Using the Free Partial Regression Software (PartReg) to Determine the Maximum Tolerance of Crops to Soil Salinity as Measured in Farm Lands.

R.J. Oosterbaan, September 2021, https://www.waterlog.info

Abstract

Due to a worldwide problem of soil salinity in irrigated crop lands in (semi)arid regions, the tolerance of crops to soil salinity has been studied extensively starting in 1962 with the Handbook 60 of the Soil Salinity Laboratory, Riverside, California, USA. This laboratory developed the well known Maas-Hofmann (MH) model presenting the crop yields versus the soil salinity expressed in electric conductivity of an extract of a saturated soil paste, ECe, in deciSiemens per meter (dS/m). The model depicts the crop yield on the Y-axis of a graph versus the ECe on the X-axis showing an initially horizontal line (the plateau), meaning that the crop yield is not negatively affected by the soil salinity, until a critical ECe point from where the crop yield diminishes with increasing ECe value. The critical point is also called threshold or breakpoint (BP) or maximum salt tolerance level (MSTL).

The majority of the data used stem from laboratory experiments in lysimeters or small trial plots. The analysis of data obtained in farm lands is exceptional. One can ask the question whether the small scale experiments are representative enough for farm practices,

The MH model and the BP value are determined by segmented regression minimizing the sum of squares of the differences between the theoretical and observed crop yields over the entire domain of ECe values measured (the MSSD method). In farmers lands it often happens that the lower yields at the higher ECe values reach an equilibrium and remain fairly constant demonstrating a horizontal tail end (the plateau). In such a situation the regression lines in the graph of yield versus salinity reveal a Z-type shape. The MSSD method, in such cases, produces a low BP value, as the horizontal tail end draws the BP level to the left and it gives a too low value of the salt tolerance of the crops.

As a response, in later world literature, the yield function of ECe has often been taken as a sigmoid (literally an inversed S-curve), also called the van Genuchten-Hoffman (vGH) model. Such a model, however, does not produce a breakpoint. To avoid this problem, the PartReg method has been developed. It does not use the MSSD principle, but it detects horizontal plateau stretches in parts of the graphs of observed yield and ECe. It will therefore be called a method instead of a model.

In this article, the MH and GH model results are compared with the PartReg method making use of data obtained in farmers' fields, which show normally much more scatter than the data obtained from small scale experiments. The crops studied comprise barley, berseem (clover), mustard (rapeseed), potato, and wheat (2 regions). The counties concerned are Egypt, India, and the Netherlands.

Contents

1. **Introduction**

Due to a worldwide problem of soil salinity in irrigated crop lands in (semi)arid regions, the tolerance of crops to soil salinity has been studied extensively starting in 1962 with the Handbook 60 of the Soil Salinity Laboratory, Riverside, California, USA *[Ref. 1*].

This laboratory developed the well known Maas-Hofmann (MH) model [*Ref. 2*] presenting the crop yields versus the soil salinity expressed in electric conductivity of an extract of a saturated soil paste, ECe, in deciSiemens per meter (dS/m). The model depicts the crop yield on the Y-axis of a graph versus the ECe on the X-axis showing an initially horizontal line, meaning that the crop yield is not negatively affected by the soil salinity, until a critical ECe point from where the crop yield diminishes with increasing ECe value. The critical point is also called threshold or breakpoint (BP) or maximum salt tolerance level (MSTL).

The MH model and the BP value are determined by segmented regression [see SegReg software, *Ref. 3*] minimizing the sum of squares of the differences between the theoretical and observed crop yields over the entire domain of ECe values measured (the MSSD method). In farmers lands it often happens that the lower yields at the higher ECe values reach an equilibrium and remain fairly constant demonstrating a horizontal tail end. In such a situation the regression lines in the graph of yield versus salinity reveal a Z-type shape. The MSSD method, in such cases, produces a low BP value, as the horizontal tail end draws the BP level to the left and it gives a too low value of the salt tolerance of the crops.

As a response, in later world literature, the yield function of ECe has often been taken as a sigmoid (literally an inversed S-curve), also called the van Genuchten-Hoffman (vGH) model [*Ref. 4*]. This model stems from the Fisk probability distribution, which is incorporated in the S-curve determination of amplified SegReg model [SegRegA, *Ref. 5*]. Such a model, however, does not produce a breakpoint.

To avoid this problem, the PartReg method has been developed [*Ref. 6*]. It does not use the MSSD principle, but it detects horizontal stretches in parts of the graphs of observed yield and ECe. It will therefore be called a method instead of a model.

