x	x	x	x		x	x			x	x	x	x						x			x	x		x	x									
	Medium	x	x	x	x		x	x			x	x	x	x						x			x	x		x	x									
	Poor					x			x	x									x		x				x											
Salinity	Non-saline Non-Sodic	x			x		x	x			x	x	x	x			x			x	x	x					x									
	Mod. Fine to Fine Saline								x	x								x	x																	
	Medium Saline Sodic		x	x		x									x	x																				
Farm Size	< 10	x	x				x				x		x		x		x	x		x	x															
	> 10			x	x			x				x		x		x						x														
Cropping Intensity	> 60					x			x	x									x	x	x						x									
	> 70	x	x	x	x												x	x				x														
Land Use Intensity	> 80					x			x	x					x	x				x	x		x	x	x	x	x									
	> 90	x	x	x	x																	x														
No. of Hits		5	2	2	7	1	12	35	3	2	15	28	17	20	4	7	29	4	11	1	1	3	0	4	1	2	7									

Table 8(d) Matrix for the Selection of Constraints to the Sugarcane Crop, IIMI Sample Survey (1995), Rechna Doab, Pakistan.

	Constraints	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Profile	Mod. Coarse																								
	Medium							x	x	x	x			x	x										
	Mod. Fine	x	x	x	x	x	x														x	x	x	x	x
	Fine	x	x	x	x	x	x														x				
Surface	Sand																								
	Loamy Sand																								
	Sandy Loam													x	x	x			x	x		x	x		
	F. Sandy Loam													x	x	x			x	x		x	x		
	Loam	x	x	x	x												x	x						x	
	Silt Loam	x	x	x	x												x	x						x	
	Silt	x	x	x	x												x	x						x	
	Sandy Clay Loam							x	x			x	x												x
	Clay Loam							x	x			x	x												x
	Silty Clay Loam							x	x			x	x												x
	Sandy Clay							x	x			x	x												x
	Silty Clay							x	x			x	x												x
	Clay							x	x			x	x												x
GWQ	Good	x		x		x		x	x	x		x	x	x											
	Medium	x		x		x		x	x	x		x	x	x											
	Poor		x		x		x				x				x	x	x		x	x	x				
Salinity	Non-saline Non-Sodic	x	x	x	x			x	x	x		x	x	x								x			
	Mod. Fine to Fine Saline					x	x														x		x	x	x
	Medium Saline Sodic										x				x	x	x	x							
Farm Size	< 10	x	x					x				x							x		x				
	> 10			x	x	x	x		x				x							x					
Cropping Intensity	> 60																						x		
	> 70																					x		x	x
Land Use Intensity	> 80																						x		
	> 90																					x		x	x
No. of Hits		6	2	14	3	7	3	17	22	92	16	19	31	23	9	12	20	49	9	26	3	32	6	5	6

Table 9(a) Salient Characteristics of IIMI Sample Farmers Grouped for Constraints to Wheat Cultivation.

Case	Cost of Land Preparation	Cost of Seed	Cost of Fertilizer	Cost of Farm Yard Manure	Cost of Plant Protection	Cost of Irrigation	Yield	Gross Income	Profit	Total Cost	No. of Farms
1	509.85	222.57	648.28	91.91	127.65	194.00	27.29	4940.53	1853.10	3087.43	34
2	613.60	234.76	785.49	172.33	134.20	200.81	29.11	5267.51	1798.87	3468.63	75
3	555.73	250.57	716.15	164.02	99.39	220.15	25.02	4494.51	1295.86	3198.65	41
4	603.00	243.73	754.37	154.29	104.29	205.83	25.71	4611.74	1202.97	3408.78	35
5	627.32	232.94	661.93	194.47	110.16	166.85	27.75	5057.26	1726.42	3330.85	95
6	589.10	223.34	660.61	143.10	136.18	189.32	28.96	5223.74	1987.67	3236.07	72

Table 9(b) Salient Characteristics of IIMI Sample Farmers Grouped for Constraints to Cotton Cultivation.

Case	Cost of Land Preparation	Cost of Seed	Cost of Fertilizer	Cost of Farm Yard Manure	Cost of Plant Protection	Cost of Irrigation	Yield	Gross Income	Profit	Total Cost	No. of Farms
1	512	214	542	143	548	236	10	9679	7110	3042	45
2	544	214	543	304	486	248	9	8304	5660	3106	12
3	437	167	611	88	432	220	15	14179	11549	3057	16
4	496	229	490	173	500	213	11	10813	8291	2997	67
5	548	200	512	150	405	231	12	10854	8368	2934	23

Table 9(c) Salient Characteristics of IIMI Sample Farmers Grouped for Constraints to Rice Cultivation.

Case	Cost of Land Preparation	Cost of Seed	Cost of Fertilizer	Cost of Farm Yard Manure	Cost of Plant Protection	Cost of Irrigation	Yield	Gross Income	Profit	Total Cost	No. of Farms
1	445.71	32.34	507.64	241.07	178.57	730.64	25.93	5833.07	2673.11	3159.96	14
2	568.20	35.11	570.67	167.50	169.66	803.76	27.16	5665.76	2342.16	3323.60	50
3	615.56	32.50	432.22	177.78	160.33	470.00	29.67	6196.11	3326.44	2869.67	9
4	547.79	34.46	552.49	223.84	160.00	606.44	25.84	5398.33	2321.26	3077.06	43
5	453.65	32.56	503.39	198.65	138.92	531.65	20.73	4298.73	1518.29	2780.44	37
6	491.82	40.05	445.27	90.91	168.64	533.64	24.55	4593.64	1874.00	2719.64	11
7	618.24	35.82	640.53	185.89	187.65	793.11	27.30	5860.62	2334.41	3526.21	37
8	522.00	32.45	602.00	240.00	215.00	444.00	27.80	5910.00	2964.84	2945.16	5
9	567.14	32.04	660.29	228.57	182.14	120.00	30.29	6694.29	3987.35	2706.93	7

Table 9(d) Salient Characteristics of IIMI Sample Farmers Grouped for Constraints to Sugarcane Cultivation.

Case	Cost of Land Preparation	Cost of Seed	Cost of Fertilizer	Cost of Farm Yard Manure	Cost of Plant Protection	Cost of Irrigation	Yield	Gross Income	Profit	Total Cost	No. of Farms
1	680	664	568	137	55	957	556	11684	2349	5591	19
2	663	856	634	263	51	839	531	11199	1672	6184	74
3	620	898	719	291	80	676	518	10988	1806	5696	92
4	534	832	748	229	61	544	490	10499	1949	5054	21
5	683	692	638	246	99	776	526	10947	1758	6148	43
6	759	661	706	235	96	781	538	11346	2061	6241	25
7	896	450	669	0	0	670	596	12408	1785	6175	6
8	797	717	563	200	117	1198	556	12533	1027	5209	6

Table 10(a) Production Functions for Wheat Crop Corresponding to Selected Case Definitions for Constraints to Productivity.

Case	Farm Holding Size (ha)	No. of Farmers	Parameters of Significance	R^2 (%)	Function
I	> 2	27	X_1 = Cost of Canal Irrigations * X_2 = Cost of Fertilizer ***	78.86	$Y = -0.3402 + (0.7746)X_1 + (0.1112)X_2$
II	> 2	61	X_1 = Cost of T.W Irrigations ** X_2 = Cost of Canal Irrigation * X_3 = Cost of Fertilizer *	68.08	$Y = 0.2588 + (0.0377)X_1 + (0.5611)X_2 + (0.1819)X_3$
	2-10	46	X_1 = Cost of T.W Irrigations ** X_2 = Cost of Canal Irrigation * X_3 = Cost of Fertilizer *	57.89	$Y = 1.1814 + (0.0551)X_1 + (0.4160)X_2 + (0.1511)X_3$
III	> 2	37	X_1 = Cost of Canal Irrigation * X_2 = Cost of Fertilizer ***	90.97	$Y = -0.0679 + (0.6213)X_1 + (0.1927)X_2$
IV	> 2	31	X_1 = Cost of Canal Irrigation ** X_2 = Cost of Fertilizer * X_3 = Cost of Weedicide *	88.71	$Y = -2.0440 + (0.2353)X_1 + (0.6753)X_2 + (0.0366)X_3$
V	> 2	58	X_1 = Cost of T.W Irrigations *** X_2 = Cost of Canal Irrigation * X_3 = Cost of Fertilizer * X_4 = Distance from the outlet *	88.71	$Y = 2.4391 + (0.0341)X_1 + (0.3587)X_2 + (0.0944)X_3 - (0.2895)X_4$
	2-10	81	X_1 = Cost of T.W Irrigations *** X_2 = Cost of Canal Irrigation * X_3 = Cost of Fertilizer * X_4 = Distance from the outlet *	73.83	$Y = 1.1123 + (0.0297)X_1 + (0.5309)X_2 + (0.1400)X_3 - (0.2163)X_4$
VI	All	72	X_1 = Cost of Canal Irrigation * X_2 = Cost of Fertilizer * X_3 = Cost of Weedicide **	90.07	$Y = -0.0936 + (0.6785)X_1 + (0.1431)X_2 + (0.0394)X_3$
	2-10	46	X_1 = Cost of Canal Irrigation * X_2 = Cost of Fertilizer * X_3 = Cost of Weedicide *	79.73	$Y = -0.0142 + (0.6918)X_1 + (0.1120)X_2 + (0.0579)X_3$
	> 10	15	X_1 = Cost of Canal Irrigation * X_2 = Cost of Fertilizer *	97.74	$Y = -0.0557 + (0.4171)X_1 + (0.3685)X_2$

* Significant at 99 percent.
** Significant at 95 percent.
*** Significant at 90 percent.

Table 10(b) Production Functions for Cotton Crop Corresponding to Selected Case Definitions for Constraints to Productivity.

Case	Farm Holding Size (ha)	No. of Farmers	Parameters of Significance	R^2 (%)	Function
I	2-10	41	X_1 = No. of Canal Irrigation *	44.77	$Y = -0.0641 + (0.5923)X_1$
	> 10	51	X_1 = No. of Canal Irrigation *	38.88	$Y = -0.0144 + (0.5771)X_1$
II	> 2	22	X_1 = Cost of Plant Protection *	32.18	$Y = 0.3303 + (0.2909)X_1$
III	All	21	X_1 = Cost of Fertilizer *	78.05	$Y = -0.5891 + (0.5975)X_1$
	> 2	18	X_1 = Cost of Fertilizer *	78.35	$Y = -0.4916 + (0.5875)X_1$
IV	All	98	X_1 = No. of T.W Irrigation *** X_2 = No. of Canal Irrigation *	45.33	$Y = -0.0742 - (0.0763)X_1 + (0.6196)X_2$
V	> 2	18	X_1 = No. of Canal Irrigation *	80.23	$Y = -0.1705 + (0.6875)X_1$
	2-10	28	X_1 = No. of Canal Irrigation *	63.31	$Y = -0.2048 + (0.7491)X_1$

* Significant at 99 percent.
** Significant at 95 percent.
*** Significant at 90 percent.

Table 10(c) Production Functions for the Rice Crop Corresponding to Selected Case Definitions for Constraints to Productivity.

Case	Farm Holding (Acres)	No. of Farmers	Parameters of Significance	R^2 (%)	Function
I	All	14	X_1 = Cost of Fertilizer X_2 = Cost of Plant Protection X_3 = Cost of Canal Irrigation	95.78	$Y = -1.2896 + (0.3460)X_1 + (0.0660)X_2 + (0.5292)X_3$
II	All	50	X_1 = Cost of Fertilizer X_2 = Cost of Canal Irrigation X_3 = Cost of Land Preparation	79.08	$Y = -0.6116 + (0.2491)X_1 + (0.4362)X_2 + (0.1321)X_3$
IV	All	25	X_1 = Cost of Land Preparation X_2 = Distance from Outlet X_3 = Cost of T.W Irrigation	93.73	$Y = -2.9687 + (0.9876)X_1 - (0.1018)X_2 + (0.0283)X_3$
	Medium	43	X_1 = Cost of Land Preparation X_2 = Distance from Outlet X_3 = Cost of T.W Irrigation	98.92	$Y = -2.7110 + (0.9584)X_1 - (0.1712)X_2 + (0.0398)X_3$
V	All	37	X_1 = Cost of Fertilizer	88.72	$Y = -2.6037 + (0.923)X_1$
	Medium	25	X_1 = Cost of Fertilizer	91.36	$Y = -2.3134 + (0.8852)X_1$
VI	All	11	X_1 = Cost of Fertilizer X_2 = Cost of Plant Protection X_3 = Cost of Farm Yard Manure	96.45	$Y = 0.041 + (0.436)X_1 + (0.1084)X_2 + (0.0976)X_3$
VII	All	37	X_1 = Cost of Canal Irrigation X_2 = Cost of Land Preparation	92.89	$Y = -1.815 + (0.4484)X_1 + (0.5051)X_2$

Table 10(d) Production Functions for Sugarcane Crop Corresponding to Selected Case Definitions for Constraints to Productivity.

Case	Farm Holding Size (ha)	No. of Farmers	Parameters of Significance	R^2 (%)	Function
I	All	25	X_1 = Cost of Fertilizer	90.24	$Y = 0.3326 + (0.9586)X_1$
II	All	50	X_1 = Cost of Fertilizer * X_2 = Cost of Canal Irrigation *	83.05	$Y = 0.3166 + (0.3664)X_1 + (0.6980)X_2$
	2-10	27	X_1 = Cost of Fertilizer * X_2 = Cost of Canal Irrigation *	78.80	$Y = 0.4096 + (0.5548)X_1 + (0.4643)X_2$
III	All	108	X_1 = Cost of Fertilizer * X_2 = Cost of Plant Protection ** X_3 = Cost of Canal Irrigation *	86.86	$Y = 0.3176 + (0.6883)X_1 + (0.1421)X_2 + (0.2674)X_3$
	2-10	72	X_1 = Cost of Fertilizer * X_2 = Cost of Canal Irrigation *	88.14	$Y = 0.3085 + (0.6866)X_1 + (0.3074)X_2$
IV	All	32	X_1 = Cost of FYM *** X_2 = Cost of Land * X_3 = Cost of Canal Irrigation *	81.36	$Y = 0.1208 + (0.1961)X_1 + (0.4721)X_2 + (0.5046)X_3$
V	Medium	35	X_1 = Cost of Land * X_2 = Cost of Canal Irrigation ***	91.44	$Y = 0.0950 + (0.3667)X_1 + (0.7308)X_2$
VI	All	35	X_1 = Cost of TW Irrigation * X_2 = Cost of Land * X_3 = Cost of Canal Irrigation ***	99.62	$Y = -0.0034 + (0.0544)X_1 + (0.9173)X_2 + (0.0397)X_3$

* Significant at 99 percent.
** Significant at 95 percent.
*** Significant at 90 percent.

REFERENCES

Chaudhry, M. G., Gill, M. A. and Chaudhry G. M., 1985, Size-Productivity Relationship in Pakistan's Agriculture in the Seventies. The Pakistan Development Review, Vol. XXIV, No. 3 & 4, Islamabad, Pakistan.

Fuss, M.; McFadden, D. and Mundlak, Y., 1978, Production Economics: A Dual Approach to Theory and Applications. Editors, Fuss, M. and McFadden, D. North Holland Publishing Company, pp. 224-225.

Government of Pakistan, 1963, Pakistan Census of Agriculture, 1960. Pakistan Agricultural Census Organization. Vol. II, West Pakistan, Karachi, Pakistan.

Government of Pakistan, 1975, Pakistan Census of Agriculture, 1972. Pakistan Agricultural Census Organization. Vol. II, Provincial Reports, Lahore, Pakistan.

Government of Pakistan, 1983, Pakistan Census of Agriculture, 1980. Pakistan Agricultural Census Organization. Vol. I, Punjab Report, Lahore, Pakistan.

Government of Pakistan, 1994. Pakistan Census of Agriculture, 1990. Pakistan Agricultural Census Organization. Vol. II, Punjab Report, Lahore, Pakistan.

Heady, E. O. and Dillon, 1969, J. L., Agricultural Production Functions. Ames: Iowa State Univ. Press.

Koutsiyiannis, A., 1977, Theory of Econometrics. London: Macmillan.

Maddala, G. S., 1988, Introduction to Econometrics, London: Macmillan.

Ramanathan, R., 1992, Introductary Econometrics with Applications. Second Edition. The Dryden Press.

Rao, P. M. and Miller, R. L., 1972, Applied Econometrics. Princeton Hall of India, Private Ltd., New Delhi.

Slavich, P.G., 1990, Soil Salinity Measurement using the Electromagnetic Soil Conductivity Meter (EM-38) Measurement Principles and Applications, IWASRI, Lahore, Pakistan.

Appendix-A

IIMI Sample Survey
Differentiation of Salinity Classes from the Total Number of EM 38 Measurements in the Rechna Doab

Appendix-A
IIMI Sample Survey
Differentiation of Salinity Classes from
the Total Number of EM 38 Measurements in the Rechna Doab

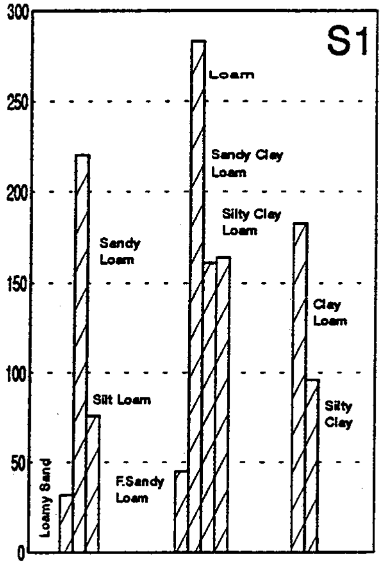
Polygon	S1	S2	S3	S4	Total
1101	41	3	5	8	57
1102	64	0	0	1	65
1106	73	0	0	0	73
1108	73	5	2	2	82
1110	73	1	0	0	74
1301	83	5	5	28	121
1302	51	7	7	4	69
1304	29	5	5	20	59
1305	37	15	16	8	76
1306	57	14	8	5	84
1403	95	14	3	0	112
1501	52	15	23	17	107
1502	81	3	3	0	87
1503	58	20	13	9	100
1504	66	7	2	7	82
1505	133	5	5	1	144
1507	131	4	4	3	142
1601	61	2	2	0	65
1602	24	11	8	5	48
1603	34	10	9	11	64
1604	61	20	10	1	92
1701	91	3	0	0	94
1702	47	17	16	2	82
2101	110	0	0	0	110
2102	120	4	0	0	124
2103	145	0	0	0	145
2104	113	0	0	0	113
2201	145	0	0	0	145
2202	145	0	0	0	145
2301	92	20	0	0	112
2401	114	13	0	0	127
2402	140	0	0	0	140
2501	75	0	0	0	75
2601	86	7	2	0	95

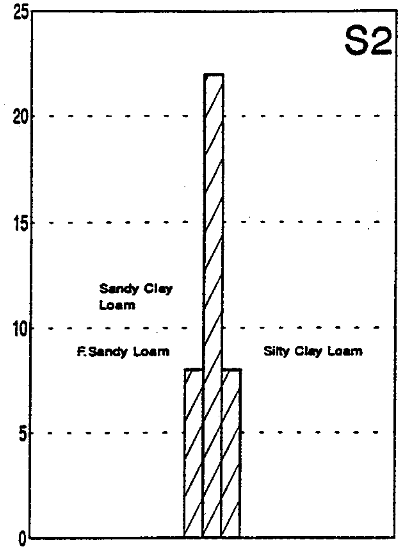
Appendix-A Continued

Polygon	S1	S2	S3	S4	Total
2701	112	11	8	1	132
2702	100	9	1	0	110
2703	104	3	0	0	107
2704	73	4	4	4	85
2705	119	0	0	0	119
2706	94	0	0	0	94
3104	57	6	1	1	65
3201	109	4	16	0	129
3202	97	3	0	0	100
3203	159	1	0	0	160
3204	101	2	0	0	103
3301	118	0	0	0	118
3302	116	0	0	0	116
3303	113	3	0	0	116
3305	91	7	5	0	103
3306	103	0	0	0	103
3307	125	6	0	0	131
3401	113	23	7	2	145
3402	94	14	7	1	116
3403	130	3	2	0	135
3501	114	8	9	2	133
3502	102	9	5	0	116
3503	102	9	5	0	116
3504	80	0	0	0	80
4201	58	3	4	1	66
4202	135	8	7	0	150
4203	67	0	0	0	67
4204	81	6	0	0	87
4207	95	11	8	1	115
4208	83	2	0	0	85
4209	103	0	0	1	104
4301	41	13	4	6	64
4302	67	20	7	6	100
4303	21	12	6	0	39
4304	41	0	0	0	41
4305	53	8	11	5	77
4306	61	0	0	0	61
4307	109	0	0	0	109
4401	58	7	8	10	83

Appendix-A Continued

Polygon	S1	S2	S3	S4	Total
4402	78	16	6	0	100
4403	125	1	0	0	126
4404	36	10	1	5	52
4407	97	13	2	0	112
4409	68	4	4	1	77
4501	101	0	0	0	101
5103	62	4	7	7	80
5104	46	7	0	1	54
5105	22	4	4	1	31
5106	51	4	14	11	80
5107	60	7	6	14	87
5108	81	3	1	0	85
5109	107	14	4	0	125
5202	96	6	8	5	115
5203	39	6	4	1	50
5204	41	0	0	0	41
5207	115	2	0	0	157
5301	162	4	5	0	171
5302	58	2	2	0	62
5304	95	0	0	0	95
5305	30	3	5	9	47
5306	100	10	6	0	115
5307	44	4	5	5	58
5309	88	1	0	0	89
5311	87	0	0	0	87
5401	79	7	1	0	87
5403	16	15	17	11	59
5404	97	1	1	1	100
5405	36	7	1	0	44
5406	48	5	3	0	56
5407	21	3	4	1	29
5411	95	2	14	5	116
5501	134	0	0	0	134
5502	73	25	12	2	112
5503	108	19	3	4	134
5506	60	19	4	1	84
5507	86	1	0	0	87
8101	101	4	1	0	106
8102	42	7	2	0	51





Y-axis: No. of Observations

Figure B8 Top Root Zone Texture Differentiated for Soil Salinity; IIMI Sample Coverage for Kot Khuda Yar Subdivision, Lower Chenab Canal Command, Rechna Doab, Pakistan.

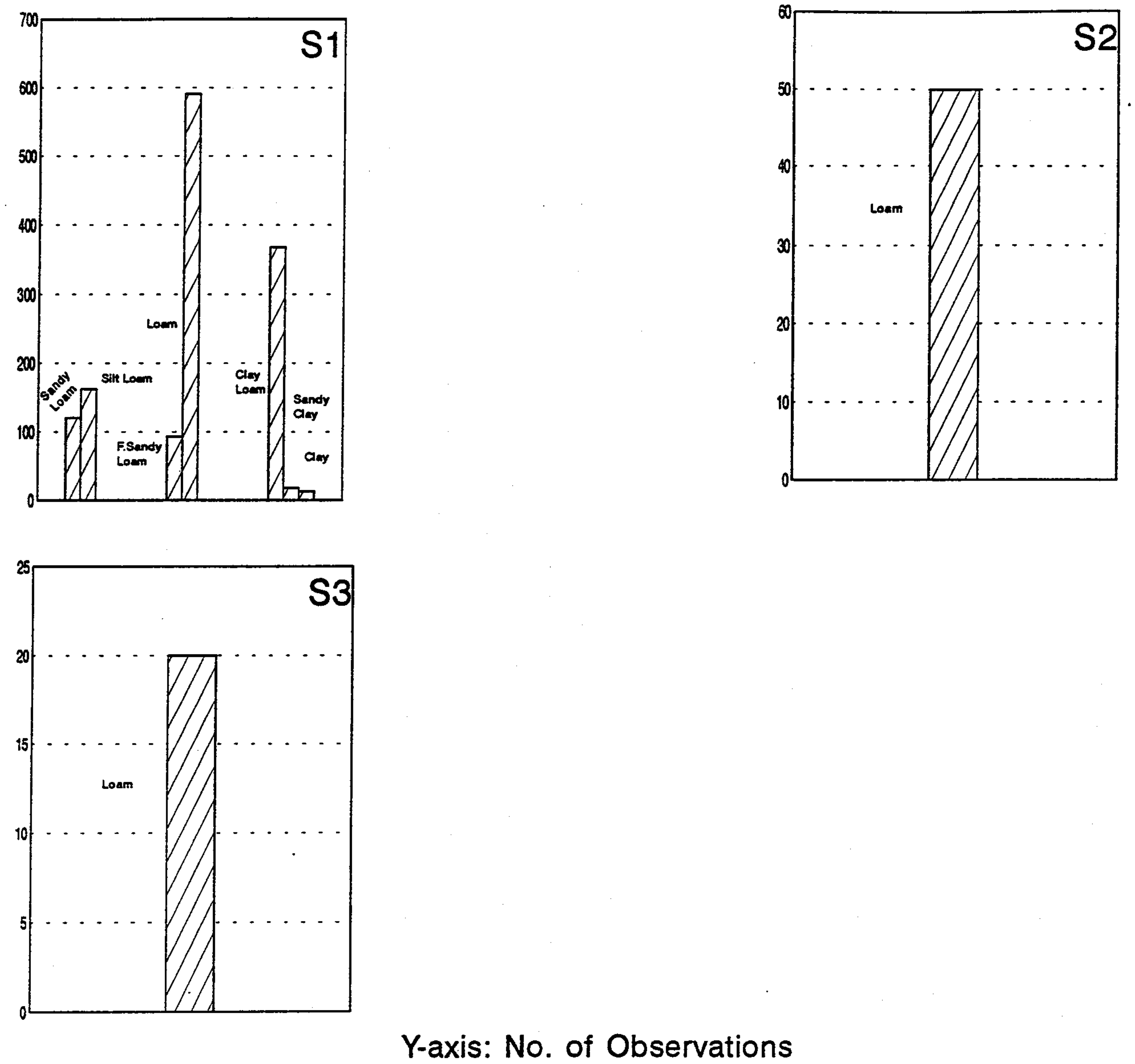
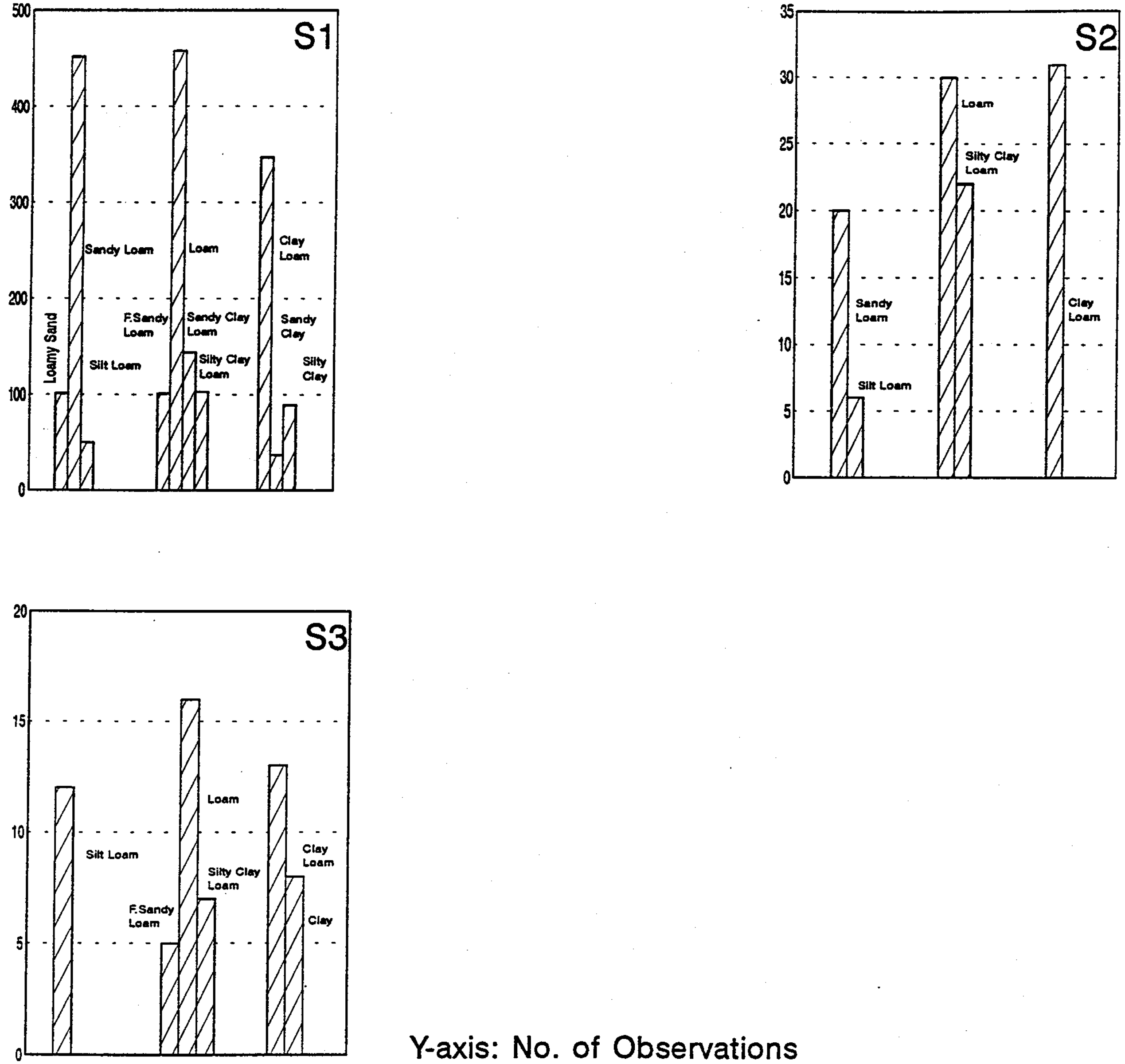
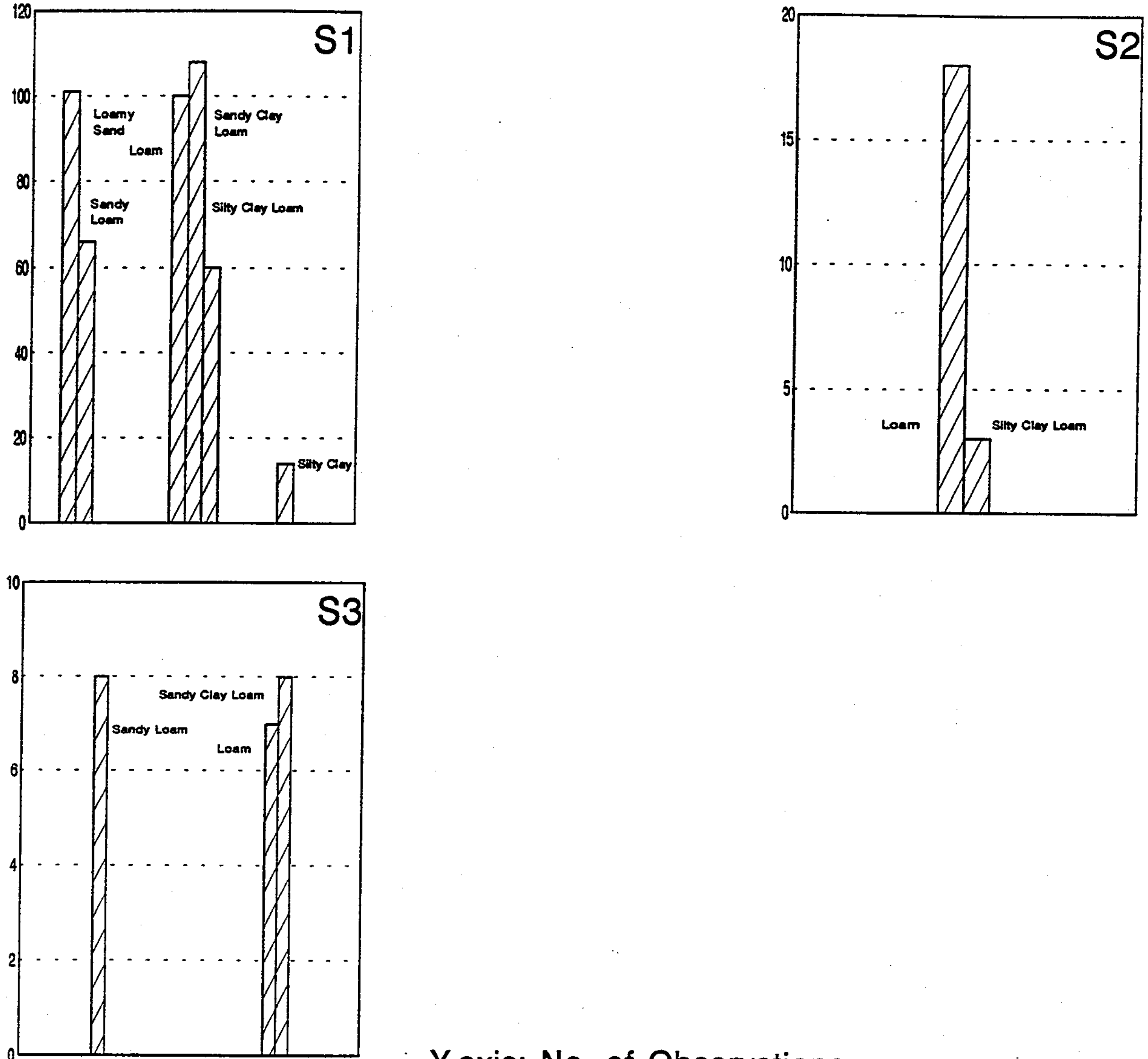


Figure B9 Top Root Zone Texture Differentiated for Soil Salinity; IIMI Sample Coverage for Dhaular Subdivision, Lower Chenab Canal Command, Rechna Doab, Pakistan.



