14. SOIL MOISTURE AND FERTILITY

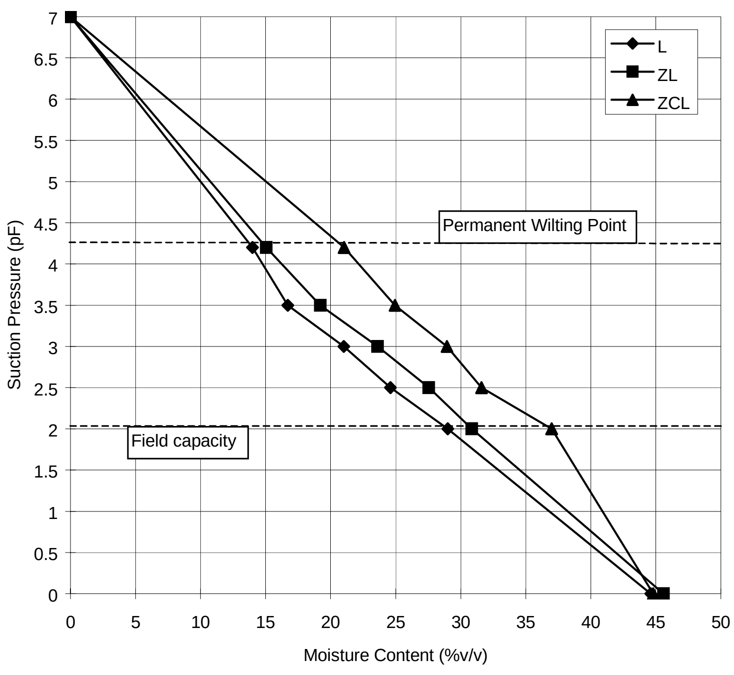
Data on these topics are presented in Section 5.

14.1 Prediction of Available Moisture

The international and local definitions of the term *soil available moisture* differ completely, despite common understanding of the term *field capacity (FC)*. The local methodology measures moisture content gravimetrically when the soil is at field capacity and oven dry, and the *weight* difference as percent of oven dry weight is the *available moisture capacity (AWC)*. International methodology measures moisture content at the same notional field capacity, but again at *permanent wilting point (PWP)* and the difference in *volume* of water, as percent of volume of dry soil, is the available moisture capacity.

Drainage under gravity from a sandy soil is rapid but from a clay soil takes place over a long period without any clearly defined point of FC. Plants vary in their tolerance of moisture stress so that PWP for a xerophyte is at lower moisture content than most plants. For these reasons, FC and PWP are defined internationally in terms of specific soil moisture tension, pF 2.0 and 4.2 respectively, as measured by pressure membrane apparatus. Curves representative of the three most commonly found soil textural classes are shown in Figure 14.1. These pF curves are from average values of the WUFMAS samples grouped on the basis of their textural classification by the international (USBR) rather than the local system.

Figure 14.1 Moisture Characteristics of Typical Soils



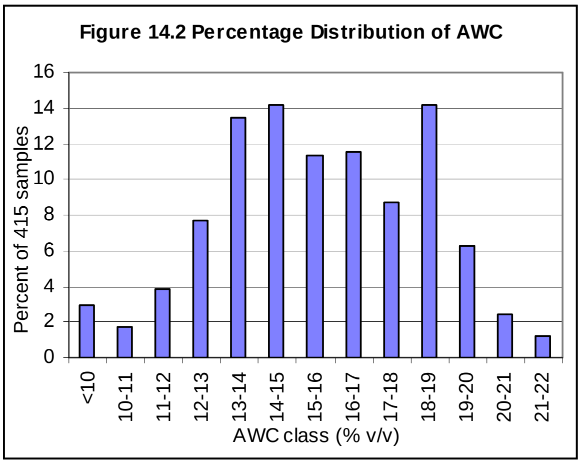
The AWC is the difference in moisture content on a volume basis between FC and PWP, and averages for these three most common soil textural classes are compared in Table 14.1 with values from an international source.

Table 14.1 Available Moisture Capacity
(% v/v)

Textural class	Local average values	International values (1) Temperate soils	Tropical soils
ZL	15.7	19	17
ZCL	16.0	17	15
L	15.2	17	16

(1) Source: Booker Tropical Soils Manual, 1991

Locally measured values tend to be slightly less than international average values but all are within the published range for each textural class. The pattern of distribution of AWC, as shown in Figure 14.2, is quite broad and mostly within the range 13 to 20 percent. This range represents a significant source of variation in the estimation of ideal irrigation schedules so that careful estimation of the AWC is a necessary part of the process of evaluating ideal irrigation schedules in individual fields.

