5. SOIL DATA

5.1 Soil Survey and Sampling

Soil sampling in WUFMAS sample fields was by enumerators using a soil auger to take samples from 10-30cm deep and at five points on each sample field, one at the centre and four at the corners marked on a field sketch. A composite sample was prepared from the five samples in each field, and after packing and labelling samples were sent to the Central Chemical Laboratory at SANIIRI, Tashkent, for physical and chemical analysis.

A special soil survey team was trained in November 1996 and made surveys through 1997 and collected samples. Soil profiles were described in the field, penetrometer readings were taken and soil texture was assessed by feel. Undisturbed soil cores were taken at 25 and 70cm from soil pits dug at the centre of every WUFMAS fields during 1996 - 1997. These cores were returned to the Central Laboratory and used to measure bulk density and moisture relationships (by pressure membrane), and sub-samples were used for measurement of texture, pH and EC.

5.2 Type and Number of Analyses

During 1996 and 1997 respectively, 360 and 182 disturbed soil samples and 463 undisturbed soil cores were taken, and were analysed as shown in Table 5.1.

Table 5.1 Number and Type of Analyses

Measurement	1996	1997
On disturbed and composite soil samples:		
pH and EC in a 1:5 suspension in water ($EC_{1:5}$)	586	403
EC of saturation extract (ECe)	-	20
Exchangeable cations (Ca, Mg, K, Na)	-	20
Cation Exchange Capacity (CEC)	-	10
Soluble cations (Ca, Mg, K, Na) in a 1:5 water extract	360	-
Soluble anions (HCO_3, Cl, SO_4) in a 1:5 water extract	360	182*
Total dissolved solids (TDS)	360	182
Exchangeable N and K, available P	360	182
Organic C	360	-
Micro-elements Cu, Mn	360	-
Texture (Kachinsky and USBR criteria)	226	221
On undisturbed soil cores:		
Bulk density	463	-
Porosity	463	-
Soil moisture at pF = 2.0, 2.5, 3.0, 4.2	463	-

* Chloride only

Local methodology was used for analysis except when the equipment supplied by WARMAP as a capital grant was used. Reagents and glassware were supplied by WARMAP through local tender. Analysis of samples taken in 1996 was completed in 1997 so that all results could not be presented in the 1996 report. Full data are available in the WUFMAS database in MS Access and only summaries are presented here, in text tables and in more detail in Appendix 2.

5.3 Soil Profile Descriptions

Soils in the region are very young but pedogenic processes depend on location. Most soil parent material is sedimentary with aeoliation as important as alluviation. The impact of aeoliation is seen in the predominance of the silt fraction (as understood internationally) in most soils of the area. Except on recent alluvial fans and terraces, soils in the foothills are more uniform, being either skeletal soils overlying rock, formed by colluviation or in deep aeolian deposits. Soils in the middle reaches of the basin are mostly formed in alluvial, aolian and lacustrine deposits and in the delta areas are particularly complex. The average number of soil horizons in the top one metre of the described profiles decreases with elevation, as summarised in Table 5.2. More detail is given in Appendix 2, Table A2.1.

Table 5.2 Effect of Elevation on Soil Horizonation

Elevation (mamsl)	River basin	No. horizons/m
873-954	Syrdariya	1.2
425	Amudariya	1.3
257-280	Syrdariya	1.6
117	Syrdariya	1.8
90	Amudariya	1.6
75-80	Amudariya	2.1

5.4 Soil Texture

International systems of soil texture vary slightly but are consistent in defining the upper size limit of “clay” particles as 0.002mm. This limit was chosen as marking significant change in the physical and chemical properties of particles greater and less than this limit. Textural classification of soils is based on two-dimensional variation, two out of sand, silt and clay (the third, being defined by the sum equal to 100 percent, is not independent). Although the foundation of the science was by Russian pedologists and Dokuchaev in particular, Kachinsky later adopted different standards to those that became internationally accepted. “Physical clay” (<0.01mm) was the term used in the uni-dimensional Soviet system of textural classification, as shown in Table 5.3.

Table 5.3 Classification of Soil Texture by Kachinsky

Class	Physical Clay (%)
Clay	>60
Heavy loam	45-60
Moderate loam	30-45
Light loam	20-30
Loamy sand	10-20
Sand	<10

The definition of “physical clay” includes all particles less than 0.01mm and the discrete fractions: colloid (<0.0001mm), fine clay (0.0001-0.0005mm), coarse clay (0.0005-0.001mm), fine “silt” (0.001-0.005mm), medium “silt” (0.005-0.01mm). By contrast, the USBR system defines silt as particles from 0.002 to 0.05mm, so that particles between 0.002 and 0.01mm that are classified as “physical clay” by Kachinsky, are “silt” in the USBR system. In view of the fact that a high proportion of the particles in soils of Central Asia fall within this range, the disparity created by Kachinsky may be seen as most unfortunate. The divergence of the basic definition of particles, and the bi- versus uni-dimensional basis of classification, make comparison between the soil textural classes of the two systems almost impossible.