Y-axis: No. of Observations

Figure B10 Top Root Zone Soil Texture Differentiated for Soil Salinity; IIMI Sample Coverage for Pacca Dala Subdivision, Lower Chenab Canal Command, Rechna Doab, Pakistan.



Y-axis: No. of Observations

Figure B11 Top Root Zone Soil Texture Differentiated for Soil Salinity; IIMI Sample Coverage for Sangla Subdivision, Lower Chenab Canal Command, Rechna Doab, Pakistab.

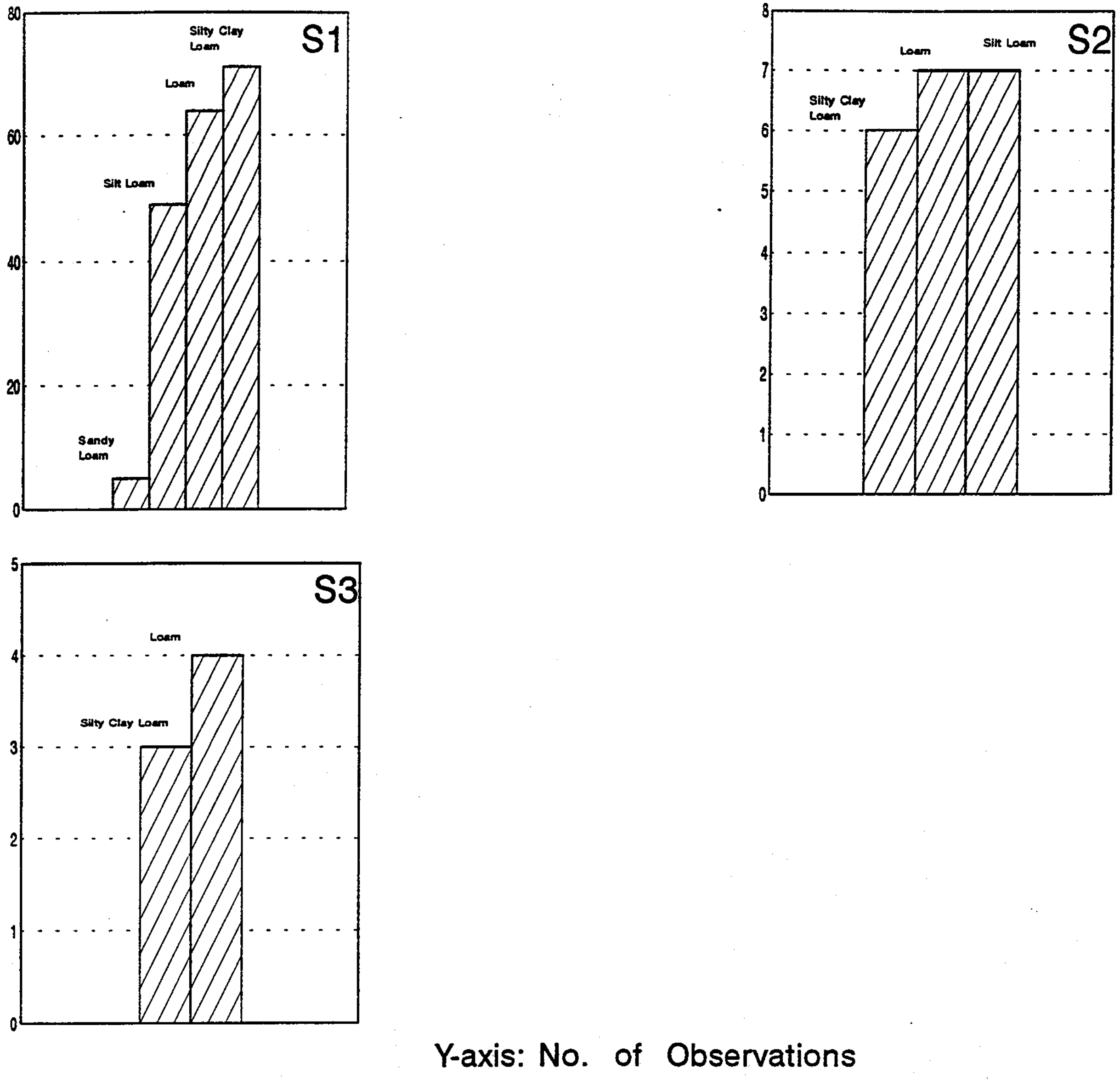
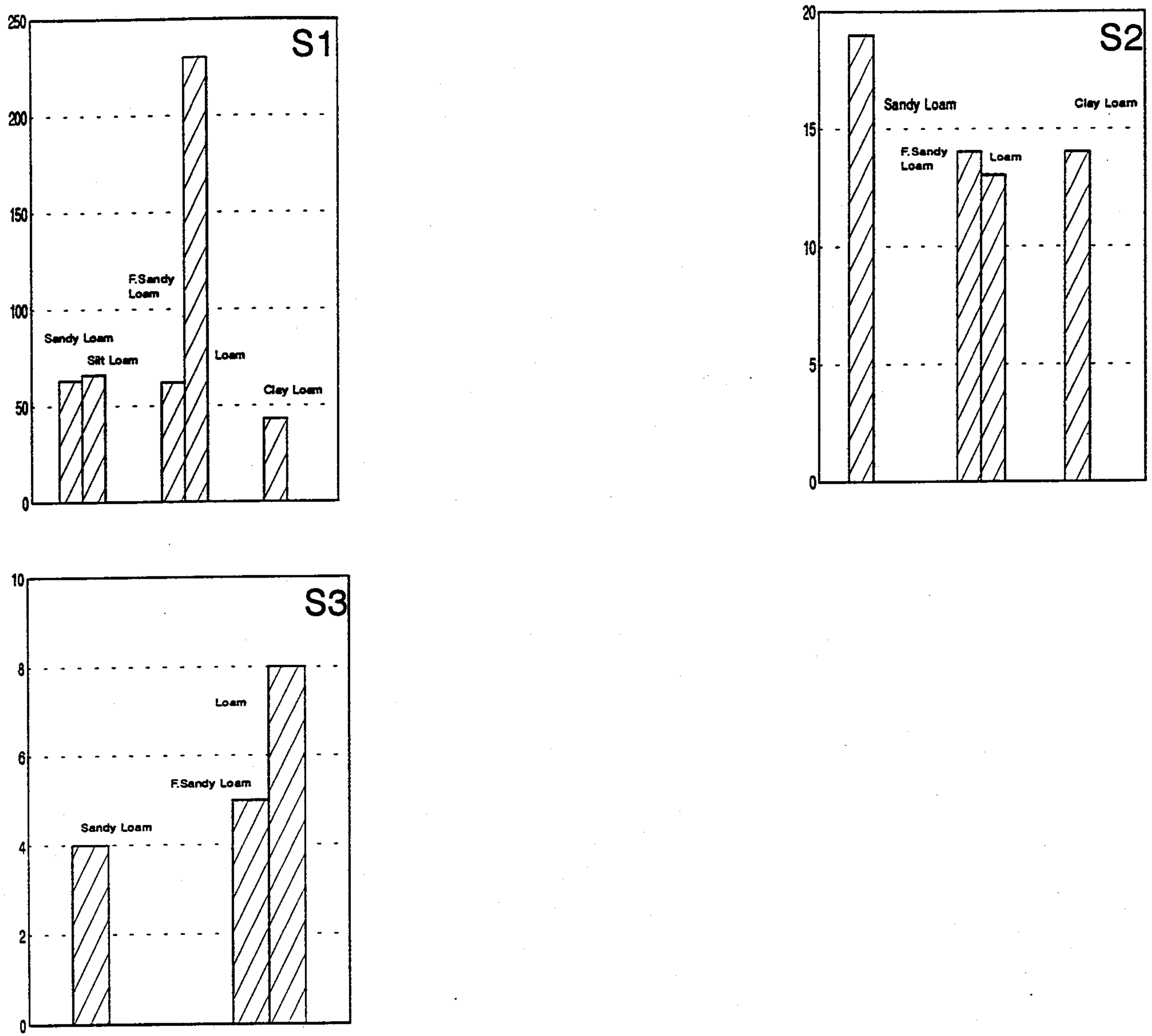
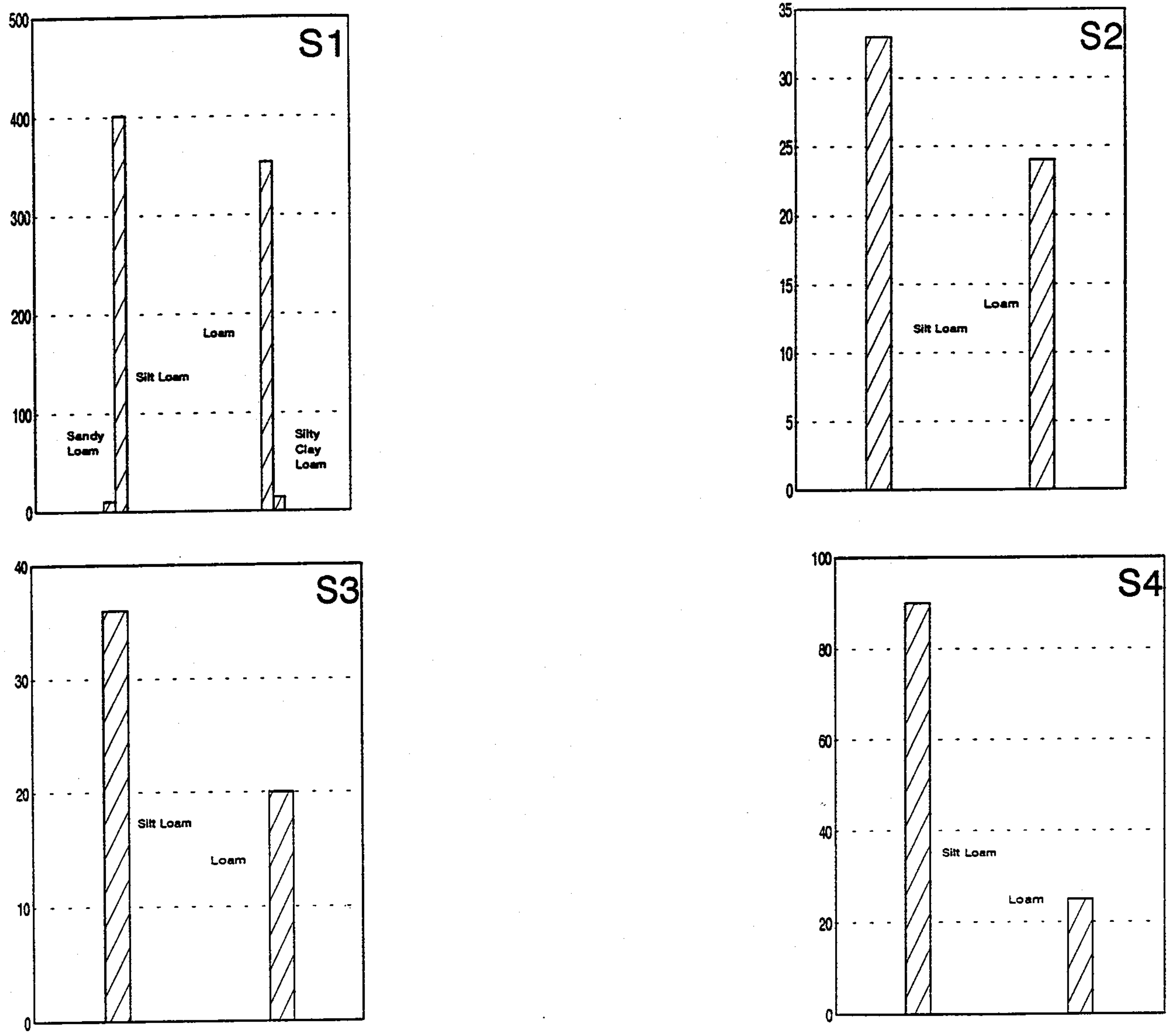


Figure B12 Top Root Zone Soil Texture Differentiated for Soil Salinity; IIMI Sample Coverage for Sultanpur Subdivision, Lower Chenab Canal Command, Rechna Doab, Pakistan.



Y-axis: No. of Observations

Figure B13 Top Root Zone Soil Texture Differentiated for Soil Salinity; IIMI Sample Coverage for Tandlianwala Subdivision, Lower Chenab Canal Command, Rechna Doab, Pakistan.



Y-axis: No. of Observations

Figure B14 Top Root Zone Soil Texture Differentiated for Soil Salinity; IIMI Sample Coverage for Tarkhani Subdivision, Lower Chenab Canal Command, Rechna Doab, Pakistan.

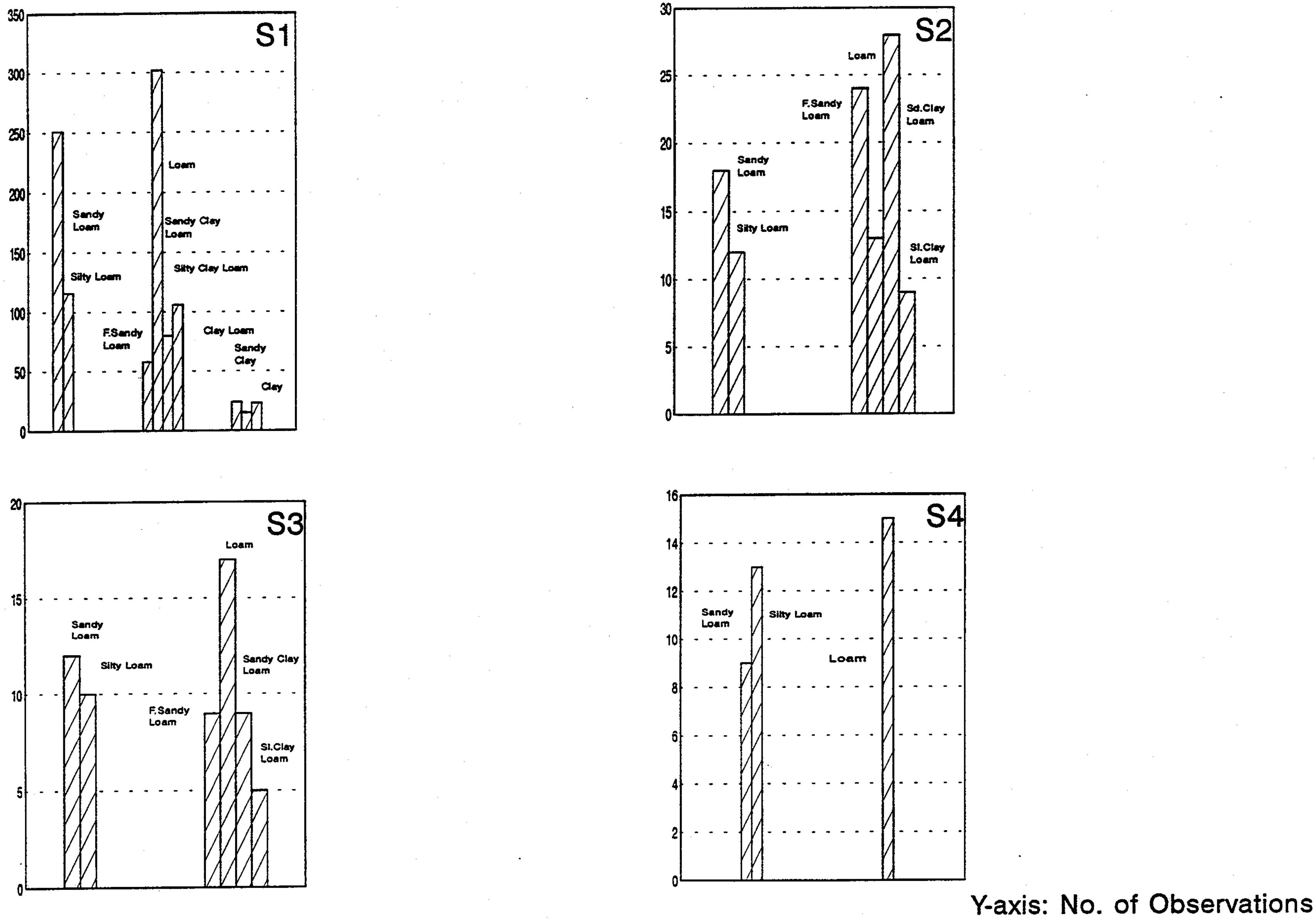


Figure B15 Top Root Zone Soil Texture Differentiated for Soil Salinity; IIMI Sample Coverage for Uqabana Subdivision, Lower Chenab Canal Command, Rechna Doab, Pakistan.

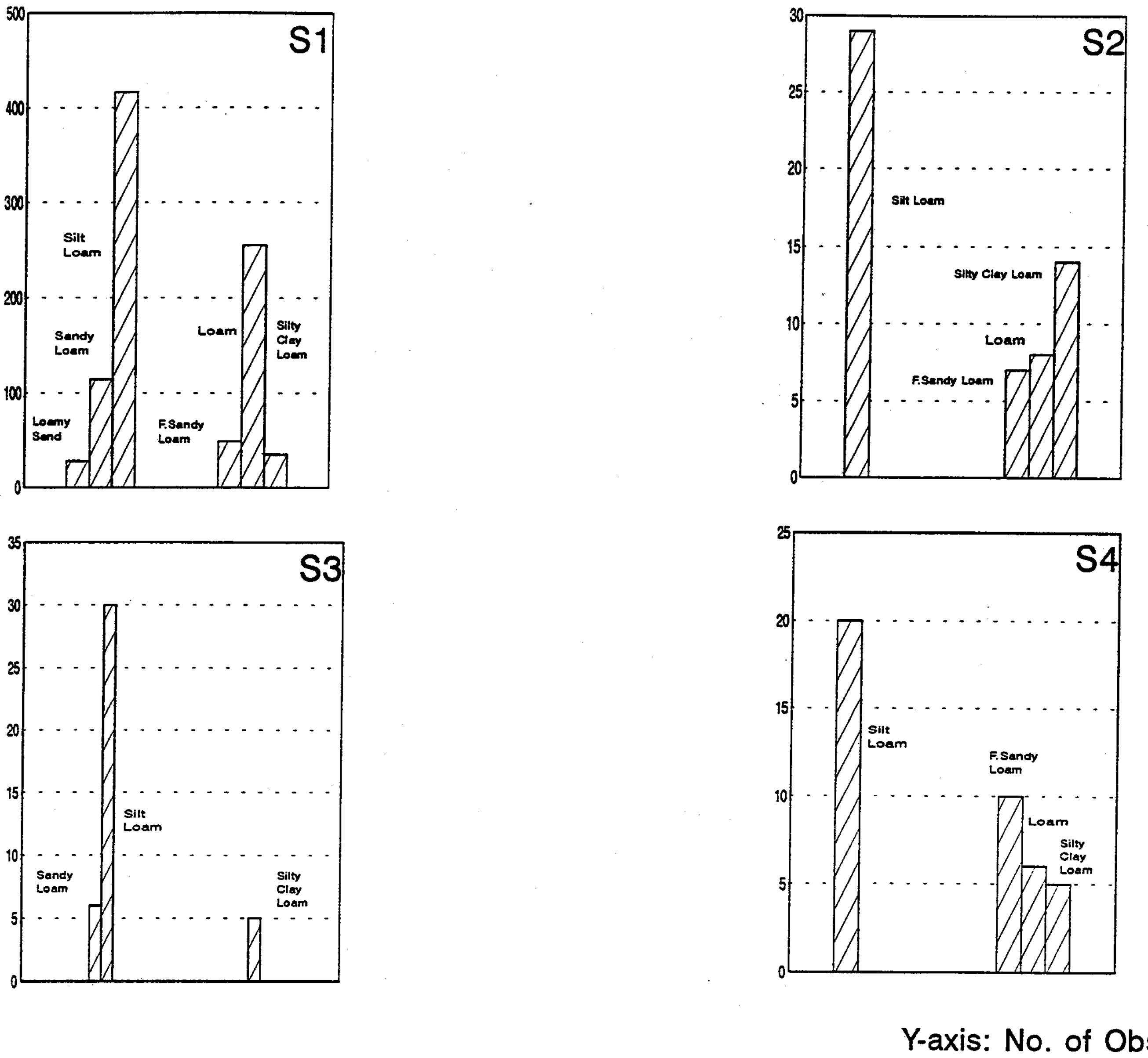


Figure B16 Top Root Zone Soil Texture Differentiated Soil Salinity; IIMI Sample Coverage for Veryam Subdivision, Lower Chenab Canal Command, Rechna Doab, Pakistan.

APPENDIX-C

IIMI Sample Survey
Differentiation of Soil Texture and Crop Cover for Soil Salinity

Appendix-A Continued

Polygon	S1	S2	S3	S4	Total
8105	81	3	2	1	87
8106	66	1	0	0	67
8107	23	7	13	37	80
8109	116	12	1	0	129
8113	91	0	1	0	92
8201	53	14	3	0	70
8203	69	3	1	0	73
8301	51	7	0	0	58
8302	86	16	6	2	110
8305	86	0	0	0	86
8306	79	0	0	0	79
8307	95	15	0	0	110
8308	78	17	5	0	100
8402	56	14	8	4	82
8405 (A)	134	9	5	0	148
8405 (B)	107	6	2	0	115
9101	68	2	0	0	70
9102	80	6	6	1	93
9103	52	0	0	0	52
9104	73	1	0	0	74
9105	77	0	0	0	77
9106	69	1	0	0	70
9107	74	6	0	0	80
9108	74	14	14	1	103
9109	35	20	14	31	100
9110	124	0	0	0	124
9113	81	13	7	3	104
9202	76	20	22	56	174
9206	73	13	5	0	91
9207	85	12	9	0	106
9301	104	13	6	1	124
9302	74	8	1	0	83
9303	68	4	0	0	72
9304	53	0	0	0	53
9305	41	2	3	0	46
9306	26	27	11	0	64
9401	72	0	0	0	72
9402	62	4	0	0	66
9403	39	3	0	0	72

Appendix-A Continued

Polygon	S1	S2	S3	S4	Total
9406	73	1	0	0	74
9409	123	19	11	2	155
9410	116	0	0	0	116
9411	86	1	0	0	87
9501	116	0	0	0	116
9502	130	0	0	0	130
9503	37	0	0	0	37

APPENDIX-B

IIMI Sample Survey
Comparison of Root Zone Soil Texture to Soil Salinity

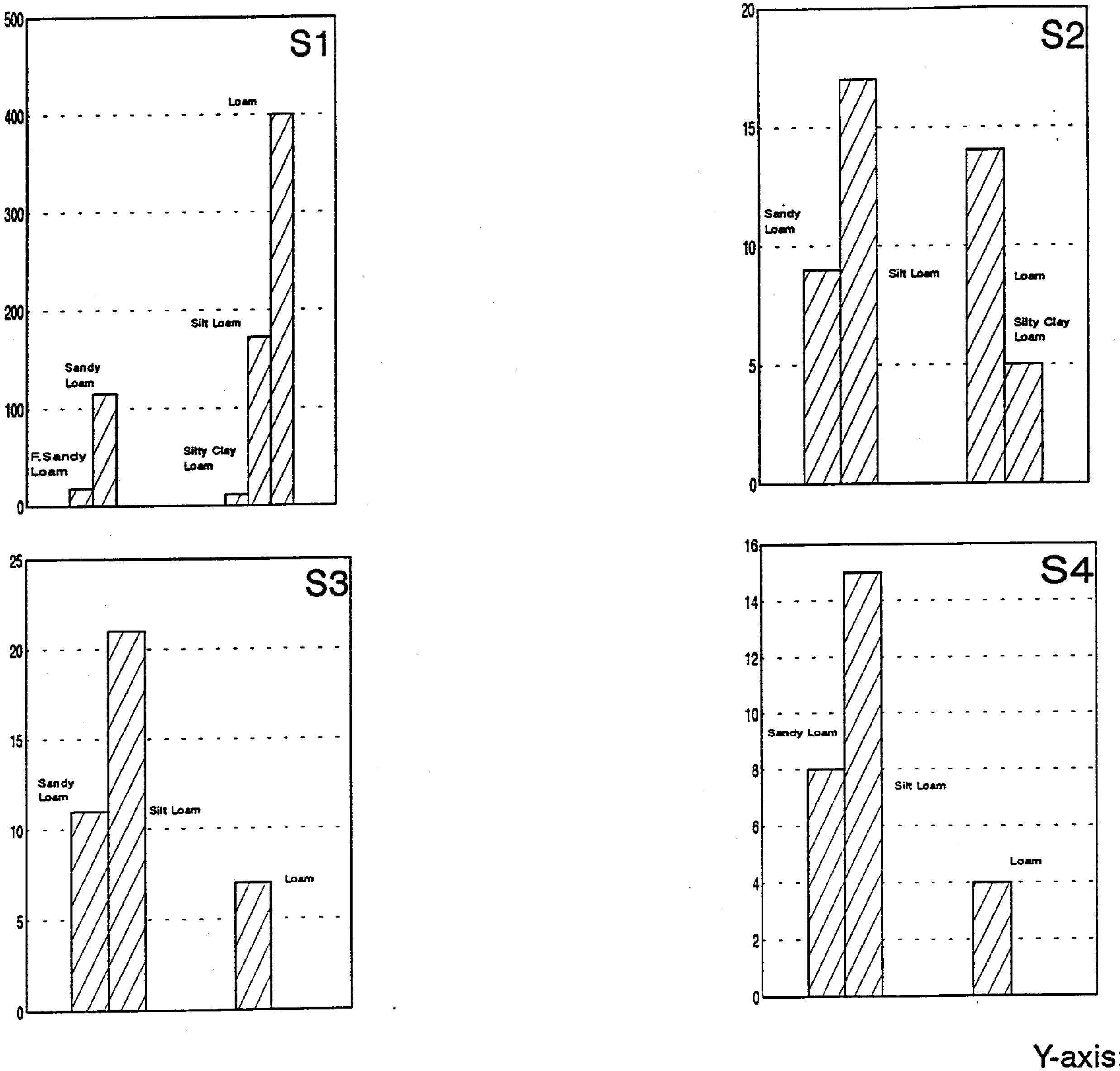
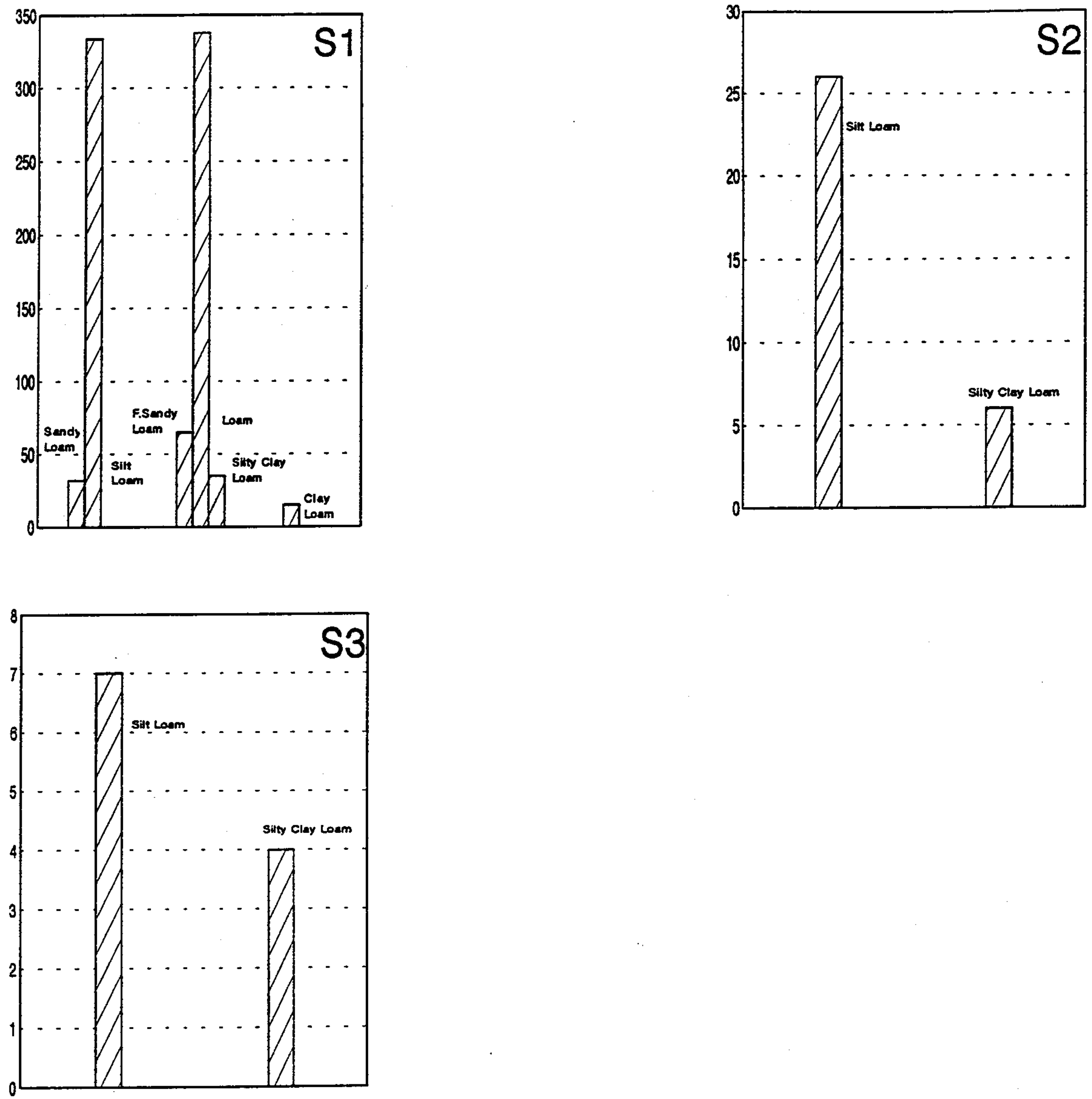


Figure B1 Top Root Zone Soil Texture Differentiated for Soil Salinity; IIMI Sample Coverage for Aminpur Subdivision, Lower Chenab Canal Command, Rechna Doab, Pakistan.



Y-axis: No. of Observations

Figure B2 Top Root Zone Soil Texture Differentiated for Soil Salinity; IIMI Sample Coverage for Bhagat Subdivision, Lower Chenab Canal Command, Rechna Doab, Pakistan.