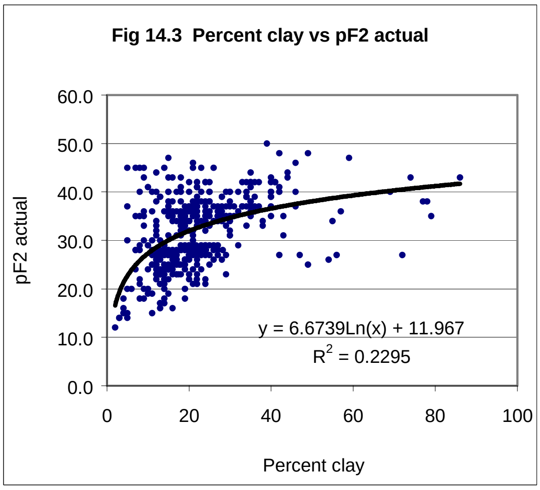


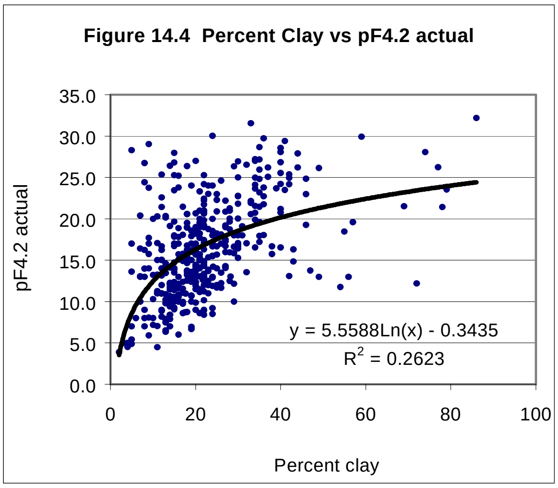
Taking undisturbed soil samples and transporting them to a central laboratory, suitably equipped with a pressure membrane apparatus, makes the process expensive. It would be very helpful to be able to estimate AWC with acceptable accuracy from soil characteristics that are easier to measure and preferably are standard measurements made previously during the original soil surveys. Multivariate analysis has been made on the WUFMAS soil database in the search for an acceptable model for predicting AWC.

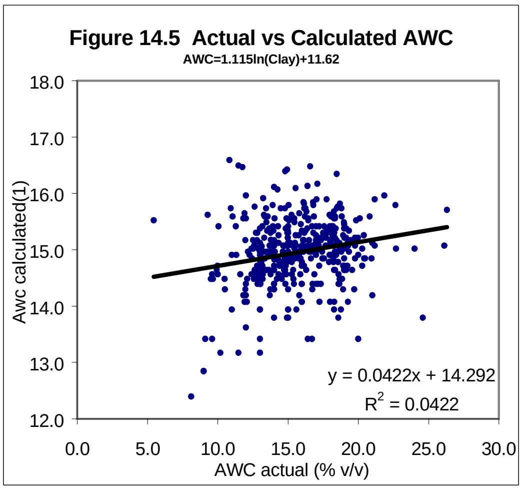
The first model uses only the percentage of clay (USBR) to calculate the moisture content at FC and PWP, the difference between the equations providing a simple predictive model for AWC. The relationships are shown in Figures 14.3 and 14.4 for pF 2.0 and 4.2 respectively. With r^2 values of 22 to 26 percent, both correlations are very highly significant. The difference between the two equations gives an equation for calculation of AWC:

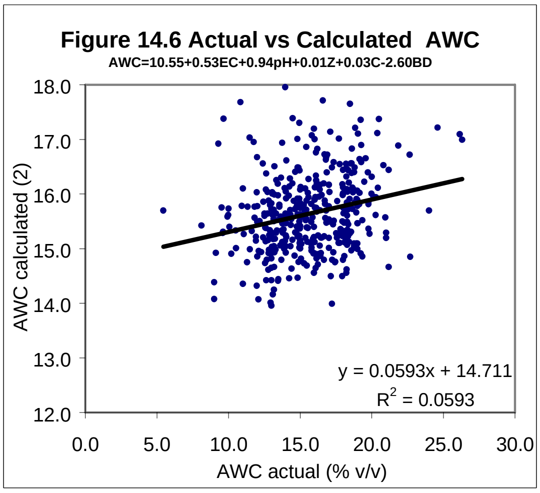
$$AWC = 1.115 Ln(clay) + 11.624$$

The plot of measured AWC values against those calculated by this simple model is shown in Figure 14.5. With an r^2 value of only 4 percent, the correlation is insignificant and as such this model is unhelpful.









