Long-term Field Experiments in Germany: Classification and spatial Representation

Meike Grosse[1], Wilfried Hierold[1], Marlen C. Ahlborn[1], Hans-Peter Piepho[2], Katharina Helming[1]

[1]Leibniz Centre for Agricultural Landscape Research (ZALF), Eberswalder Straße 84, Müncheberg, 15374, Germany
[2]Biostatistics Unit, Institute of Crop Science, University of Hohenheim, 70599 Stuttgart, Germany

Correspondence to: Meike Grosse (meike.grosse@zalf.de)

Abstract. The collective analysis of long-term field experiments (LTFE), here defined as agricultural experiments with a minumum duration of 20 years and research in the context of sustainable soil use and yield, can be used for detecting changes in soil properties and yield such as induced by climate change. However, information about existing LTFEs is scattered, and the research data are not easily accessible. In this study, meta-information on LTFEs in Germany is compiled and their spatial representation is analysed. The study is conducted within the framework of the BonaRes project, which, inter alia, has established a central access point for LTFE information and research data. A total of 205 LTFEs is identified which fit to the definition above. Of these, 140 LTFEs are ongoing. The land use in 168 LTFEs is arable field crops, in 34 trials grassland, in two trials vegetables and in one trial pomiculture. Field crops LTFEs are categorized into fertilization (n=158), tillage (n=38), and crop rotation (n=32; multiple nominations possible) experiments, while all grassland experiments (n=34) deal with fertilization. The spatial representation is analysed according to the climatic water balance of the growing season (1 May to 31 October) (CWBg), the Müncheberg Soil Quality Rating (MSQR) and clay content. The results show that, in general, the LTFEs well represent the area shares of both the CWBg and the MSQR classes. 89% of the arable land and 65% of the grassland in Germany is covered by the three driest CWBg classes, hosting 89% and 71% of the arable and grassland LTFEs, respectively. LTFEs cover all six MSQR classes, however with a bias towards the high and very high soil quality classes. LTFEs on arable land are present in all clay content classes according to ESDAC, however with a bias towards the clay content class 4. Grassland LTFEs show a bias towards the clay content classes 5, 6 and 7, while well representing the other clay content classes, besides clay content class 3, where grassland LTFEs are completetly missing. The results confirm the very high potential of LTFE data for spatially differentiated analyses and modelling. However, reuse is restricted by the difficult access to LTFE research data. The common database is an important step in overcoming this restriction.

1 Introduction

Long-term field experiments (LTFEs) are a valuable research infrastructure for terrestrial research in general and agricultural research in particular. They are here defined as agricultural field experiments with a minimum duration of 20 years and research in the context of sustainable soil use and yield. Changes in soil properties tend to occur slowly; thus, for the identification of long-term trends, experiments with a long duration are needed. However, a single LTFE allows the drawing of conclusions only for its specific site. The collective analysis of research data from different LTFEs at different locations leads to more generalizable results. On the one hand, similar experiments on similar sites will lead to better validated conclusions when analysed in combination. On the other hand, LTFEs in different experimental conditions may lead to broader implementable results by their collective analysis. Furthermore, LTFEs are expensive; a comprehensive and coordinated evaluation is also required to prove that they are worth the expense (Körschens, 2006; Berti et al., 2016). Historically, LTFEs were mainly established to answer questions regarding plant nutrition in the sense of achieving the highest possible yield (Merbach and Deubel, 2008). Later, they were used to reveal the effects of agricultural management practices (besides fertilization mainly tillage and crop rotation) on crop yield but also soil characteristics. LTFEs have been very helpful for research on soil organic carbon content or composition (Ellerbrock and Gerke, 2016; Kaiser et al., 2014; Körschens et al., 2014). LTFEs are further important for research related to questions regarding the inter annual variability of crop yield (i.e., yield stability) that can be associated with climate change (Berti et al., 2016; Reckling et al., 2018; Macholdt et al., 2019) and respective adaptation options (Hamidov et al., 2018). Valuable data can also be delivered for the validation of models (Franko et al., 2011; Ellerbrock et al., 2005) and for concepts used to evaluate soil functions (Vogel et al., 2019; Techen et al., 2020).

The joint analysis of LTFEs can go beyond the original research question of each LTFE, e.g., to answer questions about climate change, ecosystem services, nutrient cycles, or yield stability. This research could be done through the common assessment of the ‘control’ treatment of each LTFE, which is here defined as a treatment with customary tillage and fertilization and is present in most LTFEs. The combined analysis of control treatments is irrespective of the LTFE’s original research theme. This would allow us to reveal changes in soil properties independently of the original questions for which the experiments were set up, e.g., overall trends in carbon content development. Although that would be a similar analysis to what can be done with soil monitoring sites (“Bodendauerbeobachtungsflächen”), it would be a reasonable approach. It can be assumed, that LTFEs have fewer breaks during the experimental period than soil monitoring sites, as soil monitoring sites are always a "window" in real agriculture. Further on, access to data from soil monitoring sites is not neccessarily easier than that to LTFE. Of course, the strengths of the collective analysis of LTFEs is the analysis of LTFEs with similar treatments in the form of a meta- analysis.

The meta-analyses of similar LTFE, e.g., of fertilizer experiments with similar factors (e.g., with/without organic manure) or tillage experiments (e.g., conventional tillage vs. reduced tillage) has the opportunity to make use of the original research question of the LTFE. The effects and sustainability of measures can be revealed in a broader context and in different soils. This can be done with pairwise comparisons of alternative and reference management practices, such as that by Bai et al. (2018) and Sandén et al. (2018). However, because of the site specificity of soil-plant interactions and their responses to agricultural management practices, the upscaling and generalization of results requires information about the spatial representation of LTFE sites.

The statistical analysis of LTFEs poses several challenges and requires careful statistical modelling. We would recommend a mixed-model based analysis that accounts for the randomization layout of the trial (see Onofri et al., 2016, for review and some case studies). A general strategy starts out from the analysis model that would be used for a single year of data and then extend the model to account for variation across years. A specific challenge here is that during the course of the experiment, several observations are made on the same experimental units, and this serial correlation needs to be taken into account (Payne et al., 2015; Richter and Kroschewski, 2006; Singh und Jones, 2002). Also, there may be heterogeneity of variance between years, which may be related to changes in stability of the investigates systems (Macholdt et al. 2019a,b). For a recent account of several statistical issues in the design and analysis of LTFEs see Reckling et al. (2020).

A common issue with several LTFEs in Germany is that they were not properly randomized. This is mainly due to the fact that Fisher's principles of randomization and blocking were not widely known or accepted at the time when these trials were established. Instead, the systematic design originally proposed by Mitscherlich about a hundred years ago was very popular, and several LTFEs were established according to such systematic designs. For these unrandomized trials, a randomization-based analysis is obviously not available. One option then is to try spatial modelling, though it must be stressed that fitting of a spatial covariance structure cannot make up for lack of randomization. But such a modelling is perhaps the best way forward, if a sensible analysis is to be conducted for such trials. For a review of the connection between systematic designs as proposed by Mitscherlich and certain spatial covariance structures, see Piepho and Vo-Thanh (2020).

Important compilations of German LTFEs have been performed by Körschens (1994, 1997) and Debreczeni and Körschens (2003). In Körschens (1994), 97 German LTFEs with a duration of more than 20 years were listed. The starting year, the kind of factors, the cultivated crops, the size of the plots and experiments, the soil texture, the average annual air temperature and the average annual precipitation of the site are presented if available. In Körschens (1997), 50 German LTFEs with a duration of more than 30 years are listed, and similar information is presented. In Debreczeni and Körschens (2003), 94 German LTFEs with a duration of more than 20 years are listed, and information about the start, experimental aspects, cropping system and soil is provided. Körschens (1994, 1997) indicates the following constraints for the compilation of a complete overview of all LTFEs in Germany: the multitude of experiments, discontinued experiments, new experiments, or experiments not at all documented in the literature. In Debreczeni and Körschens (2003), restricted resources for data collection are also mentioned. In addition, the heterogeneous setup and the scattered distribution of LTFEs make comparisons of data difficult or impossible (Bai, 2018). To cope with these problems, in the frame of the project ‘BonaRes’, funded by the German Federal Ministry for Education and Research (BMBF), there is the focus on a central database for metadata and research data from LTFEs (BonaRes, 2020). The research data from two LTFEs (V140, Müncheberg and Dikopshof, Bonn) are available for free reuse via the BonaRes data portal (https://maps.bonares.de/mapapps/) and the research data of nine other LTFEs are very close to publication. More LTFE holders will hopefully agree to upload research data within the third (and last) funding phase of BonaRes and take the great chance for support in data processing and storage.

No information is yet available regarding the spatial representation of LTFEs in Germany with regard to important agronomic factors such as climate and soil fertility. The aim of this paper was twofold: first, to classify the LTFEs in Germany with regard to land use, research themes and farming systems. Second, the aim was to conduct a descriptive analysis of the geospatial distribution of the experimental sites with regard to key factors of agricultural production: climate and soil fertility.

2 Material and Methods

A combination of three methods was applied: a literature review to identify LTFEs in Germany, a fact sheet-based addition of information to the identified LTFEs, and a geospatial analysis employing the CWBg and the MSQR (Figure 1).
An extensive literature review was conducted to identify LTFEs. The search terms were 'long-term field experiment', 'long-term experiment', 'long-term field trial', and 'long-term trial', as well as the German items 'Dauerfeldversuch', 'Dauerdüngungsversuch', 'Dauerversuch', 'Langzeitfeldversuch' and 'Langzeitversuch'. Sources were scientific papers as well as other articles, books, trial guides and websites. The focus was on the exact position of the LTFE and the following metadata: name of the LTFE, website (if available), institution, land use category, participation in existing networks, research theme, size of the LTFE area, number of plots, size of the plots, crop rotation, start (and maybe end) of the trial, measured parameters, and trial setup including factors, treatments and randomization. For the coordination and simplification of the trial description, the BonaRes Fact Sheet was established, which asks for all relevant trial information (Grosse et al., 2019). It was sent to the trial holders, and the fact sheet was completed for 40 trials. Trial holders also delivered important information as personal communication.In compiling the dataset, special attention was paid to LTFEs with a minimum duration of 20 years. This age can be seen as a threshold for the identification of long-term trends. Attention was given to LTFEs in the context of soil research, i.e., the objects of research should at least include soil properties and yield as an important soil function. The setup of each trial should allow for statistical analyses, i.e., have clearly defined treatment factors, replications and as much as possible a static design. Lysimeter experiments were excluded because they were considered as an own category. Some reasons for this exclusion are that soils are often transferred and not undisturbed in lysimeter experiments and tillage has to be conducted by hand instead of machines, which can bias some results. Indeed, longterm lysimeter experiments exist in Germany as part of the TERENO network (TERENO, 2020).
The LTFEs were classified according to their research themes to simplify the identification of similar experiments. The field crops LTFEs could best be grouped into four clusters: fertilization, tillage, crop rotation, other. The fourth cluster "other" entails all themes that could not be grouped into the first three and appeared only in a few (maximum five) LTFE cases, so that a separate group was not justified. Two or more factorial experiments were sorted in all relevant classes, i.e., multiple nominations were possible. LTFEs on grassland exist only as fertilization trials.

109 LTFEs are precisely known in their position, and for an additional 96 LTFE the trial area is approximately known, usually on the area of the holding institution. In the latter case, either the exact position is not known or the former LTFEs are now overbuilt with streets, parking spaces or buildings.

