Evaluation of the effectiveness of mitigation measures to reduce pesticide inputs into surface water bodies via surface runoff and erosion

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Background and objectives

- Surface runoff from agricultural fields is a major input pathway of pesticides into surface waters (e.g. Wauchope, 1996)
- The aim of this project was to

1) analyze the effectiveness of various mitigation measures to reduce pesticide runoff and erosion inputs into surface waters
2) assess the suitability of the measures found effective for use in the quantitative environmental exposure assessment for authorization of plant protection products (PPP), and
3) make recommendations how the potentially suitable measures could be applied in risk assessment for pesticides in Germany

source: https://www.iconwater.com.au/Water-education/education-resources/ACT-Water-Cycle/Run-off.aspx

source: Hans Flückiger, Fachstelle Boden des Kantons Bern, CH

Selection of mitigation measures for quantitative analysis

- Following a literature analysis, 16 risk mitigation measures were presented to five experts for evaluation of effectiveness, cost-effectiveness, controllability, current distribution and dissemination potential
- Measures finally selected for quantitative analysis belong to three groups:
  1) vegetative filter strips (VFS),
  2) soil conservation measures (zero tillage, mulch-till, strip tillage etc.)
  3) microdams in row crops such as potatoes

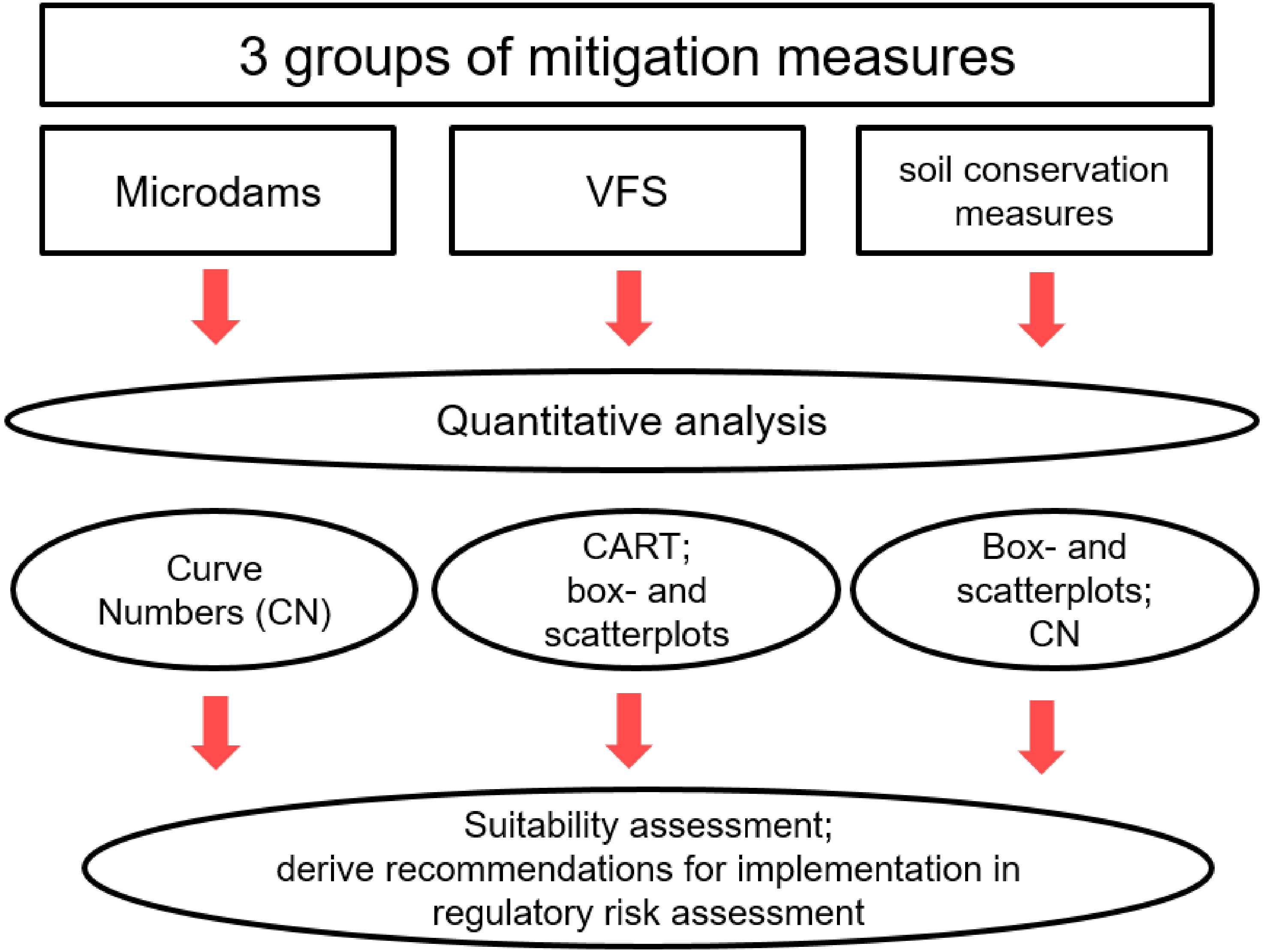
source: https://swat.tamu.edu/media/115036/k2_2_cibin.pdf

source: LfULG Sachsen

source: Sui et al. (2016)

Quantitative data analysis

- The effectiveness of the 3 groups of measures was evaluated based on experimental data.
- Due to different quality and temporal resolution of the available data different techniques were employed for the quantitative analysis



Conclusions

- Both VFS and micro-dams are effective and suitable and can therefore be recommended for application in quantitative environmental exposure assessment for pesticides.

- Soil conservation measures are in principle promising, but there is a need for more well-documented data in order to identify under which conditions they are effective.

Group of measures	availability of well-documented data	process understanding	effectiveness	recommendation for regulatory risk assessment
VFS	+++	+++	++	model with VFSMOD
microdams	++ (potatoes), + (maize)	++	++	model as CN reduction in PRZM
soil conservation measures	+/-	++	+/-	potentially include no-till as a mitigation measure; more high-quality data needed for mulch-till

Outlook

Upcoming publications:

- final project report (in German, with English summary) in press
- peer-reviewed paper (submission to Pest Management Science within the next weeks)

Many thanks for your attention!