The most comprehensive model between measured AWC and the soil variates, derived by multiple regression analysis based on the correlation matrix, was:

$$AWC = 10.55 + 0.53EC + 0.94pH + 0.01Silt + 0.03Clay – 2.60Bulk\ Density$$

The plot of measured values of AWC against those calculated by this model is shown in Figure 14.6. The r^2 of this equation is only 6 percent, indicating that it is insignificant and no more helpful than the simple model.

In the light of these findings and the importance of the search for an effective model, it is recommended that work on this issue should continue to receive support.

14.2 Soil Compaction

Soil compaction has not been given much attention in agricultural planning in the past but from the evidence available may deserve to receive more. The roots of crops must grow downwards in order to enlarge their access to the storage of available moisture and nutrients in the soil, to provide the crop requirement during the interval between irrigations and fertiliser applications. If the whole or a part of the soil profile is very compact, roots may be unable to penetrate, growth is restricted and yield reduced. Soil bulk density provides a measure of compaction and an indirect measure of the resistance to penetration that may be experienced by crop roots. A penetrometer used in the field gives a more direct measure of penetration resistance.

From international experience, bulk density greater than about 1.5 g/cm^3 is indicative of the possibility of root penetration problems for some crops, and accordingly more than one third of the sampled farm land may be affected in this way. From local experience, generalised yield losses relative to potential yield are shown in Table 14.2 in relation to the bulk density of topsoil, together with the percentage distribution of WUFMAS samples in the same classes.

Table 14.2 Effect of Bulk Density on Crop Yield

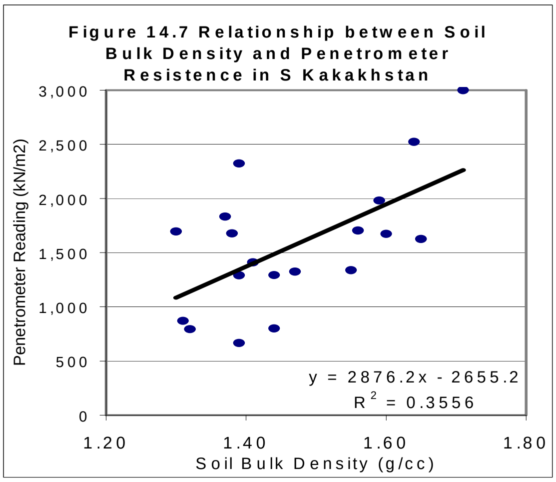
Bulk density g/cm^3	Percent of samples	Yield loss %
>1.6	13	70-75
1.5-1.6	23	40-55
1.4-1.5	27	15-20
<1.4	37	0
Weighted average		**25**

The estimated overall impact of soil bulk density is that about 25 percent of potential crop yield is being lost. Questions arise as to whether or not this degree of soil compaction is man-made, and to what extent cultural practices may alleviate the situation.

Were this degree of compaction to be caused by the use of heavy farm machinery being used, particularly when soils are wet, then annual ploughing would be expected to create less dense topsoils. It was demonstrated in Section 5 that there were few consistent differences in bulk density between topsoil and subsoil cores, except in the soils of the littoral zone. This suggests that the high density of some soils is a natural feature that is unlikely to be much improved by cultural practices. On the other hand, it is well known that soil bulk density is inversely related to the soil's organic matter content, so that farm practices designed to raise organic content are likely to reduce compaction. Selection of farm machinery might be more prudent, such as lighter equipment, broader tyres, and less energy applied to breaking natural soil aggregates. Operations might be more judicious, with fewer passes, and only when the soil is sufficiently dry. Minimum and zero tillage practices have been particularly successful in the central zone of N America, where soils are of similar origin to those in the Aral Sea Basin.

14.3 Bulk Density and Penetration Resistance

Sampling soil cores in order to measure bulk density is time-consuming and requires laboratory facilities. In contrast, a proving-ring penetrometer gives instant measurement in the field. Statistical analysis of the whole data set showed that there is no relationship in either topsoil or subsoil between resistance to penetration and content of silt and sand fractions, and to soil bulk density. The effect of ploughing in loosening soil structure may explain this phenomenon in the topsoil. The absence of a relationship between texture and compaction of the subsoil suggests that other pedogenic factors are responsible for the degree of compaction so it may not be predictable from textural analysis alone. Coarse soils with relatively high bulk density may have little strength and compaction, and soils with high gypsum content may be very impenetrable when dry, and yet have low bulk density. However, when soil bulk density is compared with penetration resistance in a sub-set of soils of similar pedogenesis, the correlation is much improved. This is illustrated in Figure 14.7 for the soils surveyed and sampled in the Chimkent region of South Kazakhstan.