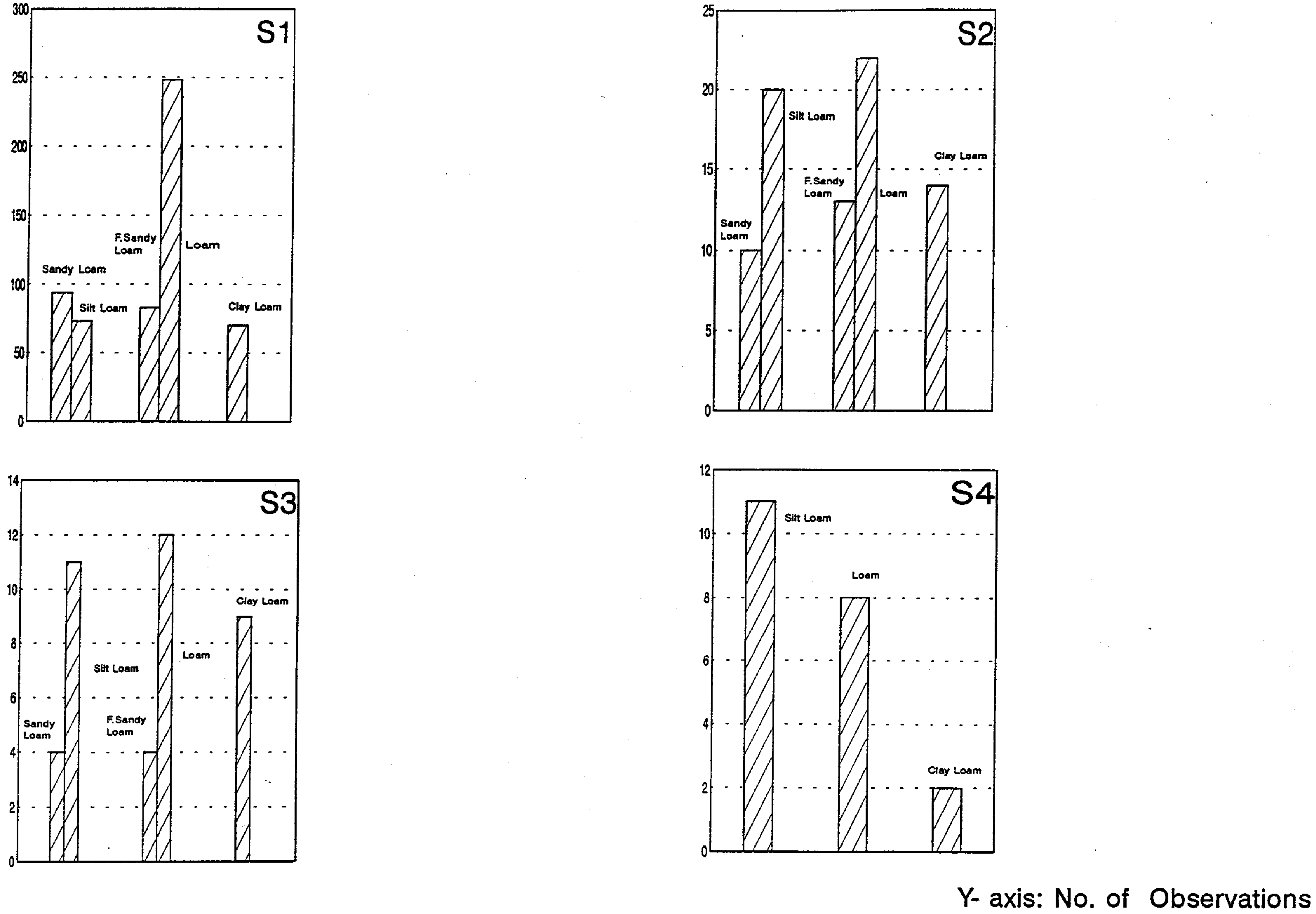
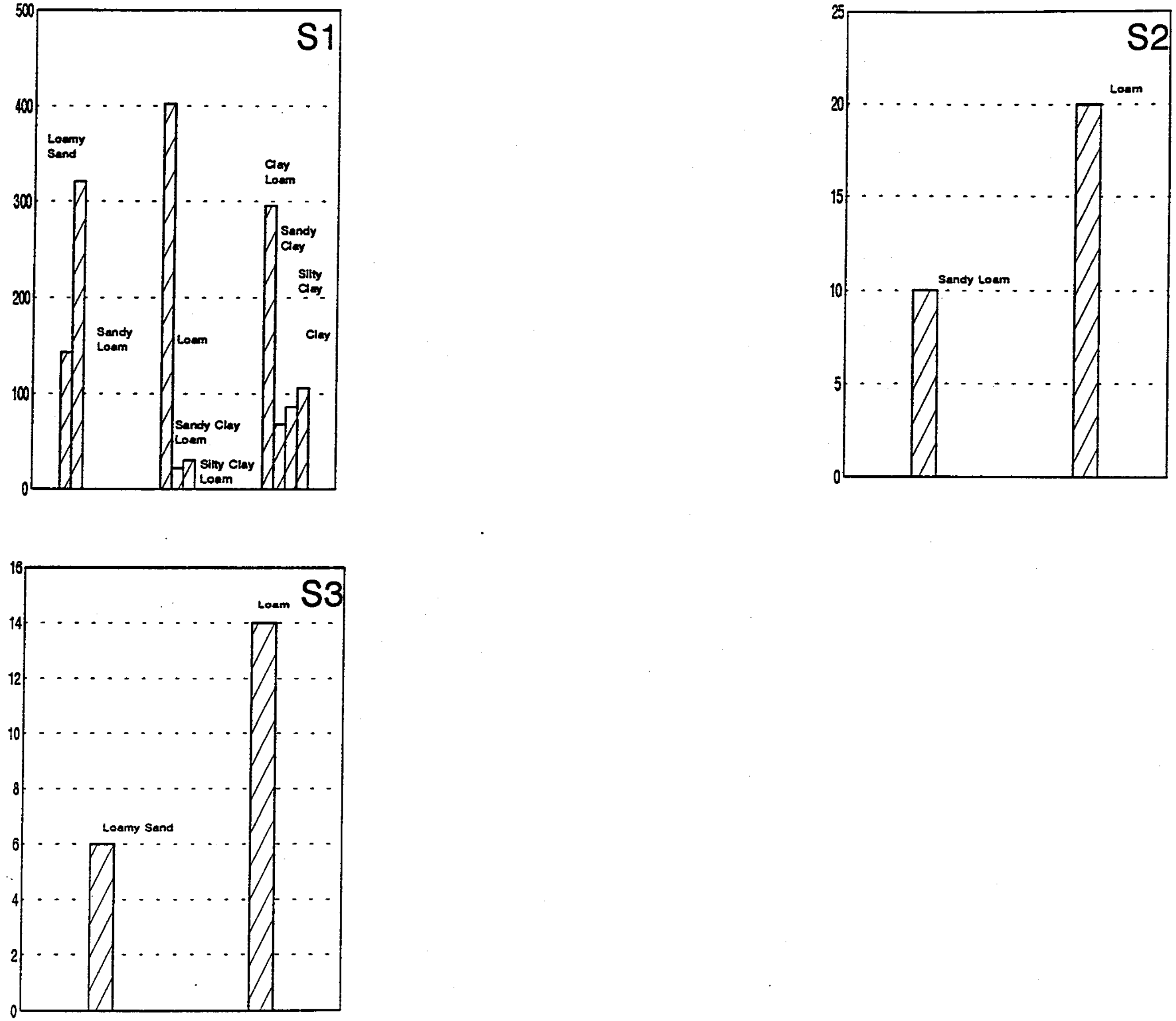
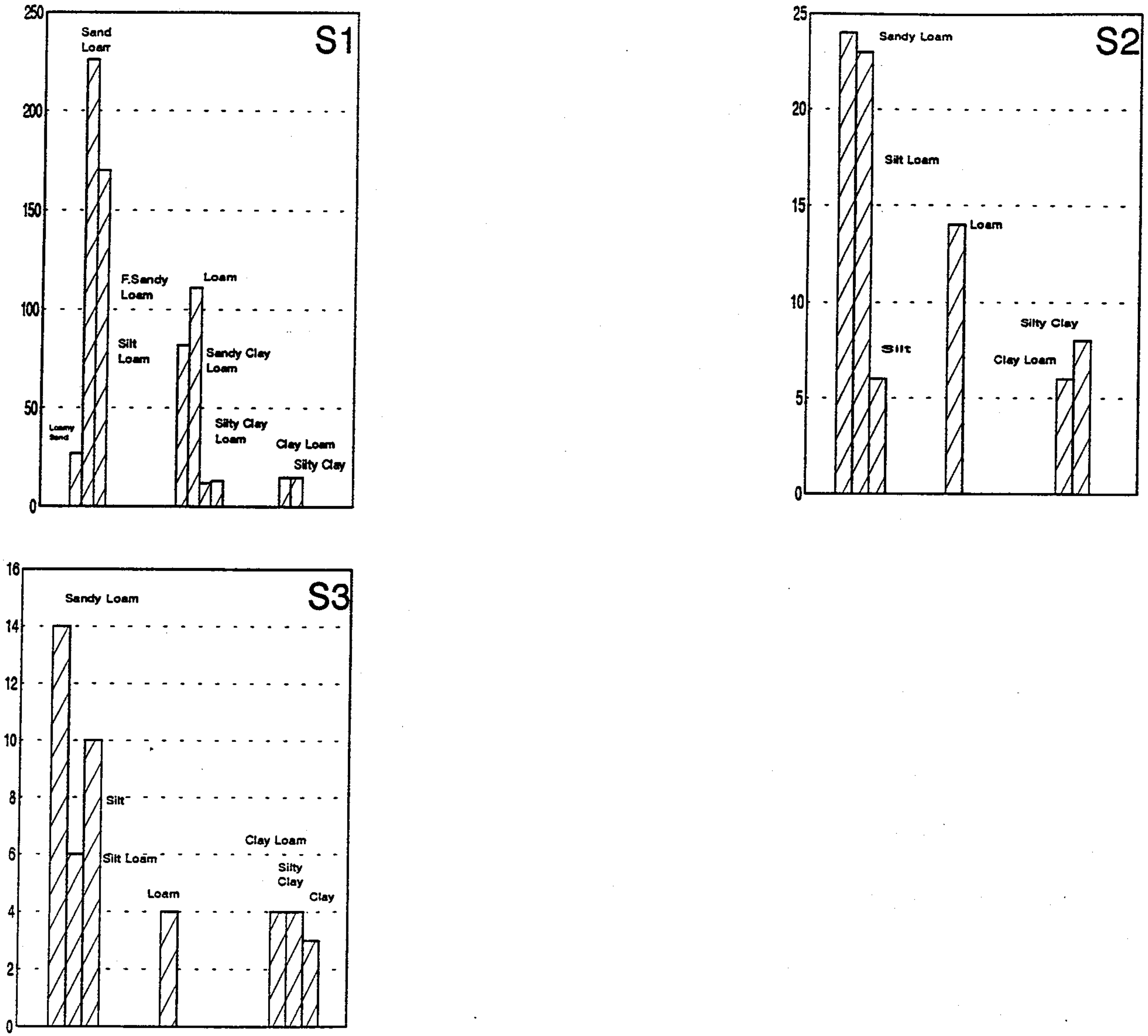


Figure B3 Top Zone Soil Texture Differentiated for Soil Sainity; IIMI Sample Coverage for Butchiana Subdivision, Lower Chenab Canal Command, Rechna Doab, Pakistan.



Y-axis: No. of Observations

Figure B4 Top Root Zone Soil Texture Differentiated for Soil Salinity; IIMI Sample Coverage for Chuharkana Subdivision, Lower Chenab Canal Command, Rechna Doab, Pakistan.



Y-axis: No. of Observations

Figure B5 Top Root Zone Soil Texture Differentiated for Soil Salinity; IIMI Sample Coverage for Dhaular Subdivision, Lower Chenab Canal Command, Rechna Doab, Pakistan.

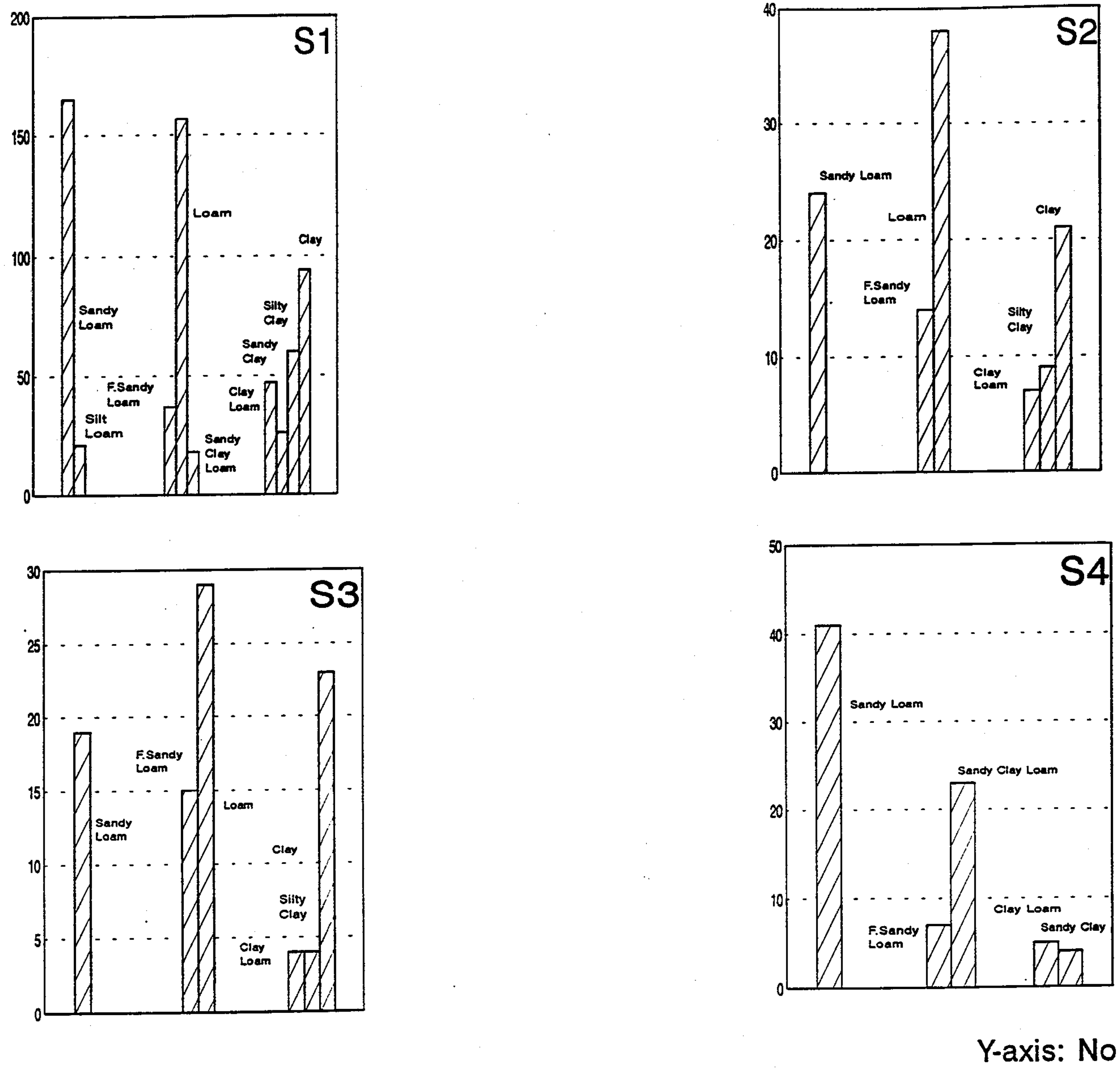


Figure B6 Top Root Zone Soil Texture Differentiated for Soil Salinity; IIMI Sample Coverage for Haveli Subdivision, Lower Chenab canal Command, Rechan Doab, Pakistan.

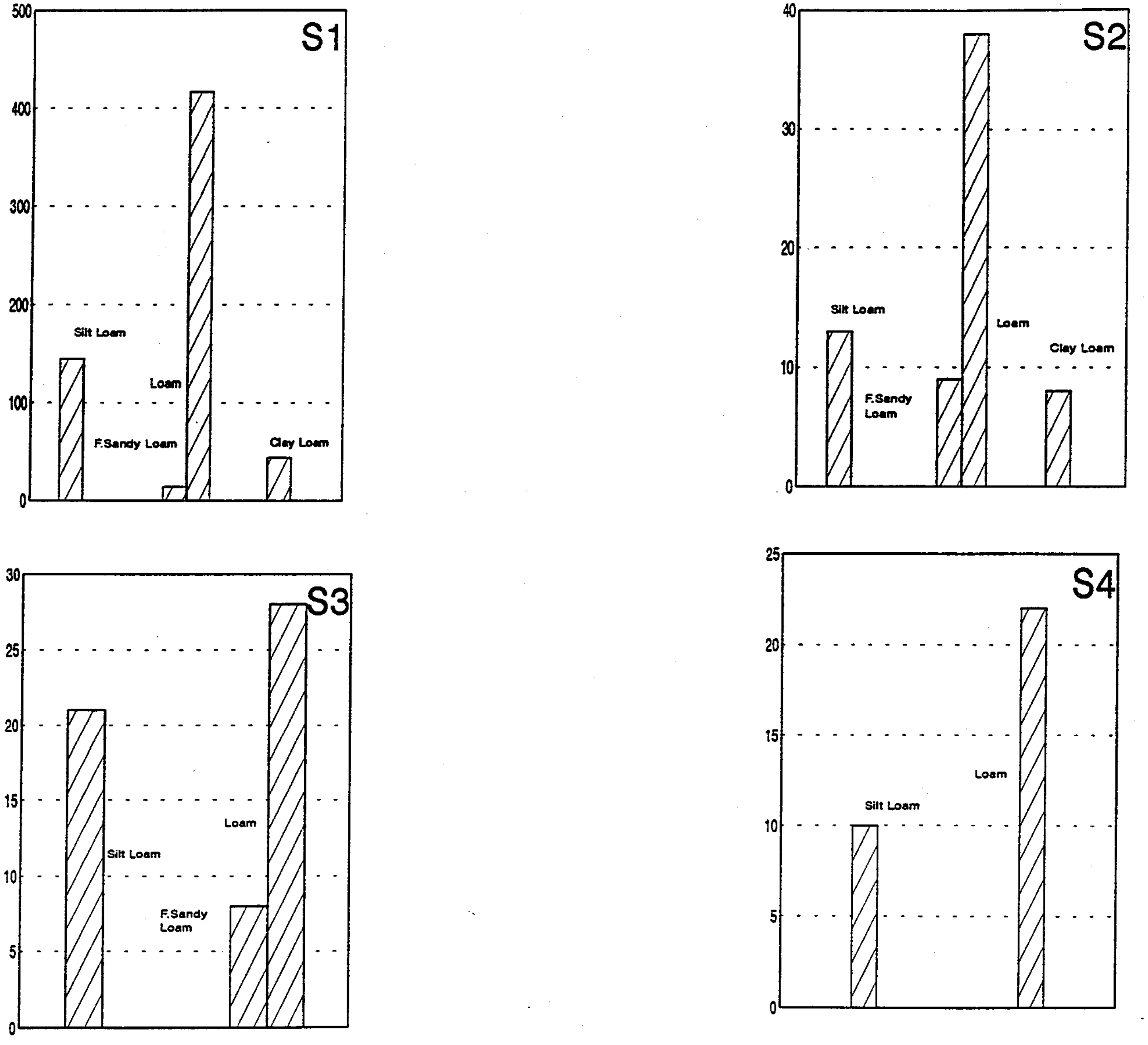


Figure B7 Top Root Zone Soil Texture Differentiated for Soil Salinity; IIMI Sample Coverage for Kanya Subdivision, Lower Chenab Canal Command, Rechna Doab, Pakistan.

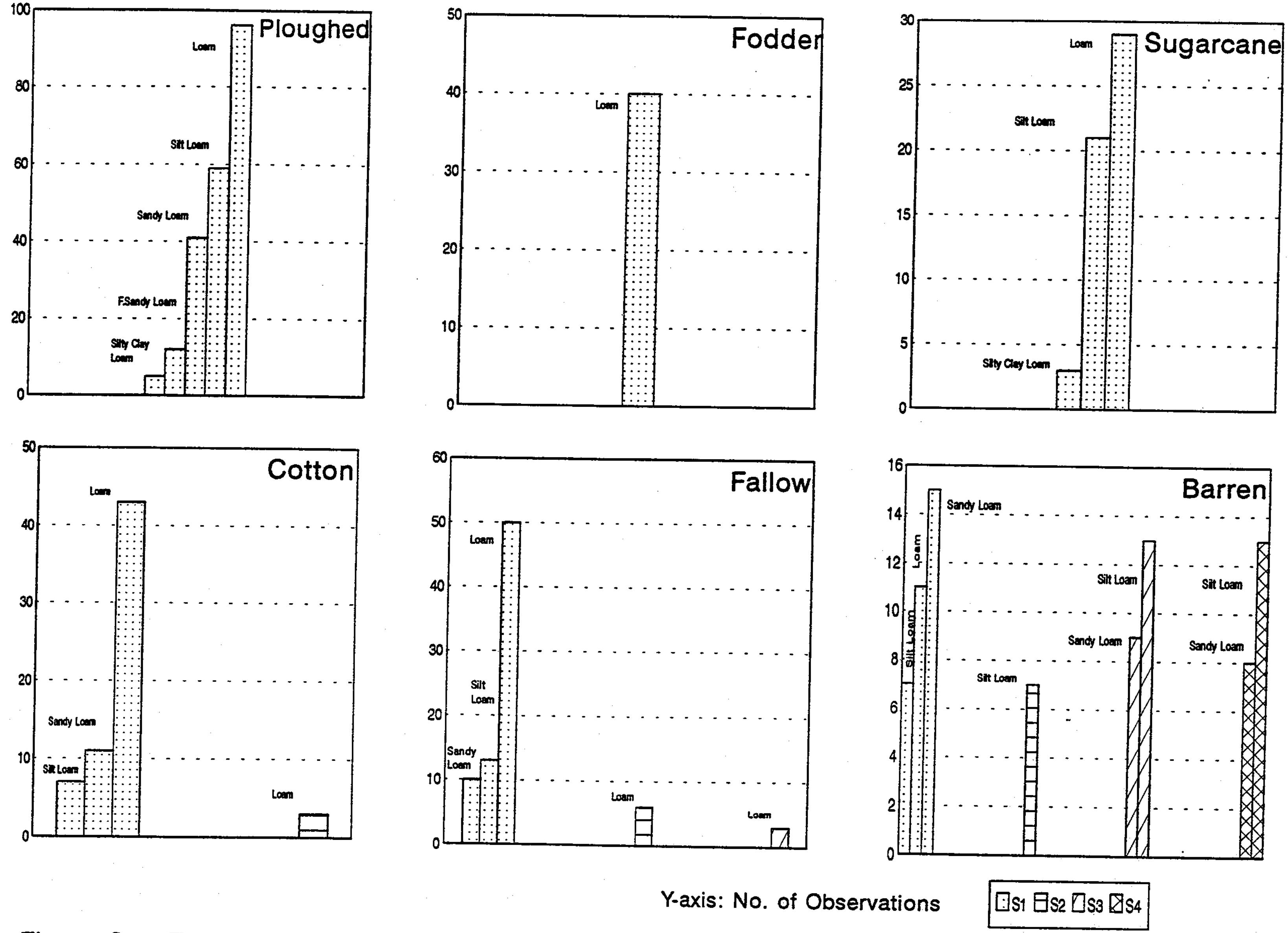


Figure C1 Top Root Zone Soil Texture and Crop Cover Differentiated for Soil Salinity; IIMI Sample Coverage for Aminpur Subdivision, Lower Chenab Canal Command, Rechna Doab, Pakistan.

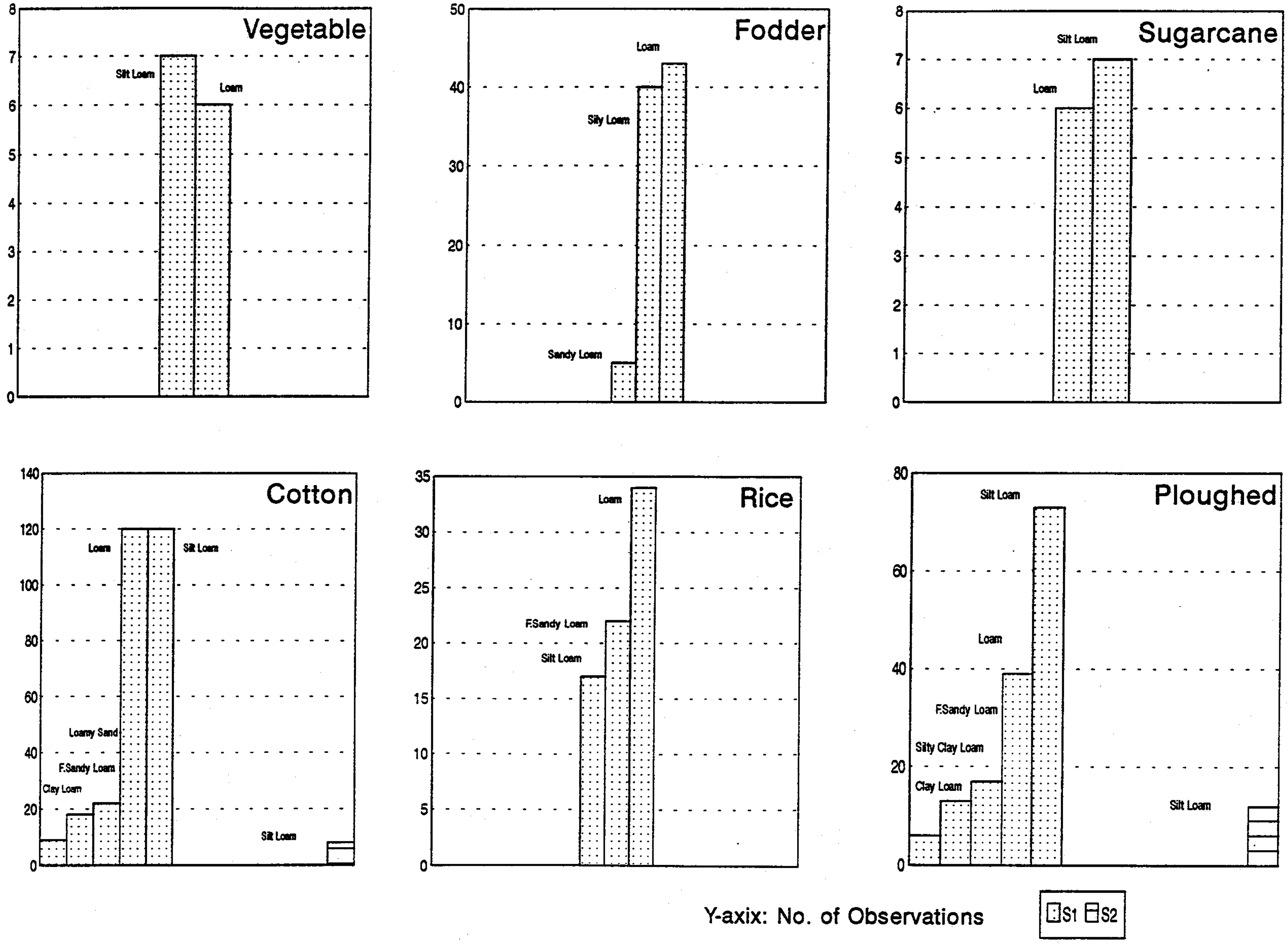


Figure C2 Top Root Zone Soil Texture and Crop Cover Differentiated for Soil Salinity; IIMI Sample Coverage for Bhagat Subdivision, Lower Chenab Canal Command, Rechna Doab, Pakistan.

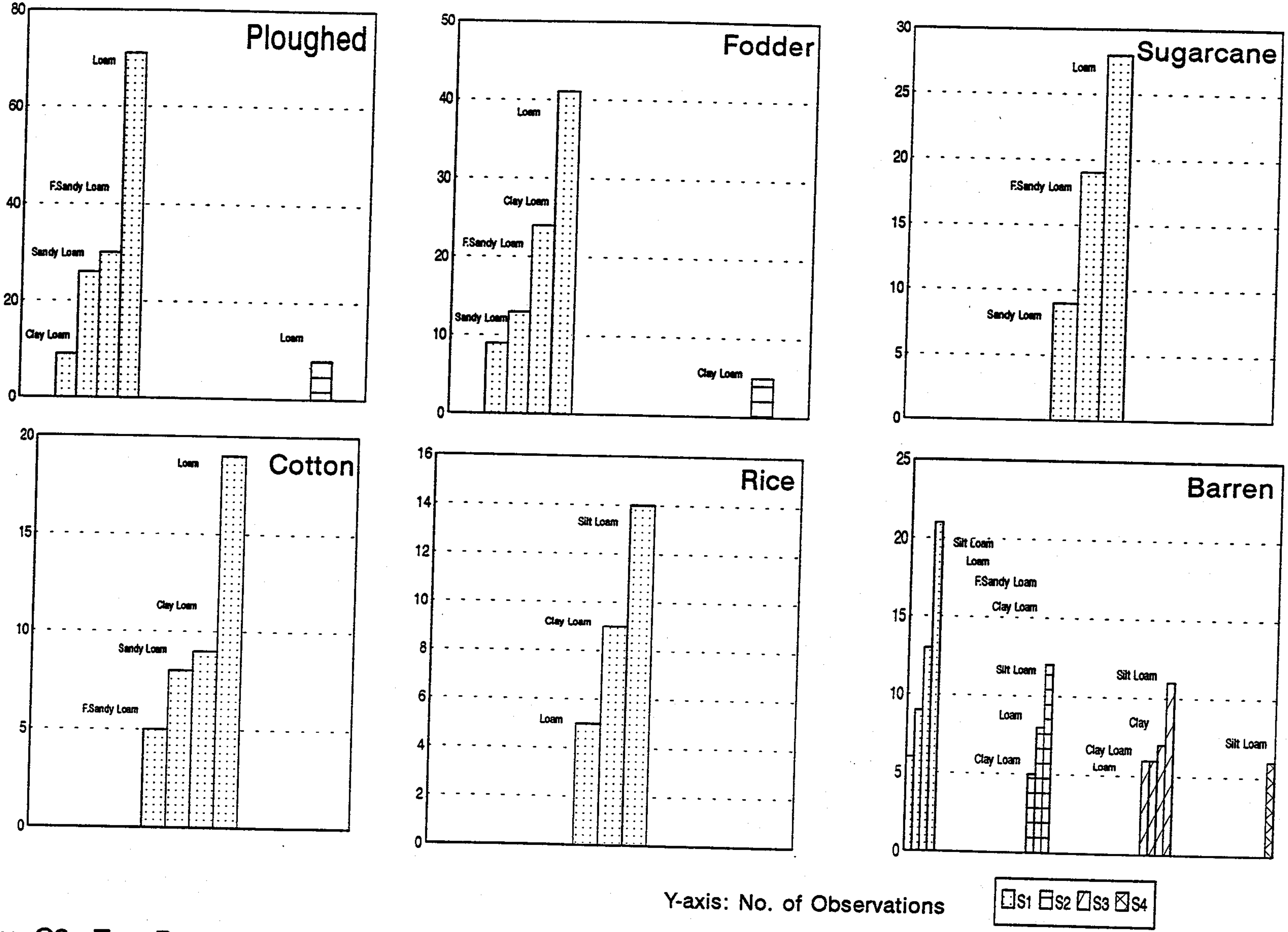


Figure C3 Top Root Zone Soil Texture and Crop Cover Differentiated for Soil Salinity; IIMI Sample Coverage for Butchiana Subdivision, Lower Chenab Canal Command, Rechna Doab, Pakistan.