The geospatial analysis was performed by comparing the regional distribution of LTFEs to that of (a) climatic water balance classes of the growing season (1 May to 31 October) (CWBg) and (b) the Müncheberg Soil Quality Rating (MSQR) as two complex site classifications. In addition, (c) clay content of the topsoil according to ESDAC (2020) was chosen. The representativeness of LTFEs according to the frequencies in the cells of this classification was assessed. LTFEs were classified according to their land use and their research themes to simplify the identification of similar experiments. The identification of suitable LTFEs in similar (or different) landscapes shall be facilitated. Therefore, a table with the IDs of all experiments, their thematic classification, their CWBg class and their MSQR class is provided in the attachment. More details for each LTFE can be identified in the published dataset (Grosse and Hierold, 2019), which is freely available in the BonaRes Repository, through the ID of the LTFE. Thus, cooperation with LTFE holders can be initiated more easily.Fourteen LTFEs were excluded from the geospatial analysis because they were dealing with research themes other than fertilization, tillage or crop rotation or did not include field crops or grassland experiments. The remaining 191 LTFEs were grouped into the four classes of fertilization experiments, tillage experiments, grassland experiments, and crop rotation experiments. The shares of LTFEs in each class were compared to that of agricultural land in Germany. For that, approximately 17.9 million hectares of agricultural land were subdivided according to their land use as arable land (approximately 13.5 million hectares) or grassland (approximately 4.4 million hectares) (Umweltbundesamt, 2019). For the descriptive statistical analyses cross-tabulations and contingency tables were used.

The CWBg was chosen as a suitable parameter to represent the climatic conditions for agricultural land use and because of its huge relevance for vegetation growth. Its impact may be even larger than that of temperature (Crimmins et al., 2011), and it may determine the growing season (Sattar et al., 2019). We used data from the German Meteorological Service (DWD) for the period 1981-2010 for the main growing season, defined from 1 May to 31 October (Ad-hoc-AG Boden, 2005). The CWB data for the growing season instead of the whole year was chosen, because regional differentiation is bigger for CWBg compared to the annual balance. The data are available for the whole territory of Germany with a pixel resolution of 1 km (DWD, 2020). The CWB is defined in Formula (1) as the difference in precipitation (P) and potential evapotranspiration (PET). It is a quantitative measure of the water supply in a given time period and for a specific region. The PET depends on location factors such as crop cover, topographical effects, soil conditions and soil water storage. It can therefore only be determined selectively. However, for a better comparison for spatial calculations, the so-called grass reference evapotranspiration is considered, which indicates the evapotranspiration of a standardized grass cover in standardized soil with optimal water supply (Pereira et al., 2015).

$$CWB = P - PET \quad (1)$$

The classification of the climatic water balance in seven classes follows the Survey Guideline KA5 (Ad-hoc-AG Boden, 2005) (≤150; -150 to <-50;-50 to <50; 50 to <150; 150 to <300; 300 to <500; ≥500 mm), which are classified there from extremely low to extremely high (Ad-hoc-AG Boden, 2005).

To derive data for agricultural areas, either arable land or grassland intersections with the CORINE Land Cover (CLC, 2018) dataset were made.

For (b), a soil quality map (BGR, 2014) is used, which applies the Müncheberg Soil Quality Rating (MSQR). It has a pixel resolution of 250 m. The BGR had applied this complex assessment procedure (Mueller et al., 2010; Ad-hoc-AG Boden, 2010), which was developed as a visual procedure for estimating yield potential in the field, by modelling data from the soil overview map (BGR, 2007), but only for arable land. It takes soil structure and soil degradation threats into account and integrates eight basic soil indicators with 13 hazard indicators into a rating of soil quality. The rating is shown on an ordinal scale of 0 to 102 and clustered into six quality classes, with higher values indicating higher yield potential (Daedlow, 2018). The eight soil indicators are substrate, A-horizon depth, topsoil structure, subsoil structure, rooting depth, profile available water, wetness and ponding, slope, and relief. The 13 hazard indicators are contamination, salinization, sodification, acidification, low total nutrient status, shallow soil depth above hard rock, drought, flooding and extreme waterlogging, steep slope, rock and surface, high percentage of coarse texture fragments, a soil thermal regime unsuitable for crop production, and miscellaneous hazards (e.g., exposure to wind and water erosion). Most of the indicators are sensitive to agricultural management, which makes the MSQR most useful for studying the effects of agricultural management on soil. The MSQR has been proven useful in other studies of geo-spatial representation (Askari et al., 2013; Hanauer et al., 2017; Smolentseva et al., 2014). Since no MSQR is available for grassland areas, the LTFEs on grassland were excluded in this analysis.

Out of the 157 fertilization, tillage or crop rotation LTFEs on arable land, 26 could not be assigned to a class of MSQR because the fields are surrounded by buildings and are therefore not part of arable land. If an LTFE did not obtain an assignment at a GIS intersection, the value was determined manually by plausibility examination of the nearest 5 to 7 grid cells. One LTFE could not be assigned to a class of MSQR because it compares three different soils in boxes.

For (c), clay content, data of the European Soil Data Centre (ESDAC) based on LUCAS topsoil data is used (ESDAC, 2020). Although clay content is included in the MSQR as part of substrate, we decided to analyse the area shares of clay content separately, as carbon content is often correlated with the clay content (Körschens, 1997). Moreover, clay content is needed to estimate the carbon balance in a model derived from the CANDY model (Franko et al., 2011). Further on, ESDAC offers international data, therefore clay content is suitable for international comparability. Due to the fact, that texture is part of the MSQR, we do not offer separate maps for clay content, but present data in tables.

Calculations always refer to utilized agricultural areas or parts thereof, arable land or grassland.

The information was analysed with Microsoft Excel. The geospatial analysis was performed using the ESRI software ArcMap 10.6.1 (ESRI, 2018).

The research on LTFEs is not completed but is ongoing. The information about LTFEs is continuously updated and expanded. New LTFEs are integrated, and the information about each LTFE is extended. The state of research is November 2019.

3 Results and Discussion

3.1 Overview of LTFEs in Germany

In total, 205 LTFEs across Germany with a minimum duration of 20 years were identified, of which 140 trials are ongoing and 65 are terminated (status: November 2019). Further LTFEs reaching the 20-year threshold within the next five years (until 2024) were also included (n=6; Figure 2). Most of the trials have a duration between 20 and 49 years (n=124; Figure 2). 50 trials have a duration between 50 and 99 years. Three trials have been running for more than 100 years (‘Ewiger Roggen’, Halle, 1878 - today; ‘Statischer Düngungsversuch V120’, Bad Lauchstaedt, 1902 – today; ‘Dauerdüngungsversuch Dikopshof’, Wesseling, 1904 - 2009). The age of 22 terminated trials is unknown since only the starting date of the trials is known but not the exact ending year. As these trials were mentioned in different important sources as being ongoing (Amberger and Gutser, 1976; Debreczeni and Körschens, 2003; Körschens, 1990, 1994, 1997, 2000), it is known that their duration was at least 20 years.

The land use in 168 LTFEs is arable field crops, in 34 trials grassland, in two trials vegetables and in one trial pomiculture . There are more long-term grassland experiments in Germany; we have not included them in our research because they are dedicated to research themes other than questions of sustainable soil use and yield.

The majority of LTFEs were established after 1947, when research was resumed after the Second World War (Figure 3). In 1996/1997, a series of grassland fertilization experiments was established by several German state authorities. This explains the high number of LTFEs established in these years (Figure 3).

The research themes of the LTFEs can be assigned to the following categories: fertilization, tillage, crop rotation, ‘other’ themes and combinations of these (Table 1). Due to trials with two or more treatment factors, multiple nominations of experiments for the different research themes were assigned (n=251). Most LTFEs were established for research on fertilization (Figure 3 and Table 1) (n=158). This result is coincident with the results from a study in the international context (Berti et al., 2016). In Germany, fertilization LTFEs can be subdivided into field crop experiments (n=124) and grassland experiments (n=34). Historically, questions regarding the effects of fertilization on plant growth were the focus of research, while more recently the effects on the soil and the environment are investigated. In the focus of the experiments are either different kinds of fertilizers or different amounts of fertilizers or comparisons with/without a specific fertilizer or combinations of these. Most frequently, organic fertilization versus mineral N fertilization is examined. In fewer experiments, the effect of straw fertilization is the subject of research. Additionally, the effects of mineral K fertilization, mineral P fertilization, liming, green manure, mineral Mg fertilization, compost, or sludge are examined (Table 1). More rarely, different points in time of the fertilizing measure are compared.

Thirty-eight LTFEs address tillage variations (Table 1). Most of these tillage experiments compare different tillage intensities. Most often, reduced tillage depth or conservation tillage are the subjects of research. Also, inversion versus non-inversion tillage is compared. Further research themes are sowing methods, different forms of primary tillage, the effects of stubble tillage, and tillage frequency (Table 1). The oldest tillage experiment started in 1923 (Statischer Dauerversuch Bodennutzung, Berlin-Dahlem), but 25 tillage experiments started in 1990 or later (Figure 3). Therefore, most of the tillage experiments are 'younger' experiments, a result also congruent with the findings of Berti et al. (2016).

Thirty-two LTFEs have the research theme 'crop rotation'. Mostly, the effect of crop rotation on soil properties and yield is investigated. Therefore, rotational cropping versus monoculture is compared. Additionally, plant health is the focus, e.g., compatibility of different cereal species or different percentages of cereals in crop rotation (Table 1). Most of the crop rotation experiments were established after 1950. 19 experiments of the 32 crop rotation experiments are still ongoing. The oldest crop rotation experiment, the 'Eternal Rye', was established in 1878 by the Martin Luther University of Halle.

Twenty-three trials address research themes other than fertilization, tillage or crop rotation. The 'other' research themes are highly diverse. 'Environmentally friendly crop protection', mainly reduced pesticide intensity, is the most frequent research theme among the 'other' research themes (n=5). 'Irrigation' is the second most frequent (n=4). 'Effects of different forms of fallow' is within the focus of three LTFEs. 'Frequency and start of utilization of grassland', 'Land use systems comparison', 'Monitoring of Organic Farming' and 'Use of biodynamic preparations' are each within the focus of two LTFEs. Three other research themes are present in only one LTFE (Table 1).

Many different parameters are measured in LTFEs. In Grosse et al. (2019) 46 different soil parameters and 29 plant parameters are listed, which were measured in LTFEs. The analysed parameters can be assigned to different soil functions. The following five soil functions were chosen as most relevant for BonaRes: biomass production, water storage and filtering, nutrient storage and recycling, carbon storage, and habitat for biological activity. In most LTFEs, parameters for biomass production were measured like yield and yield components. Nutrient storage and recycling is the second frequent soil function. Less research is conducted (in decreasing frequency) for carbon storage, habitat for biologic activity and water storage and filtering.

Archived samples are an important means of performing or repeating measurements. However, the information, if archived samples exist, is difficult to find in the literature. We have the information from a fact sheet query. Of 40 responses received, 32 LTFEs have archived samples.A total of 184 trials are set up with conventional management practices, 14 with organic management practices and five with so-called integrated agriculture. Two trials compare conventional with organic management practices.

The holding institution for 96 trials is a university or university of applied sciences, and for 61 trials, it is a state authority. 27 trials are in the responsibility of non-university scientific institutions such as research institutes. 21 trials are or were held by industry.