Supplementary slides

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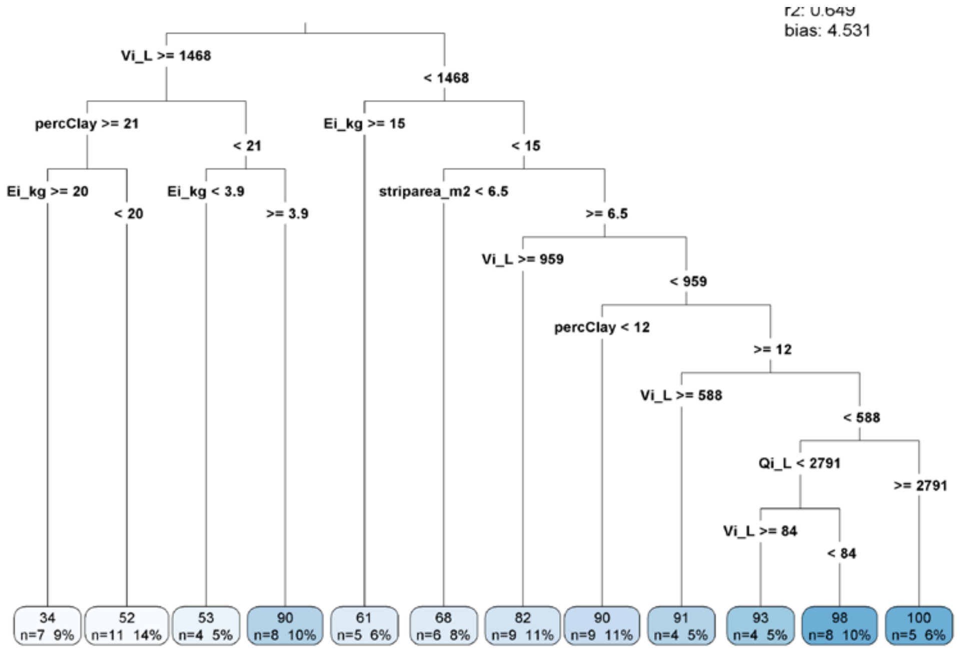
Results and Discussion: VFS

- Buffer width (VL) is not suitable for predicting any of the three target variables:
  - ΔQ (relative reduction of total inflow (run-on + precipitation) by the VFS
  - ΔE (relative reduction of sediment load by the VFS)
  - ΔP (relative reduction of pesticide load by the VFS)

- The analysis with CART (Breiman et al., 1984) revealed:
  - ΔQ can be predicted fairly well ($R^2 = 0.61$) with the available independent variables: run-on (Vi), soil loss (Ei), rainfall (P) etc.
  - ΔE cannot be predicted well ($R^2 = 0.45$), and ΔQ is necessary for the prediction.
  - ΔP can be predicted well from ΔQ, ΔE and some other variables ($R^2 = 0.78$)

- Uncertainties in ΔQ und ΔE propagate to ΔP
  → Infiltration and sedimentation in VFS should be simulated with a mechanistic model such as VFSMOD (Muñoz-Carpena and Parsons, 2020).



Results and Discussion: Microdams

- Microdams in potatoes substantially reduced the occurrence and magnitude of surface runoff from the field.
  - The effect of microdams can be modelled as a reduction of the runoff Curve Number (CN).
  - The runoff modelling should be carried out with a model such as PRZM which adjusts the CN daily based on soil water content.
- In irrigation agriculture microdams can substantially reduce the loss of irrigation water via surface runoff and thus increase irrigation efficiency (Keshavarz et al., 2020).
- Microdams also proved effective with regard to soil loss (seasonal reduction efficiency 66-99.8 %) and pesticide losses from the field: mean seasonal reduction efficiency 91 % (Olivier et al., 2014) and 84 % (Goffart et al., 2013).

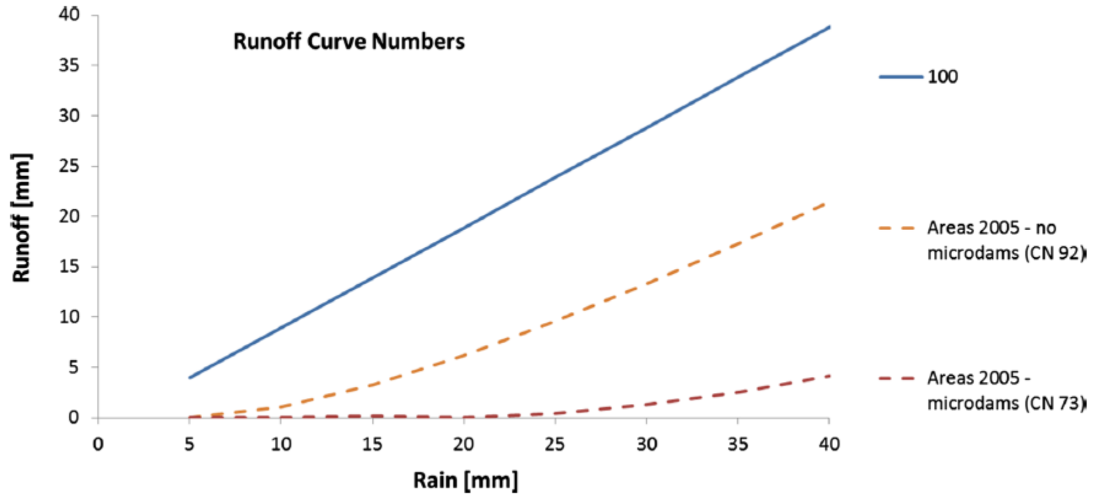


Fig. 3 Relationship between rain and runoff expressed by the runoff curve number (CN). The maximum of 100 describes a 1:1 line; CN 92 and 73 are examples from one of the trials under investigation (Areas, 2005)

source: Sittig et al. (2020)