The main reason for including this measurement in the soil survey of the sample fields is that a penetrometer can reveal the existence of indurated horizons in soil profiles. Soil survey with penetrometer readings would monitor the extent of the problem of soil compaction and identify areas where some control measures may be justified.

14.4 Plough Pans

Dense horizons may occur in the soil profile due to the development of a ploughpan, heavy soil texture or a consolidated layer of gypsum and carbonate. Three basic patterns of compaction have been identified:

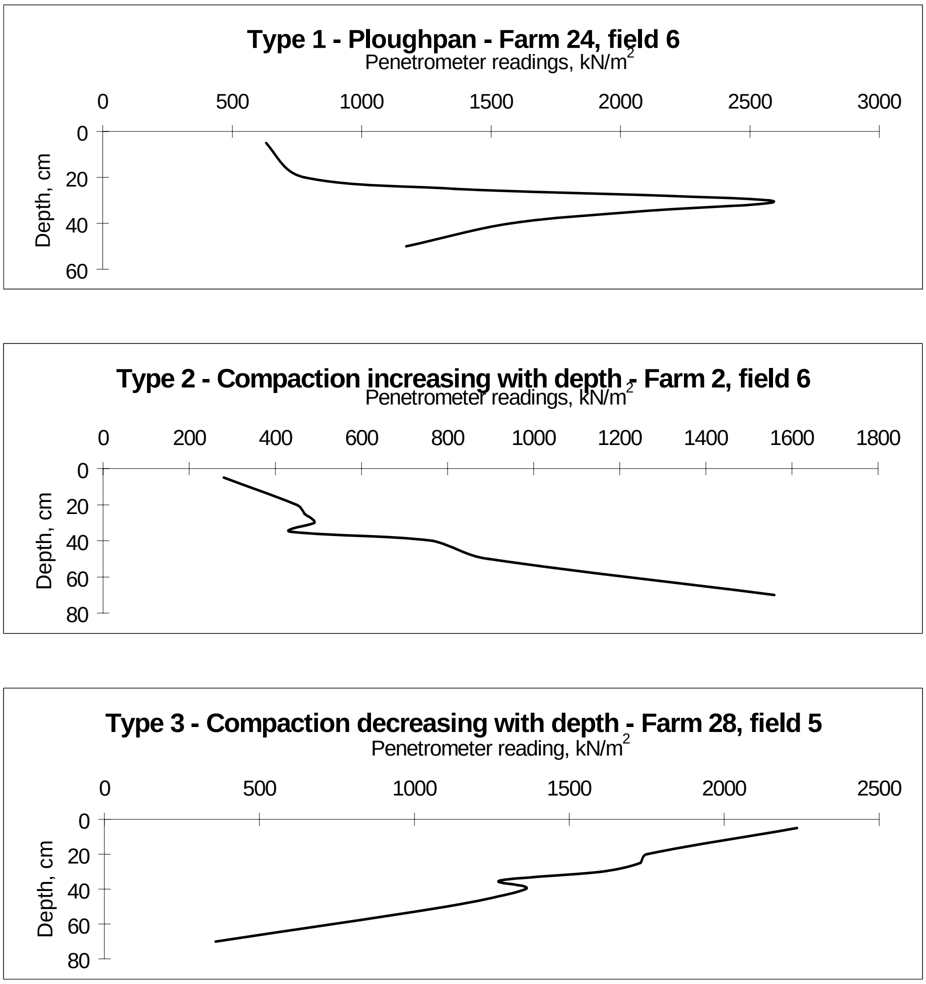
- Type 1 - ploughpan, man-made compaction at 30-40cm deep
- Type 2 - compaction increasing with depth, often indicating the presence of a gypsic or calcrete horizon
- Type 3 - compaction decreasing with depth
- Type 4 – variable pattern not conforming to any of the other three

Types 1 to 3 are illustrated in Figure 14.8 and a more detailed summary of their distribution is given in Appendix 2. Compaction types 1 and 2, representing about 60 percent of all profiles tested, have soil that is more compact in the upper 50cm of profile and are more hazardous to normal crop growth.

Plough pans, type 1 compaction, are most common in Chimkent oblast, Kazakhstan, where 85 percent of fields are affected, and in the nearby new irrigated zone of Golodneya steppe in Uzbekistan where it is 60 percent. Also seriously affected are the sample fields in Bukhara oblast (45 percent), Osh oblast in Kyrgyzstan (55 percent) and in Marie oblast in Turkmenistan (55 percent). Ploughpans are twice as common overall as the other three types of pattern, with about 41 percent of fields affected and are most common in the foothills and transition belt. These layers were developed mainly due to the many years of agricultural activity and annual ploughing to the same depth. Crop rooting depth is seriously affected by a ploughpan as demonstrated by the high proportion of shallow-rooted cotton crops. Ripping or sub-soiling is recommended in these conditions as an economically feasible measure. In allowing penetration of roots to greater depth the ideal irrigation interval is considerably lengthened and soil fertility is improved.