Compared to LTFEs worldwide, there are a comparatively large number of LTFEs in Germany. Our research revealed up to now 177 LTFEs which match our definition in the following countries: Austria, Belarus, Belgium, Bulgaria, China, Czech

Republik, Denmark, Estonia, Finnland, France, Hungary, Ireland, Italy, Moldova, Norway, Poland, Romania, Russia, Slovenia, Spain, Sweden, Switzerland, United Kingdom, Ukraine, and USA. They are comparable in age (the oldest ones started 1843) and research themes. There are international networks such as the working group IOSDV (Internationale Organische Stickstoffdauerdüngungsversuche, Körschens, 2000), the GLTEN (Global Long-Term Experiment Network, GLTEN, 2020), which was launched in 2018, and networks of organic LTFEs like RetiBio in Italy and RotAB network in France (Ciaccia et al., 2020). In order to make the best use of the great efforts and costs that are behind every single LTFE, international networks should cooperate more intensively in future and possibly also use data infrastructures jointly. We would like to point out that the BonaRes data repository can also be used by international data holders.

All information about the LTFEs in Germany is published in an online overview map (https://ltfe-map.bonares.de). The aims of the overview map are to make LTFEs more visible, to enhance networking among LTFEs and to simplify joint analyses of LTFEs. It is available in German and English. The map content can be displayed according to different categories, e.g., the research themes, land use, or duration of the LTFEs. In addition to the overview information, details about every single LTFE are provided in a pop-up window, offering valuable information for potential users for orientation and initiation of cooperation.

As limitations of existing LTFEs it can be mentioned, that erosion and compaction are typically not analysed in LTFEs and they are not designed for such questions up to now. Grassland experiments are in fact meadow experiments, whereas grazing experiments are completely missing.

3.2 Geospatial Analyses

3.2.1 Geospatial Analysis of LTFEs in Relation to the Climatic Water Balance of the growing season (CWBg) Distribution

An overview of the distribution of these CWBg classes and of LTFEs in Germany is given in Figure 4. According to Table 2 and Figure 4, arable land is distributed among classes 1-7 of the CWBg (Table 2; Figure 4): the largest shares of 33% each are classified as CWBg classes 2 (from -150 mm to <-50 mm) or 3 (from -50 mm to <50 mm), respectively. The area of CWBg class 2 is mainly located in the lowlands of Germany: in the western and northern Rhine-Main Valley, in a majority of the north-eastern lowland and the Loess Boerde. The area of CWBg class 3 is mainly distributed in the north-eastern part of Germany and in parts of the Southern German Escarpment Landscape, the northern foothills of the Alps (lower Bavarian upland) and the lower uplands, such as the Lower Saxon and Hessian lowlands, the Vogtland district and the Erzgebirge foreland. 23% of the arable land is allotted to CWBg class 1 (<-150 mm). This extremely low CWBg is located almost exclusively in eastern Germany, especially in the rain shadow of the Harz: the Fläming, the plates and lowlands of mid Brandenburg and the heathland of Brandenburg. Minor shares of 7% and 4% are allotted to CWBg classes 4 (from 50 mm to <150 mm) and 5 (from 150 mm to <300 mm), respectively. CWBg class 4 is located mainly in the foothills of the Alps and around the secondary mountains and in the western Schleswig-Holstein (moraines of Schleswig-Holstein). CWBg 5 is mainly located in Germany's southern foothills of the Alps. CWBg class 6 (from 300 mm to <500 mm) is not present in Germany's arable land, and CWBg class 7 (>500 mm) is not present in Germany's agricultural land (arable and grassland). Among the grassland, the largest share of 33% is classified as CWBg class 3 (Table 3). 23% of grassland are classified as CWBg class 5. 18% are classified as CWBg class 2, 14% as CWBg class 1 and 9% as CWBg class 4. CWBg class 6 is present in a small share (3%) of Germany's grassland at higher altitudes in the Alpine region.

To analyse sites in every CWBg class, each class would have to be represented through LTFEs. Ideally, the shares of LTFEs in each class would correspond to the agricultural area. This is, of course, not the case (Table 2), as LTFEs were not established systematically in the landscape. Each CWBg class present in the arable land is represented by LTFEs, but they are not found in the same shares. CWBg class 1 is overrepresented by all LTFE types, CWBg class 2 is underrepresented by crop rotation LTFEs, class 3 is underrepresented by fertilization LTFEs and crop rotation LTFEs, class 4 is underrepresented by tillage LTFEs and overrepresented by crop rotation LTFEs (although in number, there are only 4 crop rotation LTFEs), and class 5 again is overrepresented by crop rotation LTFEs (although in number, there are only 6 crop rotation LTFEs) (Table 2; Figure 4) Overall, the three CWBg classes 1-3 representing 89% of the arable land area also host 89% of the LTFEs with a certain bias towards the driest CWBg class 1. Given that no spatial planning was considered during the allocation of LTFEs, this is a remarkably good distribution.

Among grassland LTFEs, not every CWBg class is represented by LTFEs (Table 3). Thus, CWBg class 6 is present in a small share of grassland (3%) but is not represented by any grassland LTFEs. CWBg classes 2 and 5 are underrepresented by grassland LTFEs, while CWBg classes 3 and 4 are overrepresented by grassland LTFEs. Overall and compared to the arable land area, the three driest CWBg classes 1-3 represent only 65% of the grassland area and host 71% of the grassland LTFEs.

3.2.2 Geospatial Analysis of LTFEs in Relation to the Müncheberg Soil Quality Rating (MSQR) Distribution

An overview of the distribution of the MSQR classes and of LTFEs in Germany is given in Figure 5. Soils classified as 'very high' are located mainly in the central part of Germany. Soils classified as 'high' exist in the central part and in the south of Germany as well as in some smaller areas in the north-western region of Germany, including the coastlines. Soils classified as 'low' and 'medium' are predominant in the northern part of Germany but also exist in some areas in the middle and south of Germany. Soils classified as 'very low' mainly exist in north-eastern Germany. Soils classified as 'extremely low' exist mainly in small areas of mid-east and mid-west and north-west Germany (Figure 5).

The classification of the agricultural area into the six MSQR classes (Table 4) is as follows: The largest share (28%) of agricultural area is classified as 'medium'. The smallest shares are classified as 'extremely low' (6%) and 'very high' (10%). Medium shares are classified as 'very low' (17%), 'low' (21%) and 'high' (18%). LTFE sites exist in all MSQR classes, and overall, the distribution of the LTFE sites follows a similar pattern as that of the MSQR classes, with the exception of a bias towards the 'high' MSQR class.

3.2.3 Geospatial Analysis of LTFEs in Relation to the combined CWBg and MSQR Distribution

The share of the arable area in Germany and the share of LTFEs on arable land in every CWBg-MSQR intersection are compared (Figure 6). According to this analysis, in the MSQR class ‘extremely low’, the share of LTFEs matches the share of arable land area in each CWBg class. In the other MSQR classes, CWBg 1 is overrepresented by LTFEs compared to the respective land area. Thus, regarding climate, the distribution of LTFEs is biased towards dry areas with very low CWBg class 1. The reason for this bias is probably because most of these LTFEs are located in the region surrounding Berlin and the region Bad Lauchstädt/Halle/Seehausen, which are both historical agricultural research areas.

In CWBg class 2, the distribution of LTFEs is biased towards high and very high MSQR classes. This result is mainly caused by the sites Bonn, Braunschweig, Gießen and Göttingen.

CWBg class 3 is underrepresented by LTFEs in the MSQR classes of very low, low, medium and high.

CWBg classes 4 and 5 are rather adequately represented by LTFEs in every MSQR class. However, these CWBg classes rarely exist in Germany.

For the landscape approach proposed in this paper, more LTFEs would be required in areas with CWBg class 3 on soils classified as MSQR ‘very low’, ‘low’, ‘medium’ and ‘high’ and in areas with CWBg class 2 on soils classified as MSQR ‘very low’, ‘low’ and ‘medium’.

3.2.4 Geospatial Analysis of LTFE in Relation to the clay content Distribution

According to Table 5, every clay content class is represented by LTFEs on arable land. Clay content class 4 (17% to 19% clay content) is overrepresented by LTFE, while the high clay content classes 7 (25% to 27% clay content) and 8 (28% to 98% clay content) are underrepresented, especially by fertilization and crop rotation LTFEs.

Among grassland, LTFEs in clay content class 3 (11% to 16% clay content) are completely missing (Table 6). The clay content classes 5 (20% to 21% clay content), 6 (22% to 24% clay content) and 7 (25% to 27% clay content) are overrepresented by grassland LTFEs, while the other clay content classes are rather equally represented.

Franko et al. (2011) found in their analysis of 40 LTFEs for the validation of a C-Model that more experimental results on clay soils would be required. This could be confirmed for LTFEs on arable land in this study.

4 Conclusions

To obtain adequate information about each CWBg, MSQR and clay content class through LTFEs, more LTFEs would have to be established. However, nearly every class is represented by at least some LTFEs. For the joint analysis, there are other, more important constraints: data are not easy to access, and sometimes the older data are not digitized. Here, BonaRes offers great opportunities through the provision of support for data preparation and through the establishment of a common database. We hope that this great opportunity will be frequently used by LFTE holders in future.

Data availability

The LTFE metadata are available in the BonaRes Respository: Grosse, M., and Hierold, W.: Long-term Field Experiments in Germany [Data set], BonaRes, http://doi.org/10.20387/BonaRes-3tr6-mg8r, 2019.

Author Contribution

Conceptualization: Meike Grosse, Katharina Helming, Wilfried Hierold
Data curation: Meike Grosse and Wilfried Hierold
Formal analysis: Meike Grosse, Marlen C. Ahlborn, Hans-Peter Piepho
Supervision: Katharina Helming
Visualization: Meike Grosse, Marlen C. Ahlborn
Writing: Meike Grosse with contributions from all authors

Acknowledgements

This work was funded by the German Federal Ministry of Education and Research (BMBF) in the framework of the funding measure 'Soil as a Sustainable Resource for the Bioeconomy – BonaRes', project 'BonaRes (Module B): BonaRes Centre for Soil Research, subproject B' (Grants 031A608B and 031B0511B). Many thanks to Biljana Savic and Kevin Urbasch for help with GIS-analyses. Many thanks to three anonymous referees for most valuable and in-depths comments.

Declaration of Interest Statement

The authors declare that they have no conflict of interest.

References

Ad-hoc-AG Boden: Manual of soil mapping. 5th Ed. (KA5), edited by: Eckelmann, W., Sponagel, H., Grottenthaler, W., Hartmann, K.-J., Hartwich, R., Janetzko, P., Joisten, H., Kühn, D., Sabel, K.-J., and Traidl, R., Schweizerbart'sche Verlagsbuchhandlung, Hannover, 2005.

Ad-hoc-AG Boden: Methodendokumentation Bodenkunde. Auswertungsmethoden zur Beurteilung der Empfindlichkeit und Belastbarkeit von Böden. Auszug: Kapitel 6.3 Ackerbauliches Ertragspotential eines Standorts, 2010.

Amberger, A., and Gutser, R.: Effect of long-term potassium fertilization on crops and potassium dynamics of a brown earth (Weihenstephan), ANN AGRON, 27, 643-657, 1976.

Askari, M. S., Cui, J., and Holden, N. M.: The visual evaluation of soil structure under arable management, SOIL TILL RES, 134, 1-10, https://doi.org/10.1016/j.still.2013.06.004, 2013.

Bai, Z. C., T., Ruiperez Gonzalez, M., Batjes, N. H., Mäder, P., Bünemann, E. K., de Goede, R., Brussaard, L., Xu, M., Ferreira, C. S. S., Reintam, E., Fan, H., Mihelič, R., Glavan, M., and Tóth, Z.: Effects of agricultural management practices on soil quality: A review of long-term experiments for Europe and China, AGR ECOSYST ENVIRON, 265, 1–7, https://doi.org/10.1016/j.agee.2018.05.028, 2018.

Berti, A., Marta, A. D., Mazzoncini, M., and Tei, F.: An overview on long-term agro-ecosystem experiments: Present situation and future potential, EUR J AGRON, 77, 236-241, https://doi.org/10.1016/j.eja.2016.01.004, 2016.

