Analysis of Standard Designs Using Spatial Models

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1. Introduction
2. Material and Methods
3. Results and Discussion
4. Conclusion

1. Introduction

Standard designs (German: Standardanlage)

Adolf Zade
(1880-1949)

- have so far been used
  although widely accepted basic principles
  in the planning of experiments are violated

- specific standard design: „**Langparzellenanlage**“ / **Zade method**,
  developed by Adolf Zade (1924)

Alois Mudra
(1907-1995)

Mudra (1949):

„Die Langparzellenanordnung ist die in Deutschland am häufigsten angewandte Versuchsmethode.“

Trials with an arrangement of plots in long stripes are used most frequently in Germany.

„Langparzellenanlage“
Zade method

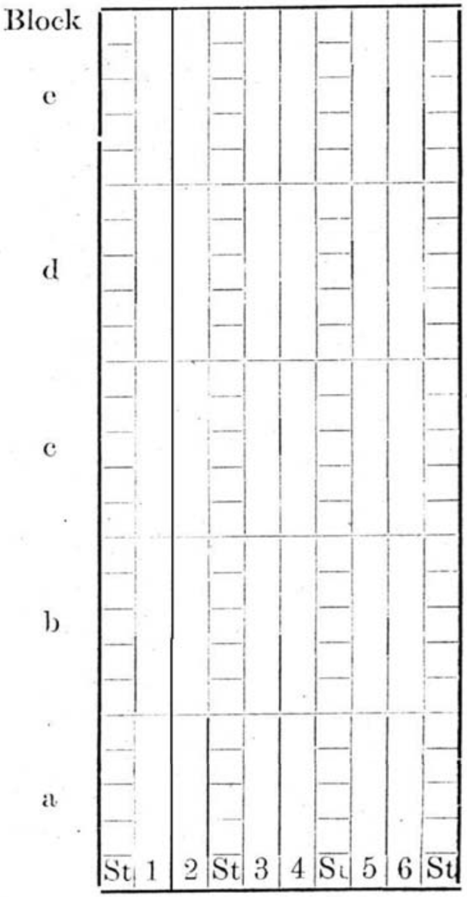
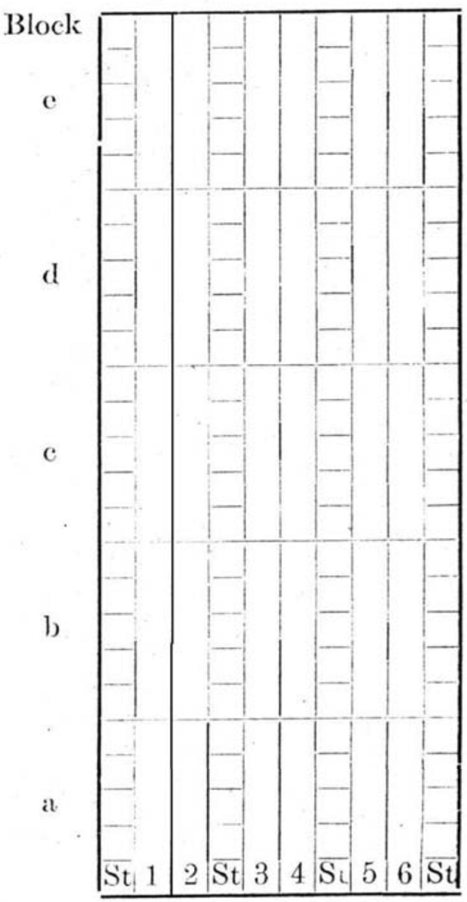


Abb. 6. Langparzellenanordnung. 6 Prüfnummern in 5 Wiederholungen

Layout from Mudra (1949)

„Langparzellenanlage“ Zade method



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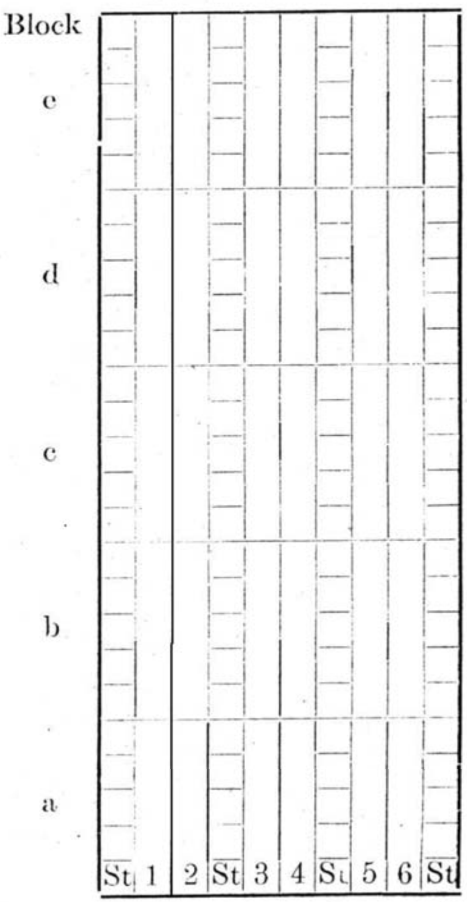
Layout from Mudra (1949)

Characteristics:

- systematic arrangement of treatments, between plots of a control treatment (= standard plots)
- standard plots serve as
  → control of soil heterogeneity
  → reference treatment
- stripes are divided into several (pseudo)replications

„Langparzellenanlage“ Zade method



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Advantages:

- simple technological demands for
  - → specific treatments
  - → on-farm trials

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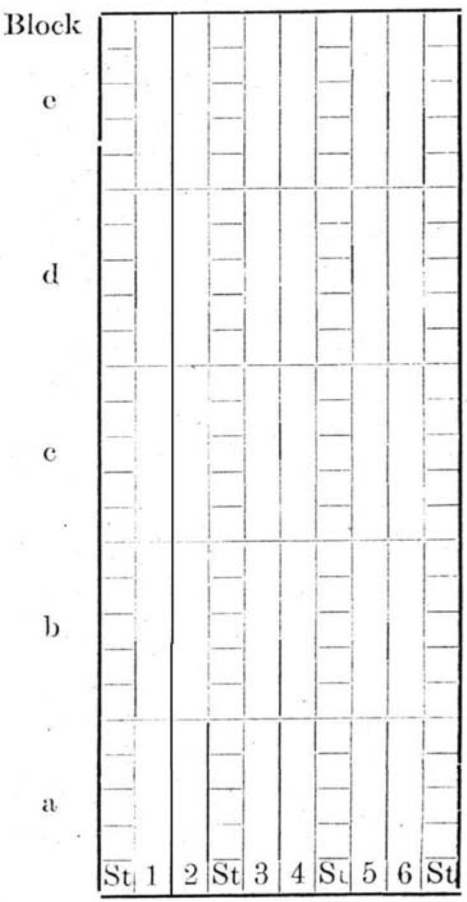