The other patterns of compaction are about equally represented overall. Type 2 is widespread, except in Chimkent oblast, but is nowhere more common than 50 percent of fields on any farm. Type 3, likewise, is widespread except in Kyzl Orda oblast but is the most common type in Karakalpakistan (60 percent of fields). The mixed pattern, type 4, is also widespread except in the Chimkent oblast and the nearby New Lands.

Figure 14.8 Illustration of Three Types of Soil Compaction



14.5 Salinity Assessment

Four different systems for assessing soil salinity have been developed by local institutes and two of them have been widely applied in annual assessments of the status of soil salinity.

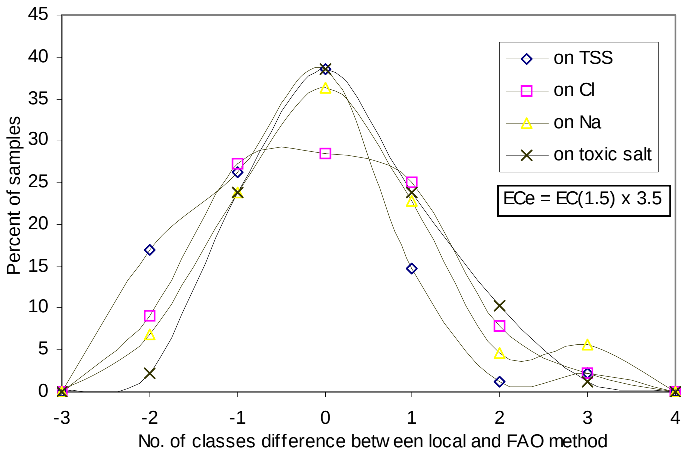
The total of soluble salts (TSS) is assessed in a water extract of the soil, dried and weighed, and is widely used in the area. This method is used in the Ferghana Valley where chloride content of soils is low. It is a relatively simple procedure requiring a minimum of equipment. Laboratory analysis of the salts provides the other three local criteria: the chloride content, the sodium content and the total of “toxic salt” (TTS) content of the soil. The TTS method is more sophisticated than the others as it takes into account the fact that soluble calcium sulphate has no osmotic effect on crops. This system takes no account of bicarbonate hazard but the low levels recorded in most samples, in practice makes this a minor drawback. The main drawback of all these local methods is one of sustainability in that they were developed during the period of adequate central laboratory facilities that are no longer available for routine assessment of salinity.

In contrast, the measurement of electrical conductivity, the internationally most widely used method, is ideally suited for use in both field and laboratory. The portable conductivity meter is relatively cheap, robust and reliable, additionally requires only calibrated tubes and a source of distilled water, and gives an instant reading of salinity. $EC_{(1:5)}$ is measured in the field by placing a unit volume of soil in the graduated tube, making up to the second mark with distilled water, shaking, and applying the meter's probe to the suspension. The drawback of this method is that the FAO salinity criteria apply to the conductivity of a saturation extract of the soil (EC_e) so a factor is required to adjust from $EC_{(1:5)}$ to EC_e. A saturated extract is withdrawn from a saturated paste of the soil under strong suction, this being made by adding only enough water to saturate the porosity of the soil, and as such this also is a laboratory method.

A commonly used factor to convert from $EC_{(1:5v/v)}$ to EC_e is 6.4 (Booker Tropical Soil Manual) but it is invalid where sulphates of divalent cations, particularly of calcium, predominate as they do in most parts of Central Asia. This factor also does not apply where $EC_{(1:5w/w)}$ is used, the Soviet standard extraction method of 1 part by weight of soil to 5 parts by weight of water.

The EC in WUFMAS samples was measured on the standard 1:5 (w/w) extract. Laboratory comparison in selected samples between EC_e and $EC_{(1:5w/w)}$ has produced conversion factors ranging from less than 2 to more than 4. The severity of salinity was determined using the standard FAO criteria applied to the calculated EC_e, with class 1 being non-saline and class 5 being very severely saline. The four local methods of salinity assessment were also applied using the criteria for the five classes as shown in Appendix 2. For each sample, comparison was made between the class assigned by the FAO method with that from the local method. In less than 50 percent of samples was there agreement in classification of salinity. The percentage of samples with the same class, or number of classes different, is plotted in Figure 14.9.

