STATISTICAL PROCEDURE TO COMPARE FARMING METHODS WITH THE OBSERVATION OF SPATIAL TRENDS AND CORRELATIONS IN ON-FARM RESEARCH

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ABSTRACT

Modern management and machines have been introduced on a demonstration farm in Ganhe (China). This has led to new methods of cultivation with effects on yields, cost structure and thus also on the economic success of the farm. These effects should be tested with the help of an on-farm trial. The cultivation methods differed in the equipment used, plant protection and fertilisation strategies. In contrast to classical field trials, normal working practice farm machinery and fields are used in on-farm research. Thus it is usually not possible to avoid the trial fields showing a soil trend as well as spatial correlations, which influence the estimated values for expected value and variance of the cultivation method. Through the use of modelling with the “procedure mixed” in the statistical software SAS 9.2, an effort is made to take into account these influences in the statistical evaluation of agricultural field trials. An accordingly important model extension is possible based on the theory of the mixed linear model. The goal is to take into account the spatial trend and correlations related to the data and thus to be able to guarantee that statistical risks are kept to. In order to record the heterogeneity of the soil a measurement was taken before the beginning of the trial to determine the apparent electrical conductivity of the soil using the soil scanner EM 38. The paper shows how soil trends and spatial correlations can be dealt with and how the evaluation results can vary depending on these. A high heterogeneity of the trial field is found particularly in precision farming trials, since these are also a part of the procedures to be tested. It is shown that, combined with suitable statistical evaluation procedures, on-farm research is an instrument for carrying out precision farming trials.

Keywords: On-Farm Research, SAS Proc mixed, EM 38

INTRODUCTION

A German-Chinese agricultural demonstration farm was set up on the state farm Ganhe (Inner Mongolia, China). The aim is to introduce modern machines and farming methods into the region of north-east China. The fields there have been farmed using the same farming techniques for several decades. This mainly involved the growing of soybeans in monocultures for which the soil was usually only cultivated to a shallow depth and acidifying nitrogen fertiliser was applied. Problems for the soil have arisen from this, such as: soil compaction, erosion damage, accumulation of herbicide residues in the soil, soil acidification (pH 4.5 – 5.5), poor nutrient availability of phosphorus and potassium. For these reasons it is necessary to introduce sustainable farming methods.

The demonstration farm was equipped with modern machines and was farmed jointly by a German and a Chinese farm manager with modern and sustainable management. This led inevitably to new cultivation methods with effects on the yield, the cost structure and thus also on the economic success of the farm. Thus, the question arose as to the economic advantages of the new cultivation methods compared to the established methods and machines used up to now in the region. Through an on-farm trial the cultivation methods should be tested for their effects on the yield and then evaluated from an economic point of view.

In contrast to classical field trials, in on-farm research normal farming practice fields and machines are used. It usually cannot be avoided that the trial fields show a trend, for instance in the soil quality and spatial correlations between the parcels, which influence the estimated values for the expected values and variance of the cultivation approach. Thus, an attempt is made to take this into account through geo-statistical modelling of these relationships. Based on the theory of the linear mixed model, an appropriate necessary extension of the model is possible. The aim is to take into account a spatial trend and correlation according to the data and thus to ensure compliance with the statistical risks.

This soil trend exists in precision farming trials in particular since this is also a part of the approach to be tested. Here it will be shown that an on-farm trial, combined with suitable statistical evaluation methods, is a suitable instrument for the comparison of cultivation methods and also how the heterogeneity in trial fields can be dealt with. The statistical evaluation of an on-farm trial is portrayed here without sub-field specific application; the approach for field trials for comparison of precision farming technologies do not differ much from this (Schneider and Spilke, 2007, Thöle, 2010).

MATERIALS AND METHODS

The location

Ganhe is located in north-east China at the edge of the north-east China lowlands (49,39715°N; 124,64678°E). Acid, degraded luvic chernosem (clay loam, Lt3) with a humus content of 4 – 8 % are characteristic for this location. The annual rainfall of 450-500 mm falls mainly in the vegetation period between June and August (summer monsoon). The vegetation period is very short (110 – 120 frost-free days), with hot summers and very cold winters. In winter the temperature sinks to -40°C with little snow cover, which is why only summer crops, such as wheat, soybeans, maize and potatoes can be grown.