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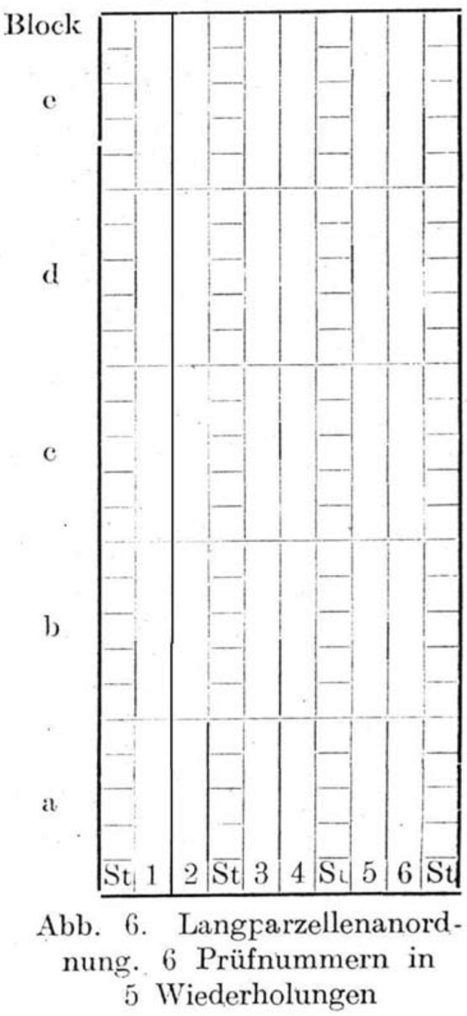
Advantages:

- simple technological demands for
  - → specific treatments
  - → on-farm trials

Disadvantages:

- no randomization
- pseudo-replications
- large area occupied by standard plots

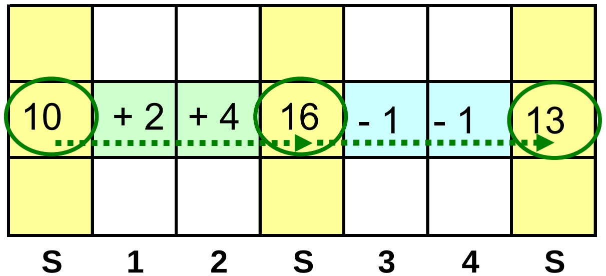
„Langparzellenanlage“ Zade method



Layout from Mudra (1949)

Basic idea to control soil heterogeneity:

1. local linear trend between neighboring standard plots
   → separate adjusting procedure for each treatments value
   → separate final analysis
   (e.g. Mudra 1949)



Problem:

• observed values for standard plots are not regarded as random values

„Langparzellenanlage“ Zade method

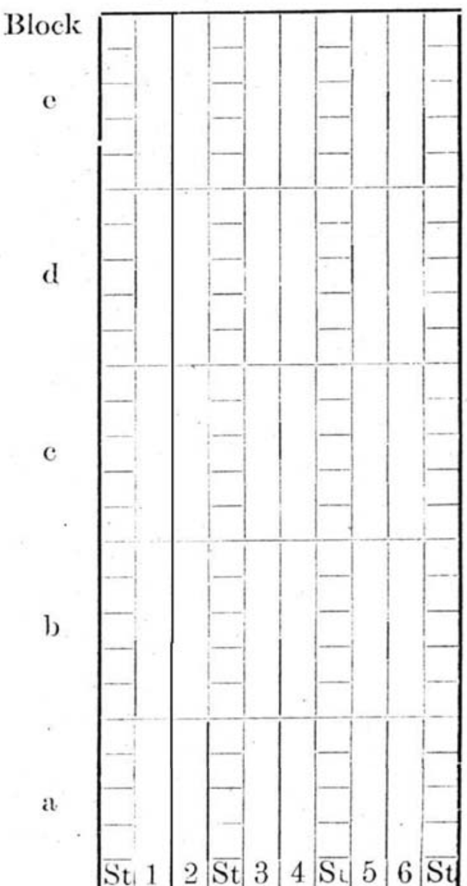


Abb. 6. Langparzellenanordnung. 6 Prüfnummern in 5 Wiederholungen

Layout from Mudra (1949)

Basic idea to control soil heterogeneity:

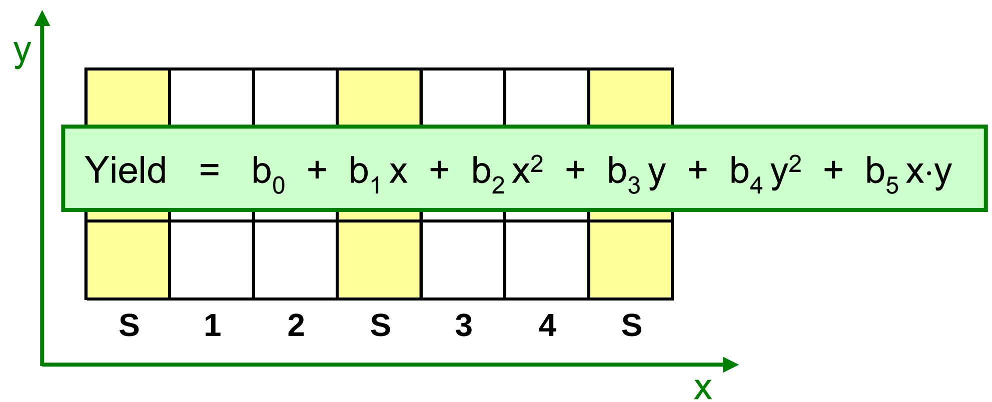
2. large-scaled polynomial trend function

   calculated from the standard plots

   → separate adjustment of each treatment value

   → separate final analysis

   (e.g. Thomas and Stressmann 1972)



