Crop yield and depth of water table, statistical analysis of data measured in farm lands.

R.J. Oosterbaan, 18-08-2019. On www.waterlog.info public domain

Abstract

Crop yields may suffer from shallow water tables in the soil. The crop tolerance to shallow water tables can be found from a statistical analysis of field measurements. When shallow water tables affecting yield negatively prevails, one speaks of a water logging problem.
The shallowest permissible depth at which no yield reduction occurs can be called critical water table depth and, it can serve as a drainage criterion
The cases discussed here are a representation of what could be found in literature on the relation between crop yield and seasonal average depth of the water table (DWT) measured in farmers' fields. Such data are relatively scarce.
Data collected in farmers' fields often show considerable scatter (random variation). One will need statistical methods to interpret the data relationships:

Method 1. Visual estimates of envelope curves
Method 2. Segmented regression
Method 3. Partial regression

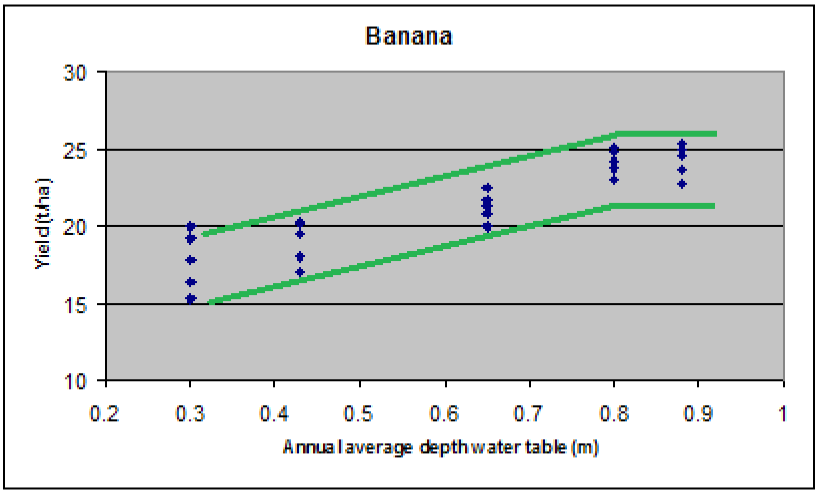
Method 1. Visual estimates of envelope curves

A first impression of the relation between depth of the water table and crop yield can be obtained using visually drawn envelope curves.

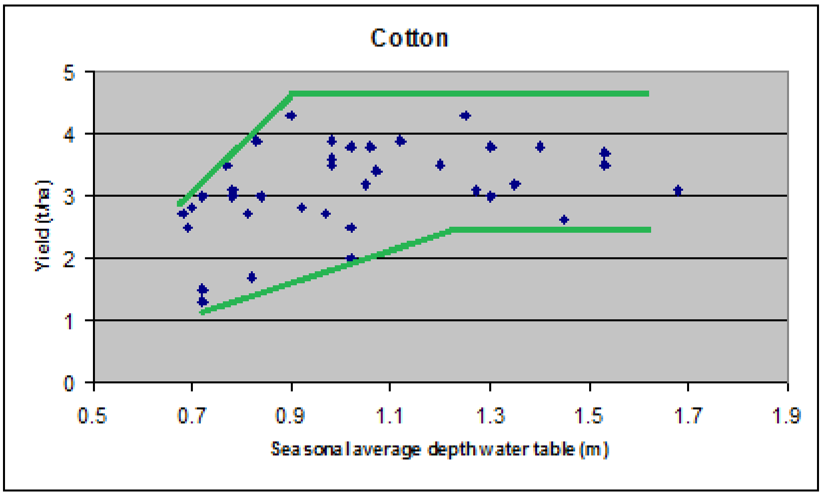
In the following examples the field data concerning the yield of crops versus the depth of the water table were obtained as follows:

- Banana (data from Surinam), [Ref. 1]
- Cotton (data from Egypt), [Ref. 2]
- Sugarcane (data from Australia), [Ref.3]
- Winter wheat (data from England), [Ref. 4]