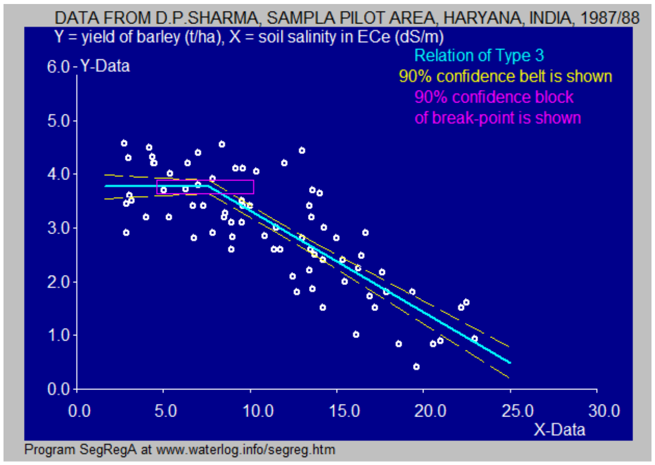
The majority of the data used stem from laboratory experiments in lysimeters or small trial plots. The analysis of data obtained in farm lands is exceptional. One can ask the question whether the small scale experiments are representative enough for farm practices,

In this article, the MH and GH model results are compared with the PartReg method making use of data obtained in farmers' fields, which show normally much more scatter than the data obtained from small scale experiments. The crops studied comprise:

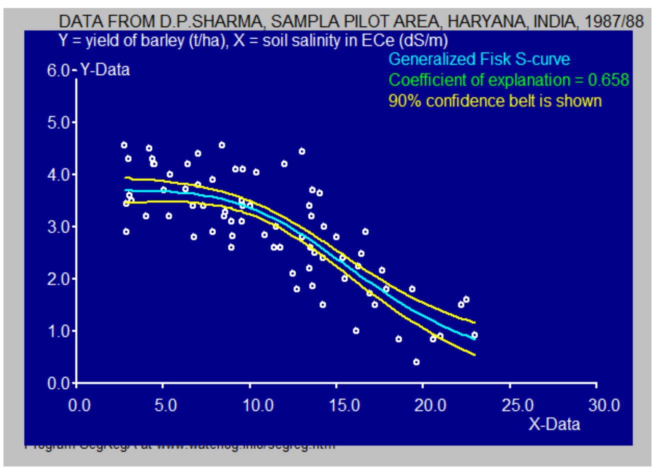
2. The barley crop (India, *Reference 8*)
3. The berseem (clover) crop (Egypt, *Reference 7*)
4. The mustard (rapeseed) crop (India, *Reference 8*)
5. The potato crop (The Netherlands, *Reference 9*)
6. The rice crop (Egypt *Reference 7*)
7. The wheat crop (India, *Reference 8)*
   7A. Gohana region
   7B, Sampla region

The maximum salt tolerance level (MSTL) of these crops will be analyzed in continuation, employing the MH model [*Ref. 2* and *Ref. 3*], the vGH model [*Ref. 4* and *Ref. 5*] and the PartReg method [*Ref. 6*].

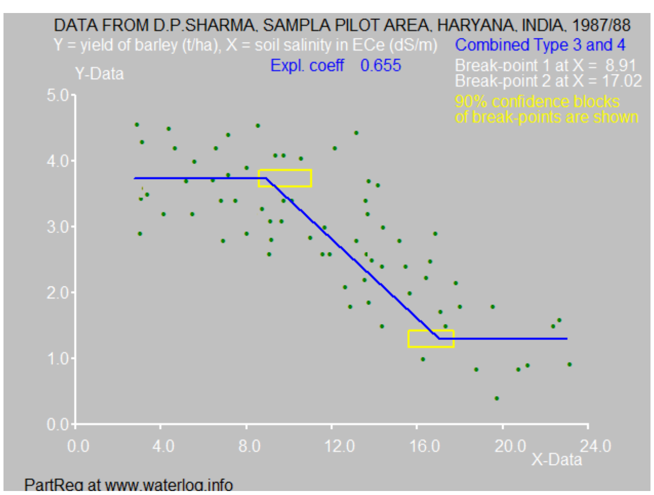
2. The barley crop (India, *Ref. 8*)



MH model (Type 3) BP = 7.6 dS/m



S-curve, BP absent



PartReg method, Z-type

Figure 2.

MH model, S-curve, and PartReg method applied to the yield of Barley versus soil salinity in dS/m as measured in farm lands in India [*Ref. 8*].

The PartReg method (*3rd picture*) yields a BP value of 8.9 dS/m, which is higher than the BP value according to the MH model (*1st picture*, BP = 7.6 dS/m).

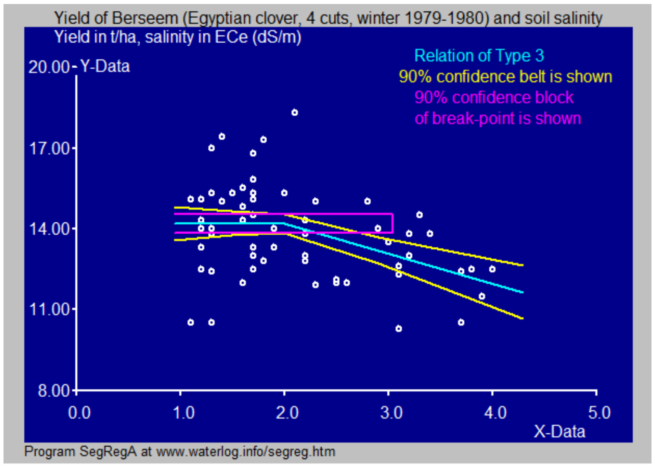
The reason of the lower BP value in the MH model is the horizontal tail-end found with the PartReg method (*3rd picture*).