Figure 14.9 Comparison of Different Methods of Soil Salinity Assessment



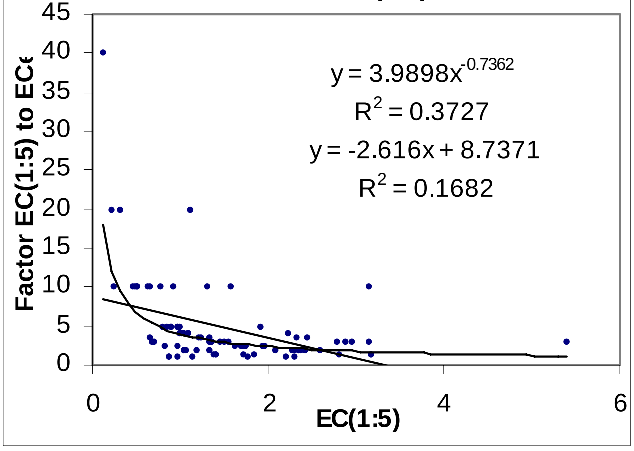
The form of these curves is affected by the value of the conversion factor used to convert from $EC_{(1:5w/w)}$ to EC_e. By trial and error, the best fit with the FAO method was obtained by using a conversion factor of 3.5, as shown in Figure 14.9. From fundamental principles, the local "toxic salt" method should best reflect the osmotic pressure of the salts in soil solution. The TSS method shows some skewing to the side of underestimating the salinity. The chloride method is the poorest in giving the widest spread either side of the "0 difference" point. As had been found by earlier local studies, the sodium method is the closest surrogate for the toxic salt method.

This figure reveals that even with the best fit, there is disagreement in classification of 60 percent of samples. The reason for the spread either side of the "0 difference" point may be a combination of two reasons. Firstly, there may be sampling and analysis errors due to dependence on several different analyses for the classification. The second reason is that although the estimate of an average conversion factor to EC_e of 3.5 may be reasonable, due to variable chemical composition the real factor for each sample is different. If the $EC_{(1:5\ w/w)}$

method, or more importantly the $EC_{(1:5\ v/v)}$ method commonly used elsewhere, is to replace the local methods of salinity assessment on the grounds of convenience, then it is important to provide a simple and effective conversion factor to EC_e.

The factor was adjusted for each soil sample so that there was perfect agreement between the salinity classes by the ECe and toxic salt methods. The correlation matrix between these estimated factors and soil analysis characteristics showed that the highest value of r was with $EC_{(1:5w/w)}$ itself, the plot of which is shown in Figure 14.10.

Figure 14.10 Conversion factor to ECe from EC(1:5)



Linear and power trendlines are shown, the power equation being a highly significant fit to the data (P=0.1%). As an alternative to the use of a standard conversion factor of 3.5, these two equations were used to calculate EC_e from $EC_{(1:5w/w)}$ and the resulting adjustment of the salinity classes in relation to the toxic salt method is shown in Figure 14.11.

Both methods reduce the spread either side of the "0 difference" point, but the percent of samples with the same classification by both EC_e and toxic salt methods is not increased by very much. The most symmetrical and best adjustment is the linear estimate of EC_e:

$$EC_e = 8.737 - 2.616.EC_{(1:5w/w)}$$

with 47 percent of samples being classified equally by the two methods, 39 percent with one class and only 17 percent out by more than one class. Applied to the data subset, the average value of ECe was 3.2 times greater than $EC_{(1:5w/w)}$, somewhat less than 3.5 by trial and error. Although the r^2 value for the power equation above was greater than the linear equation, it creates a significant bias towards overestimation of salinity by the toxic salt method (or underestimation by the EC_e method).

The linear equation above was derived from a subset of samples that had been comprehensively analysed. When this model was applied to the whole data set of $EC_{(1:5w/w)}$ values, the distribution of samples by salinity class is as shown in Table 14.3.

The table displays serious levels of salinity in more than a third of samples, and moderate salinity in more than half. This might be plausible were it not for the elevation of the salinity status of Kyrgyzstan samples from almost none to mostly severe. The reason for this is the form of the relationship in Figure 14.10 that uses a larger factor when the $EC_{(1:5\ w/w)}$ value is low, as in Kyrgyzstan. This clearly is not correct, so that further work on this matter is recommended in view of the importance of switching to field assessment of salinity using portable EC meters during the GEF project.