Problem *(both 1 and 2):*

- spatial dependency caused by missing randomization not taken into account

„Langparzellenanlage“ Zade method

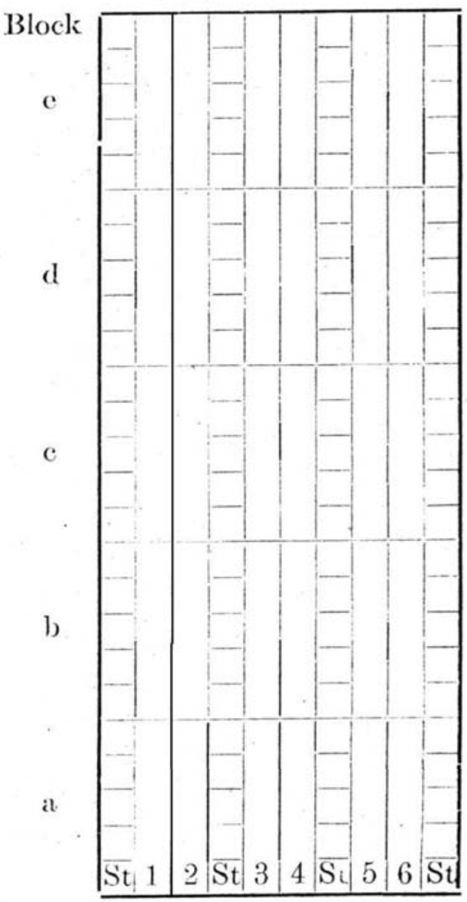


Abb. 6. Langparzellenanordnung. 6 Prüfnummern in 5 Wiederholungen

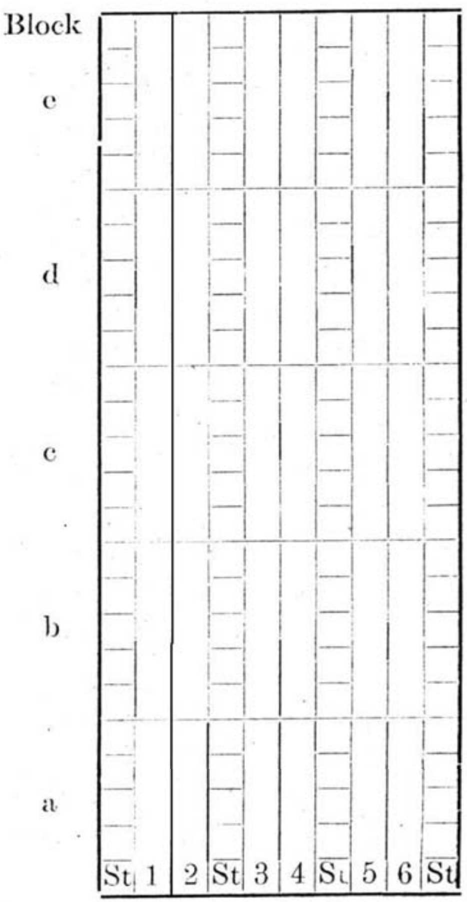
Layout from Mudra (1949)

Basic idea to control soil heterogeneity:

3. small-scaled and / or large-scaled dependency

→ integration into the final model for all observations

„Langparzellenanlage“
Zade method



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Layout from Mudra (1949)

Basic idea to control soil heterogeneity:

3. small-scaled and / or large-scaled dependency

→ integration into the final model for all observations

Objective:

Demonstration for a crop rotation experiment

(Standard design - Zade method)

→ selection of best fitting model for the final analysis

→ separate consideration of

- small-scaled dependency
- large-scaled dependency
- or combination of both ?

→ characteristic model for certain situations?

2. Material and Methods

Long-term experiment:

- located on the diluvial site Gülzow (North-Eastern Germany)
- crop rotation with 4 crops on 4 different fields per year

winter rape - **winter wheat** - **potato** - **winter barley**

- 11 treatments (P and K fertilization; standard = no fertilization)
- yields from first 2 rotations:

	1st rotation				2nd rotation			
field	1998	1999	2000	2001	2002	2003	2004	2005
1	B	R	W	P	B	R	W	P
2	P	B	R	W	P	B	R	W
3	W		B	R	W	P	B	R
4	R	W	P	B	R	W	P	B

→ 31 single trials

(focus of our paper: analysis per trial)

- layout for all fields

Standard design Zade method *(„Langparzellenanlage“)*

S	6	S	7	S	8	S	9	S	10	S
S	6	S	7	S	8	S	9	S	10	S
S	6	S	7	S	8	S	9	S	10	S
S	6	S	7	S	8	S	9	S	10	S

S	1	S	2	S	3	S	4	S	5	S
S	1	S	2	S	3	S	4	S	5	S
S	1	S	2	S	3	S	4	S	5	S
S	1	S	2	S	3	S	4	S	5	S

9 m

9 m

<u>treatments:</u>

S = standard treatment
(no fertilization)

1 … 10 = P and K fertilization

<u>harvested plot area</u>:

1.5 m x 9 m

Data analysis - model classes *(SAS 9.1.3 - Proc MIXED)*

(0) 1 basic model (model without trend and spatial correlation)

(1) 22 spatial models:

6 isotropic: exponential (exp = pow), spherical (sph), linear (lin), log linear (linl), mátern (matern), gaussian (gau)

5 anisotropic: several exponential approaches (powa, expa, expga), spherical (sphga), Gaussian (gauga) anisotropic

all with / without nugget

(2) 31 (large-scaled) trend models:

polynomial functions of the x- and y-coordinates of the plots

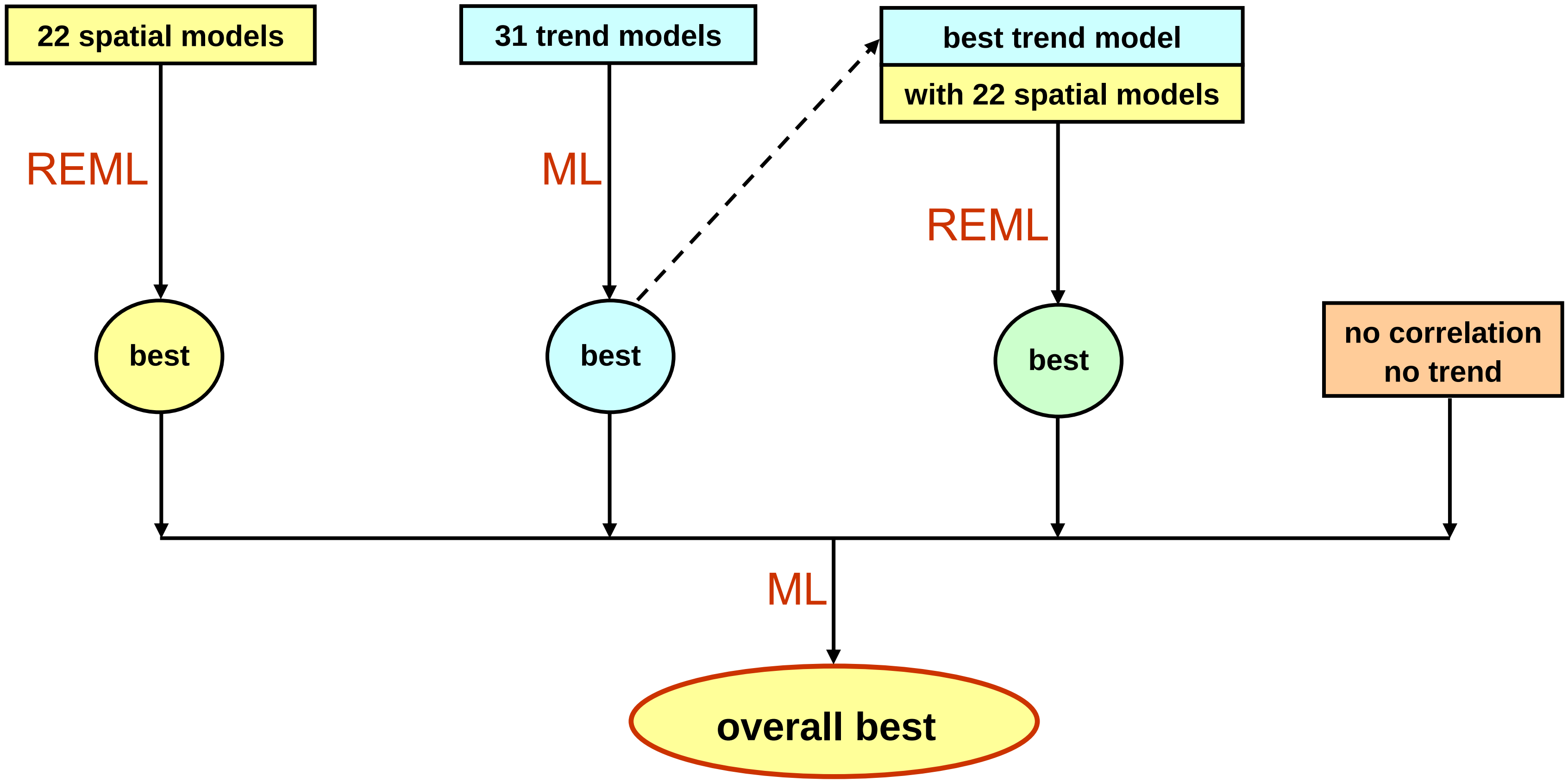
with x, y, x^2, y^2, $x \cdot y$ and all possible subsets

(3) Combination of trend and spatial models

22 spatial models x 31 trend models = 682 combined models possible!