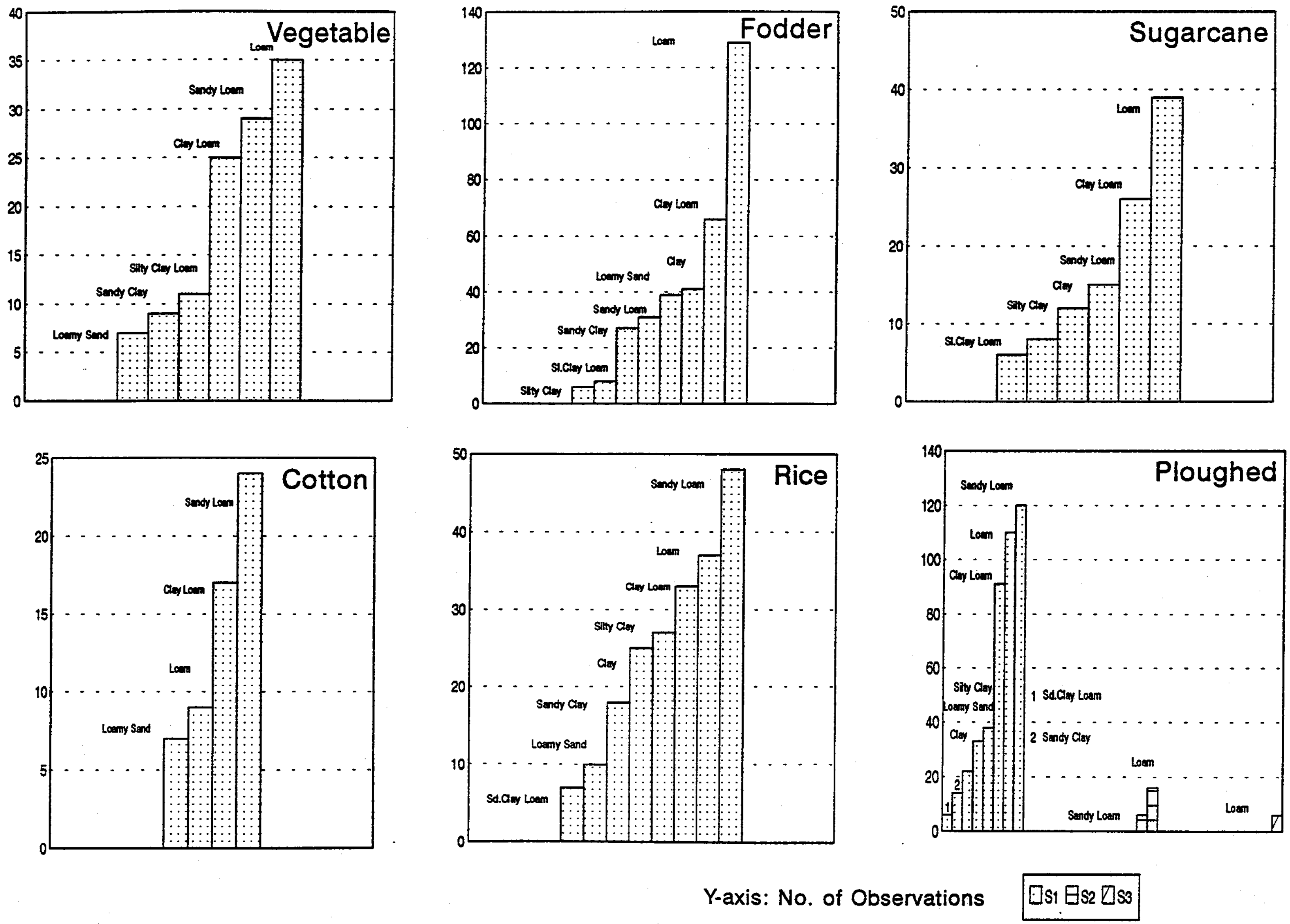


Figure C4 Top Root Zone Soil Texture and Crop Cover Differentiated for Soil Salinity; IIMI Sample Coverage for Chuharkana Subdivision, Lower Chenab Canal Command, Rechna Doab, Pakistan.

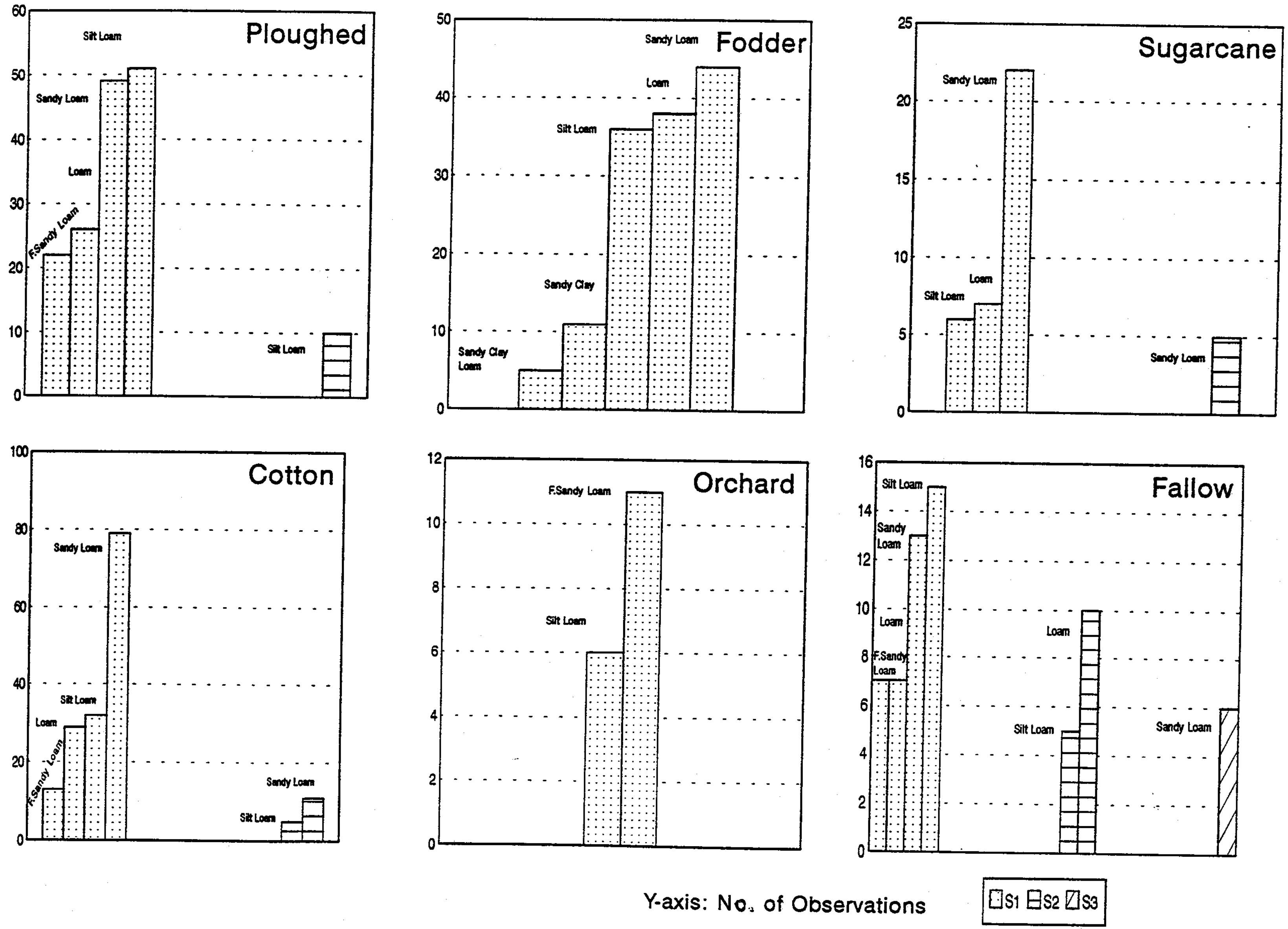


Figure C5 Top Root Zone Soil Texture and Crop Cover Differentiate for Soil Salinity; IIMI Sample Coverage for Dhaular Subdivision Lower Chenab Canal Command, Rechna Doab, Pakistan.

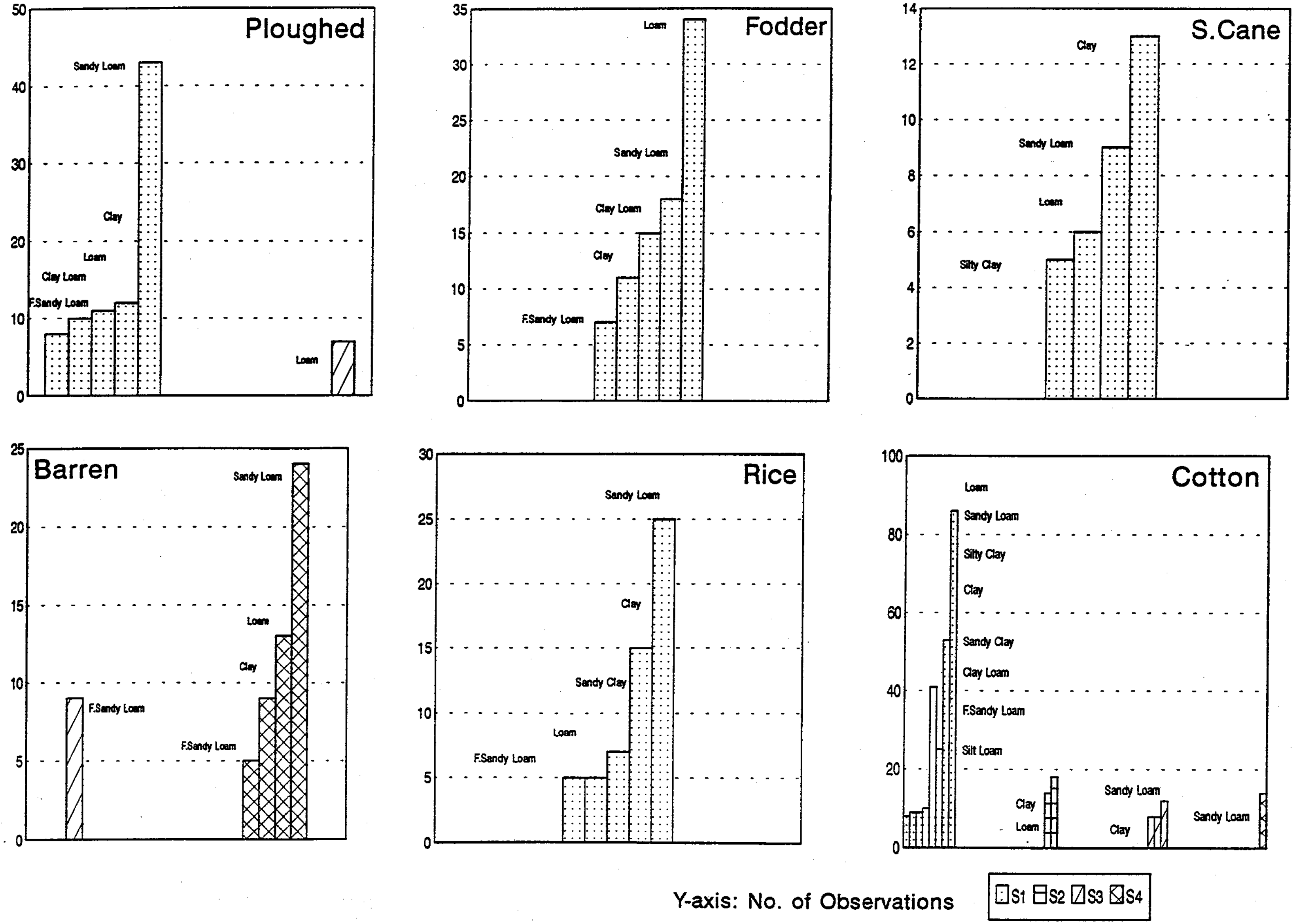


Figure C6 Top Root Zone Texture and Crop Cover Differentiated for Soil Salinity; IIMI Sample Coverage for Haveli Subdivision, Lower Chenab Canal Command, Rechna Doab, Pakistan.

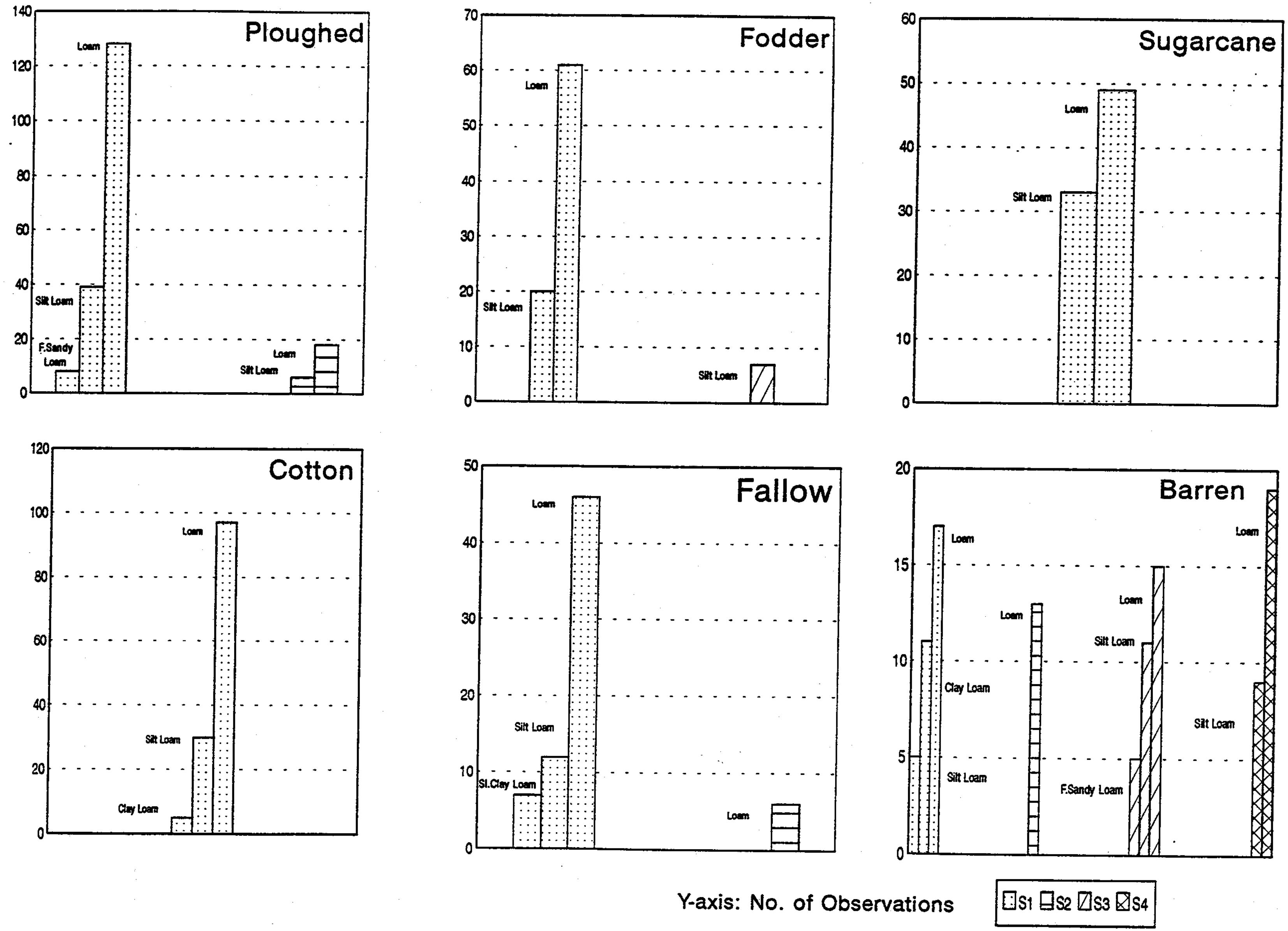


Figure C7 Top Root Zone Soil Texture and Crop Cover Differentiated for Soil Salinity; IIMI Sample Coverage for Kanya Subdivision, Lower Chenab Canal Command, Rechna Doab, Pakistan.

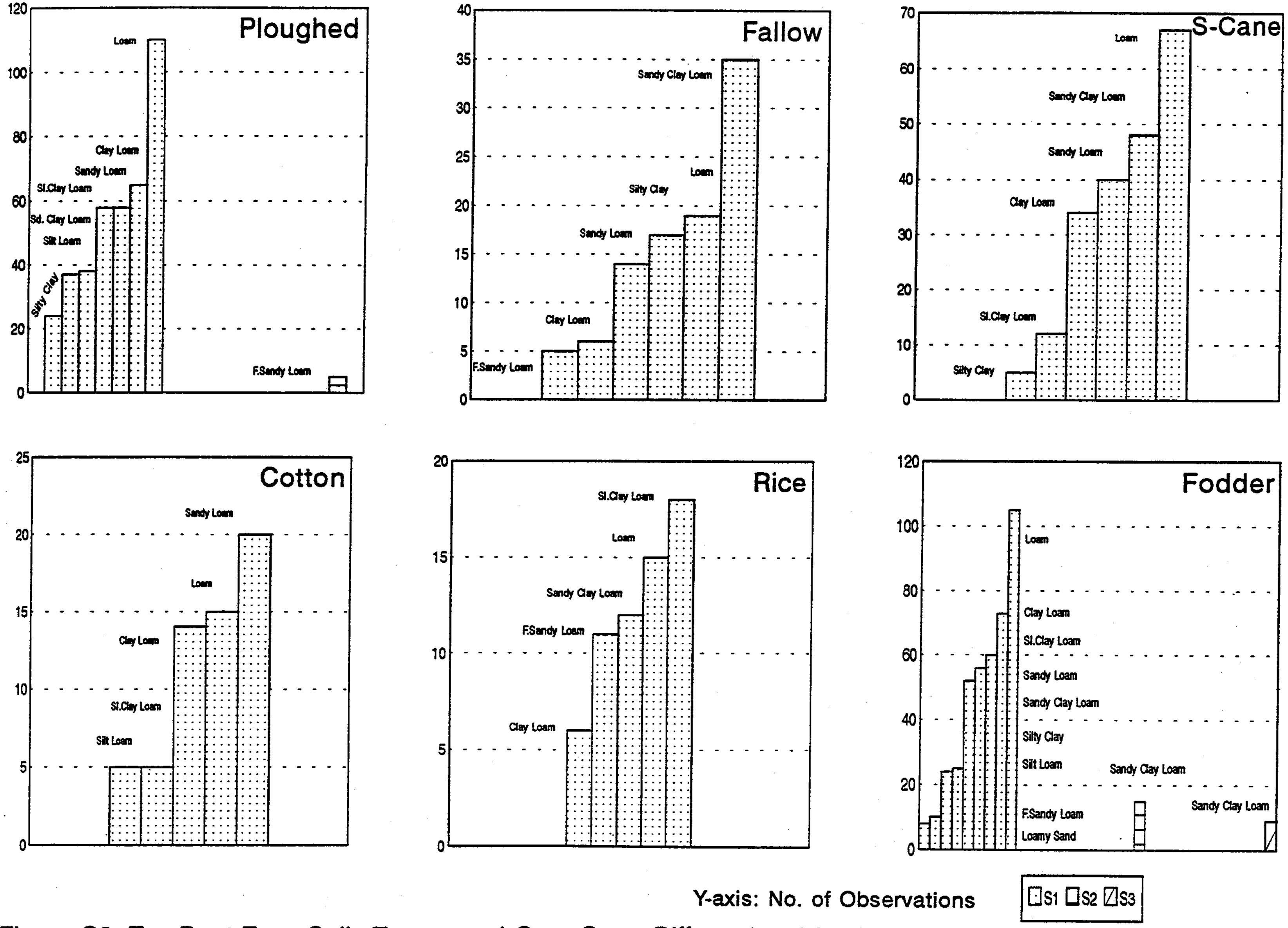


Figure C8 Top Root Zone Soils Texture and Crop Cover Differentiated for Soil Salinity; IIMI Sample Coverage for Kot Khuda Yar Subdivision, Lower Chenab Canal Command, Rechna Doab, Pakistan.

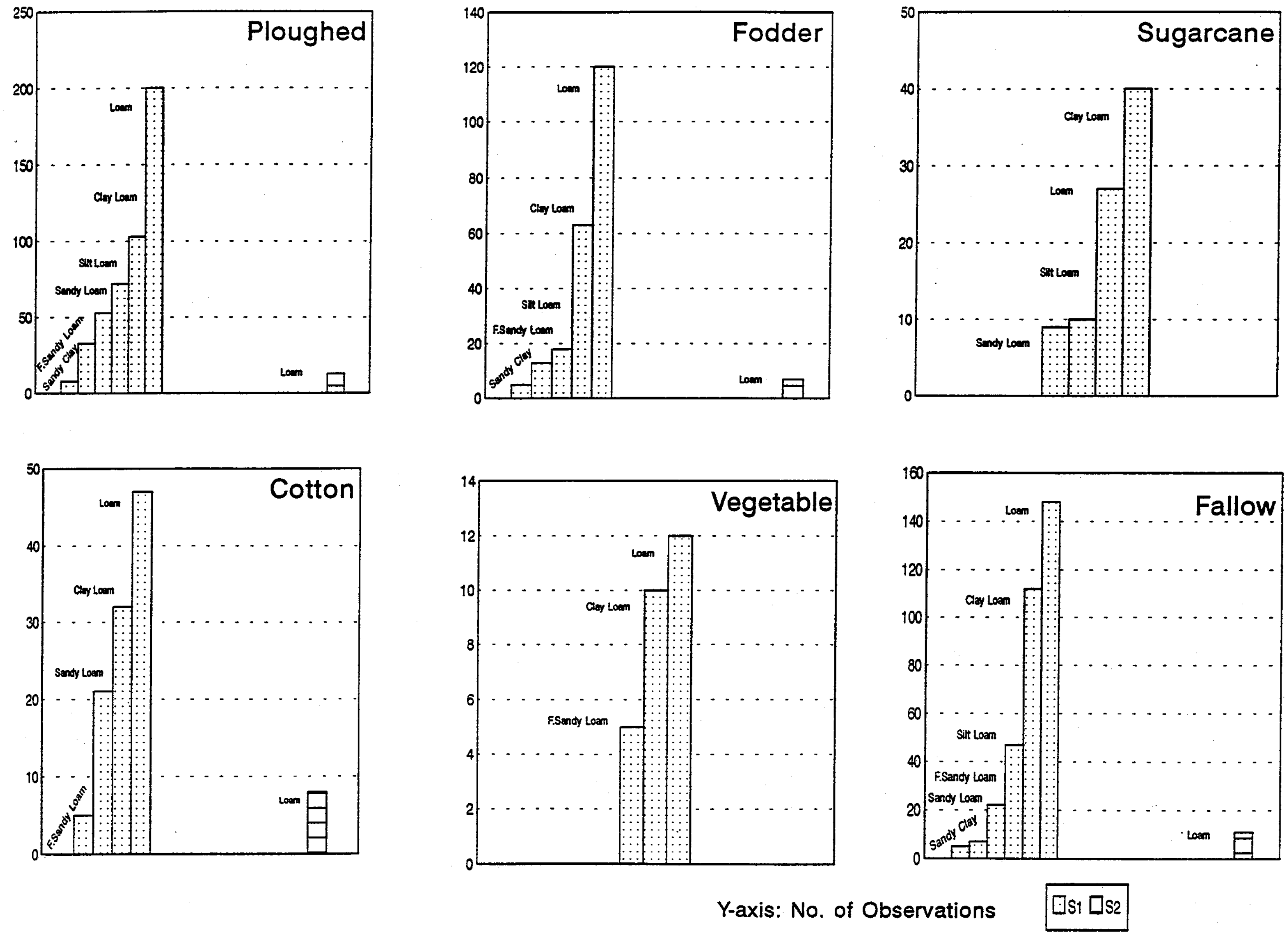


Figure C9 Top Root Zone Soil Texture and Crop Cover Differentiated for Soil Salinity; IIMI Sample Coverage for Mohlan Subdivision, Lower Chenab Canal Command, Rechna Doab, Pakistan.

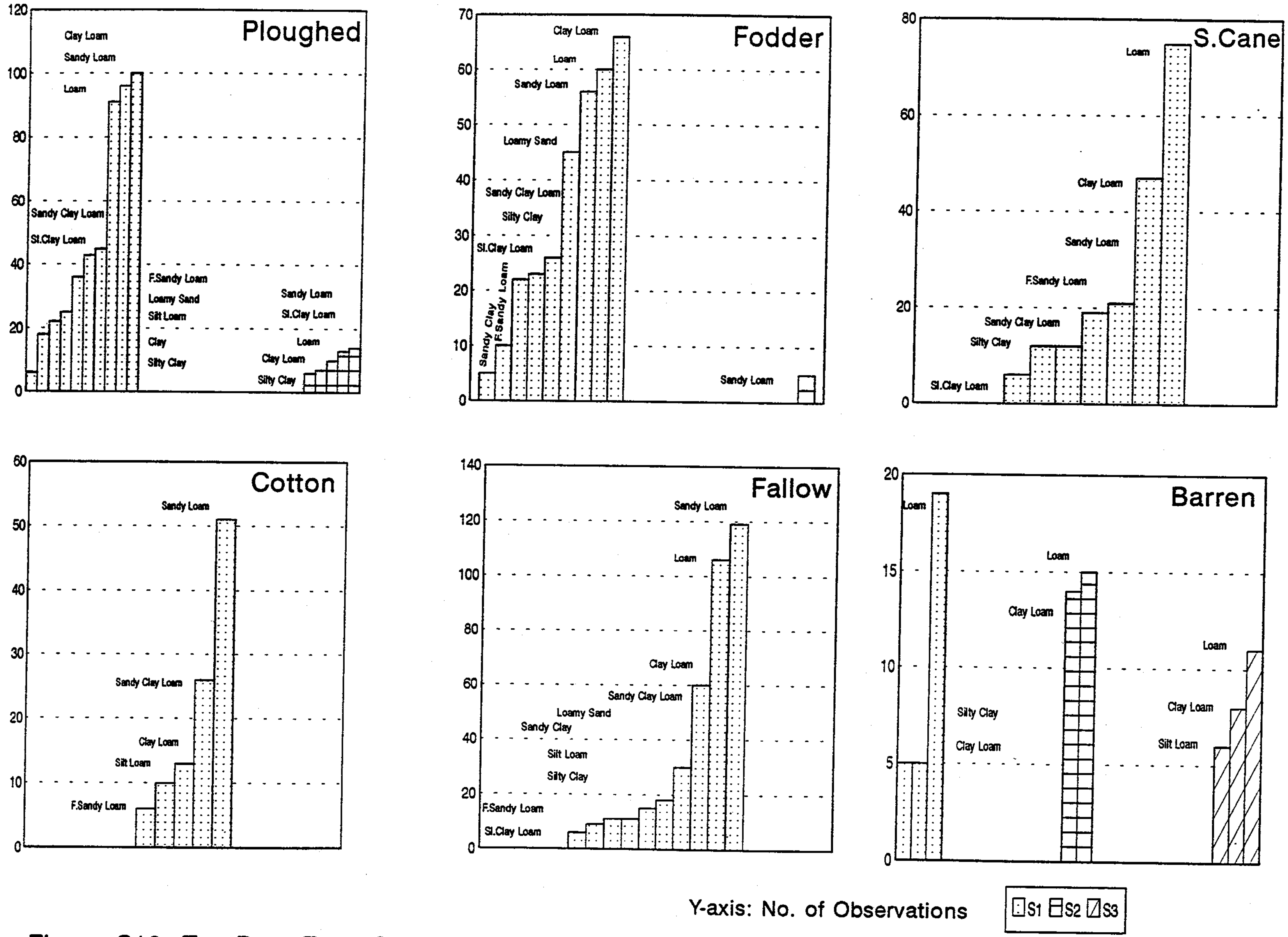


Figure C10 Top Root Zone Soil Texture and Crop Cover Differentiated for Soil Salinity; IIMI Sample Coverage for Pacca Dala Subdivision, Lower Chenab Canal Command, Rechna Doab, Pakistan.

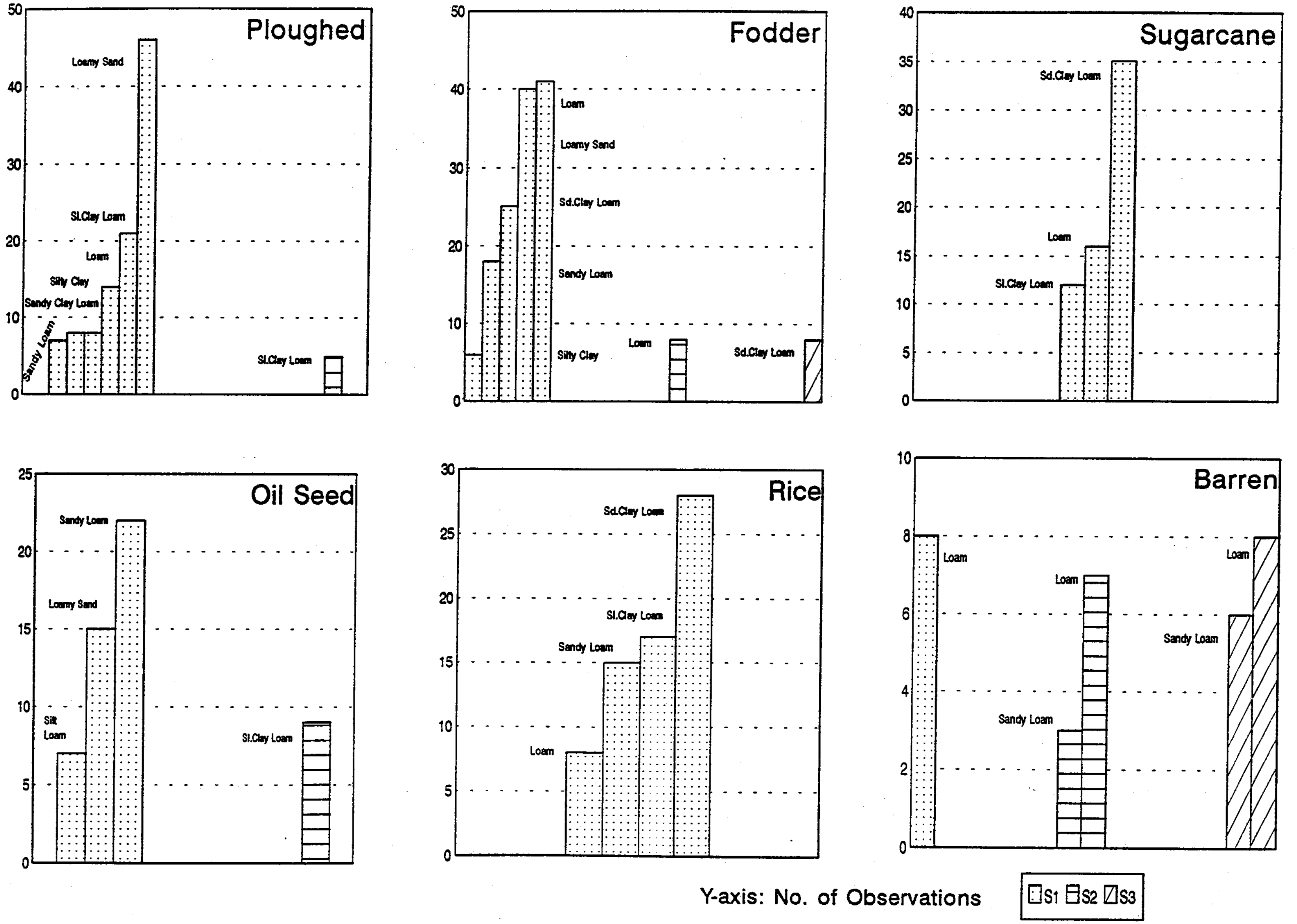


Figure C11 Top Root Zone Soil Texture and Crop Cover Differentiated for Soil Salinity; IIMI Sample Coverage for Sangla Subdivision, Lower Chenab Canal Command, Rechna Doab, Pakistan.

