CROP TOLERANCE TO SOIL SALINITY, STATISTICAL ANALYSIS OF DATA MEASURED IN FARM LANDS.

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ABSTRACT: - Field data on the relation of agricultural crop yields and soil salinity, expressed in the electric conductivity and extract of saturated soil samples (ECe in dS/m) , are analysed to find the salt tolerance level. It concerns eight different crops in three countries of which wheat occurred thrice and cotton twice.
A first attempt of analysis can be by means of a generalized cubic regression (GCR) to detect the trend of the relation between yield and salinity. When this trend suggests that a range of no effect may exist, this range is determined by linear regression using the condition that the regression coefficient, i.e. the slope of the regression line, does not differ significantly from zero. This method is called partial regression (PAR) because the trend of the data beyond the range is analysed separately. From the range of "no effect", the tolerance level, i.e. the maximum salinity level at which no yield decline sets in, can be determined. This tolerance level appears as a Break-Point (BP) between the yield-salinity relations left and right of it. This breakpoint is also called threshold, tolerance or critical level. In literature, the Maas-Hofmann (MH) model has been used frequently to detect the tolerance level, but this has occurred mainly for data obtained under controlled laboratory conditions, or in pot and lysimeter experiments. Owing to the generally flat trend at the tail-end of the yield-salinity relation, the MH model, determined by the least squares method, usually produces considerably lower BP values than the PAR method as the flat tail-end draws the BP to the left. It is questionable that the trend at the tail-end should determine the salt tolerance. The van Genuchten-Gupta (vGG) model, producing a general picture of the relation between crop yield and soil salinity, has been applied less frequently. It does not yield a well defined tolerance level. In general, a polynomial or the CGR regression produces a better fit of the data to the growth curve. In all cases in this study of field data, the "range of no effect" could be clearly defined. However, in some cases the tolerance values could be higher than determined here because prolongation of the range of no effect was prohibited due to limited number of data beyond it.
A comparison of results of field data and laboratory experiments is made, which shows the same orders of magnitude.

Key words: - crop yield, soil salinity, farm land, statistics

1 Introduction, methods used

A breakthrough in the knowledge on the relation between crop yield and soil salinity was made by the Handbook 60 published by the Riverside Salinity Laboratory [1]. Numerous crop salt tolerance levels were reported. More than two decades later the Maas-Hoffman (MH) model was developed [2]. Still more than two decades later the Canadian Government added a considerable number of cases [3]. Shortly thereafter, a summary of results was presented by the FAO [4]. There exists also a reference on the salt tolerance of fibre and grain crops [5].

All definitions of crop salt tolerance levels were derived from controlled laboratory experiments and based on the MH model.

Recently, in the Netherlands, the Salt Farm Texel [6], carried out experiments of drip irrigation with fresh water mixed with seawater in various proportions to find the critical level of the soil salinity for crop production. The soil salinity was maintained more or less constant throughout the growing season by applying daily an excessive amount of irrigation water and operating an intensive subsurface drainage system.

In their brochure the critical levels were analysed with the MH model, which was not easy and in some cases the method did not succeed, as the scatter of data was very high [6] The 90% yield points were found with the van Genuchten-Gupta (vGG) model [7]. The reason for this was not given

The question arises: are laboratory experiments under controlled conditions representative for farmers' fields in which conditions are much less precisely controlled? Another question that can be asked is: are there no other models apart from the MH and vGG models applicable and do these two models produce the best results?

To answer the two questions asked, in this paper data obtained in farmers fields are used for further analysis. The data are found in the following publications:

- Egypt: clover (berseem), cotton, maize, rice, and wheat [8].
- India: barley, mustard (rapeseed), wheat (Sampla), and wheat (Gohana) [9].
- Pakistan: cotton and sorghum [10].

The four models used in the analysis are described in continuation:

A - The MH (Maas-Hoffman) model [2]:

$$Y = Ym \qquad [S<BP] \qquad (1a)$$
$$Y = R_2.S + Q_2 \qquad [S>BP] \qquad (1b)$$

where:

Y = yield, Ym = maximum yield, R_2 = linear regression coefficient, Q_2 = linear regression constant, S = soil salinity and BP = Break-Point (threshold, tolerance level), to be optimized by iterations conditioned by the least squares principle.

B - Partial regression (PAR) to detect the maximum range of no effect [11] :

$$Y = R_1.S + Q_1 \qquad [S<BP] \qquad (2)$$

where:

Y = yield, S = soil salinity, R_1 = the linear regression coefficient conditioned by $R_1 > -\sigma_R$, σ_R being the standard deviation of R_1 so that R_1 can be taken equal to zero without committing a significant error and Y equals Q_1 (constant), BP = Break-Point (threshold, tolerance level); being the average value of Y below the largest value of S (i.e. at S=BP) where the condition for R_1 holds.