Steps of the analysis to select the best fitting model for each of the 31 trials

Model fit criterion: AICC (Akaike's Corrected Information Criterion)



Example: **winter wheat on field 1 / year 2000**

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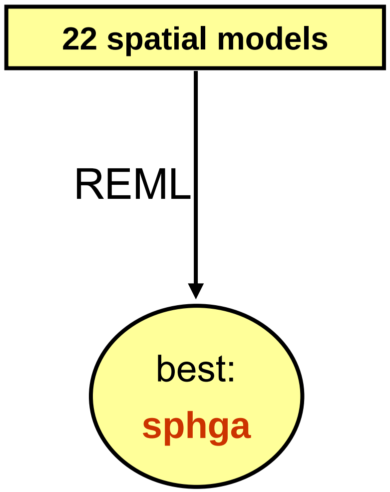

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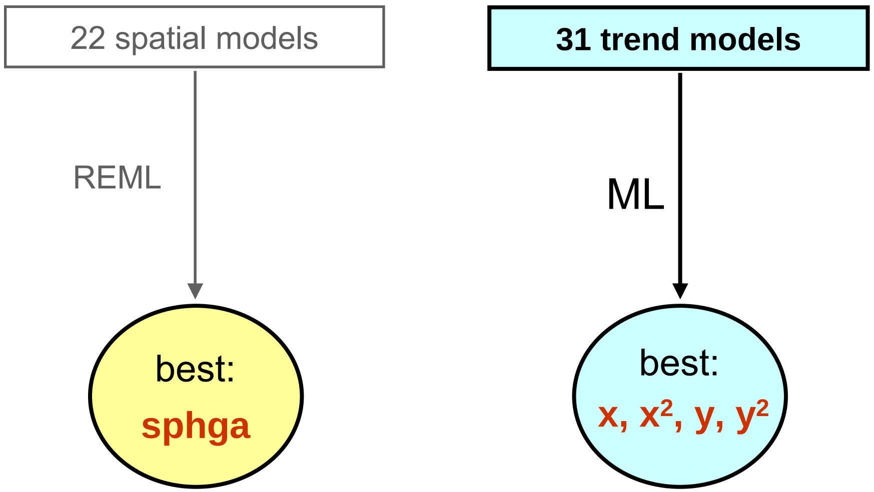

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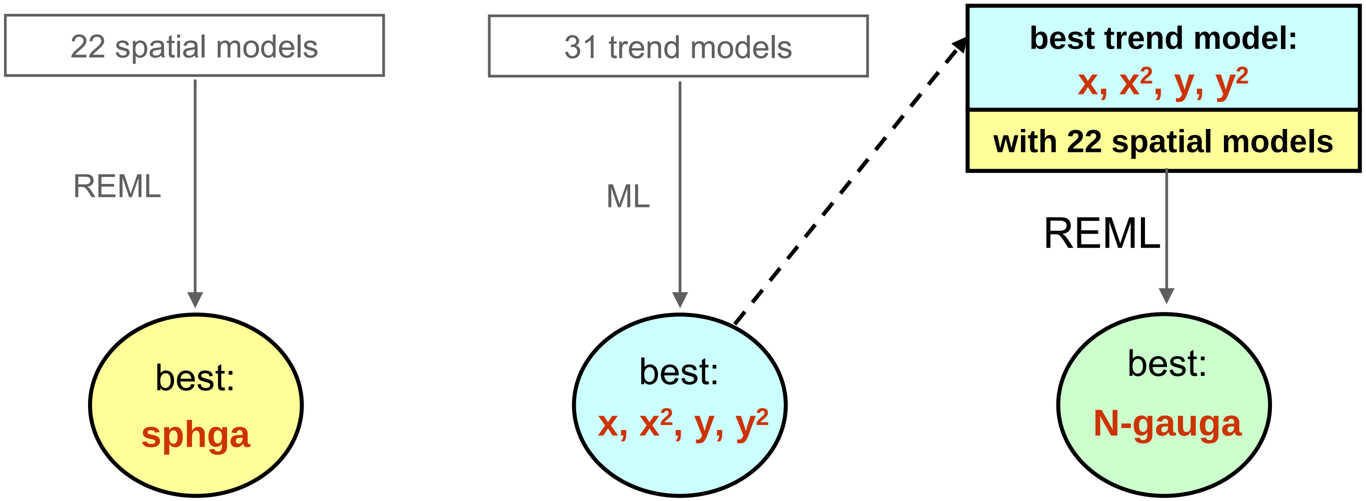