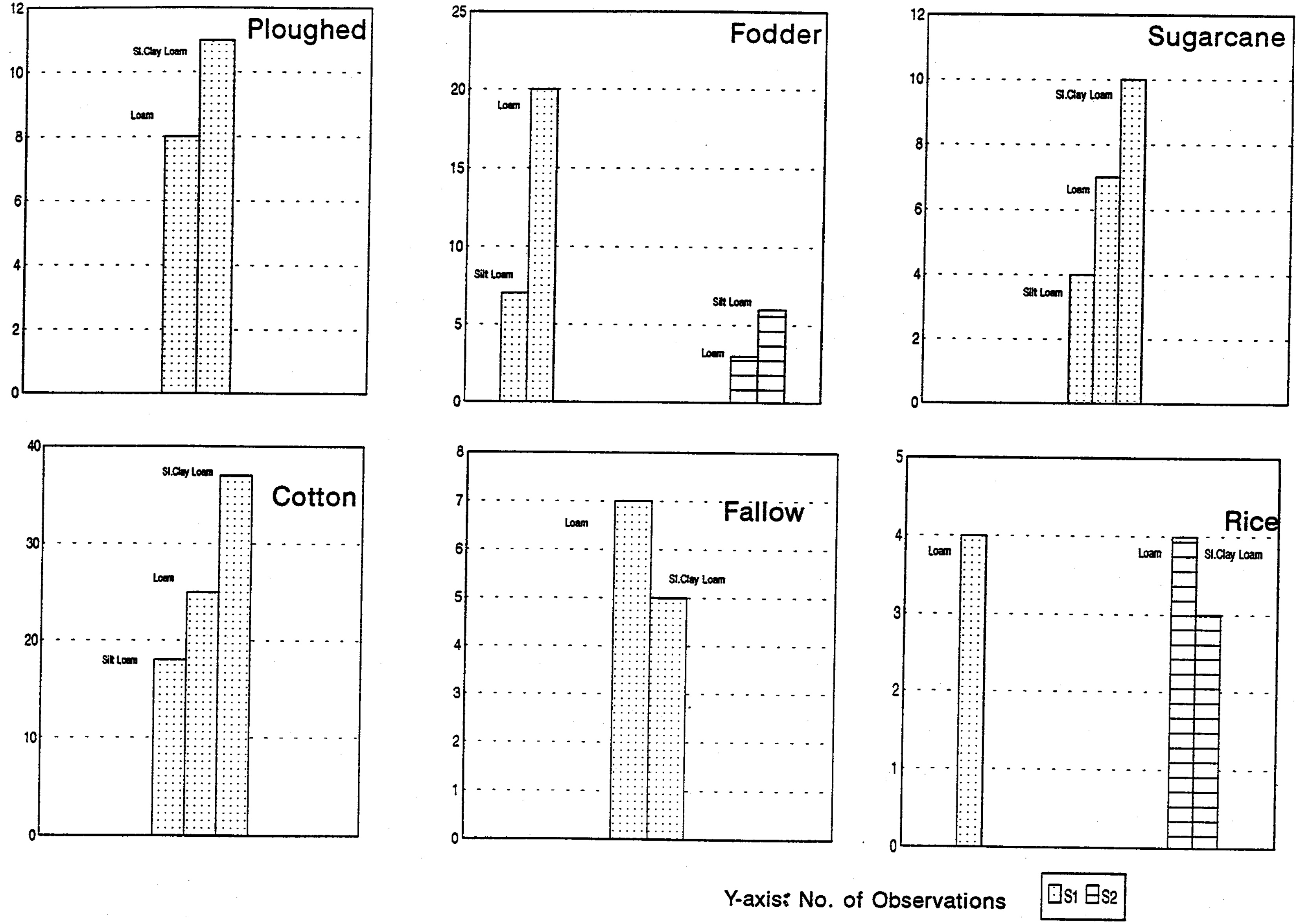


Figure C12 Top Root Zone Soil Texture and Crop Cover Differentiated for Soil Salinity; IIMI Sample Coverage for Sultanpur Subdivision, Lower Chenab Canal Command, Rechna Doab, Pakistan.

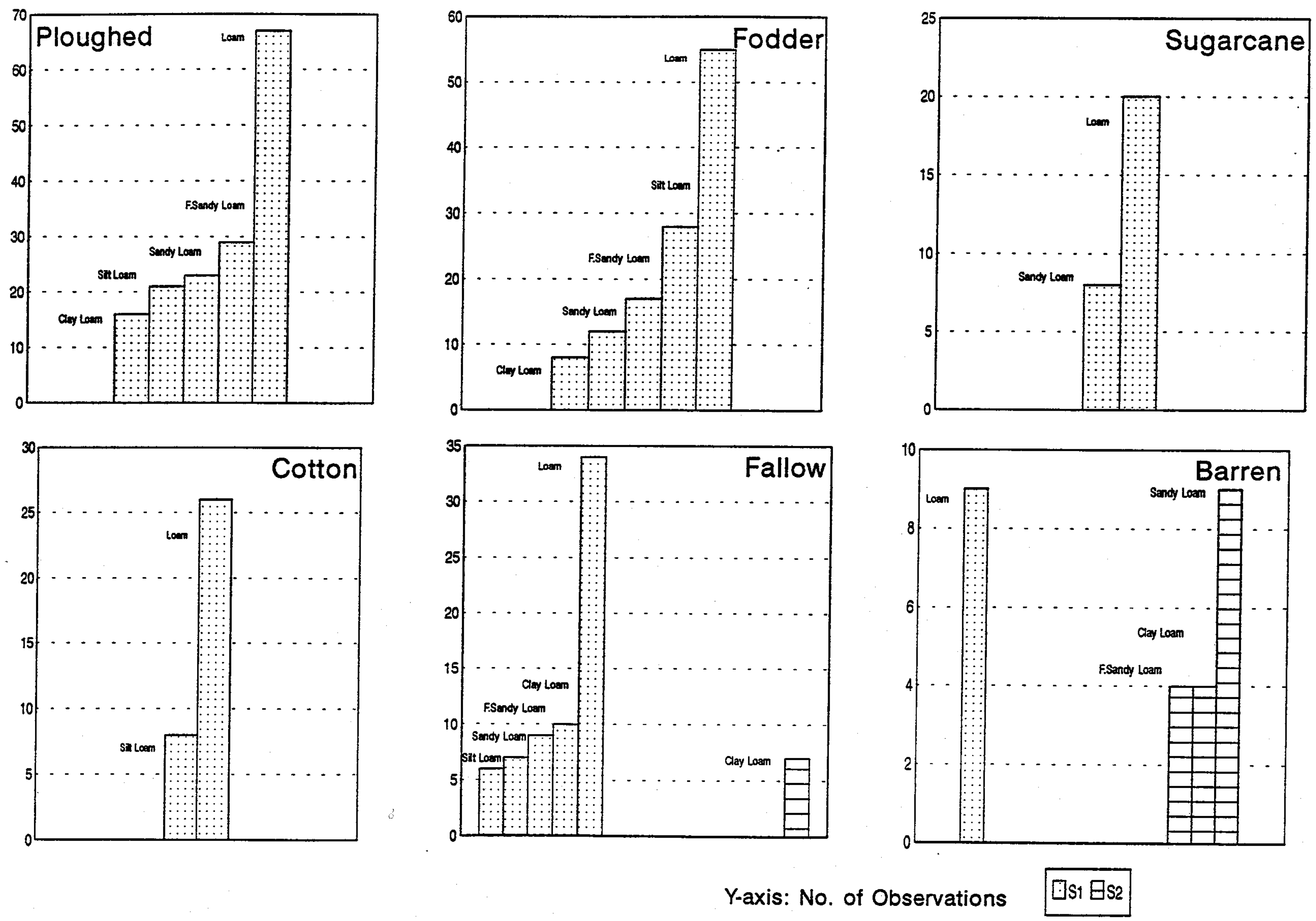


Figure C13 Top Root Zone Soil Texture and Crop Cover Differentiated for Soil Salinity; IIMI Sample Coverage for Tandlianwala Subdivision Lower Chenab canal Command, Rechna Doab, Pakistan.

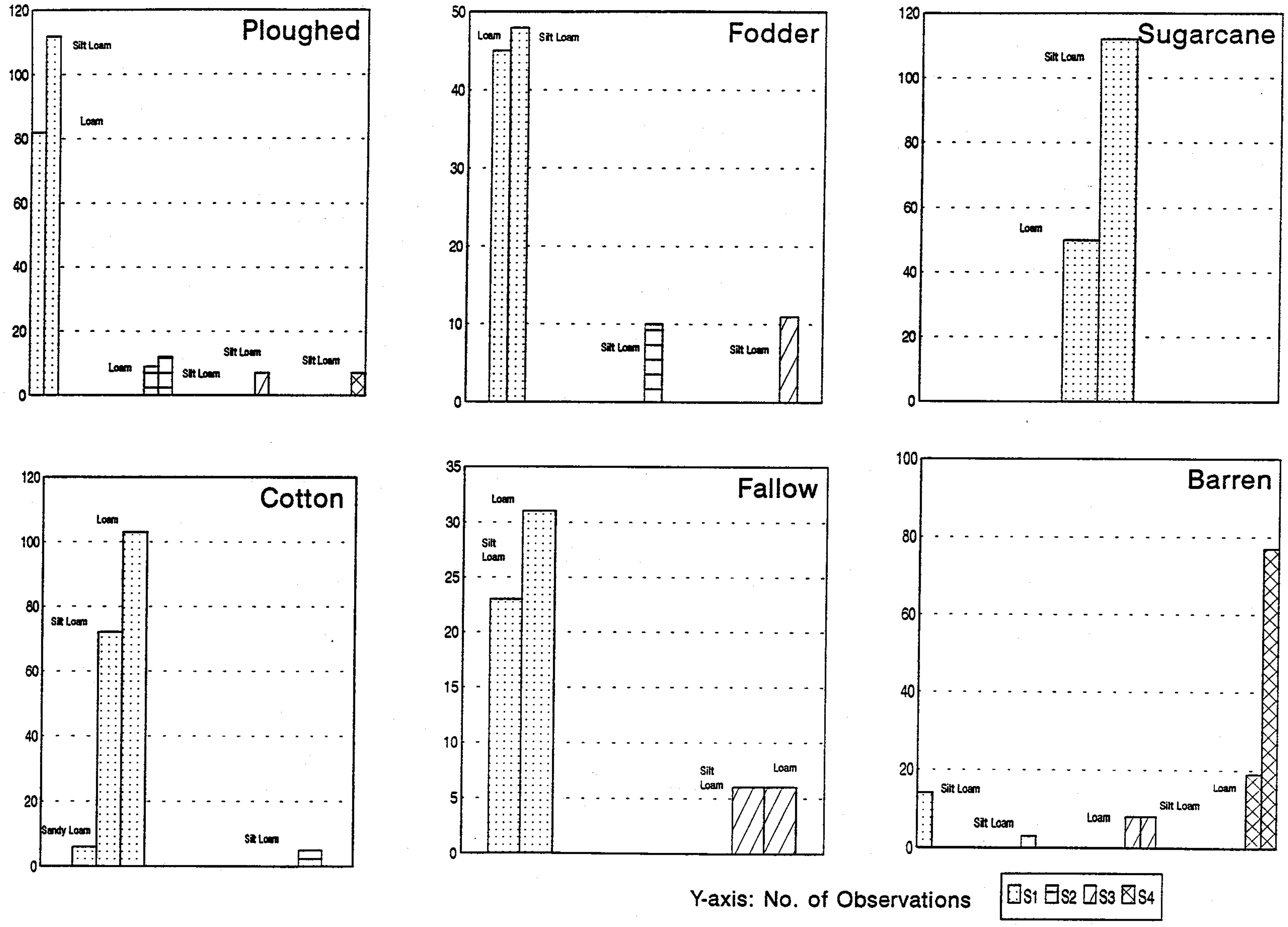


Figure C14 Top Root Zone Soil Texture and Crop Cover Differentiated for Soil Salinity; IIMI Sample Coverage for Tarkhani Subdivision, Lower Chanab Canal Command, Rechna Doab, Pakistan.

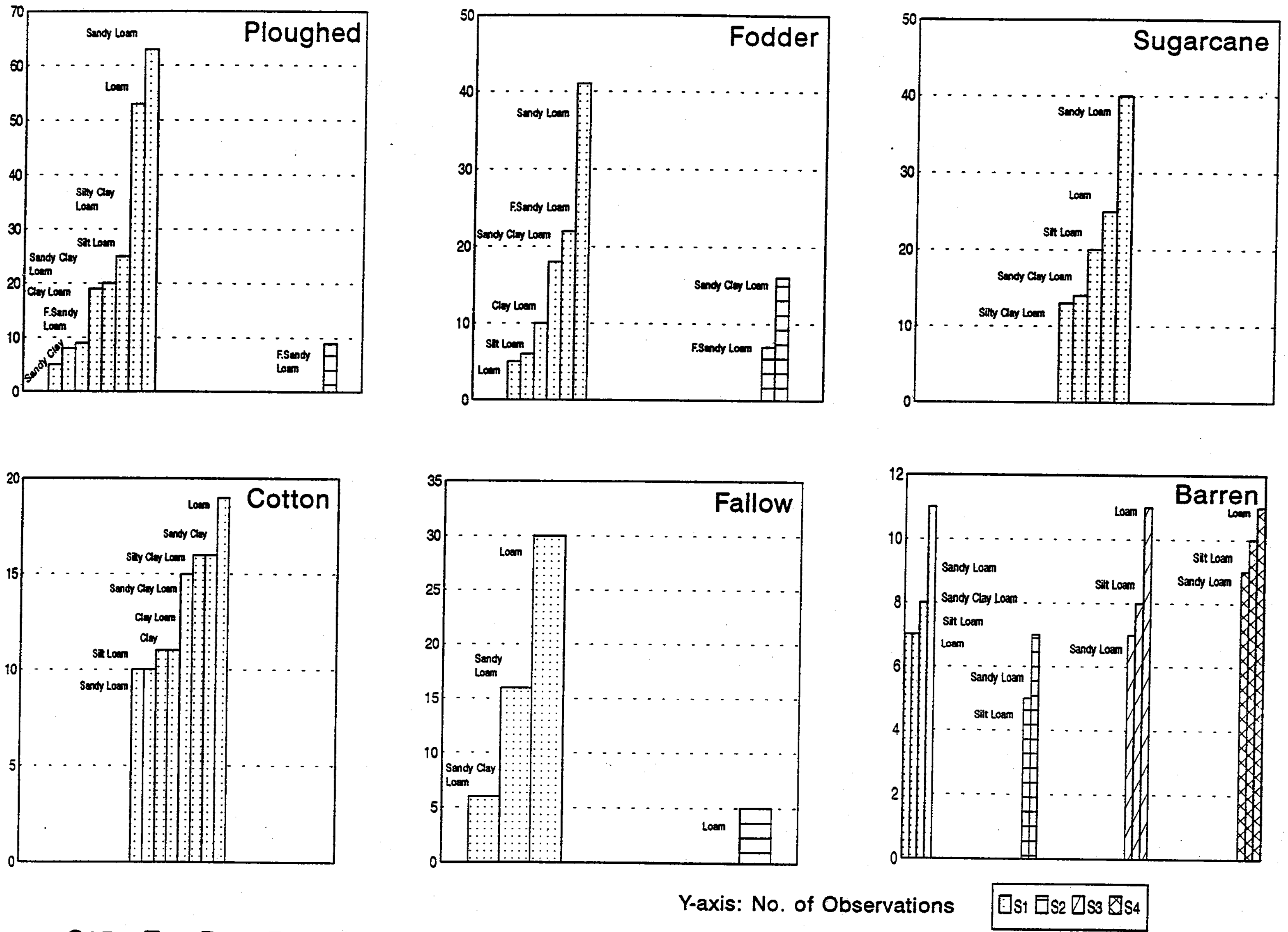


Figure C15 Top Root Zone Soil Texture and Crop Cover Differentiated for Soil Salinity; IIMI Sample Coverage for Uqbana Subdivision, Lower Chenab Canal Command, Rechna Doab, Pakistan.

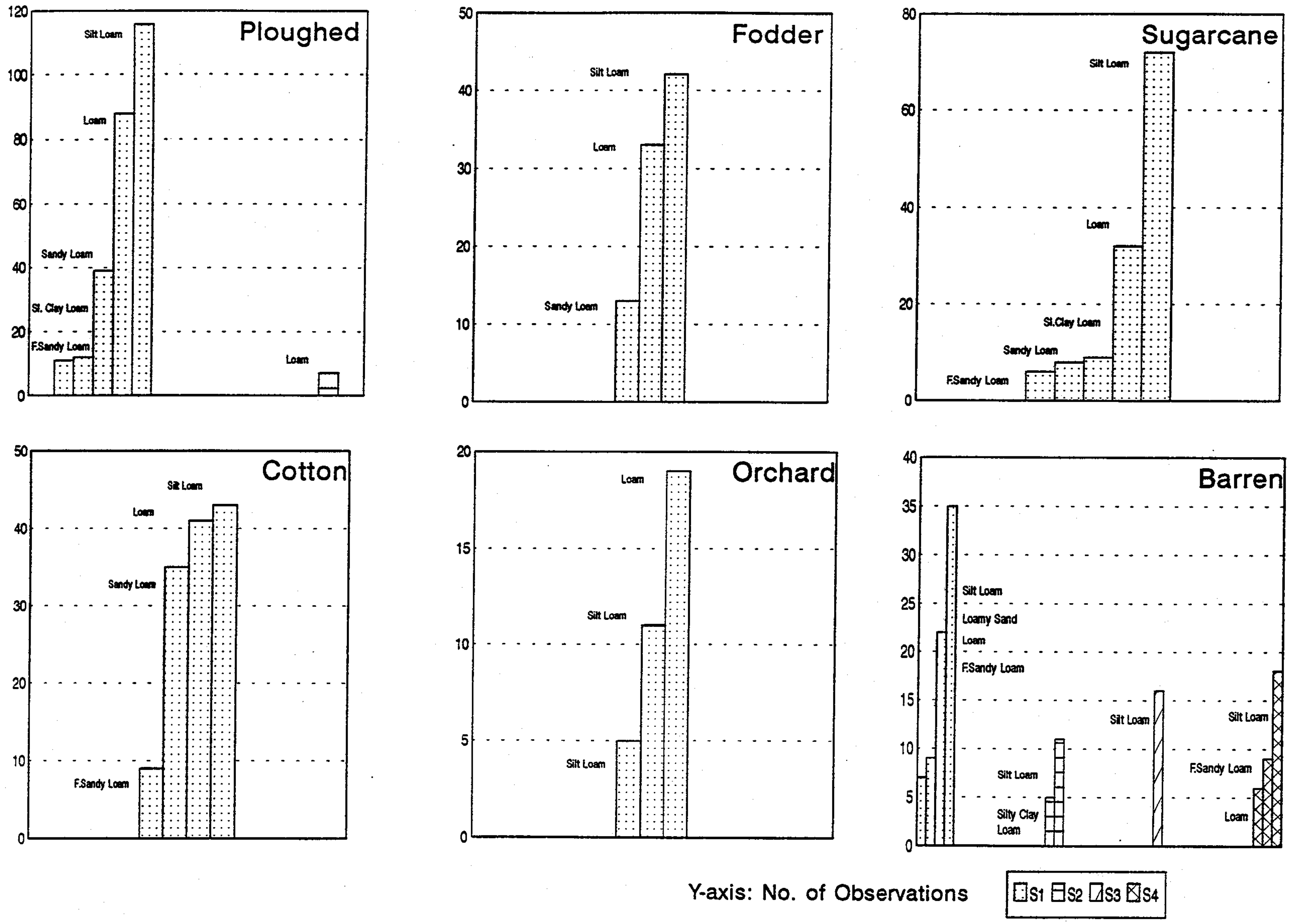


Figure C16 Top Root Zone Soil Texture and Crop Cover Differentiated for Soil Salinity; IIMI Sample Coverage for Veryam Subdivision, Lower Chenab Canal Command, Rechna Doab, Pakistan.

APPENDIX-D

IIMI Sample Survey
Questionnaire for Farm Survey

Appendix-D
IIMI Sample Survey
Questionnaire for Farm Survey

Variable Code

Sample No. ______ 1. ______

Farm Location: 1. Head ______ 2. Middle ______ 3.Tail 2. ______

How far from the recharge source (in Blocks of 25 Acres)______ 3. ______

Farm Operators Name: ______ 4. ______

Village:
______ 5. ______

Outlet #:
______ 6. ______

Sub-district : ______ 7. ______

0. Not known	1. Faisalabad	2. Jaranwala
3. Samundri	4. Gojra	5. Chiniot
6. T.T.Singh	7. Kamalia	8. Jhang
9. Shorkot	10. Kabirwala	11. Sheikhupura
12. Ahmadpur	13. Nankana	14. Chak Jhumra
15. Tandlianwala	16. Hafizabad	17. Pindi Bhattian

TENURE

Size of holding: (Acres) ______ 8. ______

No. of Parcels: ______ 9. ______

Plot Tenure:1. Owned ______ 2. Tenant ______ 10. ______
3. Lease ______ 4. Own-cum-Ten. ______

Area rented in ______ (Acres) 11. ______

Area rented out ______ (Acres) 12. ______

If on lease rent of land per year/Ac. ______ 13. ______

If tenant, quantity of produce (%) ______ 14. ______

Time req. to irrigate 1 acre of field by T/W (E/D) ______ 29. ______

Intervals in subsequent irrigation (days) ______ 30. ______

Consumption of electrical units per hour ______ 31. ______

Consumption of diesel liters per hour ______ 32. ______

Cost of irrigation per acre ______ 33. ______

Farmer's perception about the salinity/sodicity problem

What is the discharge of the T/W.
(gpm/cusec/delivery size in inches) 34. ______

Quality of T/W water:
0. Not Known ______ 1. Good ______
2. Saline/sodic ______ 3. Moderate ______ 35. ______

If saline water, during which crop growth stage you wish to avoid T/W water use
______ 36. ______

0. Not known 1. Initial stage
2. Do not care 3. Conjunctive use

For how long have you owned the Tubewell (Years) ______ 37. ______

How Deep is the well bore? (feet)______ 38. ______

Detpth to water table (feet) ______ 39. ______

Did you test the water quality before sinking the T/W. 40. ______
0. Not Known 1. Yes ______ 2. No ______

Why or why not? 41. ______

Have you ever had the water quality tested? 42. ______
0.Not known 1. Yes ______ 2. No ______

How often do you pump the water (hours/day) ______ 43. ______

Days/month ______ 44. ______

How often do you sell/purchase the water (hours/month) ______ 45. ______

Do you think that you have a water quality problem?
0. Not Known 1.Yes 2.No 46. ______

If yes for how long? (Years) ______ 47. ______

LAND USE SUMMARY

Total farm size[3]: ——————————————— (Acres) 15. ————

Waste and Uncultivated land due to water logging ————(Acres) 16. ————

Waste and Uncultivated land due to Salinity ———— (Acres) 17. ————

Waste and Uncultivated land due to Sodicity ———— (Acres) 18. ————

Fallow Land in Kharif ——————————— (Acres) 19. ————

Fallow Land in Rabi ——————————(Acres) 20. ————

Reasons for keeping land Fallow ———————— 21. ————

0. Not Fallow 1. Scarcity of water 2. Salinity
3. Sodicity 4. Salinity and scarcity of water
5. Sodicity and scarcity of water 6.Waterlogging
7. Others (Late sowing, Disease attack, Unavailability of labour, kept fallow for next crop).

Cultivated Area ——————————— (Acres) 22. ————

CROPPING PATTERN

Cropping pattern: 1. Rice-Wheat ———————— 23 ————

2. Cotton-Wheat 3. Sugarcane-Wheat ————
4. Any other (specify) ————————

Main Crop on the farm: 1. Wheat ——— 2. Rice ———— 24. ————

3. Cotton ——— 4. Sugarcane ———
5. Kharif Fodder ——— 6. Rabi. Fodder ————
7. Others (Specify) ————————

Sources of Irrigation: 1. Canal ——— 2. T/W(Elec.) ————

3. T/W(Diesel) ——————— 4. Canal + T/W (D/E) 25. ————
5. Public T/W ——————— 6. Canal + Public T/W

Location of tubewell: 26. ————

(Distance from canal/distributory/minor (Km) ———

During which month do you use maximum T/W water

Rabi ——— ——— Kharif ——— ——— 27. ————

Time req. to irrigate one acre of field by canal (hours) ———— 28. ————

---

[3] Note 8 + 11 - 12

Has the ground water changed the soil conditions? 48. ________
1. Yes 2. No. 3. Improved 4. Worsened

Do you think that your crop yields have changed over time?
0. Not known 1. No change
2. Increase 3. Decrease 49. ________

If decreased, why? 50. ________
0. Not known 1. Scarcity of water
2. T/W water 3. Salinity
4.Sodicity 5.Others(Waterlogging,Intensive cultivation,disease,etc)

If increased, what are the factors? 51. ________
0. Not known
1. Good water (installation of tubewell)
2. Good soil (Improvement in soil conditions, Cultural practices)
3. Inputs (Seed, Fertilizer, etc.)

Have you increased the average level of input use (seed/fert./water) 52. ________
0. Not Known 1. 25% ______ 2. 50% ______ 3. 75 %______

Did you ever get your soil tested?
0. Not Known 1. Yes 2. No 53. ________

If no why not? ____________________ 54. ________

If yes, what is wrong ____________________ 55. ________

Do you feel that your soil has problem of: 56. ________
0. Not known 1. Salinity 2. Sodocity
3. Saline-sodic 4. No problem 5. Waterlogging

What do you do to manage the salinity problem?
0. Not known 1. Gypsum 2. FYM
3. Heavy irrigation
4. Removal of upper soil
5. Can not manage due to scarcity of water
6. Can not manage due to high cost of reclamation
7. Acid 8. No problem
9. Others (Leveling, Sewerage water, Conjunctive use, cultivation of rice or *Janter*)

What do you do to manage the sodicity problem?
0. Not known
1. Gypsum 2. FYM
3. Heavy irrigation
4. Removal of upper soil
5. Can not manage due to scarcity of water
6. Can not manage due to high cost of reclamation
7. Acid 8. No problem
9. Others (Leveling, Sewerage water, Conjunctive use, cultivation of rice or *Jantar*)

What role do you think the govt. should play to solve the salinity problem?

0. Not known
1. Gypsum at subsidized rates
2. Increase supply of canal water
3. Lined water courses
4. Others (public tubewell on *moga,* T/W water cause of salinity)
5. Drainage

What role do you think that the govt. should play to solve the sodicity problem?

0. Not known
1. Gypsum at subsidized rates
2. Increase supply of canal water
3. Lined watercourses
4. Others (public tubewell on *moga,* T/W water cause of salinity)
5. Drainage

Any other suggestions to improve the situation in the area?

0. Not known
1. Provision of fertilizer at subsidized rates
2. Adequate supply of canal water
3. Credit disbursement
4. Cooperative farming
5. Check adulteration in chemical inputs
6. Lined water courses
7. Agricultural extension
8. Breaches in water delivery system
9. Bribery
10. Others (tubewell near recharge source,cheap electricity, good prices of outputs, provision of machinery, drainage etc.)

What is the farmers perception about the impact of privatization of Scarp Tube Wells?

0. Not known
1. SCARP Tubewells are not present here
2. Desirable
3. Undesirable
4. Others

Drainage conditions on the farm:

0. Not Known
1. Good
2. Bad due to hardening
3. Bad due to depressions
4. Others

If drainage is the problem, what is farmers perception to get rid of that problem.

0. Not known
1. No problem
2. We wait till water evaporates 3. No solution
4. Addition of FYM
5. Addition of Gypsum 6. Others

Farm Operations:

Type of Operation	No/Quantity/Acre									
	Cotton	Sugarcane		Rice		Maize	Kh. Fodder	Wheat	Rabi Fodder	Others
		Plant	Ratoon	Fine	Coarse					
Land Preparation and Sowing Deep Tillage										
Cultivation Tractor (Own)										
(Hired)										
Bullocks										
Sohaga Tractor (Own)										
(Hired)										
Bullocks										
Bund Making										
Puddling										
Seed Bed Preparation Tractor (Own)										
(Hired)										
Bullocks										
Sohaga Tractor										
Bullocks										
Drill Tractor (Owned)										
(Hired)										
Bullocks										
Weeding (Number)										
Hoeing (Number)										
Interculture (Number) Tractor (Owned)										
(Hired)										
Bullock										
Seed/Acre (Owned)										
(Purchased)										
Seed Cost										
Seed Treatment Cost										
Fertilizer Urea (bags)										
(Cost)										
DAP (bags)										
(Cost)										
NP (bags)										
(Cost)										

Type of Operation	No/Quantity/Acre									
	Cotton	Sugarcane		Rice		Maize	Kh. Fodder	Wheat	Rabi Fodder	Others
		Plant	Ratoon	Fine	Coarse					
AS (bags)										
(Cost)										
SSP (bags)										
(Cost)										
TSP (bags)										
(Cost)										
MOP (bags)										
(Cost)										
AN (bags)										
(Cost)										
Zn SO_4 Qty.										
(Cost)										
Gypsum Qty.										
(Cost)										
Others Qty.										
(Cost)										
F Y M (Area Treated)										
Trolleys										
Cart Loads										
Donkey loads										
Camel Loads										
Trucks										
Pl. Protection (# of Spray)										
Tractor (Own)										
(Hired)										
Bullocks										
Manual										
Rs./Ac/Spray										
Weedicide (Rs./Ac./Spray)										
Irrigation Total #/Ac										
(Cost)										
Canal (Own)										
Purchased										
Tube well (Own)										
Purchased										

Type of Operation	No/Quantity/Acre									
	Cotton	Sugarcane		Rice		Maize	Kh. Fodder	Wheat	Rabi Fodder	Others
		Plant	Ratoon	Fine	Coarse					
Farm Lab. (Fam. Lab.)man days										
cost/Ac										
Permanent Hired Lab. Man days										
cost/Ac										
Casual Hired Labor Man days										
cost/Ac										
Prod. of Crops (Acreage)										
Yield/Ac (Kg)										
Yield/Ac. of Gur (Mnd)										
Total Production (Mnd)										
Home Consumption (MnD)										
Price Received (Rs/Mnd)										
Total Income/Acre (Rs)										
Income (Wheat Straw) Rs/Ac										
(Cotton Sticks) "										
(Rice Straw) Rs/Ac										
(S.Cane Tops) Rs/Ac										
(Other by products)										