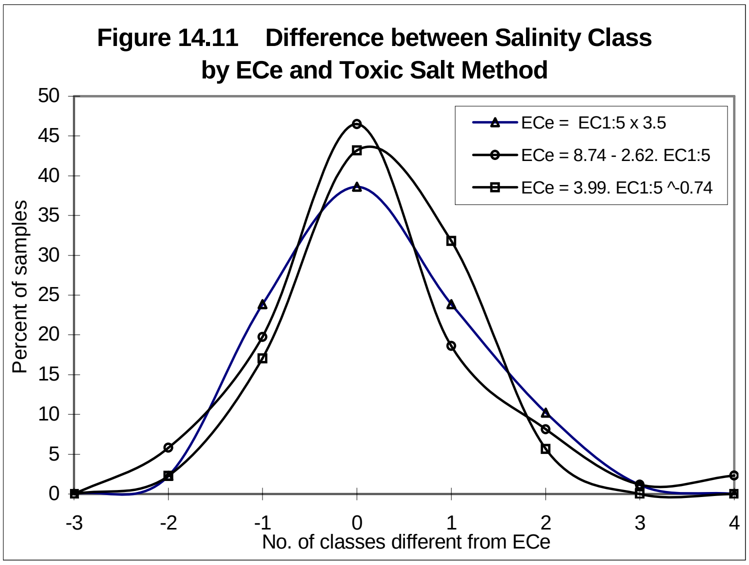


Table 14.3 Distribution of 1996 Soil Samples by ECe from Equation
(percent of total samples)

Class	ECe (dS/m)	Kazakhstan	Kyrgyzstan	Tadjikistan	Turkmenistan	Uzbekistan	Overall
very severe	>16	0	0	0	0	0	0
severe	8-16	14	88	54	36	21	37
moderate	4-8	74	12	44	62	69	56
slight	2-4	7	0	2	2	7	4
non-saline	<2	5	0	0	0	4	2
		100	100	100	100	100	100
No. samples		42	58	50	50	169	369

14.6 Soil Salinity and Yield

On most farms and in most fields, the recorded level of salinity increased between 1996 and 1997. The overall average increase in salinity measured by EC_e was 51 percent but it was more than double in the farms in Uzbekistan and five-fold in some fields. The reason for this is mostly related to the water regime in the field:

- lack of winter and spring soil leaching;
- unsatisfactory operation of the drainage system and high saline ground water table;
- use of unsatisfactory quality water for irrigation.

FAO methodology relates yield loss in crops to the level of salinity measured in terms of ECe. As discussed above, there are presently various estimates of this from $EC_{(1:5w/w)}$, but a factor of 3.0 is used here. The weighted average yield losses are given in Table 14.4 for samples taken in 1996 and 1997.

The weighted average crop losses resulting from soil salinity are not serious, but losses in the most saline fields are much more so. Certain fields of winter wheat, rice and lucerne in Kazakhstan and Uzbekistan are estimated to have lost up to 50 percent of their yield due to salinity. However, from the table above it would appear that the crop losses from salinity are not as serious as are sometimes believed. Calcium sulphate has little osmotic effect on the crop and yet is a major constituent soluble salt, and this may have given rise to the perception of the severity of salinity.

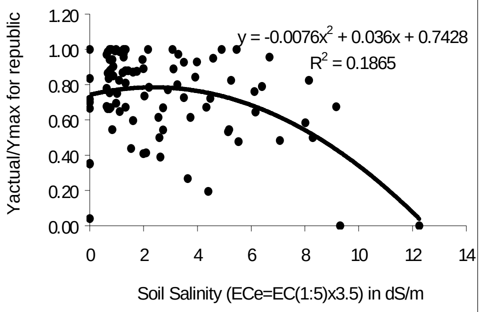
Table 14.4 Yield Loss due to Salinity
(weighted average percentage)

Crop/Year	Kazakhstan	Kyrgyzstan	Tadjikistan	Turkmenistan	Uzbekistan
1996					
Apple	0				
Barley, spring		0			0
Barley, winter		0	0		3
Cotton, pima			0		
Cotton, upland	0	0	0	0	0
Lucerne	7	1	0	2	5
Maize, grain	0	0	5	0	0
Maize, silage	0	0	0	5	7
Rice	6				1
Sugarbeet		0		0	
Tomato				0	
Wheat, spring	5	0			
Wheat, winter	0	0	0	0	1
1997					
Barley, winter					0
Cotton, pima				0	0
Cotton, upland	0		0	0	0
Lucerne	3			0	6
Maize, grain	0				
Maize, silage					0
Rice	3				8
Wheat, winter	0			0	1

Note: zero indicates no yield loss, blank indicates there were no sample fields with this crop

Another problem in analysis of the effect of salinity on crops is that it is rarely a simple issue. Most plants are much more sensitive to salinity when germinating and young, and if they survive this period, may grow on largely unaffected by salinity. In this event, the impact of salinity is on plant population, but this can take the form of a uniform stand of fewer plants or more often, bare patches in the field. Compensatory growth where plant density is reduced but uniform may fully compensate yield, whereas loss of plants in patches normally does not. For this reason, studies need to take account of plant population, and the seasonal change in soil salinity and its distribution down the soil profile. This is illustrated with data for cotton in Figure 14.12.