In the laboratory, 447 soil samples were dispersed and sampled during sedimentation. Both local and international methods use Stokes’ Law to relate sedimentation velocity to particle size, but local sample times correspond to the textural limits described above. Log-log transformed cumulative values by weight were plotted against particle diameter from which the corresponding USBR fractions were interpolated. Percentage distribution of the 447 soil samples analysed, in terms of their contents of USBR particle size fractions, is given in Table 5.4. The silt fraction predominates in the soils of the region with 62 percent of samples containing more than 50 percent of particles in the silt fraction. Only three percent of samples contained more than 50 percent of clay, and nine percent of samples contained more than 50 percent of sand.

Table 5.4 Distribution of Soils on Basis of Sand, Silt and Clay Fractions (USBR)

Range in % by weight of particles	Percent of samples		
	Sand >0.05mm	**Silt** 0.002-0.05mm	**Clay** <0.002mm
<10	21	1	10
10-20	24	4	42
20-30	24	4	31
30-40	15	11	10
40-50	6	19	4
50-60	4	30	1
>60	5	32	2
Total	100	100	100

Textural classification of soil samples, based on both the Kachinsky system given above and the USBR textural triangle, are given in more detail in Appendix 2 (Tables A2.3 and A2.4), but are summarised in Table 5.5.

Table 5.5 Comparison of Textural Classification of 445 Soil Samples by USBR and Kachinsky Systems

USBR System			Kachinsky System			Most likely USBR equiv.
Group	Class	% of samples	Group	Class	% of samples	
Clays	C	3	Clays	HC	4	C
				MC	3	ZC
Sits	Z	1		LC	9	ZCL
	ZC	4	Clays total		17	
	ZCL	14				
	ZL	47				
Silts total		**65**	Loams	HL	20	ZCL
				ML	37	ZL
Loams	CL	4		LL	16	ZL
	L	19	**Loams total**		**73**	
	SCL	1				
	SL	6				
Loams total		31	Sands	LS	7	ZL
				CnS	2	SL
Sands	LS	1	Sands total		10	

Note: C = clay, Z = silt, S = sand, L = loam, h = heavy, m = medium, l = light, cn = consolidated

The local classification placed 73 percent of samples in the *loam* group having between 20 and 60 percent of "physical clay". By contrast, the USBR classification placed 65 percent of samples in the *silt* group with more than 50 percent by weight of particles in the silt fraction. In the survey sample, **silt loam** is the most probable USBR class equivalent to the most common local classes of *medium and light loams*, and *loamy sands*. The next most probable USBR class is *silty clay loam*, corresponding to the local classes of *heavy loam* and *light clay*, but 19 percent of samples on the USBR system fell in the class of *loam*. The main soil physical and chemical properties (such as low CEC value, low organic matter content, soil aggregate structure, etc) are due to the high content of silt.

The preponderance of soils with textures in the three USBR classes, Silt Loam, Silty Clay Loam and Loam, is seen in most of the oblasts as shown in Table A2.7, Appendix 2. The sample fields in Osh oblast are much more variable, with most classes represented in the subsoils. The two Aral Sea littoral zone oblasts also show more variability, with Kyzl-Orda having heavier textures and Karakalpakistan having lighter textures.

Table A2.2 in Appendix 2 shows the percentage of sample fields with the same texture in horizons A and B, and the variation of soil textural uniformity by oblast within the basin is summarised in Table 5.6. Corresponding to the degree of horizonation recorded by the surveyors, the farms in the deltas of both rivers, Kyzl-Orda and Karakalpakistan, show the least uniformity due to the alluvial/lacustrine origin of the soils. Soils in the Osh area on the alluvial fan of the upper Ferghana Valley, and Mary area also on alluvial fans, are also more variable. The valley bottomlands, with the exception of farms in the new lands of the Golodneya Steppe, are more uniform, but not sufficiently so that the effect of horizonation can be ignored when calculating irrigation schedules.

Table 5.6 Textural Uniformity of Soil Profiles by Oblast

Republic	Oblast	Percent of fields with uniform texture to 1m
Kazakhstan	Kyzl-Orda	35
	Chimkent	75
Kyrgyzstan	Osh	33
	Bishkek	75
Tadjikistan	Leninabad	67
Turkmenistan	Mary	40
Uzbekistan	Surkhandariya	60
	Syrdariya (new)	45
	Khorezm	75
	Karakalpakistan	45
	Syrdariya (old)	60
	Bukhara	60

5.5 Soil Bulk Density

The oblast average value of bulk density in sample fields is in the range from 1.34 to 1.52 g/cm^3, depending on soil texture, with minimum values in the range of 1.1-1.3 and maximum values in the range of 1.42-1.74 g/cm^3. The overall average bulk density of 435 soil samples (horizons 30 and 70cm) from sample fields was 1.45 g/cm^3, but the range was wide from 1.10 to 1.74 g/cm^3. Percentage distribution of samples on the basis of their bulk density is given in Table 5.7.