Results and Discussion: Soil conservation measures

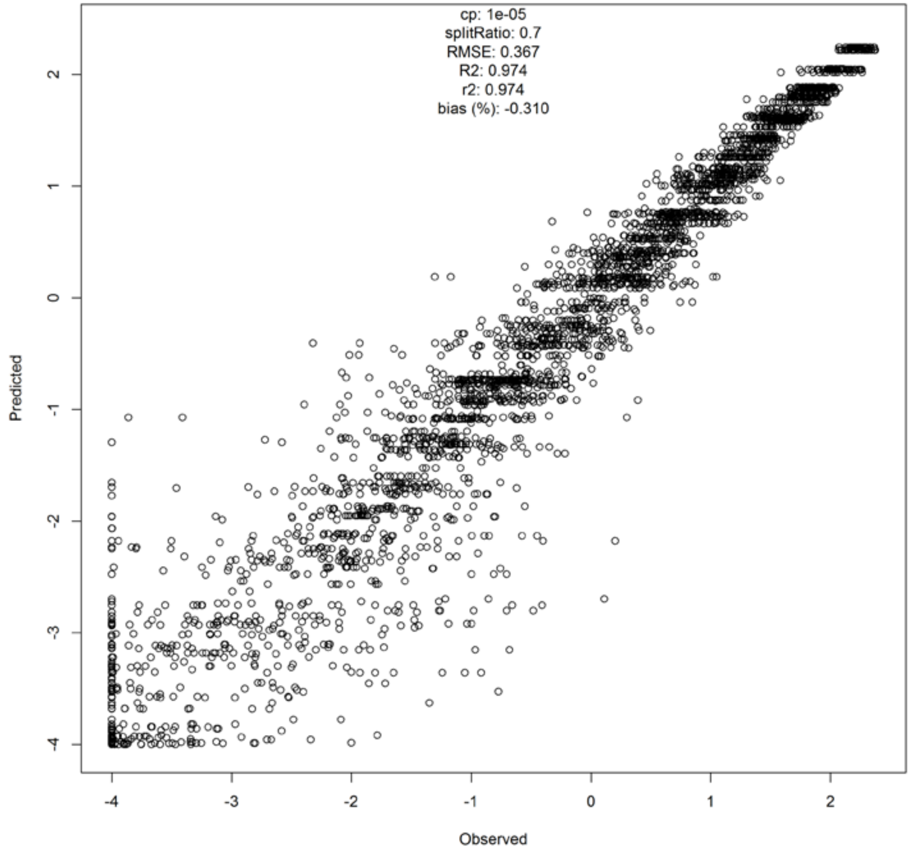
- Availability of well-documented studies less good than for VFS and microdams
- Large heterogeneity of the experimental data (temporal resolution and documentation)
- Highly variable results

- Mulch-till
  - While a clear reduction of surface runoff occurrence and magnitude was observed by Erlach (2005), the data compiled by Maetens et al. (2012) indicate a slight increase of annual surface runoff volumes compared with conventional tillage
  - Substantial reduction of soil loss in Erlach (2005), but no effect in Maetens et al. (2012)
  - Expert opinion that mulch-till is only effective if ground cover ≥ 30 % is corroborated by the results of Erlach (2005)
  - Mulch-till reduced pesticide runoff losses for most compounds in Erlach (2005), but increased losses of isoproturon in winter wheat, suggesting desorption from the mulch during runoff events.

- No-till:
  - The reported surface runoff reduction was also variable, but higher than for mulch-till.
  - Clear reduction effect with respect to erosion and high annual runoff volumes.
  - Clear reduction of seasonal pesticide runoff losses (data compiled by Fawcett et al.(1994) and Dönges (2012)): 54 % for artificial rainfall, 90 % for natural rainfall

Classification and Regression Trees

- CART (Breiman et al., 1984) is a group of decision tree learning methods.
  - oldest and most basic decision tree learning method; ancestor of Random Forest
  - Classification trees (CT): predicted variable is discrete.
  - Regression trees (RT): predicted variable is a real number
  - CART decision trees are constructed top-down, by choosing a variable at each step that best splits the data.
  - Finally, trees are "pruned" in an internal cross-validation step.
  - Test data are randomly split into a training and a validation dataset (best results often for 70/30). The training dataset is used to build the tree.