The mirrored S-curve (*2nd picture*), derived from the generalized Fisk probability distribution, reveals no BP value, but it clarifies the Z-shape found with the PartReg method (*3rd picture*).

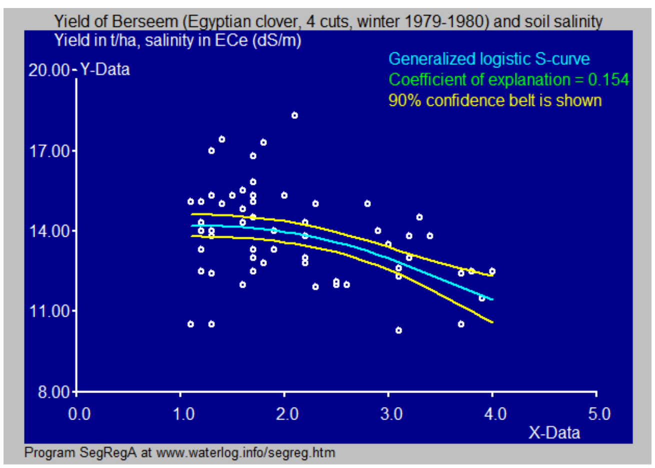
This Fisk S-curve is similar to that used van van Genuchten and Hoffman [*Ref. 4*].

The MSTL value recommended is the one found with the PartReg method: BP=8.9 dS/m.

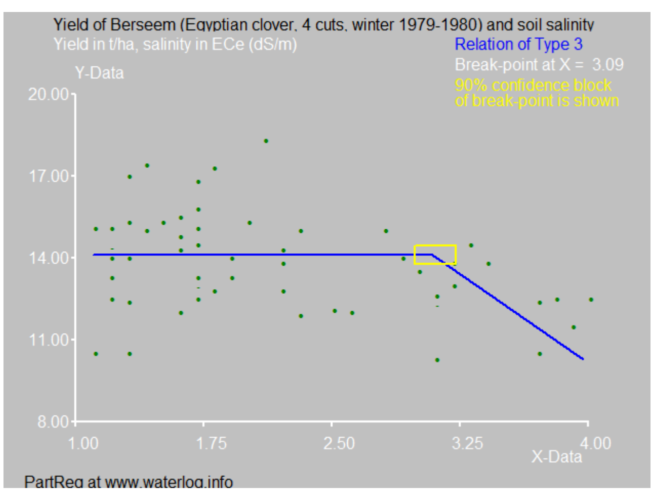
3. The berseem (clover) crop (Egypt, *Ref. 7*)



MH model (Type 3) BP = 2.0 dS/m



S-curve, BP absent



PartReg method, Type 3.

Figure 3.

MH model, S-curve, and PartReg method applied to the yield of Berseem versus soil salinity in dS/m as measured in farm lands in Egypt [*Ref. 7*].

The PartReg method (*3rd picture*) yields a BP value of 3.1 dS/m, which is higher than the BP value according to the MH model (*1st picture*, BP = 2.0 dS/m).

The mirrored S-curve (*2nd picture*), derived from the generalized logistic probability distribution, reveals no BP value. Contrary to the model used by van Genuchten and Hoffman [*Ref. 4*], which is of the Fisk type S-curve, the generalized logistic S-curve is selected as it has a higher goodness of fit.

The data show a large scatter of points in the graph, reason why the left hand side of the BP confidence block in the MH model (1st picture) is beyond the domain, This indicates that the BP value is not statistically significant [*Ref. 10*]. *)

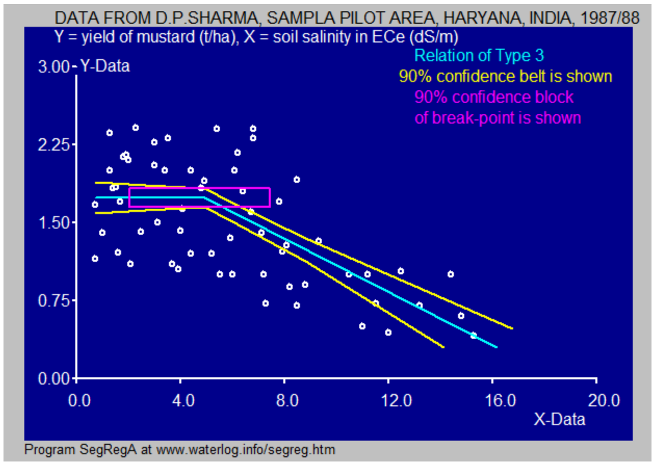
The MSTL value recommended is the one found with the PartReg method: BP=3.1 dS/m.