BGR (Bundesanstalt für Geowissenschaften und Rohstoffe): Nutzungsdifferenzierte Bodenübersichtskarte von Deutschland 1:1.000.000 - Auszug Acker: https://www.bgr.bund.de/DE/Themen/Boden/Produkte/Karten/Downloads/BUEK1000N_Acker.pdf?__blob=publicationFile&v=2, 2007.

BGR (Bundesanstalt für Geowissenschaften und Rohstoffe): Ackerbauliches Ertragspotential der Böden in Deutschland. Bewertet nach dem Müncheberger Soil Quality Rating – Final Rating (1:1.000.000) auf Basis der BÜK1000N: https://www.bgr.bund.de/DE/Themen/Boden/Bilder/Bod_SoilQualityRating1000_g.html;jsessionid=31E571D5F90D3A3D393904AD68C7F548.2_cid331?nn=4571954., 2014.

BonaRes, https://www.bonares.de/, last access: 10 September 2020.

Ciaccia, C., Ceccarelli, D., Antichi, D., and Canali, S.: Long-term experiments on agroecology and organic farming: the Italian long-term experiment network. In: Bullar, G. and Riar, A. (Eds.): Long-Term Farming Systems Research. Ensuring Food Security in Chaning Scenarios. Academic Press, 183-196, 2020.

CLC (Corine Land Cover), Version 20: https://land.copernicus.eu/pan-european/corine-land-cover/clc2018/#, 2018.

Crimmins, S. M., Dobrowski, S. Z., Greenberg, J. A., Abatzoglou, J. T., and Mynsberge, A. R.: Changes in Climatic Water Balance Drive Downhill Shifts in Plant Species' Optimum Elevations, Science, 331, 324–327, https://doi.org/10.1126/science.1199040, 2011.

Daedlow, K., Lemke, N., and Helming, K.: Arable Land Tenancy and Soil Quality in Germany: Contesting Theory with Empirics, SUSTAINABILITY-BASEL, 10, http://doi.org/10.3390/su10082880, 2018.

DWD (Deutscher Wetterdienst): Index of climate environment CDC grids Germany multi annual water balance. https://opendata.dwd.de/climate_environment/CDC/grids_germany/multi_annual/water_balance/, 2020.

Debreczeni, K., and Körschens, M.: Long-term field experiments of the world, ARCH ACKER PFL BODEN, 49, 465-483, https://doi.org/10.1080/03650340310001594754, 2003.

Ellerbrock, R. H., Kersebaum, K. C., and Kaiser, M.: Isolation and characterization of soil organic matter fractions different in solubility as a possibility to evaluate and to improve C-pools in C-turnover models, ARCH ACKER PFL BODEN, 51, 209-219, https://doi.org/10.1080/03650340400026644, 2005.

Ellerbrock, R. H., and Gerke, H. H.: Analyzing Management-Induced Dynamics of Soluble Organic Matter Composition in Soils from Long-Term Field Experiments, VADOSE ZONE J, 15, https://doi.org/10.2136/vzj2015.05.0074, 2016.

ArcGis Desktop 10.6.1, 2018.

ESDAC (European Soil Data Centre), European Commission, Joint Research Centre: https://esdac.jrc.ec.europa.eu, last access: 29.07.2020..

Franko, U., Schramm, G., Rodionova, V., Körschens, M., Smith, P. Coleman, K., Romanenkov, V., Shevtsova, L.,: EuroSOMNET - A database for Long-term experiments on soil organic matter in Europe. COMPUT ELECTRON AGRIC, 33. 233-239, https://10.1016/S0168-1699(02)00009-1, 2002.

Franko, U., Kolbe, H., Thiel, E., and Liess, E.: Multi-site validation of a soil organic matter model for arable fields based on generally available input data, GEODERMA, 166, 119-134, https://doi.org/10.1016/j.geoderma.2011.07.019, 2011.

GLTEN: https://www.glten.org/experiments, last access: 09 September 2020.

Grosse, M., Heinrich, U., and Hierold, W.: Fact Sheet for the Description of Long-Term Field Experiments / Steckbrief zur Beschreibung von Dauerfeldversuchen, https://doi.org/10.20387/BonaRes-R56G-FGRW, 2019.

Grosse, M., and Hierold, W.: Long-term Field Experiments in Germany [Data set], BonaRes, https://doi.org/10.20387/BonaRes-3tr6-mg8r, 2019.

Hamidov, A., Helming, K., Bellocchi, G., Bojar, W., Dalgaard, T., Ghaley, B. B., Hoffmann, C., Holman, I., Holzkämper, A., and Krzeminska, D.: Impacts of climate change adaptation options on soil functions: A review of European case-studies, LAND DEGRAD DEV, 29, 2378-2389, https://doi.org/10.1002/ldr.3006, 2018.

Hanauer, T., Pohlenz, C., Kalandadze, B., Urushadze, T., and Felix-Henningsen, P.: Soil distribution and soil properties in the subalpine region of Kazbegi; Greater Caucasus; Georgia: Soil quality rating of agricultural soils, ANN AGRIC SCI , 15, 1-10, https://doi.org/10.1016/j.aasci.2016.12.001, 2017.

Kaiser, M., Piegholdt, C., Andruschkewitsch, R., Linsler, D., Koch, H. J., and Ludwig, B.: Impact of tillage intensity on carbon and nitrogen pools in surface and sub-surface soils of three long-term field experiments, EUR J SOIL SCI, 65, 499-509, https://doi.org/10.1111/ejss.12146, 2014.

Körschens, M.: Dauerfeldversuche: Übersicht, Entwicklung und Ergebnisse von Feldversuchen mit mehr als 20 Jahren Versuchsdauer, Akademie der Landwirtschaftswissenschaften, Berlin, 1990.

Körschens, M.: Der Statische Düngungsversuch Bad Lauchstädt nach 90 Jahren: Einfluss der Düngung auf Boden, Pflanze und Umwelt : mit einem Verzeichnis von 240 Dauerfeldversuchen der Welt, B.G. Teubner Verlagsgesellschaft, Leipzig, 1994.

Körschens, M.: Die wichtigsten Dauerfeldversuche der Welt - Übersicht, Bedeutung, Ergebnisse, ARCH ACKER PFL BODEN, 42, 157-168, https://doi.org/10.1080/03650349709385724, 1997.

Körschens, M. (Ed.): IOSDV: Internationale organische Stickstoffdauerdüngungsversuche. Bericht der Internationalen Arbeitsgemeinschaft Bodenfruchtbarkeit in der Internationalen Bodenkundlichen Union (IUSS), UFZ-Bericht, 15/2000, Bad Lauchstädt, 2000.

Körschens, M.: The importance of long-term field experiments for soil science and environmental research – a review, PLANT SOIL ENVIRON, 52, 1-8, 2006.

Körschens, M., Albert, E., Baumecker, M., Ellmer, F., Grunert, M., Hoffmann, S., Kismanyoky, T., Kubat, J., Kunzova, E., Marx, M., Rogasik, J., Rinklebe, J., Rühlmann, J., Schilli, C., Schröter, H., Schroetter, S., Schweizer, K., Toth, Z., Zimmer, J., and Zorn, W.: Humus und Klimaänderung - Ergebnisse aus 15 langjährigen Dauerfeldversuchen, ARCH ACKER PFL BODEN, 60, 1485-1517, https://doi.org/10.1080/03650340.2014.892204, 2014.

Macholdt, J., Piepho, H.-P., and Honermeier, B.: Mineral NPK and manure fertilisation affecting the yield stability of winter wheat: Results from a long-term field experiment, EUR J AGRON, 102, 14-22, https://doi.org/10.1016/j.eja.2018.10.007, 2019a.

Macholdt, J., Piepho, H.-P., and Honermeier, B.: Does fertilization impact production risk and yield stability across an entire crop rotation? Insights from a long-term experiment. FIELD CROPS RES., 238, 82-92, https://doi.org/10.1016/j.fcr.2019.04.014, 2019b).

Merbach, W., and Deubel, A.: Long-term field experiments – museum relics or scientific challenge? PLANT SOIL ENVIRON, 219-226, http://doi.org/10.17221/395-PSE, 2008.

Mueller, L., Schindler, U., Mirschel, W., GrahamShepherd, T., Ball, B. C., Helming, K., Rogasik, J., Eulenstein, F., and Wiggering, H.: Assessing the productivity function of soils. A review, AGRON SUSTAIN DEV, 30, 601-614, https://doi.org/10.1051/agro/2009057, 2010.

Onofri, A., Seddaiu, G., and Piepho, H.-P.: Long-term experiments with cropping systems: case studies on data analysis. EUR J AGRON., 77, 223-235, https://doi.org/10.1016/j.eja.2016.02.005, 2016.

Payne, R.W.: The design and analysis of long-term rotation experiments. AGRON J, 107, 772–785, 2015.

Pereira, L. S., Allen, R. G., Smith, M., and Raes, D.: Crop evapotranspiration estimation with FAO56: Past and future, AGR WATER MANAGE., 147, 4-20, http://doi.org/10.1016/j.agwat.2014.07.031, 2015.

Piepho, H.-P. and Vo-Thanh, N.: Die Gleitmethode nach Mitscherlich und was sie mit Geostatistik zu tun hat. J KULTURPFLANZEN, 2020 (accepted).

Reckling, M., Döring, T. F., Bergkvist, G., Stoddard, F. L., Watson, C. A., Seddig, S., Chmielewski, F. M., and Bachinger, J.: Grain legume yields are as stable as other spring crops in long-term experiments across northern Europe, AGRON SUSTAIN DEV., 38, https://doi.org/10.1007/s13593-018-0541-3, 2018.

Reckling, M., Macholdt, J., Ahrends, H., Chen, T.W., Eugster, W., Hadasch, S., Knapp, S, Knaup, H., Laidig, F., Linstädter, A., Piepho, H.P., Schiffers, K., Schuh, W.D., and Döring, T.F.: A methodological guide on yield stability in long-term field experiments. A review. AGRON SUSTAIN DEV., 2020 (under review)

Richter, C. and Kroschewski, B.: Analysis of a long-term experiment with repeated-measurement models. J AGRON CROP SCI, 192, 55–71, 2006.

Sandén, T., Spiegel, H., Stüger, H. P., Schlatter, N., Haslmayr, H. P., Zavattaro, L., Grignani, C., Bechini, L., D′Hose, T., Molendijk, L., Pecio, A., Jarosz, Z., Guzmán, G., Vanderlinden, K., Giráldez, J. V., Mallast, J., ten Berge, H., and

Aitkenhead, M.: European long-term field experiments: knowledge gained about alternative management practices, SOIL USE MANAGE, 34, 167-176, https://doi.org/10.1111/sum.12421, 2018.

Sattar, A., Khan, S. A., and Banerjee, S.: Climatic water balance for assessment of growing season in the eastern Indian state of Bihar, MAUSAM, 70, 569-580, 2019.

Singh, M., and Jones, M.J.: Modeling yield sustainability for different rotations inlong-term barley trials. J AGRIC BIOL ENVIRON STAT. 7, 525–535, 2002.

Smolentseva, E., Smolentsev, B., Pachkin, K., and Mueller, L.: Assessing the Soil Quality and Crop Yield Potentials of Some Soils of Eurasia, in: Novel Measurement and Assessment Tools for Monitoring and Management of Land and Water Resources in Agricultural Landscapes of Central Asia, edited by: Mueller, L., Saparov, A., and Lischeid, G., Environmental Science and Engineering, Springer, Cham, 2014.