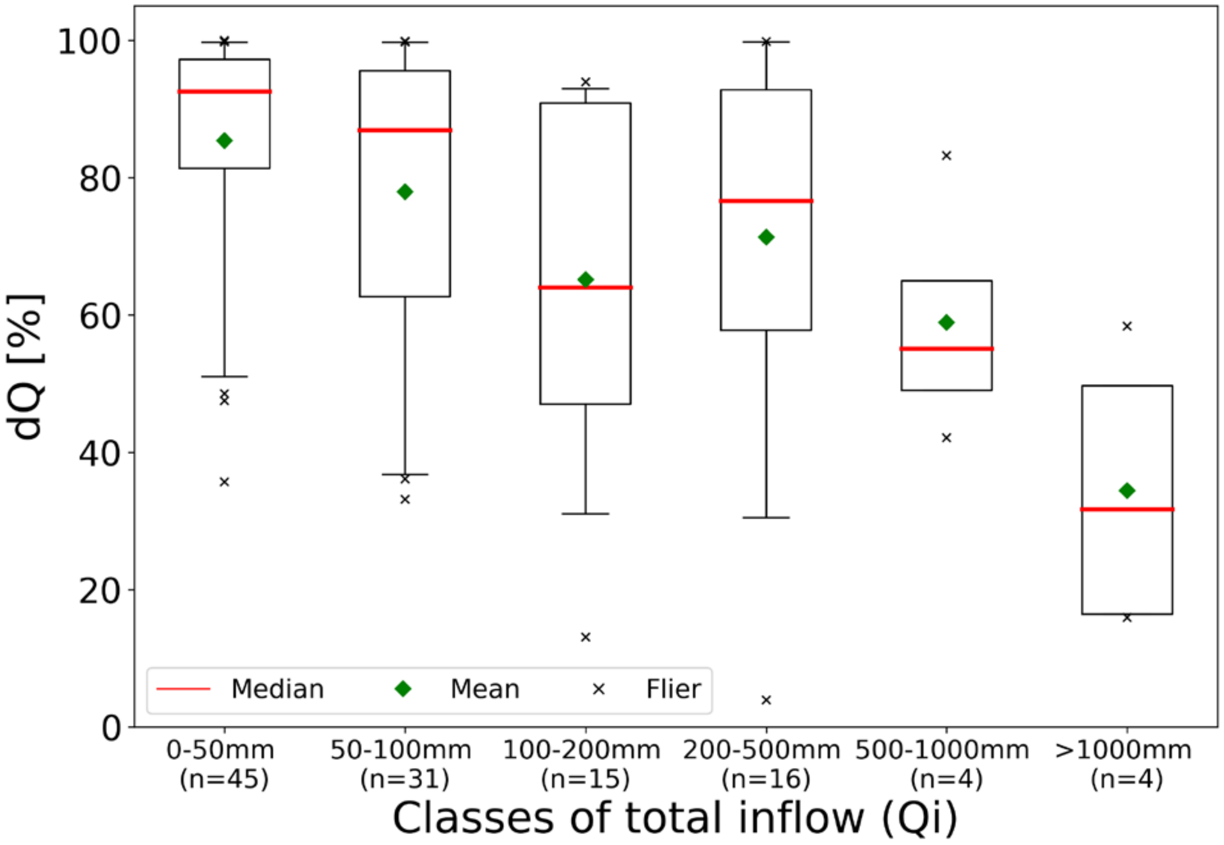


- Subgroup Regression trees (RT)
  - Tree building is strictly based on variance: Groups (nodes) are split such that the variance between the daughter nodes is maximized. → very transparent method
  - Complexity parameter (cp): If a split does not increase the overall R^2 of the model by at least cp, then that split is considered as not worth pursuing and not made.
  - minsplit: minimum size of a group for attempting a split
  - Predictions: The predicted value of the target variable is equal to the mean of the group in which a data point ends up after going through the decision tree.

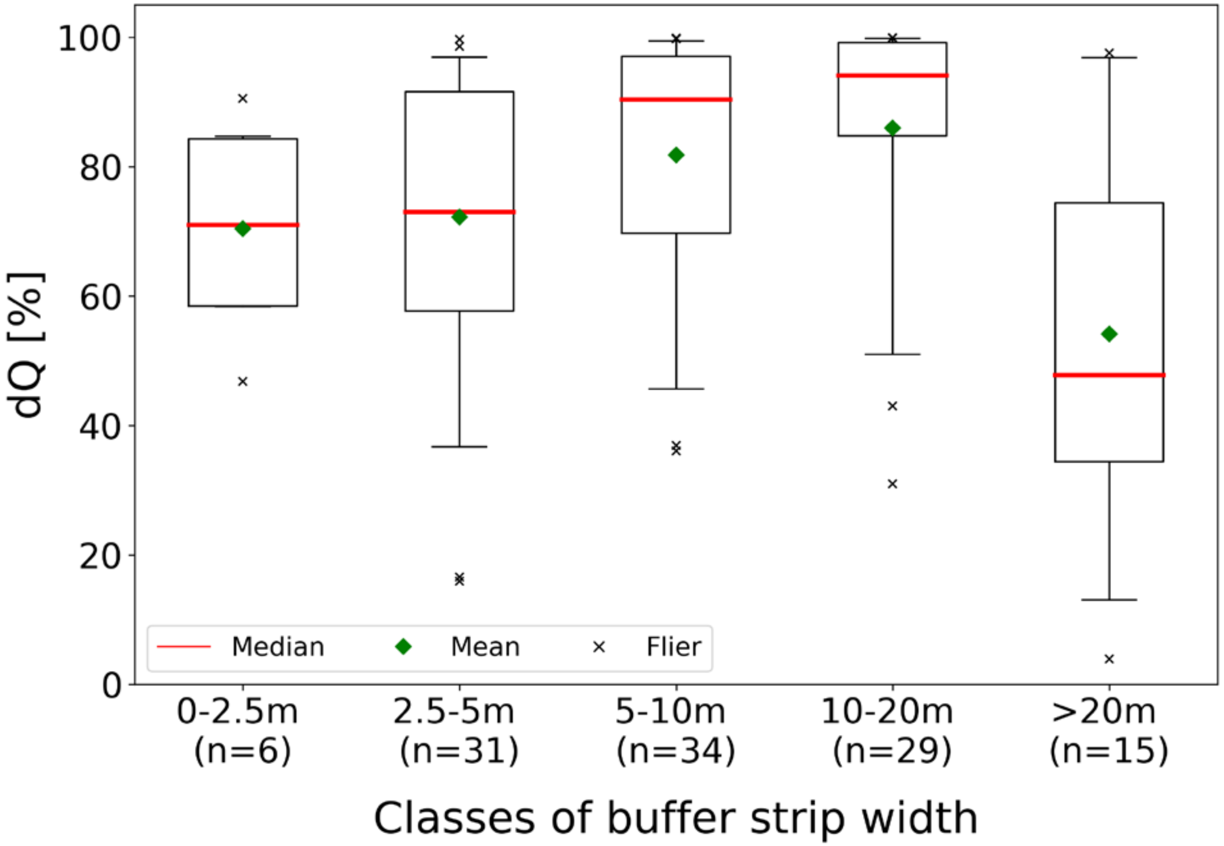
Boxplots VFS

- ΔQ is better correlated with total inflow Qi (run-on + rainfall) (left) than with buffer width VL (right).
- The same holds true for ΔE and ΔP.