C - The van Genuchten-Gupta (vGG) model [7]:

$$Y = Ym / [1 + \{S / S_{50}\}^{P}]$$

where: Y = yield, Ym = maximum yield d, S = soil salinity, S_{50} = soil salinity at 50% yield level, P = exponent whose value is to be optimized iteratively

D - Generalized cubic regression (GCR) using the third degree polygon [12] :

$$Y = A.Z^3 + B.Z^2 + C.Z + D \quad \text{with } Z = S^p$$

where: Y = yield, S = soil salinity, P = exponent to be obtained by iterative optimization, and A, B, C and D are the polynomial regression coefficients (constants) to be found by matrix and determinant inversion.

2 Analysis of Egyptian crops (berseem, cotton, maize, rice, wheat)

The data were measured in plots of some 10 m^2 selected at random. Per plot 5 salinity measurement were made, of which the average was used for further analysis.

The PAR results are shown in Fig 1.

In general, the data show a wide scatter as is to be expected in farmers' fields with less controlled conditions as in the laboratory. Also, the number of data beyond the Break-Point (BP) is limited, making it possible that, with more data on higher side, the BP shifts to the right. Apparently, farmers choose their crops in accordance to their salt tolerance and the salinity of the land. For example, berseem, which is a sensitive crop, shows no ECe values higher than 4 dS/m. On the other hand, wheat, which is a salt tolerant crop, reveals ECe values greater than 8 dS/m. Apparently the farmers in Egypt avail of salt tolerant cotton, rice and wheat varieties.

In Fig 2, illustrating the MH model [2], the BP values are lower than those determined by the PAR method.

The MH model is obtained by performing a segmented regression with a range of breakpoints and selecting the BP that corresponds to the highest goodness of fit according to the least squares principle. In that case the slope of the regression line to the right of BP influences the position of BP and when that slope is flat, the BP moves more to the left. In the PAR method this slope plays no role. Very clear examples of flat tail-end relations are shown in the next section (India).

The MH model yields zero tolerance values for cotton and maize as at any breakpoint the coefficient of determination (CD) is less than that of a straight line. The PAR yields higher CD values, as the regions left and right of BP are treated separately, be it at a low level. The PAR method produces an inverted Z image. It appears that at low yield levels the crop regains a certain salt tolerance.

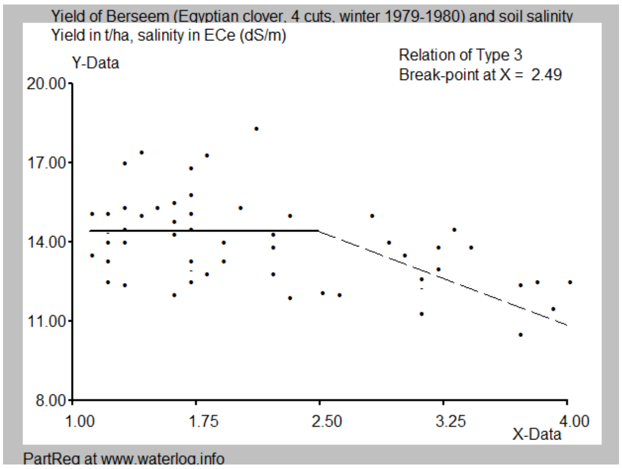

Fig. 1.1 Berseem (clover). BP=2.5 dS/m

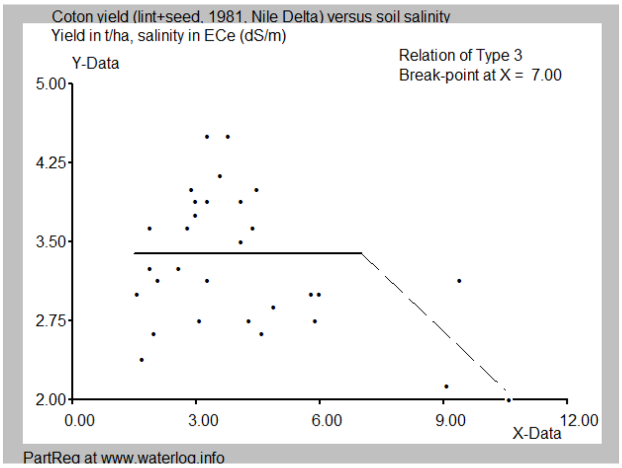

Fig. 1.2 Cotton. BP=7 dS/m.