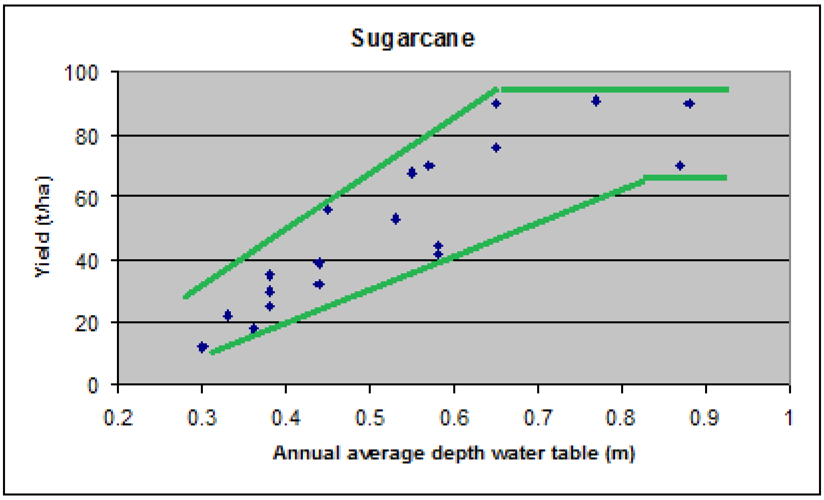
The envelopes are given in green color.



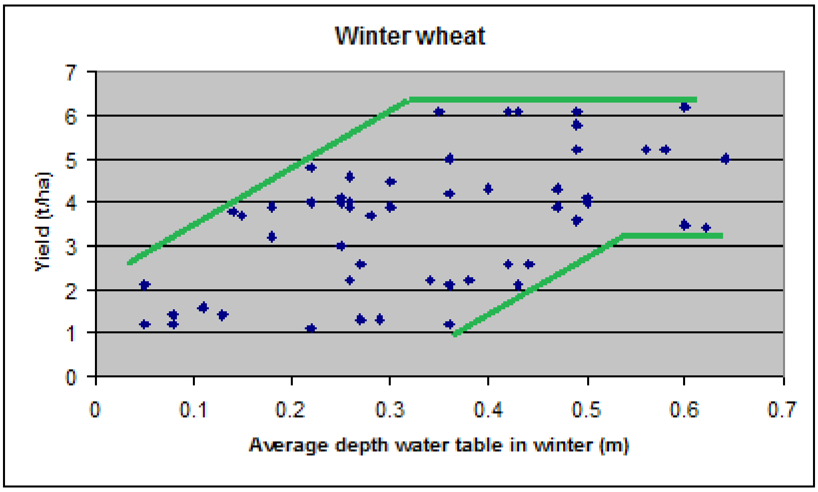
The banana plantations (banana is a perennial crop) investigated in Surinam show, in this envelope analysis, a clear yield decline at an average depth of the water table (ADWT) < 0.75 m while at ADWT values > 0.80 m there is no more yield reduction and the yield stays stable. This is the range of "no effect". The critical value of ADWT may be estimated at 0.8 m.



The field measurements of cotton yield in the irrigated lands of the Nile Delta, Egypt, when analyzed with envelope curves, show yield reductions at an average depth of the water table (ADWT) < 0.9 m whereas above this level there is no more yield decline and the yield stays stable at its maximum. This is the range of "no effect". The critical value of ADWT may be estimated in between 0.9 m for the upper envelope and 1.2 m for the lower envelope, say 1.05 m.



Sugarcane is a crop that needs at least a 9-month growing season if not 1 year or more. The data, interpreted with by envelopes, illustrate that an average depth of the water table (ADWT) < 0.60 m causes yield reductions while there is no effect when ADWT > 0.80 m. The critical value of ADWT may be estimated at 0.7 m.