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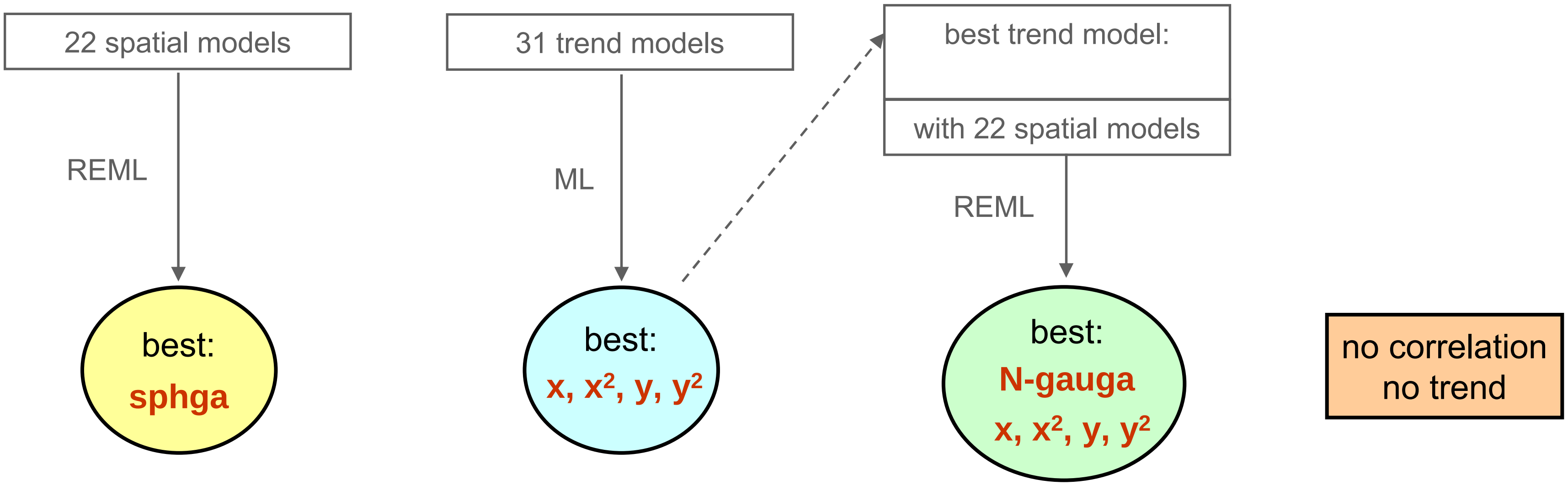
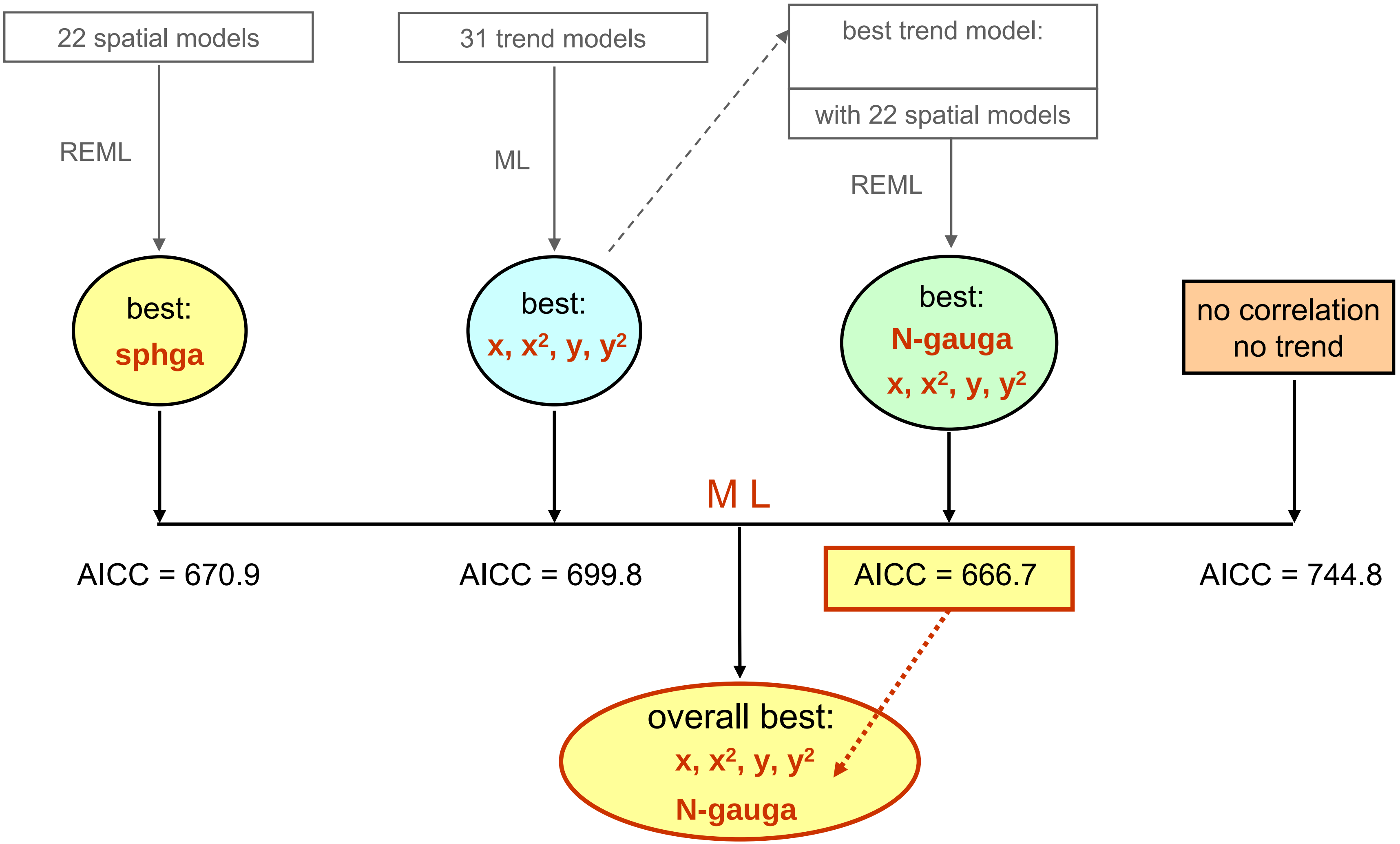


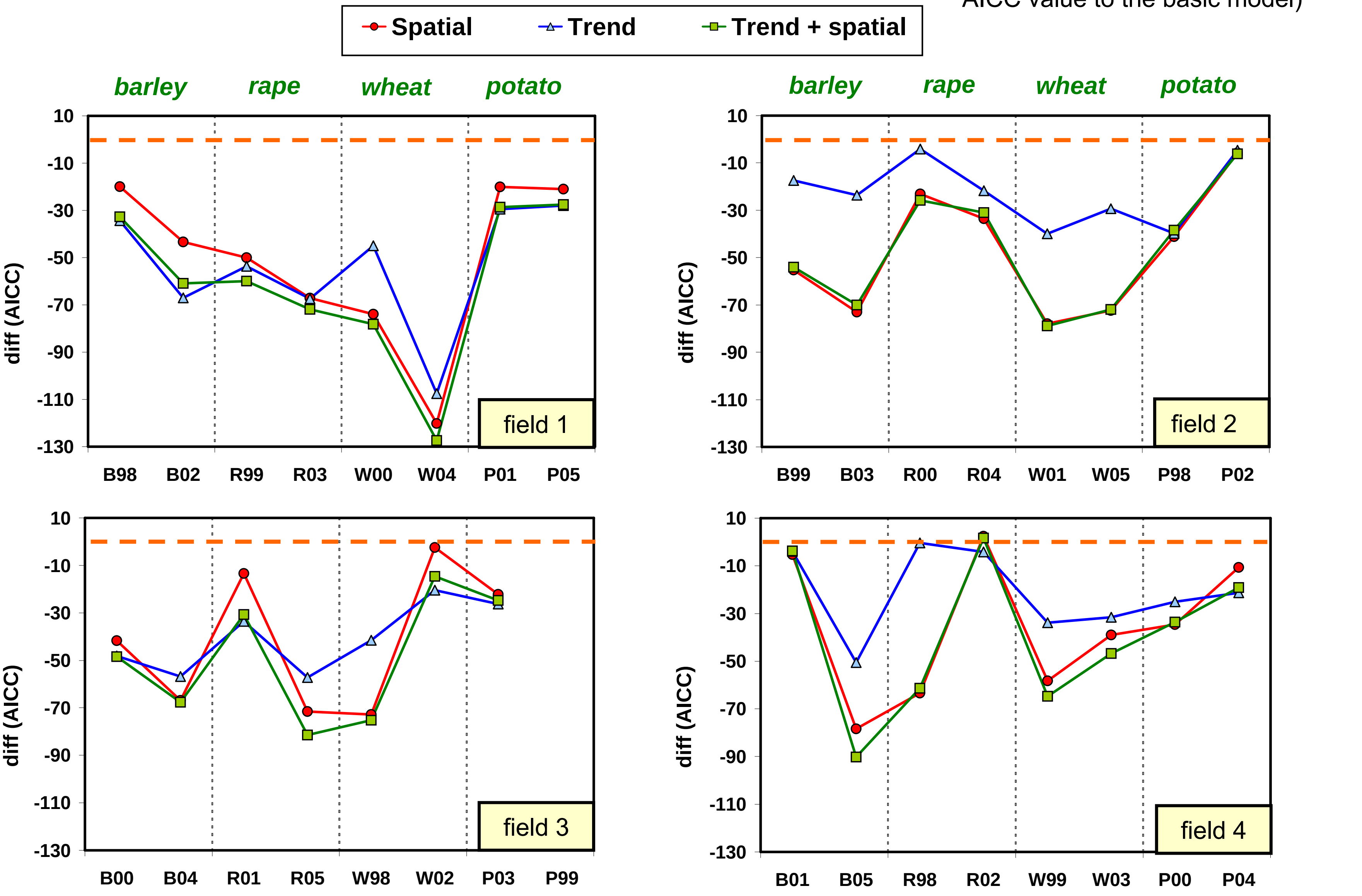
Example: winter wheat on field 1 / year 2000



3. Results and Discussion

- **Model gain for all model classes and each single trial**

(model gain: difference of the AICC value to the basic model)



Typical characteristics for fields / crops?