Qi vs. ΔQ



VL vs. ΔQ



Scatter plots VFS

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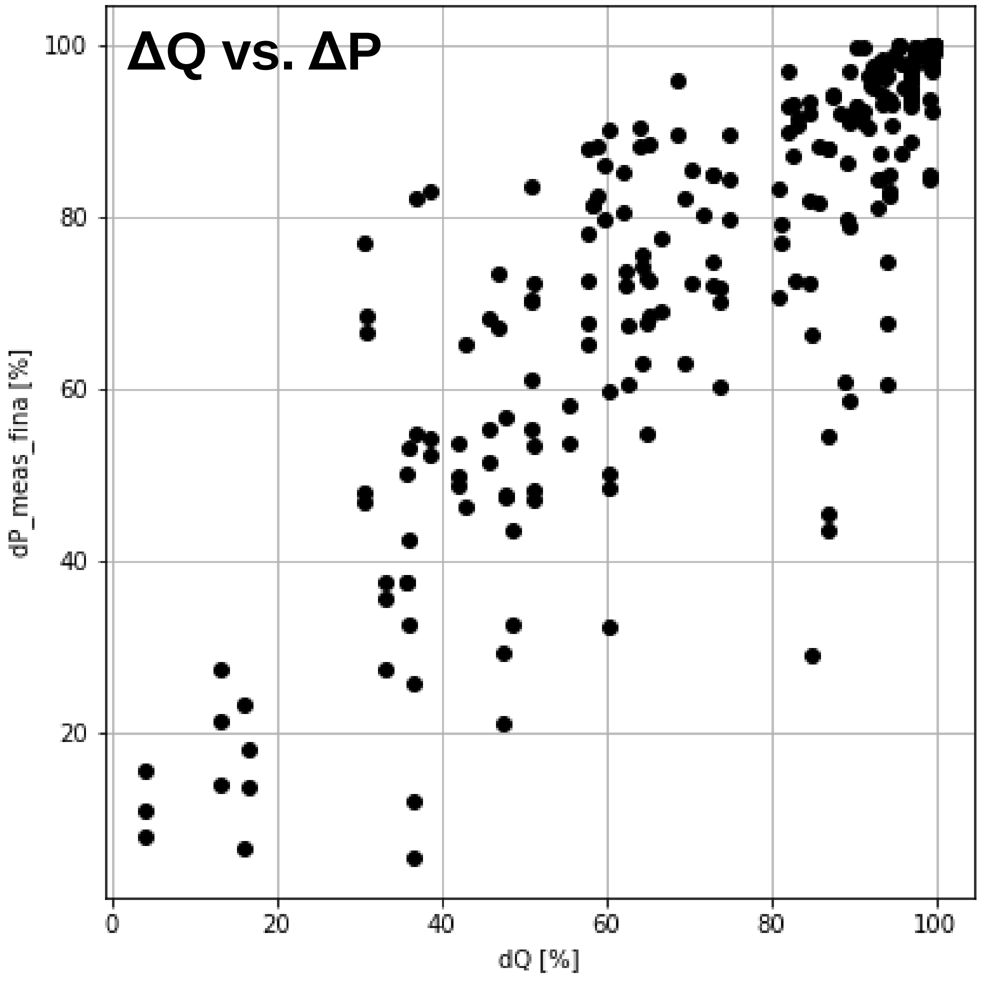