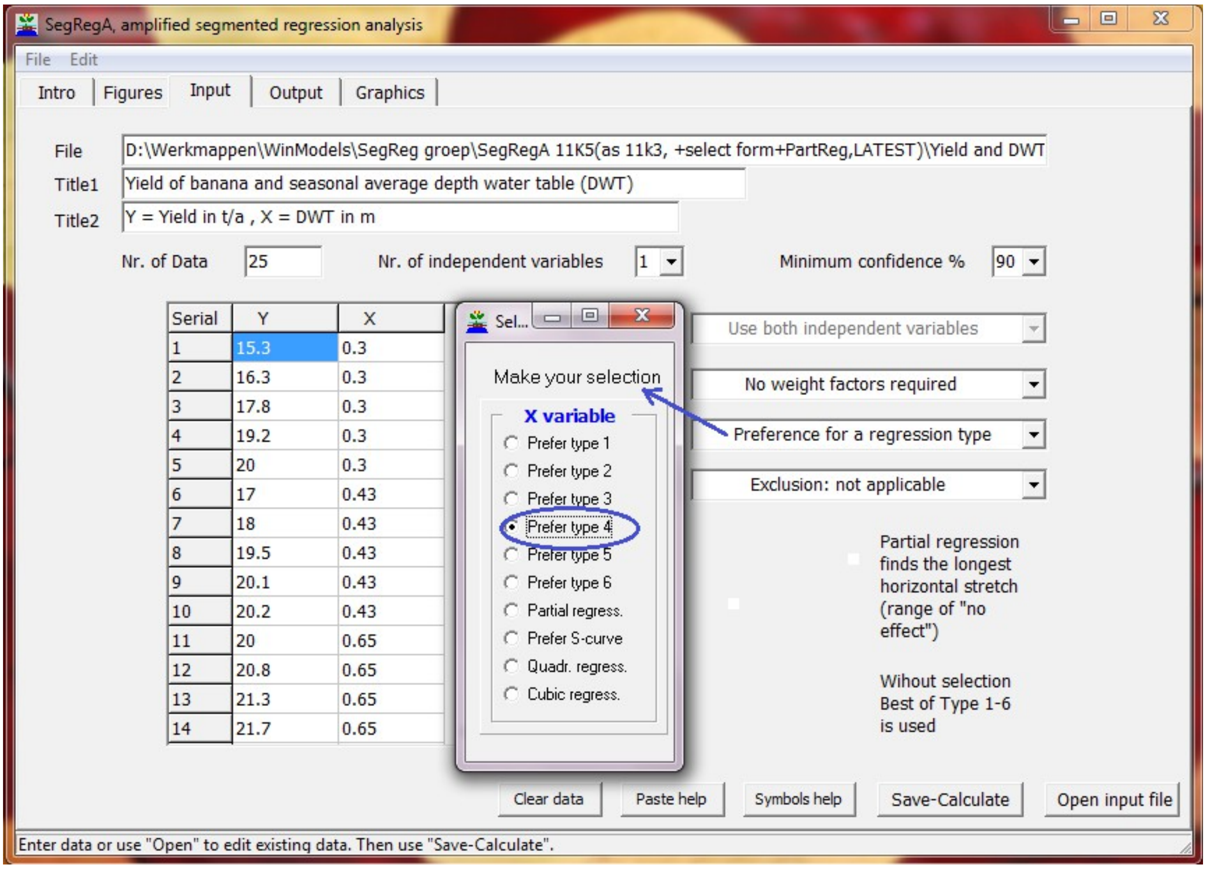


In England, the winter wheat is sown before wintertime sets in. In winter it starts its vegetative development, but maturation and harvest occur in summer. The water table depth (DWT) in summer is usually deep enough not to pose a problem. However, in winter, shallow water tables and water logging may occur, and the data, interpreted with envelopes illustrate that a DWT < 0.3 m during winter causes yield reductions while there is no effect when DWT > 0.5 m. The critical value of DWT may be estimated in between 0.3 m for the upper envelope and 0.5 m for the lower envelope, say 0.4 m