- **Model preference**

Model class	number of overall best fitting models Σ
Basic	0
Spatial	8
Trend	9
Trend + spatial	14
	31

Typical characteristics for fields / crops?

- **Model preference**

number of overall best fitting models

Model class	Σ	Field 1	Field 2	Field 3	Field 4
Basic	0	0	0	0	0
Spatial	8	0	5	0	3
Trend	9	4	0	3	2
Trend + spatial	14	4	3	4	3
	31	8	8	7	8

Typical characteristics for fields / crops?

- **Model preference**

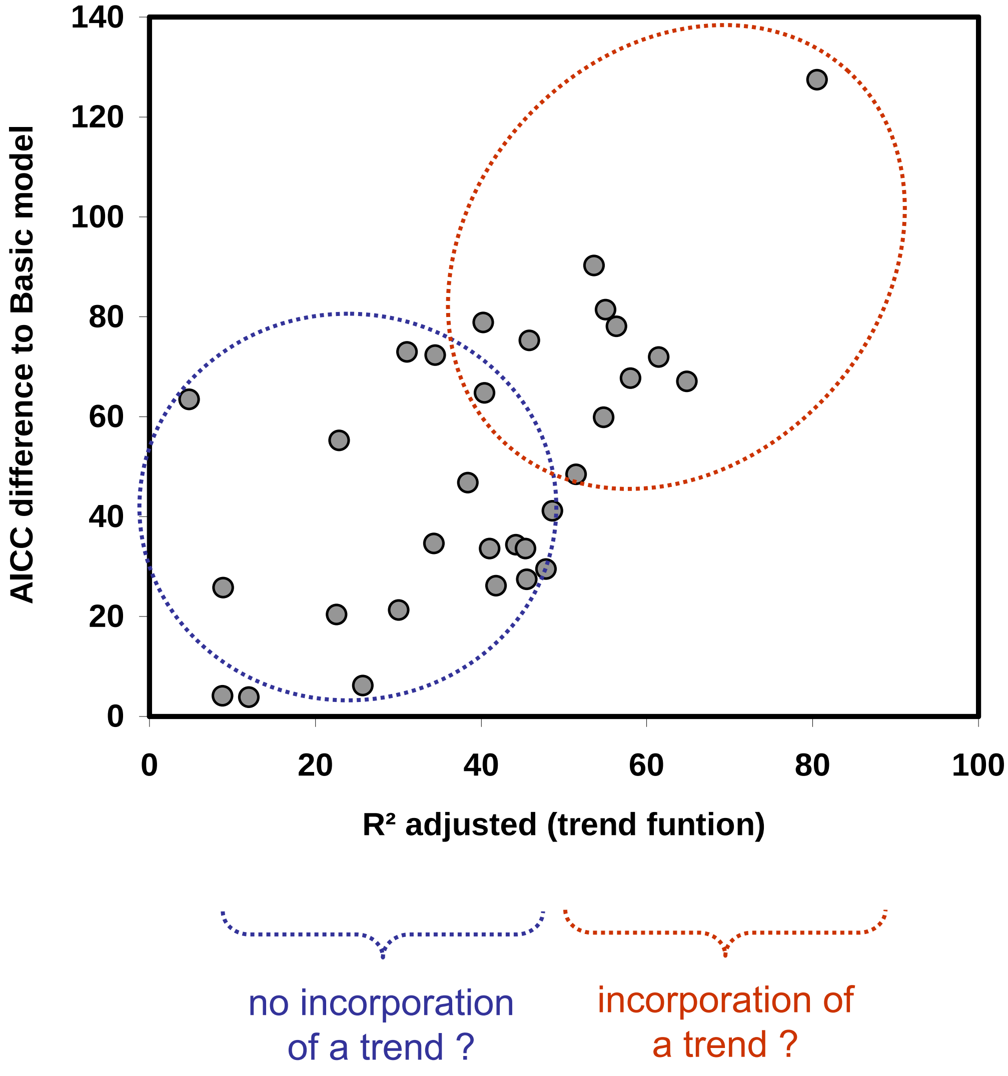
	number of overall best fitting models					mean rank of the AICC values			
		Field				Field			
Model class	**Σ**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Basic	**0**	0	0	0	0	4	4	4	3.8
Spatial	**8**	0	5	0	3	2.8	1.4	2.6	2
Trend	**9**	4	0	3	2	1.8	2.9	2	2.4
Trend + spatial	**14**	4	3	4	3	1.5	1.8	1.4	1.9
	31	**8**	**8**	**7**	**8**				

per trial: ranking of best fitting models

1 = model class with best fit
:
4 = model class with worst fit

- **Relation between R^2 of best fitting trend function and preference for a model class?**

(n = 31 trials)