NAME OF THE ENUMERATOR ____________________

APPENDIX-E

IIMI Sample Survey
Matrix for the Aggregation of Farm Level Data

APPENDIX-F

IIMI Sample Survey
Matrices for the Aggregation of Crop-Specific Data

APPENDIX-G

IIMI Sample Survey
Farm Level Characteristics

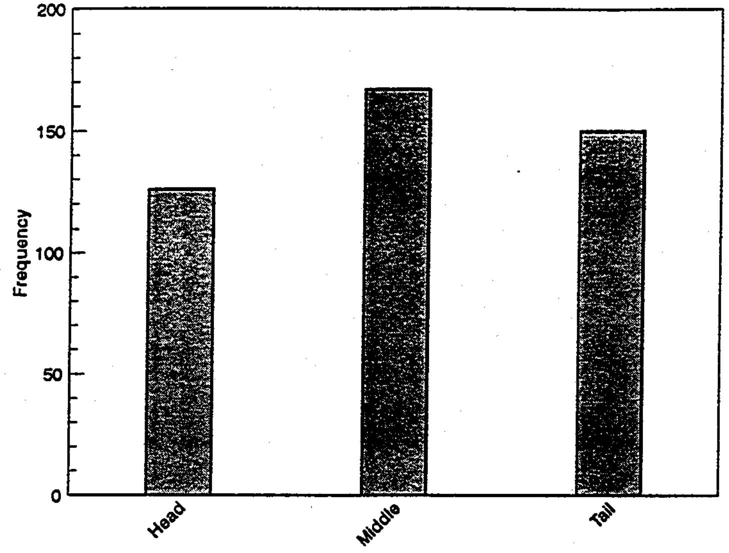


Figure G1 Location of the Farm

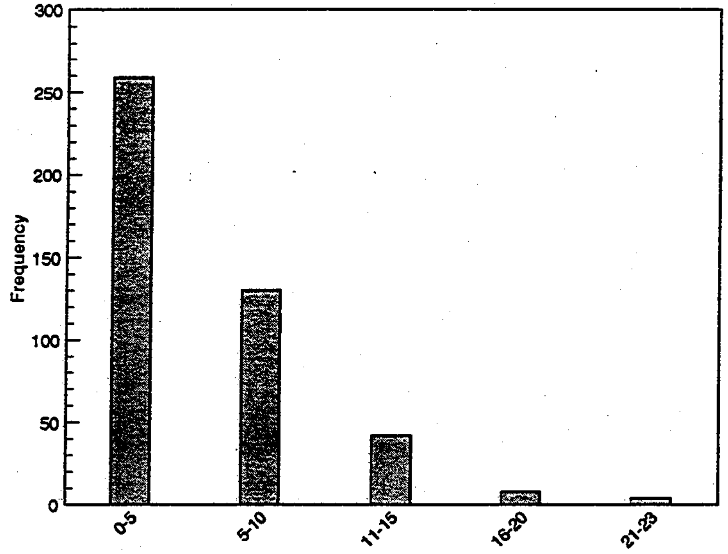


Figure G2 Distance (in Blocks of 25 Acres) from the Outlet

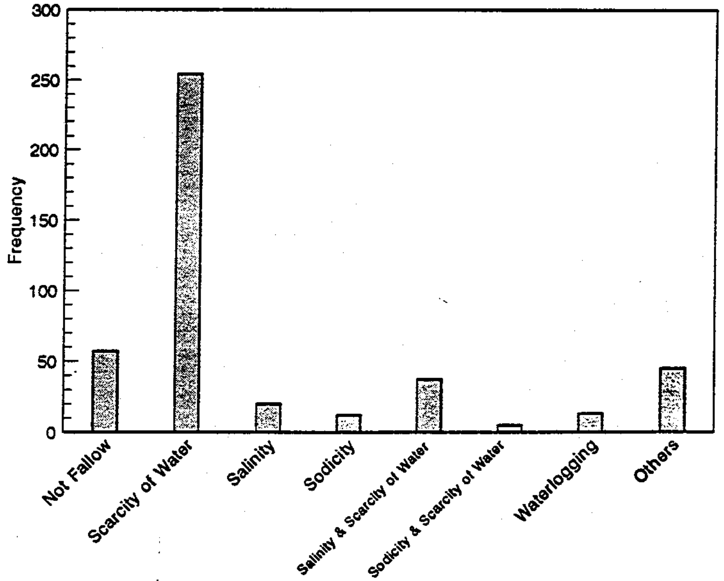


Figure G3 Constraints Necessitating Fallowing of Land

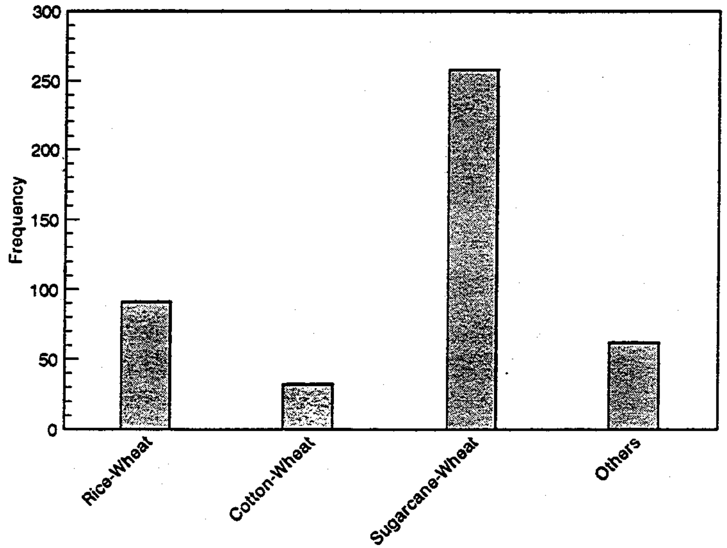


Figure G4 Cropping Pattern

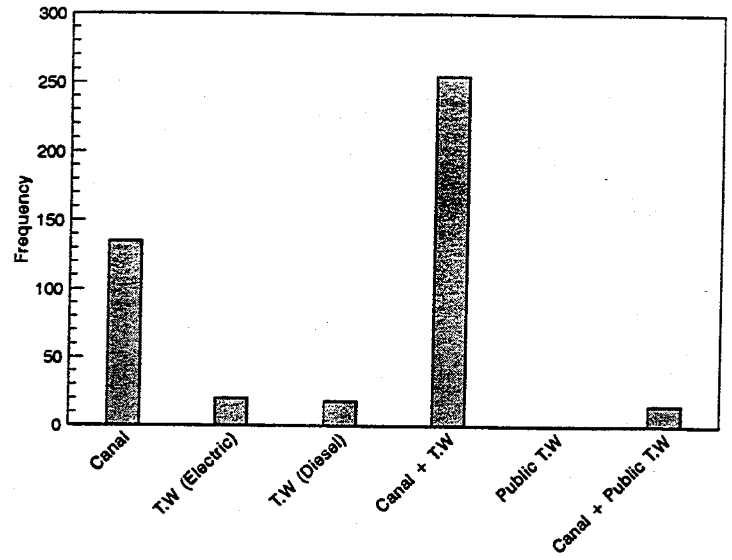


Figure G5 Source of Irrigation

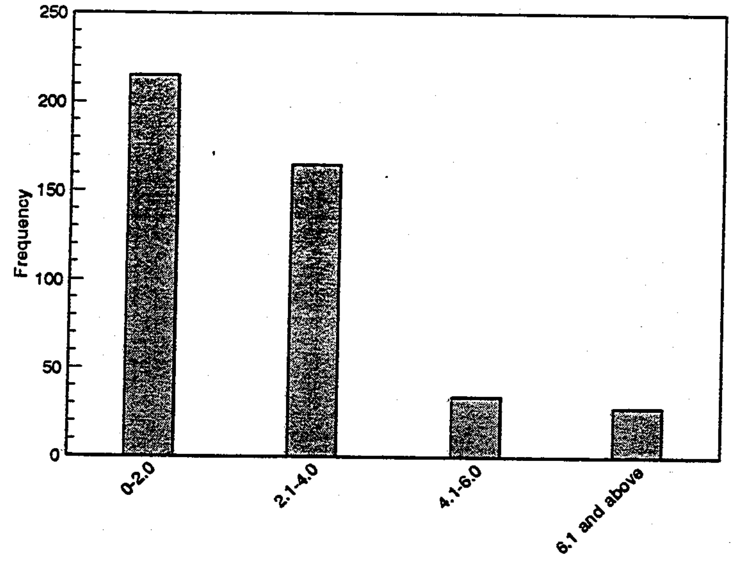


Figure G6 Time (Hours) to Irrigate an Acre with Canal Water

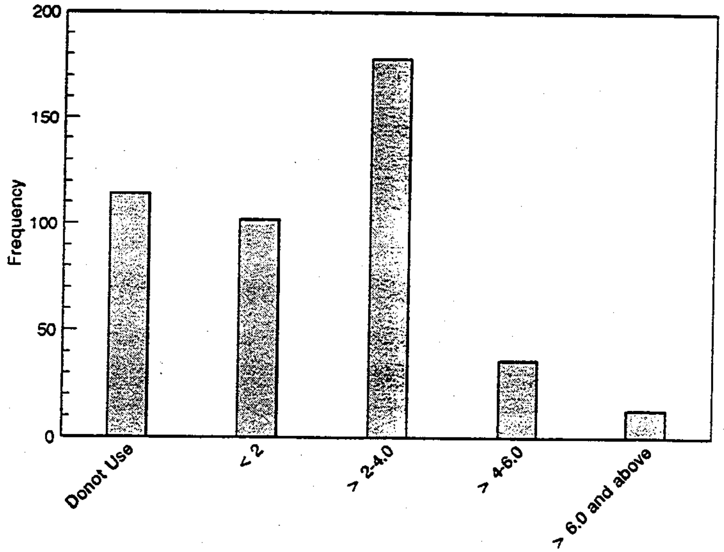


Figure G7 Time (Hours) to Irrigate an Acre with Tubewell Water

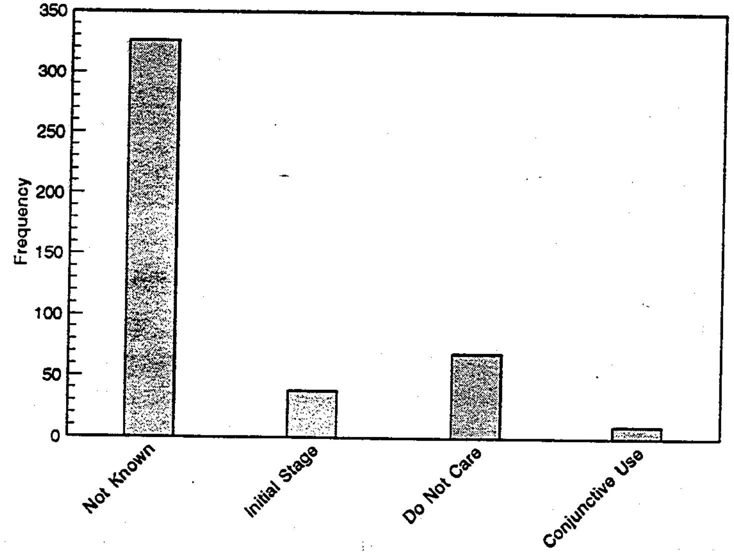


Figure G8 Stage of Avoidance of T.W Water

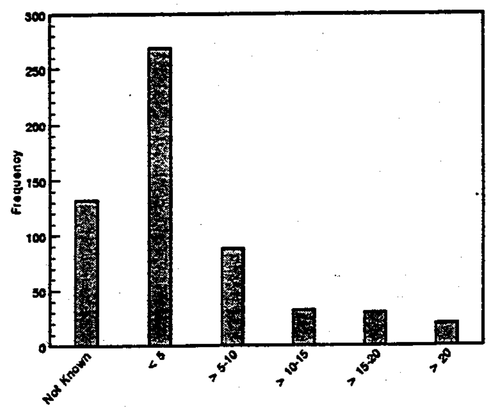


Figure G9 Period (Years) of Ownership of Tubewell

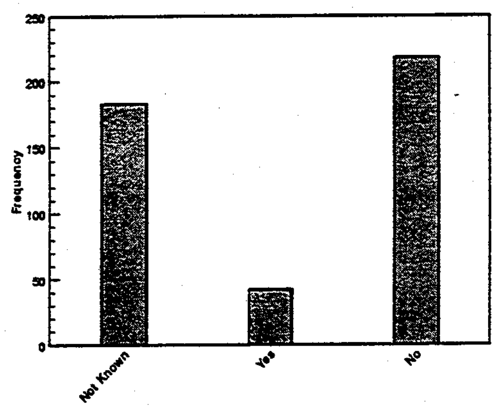


Figure G10 Test of Groundwater Quality Before T.W Installation

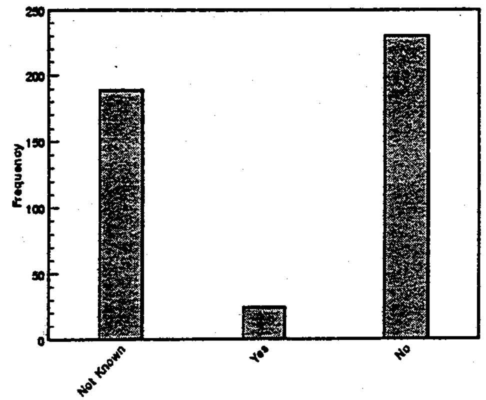


Figure G11 Test of Groundwater Quality After T.W Installation

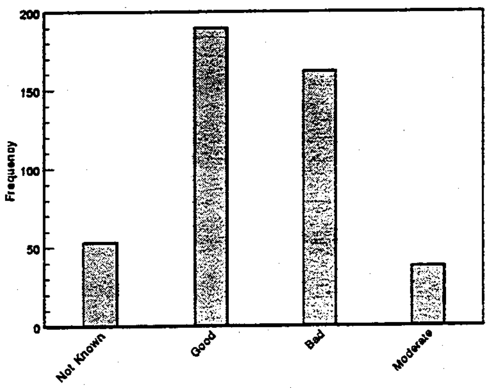


Figure G12 Perceived Ground Water Quality

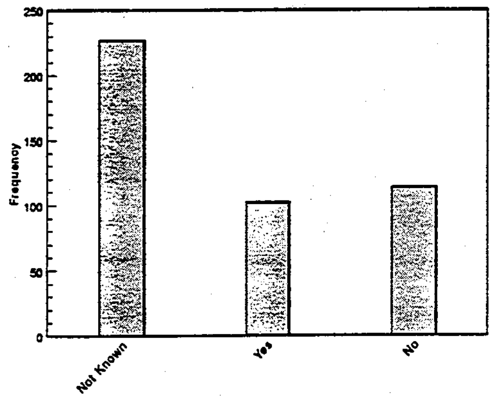


Figure G13 Perceived Detrimental Effects of Groundwater Quality

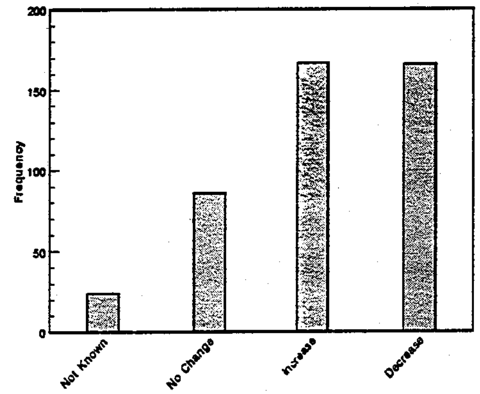


Figure G14 Impact on Crop Yield

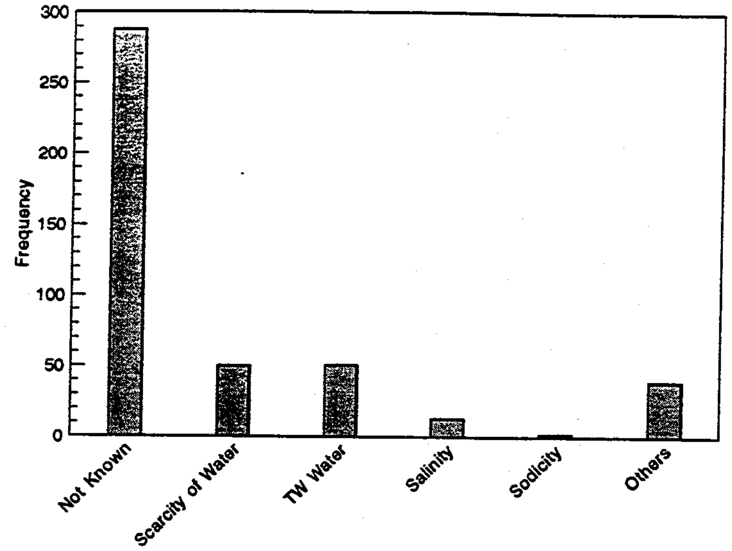


Figure G15 Constraints Attributed to Decrease in Crop Yield

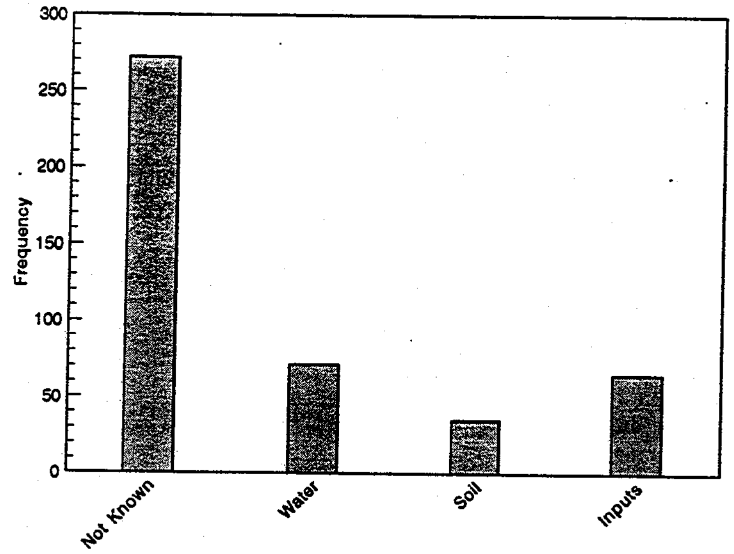


Figure G16 Factors Positively Correlated with Crop Yields

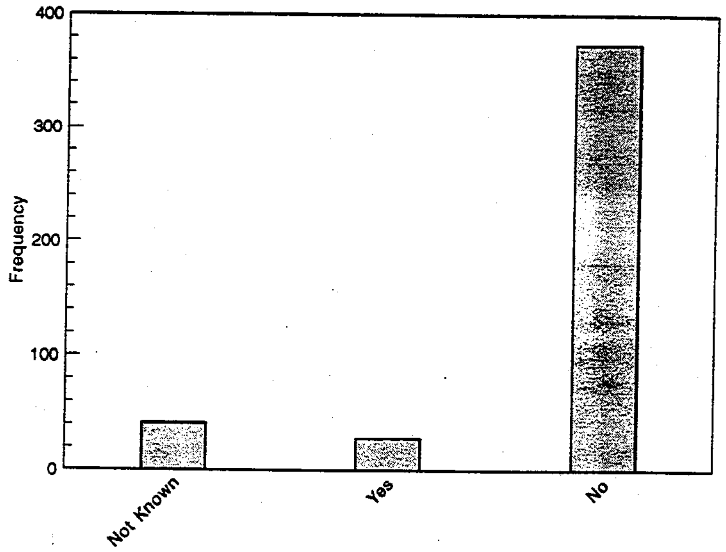


Figure G17 Test of Farm Soils

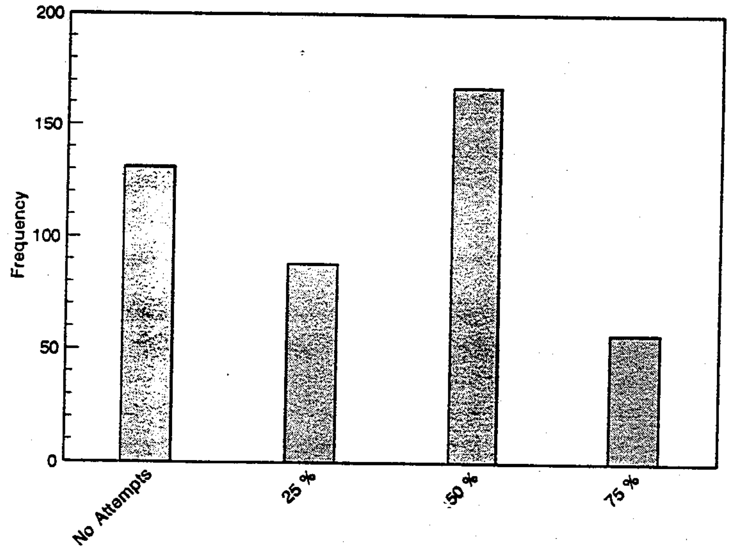


Figure G18 Attempted Increase in Farm Inputs Levels

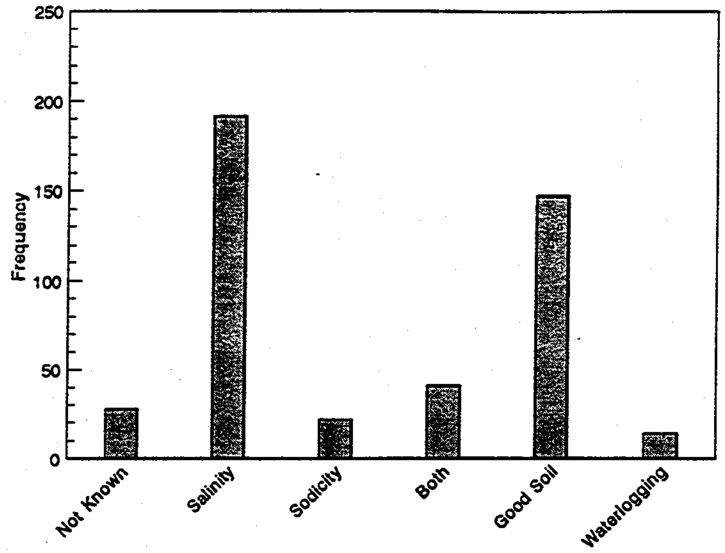


Figure G19 Reported Problems with Soils

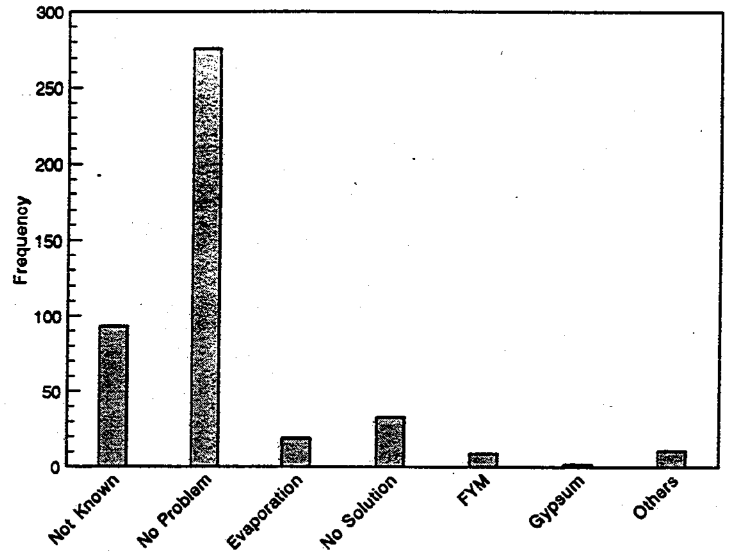


Figure G20 Drainage Conditions on the Farm

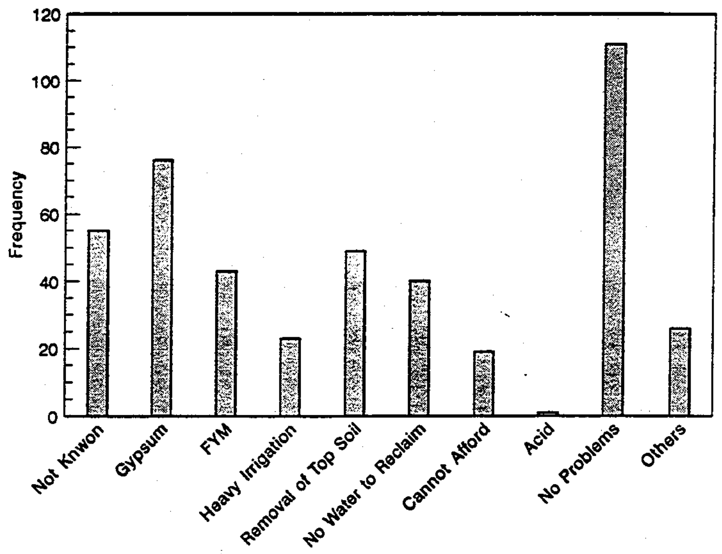


Figure G21 Management of Salinity

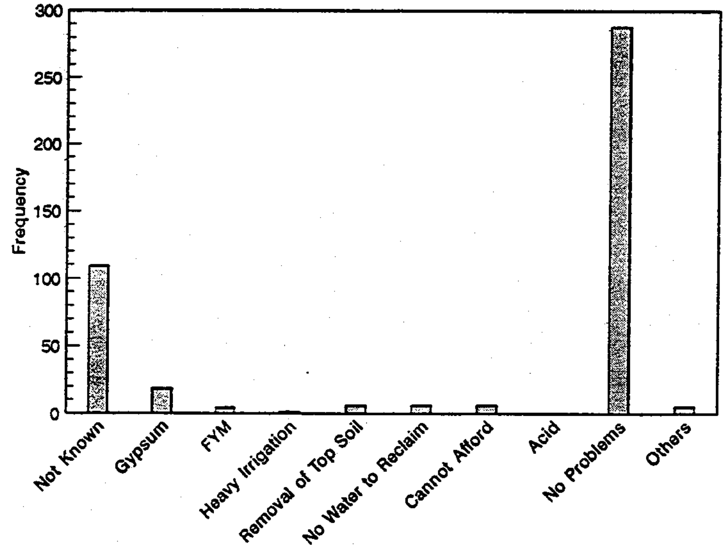


Figure G22 Management of Sodicity

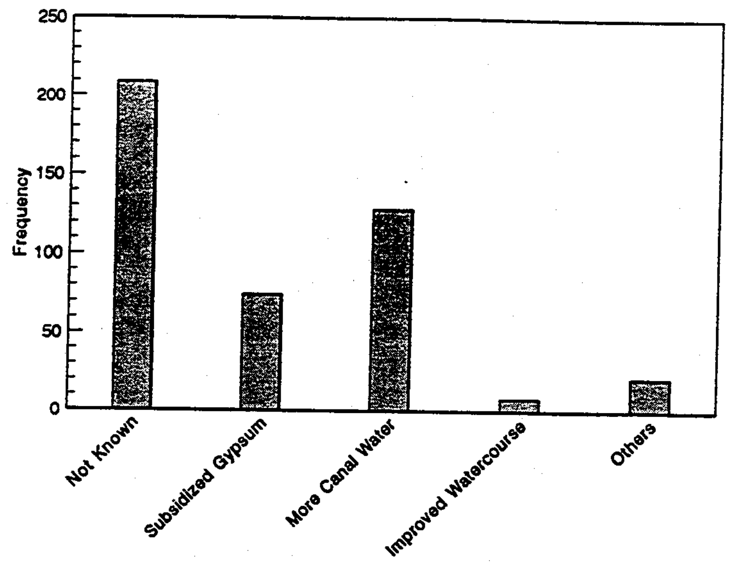


Figure G23 Preferred Government Interventions for Salinity Management

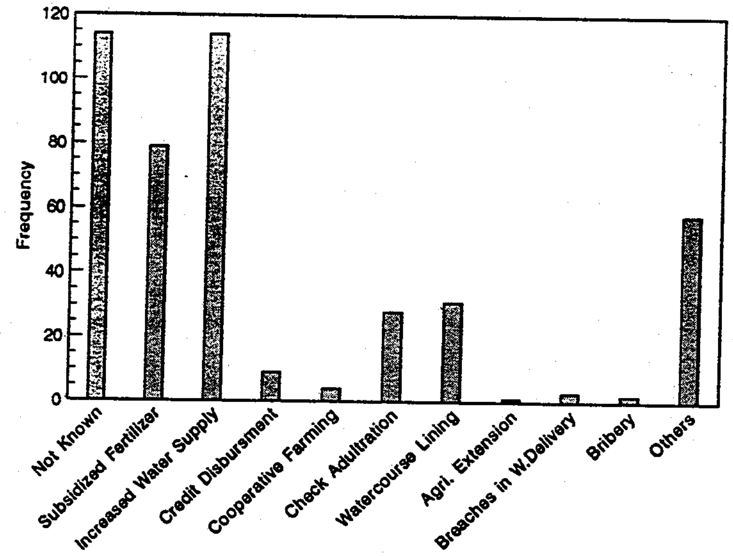


Figure G24 Suggested Improvements at the Farm Level

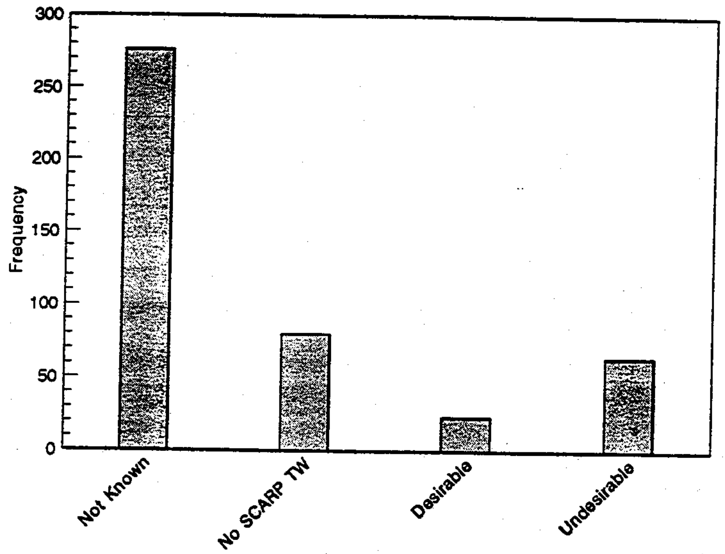


Figure G25 Response to Privatization of SCARP Tubewells

APPENDIX-H

IIMI Sample Survey
Thematic Representation of Farm Level Aggregates

Table H1. Salient Farm Characteristics Aggregated Across the Irrigation Subdivisions of the Lower Rechna Doab, Pakistan (IIMI Sample Survey, 1995).

Subdivision	No. of Farmers	Reasons for Keeping Land Fallow				Groundwater Quality				Landuse Intensity	Cropping Intensity*	Cropping Intensity**	Fallow Intensity*	Fallow Intensity**	Culturable Waste Intensity	Wheat	Cotton	Rice	Sugarcane	Major Crop Intensity
		Not Fallow	Scarcity	Salinity, Sodicity & Waterlogging	Others	Not Known	Good	Bad	Moderate											
AMINPUR	17	3	10	3	1	3	2	12		77.33	76.79	99.31	57.97	74.97	22.67	55.32	1.24	0.00	14.61	71.17
BHAGAT	20	1	15	2	2		9	8	3	95.73	109.11	113.98	70.76	73.91	4.27	38.74	19.88	5.62	6.48	70.71
BUCHIANA	21	0	15	6	0	4	9	5	3	81.89	97.66	119.25	52.59	64.22	18.11	40.47	6.46	2.69	21.77	71.40
CHUHARKANA	31	7	17	3	4		14	11	6	96.88	151.07	155.94	50.09	51.70	3.12	39.92	2.01	32.00	2.10	76.03
DHAULAR	33	7	16	4	6		19	11	3	80.51	106.84	132.70	37.74	46.87	19.49	43.82	14.61	7.50	15.07	81.00
HAVELI	37	3	12	15	7	7	15	8	7	70.95	109.30	154.05	32.66	46.02	29.05	41.19	25.88	6.00	5.91	78.98
KANYA	8	1	3	3	1	2	1	4	1	75.68	118.42	156.47	35.96	47.51	24.32	34.70	1.74	2.89	22.50	61.83
KOT KHUDA YAR	25	1	14	5	5		11	10	4	82.11	106.77	130.02	66.47	80.94	17.89	37.29	0.57	2.35	21.56	61.77
MOHLAN	36	5	26	1	4	9	18	6	3	94.99	129.47	136.30	40.37	42.50	5.01	42.16	2.95	19.23	13.26	77.60
PACCA DALA	45	5	28	7	5	5	21	18	1	92.64	129.42	139.69	42.50	45.88	7.38	38.94	1.29	13.85	8.39	62.48
SAGAR	3	0	2	1	0		2	0	1	96.10	164.94	171.62	24.68	25.68	3.90	44.09	0.00	29.92	2.36	76.38
SANGLA	9	1	6	1	1	1	5	3		90.62	124.90	137.82	58.92	65.02	9.38	41.53	0.00	12.96	4.65	59.14
SULTANPUR	6	1	2	3	0		5	1		69.01	124.42	180.31	12.87	18.64	30.99	37.37	11.75	15.98	6.47	71.56
TANDILIANWALA	20	2	14	3	1	4	9	3	4	95.57	142.01	148.59	38.95	40.75	4.20	33.03	6.08	2.61	14.26	55.98
TARKHANI	40	8	25	5	2	3	14	23		82.84	97.96	118.25	40.90	49.37	18.76	38.59	14.07	0.71	15.05	68.42
UCC_2	14	2	3	5	4		11	2	1	93.87	151.41	161.30	37.63	40.08	6.13	36.74	0.00	38.10	0.95	75.78
UQBANA	44	5	24	14	1	13	7	23	1	83.91	96.22	114.67	52.88	63.01	16.09	37.11	3.48	5.34	17.72	63.66
VERYAM	30	3	20	6	1	2	14	14		87.82	86.43	98.41	67.20	76.52	12.18	46.40	1.97	3.01	19.49	70.86
WER	4	2	2	0	0		4	0		100.00	94.91	94.91	46.30	46.30	0.00	43.90	0.00	0.00	29.27	73.17

Cropping Intensity* = (Cropped Area / Farm Area Total)*100

Cropping Intensity** = (Cropped Area / Cultivated Area Total)*100
Formula based on Agri. Census Report (1990)

Fallow Intensity* = (Total Fallow Area (Per Year) / Farm Area Total)*100

Fallow Intensity** = (Fallow Area (Per Year) / Cultivated Area Total)*100
Formula based on Agri. Census Report (1990)

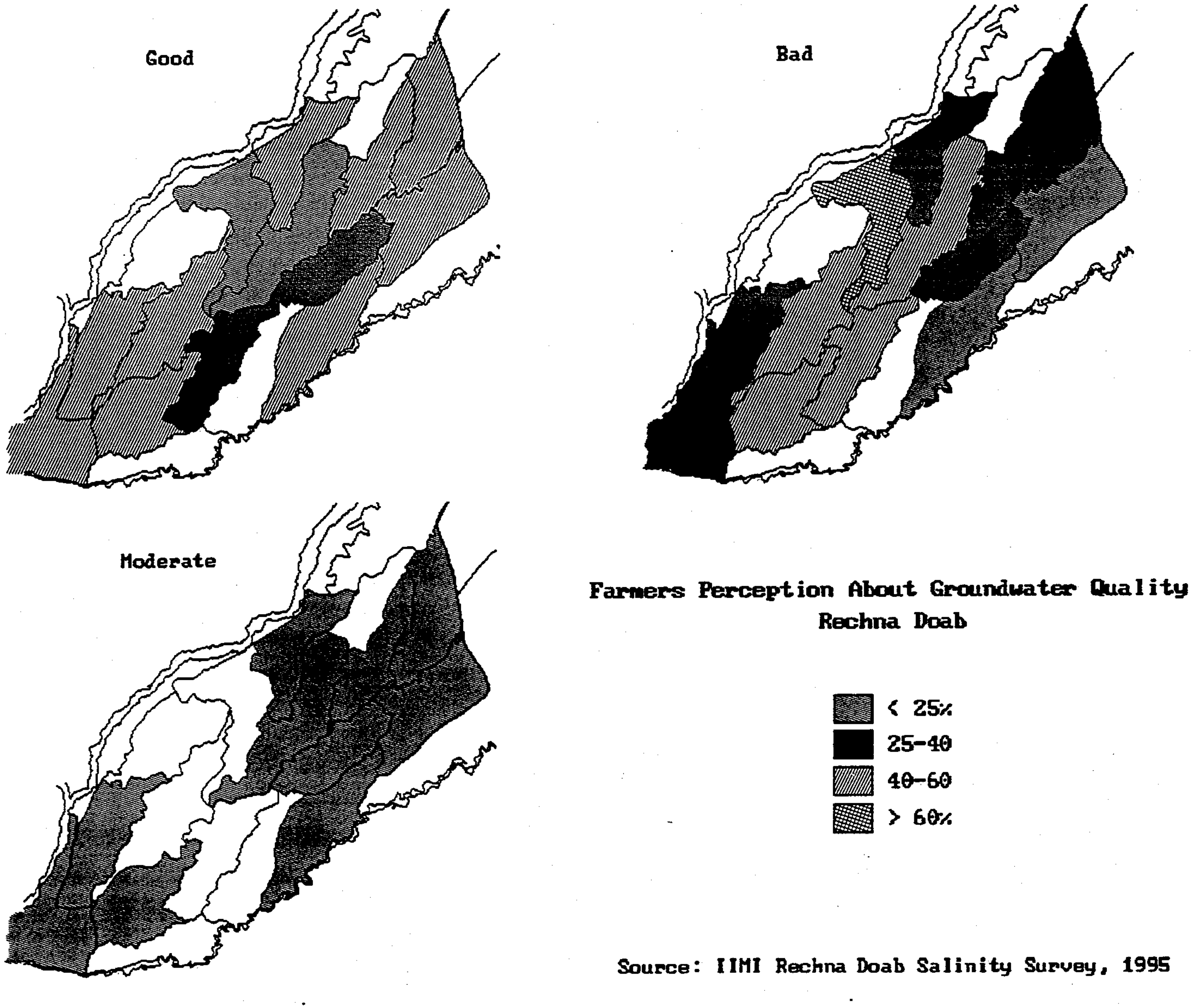


Figure H1 Farmers' Perception about Groundwater Quality in the Irrigation Subdivisions of the Lower Rechna Doab, Pakistan.