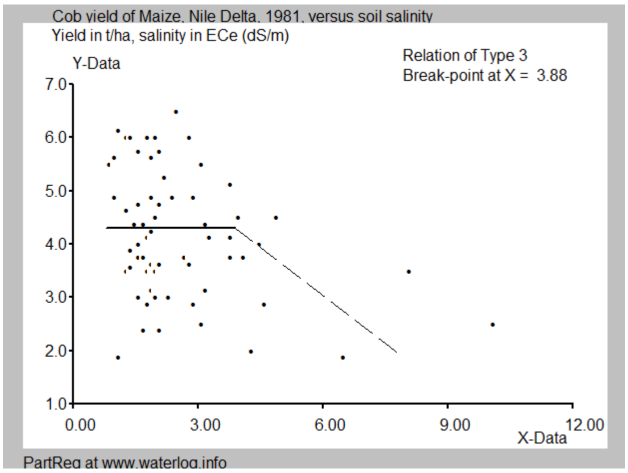

Fig. 1.3 Maize. BP= 4 dS/m

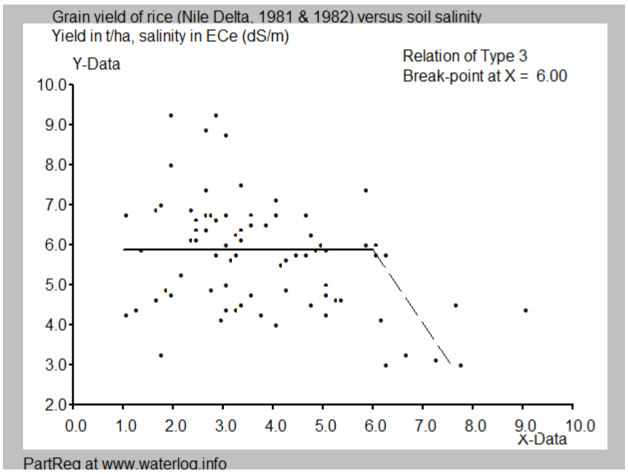

Fig. 1.4 Rice. BP=6 dS/m

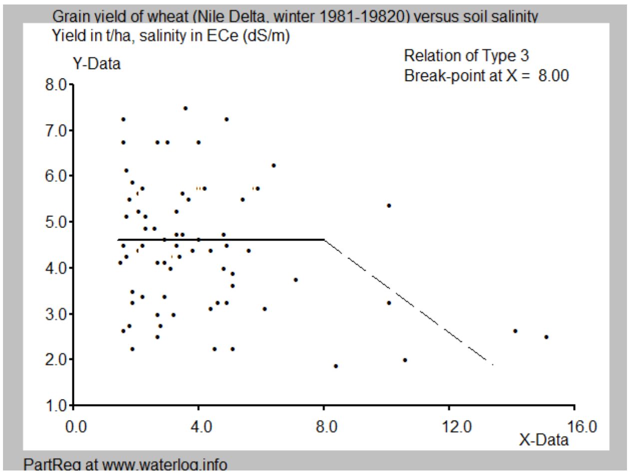

Fig. 1.5 Wheat. BP=8 dS/m

Fig. 1. Yield and soil salinity of field crops in Egypt using the PAR method.
(BP = ECe at Break-Point)**.**