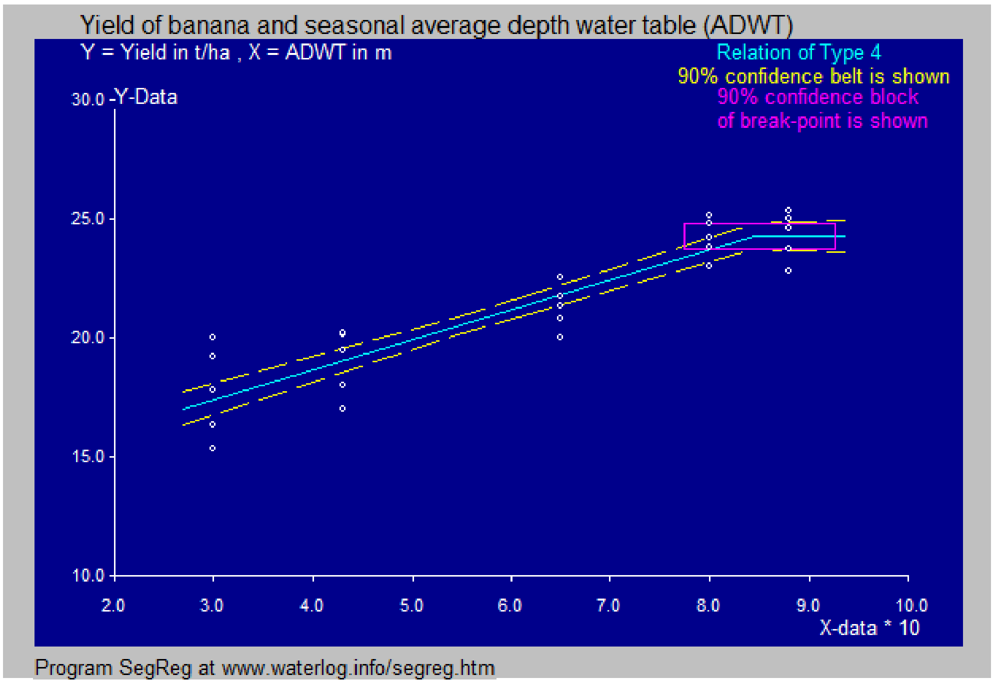
Method 2. Segmented regression

With segmented regression the breakpoint (BP) between the horizontal line and the downward sloping line can be found by a numerical procedure, assuming a range of BP values doing a linear regressions to the left and one to the right of the BP and taking care that the two lines intersect each other in the BP, and finally selecting that BP value that produces the least sum of squares of deviations of observed values from the regression lines (Least Squares or LS method).

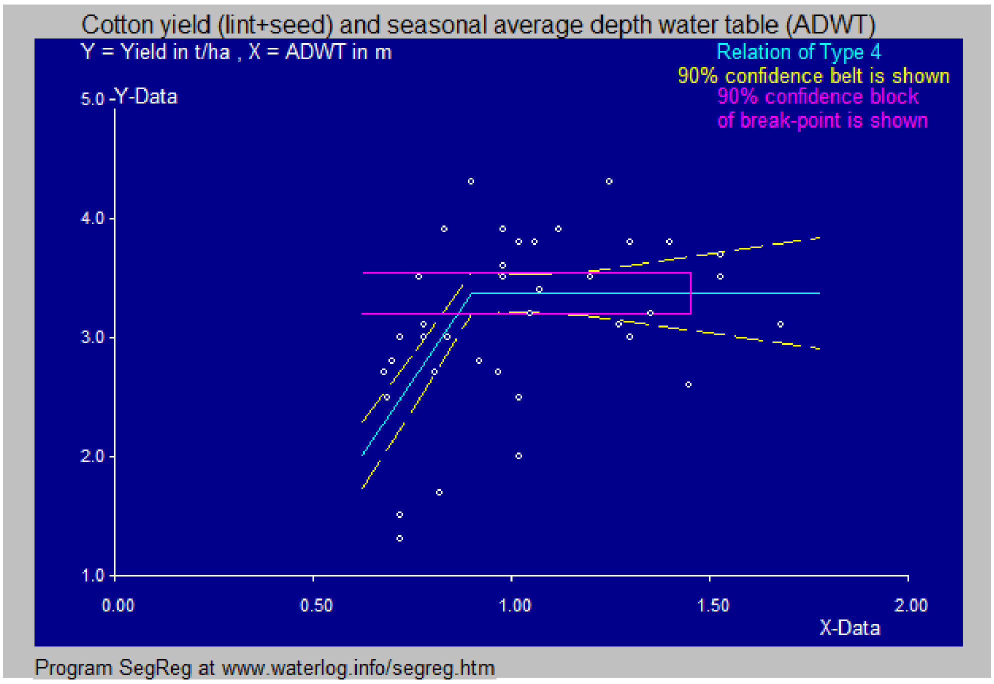
The software program SegRegA [Ref. 5] does such a kind of analysis and is used in the following computations. The type of segmented analysis was taken as 4, as shown in the next figure.