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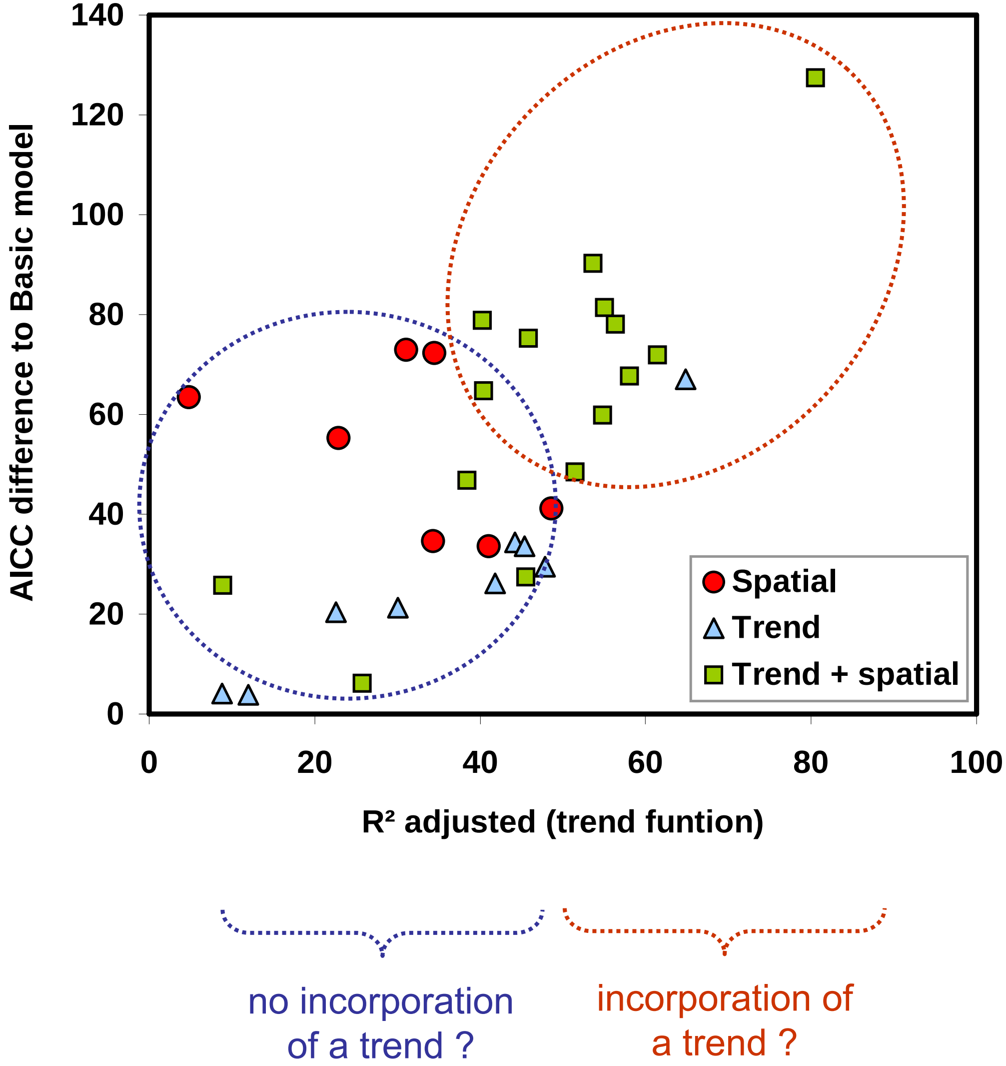
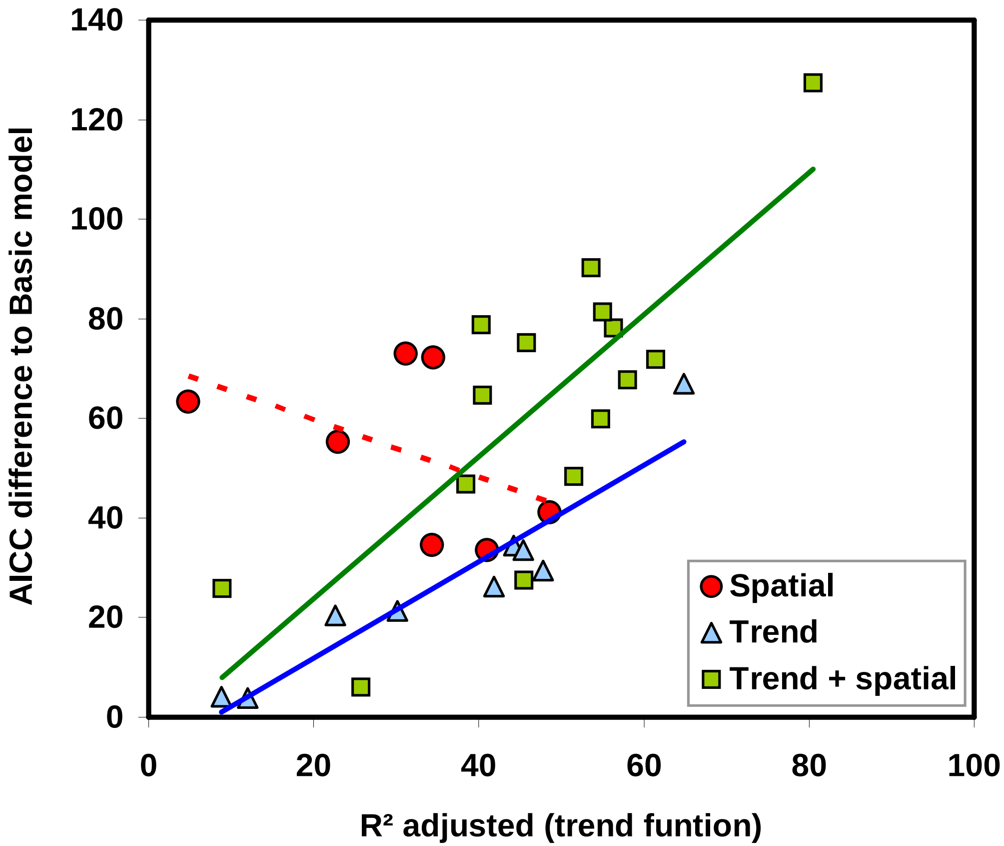


- **Relation between R^2 of best fitting trend function and preference for a model class?**

(n = 31 trials)

per trial:
model gain of the „overall best fitting model“



per trial: fit of best fitting trend function

- **Consistency of large-scaled trends:**

→ correlation between predicted plot yields of best fitting trend functions

Example:

wheat 2000 (field 1): $-0.857\,x + 0.0088\,x^2 - 0.828\,y + 0.0106\,y^2$

↕

wheat 2004 (field 1): $-0.478\,x + 0.0068\,x^2 - 0.488\,y + 0.0073\,y^2$

0.947

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Correlation coefficients between predicted plot yields (trend function)

Crop	Field 1	Field 2	Field 3	Field 4
Barley - Barley	**0.930**	**0.816**	**0.746**	**0.816**
Rape - Rape	**0.838**	0.294	**0.955**	0.000
Wheat - Wheat	**0.947**	**0.972**	0.439	**0.854**
Potato - Potato	**0.952**	0.488	none	0.360

red: $r > 0.9$
green: $r > 0.75$

• Consistency of spatial model type

both model classes show:
- same isotropy (10 trials)
- same anisotropy (17 trials)
- different behavior (4 trials)

Field	Model class	rape		wheat		barley		potato	
1	Spatial	pow	sphga	sphga	sphga	N_powa	N_lin	pow	expga
	Trend + spatial	gau	powa	N_gauga	sphga	lin	powa	gau	gauga
2	Spatial	gauga	sphga	matern	expa	powa	sph	N_sphga	linl
	Trend + spatial	gauga	sphga	sph	N_gauga	powa	sph	pow	pow
3	Spatial	pow	sphga	powa	pow	lin	sphga	N_sph	
	Trend + spatial	lin	sphga	powa	expa	pow	sphga	N_sph	
4	Spatial	N_powa	gauga	gauga	gauga	sphga	gauga	pow	N_lin
	Trend + spatial	N_powa	gauga	gauga	gauga	sphga	gauga	pow	lin

- **Converged models (%) depending on parameter initialization**

model	without nugget		with nugget	
	no p.i.	p.i.	no p.i.	p.i.
pow	100	100	81	87
powa	100	100	84	97
expa	97	100	39	61
expga	48	97	19	87
sph	100	100	81	94
sphga	42	94	81	94
lin	97	68	58	68
linl	42	19	81	26
matern	71	71	45	48
mathsw	71	71	58	61
gau	3	97	0	94
gauga	0	97	0	94

n = 31 trials;

model class: spatial

no p.i. = no parameter initialization

p.i. = <u>with</u> ~

red: > 80% Convergence

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gauga	0	97	0	94

n = 31 trials;

model class: spatial

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p.i. = with ~

red: > 80% Convergence

4. Conclusion

Finding of special models for certain situations for the final analysis:

(1) consideration of both small-scaled and large-scaled dependency is necessary

→ combined trend + spatial model fitted often best

(2) large-scaled trend

→ frequently similar on the same field

→ model fit of best fitting trend function affects model selection

→ best way of controlling large-scaled trend: blocking!