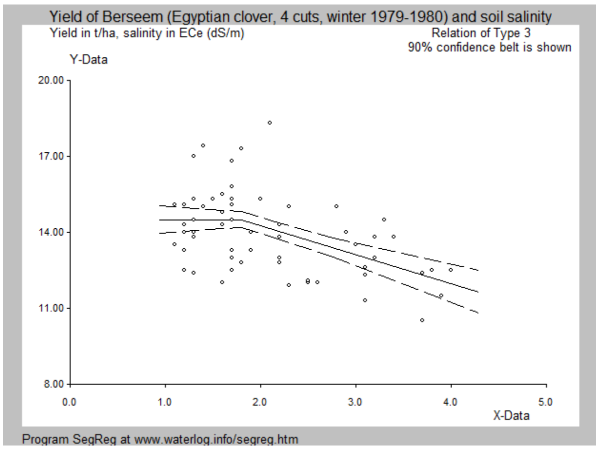

Fig. 2.1 Berseem. BP=1.8 dS/m

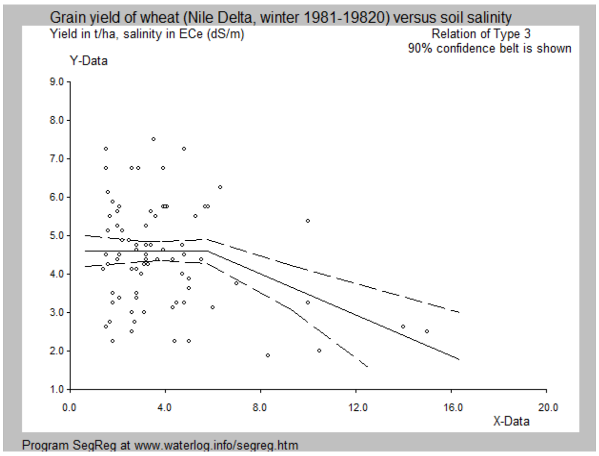

Fig. 2.2 Wheat. BP=6 dS/m

Fig. 2. Examples of results using the MH model for two Egyptian crops

3. Analysis of Indian crops (barley, mustard (rapeseed), wheat-Sampla, wheat-Gohana)

The data were measured in plots of some 10 m^2 selected at random. Per plot 5 salinity measurement were made, of which the average was used for further analysis.

The PAR results are shown in figure 3.

Contrary to the situation in Egypt, the data sets from India contain a large number of observations beyond the breakpoint (BP, Fig 3), reason why BP can be determined more precisely.

In the cases of barley, mustard and wheat-Sampla, there is a trend at the tail-end for the relation to show, like at the head end, a range of no effect: the yield tends to remain constant,

Fig. 3.3 shows a confidence block of the breakpoint. It is very narrow, indicating a high precision. The lower and upper limits are found by replacing (in Eq.2) σ_R by $0.5\sigma_R$ respectively $2\sigma_R$.

For comparison, the BP value of the wheat in Egypt equalled 8 dS/m, a higher value than in India (5 and 7 dS/m). This is one of the reasons why in India the number of data at the tail-end is relative large. The variation in tolerances proves that wheat crop does not have a unique salt tolerance.

The barley (Fig. 4.1) and the wheat-Sampla yield in India show similar BP values for the PAR and MH techniques in Fig 3, but like the Egypt cases, the BP values for mustard (Fig. 4.2) and wheat-Gohana are considerably lower using the MH model instead of the PAR method. This is owing to the flatter slopes of the lines to the right of BP and the use of the least squares method in the MH model, which causes the tail-end trend to move the BP to the left. Moreover, the confidence interval of BP in the MH models is very wide, indicating a limited reliability.

The confidence interval can be calculated using the expression for BP in terms of S ,Y and R and applying the laws of propagation of errors in additions and multiplications on the basis of standard errors of S, Y and R, to find the standard error of BP [13], followed by application of Student's t-distribution [14] to convert this into a confidence interval. When the number of data is large enough (say >20) the normal distribution [15] can also be used.

The MH model, being based on the least squares principle, should come with an ANOVA (analysis of variance) table [16] and Fisher's F-test [17] .

Table 1 shows that the MH model applied to the mustard data (Fig 4.2) has no significant extra explanation compared to that of the simple straight line (linear) regression model, and therefore it is not acceptable in this case.