Table 5.7 Distribution of Samples by Bulk Density

Bulk density range (g/cm^3)	Percent of samples
>1.6	13
1.5-1.6	23
1.4-1.5	27
<1.4	37

Generally, there is little difference in bulk density between the topsoil and subsoil (Appendix 2, Table A2.5). Exceptions were noted in Kzyl-Orda oblast, where the bulk density is higher in the subsoil, and in Karakalpakistan, where bulk density is higher in the topsoil. The lowest topsoil bulk density, 1.27 g/cm^3 is in Kzyl-Orda oblast. Bulk density higher than 1.5 g/cm^3 is most commonly observed in Turkmenistan (80-89 percent of samples), Karakalpakistan (70 percent), Surkhandariya oblast (54-63 percent) and in Khorezm oblast (53-55 percent). Generally it seems that the lower reaches of the desert zone have the most compact soils.

After grouping soil samples on the basis of their classification, statistical analysis confirmed a relationship between soil textural class and bulk density (Appendix 2, Table A2.4). Mean bulk densities of groups of samples, according to the USBR system of textural classification, are very highly significantly different. This is illustrated in Table 5.8, with classes arranged in order of decreasing mean value. The least significant difference, with 5 percent probability, is 0.05 g/cm^3, so that textural classes without the same letter are significantly different to each other.

Table 5.8 Soil Bulk Density by Textural Class

Texture class	Mean (g/cm^3)	Sig. Diff. (1)	Maximum (g/cm^3)	Minimum (g/cm^3)
SL	1.52	a	1.73	1.30
L	1.48	ab	1.74	1.23
ZCL	1.48	ab	1.71	1.10
ZL	1.44	bc	1.73	1.13
CL	1.42	cd	1.65	1.10
LS	1.38	de	1.53	1.27
ZC	1.37	def	1.65	1.11
SCL	1.36	ef	1.46	1.25
C	1.34	ef	1.49	1.15
Z	1.32	f	1.42	1.27
S	Unmeasurable		-	-
Overall	1.45		1.74	1.10
SE Mean	*0.02*	Note (1): soil types with the same letter are not significantly different with p=5%		
LSD (P=5%)	*0.05 ****			

5.6 Soil Penetration Resistance

Field measurements of soil penetration resistance were made with a proving-ring, cone penetrometer, within the range of possible measurements 0-3000 kN/m^2. Coefficient of variation for this variable is very high, as shown in the statistical summary, Table A2.4, Appendix 2, and minimum and maximum reading within the same farm can differ by as much as a factor of 10 times. One reason for variability is that soil strength and penetration resistance are affected by the wetness of the soil at the time of making the measurement. Surveyors had to take measurements during their only visit to each site and were unable to influence conditions at the time.

Table 5.9 Soil Compaction by Republic and Oblast

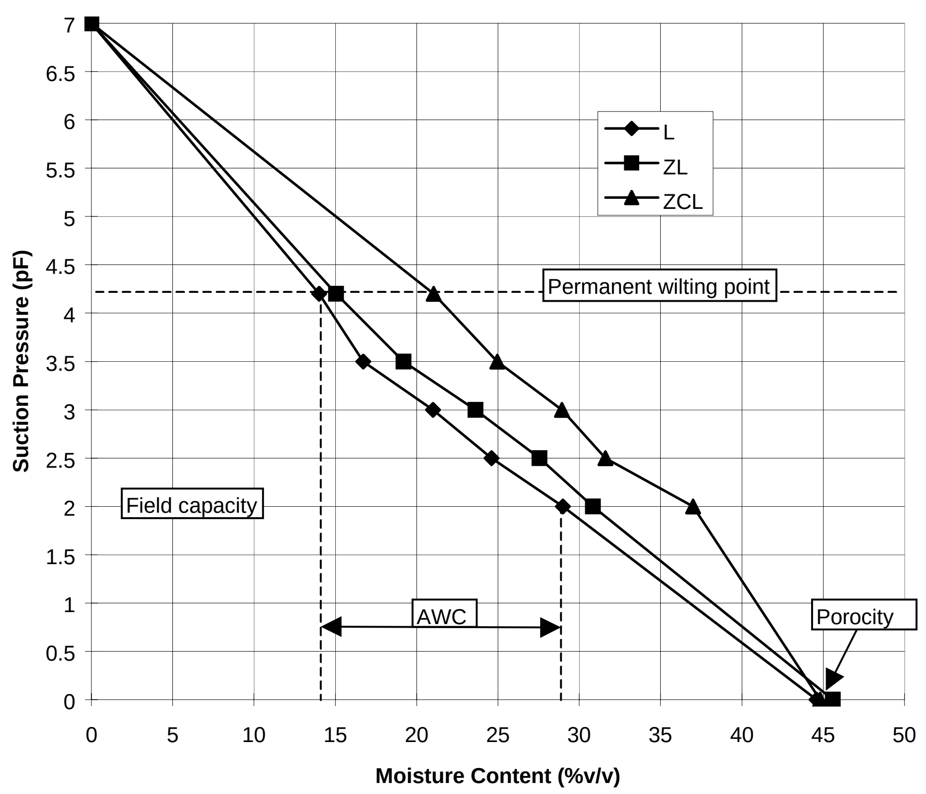
Republic	Oblast	Percentage of samples in compaction class		
		Moderately compact 500-1500 kN/m^2		Compact >1500 kN/m^2
		Mean	Range	Mean
Kazakhstan	All oblasts	80	60-100	20
Kyrgyzstan	All oblasts	79	60-100	15
Tadjikistan	All oblasts	67		0
Turkmenistan	All oblasts	75	60-90	0
Uzbekistan	All oblasts	57	30-90	36
	Bukhara			50
	Surkhandariya			45
	Khorezm			40
	Karakalpakistan			35

Appendix 2, Table A2.6 illustrates the non-uniformity of soil profiles in terms of the distribution of fields within three classes of penetrometer reading: “loose soil” < 500 kN/m^2, “moderately compact soil” 500-1500 kN/m^2, and “compact soil > 1500 kN/m^2. Most of the surveyed profiles have penetrometer readings in the “moderate” range, as shown in Table 5.9. The most impenetrable soils were found in the oblasts of Uzbekistan.