Techen, A.-K., Helming, K., Brüggemann, N., Veldkamp, E., Reinhold-Hurek, B., Lorenz, M., Bartke, S., Heinrich, U., Amelung, W., and Augustin, K.: Soil research challenges in response to emerging agricultural soil management practices, ADV AGRON, https://doi.org/10.1016/bs.agron.2020.01.002, 2020.

TERENO: https://www.tereno.net/joomla/index.php, last access: 09. September 2020.

Vogel, H.-J., Eberhardt, E., Franko, U., Lang, B., Ließ, M., Weller, U., Wiesmeier, M., and Wollschläger, U.: Quantitative Evaluation of Soil Functions: Potential and State, FRONT ENVIRON SCI., 7, https://doi.org/10.3389/fenvs.2019.00164, 2019.

Figures and Tables

(In the order of their appearance)

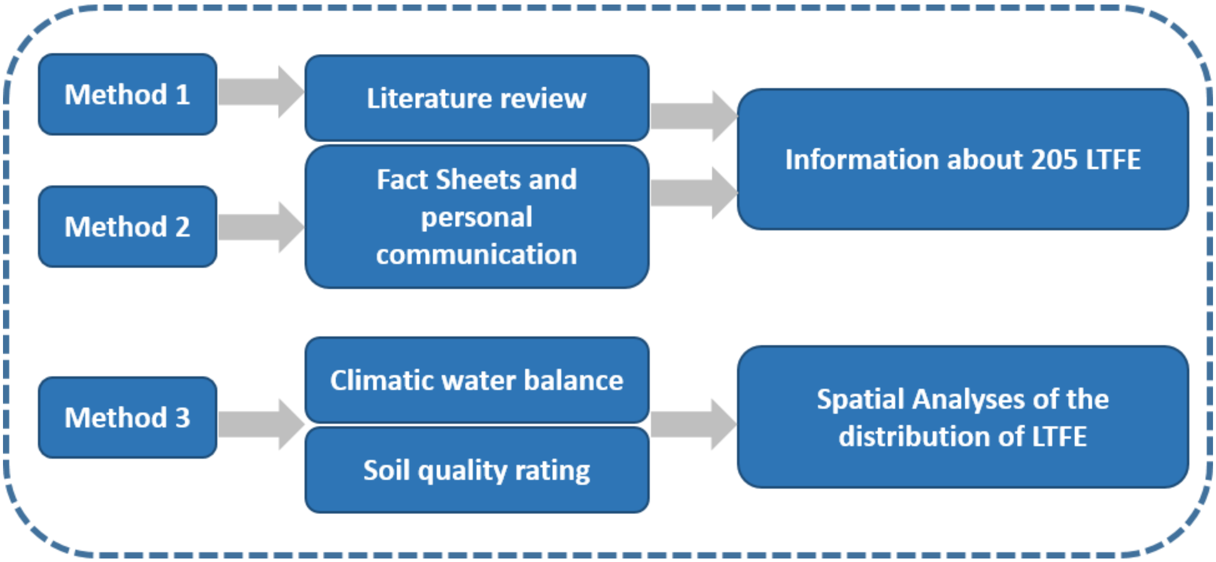


Figure 1: Methods used for assessing the representativeness of the LTFE distribution in Germany.

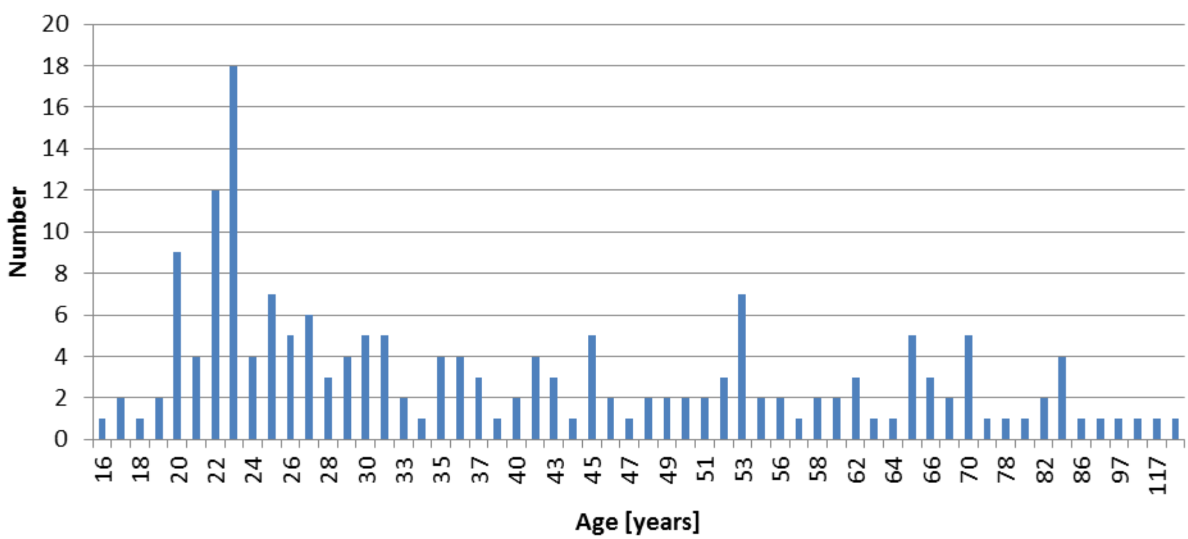


Figure 2: Number of LTFEs per age in 2019 (n=183; age of 22 LTFEs unknown)

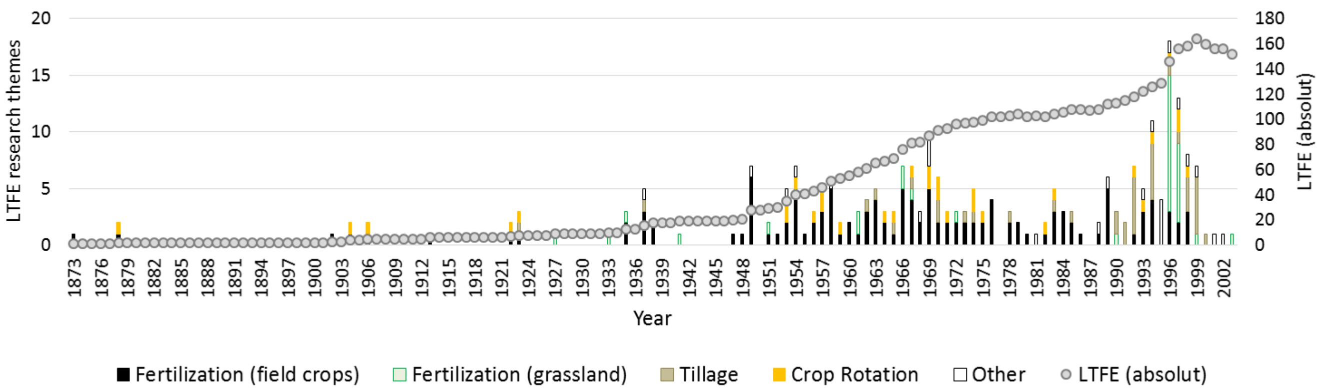


Figure 3: Number of LTFEs' set up per year according to the research themes of the experiments (multiple nominations possible, n=251) and total number of LTFEs per year (= established LTFE minus terminated LTFE).

Table 1: Research themes in LTFEs (multiple nominations possible, sorted by frequency).

Theme	Number of trials
Fertilization – field crops experiments	**124**
Manure fertilization	58
Mineral N-fertilization	55
Straw fertilization	24
Mineral K-fertilization	15
Mineral P-fertilization	14
Liming	10
Green manure (with *vs*. without)	8
Mineral fertilization (not specified)	6
Mineral Mg-fertilization	4
Compost	3
Sludge	2
Tillage – field crops experiments	**38**
Reduced depth or conservation tillage	24
Inversion *vs*. non-inversion tillage	12
Sowing methods	10
Different forms of primary tillage	7
Stubble tillage (with *vs*. without)	3
Tillage frequency	3

Other	2
Fertilization – grassland experiments	**34**
Mineral P-fertilization	11
Mineral K-fertilization	10
Mineral N-fertilization	6
Liming	4
Manure fertilization	2
Sludge	2
Mineral fertilization (not specified)	1
Acid *vs*. alkaline fertilization	1
Crop rotation – field crops experiments	**32**
Crop rotation (not specified)	23
Rotational cropping *vs*. monoculture	4
Effect of pre crop	2
Crop rotation organic *vs.* integrated	1
Different percentages of cereals	1
Different percentages of wheat	1
Other – field crops and grassland experiments	**23**
Crop protection	5
Irrigation	4
Effects of different forms of fallow	3
Frequency and start of utilization of grassland	2
Land use systems comparison	2
Monitoring of Organic Farming	2
Use of biodynamic preparations	2
Chopped woody plants for weed suppression	1
Effect of weather conditions	1
Thistle control	1

Table 2: Climatic water balance of the growing season (1 May to 31 October) (CWBg) classification of arable land in Germany and the number or share of the different LTFE types in each CWBg class.

CWBg class	Range [mm/yr]	Agricultural area (arable)		LTFE total (arable land) (n=169)		Fertilization LTFE* (n=124)		Tillage LTFE* (n=38)		Crop rotation LTFE* (n=32)	
		area [ha]	share [%]	number	share [%]	number	share [%]	number	share [%]	number	share [%]
1	<-150	3 135 676	23	66	39	49	40	13	34	13	41
2	-150 - <-50	4 473 111	33	49	29	39	31	12	32	6	19
3	-50 - <50	4 468 852	33	35	21	21	17	11	29	3	9
4	50 - <150	926 798	7	10	6	10	8	1	3	4	13
5	150 - <300	492 110	4	9	5	5	4	1	3	6	19
6	300 - <500	0	0	0	0	0	0	0	0	0	0
7	>500	0	0	0	0	0	0	0	0	0	0

*multiple nominations possible

Table 3: Climatic water balance of the growing season (CWBg) classification of agricultural area used for grassland in Germany and the number or share of the LTFEs on grassland in each CWBg class.