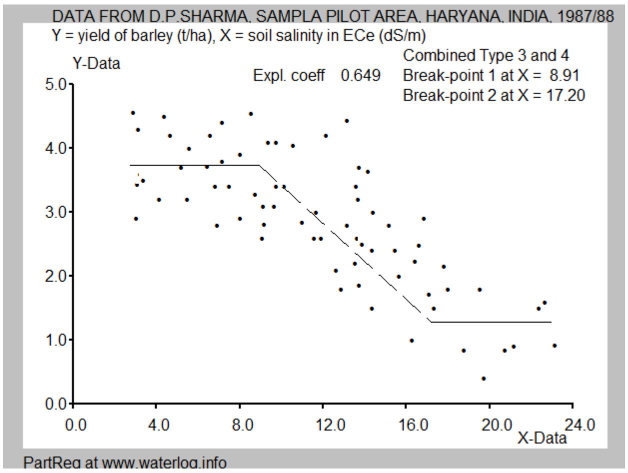

Fig. 3.1 Barley. BP=9 dS/m

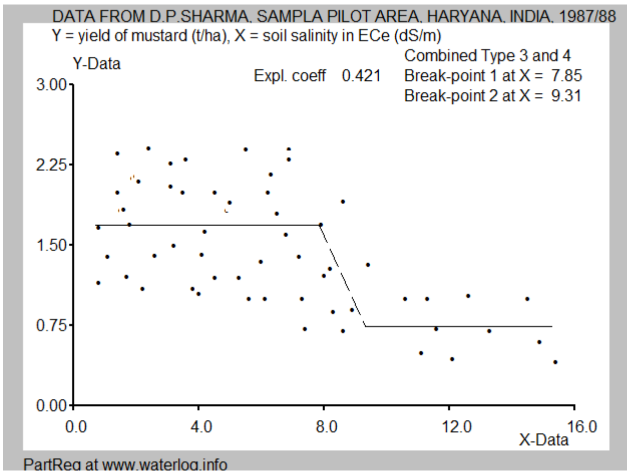

Fig. 3.2 Mustard (rapeseed). BP=8 dS/m

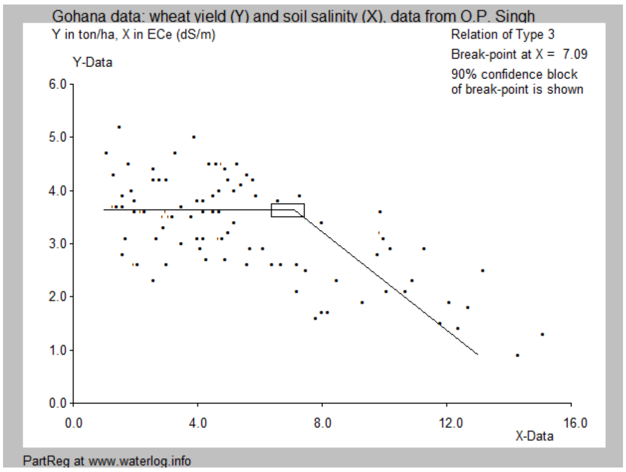

Fig. 3.3. Wheat at Gohana. BP=7 dS/m

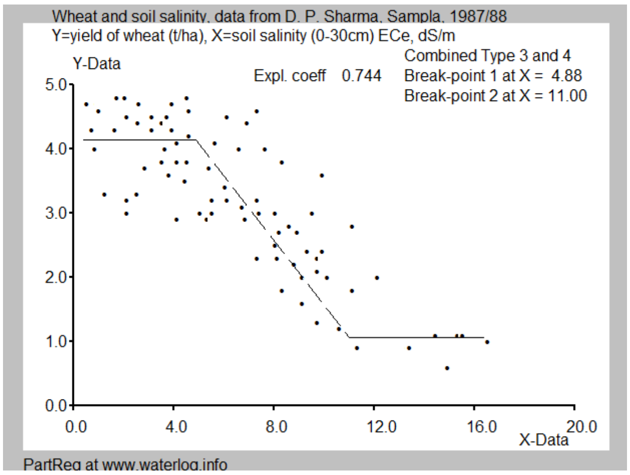

Fig. 3.4 Wheat at Sampla. BP=5 dS/m

Fig 3. Yield and soil salinity of field crops in India using the PAR method (BP = ECe at break-Point).

Table 1.Variance Analysis, ANOVA table, MH model, crop: mustard.

File Name : C:\ SegRegA\Mustard.var						
Sum [(Y-Av.Y)sq.] = 19.10 (total sum of squares of deviations of yield values from the average yield) Total nr. of data = 60 Degrees of freedom = 59						
Description of deviations	Sum of squares of deviations	Degrees of freedom	Variance	Fisher's F-test [16]	Probability	Significance
Explained by linear regression	7.300	1	7.300	F[1,58) = 35..9	99.9 %	Highly significant
Remaining unexplained	11.800	58	0.203	- - -	- - -	- - - -
Extra explained by MH model	0.606	2	0.303	F(2,56) = 1.52	77 %	Risk 23 % not significant
Remaining unexplained	11.194	56	0.200	- - -	- - -	- - - -