The cultivation methods

The state farm of Ganhe owns a farm area of ca. 20,000 ha, of which only a part is farmed by the enterprise itself; most of the area is rented out to the local people living on the land, who farm the fields as rent-bound small farmers. The state farm owns machines produced in China, which are simply made but have a large working width. The small farmers, in contrast, only rent a small area per household and thus only own simple machines that are locally produced with a small working width and thus use more man-power for production. The farming approaches differ in the equipment used (German – Chinese equipment, working width and quality of work) as well as plant protection and fertilisation strategies. The treatments to be tested (farming methods) are:

- farming method 1 – German demo farm
- farming method 2 – Chinese state farm
- farming method 3 – Chinese small farmer household

To compare the farming methods two on-farm trials were set up with summer wheat and soybeans in order to compare the three different farming approaches over three trial years. In the set-up of on-farm trials the same basic conditions are valid as for classical field trials, i.e. randomisation, forming of blocks and repetition. These basic conditions should also be upheld in OFR (IBS-DR, 2010). However, in practice the randomisation can often not be completely implemented due to organisational or natural conditions. The trial design corresponds to a systematic block design with three blocks and three repetitions. The trial fields are 27 ha in size with a parcel width of 60 m (Brigade 5) and 21 ha with a parcel width of 45 m (Brigade 10). The soil varies greatly within a field with respect to the type and possible yield. Thus the field shows a soil trend perpendicular to the direction of cultivation, which is why the trial was sub-divided once more into three blocks and the electrical conductivity of the soil was recorded as a covariate.

Recording of covariates: measurement of apparent electrical conductivity

In the autumn of 2009, before the trial fields were laid out, the electrical conductivity (EC data) was measured with the soil scanner EM38. From experience, the data can be used as covariates for the identification of spatial trends in the geo-statistical evaluation. As part of the model selection, it is then tested whether this characteristic should be used as a covariate.

Recording of the verification characteristic: yield mapping

The parcels were harvested in strips with a normal practice combine harvester with geo-referenced online-yield recording. With this, four or six harvest passes per parcel are evaluated after the data processing. After the threshing, the whole yield per parcel was determined. A correction factor was calculated from the average parcel yield of the yield logging and the real weighing, in order to calibrate the data of the yield logging of each parcel individually. The yield points portray non-randomised measurement repetitions within a parcel, which show positive correlations among themselves.

About data preparation of the verification characteristics and covariates

Before a statistical evaluation, a cleaning of the yield data and verification of the plausibility is necessary since the raw data are usually prone to errors. For this the headland (30m), the plot margins (each 7.5 m), sub-widths from harvest and outliers were deleted and a moisture correction to 86 % dry matter content was carried out. The EC data were recalculated using the formula from Durlesser (Durlesser, 1999) to a soil temperature of 25°C. Furthermore, the EC data were related to the yield points through kriging and then brought together. With this a data set with geo-referenced points with data about yield and electrical conductivity was set up. For the modelling of spatial correlations, the decimal coordinates (WGS84) must be changed to metric UTM coordinates.

Statistical evaluation of the trial results

In on-farm trials it cannot be avoided that soil trends and spatial correlations occur that can influence the estimated values for expected values and the variance of the treatments. Thus an attempt is made to include these disturbances through a geo-statistical evaluation. This is practically implemented through modelling with the procedure mixed in the statistical software SAS 9.2. The approach for evaluation is shown here using the example of a trial (soybeans, 2011, field: Brigade 5). In this, the approaches evaluation as block design and the geo-statistical evaluation are gone into. The data structure of the example is shown briefly in table 1. What is noticeable is that in variation 1 (demo farm) there are lower average EC25 values compared to the other variations. This shows that there is heterogeneity that can influence the yield of the treatments.