CWBg class	Range [mm/yr]	Agricultural area (grassland)		Grassland LTFE (n=34)	
		area [ha]	share [%]	number	share [%]
1	<-150	599 247	14	6	18
2	-150 - <-50	792 064	18	3	9
3	-50 - <50	1 420 319	33	15	44
4	50 - <150	398 496	9	7	21
5	150 - <300	1 009 952	23	3	9
6	300 - <500	137 968	3	0	0
7	>500	0	0	0	0

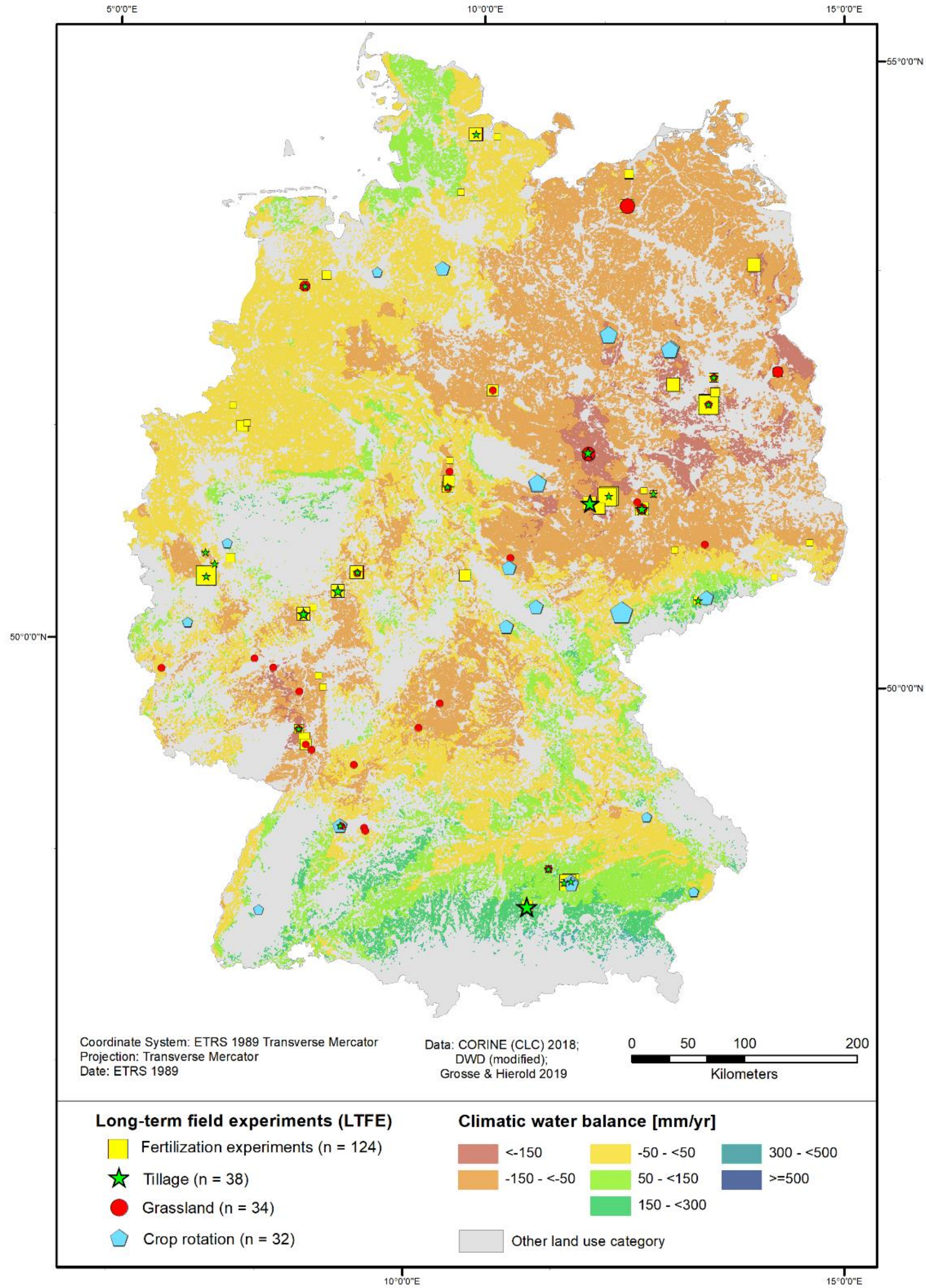
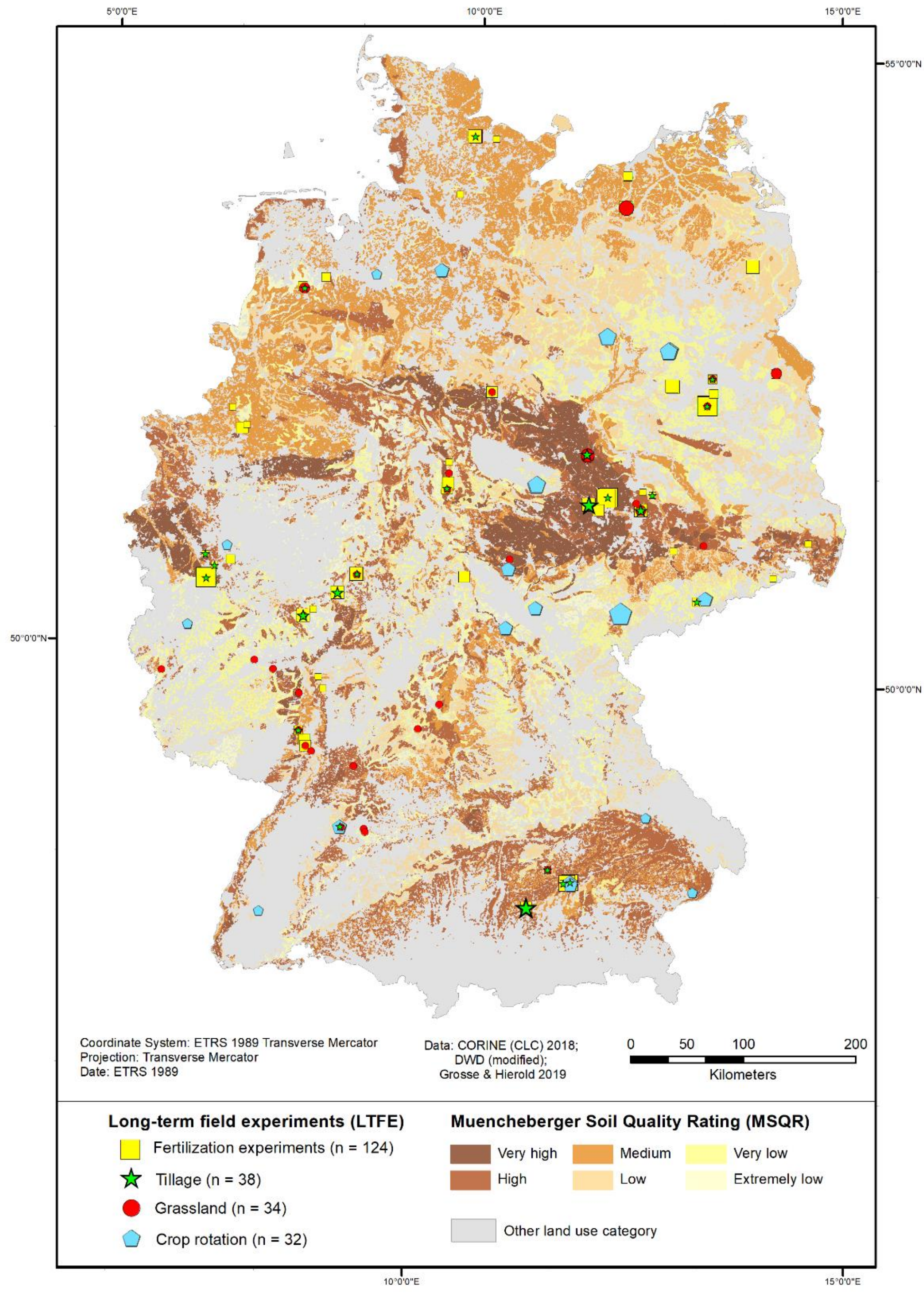


Figure 4: Overview of the distribution of the different climatic water balance classes of the growing season and the different LTFE types in Germany.. The size of the symbols varies according to the amount of LTFEs at one place.

Table 4: Müncheberg Soil Quality Rating (MSQR) classification of arable land in Germany and the number or share of the different LTFE types in each MSQR class.

MSQR	Agricultural area		LTFEs total (arable land) (n=169)		Fertilization LTFEs* (n=123)		Tillage LTFEs* (n=38)		Crop rotation LTFEs* (n=32)	
	area [ha]	share [%]	number	share [%]	number	share [%]	number	share [%]	number	share [%]
extremely low	705 687	6	9	5	5	4	4	11	3	9
very low	2 149 584	17	29	17	22	18	5	13	5	16
low	2 656 535	21	18	11	13	11	3	8	1	3
medium	3 532 109	28	32	19	28	23	6	16	4	13
high	2 182 221	18	45	27	28	23	13	34	11	34
very high	1 181 237	10	36	21	27	22	7	18	8	25

*multiple nominations possible



545 Figure 5: Overview of the distribution of the different Müncheberg Soil Quality Rating classes and the different LTFE types in Germany. The size of the symbols varies according to the amount of LTFEs at one place.

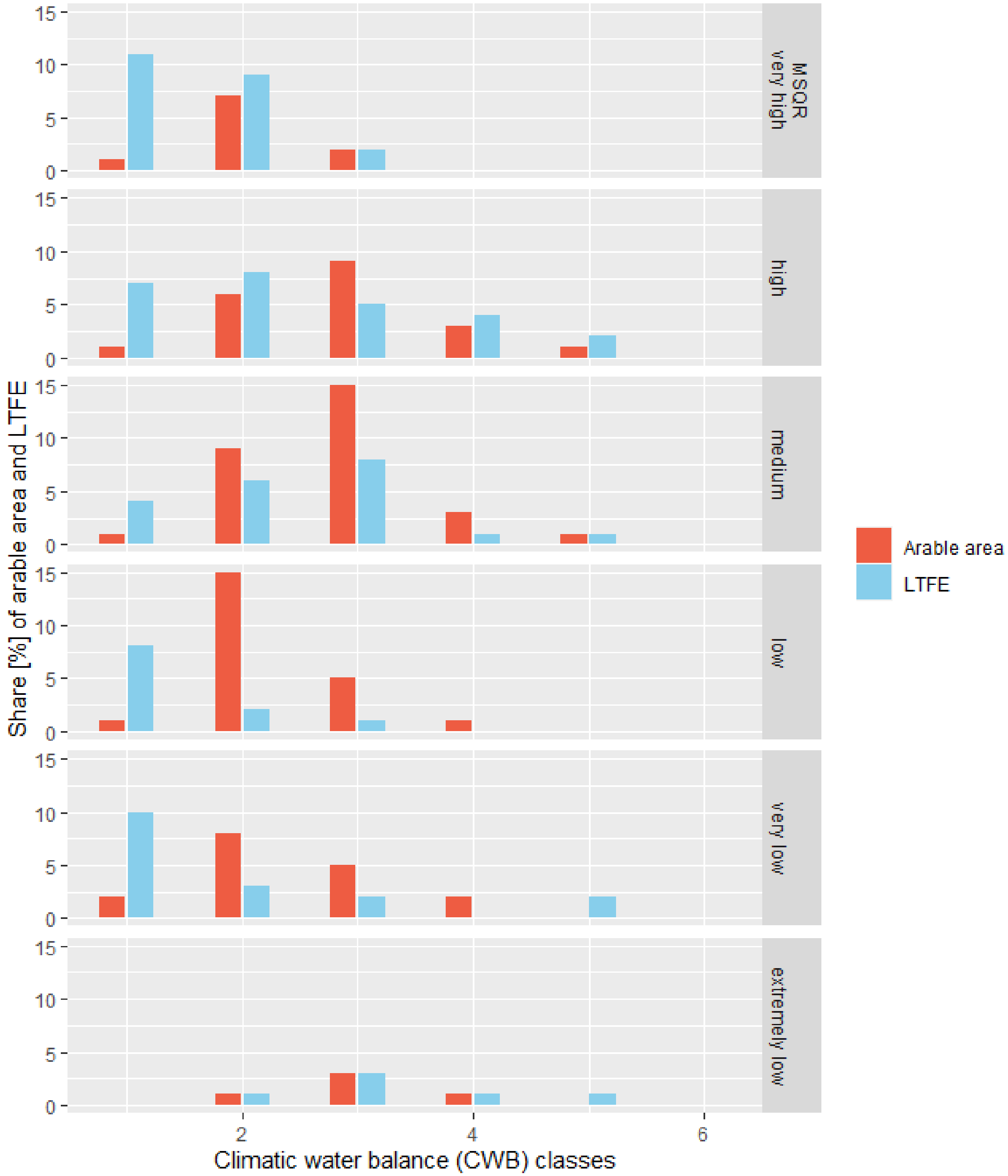


Figure 6: Share of arable area and LTFEs in every climatic water balance – Müncheberg Soil Quality Rating combination.

Table 5: Clay content classification according to ESDAC (2020) of arable land in Germany and the number or share of the different LTFE types in each clay content class.