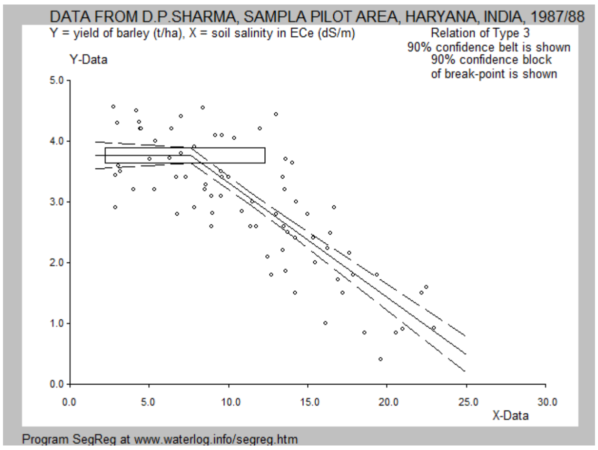

Fig. 4.1 Barley. BP=7.6 dS/m

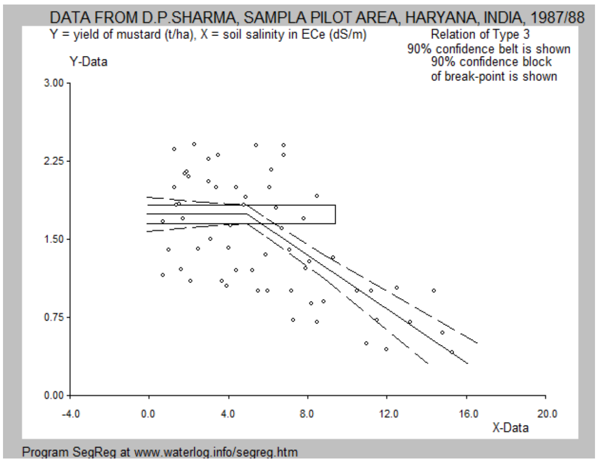

Fig 4.2 Mustard (rapeseed). BP=5 dS/m

Fig. 4 Examples of yield and soil salinity of field crops in India using the MH model (BP = ECe at Break-Point)**.**

4 Older method of envelopes

When the two articles from which the data were derived [8, 9, and 10] were published, laptops and software, like spreadsheets, were hardly available, so that a statistical analysis with numerous iterations was difficult to perform. The authors used envelopes constructed by eye-estimate to assess the critical salinity levels.

Two examples are given in Fig. 5.

It is a general feature that the upper breakpoint is at a lower salinity level than the lower one, which suggests that the higher yields are more sensitive to soil salinity than the lower yields.

To provide a single value for the critical ECe value, the average of the lower and upper BP values were taken. For Gohana-wheat this gives BP = 0.5(6+10) = 8 dS/m and for Sampla wheat BP = 0.5(7+8) = 7.5 dS/m. The average BP for Gohana wheat (8) is slightly higher than that obtained with the PAR method (7, Fig. 3.3). For Sampla the average BP of wheat it is considerably higher (7.5) than according to the PAR method (5, Fig. 3.4). The average BP's are still higher compared to the outcomes of the MH model.

From the analysis by envelope curves of the crops in Pakistan [10], it was found that the BP values of cotton and sorghum in the Khairpur region were respectively 9 (Fig. 6) and 8 dS/m. The MH method was not applicable to Sorghum, as it yielded a BP value of zero.

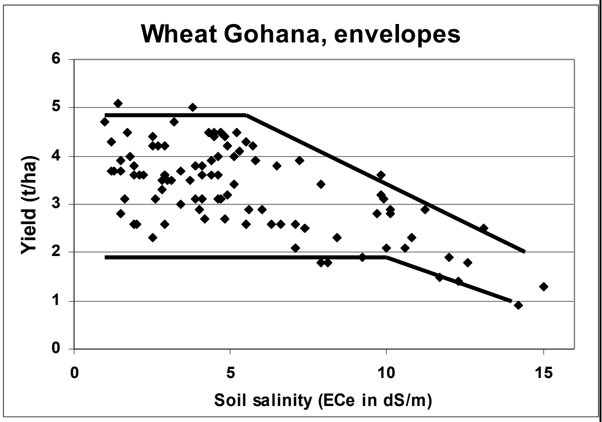

Fig. 5.1 Lower BP at ECe=6, upper BP at ECe=10

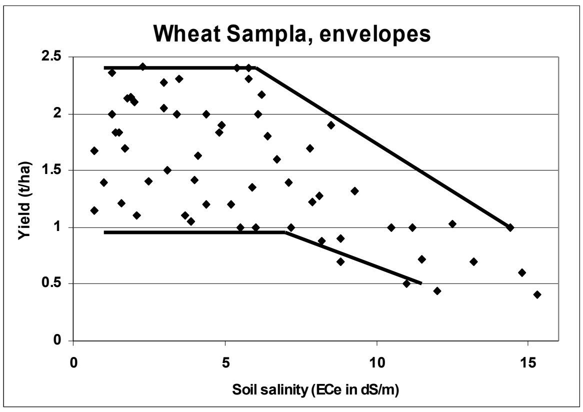

Fig 5.2 Lower BP at ECe=7, upper BP at ECe=8

Fig. 5 Traditional method of estimating salt tolerance of field crops using envelopes constructed at eye-sight