5.7 Moisture Characteristics

Soil moisture characteristics were measured in undisturbed top- and subsoil samples using pressure membrane apparatus in the SANIIRI laboratory. Soil moisture content was measured by weighing, after stabilising the soil samples at a range of soil suction pressures equivalent to pF 2.0, 2.5, 3.5 and 4.2. In addition, soil porosity was estimated in all samples and the pF curves were plotted. With some smoothing of the curves, soil moisture content at pF values of 2.0 and 4.2 were interpolated, and taken to be equivalent to field capacity and permanent wilting point respectively (Figure 5.1). The difference in moisture content at these two suction pressures is the Available Moisture Capacity (AWC), for use directly in irrigation scheduling and soil leaching recommendations.

Figure 5.1 Moisture Characteristics of Typical Soils

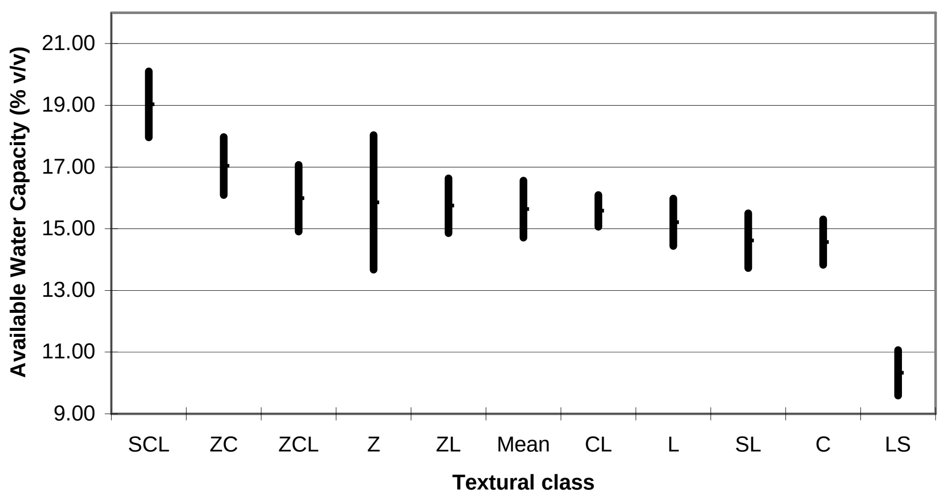


Summary statistics of pF and porosity for samples grouped into USBR textural classes are given in Table A2.4 in Appendix 2. Coefficients of variation within soil classes are moderate, and low in the cases of porosity and AWC. Differences between soil classes are highly significant for each of the measurements. A summary of these statistics is given in Table 5.10. Moisture characteristics vary widely in relation to soil texture. This is apparent particularly in available soil moisture capacity, with textural classes arranged in order of decreasing mean value in Table 5.11. The overall mean AWC is 15.6 percent (156mm of water per m of soil profile), with a range in measured values from 26.3 to 5.4 percent. This extreme range was found only in the soil class silty clay loam and raises doubts about the accuracy of the measurements: these extreme values tend to compensate for each other so that the mean may be little affected. The soil textural classes are highly significantly different in mean values of AWC, as shown by classes with different letters in the Table: there are five groups of textural class that differ with a probability of 5 percent. The limits of the 75 percent probable range are shown in Table 5.11 for every class and graphically in Figure 5.2 to illustrate the overlap of the ranges. Only the classes silty clay loam and loamy sand are distinct at a 75 percent probability level: other classes show some degree of overlap. In terms of the occurrence of the textural classes, about 98 percent of fields surveyed fall in the other classes. Without regard to textural class, there is a 75 percent probability that a sample field on the farms surveyed will have an AWC in the range from 14.7 to 16.6 percent, around the mean of 15.6 percent. Clearly, this range does not apply to land outside the WUFMAS sample farms.