Clay content class	Range [%]	Agricultural area (arable)		LTFEs total (arable land) (n=169)		Fertilization LTFEs* (n=124)		Tillage LTFEs* (n=38)		Crop rotation LTFEs* (n=32)	
		area [ha]	share [%]	number	share [%]	number	share [%]	number	share [%]	number	share [%]
1	0 to 5	1 748 393	14	25	15	19	15	6	16	3	9
2	6 to 10	2 404 798	19	24	14	19	15	6	16	3	9
3	11 to 16	2 265 517	18	29	17	20	16	5	13	4	13
4	17 to 19	1 523 493	12	42	25	37	30	6	16	6	19
5	20 to 21	1 179 602	9	15	9	12	10	2	5	8	25
6	22 to 24	1 553 463	12	20	12	11	9	5	13	6	19
7	25 to 27	1 097 725	9	4	2	1	1	3	8	1	3
8	28 to 98	1 082 066	8	10	6	5	4	5	13	1	3

Table 6: Clay content classification according to ESDAC (2020) of agricultural area used for grassland in Germany and the number or share of the LTFEs on grassland in each clay content class.

Clay content class	Range [%]	Agricultural area (grassland)		Grassland LTFEs (n=34)	
		area [ha]	share [%]	number	share [%]
1	0 to 5	715 137	11	3	9
2	6 to 10	941 166	15	5	15
3	11 to 16	952 126	15	0	0
4	17 to 19	821 432	13	4	12
5	20 to 21	710 826	11	6	18
6	22 to 24	978 366	15	5	15
7	25 to 27	651 066	10	8	24
8	28 to 98	639 561	10	3	9

Appendix

Table A 1: IDs of all long-term field experiments, their original name, their place, their CWBg class (1 May to 31 October), their MSQR class, and their thematic classification. The institutional address is indicated by a number and given below the table. More details about the LTFEs can be found in the complete dataset (Grosse & Hierold, 2019).

ID	LTFE Name	Place of LTFE	Address (see below)	CWBg Class	MSQR Class	Thematic Classification
			Fieldcrops LTFE			
1	Bodenbearbeitungsversuch Dichtelbach	Dichtelbach (Hunsrück)	1	3	very low	Tillage
2	Bodenbearbeitungsversuch Welschbillig	Welschbillig (Eifel)	1	3	very low	Tillage
3	Bodenbearbeitungsversuch Wintersheim	Wintersheim (Rheinhessen)	1	1	very high	Tillage
4	Statischer Düngungsversuch V120	Bad Lauchstädt	2	1	very high	Fertilization
5	Erweiterter Statischer Düngungsversuch V120a	Bad Lauchstädt	2	1	very high	Fertilization
6	Modellversuch Stalldungsteigerung	Bad Lauchstädt	2	1	very high	Fertilization
7	Bracheversuch V505a	Bad Lauchstädt	2	1	very high	Other
8	Statischer Stickstoffdüngungsversuch	Bad Salzungen	3	2	very low	Fertilization
9	Statischer Kalkdüngungsversuch M16	Bad Salzungen	3	2	very low	Fertilization
11	Dauerdüngungsversuch L28	Bad Salzungen	3	2	very low	Fertilization
13	Statischer Dauerversuch Bodennutzung (BDa_D3)	Berlin-Dahlem	4	1	very low	Fertilization/Tillage/ Crop rotation
14	Internationaler Organischer-	Berlin-Dahlem	4	1	very low	Fertilization

	Stickstoff-Dauerdüngungsversuch (BDa_IOSDV)					
15	Agrarmeteorologisches Intensivmessfeld (BDa_E-Feld)	Berlin-Dahlem	4	1	very low	Other
16	Bodenbearbeitungsversuch (Versuchsfeld Westerfeld)	Bernburg-Strenzfeld	5	1	very high	Tillage
17	Anbausysteme-Vergleich	Bernburg-Strenzfeld	6	1	very high	Crop rotation/Other
18	Grundbodenbearbeitung und Distelbekämpfung, ö• kologisch viehlos	Bernburg-Strenzfeld	6	1	very high	Tillage/Crop rotation/Other
19	Bodenbearbeitung und Bestelltechnik in der Fruchtfolge	Bernburg-Strenzfeld	6	1	very high	Tillage/Other
20	Dauerdüngungsversuch Dikopshof	Wesseling-Dikopshof	7	2	very high	Fertilization/Crop rotation
21	Selektions-Dauerversuch SDV	Klein Altendorf	7	3	very high	Crop rotation
22	Strohdüngung zu Getreide	Meckenheim	7	2	very high	Fertilization
23	Phosphatformenversuch	Meckenheim	7	2	very high	Fertilization
24	Organische Düngung	Meckenheim	7	2	very high	Fertilization
25	Strohdüngung mit Faulschlamm	Meckenheim	7	2	very high	Fertilization
26	Kaliformenversuch	Meckenheim	7	2	very high	Fertilization
27	Strohdüngung mit verschiedenen N-Formen	Meckenheim	7	2	very high	Fertilization
28	Phosphatvorratsdüngung	Meckenheim	7	2	very high	Fertilization
29	Kalkversuch mit Spurenelementen	Meckenheim	7	2	very high	Fertilization
30	Versuch mit Faulschlämmen	Meckenheim	7	2	very high	Fertilization

31	Dauerdüngungsversuch	Bonn-Poppelsdorf	7	2	high	Fertilization/Crop rotation
33	Langzeit Düngungsversuch (FV4)	Völkenrode	8	2	very high	Fertilization/Tillage
34	C-Dauerfeldversuch (FV36)	Völkenrode	8	2	very high	Fertilization
35	Südfeld-Düngungsversuch	Völkenrode	9	2	very high	Fertilization
36	Folgenabschätzung der Wechselwirkung von Fruchtfolge, Düngung und Pflanzenschutz	Dahnsdorf	10	1	high	Other
37	Langzeit-Düngungsversuch	Darmstadt	11	2	low	Fertilization
38	Klassischer DFV (4b2, organische und mineralische Düngung)	Dülmen	12	3	medium	Fertilization
39	Dauerdüngungsversuch IOSDV	Dülmen	12	3	medium	Fertilization
40	Zuckerrübenfruchtfolgeversuch	Etzdorf	13	1	very high	Fertilization/Crop rotation/Other
41	Dauerdüngungsversuch (Zuckerrübenmonokultur)	Etzdorf	13	1	very high	Fertilization/Crop rotation
42	Dauerdüngungsversuch Getreide (Getreidedauerversucht)	Etzdorf	13	1	very high	Fertilization/Crop rotation
43	Dauerdüngungsversuch Getreide (Getreidedauerversuch zur Bekämpfung der Halmbruchkrankheit)	Etzdorf	13	1	very high	Fertilization/Crop rotation
44	N-Formen-Versuch	Freising	14	4	high	Fertilization/Crop rotation

45	P-Düngung	Freising	14	4	high	Fertilization
47	Stroh/Stalldung-Fruchtfolge	Freising	14	4	high	Fertilization
48	N-Düngung/Fruchtfolge	Freising	14	4	high	Fertilization
49	N-Steigerung mit Kalkstickstoff	Freising	14	4	high	Fertilization
50	Versuch 020 N-Formen-Versuch	Freising	14	3	high	Fertilization
51	Bodenbearbeitungsversuch Südzucker	Friemar	15	2	very high	Tillage
52	Erschöpfungsversuch (EV)	Gießen	16	2	low	Fertilization
53	Kalkdüngungsversuch	Gießen	16	2	high	Fertilization
54	Dauerversuch Biologische Stickstofffixierung (BSG)	Gießen	16	2	high	Fertilization/Crop rotation
55	Ökologischer Ackerbauversuch Gladbacherhof	Villmar	17	2	extremely low	Fertilization/Tillage/ Crop rotation
56	Bodenbearbeitungsversuch Hohes Feld	Nörten-Hardenberg	18	3	high	Tillage
57	Garte-Süd-Bodenbearbeitung (Reinshof)	Göttingen	18	2	very high	Tillage
58	Garte-Nord-Bodenbearbeitung (Reinshof)	Göttingen	18	2	high	Crop rotation
59	Langzeitversuch zur P- und K-Düngung auf dem Reinshof	Nörten-Hardenberg	19	2	high	Fertilization
60	Bodenbearbeitungsversuch Südzucker	Grombach	15	3	high	Tillage
61	Kastenparzellenversuch Sandboden / Lehmboden / Tonboden	Großbeeren	20	1		Fertilization
62	PK-Mangelversuch	Groß Gerau	16	1	very low	Fertilization
63	Dauerfeldversuch P60	Groß Kreutz	21	1	low	Fertilization

64	Dauerfeldversuch M4	Groß Kreutz	21	1	very low	Fertilization
65	Versuchsfeld der Versuchsstation Groß Lüsewitz	Groß Lüsewitz	22	2	very low	Other
66	Ewiger Roggen	Halle	23	1	medium	Fertilization/Crop rotation
67	Schmalfuss'scher Dauerversuch, Feld A, Kalkdüngung	Halle	23	1	very high	Fertilization
68	Schmalfuss'scher Dauerversuch, Feld C, Kaliumdüngung	Halle	23	1	very high	Fertilization
69	Schmalfuss'scher Dauerversuch, Feld D, Phosphordüngung	Halle	23	1	very high	Fertilization
70	Organische Düngung (Feld F)	Halle	23	1	very high	Fertilization
71	Dauerfeldversuch "Bodenfruchtbarkeit"	Hennef	7	3	very high	Fertilization
72	Dauerversuch Düngung-Fruchtfolge	Renningen	24	4	medium	Fertilization/Crop rotation
73	Versuch zur Bodenbearbeitung	Renningen	24	3	low	Tillage
74	Dauerdüngungsversuch	Hohenschulen	25	3	high	Fertilization
75	Stickstoffversuch "Decline-Versuch"	Hohenschulen	25	3	medium	Fertilization
76	Fruchtfolgeversuch	Hohenschulen	25	3	medium	Fertilization/Crop rotation
77	N-Düngung zu Wintergerste	Hohenschulen	25	3	medium	Fertilization
78	Düngerartenvergleich (Versuch I)	Lauterbach	23	5	medium	Fertilization/Crop rotation
79	Kombinationswirkung (Versuch II)	Lauterbach	23	5	very low	Fertilization

80	Nährstoffverhältnisversuch	Limburgerhof/Bruch	26	1	very low	Fertilization
81	Feldwirtschaftsversuch	Limburgerhof/Bruch	26	1	low	Fertilization
82	Nährstoffmangelversuch	Limburgerhof	26	1	low	Fertilization
83	WW-Fruchtfolgeversuch	Ludwigshafen/Ruchheim	26	1	low	Fertilization/Crop rotation/Other
84	Bodenbearbeitungsversuch	Ludwigshafen/Ruchheim	26	1	high	Fertilization/Tillage
85	Bodenbearbeitungsversuch	Lüttewitz	15	2	high	Tillage
86	Dauerdüngungsversuch L28	Methau	27	3	high	Fertilization
87	Dauerdüngungsversuch (V140)	Müncheberg	28	1	low	Fertilization
88	Bodenbearbeitung (V760)	Müncheberg	28	1	low	Tillage
89	Modellbetrieb Organischer Landbau, Felder 931 - 934	Müncheberg	28	1	low	Other
90	Kalium-Steigerungsversuch Höckelheim/Südniedersachsen	Northeim/Höckelheim	29	2	low	Fertilization
91	P-Düngung auf Sandmischkultur	Oldenburg/Friesoythe	29	3	medium	Fertilization
92	Bodenbearbeitung/Fruchtfolge	Oldenburg/Friesoythe	18	3	extremely low	Tillage/Crop rotation
93	Bodenbearbeitung	Oldenburg/Friesoythe	18	3	extremely low	Tillage
94	Internationaler Organischer Stickstoffdüngungs-Versuch (IOSDV)	Oldenburg	30	3	extremely low	Fertilization
96	Dauerversuch 'Auswirkung von Daueranbau'	Puch	31	5	extremely low	Crop rotation
97	Verbesserte Dreifelderwirtschaft	Puch	31	5	high	Crop rotation
98	Getreide/Mais Fruchtfolge	Puch	31	5	high	Crop rotation
99	Einfluss von Grundbodenbearbeitung	Puch	31	5	high	Tillage