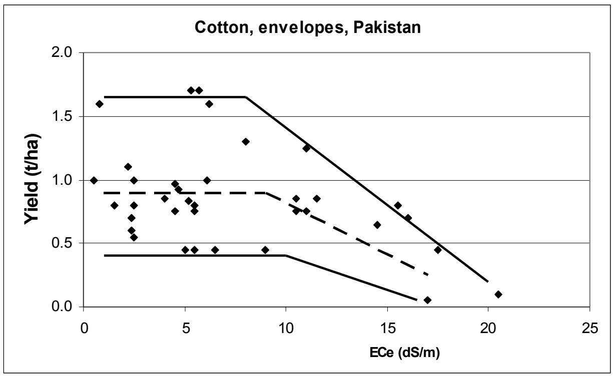

Fig. 6. Traditional method of estimating salt tolerance of cotton in Pakistan using envelopes and central tendency constructed visually.

The main difference between the cotton data from Egypt and Pakistan is that the average yield in the first case is much higher (3.3 t/ha lint + seed) than in the second (only 0.93 t/ha). Also the sorghum yield in Pakistan was very low (0.73 t/ha).

The crops in the Khairpur area lacked sufficient irrigation water to guarantee a high production. This apparently led to relatively high BP values. It would be worth while to embark on a study of the relation between average yield below BP (Ymax) and the value of BP itself. It might be Ymax and BP are inversely related. However, data on this aspect are not available.

5 Comparison of vGG and GCR outcomes

In Fig. 7 the outcomes of the vGG and GCR procedures for the berseem and crop in Egypt are compared.

In this figure it is seen that the goodness of fit (indicated by the coefficient of determination, also known as CD or Rsquared) is higher for the GCR method than for the vGG model. Moreover, Fig. 7.2 indicates an initially rising trend. To get a general impression of the growth curve, the GCR method can be used with preference as it is more versatile.

In Fig. 8, the general GCR pattern shows an inverted S-curve, corresponding to the inverted Z-models shown in figures 3.1 and 3.4. Initially the crop yield descends slowly, then more steeply, and finally the curve curls up. The tail-end features appear clearly because there are enough data beyond the breakpoint. The upward curling tail explains why the MH model yields low BP values.

In literature graphs of yield-salinity relations are seldom given. So it is not possible to judge the scatter of data and to test the difference, if any, in outcomes of the MH model and the PAR method. Also, at this stage, it is not possible to compare the yield level in laboratory tests and in farmers' fields to see if that factor is influential on the BP value.

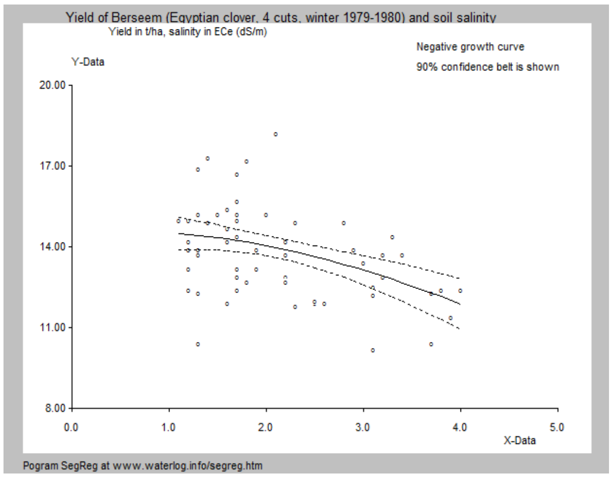

Fig. 7.1 vGG model. Berseem, Egypt. CD = 15%

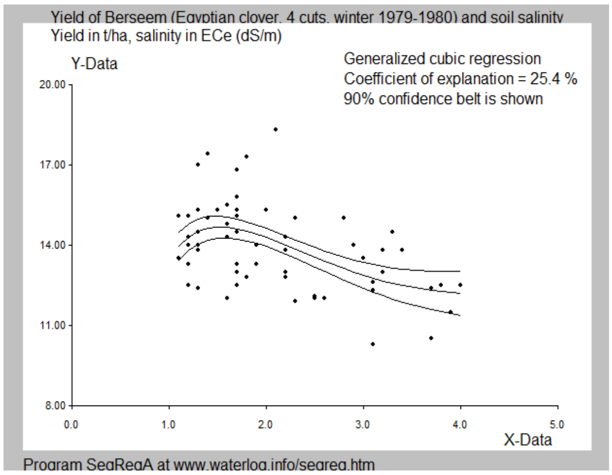

Fig. 7.2 GCR method. Berseem, Egypt. CD= 25%

Fig.7 Comparison of the vGG and GCR outcomes for berseem in Egypt
(CD is the Coefficient of Determination for goodness of fit).