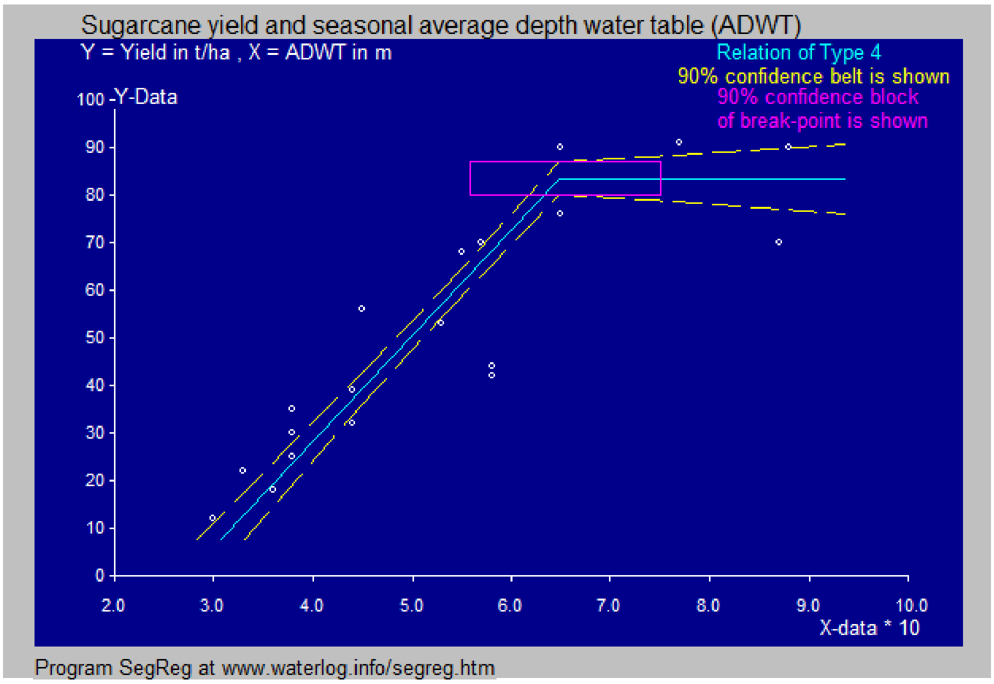
The results of SegRegA for the same crops as used in Method 1 are demonstrated below.



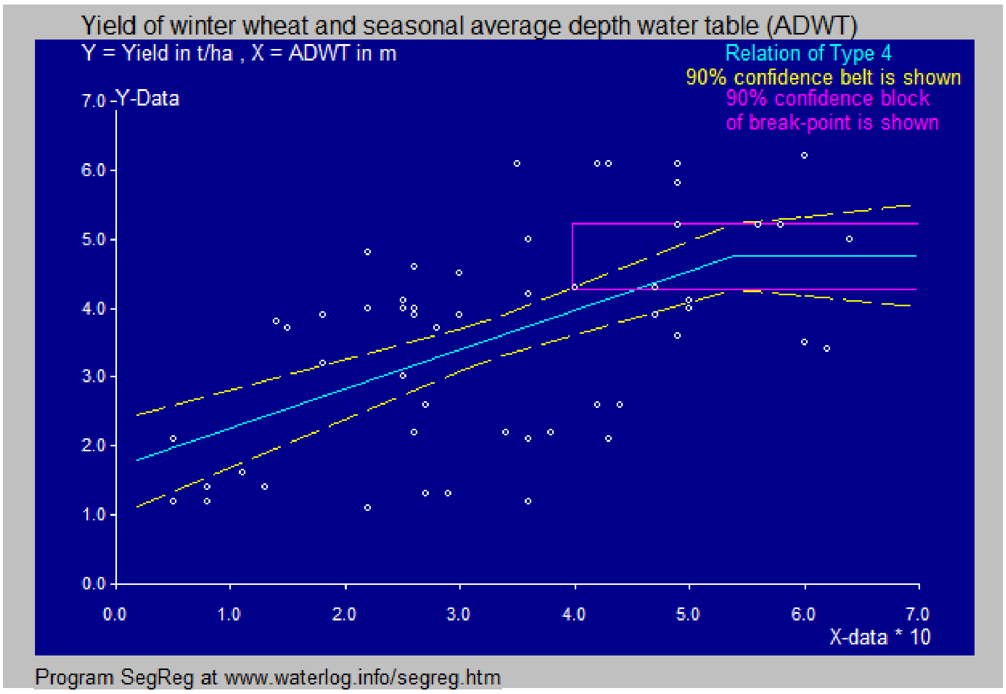
The breakpoint (BP) for banana is at ADWT= 0.85 m.



The breakpoint (BP) for cotton is at ADWT= 0.85 m. Owing to the large variation of the data in vertical direction, the confidence interval of BP is quite wide.



The breakpoint (BP) for sugarcane is at ADWT= 0.65 m.