<u>Note</u>

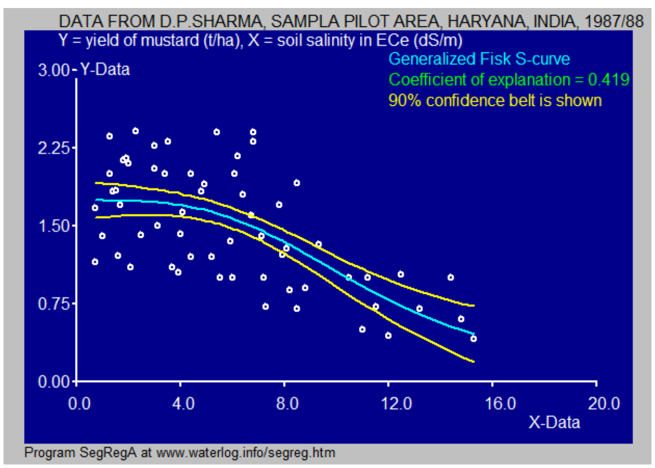
According to the ANOVA (Analysis of Variance) table made by SegRegA, the S-curve in the 2nd picture does not give a statistically significant improvement over a simple straight line and therefore is not valid [*Ref. 11*].

*) *Reference 10* explains the determination of the confidence block of BP

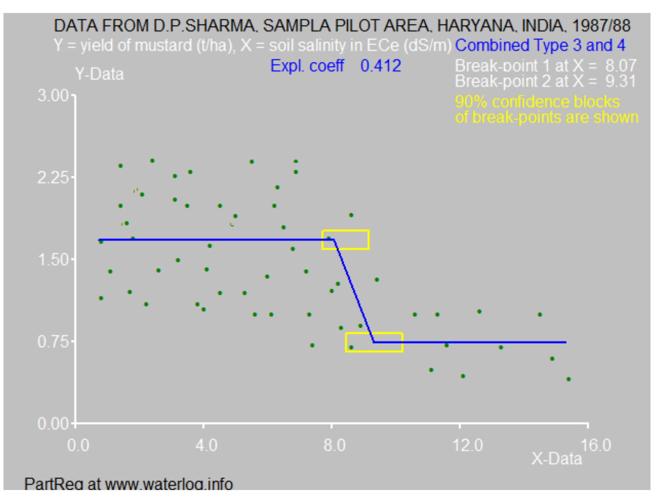
4. The mustard (rapeseed) crop (India, *Ref. 8*)



MH model (Type 3) BP = 4.9 dS/m



S-curve, BP absent



PartReg method, Z-Type.

Figure4.

MH model, S-curve, and PartReg method applied to the yield of Mustard (rapeseed) versus soil salinity in dS/m as measured in farm lands in India [*Ref. 8*].

The PartReg method (*3rd picture*) yields a BP value of 8.1 dS/m, which is higher than the BP value according to the MH model (*1st picture*, BP = 4.9 dS/m).

The reason of the lower BP value in the MH model is the horizontal tail-end found with the PartReg method (*3rd picture*).

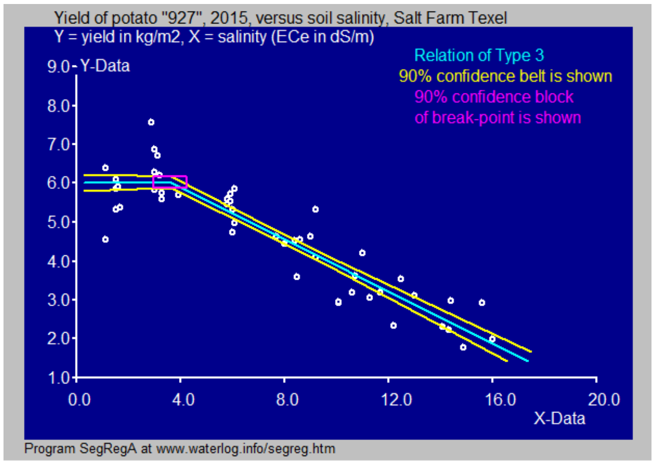
The mirrored S-curve (*2nd picture*), derived from the generalized Fisk probability distribution, reveals no BP value, but it clarifies the Z-shape found with the PartReg method (3rd picture).

This Fisk S-curve is similar to that used van van Genuchten and Hoffman [*Ref. 4*].

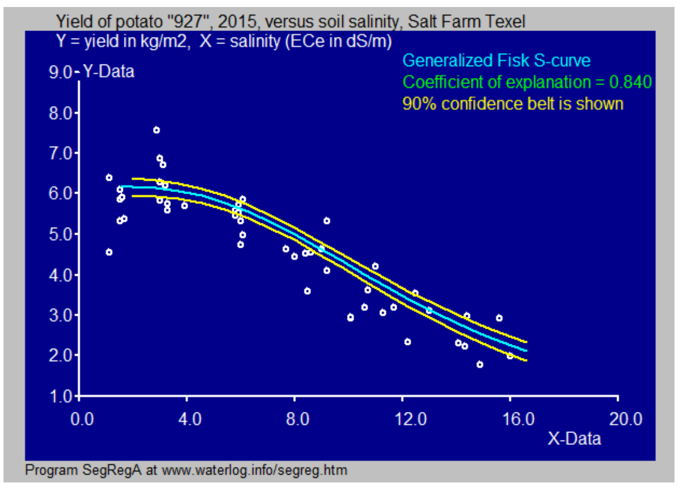
The data show a large scatter of points in the graph, as may be expected from surveys in farmers' fields. The confidence block of BP is therefore quite wide.