Table 5.10 Porosity and Moisture Content at Different Tensions
By Soil Textural Class

Textural class (USBR)	Soil moisture content in percent on v/v basis								
	Porosity			Field Capacity (pF2.0)			Permanent Wilting Point (pF 4.2)		
	Mean	**Max.**	**Min.**	**Mean**	**Max.**	**Min.**	**Mean**	**Max.**	**Min.**
C	49.7	56.7	44.1	35.5	47.0	26.0	20.9	32.2	11.7
CL	46.7	58.8	38.3	34.2	42.0	27.0	18.7	26.3	12.2
L	44.6	53.9	34.8	29.2	45.0	16.0	14.0	30.0	6.0
LS	48.2	52.4	42.5	16.0	20.0	14.0	5.7	7.0	5.0
SCL	49.1	53.3	45.4	37.0	46.0	24.0	18.0	23.3	11.0
SL	43.2	51.3	35.2	27.2	41.0	18.0	12.6	25.2	5.0
Z	50.4	52.4	46.8	31.5	45.0	12.0	15.6	28.3	3.9
ZC	48.6	58.4	38.1	39.2	48.0	25.0	22.2	29.4	13.0
ZCL	44.8	58.8	35.9	37.3	50.0	23.0	21.3	31.6	10.0
ZL	45.6	57.7	35.4	30.9	47.0	14.0	15.1	29.0	4.5
S					Unmeasurable				
Overall	45.6	58.8	34.8	31.9	50.0	12.0	16.2	32.2	3.9
SE Mean	*0.72*			*1.02*			*0.77*		
LSD (P=5%)	*2.0 ****			*2.8 ****			*2.1 ****		

Figure 5.2 Seventy-five Percent Probable Range in AWC by Soil Class



The correlation matrix between soil physical characteristics is shown in Table A2.8, Appendix 2. Few coefficients are statistically significant, and these mostly indicate the obvious relationships between moisture content at different pF values. There seems little prospect of predicting AWC on the basis of simply-measured soil parameters, and the R^2 value of the multiple regression, of AWC against most of the parameters in the correlation matrix, was only 6 percent. The value of r = 0.70 for the correlation between AWC and soil porosity is interesting and merits further investigation. Some correlation coefficients, although not significant, were large enough to suggest the possibility of some relationship between AWC and salinity. The existence of significant correlation is not proof of a causal relationship, since both parameters may be correlated with another factor, which may or may not have been measured.

Table 5.11 Summary Statistics of Available Moisture Capacity by Soil Class

Textural class (USBR)	Signif-Icant differ-ence	% of samples in soil class	Available Soil Moisture Capacity (AWC as %, v/v)					Published values (AWC as %, v/v)	
			Mean	Min.	Max.	75% probable		Ref.1	Ref. 2
						Lower	Upper		
SCL	a	1	19.0	13.0	22.7	18.0	20.1	14-17	
ZC	b	4	17.0	12.0	22.6	16.1	18.0	16	18-23
ZCL	c	14	16.0	5.4	26.3	14.9	17.1	17	
Z	c	1	15.9	8.1	24.6	13.7	18.0		
ZL	cd	47	15.7	9.1	26.1	14.9	16.6	19	
CL	cd	4	15.6	13.2	18.5	15.1	16.1	15	16-22
L	cd	19	15.2	10.0	21.0	14.4	16.0	17	14-20
C	d	3	14.6	10.8	18.5	13.8	15.3	14	20-25
SL	d	6	14.6	11.0	21.0	13.7	15.5	12-17	9-15
LS	e	1	10.3	9.0	13.0	9.6	11.1	8-14	
S			Unmeasurable						6-10
Overall			*15.6*	*5.4*	*26.3*	*14.7*	*16.6*		
SE Mean			*0.44*						
LSD (P=5%)			*1.21* ***						

Ref 1: Tropical Soil Manual, Ed. Landon J R, Longmans, 1991
Ref 2: Agricultural Compendium, Ed. Euroconsult, Elsevier, 1989

5.8 Soil Alkalinity

Water extracts of regional soils commonly are contaminated by high concentrations of alkaline soluble salts, with pH from 7.3 to 8.6. Values greater than 8.3 are indicative of the presence of HCO_3^- ions and the possibility of problems in reclaiming saline soils. Percentage distribution of the average pH values of the 1996 and 1997 samples are given in the Table 5.12.

Table 5.12 Distribution of Soil Samples by pH Class and Republic

PH Class	pH range	Kazakh-Stan	Kyrgyz-stan	Tadjiki-stan	Turkmeni-stan	Uzbeki-stan	Overall
Extremely high	>8.5	0	0	0	0	0	0
Very high	8.0-8.5	0	0	0	5	0	1
High	7.0-8.0	98	0	100	95	100	99
Medium	5.5-7.0	3	0	0	0	0	1
Low	<5.5	0	0	0	0	0	0
No. samples		40	0	2	20	100	162

Overall, 99 percent of samples had pH in the slightly alkaline range 7.0 to 8.0, but surprisingly, a few samples from Kazakhstan were slightly acid after rice production. Most significantly, some of the samples from Turkmenistan were seriously alkaline and indicate that only in the Mary region (of those sampled) is there a potential problem of soil alkalinity.

5.9 Soil Organic Matter

The content of organic carbon in the fine earth fraction of the soil was measured by dichromate oxidation. The values multiplied by 1.72 are taken to be an estimate of the organic matter in the soil. Not all of this is necessarily humus since particles of plant residues can pass the sieve into the fine earth fraction. The data are summarised in Table 5.13.