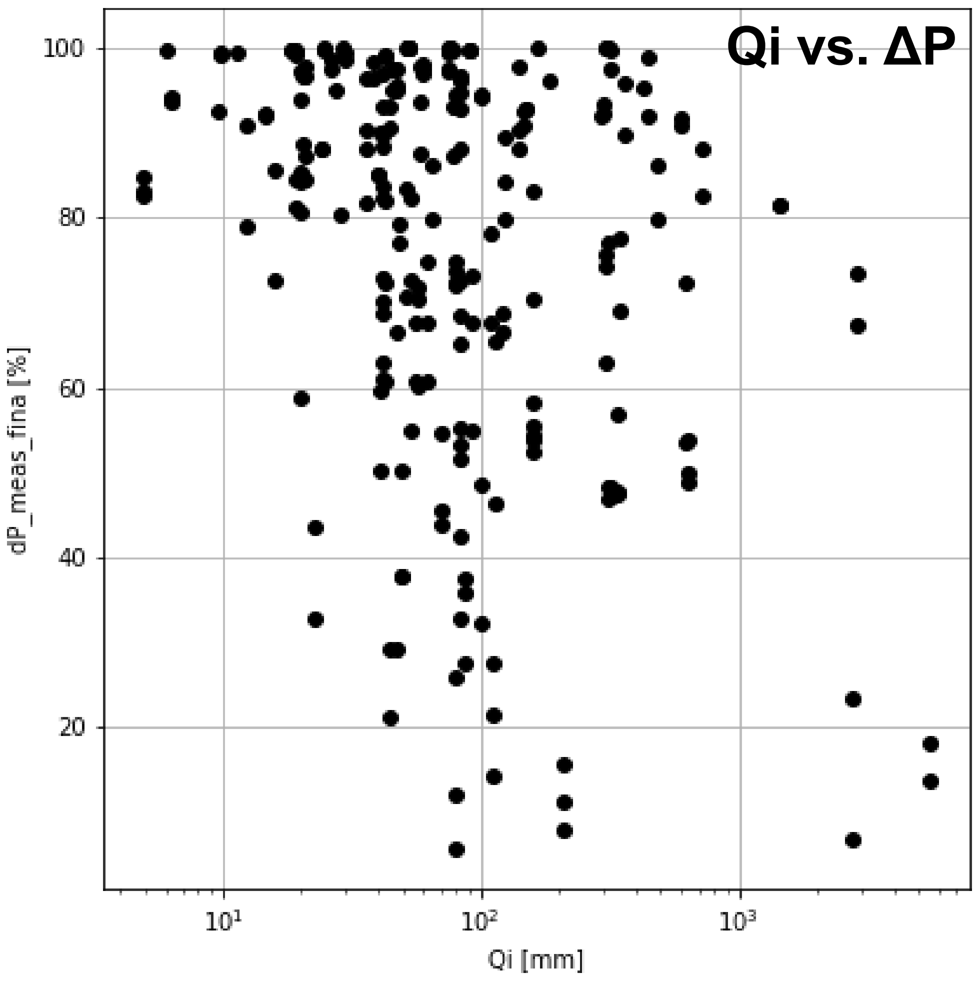
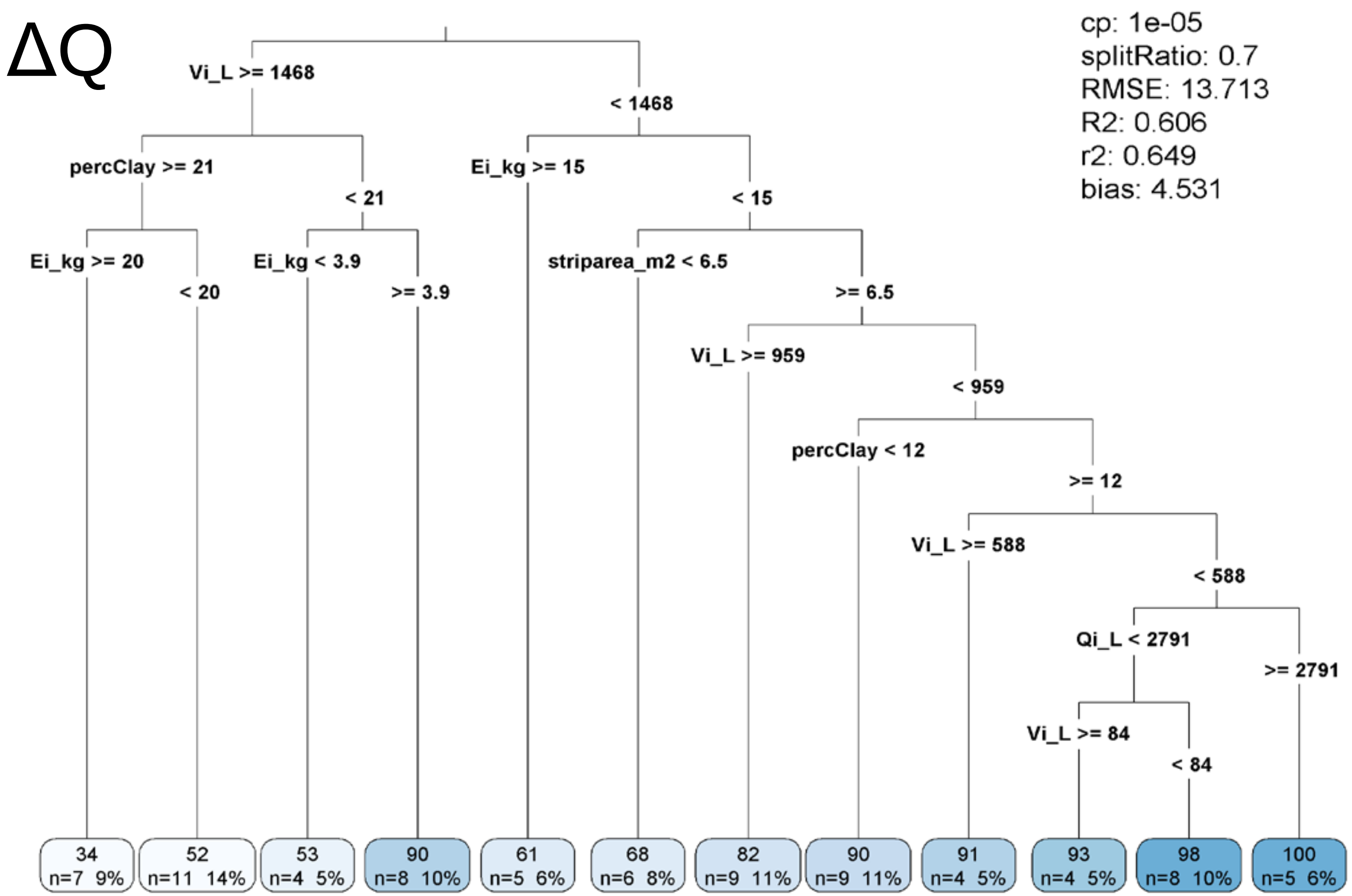
- ΔP and ΔE are better correlated with ΔQ (left) than with Qi (right).

