Modelling European Agriculture with Climate Change for Food Security
– a FACCE JPI knowledge hub –

FACCEJPI MACSUR

zalf Leibniz-Zentrum für Agrarlandschaftsforschung (ZALF) e.V.

Leibniz Gemeinschaft

Leibniz Centre for Agricultural Landscape Research

No data? No models
The future of modelling for food security with climate change

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XLV Congress of Italian Society of Agronomy

Sassari 20.9.2016

Outline

- Key questions to be adressed for sustainable development and food security?
- The role of data for modelling
- Data requirements for modelling
- Assessment of data suitability for modelling
- Role of long term experiments
- Deficits and requirements for improvement

Broadbalk experiment
Hertfordshire, UK
DL Science Societies of America

Key questions to be adressed (in MACSUR):

- **What are potentials and risks for food production under climate change.**
- **How is European agriculture going to adapt to Climate Change and variability.**
- **How adaptation and mitigation measures are linked to other sustainability targets?**
- **How can we achieve sustainable intensification.**
- **Are mitigating measures effective and realistic?**
- **What is the impact of agricultural and environmental policies and market conditions on European agriculture?**
- **Which regions and sectors have potential to contribute to agricultural mitigation measures in a cost-effective manner?**
- **What is the potential for EU agriculture to enhance a circular economy in Europe to improve nutrient recovery and foster short distance food cycles?**

Models are the ultimate tool for climate impact assessment ...

..., but observed data are the indispensable backbone of all modelling efforts to:

- Develop, calibrate and validate models at different scales
- Prove model consistency across variables and conditions
- Provide specific inputs for regional and pan-European model assessments with an adequate resolution and accuracy
- Analyze spatio-temporal trends within and across regions
- Test upscaling and downscaling methods
- Identify relations between variables and impacts

MACSUR activities:

Data … for better understanding and modelling climate change impact

- Defining international standards for the evaluation of data quality (platinum, gold, silver) (Kersebaum et al. 2015)
- Quantify data gaps for modeling
- Empirical analysis of crop responses to past climate variability and change
- Observed adaptation options and their efficacy
- Effect of extreme events (past analysis and projections)
- Climate change scenarios
- Analyzing effects of data resolution (scaling)
- Concept for open data management, data journal
- …

Why suitable data sets for modelling are required?

- Calibration of model parameters (actualized varieties, new crops)
- Testing the validity of models on sites where they are not calibrated (validation/evaluation)
- Testing the sensitivity of models to external factors (climate, soils, management)
- Prove the consistency of model behavior (inter-relation of state variables)
- Identification of gaps and missing or inadequately described processes
- Development of sub-models for new relevant processes

Therefore, it is recommended to apply models

- under different climate conditions
- in different years (inter-annual weather variability)
- on different sites/soils
- with different management (e.g. water and nutrient supply, tillage, rotation etc.)

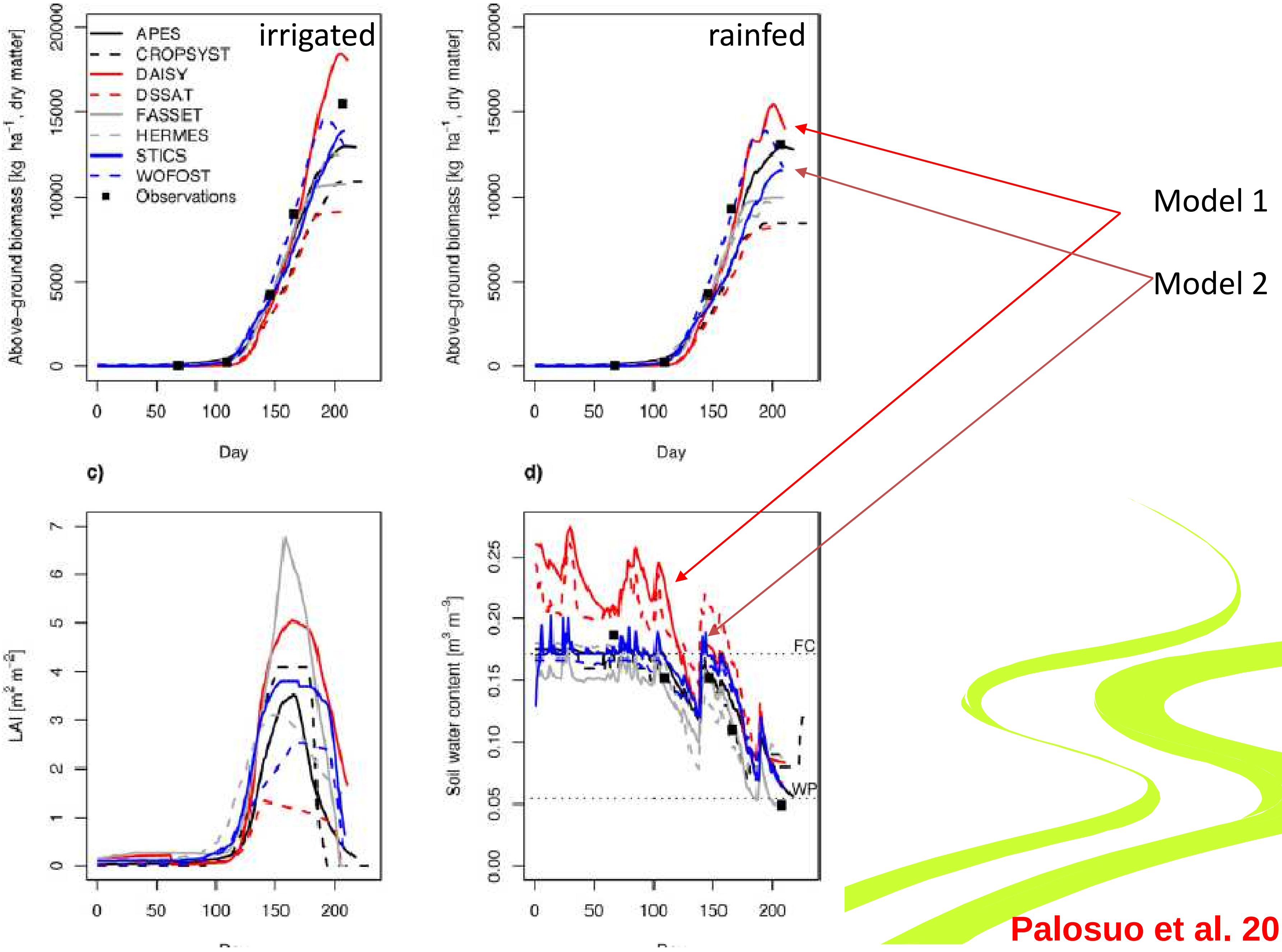
What are requirements to data?

Data should

- provide data for as many output variables of the model as possible (consistency)
- contain replicates to estimate their uncertainty/variability
- have a spatio-temporal resolution which allows process parameters in the model to be adjusted and model assumptions to be tested
- provide data of multiple years for the same crop/variety
- have different treatments (manipulated experiments) e.g., rainfed/irrigation, fertilization, CO_2 , tillage
- have a reliable and representative spatio-temporal relation to driving input data (e.g. weather data)

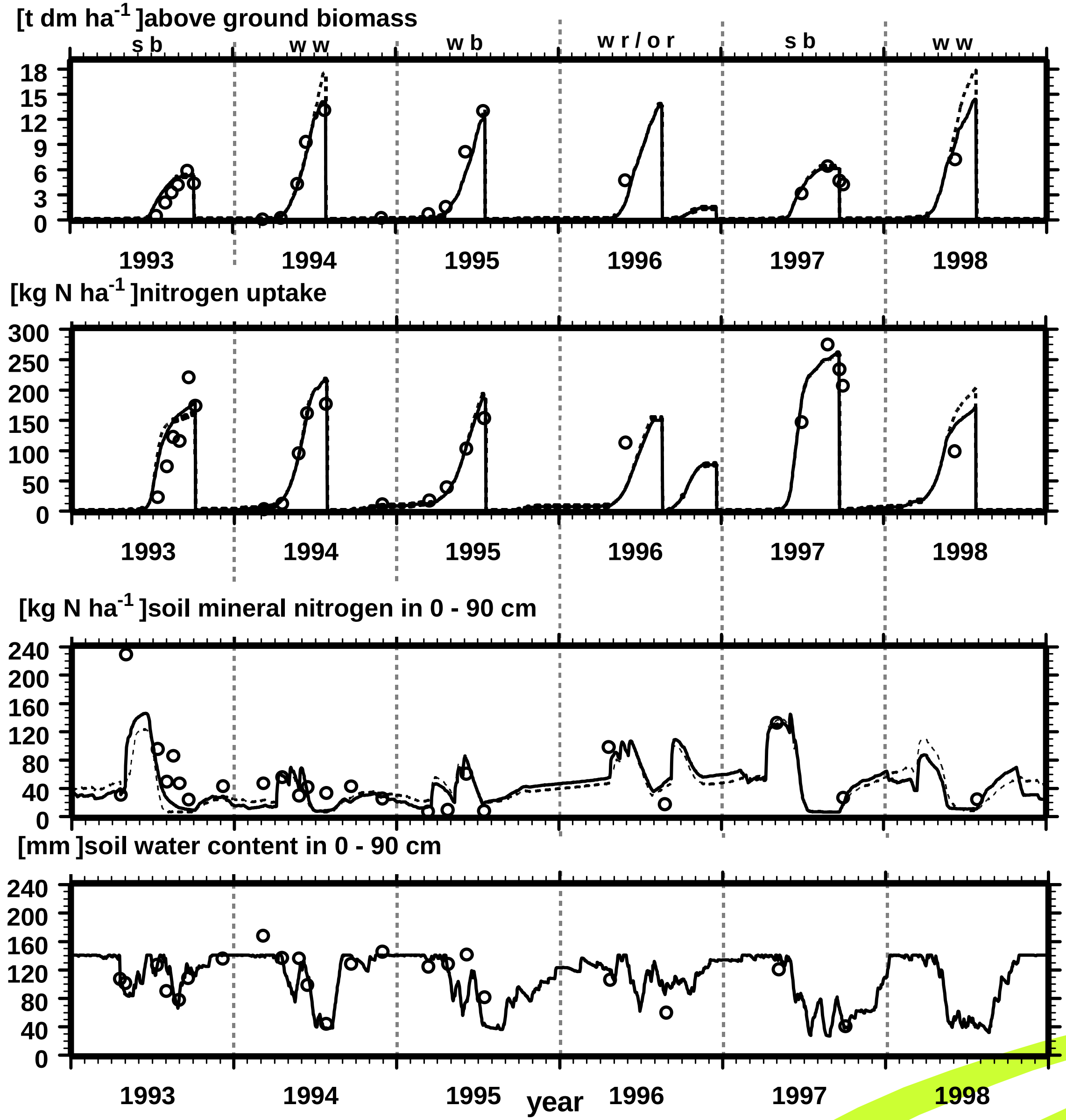
However, requirements vary depending on the purpose of use, e.g. calibration, evaluation/validation, improvement

Do we achieve a good result on the right conditions?