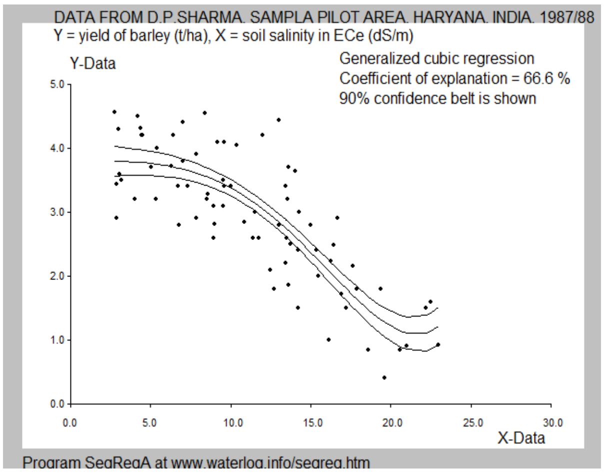

Fig. 8.1 Barley

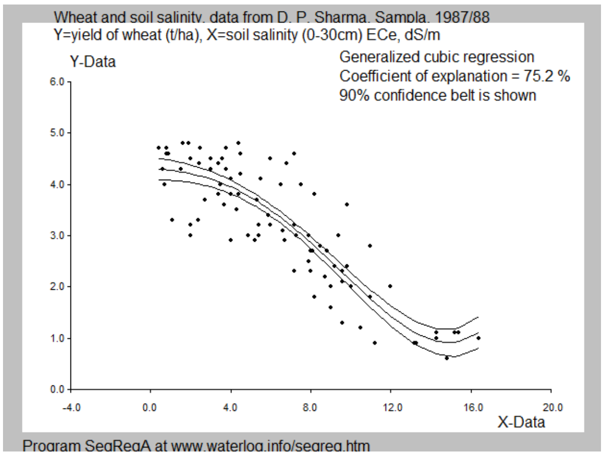

Fig. 8.2 Wheat-Sampla

Fig. 8 Examples of generalized cubic polynomial regression (CGR) for barley and wheat at Sampla in India.

6 Comparison with BP values found in literature

For reference of BP values found here to those encountered in literature, the on-line publication of the U.S. Salinity Laboratory, United States Department of Agriculture, Agricultural Research Service [5] and the FAO Annex 1 [18] is used.

Table 2 shows that the BP values found in famers' fields in Egypt are mostly higher than those found in literature, which are based on experiments under controlled conditions. The Indian crops, except barley, show some what lower values. The reason is not known.

7 Conclusions

The PartReg (PAR) method that, in the yield-salinity relation, finds the longest stretch over which the yield is not affected by soil salinity, finds higher salt tolerance (breakpoint, BP, threshold) values than the Maas-Hoffman (MH) model. The BP in the latter is influenced by the trend at the tail-end of the relations owing to the use of the least squares principle, while in the PAR method the trend at the tail-end has no influence.

To obtain a general impression of the yield salinity relation as a continuous curve without breakpoints, the third degree polynomial is effective. It gives more refinement than the vGG model.

The data analysed reveal breakpoints (thresholds) that differ form those reported in literature. This is likely due to the fact that the data analysed were obtained under farming conditions whilst the literature data stem from small scale, highly controlled, experiments. Also the crop varieties are probably not the same. It is recommedable to present for each crop a range of possible tolerance values, rather one precise value.

The results reported in literature are presumably based on the MH model, but generally no scatter diagrams are presented. So it would not be possible to obtain an impression of the statistical significance and precision of the results.

Table 2. Comparison of threshold (BP) values with those found in literature.

Crop	Botanical Name	Breakpoint, BP, threshold, ECe in dS/m		Classification [1] (PAR results)
		US Salinity Lab.	**PartReg (PAR)**	
Barley	*Hordeum vulgare*	8	9 (India)	Tolerant
Berseem (clover)	*TrIfolium alexandrinum* L.	1.5	2.5 (Egypt)	Very sensitive
Corn (Maize)	*Zea mays*	1.7	4 (Egypt)	Sensitive
Cotton	*Gossipium vulgare*	7.7	7 (Egypt) 10 (Pakistan)	(moderatley) Tolerant
Mustard (Rapeseed)	*Brassica campestris* L.	10	8 (India)	Tolerant
Rice	*Oryza sativa*	3.0	6 (Egypt)	Moderately tolerant
Sorghum	*Sorghum bicolor* L.	6.8	8 (Pakistan)	Tolerant
Wheat	*Titricum aestivum*	8.6	8 (Egypt) 7 (Gohana, 5 (Sampla)	(moderately) Tolerant

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