The MSTL value recommended is the one found with the PartReg method: BP=8.1 dS/m.

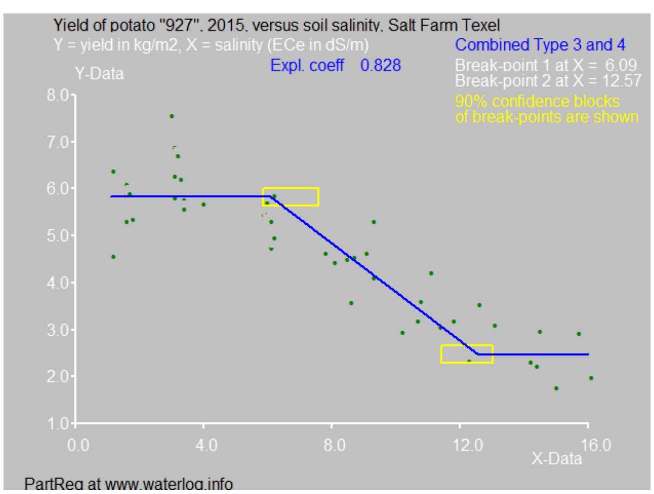
5. The potato crop (The Netherlands, *Ref. 9*)



MH model (Type 3) BP = 2.9 dS/m



S-curve, BP absent



PartReg method, Z-type.

Figure 5.

MH model, S-curve, and PartReg method applied to the yield of patoto variety “927” versus soil salinity in dS/m as measured in experimental plots in the Netherlands [*Ref. 9*].

The PartReg method (*3rd picture*) yields a BP value of 6.1 dS/m, which is higher than the BP value according to the MH model (*1st picture*, BP = 2.9 dS/m).

The reason of the lower BP value in the MH model is the horizontal tail-end found with the PartReg method (*3rd picture*)

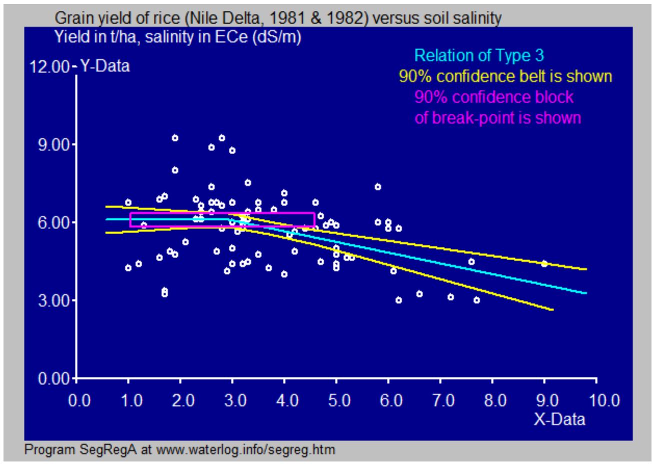
The mirrored S-curve (*2nd picture*), derived from the generalized Fisk probability distribution, reveals no BP value, but it clarifies the Z-shape found with the PartReg method (3rd picture).

This Fisk S-curve is similar to that used van van Genuchten and Hoffman [*Ref. 4*].

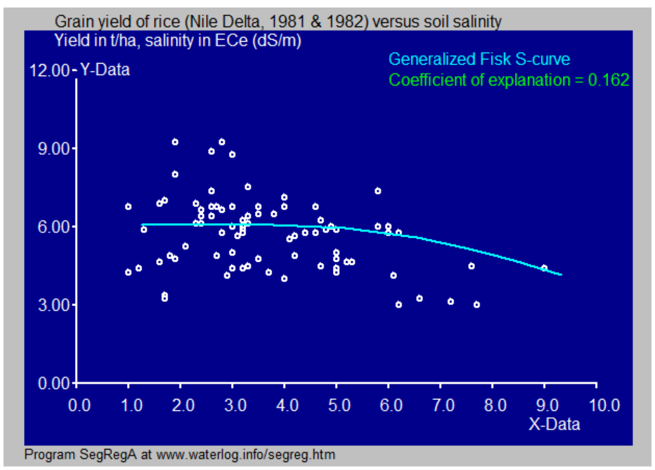
The data show a lesser scatter of points in the graph, as the data were gathered in experimental plots and not in farmers’ fields as in the previous examples.

The MSTL value recommended is the one found with the PartReg method: BP=6.1 dS/m.