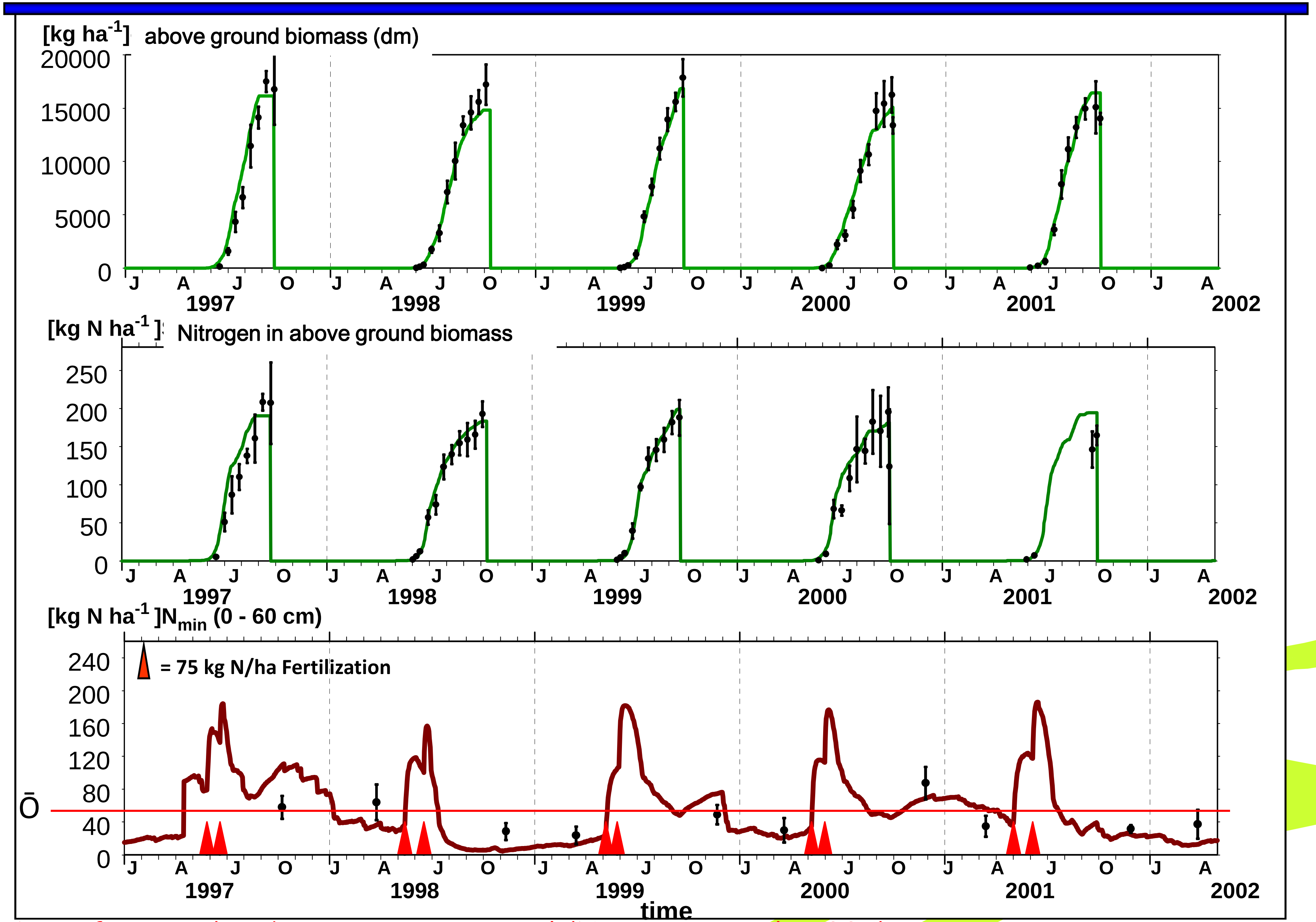


Palosuo et al. 2011

Validation of complex models requires consistent data sets of different observed state variables

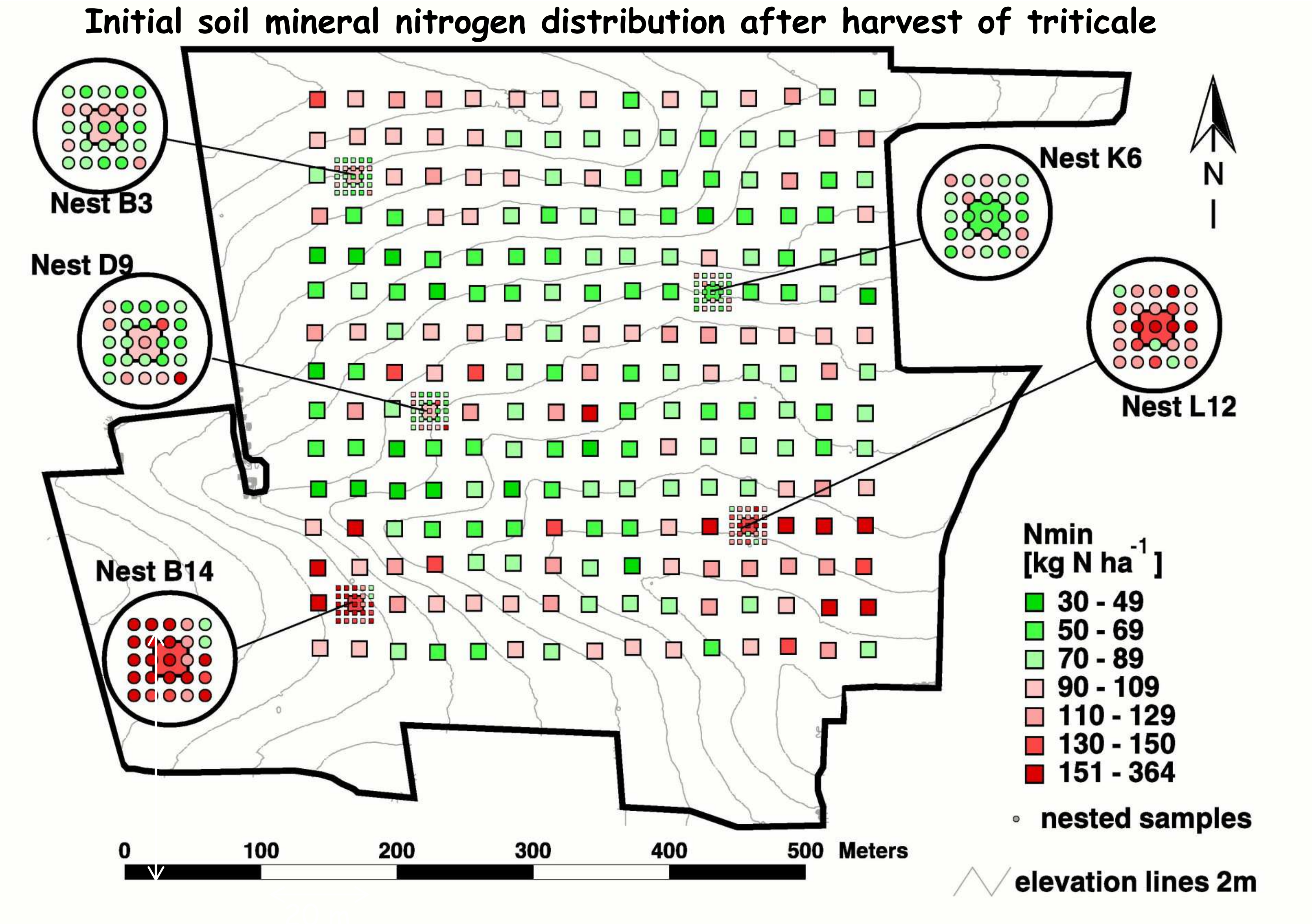


Be aware of errors/variability in measurements



Data from Karkendamm, University Kiel (Herrmann et al., 2005)

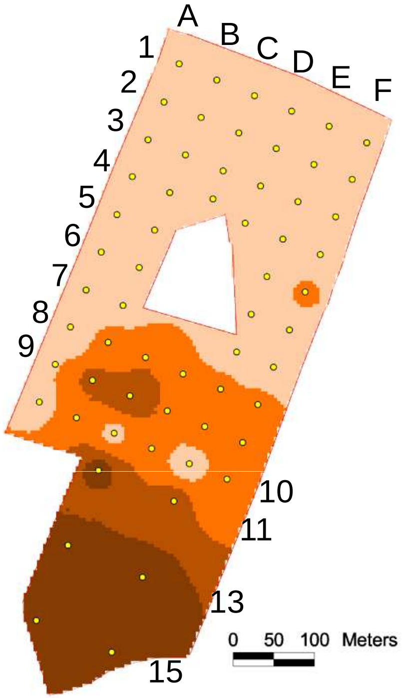
Small scale variability might be very large