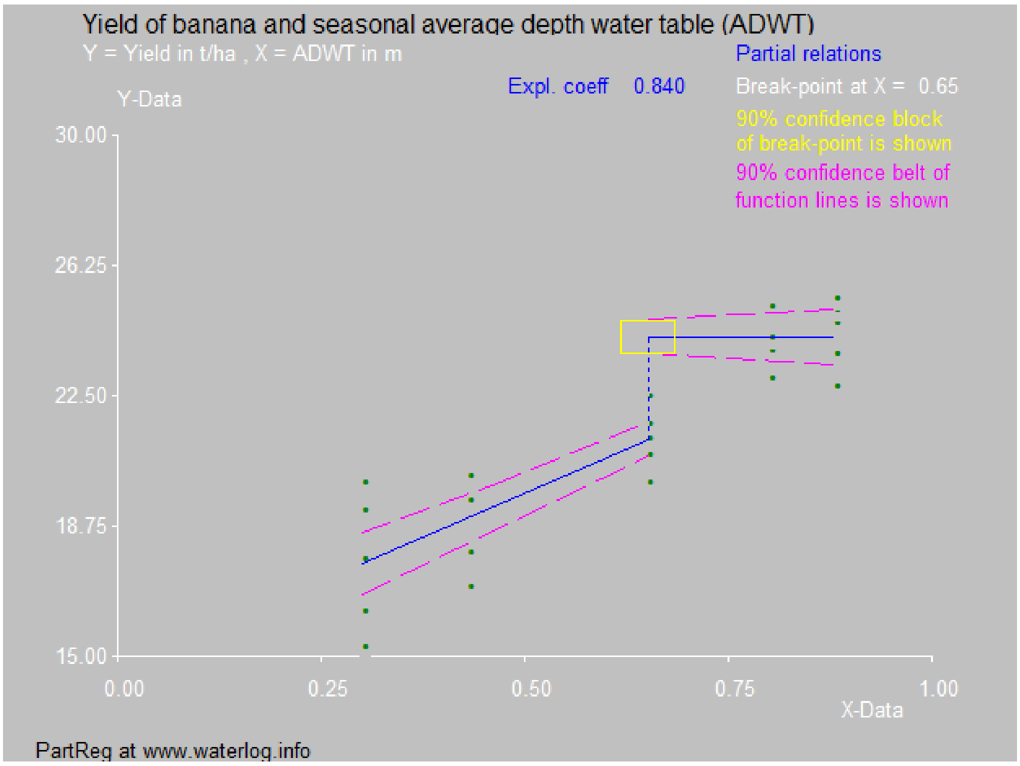
The breakpoint (BP) for winter wheat is at ADWT= 0.54 m. Owing to the large variation of the data in vertical sense and the limited number of data to the right of BP, the confidence interval of BP is quite wide. The winter wheat is grown in an area with water logging problems as the majority of the data are to the left of BP. This is also the reason why the variance analysis (ANOVA table) concludes that the Type 4 is statistically not significantly different from a straightforward simple regression line and therefore not valid actually.

The use of SegReg entails the benefit of the confidence interval of BP, which, when wide, gives a warning that its statistical significance is limited. Also the ANOVA table helps to interpret the statistical significance of the results.