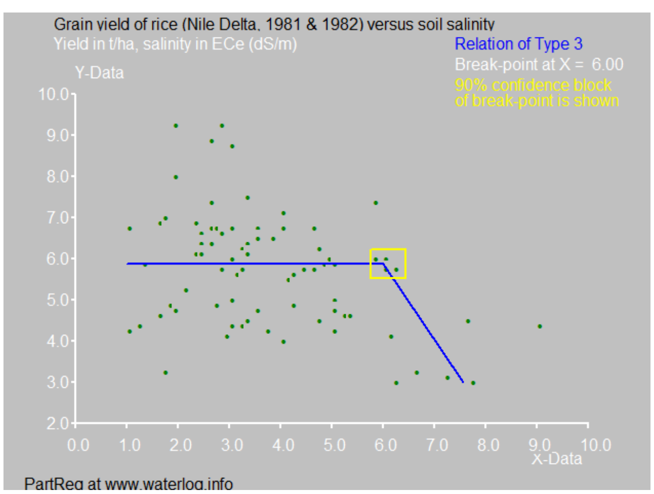
6. The rice crop (Egypt, *Ref. 7)*



MH model (Type 3) BP = 2.9 dS/m



S-curve, BP absent



PartReg method, Type 3.

Figure 6.

MH model, S-curve, and PartReg method applied to the yield of rice versus soil salinity in dS/m as measured in farm lands in Egypt [*Ref. 7*].

The PartReg method (*3rd picture*) yields a BP value of 6.0 dS/m, which is higher than the BP value according to the MH model (*1st picture*, BP = 2.9 dS/m).

The mirrored S-curve (*2nd picture*), derived from the generalized Fisk probability distribution, reveals no BP value. Also it does not depict a flattening tail-end. Same is true in the 3rd picture for the PartReg method. See also the 3rd picture in *figure 3*.

The data show a large scatter of points in the graph, reason why the confidence block of BP is quite wide. This indicates that the BP value is not very reliable [*Ref. 10*]. *)

The MSTL value recommended is the one found with the PartReg method: BP= 6.0 dS/m.

Note

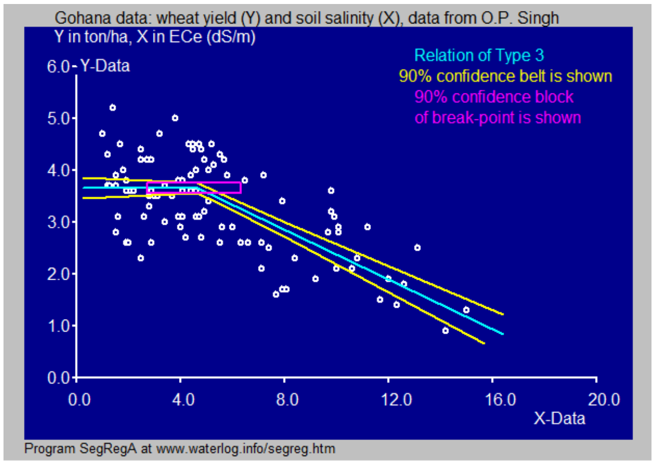
According to the ANOVA (Analysis of Variance) table made by SegRegA, the S-curve in the 2nd picture does not give a statistically significant improvement over a simple straight line and therefore is not valid [*Ref. 11*] . #)

*) *Reference 10* explains the determination of the confidence block of BP

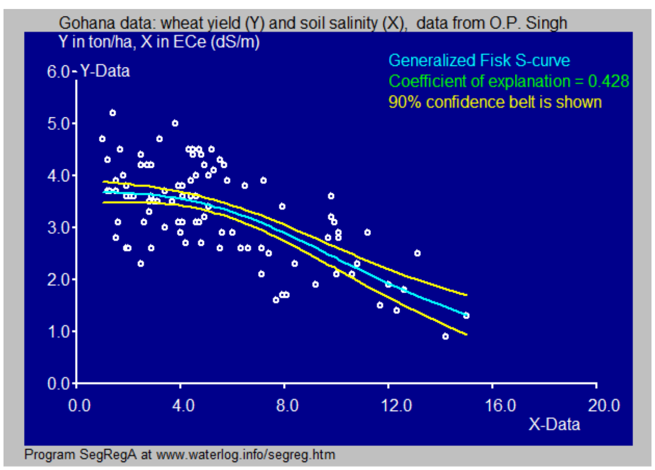
#) *Reference 11* explains the determination of the ANOVA table in SegReg.

7. The wheat crop (India, 2 regions, *Ref. 8*)

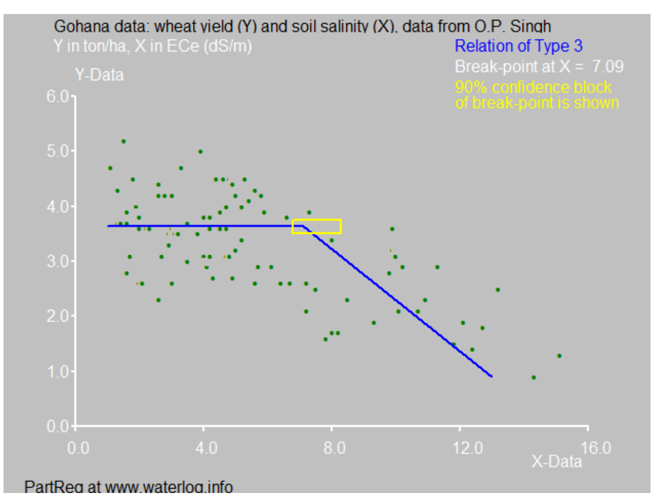
7A. Gohana region



MH model (Type 3) BP = 4.6 dS/m



S-curve, BP absent



PartReg method, Type 3.