Kersebaum et al. 2002

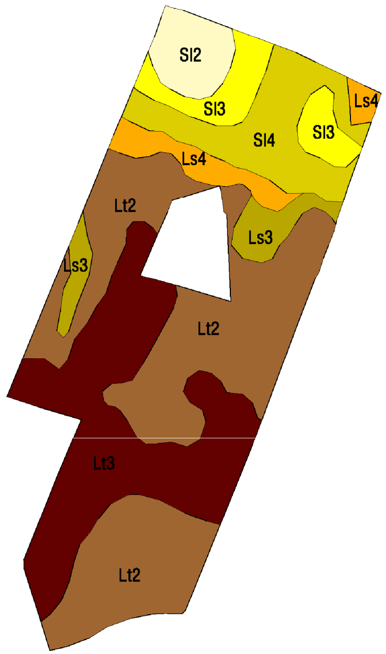
Spatial variability offers a chance to test model sensitivity

stone content



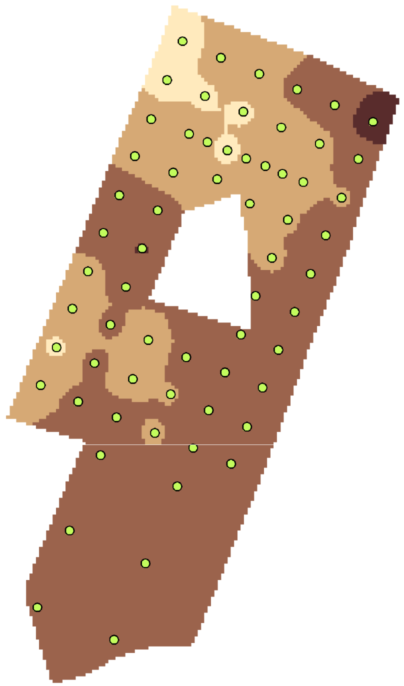
Stone percentage in 60-90 cm [%]:
- 0 - 20
- 20 - 30
- 30 - 40
- 40 - 50

soil texture



- Sl2 (loamy sand)
- Sl3 (very loamy sand)
- Sl4 (sandy loam)
- Ls4 (loam)
- Ls3 (sandy clay loam)
- Lt2 (clay loam)
- Lt3 (silty loam)

organic carbon



sampling points

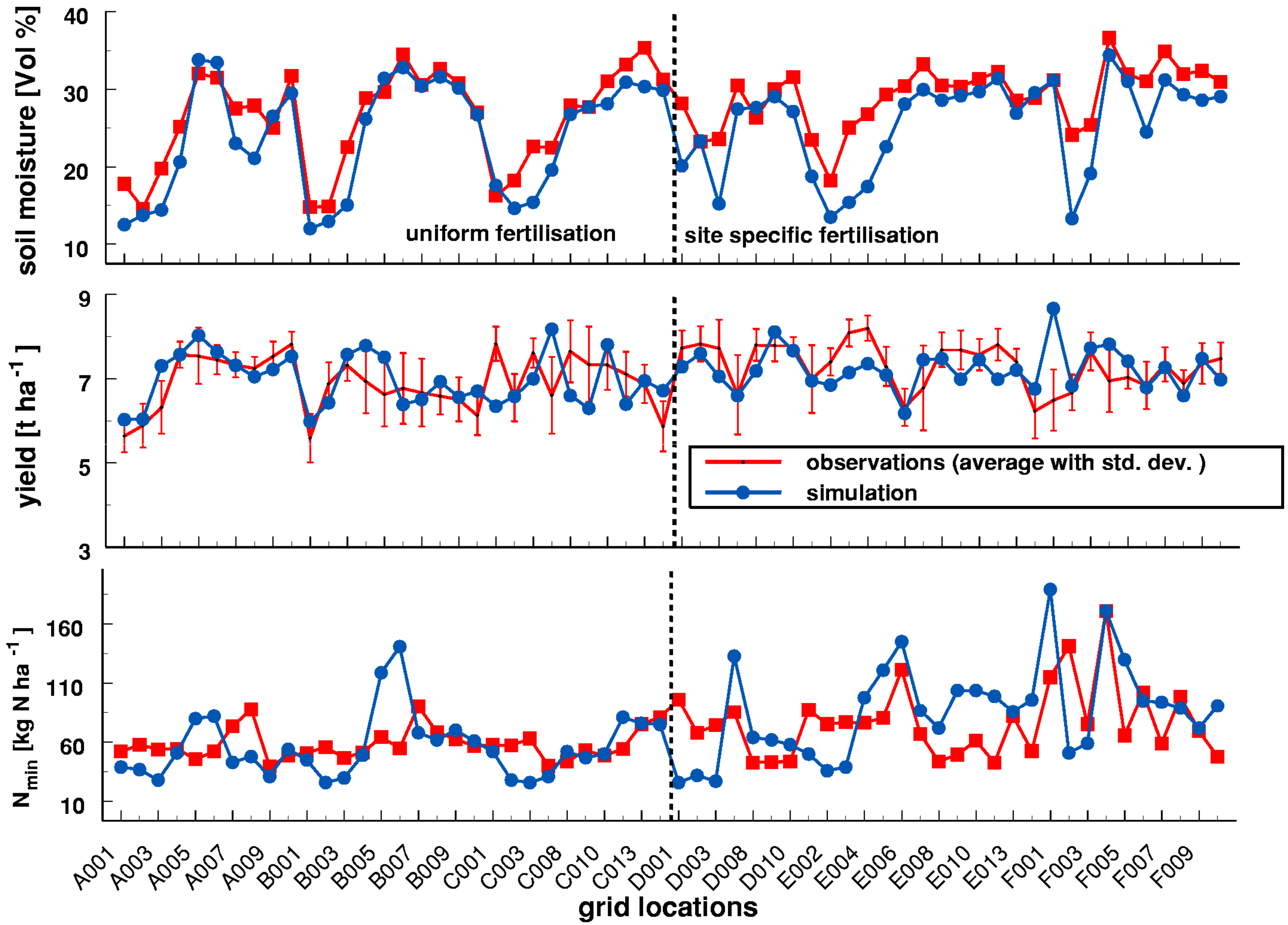
Corg [%]
- < 1.1
- 1.1 - 1.7
- 1.7 - 2.5
- > 2.5
- No Data

initial soil mineral N (15. September 1999)

Nmin 0-90 cm [kg N*ha $^{-1}$]:
- 70 - 100
- 100 - 130
- 130 - 160
- 160 - 200
- 200 - 320
- No Data

Kersebaum et al. 2002

Spatial validation with grid observations at harvest



soil moisture

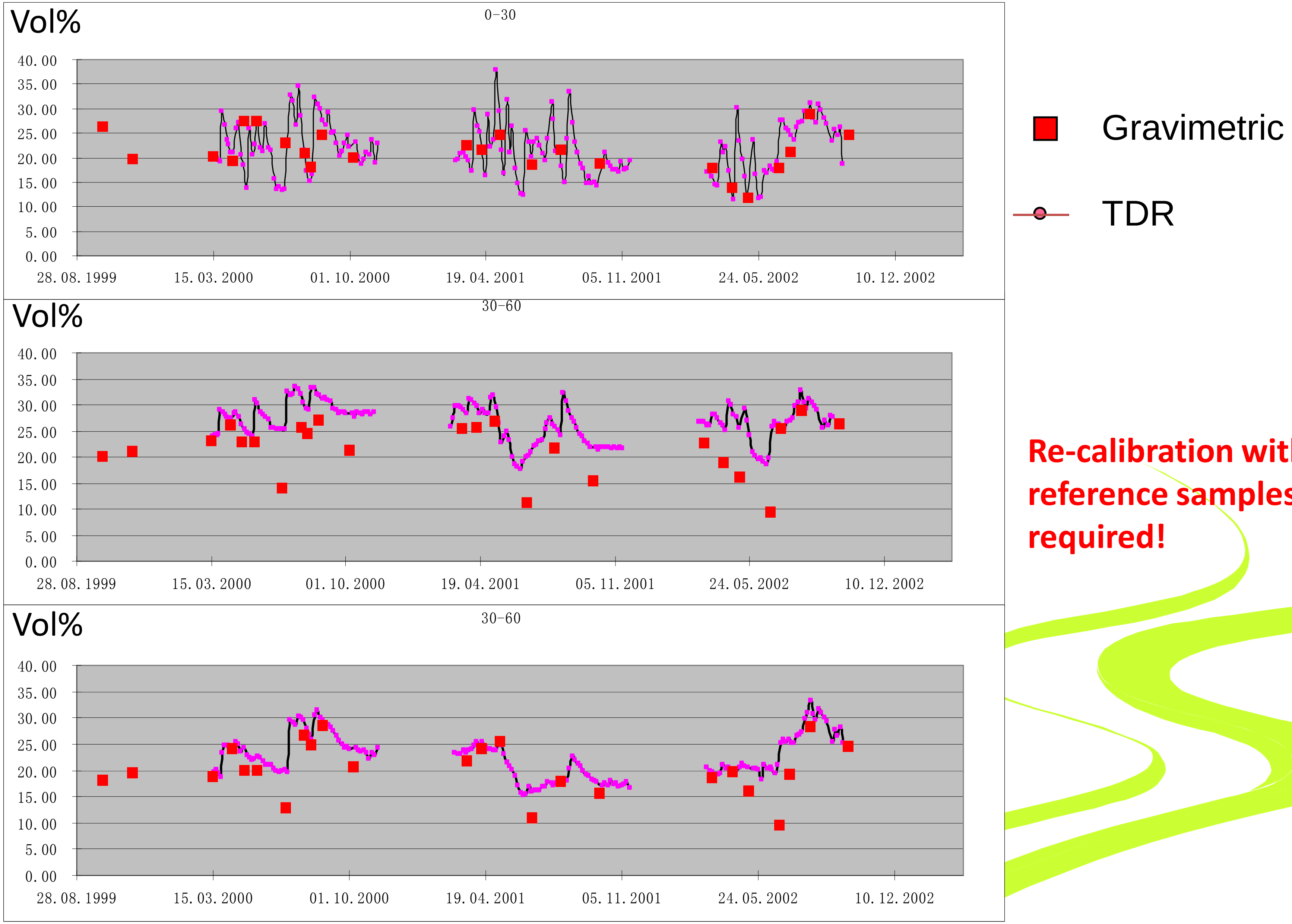
grain yield

soil mineral nitrogen

and may explain differences between replicates!