Figure 14.12 Effect of Soil Salinity on Yield Achievement in Cotton



Salinity in the topsoil, in this instance is calculated from $EC_{(1:5w/w)}$ using a factor of 3.5. In order to eliminate regional differences in cotton yield, it is measured in relation to the highest yield recorded in sample fields in each republic. The polynomial trendline shown is a highly significant fit to the data, but is strongly influenced by the two points with zero yield. These fields were planted to cotton, and in one case replanted, but germination was so poor that the fields were abandoned. Without these two points in the data set, there clearly is no relationship between salinity and yield over the range of soil salinity recorded.

Further work on this topic is recommended.

14.7 Soil Fertility and Fertiliser Use

Soil fertility is strongly influenced by the organic matter content of the soil. The levels of soil organic matter recorded in Section 5 are mostly low and very low but normal for soils in an area of seasonal rainfall and very high summer temperatures. The increased removal of crop residues from fields in recent years may only be aggravating the situation but the pedogenesis of the soil has a bearing on the organic matter content. The highest levels were recorded in the soils of the deltas of both rivers.

Analysis of the soil content of nitrogen has rarely provided an index of the soil status for crop production. There are three forms of nitrogen in soil, the mineral forms of NO_3-N and NH_4-N as salts and ions, and in various organic forms. The cationic form derives from the use of ammonia-based fertilisers and urea, the cations in soil solution being adsorbed on the cation exchange complex. Ultimately these are nitrified to the anionic form and as the anion exchange capacity is much less, they are leached by irrigation water unless absorbed by organisms. The soil's total nitrogen content was not measured, but the predominant form in the soil is organic, as deduced from the very high $C:N_{mineral}$ ratios. Without measured values of total nitrogen, it is not possible to speculate on the humus content of the soils.

The solubility of phosphorus applied in fertiliser depends on its chemical form, but in most fertilisers, only a part of the P is soluble, the remainder being released by microbial activity. A close relationship between soil organic matter content and available P is expected, but the relationship in this database is not a strong one. The orthophosphate radical $H_2PO_4^-$ is the form most commonly absorbed by crops but it rapidly forms insoluble complexes with Ca and Mg at the high pH encountered in local soils. The soil content of available P is rather higher than may be expected of tropical and sub-tropical soils in general. Data in Section 5 show that one third of soils sampled are high in available P and crop response to fertiliser P would be unlikely. In 54 percent of samples the available P was medium and a response to fertiliser P would not be expected in these fields, or it would not be large except in particularly demanding crops. In only 13 percent of fields was the available P level deficient, where a response to fertiliser P would be expected in most crops. The reason for this situation may be that excessive doses of phosphate fertilisers have been applied in past years due to the very high "normative" rates of the Soviet period. Once "fixed" in the soil, P compounds are not leached but are released slowly for the benefit of subsequent crops. Cropping may now be enjoying the benefit but because rates of use are now mostly very low, crop production may be "living on borrowed capital". Table 14.5 provides evidence of this, where the proportion of samples in the "high" class fell from 44 percent in 1996 to 9 percent in 1997 (this result may be influenced by the smaller number of samples in 1997).

As explained in Section 5, criteria for the status of soil potassium apply only to the amount of K adsorbed on the cation exchange complex, "exchangeable" K. The Palintest method, used on the samples from 1996 and 1997, extracts soluble as well as exchangeable K and unless the former is measured by a separate method, the value cannot be broken down into its components. Soluble cations were measured only in the 1996 samples. On the basis of this smaller subset of data, 16 percent of fields were estimated to be deficient in soil K, where a response to fertiliser K would be expected in most crops. Ten percent of fields were in the marginal category for soil K, in which a response to K-demanding crops would be likely, the two most commonly grown being potatoes and cotton. The conclusion from this evidence is that yield of cotton is being lost as a result of no K fertilisers being applied, in at least a quarter of fields.

Table 14.5 Change in Soil Available P 1996-1997

Class	Range mg/kg (ppm)	Sampled in 1996		Sampled in 1997	
		No. of samples	% of Total	No. of samples	% of Total
High	>14	157	44	14	9
Medium	7-14	158	45	119	73
Low	<7	39	11	29	18
Total		354	100	162	100

It is recommended that work on soil fertility and changes taking place with time should be expanded.