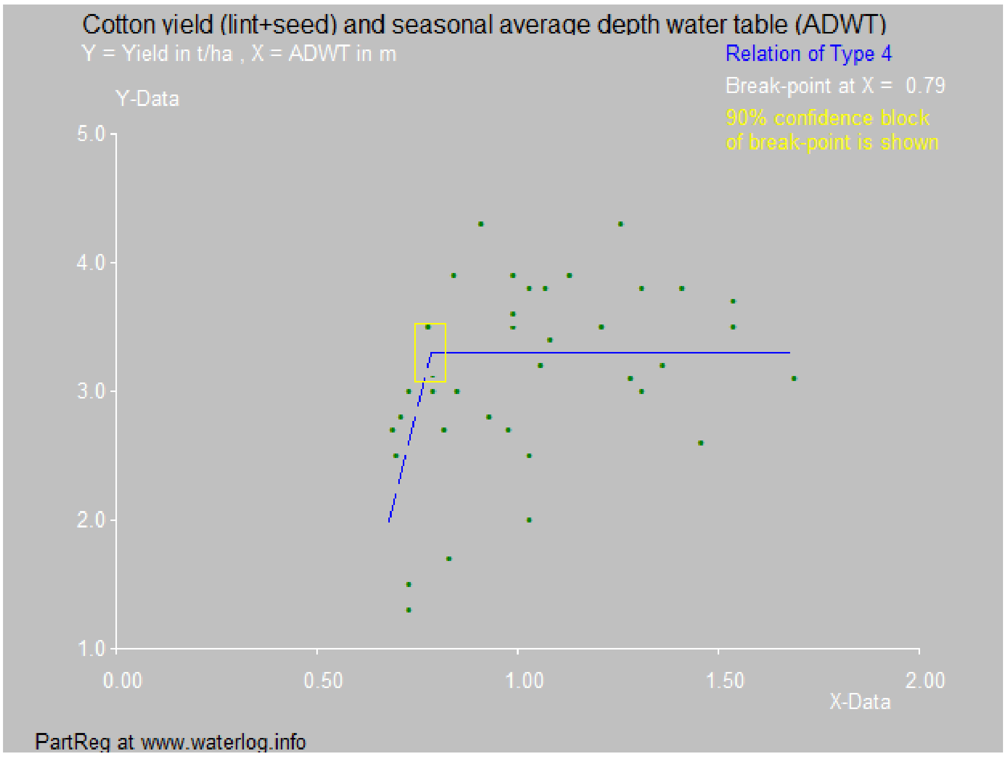
Method 3. Partial regression

Instead of using a regression model (in this case Type 4), that has a preconceived structure with parameters that need to be optimized using the Least Squares (LS) principle, one can also try to detect the longest range of X data over which there is no effect on the Y value. This is call Partial Regression and can be performed using the PartReg program [Ref. 6]. PartReg is not based on a model, and it has no parameters so that the LS method is not used. It simply tries to detect a stretch of X data over which the best fitting line with the observed Y values can be taken horizontal.

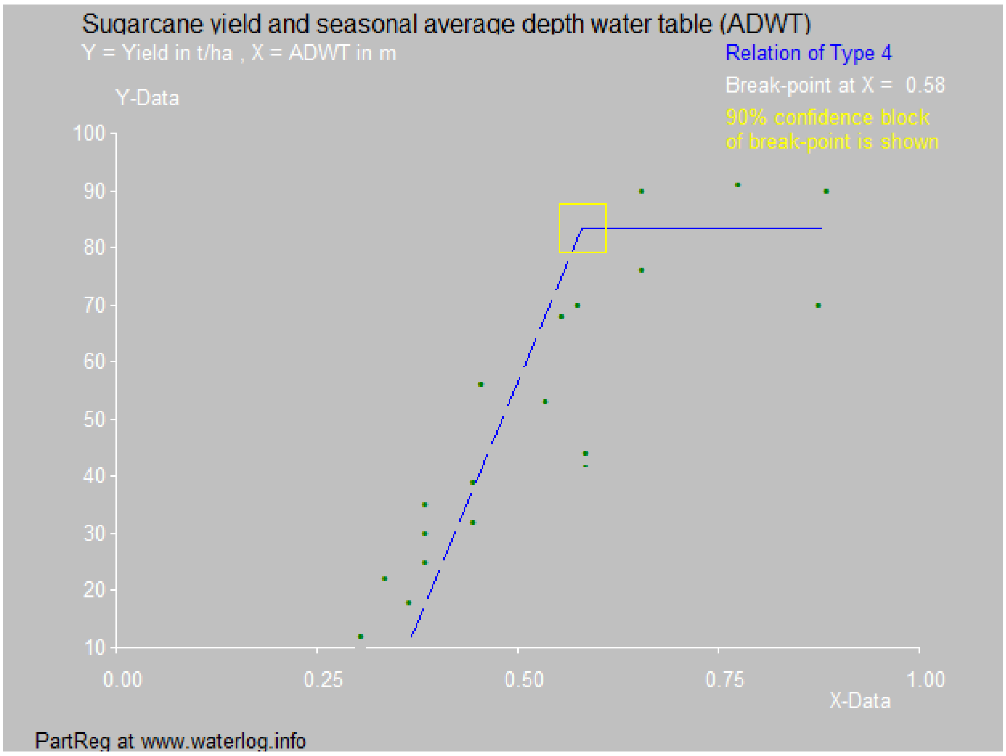
The results for the same crops as used in Method 1 and 2 are demonstrated below.