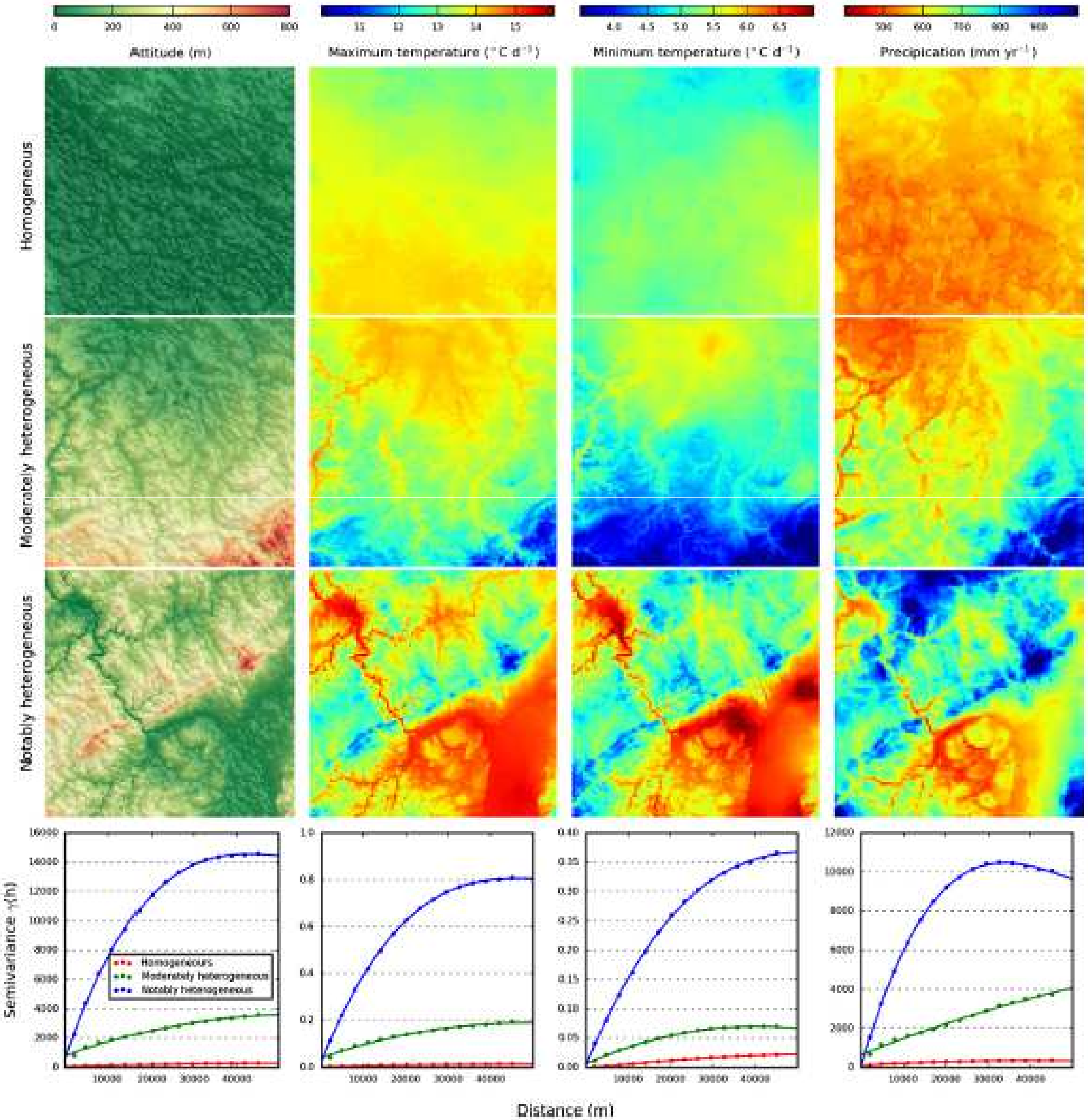
How far can we trust our measurements?

Measured water contents gravimetric and with TDR



Re-calibration with reference samples required!

Are meteorological inputs representative for the experiment?



Zhao et al. 2015

Data requirements depend on the purpose

Background: Extended AgMIP sentinel site classification system

Rosenzweig et al. 2013
Boote et al. 2015

Qualitative ranking of data for Sentinel sites in AgMIP

Table 3. Criteria on which to rank data sets as Platinum Sentinel Site Data

Required criteria	Desirable observations
All platinum site data	
Weather (all measured on site)	
Soil traits (texture and water-holding capacity measured onsite)	Rooting depth
All management inputs	
Final yield and yield components	
Crop phenology, anthesis or maturity	
In-season leaf-area index, biomass and grain measurements (4 times), well bordered	
	In-season tissue N concentration
	Diverse environment, sowing date, management, etc.
	Process data (evapotranspiration, C exchange rate)
For potential production	
Absence of water, N, P, Al, water-logging, and pest stresses	
For Water-limited production	
Initial soil water measured	
In-season soil water measured	
	Process data (evapotranspiration, conductance)
	Diverse water and soil traits
For N-limited production	
Initial soil water measured	
Initial soil NO_3, NH_4, residue	
Soil organic carbon	
In-season N concentration in tissues	
In-season soil N measurements	
In-season soil water measured	
	Diverse N, water, soil traits

Boote et al. 2015

Quantitative data classification scheme and software

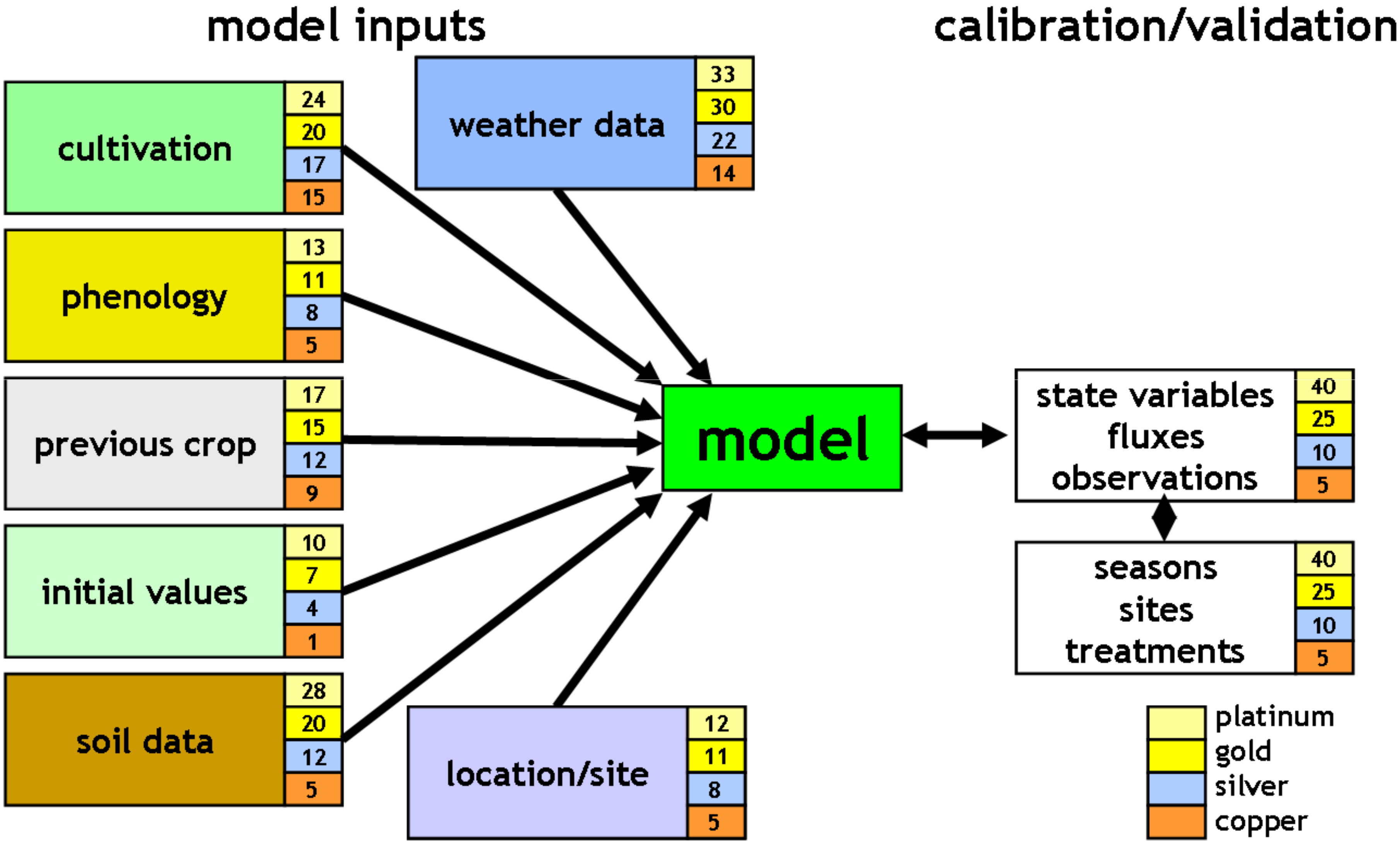
Aims

- Provide a platform to evaluate data set suitability for modelers to use data for different modelling purposes
- Give information on minimum requirements for data for crop modelling
- Disseminate the data requirements of modellers to experimentalists
- Demonstrate the added value of single measurements to improve data set ranking
- Show critical criteria for specific measurements to ensure their quality
- allow quick evaluation on data set suitability out of a large population of data sets

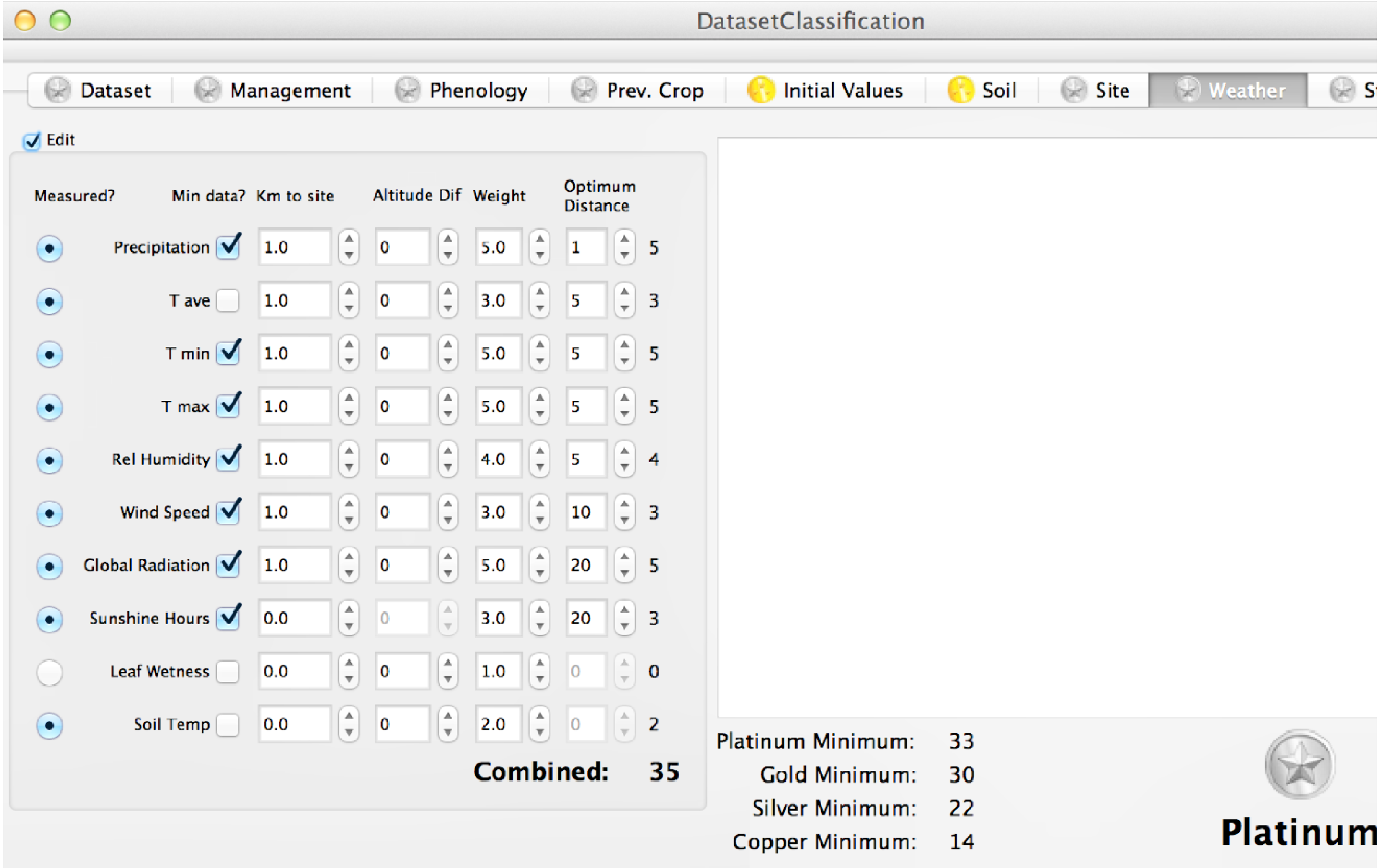
Software available under:

ftp://tran.zalf.de/pub/out/lsa/kersebaum/DatasetRanker.zip

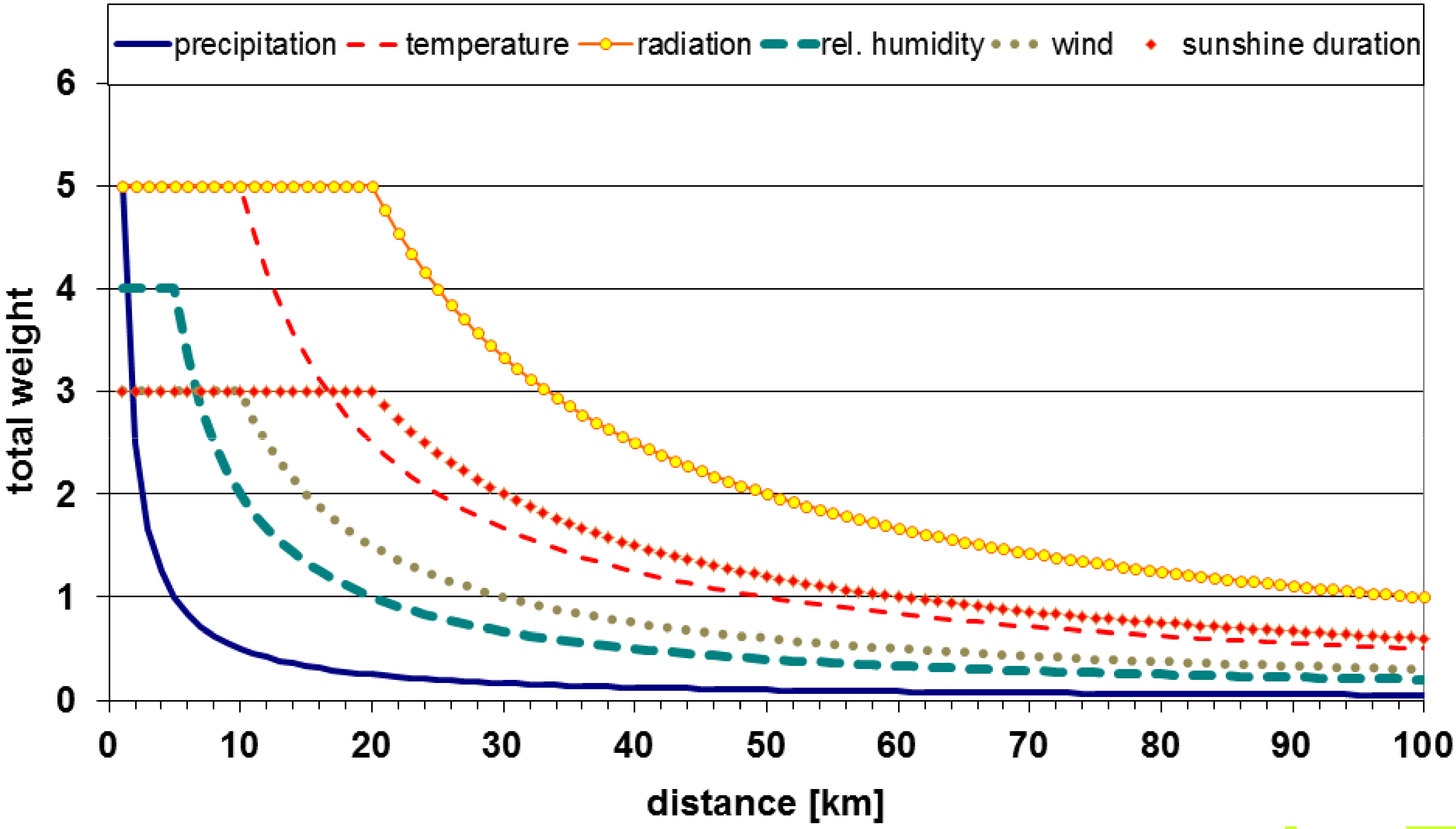
Data classification blocks



Data classification block weather data

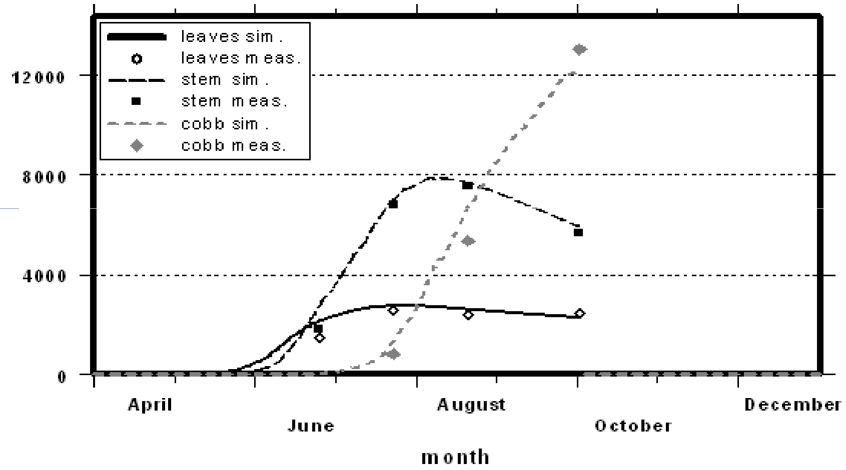


Decreasing weight for weather variables with distance

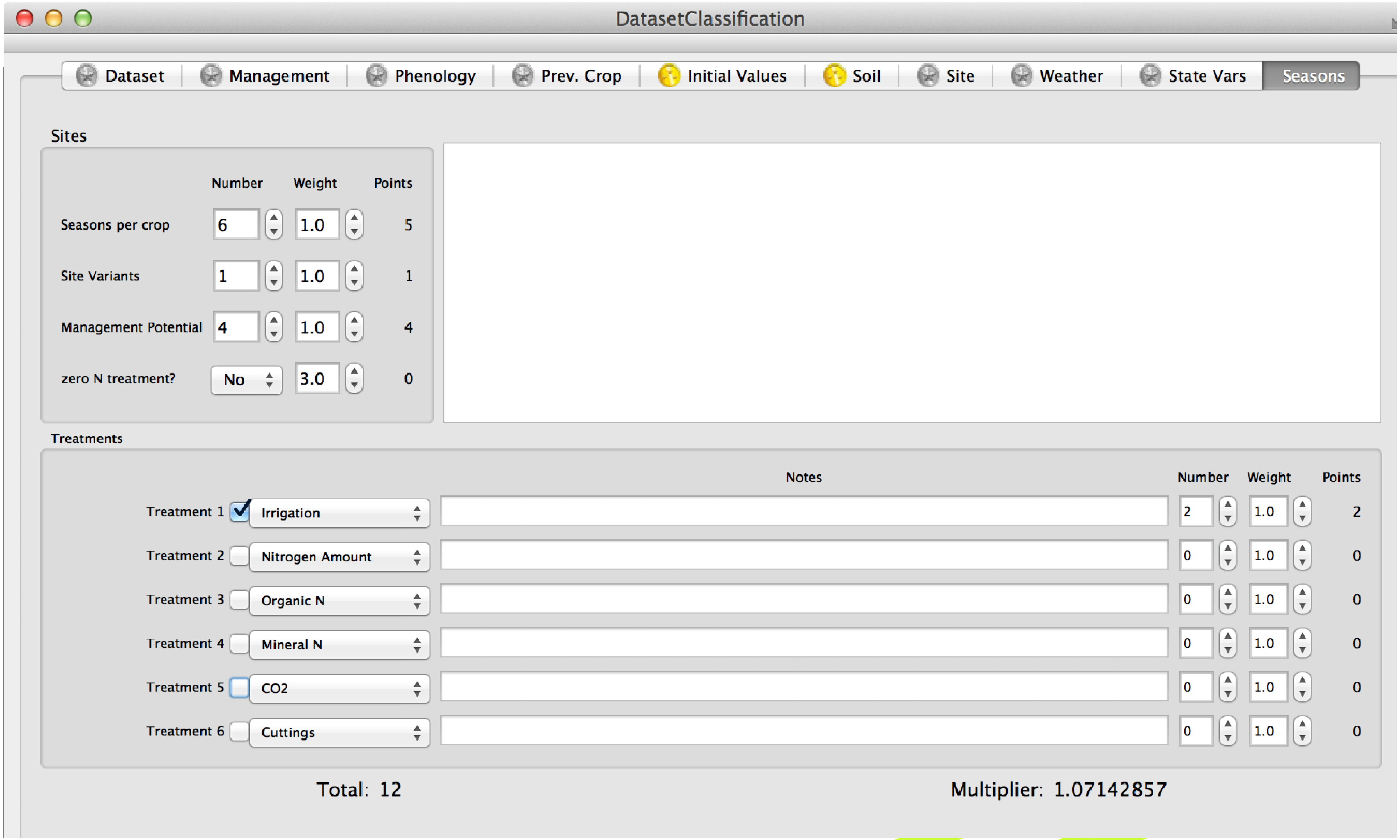


Data classification block calibration/validation data

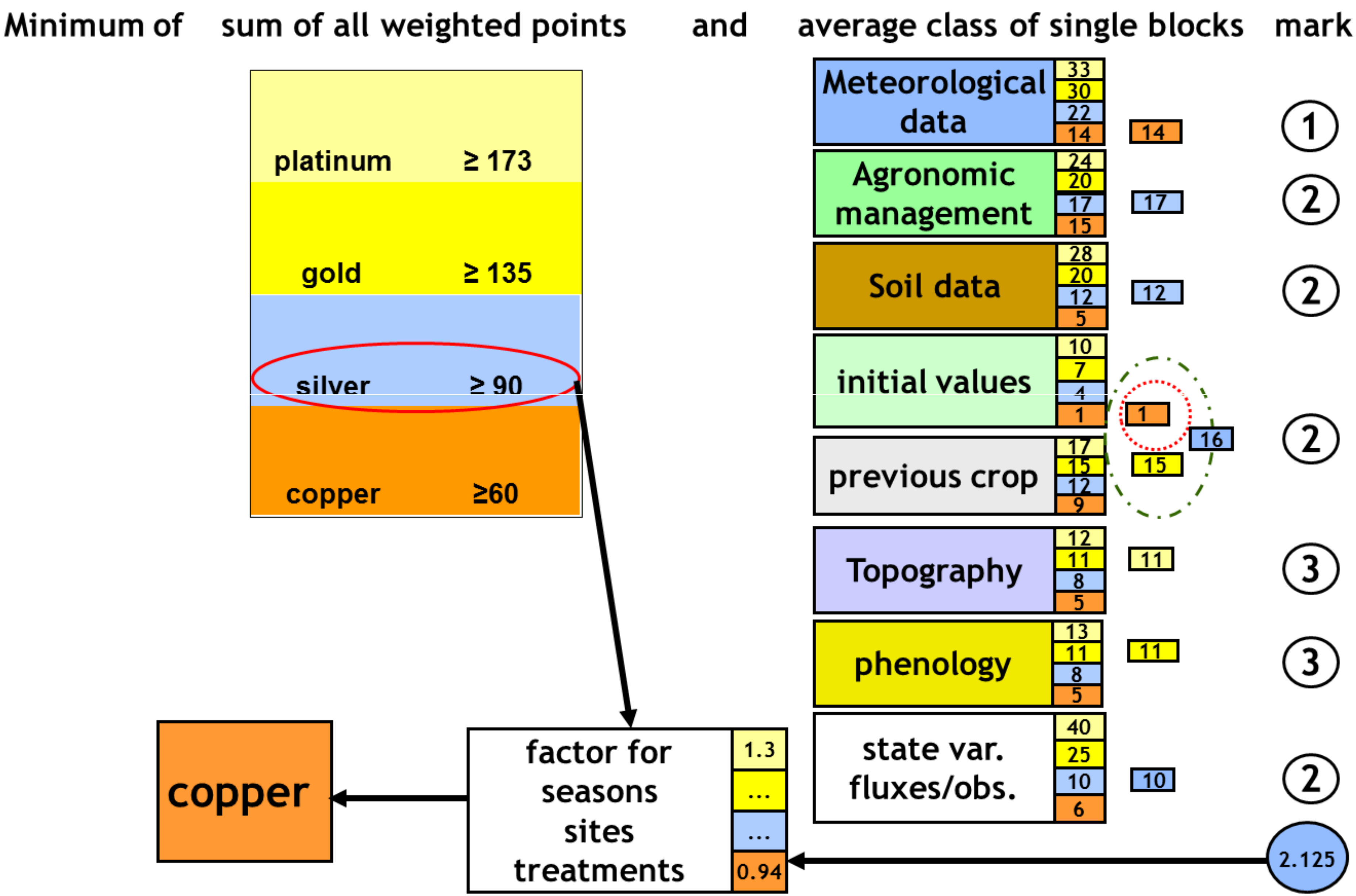
Variable	Relevance	Weight condition	Factor for total weight	Maximum weight
Phenology				
Emergence	3	0/1	0/1	3
Tillering/stem elong./other	2	0/1	0/1	2
Ear emergence/other	2	0/1	0/1	2
Flowering#/other	5	0/1	0/1	5
Maturity/other	3	0/1	0/1	3
Crop growth				
Yield	5	0/1	+MIN(no.repl.-1)*.05);1)	6
Above ground biomass	4	0/1	*MIN(no. observ/3;1.25) *MIN(no. Replic/3;1.2)	6
Weight single organs (leaves, stems, etc.)	3	0/1	*MIN(no. organs/3;1.25) *MIN(no. observ/3;1.2) *MIN(no. Replic/3;1.1)	4.95
Root biomass	3	0/1	dto.	4.95
Nitrogen in above ground biomass	3	0/1	*MIN(no. observ/3;1.25) *MIN(no. Replic/3;1.2)	4.5