Figure 7A.

MH model, S-curve, and PartReg method applied to the yield of Wheat versus soil salinity in dS/m as measured in farm lands in India, Gohana region [*Ref. 8*].

The PartReg method (*3rd picture*) yields a BP value of 7.1 dS/m, which is higher than the BP value according to the MH model (*1st picture*, BP = 4.6 dS/m).

The mirrored S-curve (*2nd picture*), derived from the generalized Fisk probability distribution, reveals no BP value.

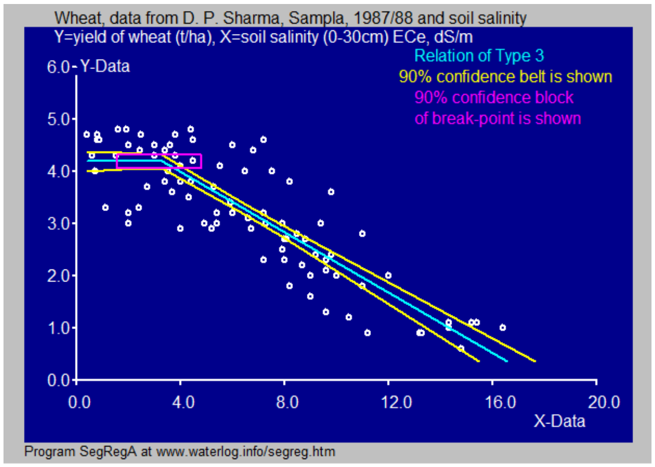
This Fisk S-curve is similar to that used van van Genuchten and Hoffman [*Ref. 4*].

The scatter of the data in the graph is not a high as in previous cases, reason why the confidence block of BP is not very wide (*1st picture*).

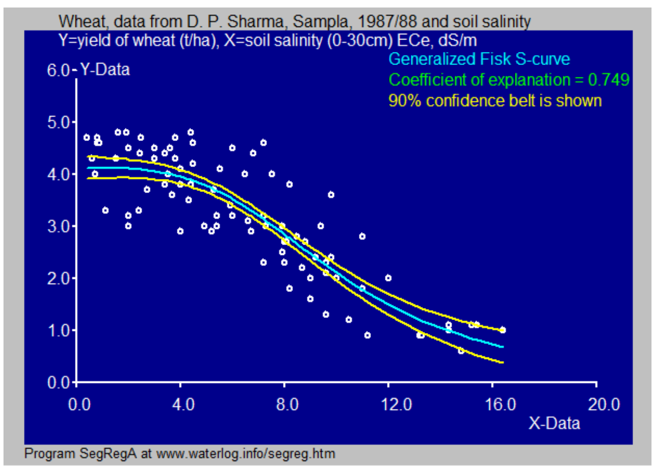
The PartReg method (*3rd picture*) does not reveal a Z-type shape as in some previous cases. Hence, the horizontal tail-end is mssing.

The MSTL value recommended is the one found with the PartReg method: BP=7.1 dS/m.

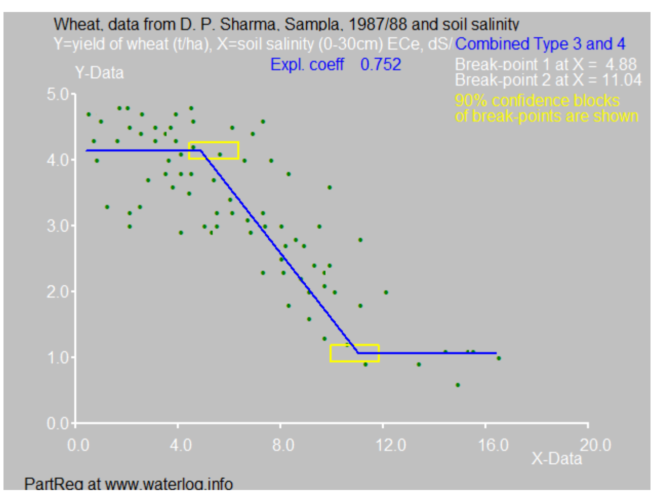
7B. Sampla Region



MH model (Type 3) BP = 3.2 dS/m



S-curve, BP absent



PartReg method, Z-type.

Figure 7B.

MH model, S-curve, and PartReg method applied to the yield Wheat versus soil salinity in dS/m as measured in farm lands in India, Sampla region [*Ref. 8*].