Table 1. Data structure of the trial example: soybeans - 2011- Brigade 5

Soybean - 2011 - Brigade 5	Demo farm	State farm	Household
observations [n]	466	546	546
mean EC-data [ms/m]	37.26	40.61	41.17
mean of yield [t/ha]	2.827	2.925	2.736

Approach 1: Evaluation as block design

An on-farm trial can also be evaluated as a block. In this, the average value of all yield points within a randomisation unit (parcel) are formed and evaluated using a classical variance analysis. This approach has the advantage that it is simple to implement and serves as a back-up for the results of the geo-statistical evaluation. The results of the trial example are shown in table 2. Usually, in a classical evaluation as block design (approach 1), recording of this heterogeneity is not possible through block formation alone.

Table 2. Results of the statistical evaluation as block design (Soybean-2011-Brigade 5)

LSMeans [t/ha]	**Estimate**	**SE**	**DF**	**t value**	**Pr> t**
Demo farm	2.874	0.079	4	36.390	<.0001
State farm	2.926	0.079	4	37.040	<.0001
Household	2.727	0.079	4	34.520	<.0001
Differences of LSMeans [t/ha]	**Estimate**	**SE**	**DF**	**t value**	**Pr> t**
Demo farm – State farm	-0.050	0.112	4	-0.460	0.669
Demo farm – Household	0.147	0.112	4	1.320	0.258
State farm – Household	0.199	0.112	4	1.780	0.150

Approach 2: Evaluation including the geo-referenced yield values (geo-statistical evaluation)

A further evaluation alternative is the inclusion of all geo-referenced yield points in a geo-statistical evaluation. In this the inclusion of fixed and variable disturbances is taken into account, which leads to the use of a linear mixed model. The basic model (Hu et. al., 2006) has the following form in matrice format:

$$Y = X ß + Zu + e$$

when β and u are the unknown parameters and X and Z the related trial plan matrices and e the unknown residual effects.

The process of model selection is particularly important in the geo-statistical evaluation of on-farm trials. In this, the question arises as to which fixed and random variables should be included in the evaluation model. For this a pragmatic approach (Schneider et. al., 2007 und Spilke, 2011) is chosen in two steps, which allows a systematic model selection with the help of analytical criteria. For this the AICC (corrected Akaike Information Criterion) is used according to Hurvich and Tsai (1989), which is an extension of the AIC (Akaike, 1969). With the help of the AICC a penalty term for the model complexity is used to decide between over- and under- fit of the evaluation model. Furthermore, it is dependent on the size of the random sample (n).
In step 1 the AICC is used with the maximum likelihood method (ML-method). For step 2 the restricted maximum likelihood method (REML-method) is used. The lower the calculated AICC, the better the fit of the model to the data.

The equation for the AICC (ML):

$$AICC_{ML} = -2L + \frac{2n\,(p_{Rank} + q)}{n - (p_{Rank} + q) - 1}$$

The equation for the AICC (REML):

$$AICC_{REML} = -2L_R + \frac{2\,n\,q}{n-q-1}$$

$$L = maximum\ value\ of\ the\ loglikelihood\ (ML)$$
$$L_R = maximum\ value\ of\ the\ restricted\ loglikelihood\ (REML)$$
$$p_{Rank} = rank\ of\ the\ design\ matrix\ for\ fixed\ effects$$
$$q = number\ of\ variance\ parameters$$
$$n = sample\ size$$

This approach has the advantage that the evaluation model is selected in a gradual and systematic fashion. It is also possible to check the residues for distortion in order to inspect and correct the selection of the included fixed effects, if necessary.

A model selection with analytical criteria alone can be prone to errors, which is why it is always important to carry out a check of the results. With the help of the residual analysis of the different tested models, possible trends can be recognised and the model results checked for distortion. In order to avoid incorrect results in the evaluation, the standard automatic evaluation steps must not be used (Spilke, 2011).

1st step: optimisation of the expected value structure

For the selection of the model a simple initial model is first elaborated: yield = treatment. This initial model is then extended gradually by adding the fixed effects, such as trial design (replication and blocks), and covariates (EC data and x-y coordinates) in order to describe the spatial trend (see table 3). The model 1.8 proved to be the model with the best fit to the data. The results of the “best model” (model 1.8) are shown in table 4. However, it is shown that the degree of freedom (DF) was calculated under the assumption of independent observations (DF = n-p_x = 1558 - 9 = 1549). This assumption appears, however, not to be realistic. Thus the yield points were taken to be replications, which is not the case, since these are only pseudo repetitions (IBS-DR, 2010).