Nitrogen in single organs	3	0/1	*MIN(no. organs/2;1.25) *MIN(no. observ;1.2) *MIN(no. Replic/3;1.1)	4.95
Leaf area index	4	0/1	*MIN(no. observ/3;1.25) *MIN(no. Replic/3;1.2)	6
Soil				
Soil water gravimetric	3	0/1	*MIN(no. depths/3;1.25) *MIN(no. observ/5;1.2) *MIN(no. replic/3;1.1)	4.95
Pressure heads	2	0/1	*MIN(no. depths/3;1.25) *MIN(no. observ/20;1.2) *MIN(no. replic/3;1.1)	3.3
Soil mineral nitrogen	3	0/1	*MIN(no. depths/3;1.25) *MIN(no. observ/3;1.2) *MIN(no. replic/3;1.1)	4.95
Soil water calibrated sensor	3	0/1	*MIN(no. depths/3;1.25) *MIN(no. observ/50;1.2) *MIN(no. replic/3;1.1)	4.95
Deep percolation flux	3	0/1	*MIN(no. obs./10;1.25)	4
Deep nitrogen leaching	2		*MIN(no. obs./10;1.25)	2.5
Surface fluxes				
Evapotranspiration	3	0/1	0/1	3
CO_2 flux (CO_2 exchange)	3	0/1	0/1	3
NH_3 flux (volatilisation)	2	0/1	0/1	2
N_2 flux (denitrification)	2	0/1	0/1	2



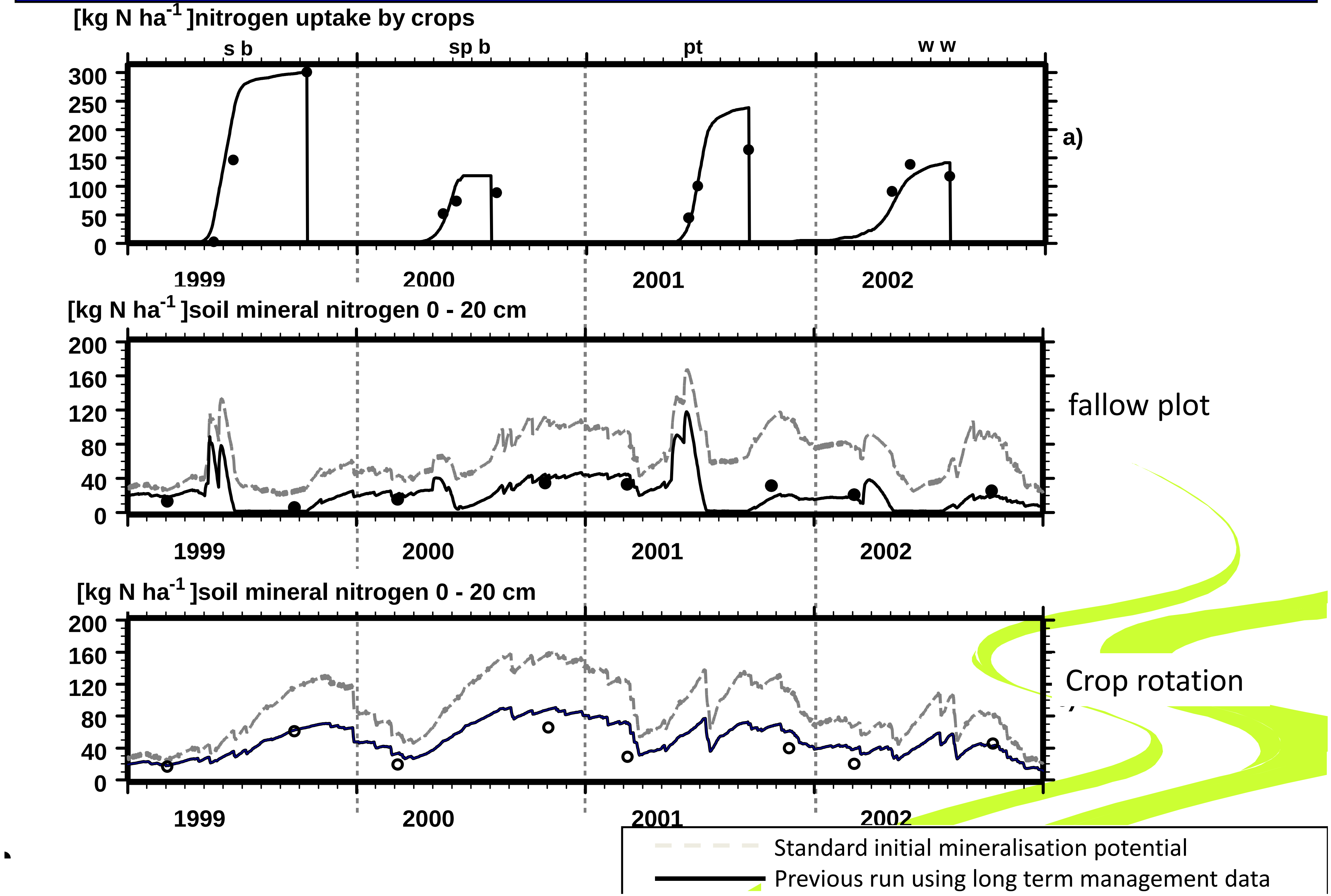
Up/downgrading for multiple seasons/treatments and optimum/minimum conditions