Table 5.13 Soil Organic Matter

Class	% OM range	No. of samples	% of Total
V low	<0.5	111	30
Low	0.5-1.0	150	41
Medium	1.0-2.0	103	28
High	>2.0	1	0
Total		365	100

Of the 365 topsoil samples measured, about 40 percent have a "low" content of organic matter, between 0.5 and 1.0 percent. The remaining samples are evenly spread between the "very low" and the "medium" categories, but only one sample had more than 2 percent organic matter.

5.10 Plant Nutrients

Extractable components of the major plant nutrients, NO_3-N, NH_4-N, P and K, were measured by Palintest kit in topsoil samples. The methods of extraction developed for this field kit, in some cases do not conform to standard laboratory methods so that internationally accepted interpretative values cannot be applied.

The results of extraction of the two mineral nitrogen forms are summarised in Table 5.14.

Table 5.14 Mineral Nitrogen in Soil

Class	Range	Extractable NO_3		Extractable NH_4	
	mg/kg	No. samples	% of Total	No. samples	% of Total
V high	>50	0	0	11	2
High	35-50	0	0	23	4
M high	25-35	0	0	78	15
Medium	15-25	5	1	208	40
Low	5-15	185	36	195	38
V low	<5	326	63	1	0
Total		516	100	516	100

Rather more mineral nitrogen is in the cationic than anionic form. The majority of the soil samples had NO_3-N in the very low class, compared with most samples in the medium to low classes for NH_4-N.

Soil phosphorus is extracted by the standard method of Olsen and as such, international class thresholds may be used to assess the status. Results are summarised in Table 5.15.

Table 5.15 Soil Available P (Olsen Method)

Class	mg/kg (ppm)	No. of samples	% of Total
High	>14	171	33
Medium	7-14	277	54
Low	<7	68	13
Total		516	100

The samples are well distributed about the range from low to high soil content of available P.

The situation with soil potassium is more complex due to the relative abundance of saline soil samples with potassium enrichment from groundwater. Extraction of K by the Palintest method using magnesium acetate extracts both exchangeable and soluble K. A subset of samples was analysed for water-soluble salts, so that subtraction of soluble K from extractable K gives a measure of exchangeable K. Results of these analyses are summarised in Table 5.16.

Table 5.16 Soil Potassium

Class	Range	Extractable K		Exchangeable K	
	me/100g	No. of samples	% of Total	No. of samples	% of Total
Rich	>0.5	419	81	44	49
Adequate	0.3-0.5	94	18	22	25
Marginal	0.15-0.3	2	0	9	10
Deficient	<0.15	1	0	14	16
		516	100	89	100

If interpretative criteria are applied to values of extractable K, the majority of samples are rated as rich in K. After allowing for water soluble K that would be leached were the groundwater contribution to be eliminated, the pattern of exchangeable K presents a different picture. In this subset of samples (that are more saline than average), some 26 percent are in the deficient and marginally deficient classes.

5.11 Soluble Salts in Soil Samples

The results of analysis of soluble salt content in aqueous extracts of soil samples are summarised in terms of the percentage distribution by range in Table 5.17 and overall average composition in Table 5.18. Analytical data were checked both by balancing total dissolved solids against the gravimetric sum of cations and anions, and comparison of the total equivalent weights of cations and anions. A significant number of samples failed to show closer than 90 percent comparability in these tests and were not included in the summaries. This indicates that laboratory procedures need review, to improve techniques and at least to explain the disparity. Partly on account of the lack of resources, but mainly due to the level of soluble salts in the majority of soil samples, exchangeable levels of cations and anions were not determined in most samples, but values would be expected to reflect the ionic composition of the soluble salts.

Table 5.17 Overall Average Ionic Composition of Soluble Salts in Soil Samples

Cations	Concentration		Anions	Concentration	
	me/100g	%		me/100g	%
Ca^{++}	6.04	48	SO_4^{--}	10.92	87
Mg^{++}	3.06	24	Cl^-	1.46	12
Na^+	3.19	25	HCO_3^-	0.24	2
K^+	0.30	2			
Sum	12.59	100	Sum	12.62	100

Gypsum ($CaSO_4.2H_2O$) in the soil profile clearly influences the composition of the soluble salts in the soils of the basin even though its solubility in water at average soil temperatures is not great. Forty five percent of samples contained more than 6me/100g soil of Ca^{++}, equivalent to 22t/ha of gypsum in the topsoil, and 70 percent of samples contained more than half this amount. Many soil profiles show foci of crystalline gypsum and a significant proportion of irrigated land has a pronounced gypsic horizon in the profile. The ionic balance between calcium and magnesium was generally favourable, and in only 27 percent of samples was the ratio greater than three.

Epsom salt ($MgSO_4$) is the next most common, followed by Na_2SO_4, with the chlorides and bicarbonates of potassium and sodium of minor importance. Seventy percent of samples contain more than 1.3me/100g of soil of Mg^{++}, equivalent to more than 3.8t/ha of Epsom salt in the topsoil. Since the osmotic pressure created by $MgSO_4$ is greater than that of $CaSO_4$ it seems that in most situations, salinity effect on crop yield is most often the consequence of this salt.