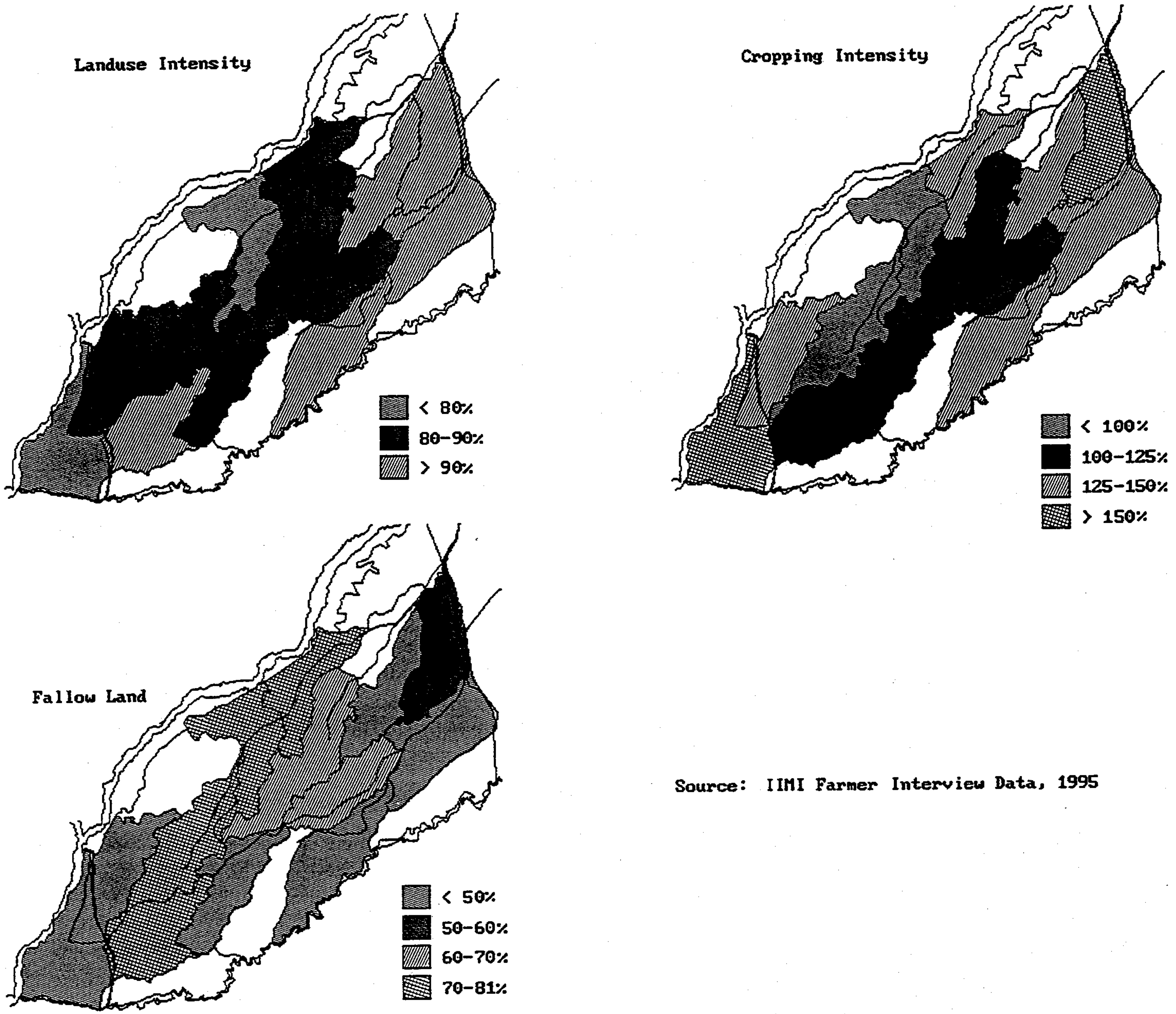


Figure H2 Aggregate Land Use within Irrigation Subdivisions of the Lower Rechna Doab, Pakistan.

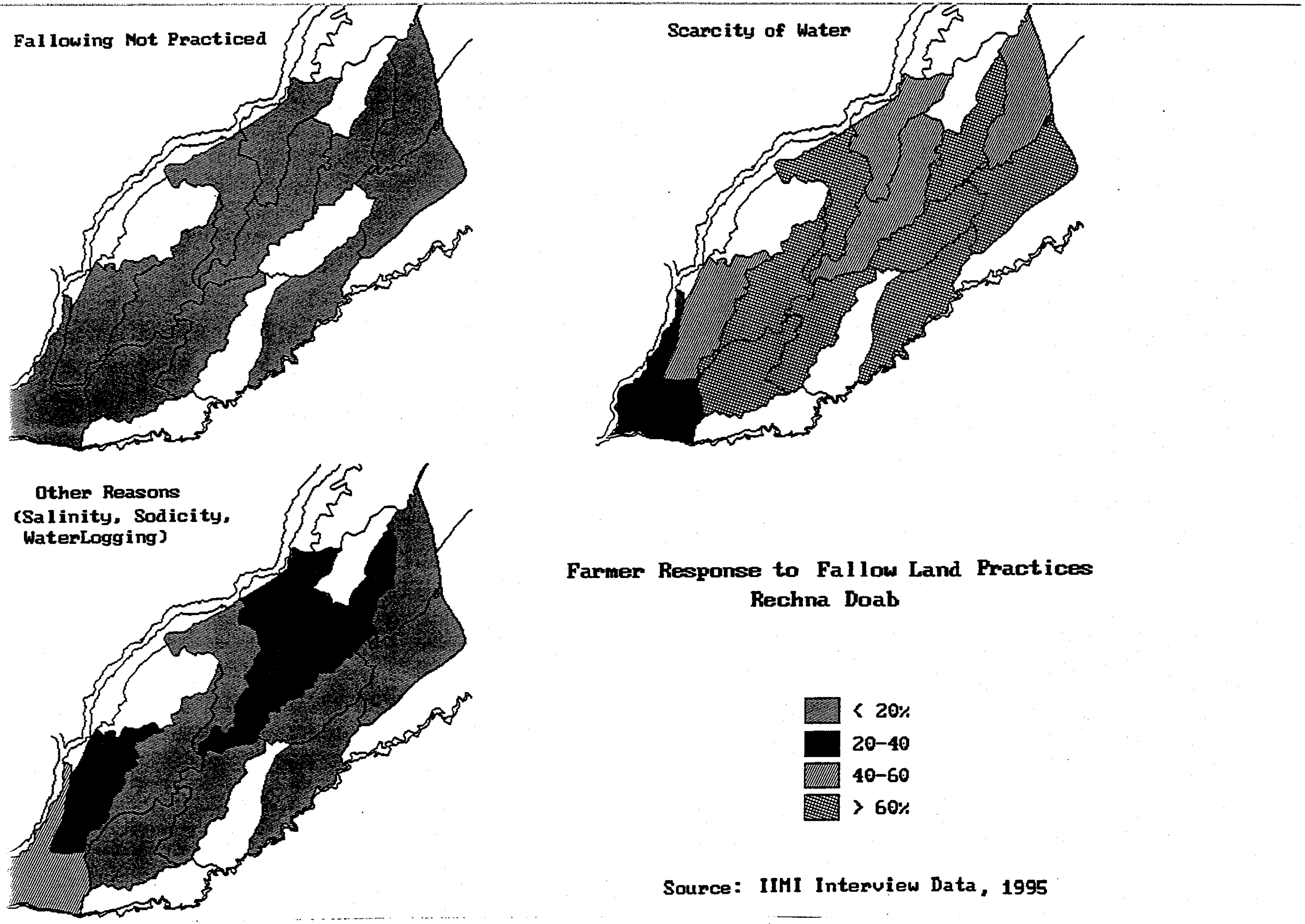


Figure H3 Farmer Response to Fallow Land Practices in the Irrigation Subdivisions of the Lower Rechna Doab, Pakistan.

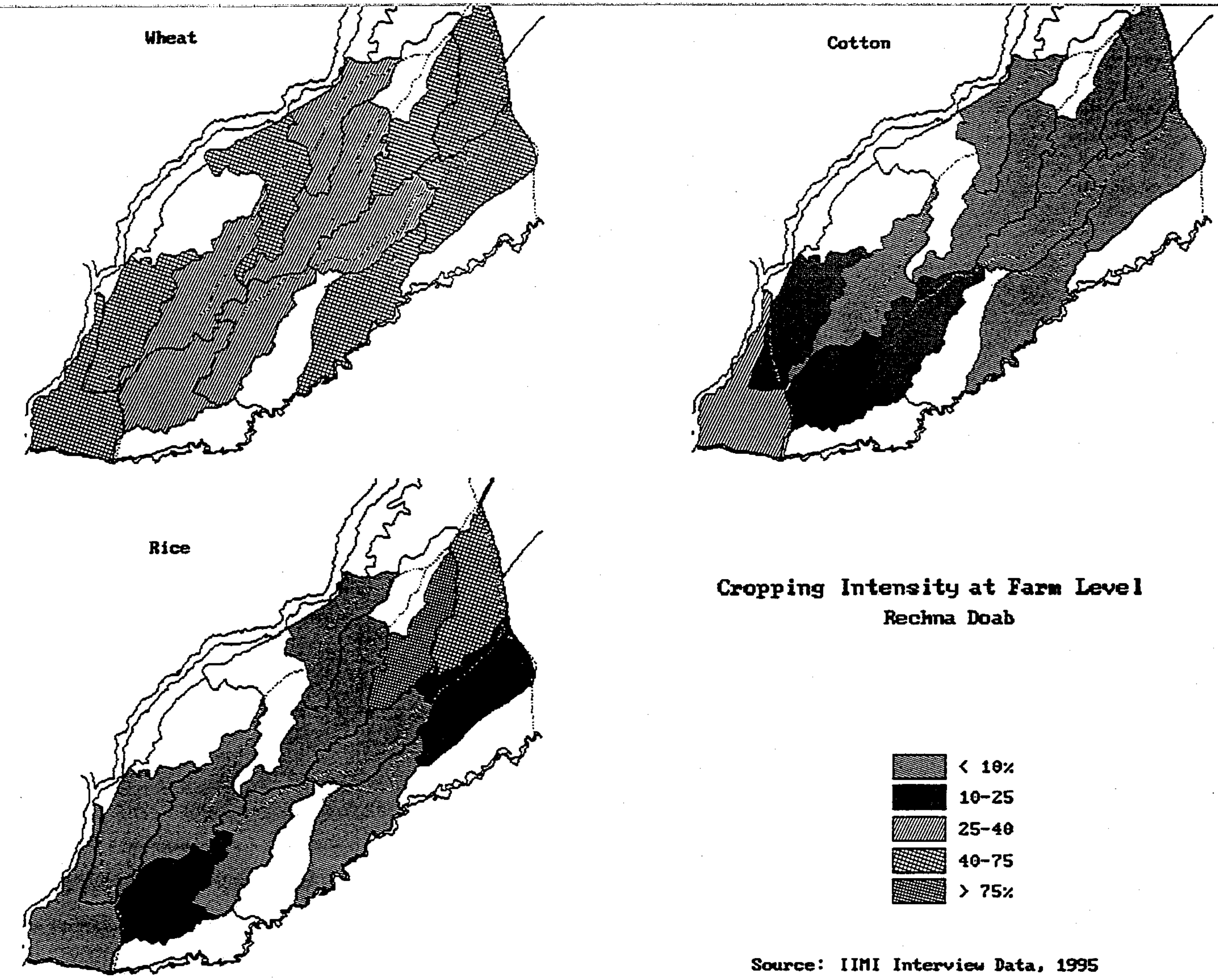


Figure H4 Average Cropping Intensity within Irrigation Subdivisions of the Lower Rechna Doab, Pakistan.

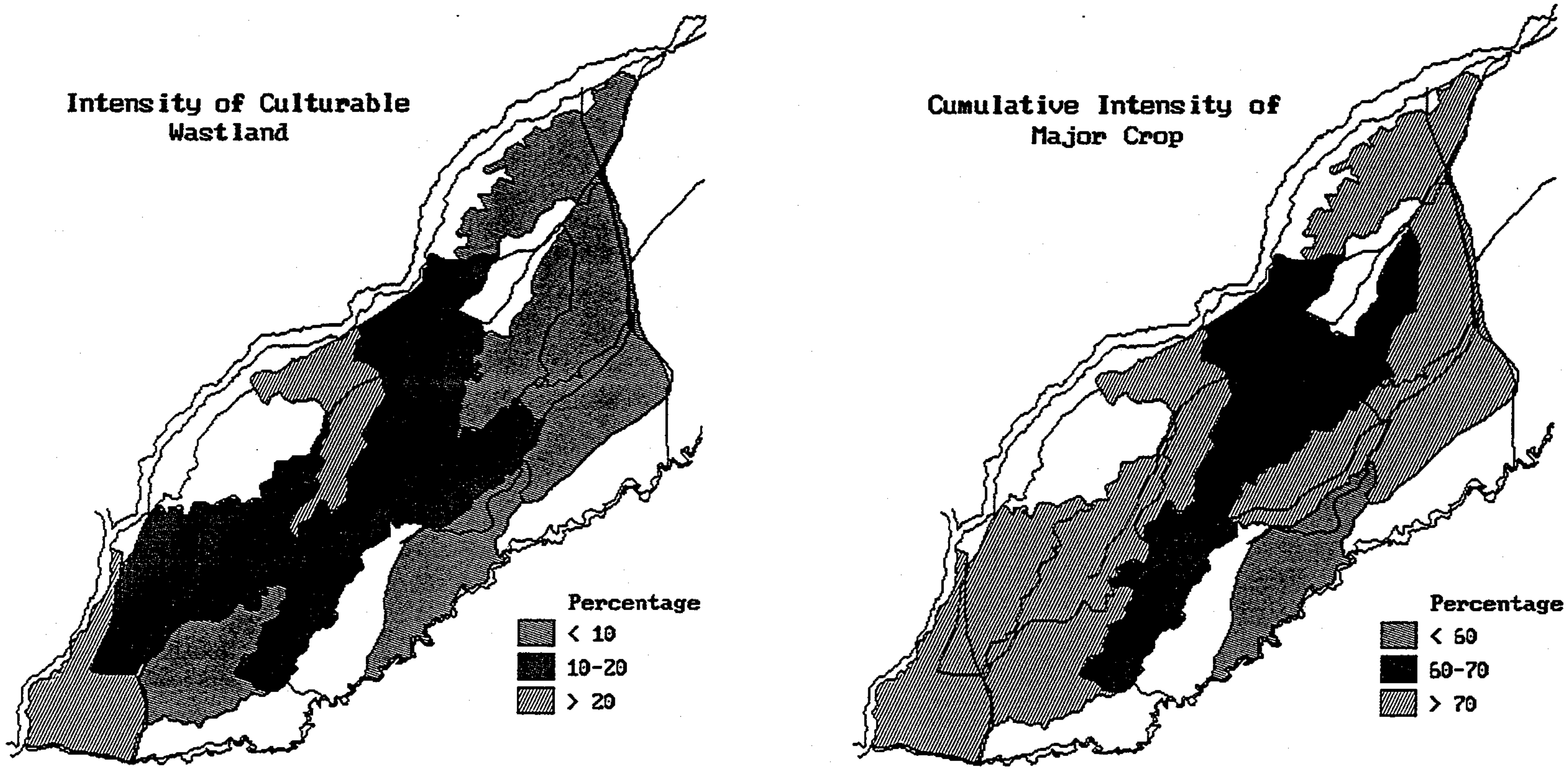


Figure H5 Intensity Distribution of Land Use Under Major Crops in comparison to the Culturable Waste within Irrigation Subdivisions of the Lower Rechna Doab, Pakistan.

Table H2. Gross Farm Inputs and Returns for Wheat Crop (in Rupees) Across the Irrigation Subdivisions of the Lower Rechna Doab, Pakistan.

SUBDIVISION	COST OF LAND	COST OF SEED	COST OF FERTILIZER	COST OF FARM YARD MANURE	COST OF PLANT PROTECTION	COST OF IRRIGATION	YIELD (Kg/ha)	TOTAL COST	GROSS INCOME	PROFIT	No. OF FARMERS
AMINPUR	1,257	510	1,436	582	185	110	2,979	7,674	14,012	6,338	14
BHAGAT	1,503	588	1,706	332	290	796	3,158	9,115	13,967	4,852	19
BUCHIANA	1,469	535	1,622	550	454	393	2,832	8,670	13,020	4,350	20
CHUHARKANA	1,517	534	1,512	599	368	558	2,859	8,861	13,050	4,189	29
DHAULAR	1,213	597	1,833	236	97	877	2,554	7,815	11,198	3,383	32
HAVELI	1,294	596	1,901	247	303	331	2,167	6,042	9,462	3,420	37
KANYA	2,012	568	1,678	340	388	119	2,632	8,744	12,057	3,313	8
KOT KHUDA YAR	1,478	579	1,782	461	81	557	2,550	8,297	11,648	3,351	25
MOHLAN	1,466	556	1,402	201	360	578	2,641	7,672	11,876	4,203	32
PACCA DALA	1,483	553	1,493	743	365	273	3,014	8,101	13,814	5,713	43
SAGAR	1,326	577	1,478	329	165	214	2,142	7,501	9,905	2,404	3
SANGLA	1,753	578	1,502	741	159	178	2,442	7,714	11,256	3,542	7
SULTANPUR	1,470	639	1,677	535	647	395	2,092	8,258	9,235	976	6
TANDILIANWALA	1,448	541	1,429	462	306	288	2,622	8,018	11,964	3,947	19
TARKHANI	1,540	560	1,923	283	472	365	3,099	9,146	13,728	4,582	37
UCC_2	1,581	569	1,897	106	311	537	2,725	8,313	12,387	4,074	14
UQBANA	1,413	545	1,657	504	330	213	2,648	8,500	12,216	3,715	43
VERYAM	1,338	564	1,689	419	179	278	2,460	7,971	11,030	3,059	28
WER	1,863	510	1,709	494	0	488	2,768	7,649	12,301	4,652	4

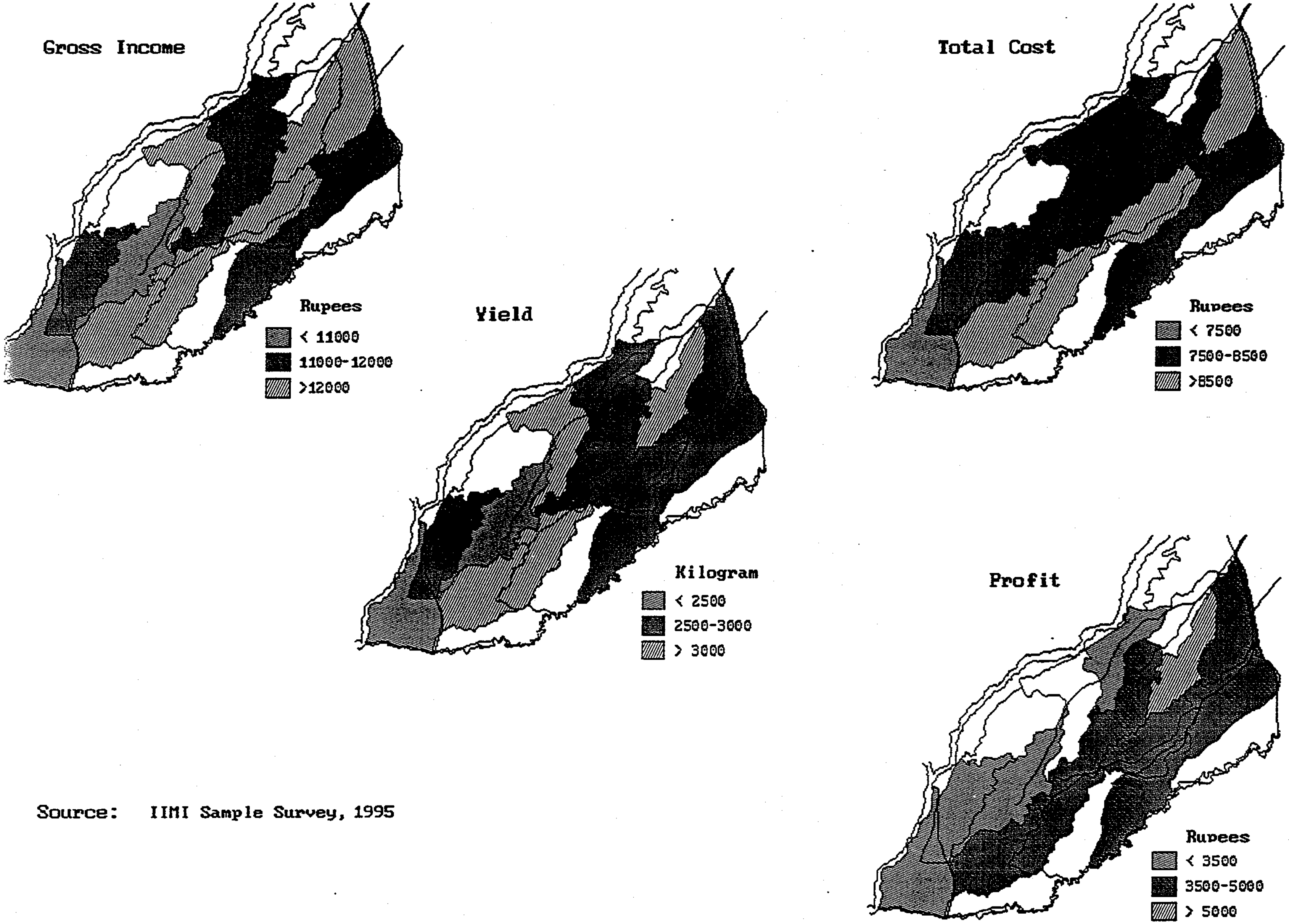


Figure H6 Macro Level Indicators of Farm Economics in Comparison to Wheat Yield across the Irrigation Subdivisions of the Lower Rechna Doab, Pakistan.

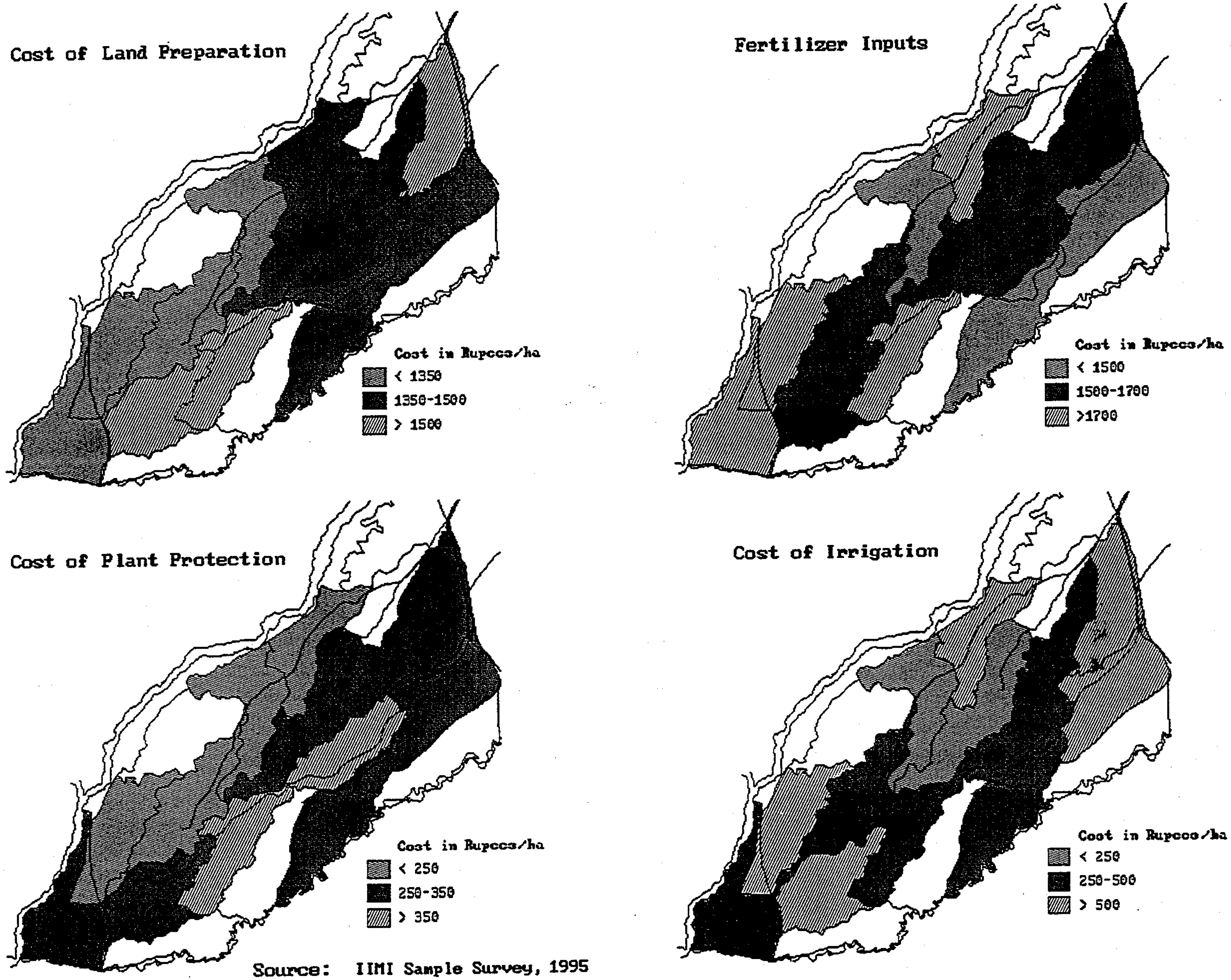
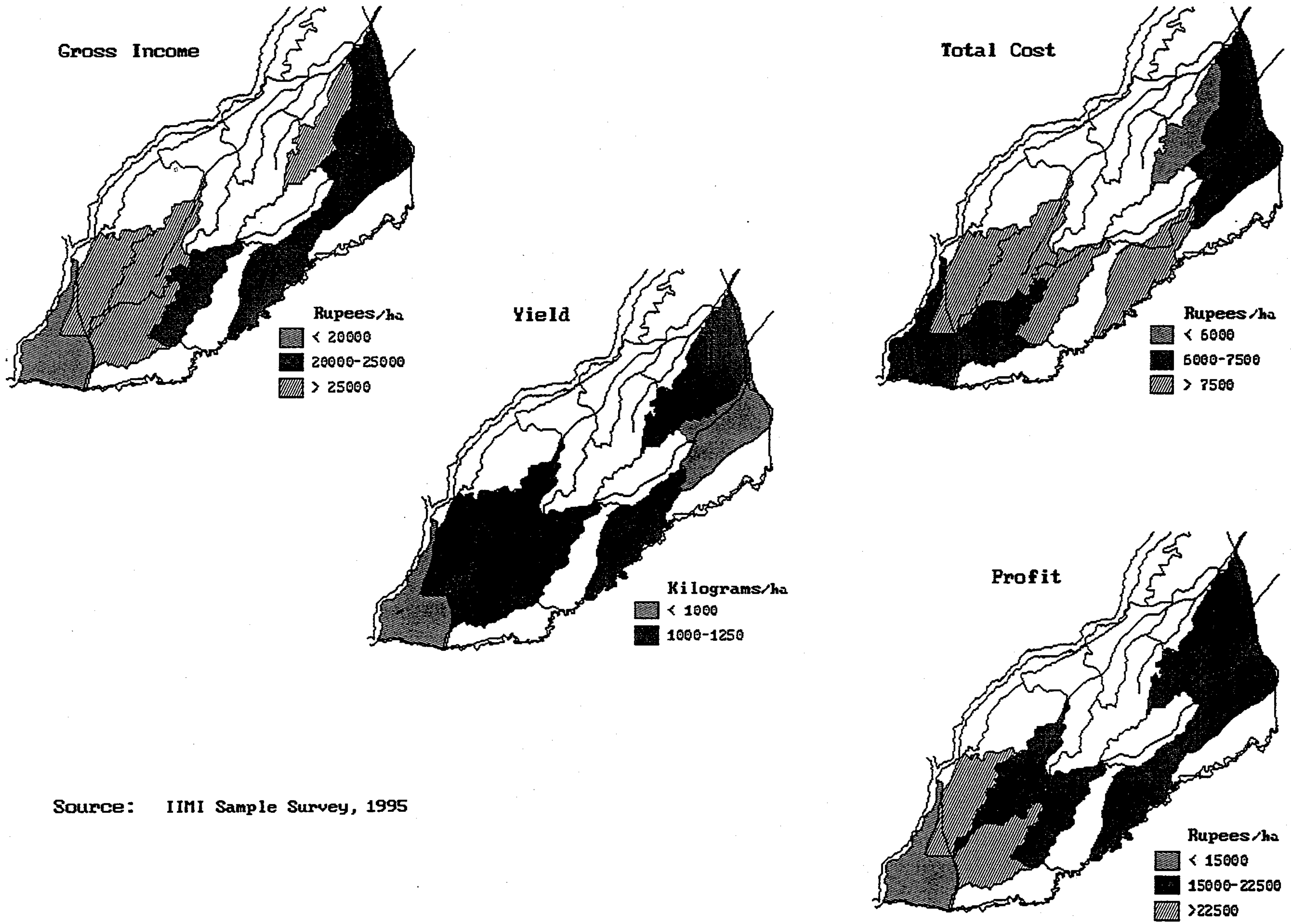


Figure H7 **Cost Distribution of Gross Farm Inputs for Wheat Crop in the Irrigation Subdivisions of the Lower Rechna Doab, Pakistan.**

Table H3. Gross Farm Inputs and Returns for Cotton Crop (in Rupees) Across the Irrigation Subdivisions of the Lower Rechna Doab, Pakistan.