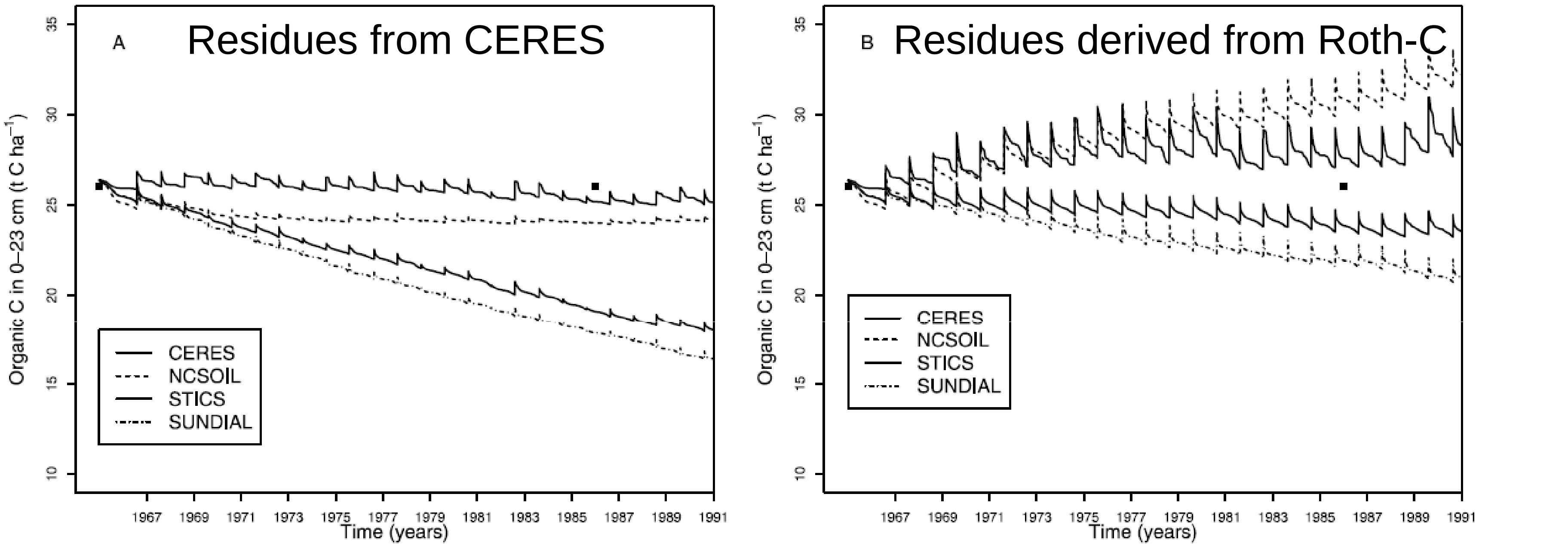
Final classification calculation



Influence of historical management on model performance regarding soil mineral nitrogen.(data Bad Lauchstedt, Franco et al. 2007)



Although showing good performance over shorter periods deviations can be high on a long run



Differences are due to:

- Different pools und temperature/moisture response functions
- Uncertainty regarding the input of crop residues.

Gabrielle al. 2002

Some effects are only detectable over after a long time, e.g. tillage

200 kg N ha $^{-1}$

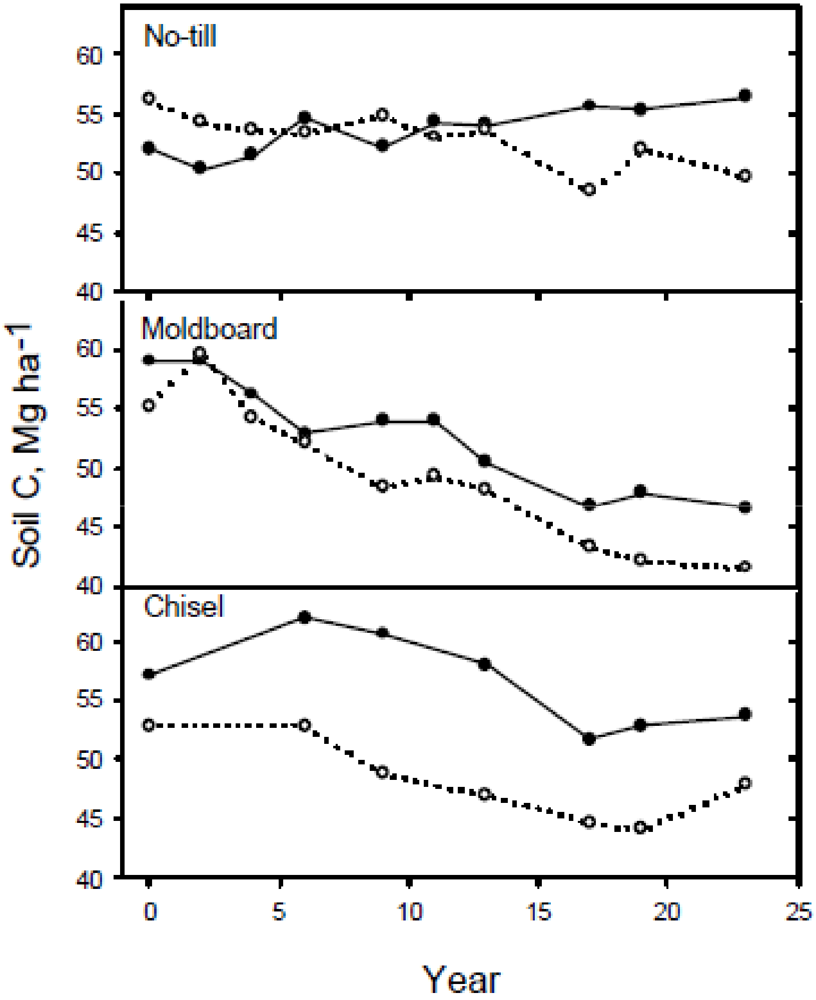


Figure 5 a. SOC at the 0 to 15 cm depth over a 25-year period as influenced by tillage treatments with (–) and without (. . .) stover return.

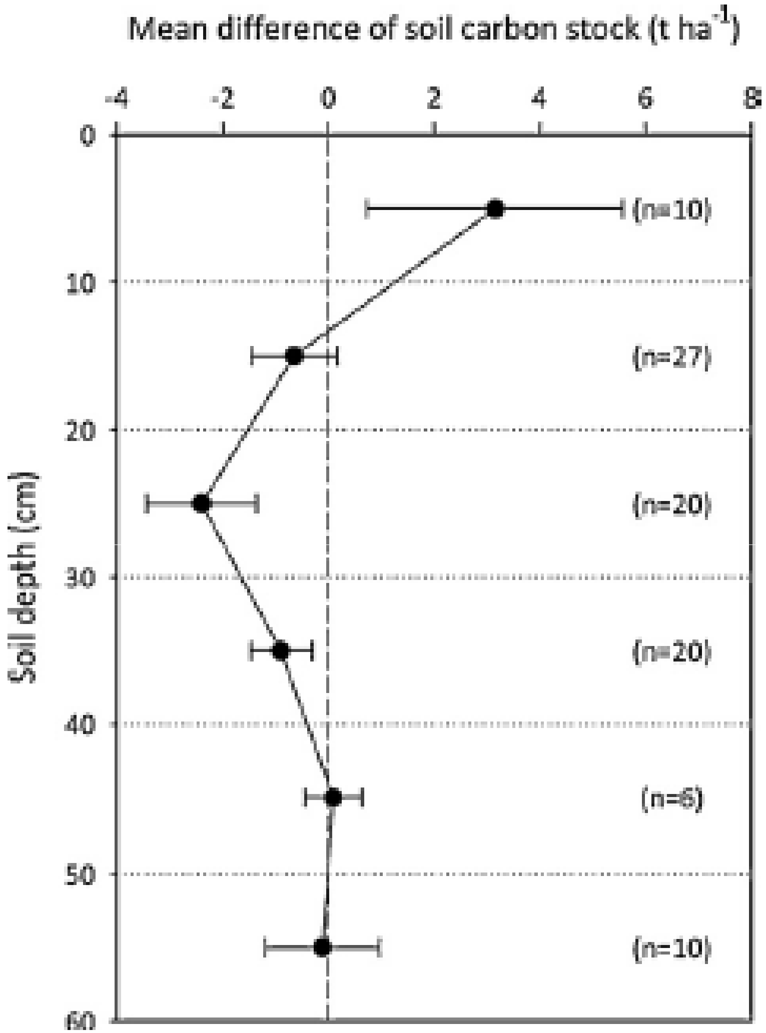
Clapp et al. 2007

Is this the whole story?

What about deeper layers?

How under different climate or soil conditions

Can no-till improve carbon sequestration?



Review of 69 pairwise long term tillage experiments
Average difference of carbon stocks of no-till to conventional ploughed plots.
(**Luo et al. 2010**)

Change to no-till seems not to increase total organic carbon stocks on average

– maybe the increase at thesurface improves some soil funtions (e.g. Infiltration).

Long term effects of tillage may vary between sites

-> requires process understanding and modeling

What is the benefit from long term experiments

- Some of the measures proposed to achieve targets of sustainable development (e.g. 4 per mille) are only visible after long periods.
- Especially soils are very slow in their response to changing management.
- The feed back between changes in management, soil properties and crop production can be detected only after a long period.
- It may take decades to reveal an ongoing negative trend of depletion of a soil’s productivity and it can take an equally long time to restore it and register the degree of recovery.
- It is thus urgent to have access to adequate research and monitoring systems to follow possible changes related to the choice of agricultural land use practices, as well as climatic change.
- Long term experiments are necessary to test and adjust models to make shure that they give the right long term response of measures influencing the development of the future under different boundary conditions.
- Long-term experiments may also be regarded and utilised as monitoring systems reflecting effects of atmospheric pollutants and climatic changes.