Table 3. Verification models in step 1

model no.	**Test model**	**AICC**
1.1	Yield2011 = 0	
1.2	Yield2011 = treatment	-596.3
1.3	Yield2011 = treatment, replication	-674.2
1.4	Yield2011 = treatment, replication, block	-684.5
1.5	Yield2011 = treatment, replication, block, EC	-748.4
1.7	Yield2011 = treatment, replication, block, EC, x	-751.1
1.8	**Yield2011 = treatment, replication, block, EC, x, y**	**-773.6**
1.9	Yield2011 = treatment, replication, block, EC, x, y, x*y	-773.6

Table 4. Results of the „best model“ in step 1 (model 1.8)

LSMeans [t/ha]	**Estimate**	**SE**	**DF**	**t value**	**Pr> t**
Demo farm	2.897	0.020	1549	141.79	<.0001
State farm	2.913	0.008	1549	348.8	<.0002
Household	2.685	0.024	1549	113.97	<.0003
Differences of LSMeans [t/ha]	**Estimate**	**SE**	**DF**	**t value**	**Pr> t**
Demo farm – State farm	-0.015	0.023	1549	-0.650	0.5152
Demo farm – Household	0.213	0.042	1549	5.040	<.0002
State farm – Household	0.228	0.023	1549	9.770	<.0003

2nd step: optimisation of covariance structure

In agricultural field trials spatial correlations exist between neighbouring observations, which are dependent on their distance to one another (Richter and Kroschewski, 2009). This means that the shorter the distance between the observations, the higher the correlation is between them. These covariances can be traced back to the differences in the soil characteristics and the environmental conditions in the crop. These can be described through different spatial models (Schabenberger and Pierce, 2002) and should be included in the statistical evaluation in order to obtain undistorted results. The selection of the suitable model gains in importance since otherwise precision can be lost if the wrong model is chosen (Spilke et.al. 2010).

In the second step the best model from step 1 is extended with random effects and their spatial correlation structure and checked again through the use of the AICC. For this, models with different spatial correlation structures, with and without nugget effects (local), as well as anisotrope models are tested (SAS, 2003).

- Type (exp) (x y) - exponential
- Type (expga) (x y) - geometrically anisotropic exponential
- Type (sph) (x y) - spherical
- Type (sphga) (x y) - 2D sperical, geometrically anisotropic
- Type (gau) (x y) - Gaussian
- Type (gauga) (x y) - 2D Gaussian geometrically anisotropic

A further option is to limit the influence of interaction in the trial field. For this models were tested with the assumption that the dependence of the yield point exists only within the parcel (subject = plot), the blocks (subject = block) or over the whole trial field (subject = intercept) (Piepho et al. 2011). 36 verification models were tested for the model selection in step 2. The results of different verification models tested are shown in table 5 as examples. The model 2.11 proved to be the evaluation model with the best fit to the data.

The results of the evaluation model (model 2.11) are shown in table 6. The variation demo farm obtained the highest average yield with 2.905 t/ha. The small farm households, in contrast, obtained a lower yield with 2.653 t/ha; however, using the multiple t-Test and with a significance level of $\alpha = 0.05$ they were not found to be significantly different from one another.

Table 5. Examples of the verification model in step 2

Model no.	Verification model		AICC
Model 1.8	**Yield2011= treatment replication block ec x y**		**-773.6**
2.1	Type = sp(exp) (x y);	Subject = intercept	-920.1
2.11	**Type = sp(expga)(x y)local ;**	**Subject = block**	**-1768.9**
2.12	Type = sp(expga) (x y) local;	Subject = parcel	Infinity
2.14	Type = sp(sph) (x y);	Subject = block	-687.7
2.23	Type = sp(sphga) (x y) local;	Subject = block	-1738.9

*alle Modelle unter DDFM=KR(firstorder)