The PartReg method (*3rd picture*) yields a BP value of 4.9 dS/m, which is higher than the BP value according to the MH model (*1st picture*, BP = 3.2 dS/m).

The reason of the lower BP value in the MH model is the horizontal tail-end found with the PartReg method (*3rd picture*).

The mirrored S-curve (2nd picture), derived from the generalized Fisk probability distribution, reveals no BP value, but it clarifies the Z-shape found with the PartReg method (*3rd picture*).

This Fisk S-curve is similar to that used van van Genuchten and Hoffman [*Ref. 4*].

The scatter of the data in the graph is not a high as in previous cases, reason why the confidence block of BP is not very wide (*1st picture*).

The MSTL value recommended is the one found with the PartReg method: BP=6.1 dS/m.

9. Summary and conclusions

Table 1. Comparison of threshold (BP) values with those found in literature.

Crop	Botanical Name	Breakpoint, BP, threshold, MSTL ECe in dS/m			Classification (PartReg results)
		MH model	**PartReg method**	**FAO #)**	
Barley (India)	*Hordeum vulgare*	7.6	8.9	8	Tolerant
Berseem (clover, Egypt)	*TrIfolium alexandrinum* L.	2.0	3.1	1.5	Sensitive
Mustard, India (Rapeseed)	*Brassica campestris* L.	4.9	8.1	10	Tolerant
Rice (Egypt)	*Oryza sativa*	2.9	6.0	3.0	Moderately tolerant
Wheat (India)	*Titricum aestivum*	4.6 (Gohana)	7.1 (Gohana)	8.6	Moderately tolerant
		3.2 (Sampla)	4.9 (Sampla)		Slightly sensitive

#) **K.K. Tanji and N.C. Kielen.** ***Agricultural drainage water management in arid and semi-arid areas*. FAO irrigation and drainage paper 61. FAO, Rome. 2002.** Annex 1. Crop salt tolerance data. **http://www.fao.org/docrep/005/y4263e/y4263e0e.htm**

In all cases it was explained that the PartReg method deserves preference over the MH model either because of the horizontal tail-end (plateau) in the graph of the data moves the BP value to the left, causing a low Maximum Salt Tolerance Level (MSTL), or owing to a wide confidence block of BP.

The S-curves are unable to help in finding an MSTL value and are therefore not useful for this purpose. In addition, it was found in two cases that the S-curve was statistically not acceptable as it did not differ significantly from a simple straight line.

9. References.

[Ref. 1] Richards, 1954, *Saline and Alkali Soils*, USDA Handbook 60. On line: https://www.ars.usda.gov/ARSUserFiles/20360500/hb60_pdf/hb60complete.pdf

[Ref. 2] E.V. Maas and G.J. Hoffman, 1977. *Crop salt tolerance-current assessment.* Journal of the Irrigation and Drainage Division, American Society of Civil Engineers 103: 115–134.

[Ref. 3] SegReg, free calculator for segmented regression. In the calculator the MH model is called Type 3. It includes confidence belt, coefficient of determination, and ANOVA table. Download from: https://www.waterlog.info/segreg.htm

[Ref. 4] M.T. Van Genuchten and G. Hoffman. *Analysis of crop salt tolerance data.* In: I. Shainberg, J. Shalhevet (Eds.), Soil Salinity under Irrigation - Process and Management. Vol. Ecological Studies, Springer Verlag, Berlin (1984), pp. 258-271

[Ref. 5] SegRegA. *A calculator for segmented and generalized polynomial regressions (free).* Includes generalized S-curve regressions, confidence belt, coefficient of determination, and ANOVA table. On line https://www.waterlog.info/sigmoid.htm

[Ref. 6] PartReg2. *A free calculator for partial regression.* (to find the longest stretch of no effect). Includes confidence interval, coefficient of termination and ANOVA table. Download from https://www.waterlog.info/partreg.htm

[Ref. 7] H.J. Nijland and S. El Guindy, *Crop yields, water table depth and soil salinity in the Nile Delta, Egypt*. In: Annual report 1983, p. 19-28. International Institute for Land Reclamation and Improvement (ILRI), Wageningen, Netherlands. https://www.waterlog.info/pdf/egypt.pdf

[Ref. 8] D.P. Sharma, K.N. Singh and K.V.G.K. Rao. *Crop Production and soil salinity: evaluation of field data from India.* Paper published in Proceedings of the Symposium on Land Drainage for Salinity Control in Arid and Semi-Arid Regions, February 25th to March 2nd, 1990, Cairo, Egypt, Vol. 3, Session V, p. 373 – 383. https://www.waterlog.info/pdf/segmregr.pdf

[Ref. 9] On line: The potato variety "927" tested at the Salt Farm Texel,The Netherlands, proved to be highly salt tolerant
or: https://www.waterlog.info/pdf/Potato 927.pdf

[Ref. 10] Determination of the standard error of the breakpoint BP in SegReg. On line: https://www.waterlog.info/pdf/bptype2.pdf

[Ref. 11] Principles of analysis of variance in segmented regression. On line; https://www.waterlog.info/pdf/ANOVA.pdf