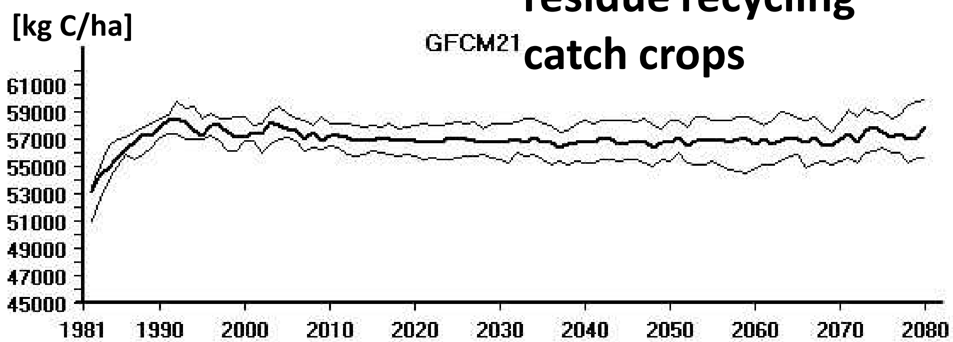
Adapted from Andersson 2007

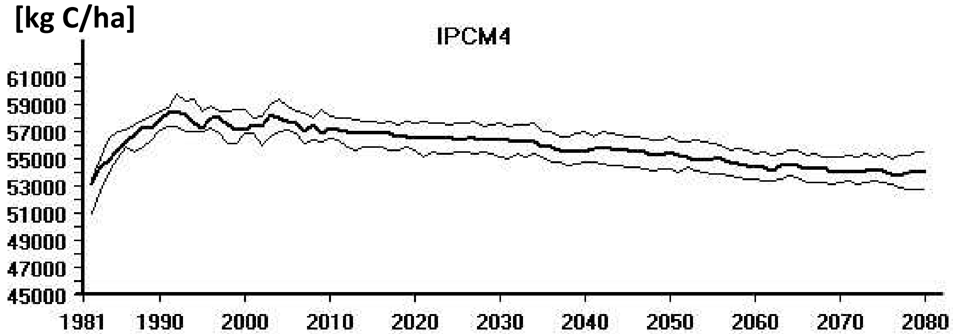
Assessing long-term management effects

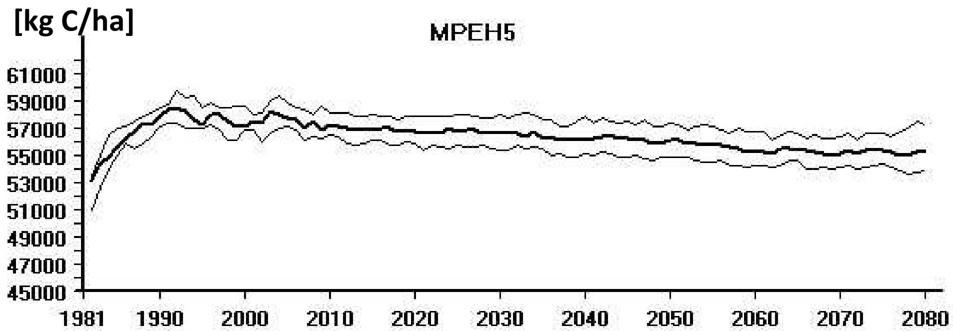
- Climate change may contradict efforts of carbon sequestration

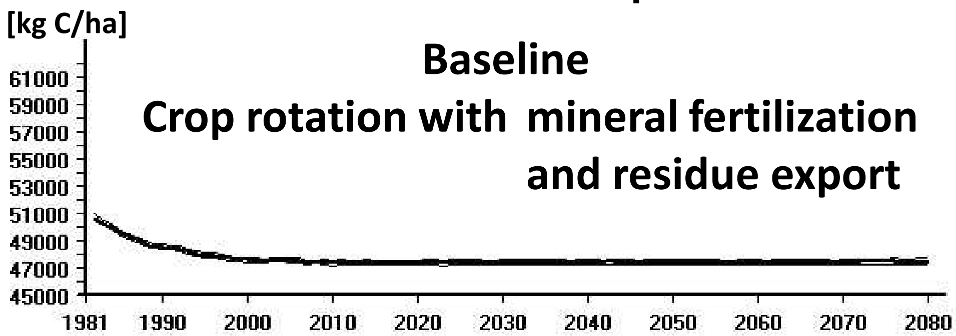
Different climate change scenarios

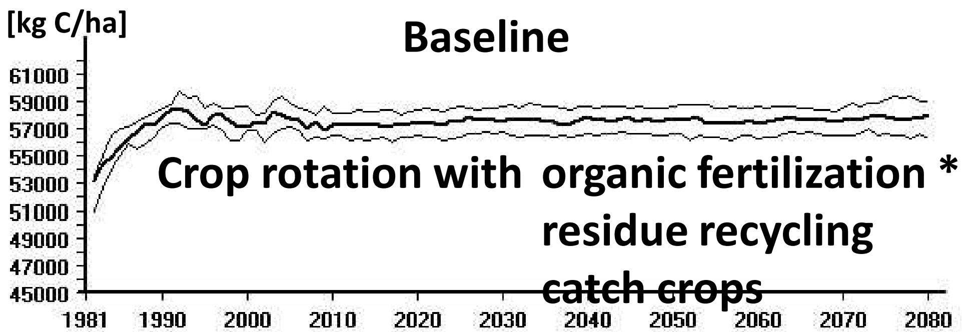
Crop rotation with organic fertilization
residue recycling
catch crops











First results of <u>one model</u> from a model ensemble applied for a site in Czechia

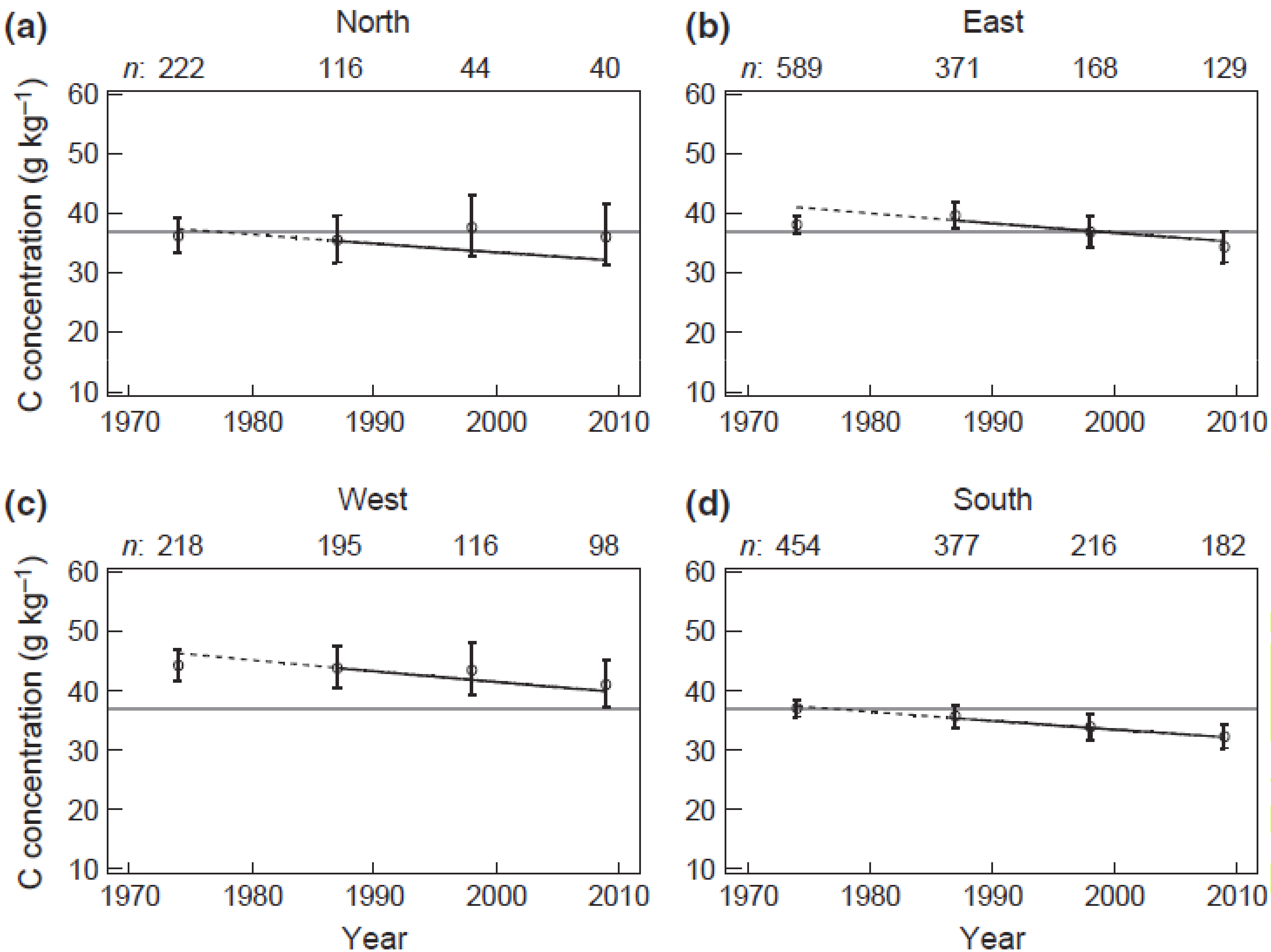
*** Measures proved to increase SOC in Denmark**

However, potential for C sequestration was assessed to be low
(Taghizadeh-Toosi & Olesen 2016)

Long term monitoring to detect changes

Soil organic matter stocks are decreasing in many parts of Europe (Smith et al. 2010)

Observed changes in C_{org} contents in Finnish mineral soils between 1974 and 2009



Heikkinnen et al. 2013, Global Change Biol.

How to establish a good long term experiment

Experimental design forms the basis for the possibility to later on harvest high quality and interpretable data. Therefore, a good long term experiment (LTE) should:

- be characterized by a timeless design meeting questions, which may be raised in the future.
- have rather few and basic treatments and include adequate reference plots.
- have enough replicates and allow ad-hoc studies, which may need soil sampling possibilities, e.g. enough plot size.
- have an experiment administration that guarantees the continuity of the long-term experiments, i.e. a well described plot treatment plan, a solid data archive system where the individual data is easily identified also for outside users. Organisations, where only one person is in charge with the long-term experiments constitute a vulnerable situation regarding their continuity.

Acc. To Andersson 2007

Deficits and requirements for improvement (outcome of MACSUR activities so far)

- Various crops within rotations are still not sufficiently parametrized (Kollas et al 2015) **-> better/more data sets required**
- Improve crop models to better capture **extremes -> develop new stress functions and link to probabilistic approaches (Trnka et al. 2015) -> requires data (deficit of experimental failure and spatial damage monitoring!)**
- Improve crop model by linking pest & disease models -> **data of P&D pressure and damages -> requires link of data from different scientific fields**
- Complement knowledge from crop models with **empirical crop-weather** analysis **-> meta-analysis of big data**
- Consider **management variables** in simulations to evaluate **adapation and mitigation** options **-> site specific and long-term experiments**
- **Landscape hydrology and multi-sectoral water demand needs to be considered to assess water availability for agriculture. -> link to geo-data required**
- **Modelers and experimentalist need a closer cooperation designing and operating experiments.**
- **Experiments, which cannot be used for modelling are to some extent wasted money, since the results cannot be compared or extrapolated to other conditions**
- **Data may exist at many locations, but are often not accessible!**
- **Developing of an open European (world) database for model development needed**
- **Creating a spatial monitoring network and data access for relevant inputs would be very useful.**

Thank you

for your attention

LTER plot Hickory corners, MI, USA
DL Science Societies of America

All models are wrong,
some models are useful G.E.P.Box, 1979