Table 6. Results of the evaluation model 2.11 in step 2

LSMeans	Estimate	SE	DF	t value	Pr> t
demo farm	2.905	5.427	1	0.540	0.6871
state farm	2.883	0.603	1	4.780	0.1313
Household	2.653	6.562	1	0.400	0.7554
Differences of LS Means [t/ha]	**Estimate**	**SE**	**DF**	**t value**	**Pr> t**
demo farm – state farm	0.022	6.027	38.8	0.000	0.997
demo farm – household	0.215	11.988	49.4	0.020	0.983
state farm – household	0.230	5.962	42.1	0.040	0.970

In comparison to the best model in step 1 (table 2), one can determine that the degree of freedom (DF), standard error (SE), t-value and thus also the significance of the difference has changed. With the optimisation of the covariance structure, a loss in significance can also be determined here. Nevertheless, the model 2.11 should be used as the evaluation model, since it is best fitted to the data and thus describes the heterogeneity of the location (unavoidable in on-farm trials) through covariates and also includes the spatial relationship of the geo-referenced yield points.

RESULTS AND DISCUSSION

The approach shown here was carried out for all trial fields. The results of both trial years are shown in this section. The trial results for soybeans of the two trial years are summarised in table 7. In 2010 the small farmers obtained the highest yields, which were significantly different from the other two treatments. In trial year 2011, however, the yields of the farming approaches lay closer together, so that no significant differences could be found. It is noticeable that the results of the geo-statistical evaluation shifted somewhat compared to the evaluation as a block design. This can be traced back to the inclusion of the covariates in the evaluation model.

Table 7. Results of the statistical evaluation for soybeans

Trial year	**2010**			**2011**		
Farming method	**Demo farm**	**State farm**	**House Hold**	**Demo farm**	**State farm**	**House Hold**
observations [n]	520	487	512	466	546	546
means-EC-data [ms/m]	35.33	35.95	36.45	37.26	40.61	41.17
means - yield [t/ha]	1.741	2.034	2.344	2.827	2.925	2.736
Statistical analysis	**LSMeans - yield [t/ha]**					
approach 1: block design	1.740	2.034	2.361*	2.874	2.926	2.727
approach 2: geostatistic	1.848*	1.976*	2.360*	2.897	2.885	2.661

*Means are significant (α = 0.05)

Very different results were shown for summer wheat for the two trial years. In 2010 the small farmers achieved the highest yield with ca. 3.3 t/ha. In contrast, in 2011 the results for the yield were higher but lay closer together, whereby no significant differences in yield were shown. However, it must be noted for the results for 2011 that there were huge problems in layout of the trial field and with weed control and thus a large portion of the trial fields could not be evaluated. For this reason, the results for summer wheat in 2011 are not statistically valid and no evaluation as a block design was possible.

Table 8. Results of the statistical evaluation for summer wheat in 2010/2011

Trial year	**2010**			**2011**		
Farming method	**Demo farm**	**State farm**	**House hold**	**Demo farm**	**State farm**	**House Hold**
observations [n]	685	764	817	145	244	308
mean -EC-data [ms/m]	37.84	40.79	41.85	37.51	38.59	39.76
means -yield [t/ha]	2.505	2.860	3.175	4.461	4.318	3.969
Statatistical Analysis	**LSMeans - yield [t/ha]**					
approach 1: block design	2.582	2.871	3.295*	-	-	-
approach 2: geostatistic	2.696*	2.519*	3.302*	(4.698)	(4.359)	(3.787)

*Means are significant (α = 0.05)

CONCLUSIONS

The geo-statistical evaluation of on-farm trials provides a good alternative to the classical evaluation of on-farm trials. As shown, it is possible to include the geo-referenced yield points and the covariates in the geo-statistical evaluation and thus use this extra information in order to describe the heterogeneity of the trial field. In order to verify the results, a classical evaluation as a block structure should always be carried out here. With respect to the results, one should note that there were some problems with the adaptation and adjustment of the new machines of the demonstration farm and the problems mentioned with the location, such as soil compaction, acidification of the soil, and the poor nutrient availability had a negative effect so that it was not possible to obtain optimal results. After the field trials, an economic evaluation was carried out on the basis of the estimated yields from linear mixed model. The approach and results will be shown elsewhere.

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