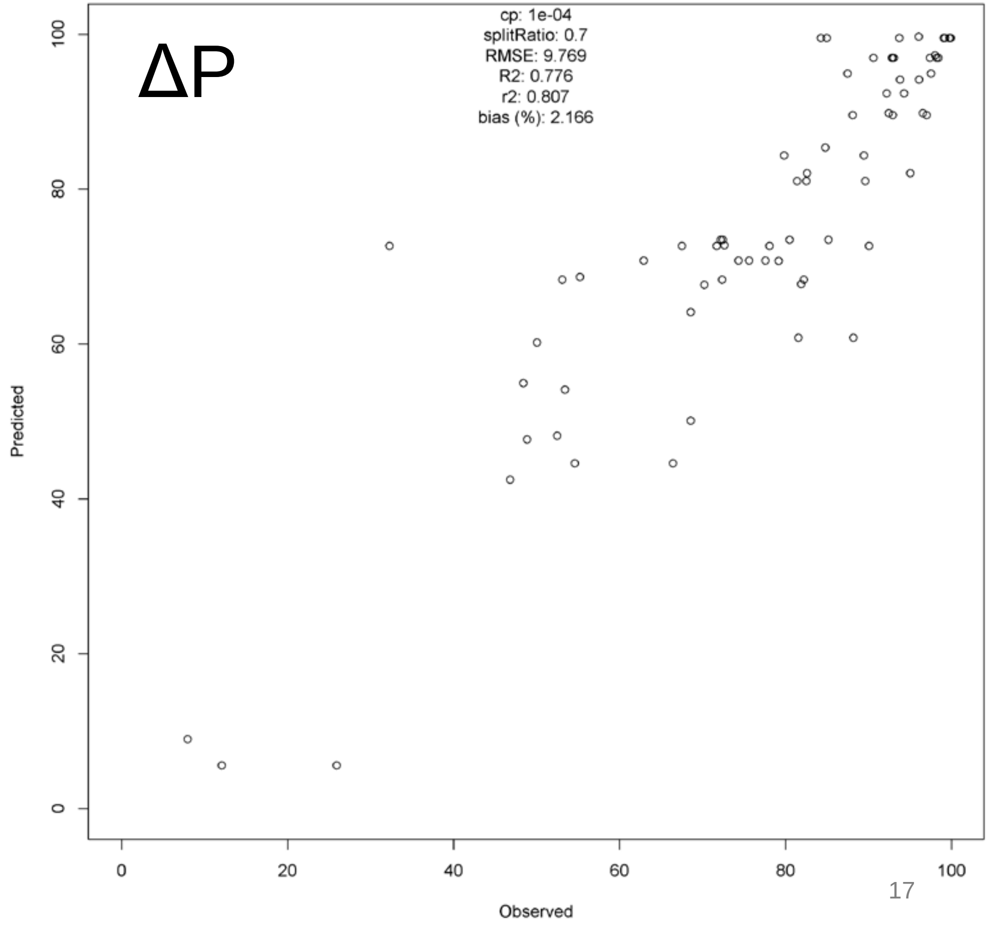




Results CART

- ΔQ: best R^2 = 0.61 (cf. figure left); most important variables: Vi (run-on) und Ei (soil loss from field)
- ΔE: best R^2 = 0.45; most important variable: ΔQ (reduction of total inflow)
- ΔP: best R^2 = 0.78 (cf. figure right); most important variables: ΔQ and ΔE





Conclusions on VFS effectiveness

- Buffer width (VL) is not suitable for predicting any of the three target variables:
  - ΔQ (relative reduction of total inflow (run-on + precipitation) by the VFS
  - ΔE (relative reduction of sediment load by the VFS)
  - ΔP (relative reduction of pesticide load by the VFS)
- ΔQ can be predicted fairly well with the available independent variables: run-on (Vi), soil loss (Ei), rainfall (P) etc.
- ΔE cannot be predicted well, and ΔQ is necessary for the prediction.
- ΔP can be predicted well from ΔQ, ΔE and some other variables (e.g. Kd)
- However, uncertainties in ΔQ und ΔE propagate to ΔP.

→ mechanistic modelling of infiltration and sedimentation (ΔQ and ΔE) is necessary, e.g. with VFSMOD

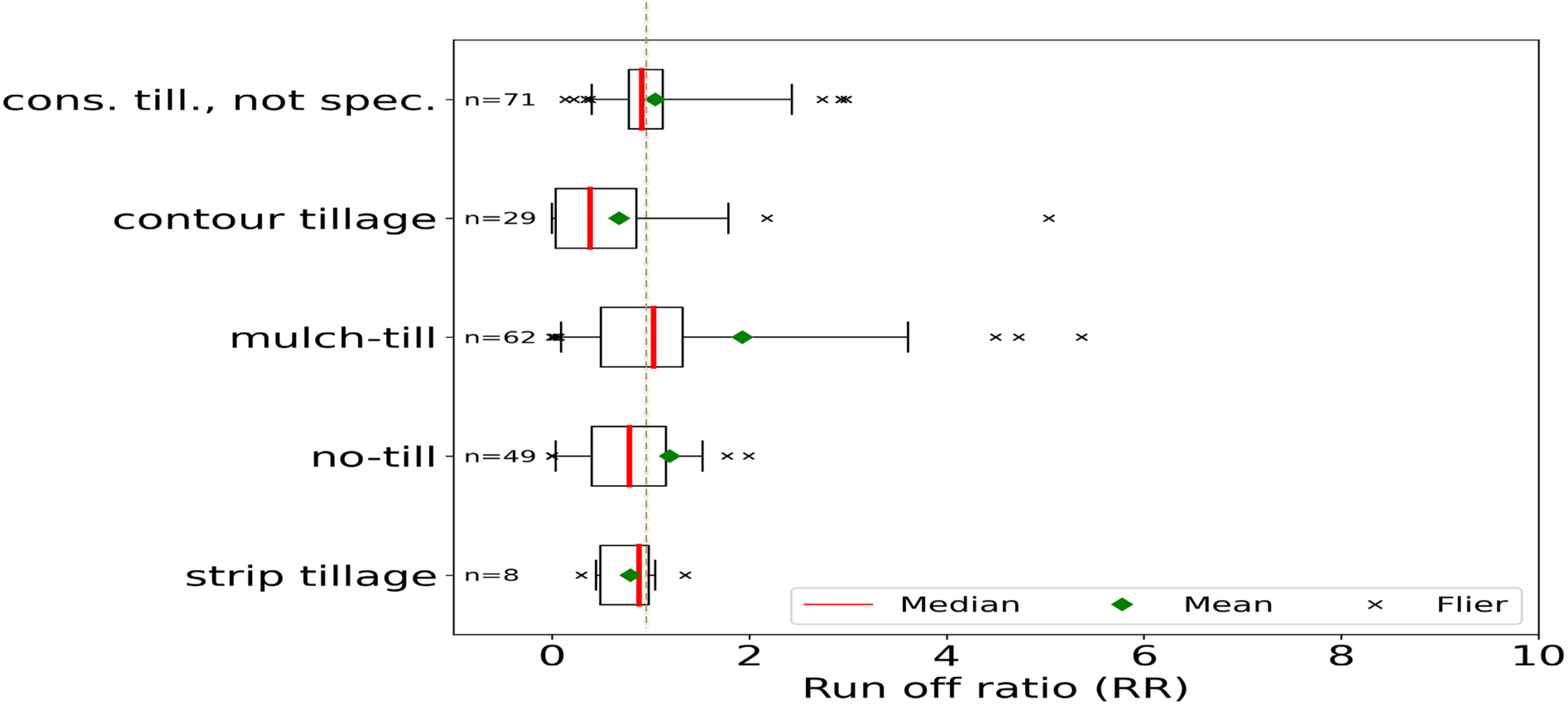
→ calculation of ΔP from ΔQ and ΔE is less critical

- four options of trapping equations available in VFSMOD
- e.g. analytical mass balance trapping equation (Reichenberger et al., 2019)

$$\frac{\Delta P}{100\%} = \frac{\left(\frac{\Delta Q}{100\%} V_i + \frac{\Delta E}{100\%} K_d E_i\right)}{(V_i + K_d E_i)}$$