SUBDIVISION	COST OF LAND	COST OF SEED	COST OF FERTILIZER	COST OF FARM YARD MANURE	COST OF PLANT PROTECTION	COST OF IRRIGATION	YIELD (Kg/ha)	TOTAL COST	GROSS INCOME	PROFIT	No. OF FARMERS
AMINPUR	1,730	1,527	5,861	2,441	1,831	245	494	21,621	26,561	4,937	2
BHAGAT	1,342	799	1,522	350	544	492	1,302	7,490	32,279	24,790	12
BUCHIANA	1,711	398	1,637	680	1,029	723	1,005	8,166	23,091	14,926	4
CHUHARKANA	1,135	508	1,186	459	1,476	546	999	6,661	24,252	17,591	7
DHAULAR	1,063	494	1,219	414	1,472	930	1,438	8,287	37,649	29,362	20
HAVELI	1,235	503	1,616	293	1,283	435	1,170	7,701	26,762	19,062	19
KANYA	2,076	198	618	0	988	124	1,779	5,217	37,584	32,367	1
KOT KHUDA YAR	0	0	0	0	0	0	0	0	0	0	0
MOHLAN	980	360	1,100	0	1,021	788	972	6,290	21,457	15,167	6
PACCA DALA	1,344	356	725	655	686	272	1,176	5,600	25,632	20,031	10
SAGAR	0	0	0	0	0	0	0	0	0	0	0
SANGLA	0	0	0	0	0	0	0	0	0	0	0
SULTANPUR	1,586	399	975	659	517	815	758	7,386	17,882	10,496	3
TANDILIANWALA	1,322	387	1,705	469	2,520	366	1,285	9,447	27,650	18,204	5
TARKHANI	1,608	794	1,533	285	1,398	564	1,163	8,902	27,097	18,195	13
UCC_2	0	0	0	0	0	0	0	0	0	0	0
UQBANA	1,070	542	1,440	494	1,747	526	1,059	7,209	24,516	17,306	7
VERYAM	1,316	393	1,143	1.081	1,742	562	1,631	10,112	40,104	29,992	4
WER	0	0	0	0	0	0	0	0	0	0	0



Source: IIMI Sample Survey, 1995

Figure H8 **Macro Level Indicators of Farm Economics in Comparison to Cotton Yield across the Irrigation Subdivisions of the Lower Rechna Doab, Pakistan.**

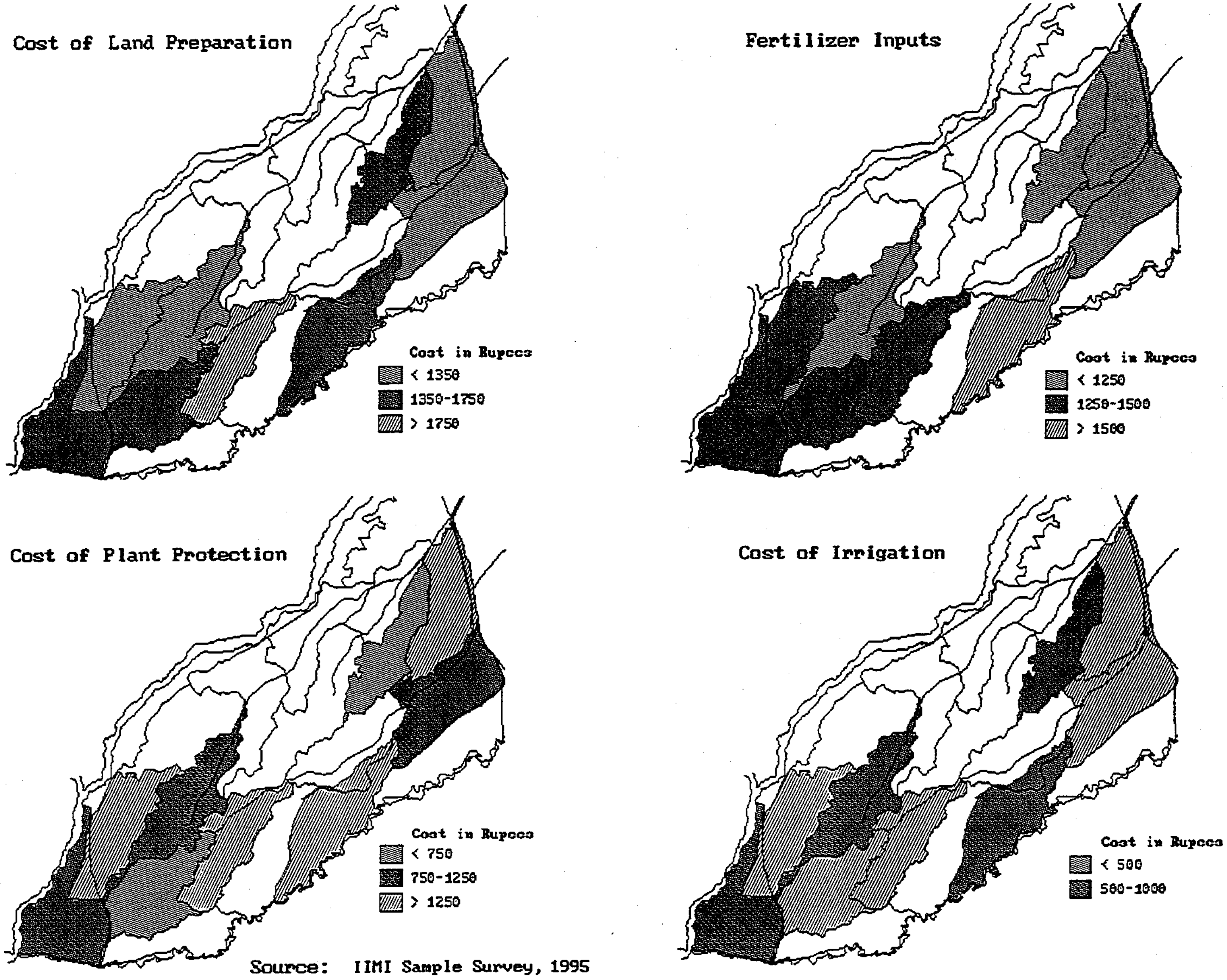


Figure H9 **Cost Distribution of Gross Farm Inputs for Cotton Crop in the Irrigation Subdivisions of the Lower Rechna Doab, Pakistan.**

Table H4. Gross Farm Inputs and Returns for Rice Crop (in Rupees) Across the Irrigation Subdivisions of the Lower Rechna Doab, Pakistan.

SUBDIVISION	COST OF LAND	COST OF SEED	COST OF FERTILIZER	COST OF FARM YARD MANURE	COST OF PLANT PROTECTION	COST OF IRRIGATION	YIELD (Kg/ha)	TOTAL COST	GROSS INCOME	PROFIT	No. OF FARMERS
AMINPUR	0	0	0	0	0	0	0	0	0	0	0
BHAGAT	1,334	68	899	0	0	3,196	2,438	7,983	9,933	1,950	3
BUCHIANA	1,529	120	1,510	432	695	911	2,446	7,654	11,601	3,947	4
CHUHARKANA	1,558	89	1,685	585	344	2,148	2,774	8,999	15,368	6,369	28
DHAULAR	1,236	136	1,053	0	306	1,675	3,138	7,209	14,304	7,096	8
HAVELI	1,269	151	1,104	332	432	892	2,669	5,820	11,393	5,573	16
KANYA	1,120	97	715	0	0	202	1,779	4,726	9,752	5,026	3
KOT KHUDA YAR	1,326	79	525	474	175	1,698	2,537	6,798	13,774	6,976	6
MOHLAN	1,288	89	1,450	173	521	2,608	2,298	8,533	12,440	3,908	20
PACCA DALA	1,498	88	1,498	614	491	961	2,599	7,494	13,724	6,230	28
SAGAR	1,853	62	1,499	741	165	1,433	3,130	7,555	16,185	8,630	3
SANGLA	1,446	92	1,600	741	124	436	4,028	7,681	20,945	13,263	4
SULTANPUR	1,540	156	2,220	412	1,067	231	922	7,376	3,921	-3,455	3
TANDILIANWALA	1,215	96	1,647	0	947	662	2,933	7,965	15,394	7,429	3
TARKHANI	0	0	0	0	0	0	0	0	0	0	0
UCC_2	1,777	84	1,456	477	651	3,267	2,541	10,402	13,215	2,812	14
UQBANA	1,469	63	990	828	292	340	2,639	6,635	13,867	7,232	10
VERYAM	939	180	902	494	371	2,496	2,965	7,502	14,579	7,077	2
WER	0	0	0	0	0	0	0	0	0	0	0

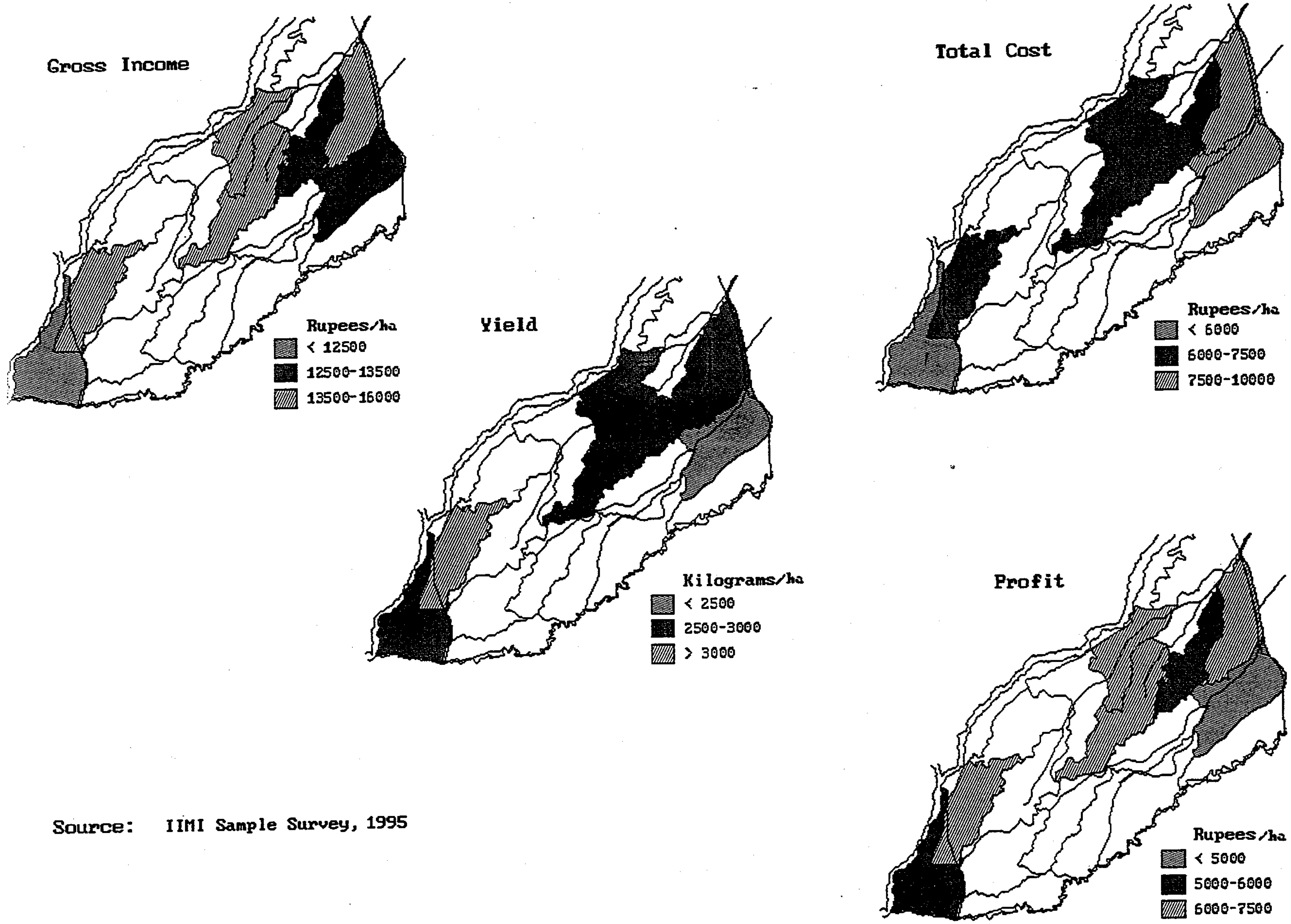


Figure H10 Macro Level Indicators of Farm Economics in Comparison to Rice Yield across the Irrigation Subdivisions of the Lower Rechna Doab, Pakistan.

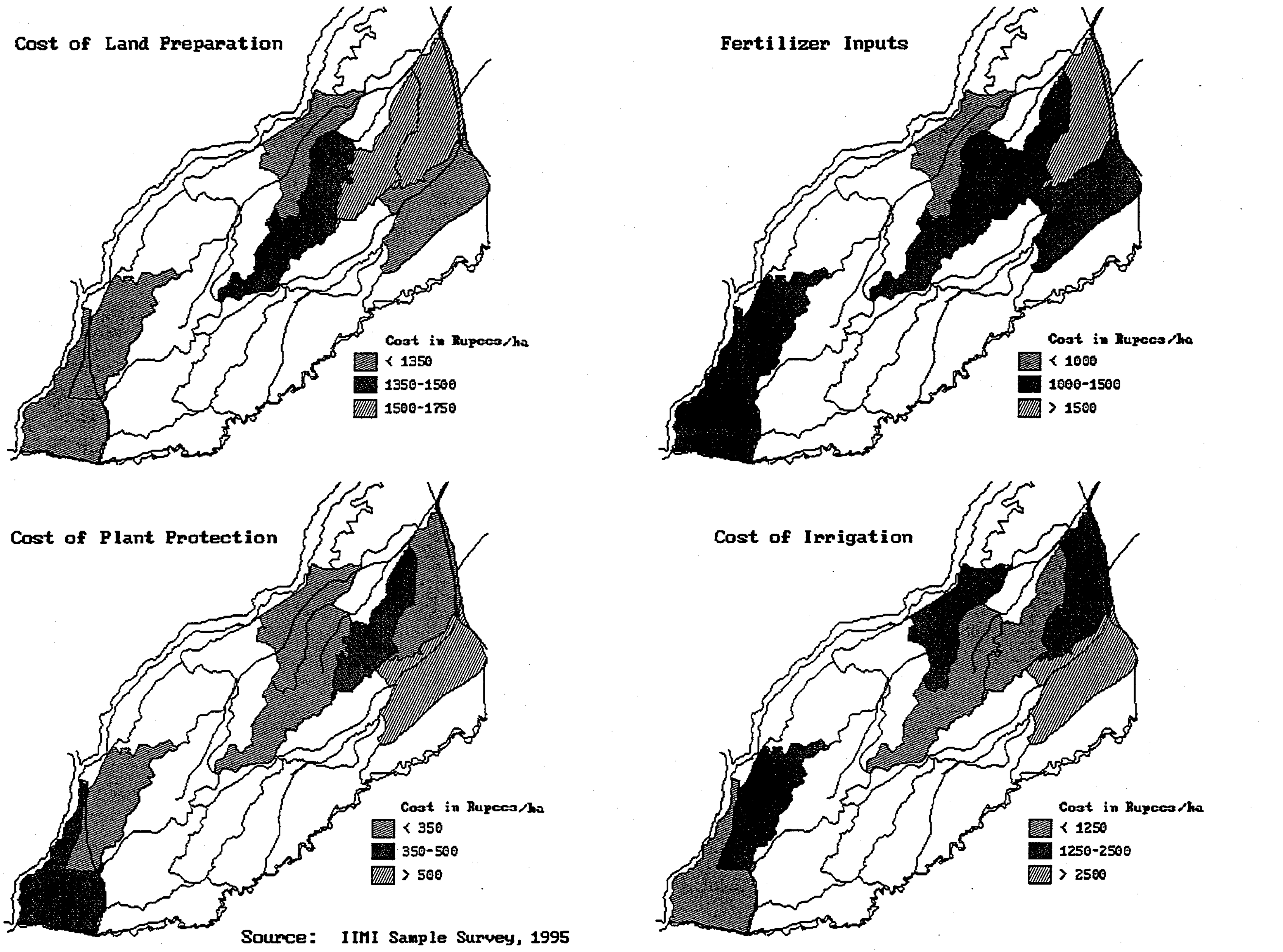
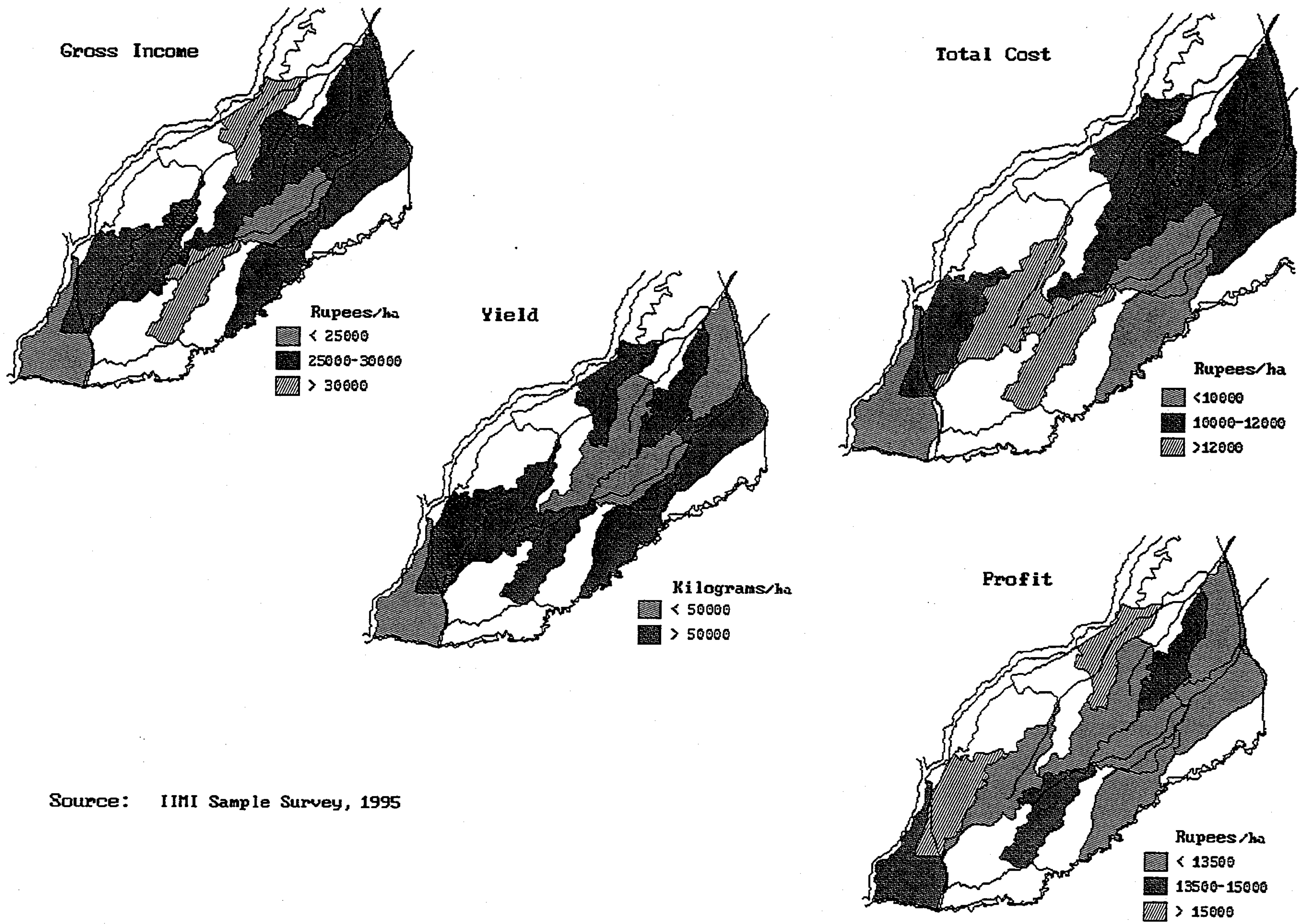


Figure H11 **Cost Distribution of Gross Farm Inputs for Rice Crop in the Irrigation Subdivisions of the Lower Rechna Doab, Pakistan.**

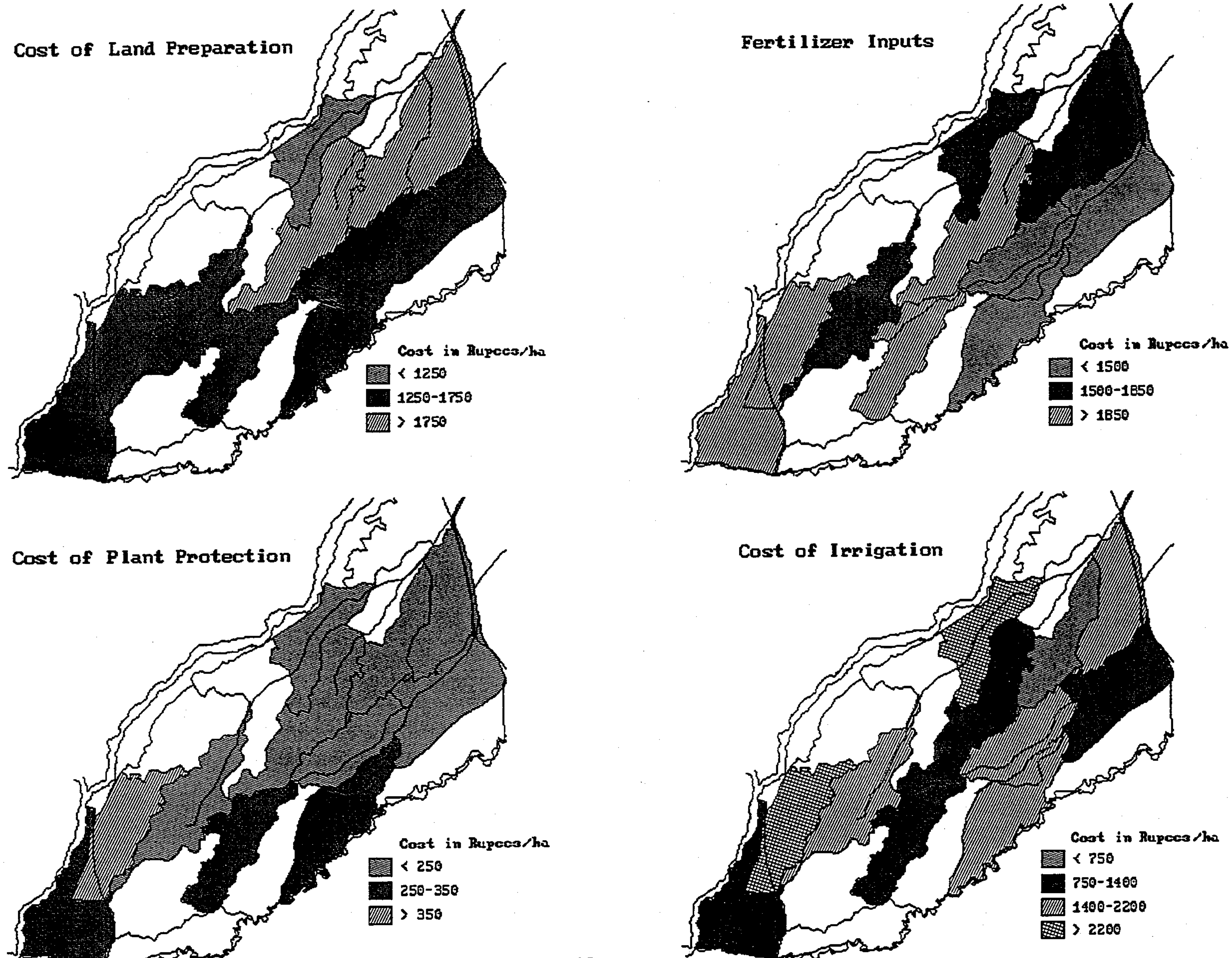
Table H5. Gross Farm Inputs and Returns for Sugarcane Crop (in Rupees) Across the Irrigation Subdivisions of the Lower Rechna Doab, Pakistan.

SUBDIVISION	COST OF LAND	COST OF SEED	COST OF FERTILIZER	COST OF FARM YARD MANURE	COST OF PLANT PROTECTION	COST OF IRRIGATION	YIELD (Kg/ha)	TOTAL COST	GROSS INCOME	PROFIT	No. OF FARMERS
AMINPUR	1,927	2,235	1,711	530	341	141	48,149	10,435	23,051	12,616	7
BHAGAT	1,619	3,006	1,351	535	144	6,033	41,184	15,580	22,157	6,576	6
BUCHIANA	1,660	1,435	1,342	423	243	1,727	45,343	9,582	23,768	14,186	16
CHUHARKANA	2,234	1,682	1,833	627	124	2,175	46,455	10,987	25,266	14,279	13
DHAULAR	1,432	2,109	1,959	549	460	2,333	55,735	11,717	29,645	17,928	18
HAVELI	1,443	1,612	1,859	435	276	984	44,198	8,826	22,094	13,267	23
KANYA	1,730	1,054	2,216	807	206	278	46,356	8,440	24,745	16,305	6
KOT KHUDA YAR	1,112	1,747	1,643	723	12	2,595	58,686	11,933	31,863	19,930	16
MOHLAN	1,693	1,960	1,443	450	124	1,252	51,068	11,606	27,305	15,699	18
PACCA DALA	2,148	2,270	1,562	1,008	200	618	52,776	10,660	28,024	17,364	32
SAGAR	0	0	0	0	0	0	0	0	0	0	0
SANGLA	2,537	2,471	2,084	1,153	0	445	56,010	11,534	28,828	17,295	3
SULTANPUR	1,874	2,471	1,170	494	0	3,081	36,242	13,587	18,347	4,760	3
TANDILIANWALA	1,306	1,717	1,374	519	273	1,720	50,144	9,904	25,731	15,828	15
TARKHANI	1,494	2,142	2,026	910	287	924	56,073	13,145	29,797	16,652	26
UCC_2	1,944	1,647	1,528	0	0	1,927	52,714	10,556	25,534	14,978	3
UQBANA	1,757	1,883	2,042	710	231	773	49,025	11,484	25,388	13,904	34
VERYAM	1,409	2,888	1,644	769	166	1,512	58,398	13,777	28,708	14,932	18
WER	404	2,306	1,530	329	0	1,837	49,420	10,238	23,639	13,401	3



Source: IIMI Sample Survey, 1995

Figure H12 Macro Level Indicators of Farm Economics in Comparison to Sugarcane Yield across the Irrigation Subdivisions of the Lower Rechna Doab, Pakistan



Source: IIMI Sample Survey, 1995

Figure H13 Cost Distribution of Gross Farm Inputs for Sugarcane Crop in the Irrigation Subdivisions of the Lower Rechna Doab, Pakistan.

APPENDIX-I

IIMI Sample Survey
Description of Farm Level Aggregations for Production Function Modeling

Appendix-I

IIMI Sample Survey
Description of Farm Level Aggregations for Production Function Modeling

Summary of Case Selections for the Wheat Crop

Case 1: Uniform moderately fine to fine textures have been targeted across the soil profiles for subtle variations in groundwater quality without the hazards of salinity. Moderately fine to fine soils are not preferred for wheat because of difficulties in root penetration. The purpose is to explore the peculiarities of this behavior in terms of farm sizes and changes internal to the land use within the farm. The emphasis is on capturing a larger variation in cropping intensity (CI), but limited to farms that have a high land use intensity (LUI). One extreme scenario accounts for a medium soil overwash with groundwater quality (GWQ) and salinity disfavoring crop growth.

Case 2: Medium soils are most preferred for the wheat crop. On the high productivity side, i.e. higher CI and LUI, the response of farm sizes is explored with no other limitations. One of the scenarios examines the impact of salinity limited to larger farm sizes only. This case sets a good example for the potential utilization of groundwater supplies as a means to offset the effects of salinity.

Case 3: Again, for the medium soils, the impact of negative contributions is explored but the LUI restraint is not present as in Case 1. The variation draws more on farm size differentiation while maintaining soil salinity throughout the scenarios. In Scenario 17, a finer overwash is assumed for poor soil and water conditions for which the response is expectedly low. The farmers do prefer finer overwash, as is evident from Scenarios 8 & 9, however in 17 there are too many constraints to sustain crop productivity.

Case 4: Medium soil profiles overlain by moderately coarse soils. The response pattern is obtained through combinations of farm sizes, water quality and salinity. Higher CI and LUI regimes are especially targeted.

Case 5: Finer overwash compared for changes in GWQ.

Case 6: Finer profiles compared with respect to surface strata for poor soil and water conditions versus better soils and groundwaters.

Summary of Case Selections for the Cotton Crop

Case 1: For medium and non-saline soils, usually the most preferred soils for the growth of cotton, the variations in water quality are compared against farm size, with or without the specifications of CI or LUI. The emphasis is on farm size variations.

Case 2: Very nearly the converse of Case 1 with respect to soil salinity, other conditions remaining the same.

Case 3: Non-saline to saline conditions for finer soils are considered without the detrimental effects of adverse groundwater quality. Farm sizes are not constrained.

Case 4: Somewhat similar to Case 1, wherein the specific impact of medium surface textures is explored for saline and non-saline conditions across variations in farm sizes. There is no restriction on the profile texture, CI, and LUI.

Case 5: Only for finer surface textures with no incidence of salinity, the farm sizes are compared. Again, there is no restriction on the profile texture, CI, and LUI.

Summary of Case Selections for the Rice Crop

Case 1: Medium soils are considered for saline to non-saline conditions and mostly useable groundwater quality. Almost all of the cases are considered for higher CI and LUI.

Case 2: Same as Case 1, except finer soils are compared.

Case 3: Finer soils are compared for finer surface textures and contrasted for saline and non-saline soils and useable versus non-useable GWQ. In both cases, lower CI and LUI are considered.

Case 4: Finer surface textures are compared with respect to variations in farm size.

Case 5: Medium soils with medium surface textures are compared for no adversity in soil salinity and groundwater quality. Farm sizes are differentiated.

Case 6: Same as above, but soil salinity is induced for lower LUI.

Case 7: Moderately fine to fine soils with medium surface texture compared for non-saline (smaller farms) and saline conditions. One situation also compares poor GWQ with salinity and without the limitation of the farm size.

Case 8: Moderately coarse soils are compared for variations in groundwater quality for lower CI and LUI.

Case 9: Variations in surface texture are explored for moderately coarse soils and low LUI.

Summary of Case Selections for the Sugarcane Crop

Case 1: Moderately fine to fine soils with medium surface textures are compared for variations in groundwater quality and farm size.

Case 2: Medium soils with finer surface textures are compared for non-saline conditions and varying farm sizes. Finer surface textures are also exclusively compared for variations in farm size.

Case 3: Medium soils are compared for variation in groundwater quality and salinity.

Case 4: Medium soils with moderately coarse surface texture are compared for variations in groundwater quality and salinity.

Case 5: Medium surface textures are compared for saline conditions.

Case 6: Moderately coarse surface textures are compared for poor groundwater quality and soil salinity. Farm size also varies.

Case 7: Moderately fine to fine saline soils with changes in groundwater quality compared for variations in farm size.

Case 8: Moderately fine soils are compared for variations in soil salinity, CI, and LUI.

Table 11. Aggregation of Farm-Level Data as per Definition of Crop-Specific Cases for Constraints to Productivity.

Crop	Case #	List of Simulation nos., as per Constraint Definitions under Table 8.	Total no. of Hits
Wheat	1	1, 2, 11 & 12	34
	2	4, 5 & 15	75
	3	4, 7, 13, 14, 16, 17, 18, 19 & 20	41
	4	23, 24, 27, 28, 29 & 30	35
	5	8 & 9	95
	6	10, 22, 31 & 32	72
Cotton	1	2, 3, 6 & 7	45
	2	1, 4, 5 & 8	12
	3	9, 10, 15, 16 & 17	16
	4	11, 12 & 18	67
	5	13 & 14	23
Rice	1	1, 2, 3, 4 & 5	14
	2	6, 7 & 8	50
	3	9 & 26	9
	4	10 & 11	43
	5	12 & 13	37
	6	14 & 15	11
	7	16, 17 & 18	37
	8	19, 20 & 21	5
	9	22, 23, 24 & 25	7
Sugarcane	1	1, 2, 3 & 4	19
	2	7, 8, 11 & 12	74
	3	9 & 10	92
	4	13 & 14	21
	5	16 & 17	43
	6	15, 18 & 19	25
	7	5, 6 & 20	6
	8	21, 22, 23 & 24	6

Note: Some of the 'Hits' listed here differ from Table 8 due to the exclusion of those farm holdings that were identified as having suffered from crop damage.