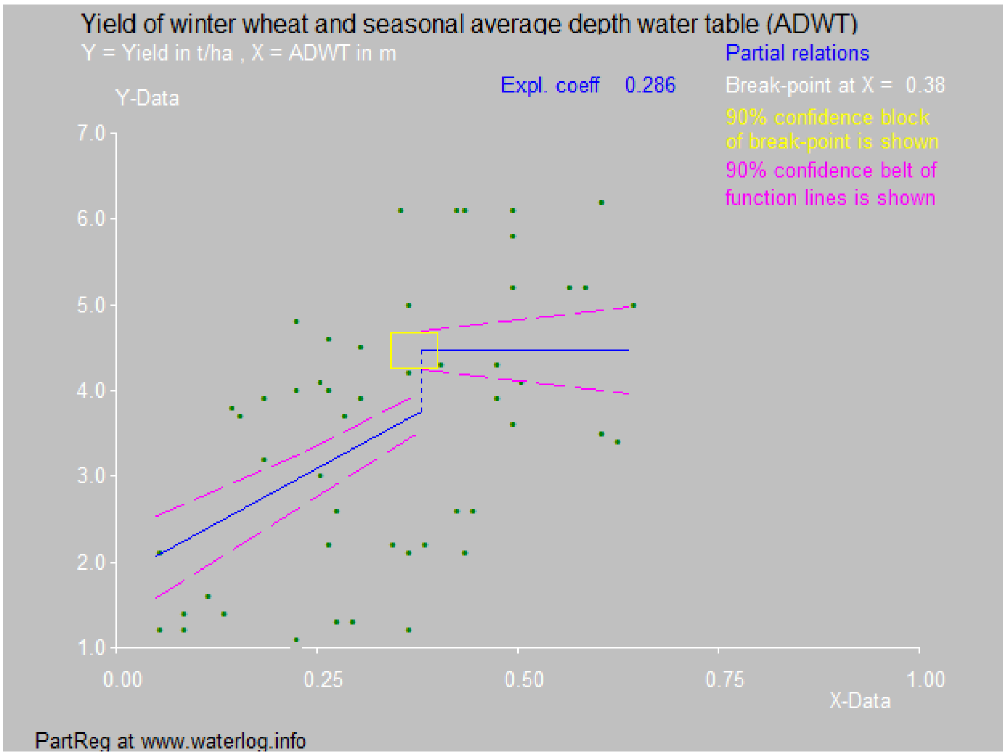
The breakpoint (BP) for banana is at ADWT= 0.65 m.



The breakpoint (BP) for cotton is at ADWT= 0.79 m.



The breakpoint (BP) for sugarcane is at ADWT= 0.58 m.



The breakpoint (BP) for winter wheat is at ADWT= 0.38 m.

Conclusions

The following table shows the critical depth of the water table (in m.) for the crops studied and the methods used

Crop	Method 1 (visual)	Method 2 (SegReg)	Method 3 (PartReg)
Banana	0.80	0.85	0.65
Cotton	1.05	0.85	0.79
Sugar cane	0.70	0.65	0.58
Winter wheat	0.40	0.54	0.38

The winter wheat is the most tolerant crop to shallow water tables and cotton the most sensitive. Method 3 gives the shallowest water tables below which the crop yield declines. It suggests the highest crop tolerance to shallow water tables. Also it demonstrates that the regression line below the breakpoint (BP) not necessarily intersects the horizontal line precisely at BP itself.

References

1. Lenselink, K.J. 1972. Drainage requirements for banana in the coastal plain (in Dutch, title translated by author). In journal: De Surinaamse Landbouw, Vol. 20, pp. 22-36.

2. Nijland, H.J. and S. El Guindy 1984. Crop yields, soil salinity and water table depth in the Nile Delta. In: ILRI Annual Report 1983, Wageningen, pp. 19-29. On line: https://www.waterlog.info/pdf/egypt.pdf

3. Rudd, A.V. and C.W Chardon 1977. The effects of drainage on cane yields as measured by water table height in the Machnade Mill area. In: Proceedings of the 44th Conference of the Queensland Society of Sugar Cane Technology, Australia.

4. FDEU 1972. Annual Report. Field Drainage Experimental Unit, Ministry of Agriculture, Cambridge, UK.

5. SegRegA, free software for segmented and other types of regression analyses. Download from: https://www.waterlog.info/segreg.htm

6. PartReg2, free software for partial regression analysis to detect a horizontal segment in the Y-X relation. Download from: https://www.waterlog.info/partreg.htm

List of publications in which SegReg is used:

https://www.waterlog.info/pdf/segreglist.pdf