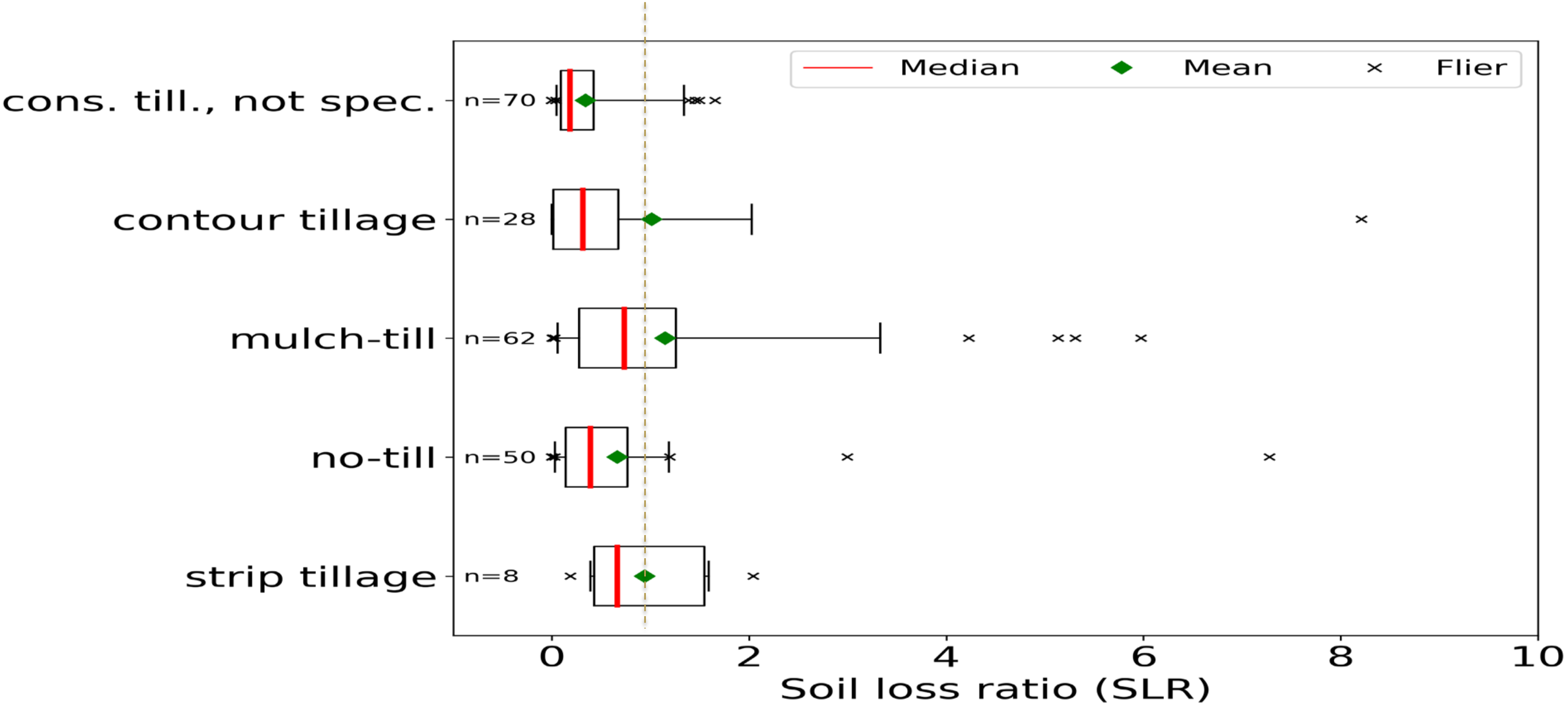
Ratio of annual surface runoff volume with soil conservation measures to the runoff volume without measure (run-off ratio, RR) in arable crops

Data: Maetens et al. (2012)



Ratio of annual soil loss with soil conservation measures to the soil loss without measure (soil loss ratio, SLR) in arable crops

Data: Maetens et al. (2012)



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Recalibration and cross-validation of pesticide trapping equations for vegetative filter strips (VFS) using additional experimental data

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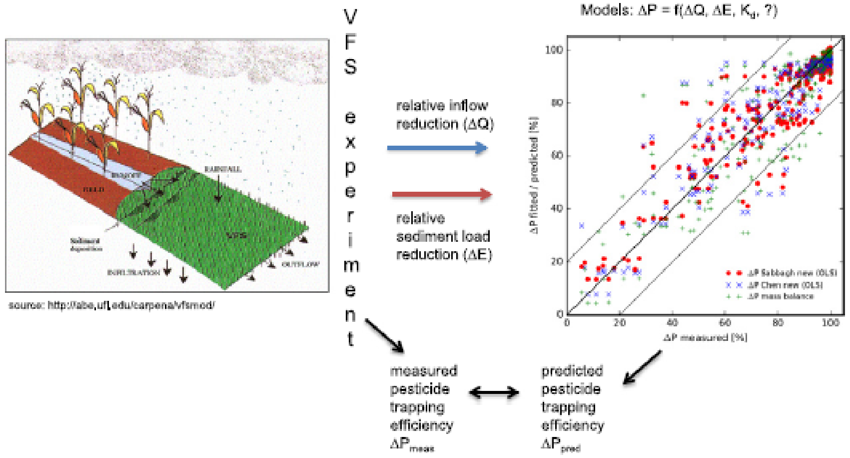
HIGHLIGHTS

- Lack of parsimonious mechanistic approaches for modelling pesticide trapping in filter strips
- Sabbagh regression equation needed broader data basis and rigorous evaluation
- Experimental data basis has been considerably widened
- Suitability of Sabbagh equation for modelling pesticide trapping in vegetative filter strips has been confirmed
- Regression-free mass balance approach is viable alternative

GRAPHICAL ABSTRACT



Sittig *et al. Environ Sci Eur* (2020) 32:86
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Environmental Sciences Europe

RESEARCH

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Consideration of risk management practices in regulatory risk assessments: evaluation of field trials with micro-dams to reduce pesticide transport via surface runoff and soil erosion

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