(3) no specific spatial model type, but

→ anisotropic models are dominant

→ nugget variance seldom

(4) typical behavior

→ of fields: spatial or trend component dominant

→ for crops difficult do derive

Convergence problems:

- parameter initialization often necessary
- difficult to handle in routine data analysis

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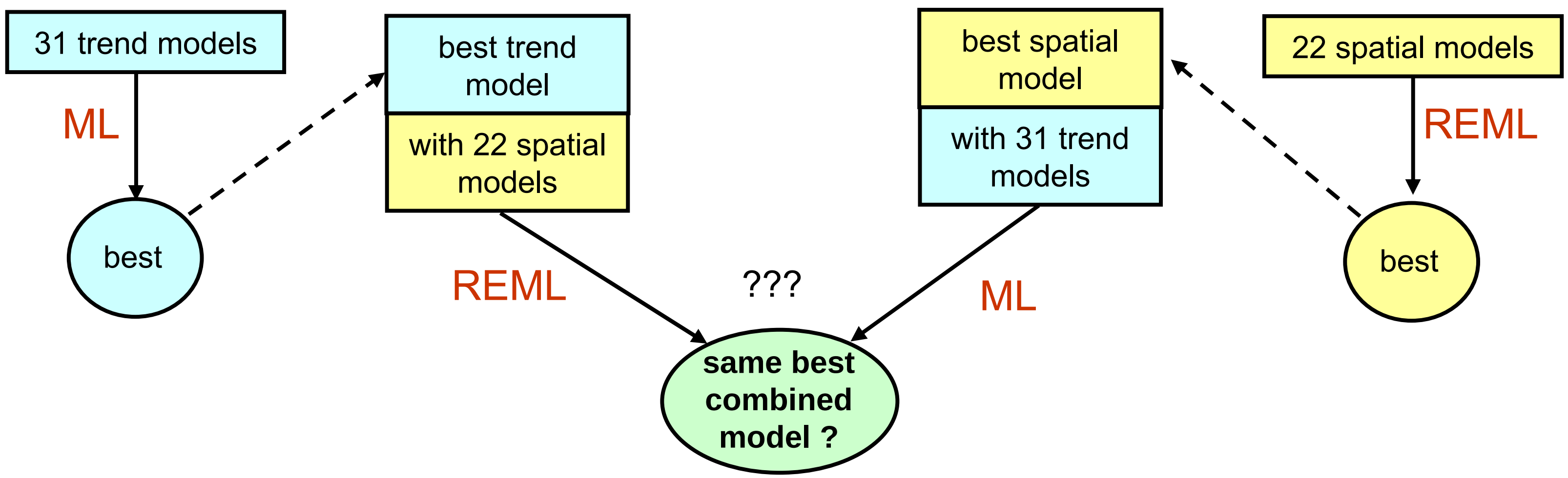
Number of trend and spatial model combinations: 682 *(22 spatial models x 31 trend models)*

→ all calculations hardly possible (necessary parameter initialization due to convergence problems)



Consequences for the choice of the „best overall model“:

Model class	# trials		# trials	*same specific model retained*
Basic	0		0	
Spatial	8		3	*3*
Trend	9	5	9	*9*
Trend + Spatial	14		19	*4*
Spatial + Trend	-			-
	31		31	*16*

Field 1:

Model class	Barley 98	Rape 99	Wheat 00	Potato 01
Spatial	N_powa	pow	sphga	pow
Trend ***R^2 adj.%***	x^2, y, y^2 ***44.2***	x, x^2, y, xy ***54.8***	x, x^2, y, y^2 ***56.3***	x, y^2 ***47.8***
Trend + spatial	x^2, y, y^2 lin	x, x^2, y, xy gau	x, x^2, y, y^2 N_gauga	x, y^2 gau

Model class	Barley 02	Rape 03	Wheat 04	Potato 05	Σ
Spatial	N_lin	sphga	sphga	expga	*0*
Trend ***R^2 adj.%***	x, y^2, xy ***64.8***	x^2, y, y^2, xy ***61.4***	x, x^2, y, y^2 ***80.5***	x, y, xy ***45.5***	*4*
Trend + spatial	x, y^2, xy powa	x^2, y, y^2, xy powa	x, x^2, y, y^2 sphga	x, y, xy gauga	*4*

Field 2:

Model class	Potato 98	Barley 99	Rape 00	Wheat 01
Spatial	N_sphga	powa	gauga	matern
Trend *R^2 adj.%*	x, x^2 ***48.6***	x, y, y^2, xy ***28.9***	xy ***8.9***	x, x^2, y, y^2, xy ***40.3***
Trend + spatial	x, x^2 pow	x, y, y^2, xy powa	xy gauga	x, x^2, y, y^2, xy sph

Model class	Potato 02	Barley 03	Rape 04	Wheat 05	Σ
Spatial	linl	sph	sphga	expa	*5*
Trend *R^2 adj.%*	x, x^2 ***25.7***	x, x^2, y, y^2, xy ***31.1***	x, y, y^2, xy ***41.0***	x, x^2, y, y^2, xy ***34.5***	*0*
Trend + spatial	x, x^2 pow	x, x^2, y, y^2, xy sph	x, y, y^2, xy sphga	x, x^2, y, y^2, xy N_gauga	*3*

Field 3:

Model class	Wheat 98	Potato 99	Barley 00	Rape 01
Spatial	powa	*experiment excluded*	lin	pow
Trend ***R^2 adj.%***	x, x^2, y^2 ***45.8***		x^2, y^2, xy ***51.5***	y, y^2, xy ***45.4***
Trend + spatial	x, x^2, y^2 powa		x^2, y^2, xy pow	y, y^2, xy lin

Model class	Wheat 02	Potato 03	Barley 04	Rape 05	Σ
Spatial	pow	N_sph	sphga	sphga	*0*
Trend ***R^2 adj.%***	x, y, y^2 ***22.6***	x^2, y^2, xy ***41.8***	x, x^2, y^2, xy ***58.0***	y, y^2, xy ***55.0***	*3*
Trend + spatial	x, y, y^2 expa	x^2, y^2, xy N_sph	x, x^2, y^2, xy sphga	y, y^2, xy sphga	*4*

Field 4:

Model class	Rape 98	Wheat 99	Potato 00	Barley 01
Spatial	N_powa	gauga	pow	sphga
Trend *R^2 adj.%*	y^2 **4.8**	x, y, y^2 **40.4**	x, y **34.3**	x, y **12.0**
Trend + spatial	y^2 N_powa	x, y, y^2 gauga	x, y pow	x, y sphga

Model class	Rape 02	Wheat 03	Potato 04	Barley 05	*Σ*	*ΣΣ*
Spatial	gauga	gauga	N_lin	gauga	*3*	*8*
Trend *R^2 adj.%*	x^2 **8.8**	x, x^2, y, y^2 **38.4**	x, y, y^2 **30.1**	y, y^2, xy **53.6**	*2*	*9*
Trend + spatial	x^2 gauga	x, x^2, y, y^2 gauga	x, y, y^2 lin	y, y^2, xy gauga	*3*	*14*
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