Only in a third of samples was sodium more than 40 percent of cationic concentration in solution, and in only one percent of samples was it as much as 70 percent. On this evidence, sodic soils would be expected to be rare in the basin. Measured bicarbonate concentrations are generally low indicating that carbonate mostly determines soil pH. High pH in soil samples did not correspond with high bicarbonate concentration, suggesting that spurious data may remain in the database. As such, there is no clear evidence of the existence of seriously alkaline soils. Although calcium carbonate is common in the soil matrix, soluble carbonate salts are not present in significant quantity.

Table 5.18 Distribution of Soil Samples By Content of Soluble Salts

Class	Range	No samples	Percent	Class	Range	No samples	Percent
Soluble Sodium in me/100g soil				**Ratio Soluble Na/Soluble K**			
High	>10	3	3	High	>30	16	18
Medium	5-10	13	15	Medium	20-30	19	21
Low	<5	73	82	Low	<10	54	61
		89	100			89	100
Soluble Potassium in me/100g soil				**Soluble Bicarbonate in me/100g soil**			
High	>0.6	7	8	High	>0.4	3	3
Medium	0.2-0.6	39	44	Medium	0.2-0.5	22	25
Low	<0.2	43	48	Low	<0.2	64	72
		89	100			89	100
Soluble Calcium in me/100g soil				**Soluble Chloride in me/100g soil**			
High	>6	40	45	High	>3	7	8
Medium	3-6	22	25	Medium	1-3	37	42
Low	<3	27	30	Low	<1	45	51
		89	100			89	100
Soluble Magnesium in me/100g soil				**Soluble Sulphate in me/100g soil**			
High	>4	23	26	High	>10	47	53
Medium	0.5-4	56	63	Medium	5-10	20	22
Low	<0.5	10	11	Low	<5	22	25
		89	100			89	100
Sodium as percent total cations				**Ratio Soluble SO4/Soluble Cl**			
High	>40	29	33	High	>10	39	44
Medium	15-40	34	38	Medium	1-10	48	54
Low	<15	26	29	Low	<1	2	2
		89	100			89	100
Ratio of soluble Ca to Mg				**Total soluble cations in me/100g soil**			
High	>5	6	7	High	25-40	2	2
Medium	3-5	18	20	Medium	5-25	73	82
Low	<3	65	73	Low	<5	14	16
		89	100			89	100

Ten percent of soil samples contained more than 2me/100g of soluble Cl^-, and with one exception, they were all collected in the middle and lower reaches of the Amudariya River basin. However, this concentration of chloride is not high in the context of sulphate:chloride ratios being generally high also. In only two percent of samples was sulphate concentration less than that of chloride, and in 44 percent of samples it was more than 10 times greater.

5.12 Cation Exchange Capacity

With most soils contaminated by soluble salts, measurement of exchangeable cations and cation exchange capacity is laborious and not very meaningful. Twenty samples were selected from the fields in farms Garfar Guliyam (Syrdariya) and Shortanbey (Karakalpakistan) for detailed analysis: data are given in Table A2.10, Appendix 2. Cation exchange capacity ranged from 8.3 to 15.0 me/100g soil, which is fairly low.

Clay contents were also low, in the range 8 to 27 percent, and organic carbon contents around 0.2 to 0.5 percent were also low. Approximate cation exchange capacity of the clay fraction was calculated by allowing 1me/100g soil for the contribution from organic matter (200 me/100g OM) and from silt and sand fractions. The mean value for Gafar Guliyam was 93 me/100g clay and in Shortanbey was 80 me/100g clay, with pH respectively 8.2 and 7.9. Clearly clays are of the 2:1 lattice configuration as expected at such high pH, with a higher proportion of vermiculite to montmorillonite in the Golodneya Steppe on account of the higher pH. The values varied considerably from field to field, down to 39 me/100g clay in one Shortanbey sample, indicating substantial illite clay.

Base saturation was 100 percent in these high pH soils, with Mg^{++} exceeding Ca^{++} in 85 percent of samples. All of the Shortanbey and half of the Gafar Guliyam soils were sodic, with sodium absorption ratio greater than 15 percent. This is surprising in view of the preponderance of gypsum, but may be explained by the failure of the field drains. Local experience at Gafar Guliyam is that when drains were functioning, leaching quickly reduced sodicity. Further work on this topic is recommended.

5.13 Soil Salinity

Local classification of salinity is commonly based on the percentage of salts by weight in an aqueous extract of soil (TSS) and on chloride concentration. International classification of salinity in soils is based on the electrical conductivity of a saturation extract of the soil (EC_e), because this more nearly reflects the osmotic pressure of the soil solution on plant roots. Saturation extracts of soil samples were not possible as the SANIIRI laboratory does not have a vacuum pump, so electrical conductivity ($EC_{1:5}$) was measured in a $1:5_{(w/w)}$ soil:water suspension. Based on the dilution ratio of this w/w method and the bulk density of the soil, the conversion factor from $EC_{1:5}$ to ECe ought to be in the order of 10. This is confirmed by the equation from *Agricultural Compendium, Elsevier, 1989*:

$$ECe = 500/SP \times EC_{1:5}$$

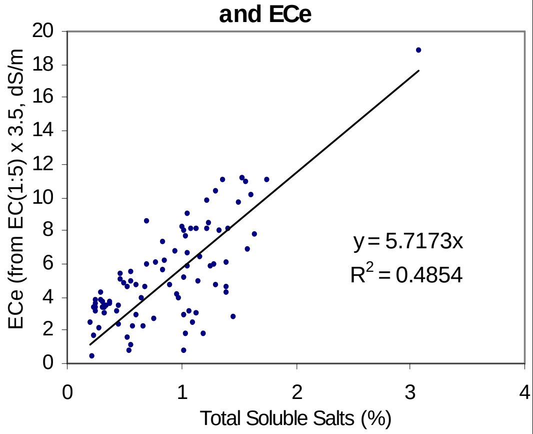
(where SP is saturation percentage), in contrast to the commonly used factor of 6.4, which is based on a v/v method (*Booker Tropical Soil Manual, Longman, 1991*). However, the solubility of salts is affected by dilution, and a saturated solution of gypsum, dominant in most soils of the region, has an EC of only 2.2dS/m at 25°C. With the divalent sulphates predominant as the soluble salts in most soil samples, problems therefore arise in establishing both

- a clear relationship between percentage of total soluble salts (TSS) and EC
- a suitable value for K, the conversion factor from $EC_{(1:5, w/w)}$ to ECe.

5.13.1 Soluble Salts and Electrical Conductivity in Soil

The plot of percentage total soluble salts, the local method of salinity assessment, and electrical conductivity is shown in Figure 5.3.

Figure 5.3 Relationship between TSS and ECe



The correlation coefficient of 0.7 is highly significant but the scatter of points is such that the estimated conversion factor of 5.7 would not be meaningful for a substantial number of samples. The reason for the scatter of points (apart from possible laboratory error) is the considerable but variable quantity of gypsum in the soils, which contributes proportionally more to SSP than to ECe. The relationship could only be improved by a multiple regression approach, taking into account the chemistry of each sample. Further work on this topic is recommended.

5.13.2 Conversion factor from $EC_{(1:5)}$ to EC_e

The pressure membrane apparatus was used to extract soil solution from saturated pastes. Conductivity of the fraction varied with the time of extraction so that a representative value was difficult to establish. $EC_{(1:5,\ w/w)}$ and ECe values were determined in saline soil samples, selected from the main textural classes ZCL, ZL and L, and estimates of K were made, as summarised in Table 5.19.

Table 5.19 Estimated Values of Conversion Factor from $EC_{1:5}$ to EC_e

Soil type by texture	Range of values of K
ZL	1.1 - 3.2
ZCL	-
L	1.0 - 4.9

The variability of the factor makes the conversion of $EC_{(1:5,w/w)}$ to EC_e values unreliable. If a conversion factor of 2 is applied to $EC_{(1:5,w/w)}$ the resulting distribution of samples on the basis of salinity class is shown in Table 5.20. On this basis, only 6 percent of samples were slightly saline and the majority was non-saline. This contrasts markedly with the classification of samples on the basis of local methodologies: total soluble salts, chloride, sodium and total “toxic salts” in an aqueous extract, all of which classify salinity as much more serious. Salinity was most serious on the sample farms of Kazakhstan, followed by Uzbekistan, Turkmenistan and Tadjikistan. Soils on the Kyrgyzstan farms are not saline.

Table 5.20 Distribution of 1996 Soil Samples by Electrical Conductivity
(percent of samples, using factor 2)

Class	ECe (dS/m)	Kazakhstan	Kyrgyzstan	Tadjikistan	Turkmenistan	Uzbekistan	Overall
very severe	>16	0	0	0	0	0	0
severe	8-16	0	0	0	0	1	0
moderate	4-8	13	0	2	2	8	6
slight	2-4	26	0	6	8	15	12
non-saline	<2	62	100	92	90	76	82
		100	100	100	100	100	100
No. samples		39	58	50	50	169	366

As explained in Section 14, there is evidence from a subset of more saline samples that the value of the conversion factor may lie between 3 and 3.5 on average. In this event, 5 percent of samples are seriously saline, 9 percent moderately so, and 29 percent are slightly saline. The ranking of the republics is unchanged but 5 percent of samples from Kyrgyzstan become slightly saline.

The change in salinity between the samples from 1996 and 1997 is unaffected by the factor used. Fewer soil samples were received for analysis in 1997 and these may have been from more saline sites than those in 1996. Comparison of the change based on the subset of comparable data is shown in Table 5.21.

At only three farms was there a reduction in average soils salinity in the 10 sample fields, and this was mostly small. At the other farms the salinity increased in this period, overall by an average of 51 percent. The increase in salinity was very serious at farm numbers 21, 24 and 27 in Uzbekistan, considerably more than double.

Table 5.21 Percentage Change in ECe Between 1996 and 1997

Farm no.	Month in 1996	Month in 1997	Change (%)
1	Jun	Sep	9
2	Jun	Sep	-15
3	Jun	May	41
4	May	May	11
17	May	Apr	-28
18	May	May	77
21	May	Mar	132
22	Apr	May	45
23	May	Mar	85
24	Apr	Mar	176
25	Oct	Sep	1
26	Nov	Sep	48
27	Apr	Apr	181
28	Apr	Apr	44
35	Jul	May	-10
36	May	May	22
Overall average			**51**