100	Internationaler Organischer Stickstoffdüngungs-Versuch (IOSDV)	Puch	31	5	high	Fertilization
101	Internationaler Organischer Stickstoffdüngungs-Versuch (IOSDV)	Rauischholzhausen	16	2	high	Fertilization
102	Organische Düngung / Stalldung Schafpferchversuch	Rauischholzhausen	16	2	high	Fertilization
103	Gründüngung / Strohdüngungsversuch	Rauischholzhausen	16	2	high	Fertilization
104	Bilanzversuch Kastenanlage	Rauischholzhausen	16	2	high	Fertilization
105	Wirkungen differenzierter Bodenbearbeitungssysteme im Dauerversuch Scheyern	Scheyern	32	4	high	Fertilization/Tillage/Cr rotation
106	Fruchtfolgedüngungsversuch	Seehausen	23	1	high	Fertilization/Crop rotation
107	Konzentrationsversuch	Seehausen	23	1	high	Crop rotation
108	Düngungs-Kombinationsversuch Seehausen (F1-70)	Seehausen	23	1	high	Fertilization
109	Bodenbearbeitungsversuch	Seehausen	23	1	high	Tillage
110	Gülledauerversuch	Seehausen	23	1	high	Fertilization
111	Bodenfruchtbarkeitsversuch	Seehausen	23	1	high	Fertilization/Tillage
112	Internationaler Organischer Stickstoffdüngungs-Versuch (IOSDV)	Speyer	33	2	high	Fertilization/Tillage
113	Humusversuch	Speyer	33	2	medium	Fertilization/Other
114	Kali-Magnesium-Kalk-Versuch	Speyer	33	2	medium	Fertilization
115	Klärschlammversuch	Speyer	33	2	medium	Other

116	Bracheversuch	Speyer	33	2	medium	Other
117	Dauerdüngungsversuch L28	Spröda	27	1	medium	Fertilization
119	Düngungs- und Beregnungsversuch (Thy_D1)	Thyrow	34	1	high	Fertilization/Other
120	Stroh- und N-Düngung in Fruchtfolgen mit unterschiedlichem Getreideanteil (Thy_D5)	Thyrow	34	1	very low	Fertilization/Crop rotation
121	Statischer Nährstoffmangelversuch (Thy_D41)	Thyrow	34	1	very low	Fertilization
122	Nährstoffmangelversuch Winterroggen Monokultur (Thy_D42)	Thyrow	34	1	very low	Fertilization
123	Statischer Bodenfruchtbarkeitsversuch (Thy_D6)	Thyrow	34	1	very low	Fertilization
125	Strohdüngungsversuch (Thy_D2)	Thyrow	34	1	very low	Fertilization
136	Modellbetrieb Organischer Landbau, Felder 901 - 904	Müncheberg	28	1	very low	Other
137	Statischer Dauerfeldversuch "organisch-mineralische N-Düngung"	Großbeeren	20	1		Fertilization
138	Versuch zur Bodenbearbeitung	Schönberg	35	3	low	Tillage
139	Gehölzhäckselapplikation	Schönberg	35	3	very low	Other
140	Versuch 700 (Reduzierte Bodenbearbeitung)	Schönberg	35	3	extremely low	Tillage
142	Effiziente Nährstoffverwertung, K-	Pommritz	27	2	extremely low	Fertilization

	Eichversuche					
143	Effiziente Nährstoffverwertung, K-Eichversuche	Forchheim	27	4	extremely low	Fertilization
144	Referenzfläche	Hennef	7	3	medium	Fertilization
146	Statischer Versuch Bodennutzung (Thy_D3/1)	Thyrow	34	1	very low	Fertilization/Tillage
147	Statischer Dauerfeldversuch Organische Düngung und Humusreproduktion (Thy_D3/2)	Thyrow	34	1	medium	Fertilization
148	Statischer N-Düngungsversuch in Winterroggen-Monokultur (Thy_D7)	Thyrow	34	1	very low	Fertilization
149	Alte dreifeldrige Fruchtfolge	Puch	31	5	very low	Fertilization/Crop rotation
150	Fruchtfolgen im ökologischen Landbau	Puch	31	5	very low	Fertilization/Crop rotation
151	Fruchtfolgen im ökologischen Landbau	Viehhausen	31	4	high	Fertilization/Crop rotation
152	Fruchtfolgeversuch (FF)	Rauischholzhausen	16	2	high	Crop rotation
153	Bodenbearbeitungs-Versuch (BB)	Rauischholzhausen	16	3	high	Tillage
154	Bodenbearbeitungsversuch Südzucker	Zschortau	15	1	high	Tillage
155	Bodenbearbeitungsversuch Südzucker	Insultheim	15	2	high	Tillage
156	Bodenbearbeitungsversuch Südzucker	Sailtheim	15	3	high	Tillage
157	Bodenbearbeitungsversuch	Gieshügel	15	2	medium	Tillage

	Südzucker					
158	Strategievergleich umweltschonender Pflanzenschutz (BS1)	Dahnsdorf	10	1	low	Other
159	Ökologischer Landbau (öko1)	Dahnsdorf	10	1	high	Other
160	Strategien zur Minderung der Anwendung chemischer Pflanzenschutzmittel (BS4)	Dahnsdorf	10	1	high	Other
161	Kalk-Düngungsversuch	Weilmünster-Ernsthausen	36	3	high	Fertilization
162	Phosphordüngungsstrategien	Biestow	37	2	high	Fertilization
165	Körnermais Daueranbau	Rotthalmünster	38	3	extremely low	Fertilization
166	Winterweizen Daueranbau	Rotthalmünster	38	3	medium	Other
167	E-Feld (bis 1957)	Göttingen	18	3	medium	Fertilization
193	Dauerfeldversuch (DE-1b-F-1, Am Kotten)	Rosendahl Holtwick	12	3	medium	Fertilization
194	Dauerfeldversuch (DE-1b-F-2, Am Hof)	Dülmen Karthaus	12	3	no data	Fertilization
195	Dauerfeldversuch (DE-1b-F-3, IPU Schlag 9)	Dülmen	12	3	medium	Fertilization
197	Feldmodellversuch "Krumenaufbau"	Müncheberg	28	1	medium	Fertilization/Tillage
203	Kalkformenversuch	Cunnersdorf	39	3	medium	Fertilization
205	Dauerdüngungsversuch (M70)	Groß Kreuz	40	1	low	Fertilization
206	Getreidedauerversuch	Noitzsch	13	1	very low	Fertilization/Crop rotation/Other
207	Stroh-Stallmistversuch	Lentföhrden	25	3	very low	Fertilization
208	Phosphor-Steigerungsversuch	Schädtbek	25	2	very low	Fertilization
209	Fruchtfolgeversuch	Gülzow	41	2	medium	Fertilization/Tillage

	Bodenbearbeitung/organische Düngung Winterraps (FF 1.1)					
210	Fruchtfolgeversuch Bodenbearbeitung/organische Düngung Sommerweizen (FF 1.2)	Gülzow	41	2	medium	Fertilization/Tillage
211	Fruchtfolgeversuch Bodenbearbeitung/organische Düngung Winterweizen (FF 2.1)	Gülzow	41	2	medium	Fertilization/Tillage
212	Fruchtfolgeversuch Bodenbearbeitung/organische Düngung Silomais (FF 2.2)	Gülzow	41	2	medium	Fertilization/Tillage
213	Schmalfuss'scher Dauerversuch, Feld B (physiologischen Reaktion von Düngemitteln)	Halle	23	1	medium	Fertilization
214	Schmalfuss'scher Dauerversuch, Feld E, Stickstoffdüngung	Halle	23	1	medium	Fertilization
217	E-Feld (ab 1957)	Göttingen	18	3	very high	Fertilization
218	Modellversuch zur Bodenbildung	Halle	23	1	very high	Fertilization
219	Weihenstephaner Kali-Formenversuch	Weihenstephan	30	4	no data	Fertilization
220	Kleinparzellenversuch Hu1 bzw. Hu1To9	Rostock	37	2	no data	Fertilization
221	Organische Düngestoffe - Wirkung (V140/06)	Dedelow	28	1	low	Fertilization
222	Organische Düngestoffe -	Dedelow	28	1	low	Fertilization

	Wirkung (V140/07)					
223	Organische Düngestoffe - Wirkung (V140/08)	Dedelow	28	1	low	Fertilization
224	Organische Düngestoffe - Wirkung (V140/09)	Dedelow	28	1	low	Fertilization
225	Bodenbearbeitungsversuch am Galgenberg	Bingen-Büdesheim	42	1	very low	Tillage/Other
			Grassland LTFE			
10	Stickstoffdüngung auf Grünland	Iden	6	1		Fertilization
12	Stickstoffdüngung auf Grünland	Hayn	6	3		Fertilization
32	Schachbrettversuch / Dauerdüngungsversuch auf Grünland	Daun	7	4		Fertilization
46	K-, P-, N-Steigerung zu Grünland	Freising	14	4		Fertilization
95	Grünlanddauerversuch (V102)	Paulinenaue	28	1		Fertilization
118	P-Düngungsversuch	St. Peter	36	5		Fertilization
135	Grünlandversuch Weiherwiese	Steinach	31	3		Fertilization
141	Kalk-Düngungsversuch	Rösrath	36	4		Fertilization
163	Grünlandversuch Veitshof	Veitshof	43	3		Fertilization
164	Statischer Dauerdüngungsversuch	Rotthalmünster	38	3		Fertilization
168	Phosphordüngung auf Grünland	Christgrün	27	3		Fertilization
169	Kaliumdüngung auf Grünland	Christgrün	27	3		Fertilization
170	Phosphordüngung auf Grünland	Forchheim	27	4		Fertilization
171	Kaliumdüngung auf Grünland	Forchheim	27	4		Fertilization

172	Phosphordüngung auf Grünland	Hayn	6	3	Fertilization
173	Kaliumdüngung auf Grünland	Hayn	6	3	Fertilization
174	Phosphordüngung auf Grünland	Iden	6	1	Fertilization
175	Kaliumdüngung auf Grünland	Iden	6	1	Fertilization
176	Phosphordüngung auf Grünland	Oberweißbach	44	5	Fertilization
177	Kaliumdüngung auf Grünland	Oberweißbach	44	5	Fertilization
178	Überprüfung der Kalkempfehlung für Grünland	Christgrün	27	3	Fertilization
179	Umweltbewusste Grünlandbewirtschaftung	Christgrün	27	3	Fertilization/Other
180	Grunddüngung im Grünland	Christgrün	27	3	Fertilization
181	Phosphordüngung auf Grünland	Heßberg	44	3	Fertilization
182	Kaliumdüngung auf Grünland	Heßberg	44	3	Fertilization
183	Phosphordüngung auf Grünland	Paulinenaue	21	1	Fertilization
184	Kaliumdüngung auf Grünland	Paulinenaue	21	1	Fertilization
185	Phosphordüngung auf Grünland	Wechmar	44	2	Fertilization
186	Kaliumdüngung auf Grünland	Wechmar	44	2	Fertilization
187	Niederblockland	Bremen	45	2	Fertilization
188	Kalkbedarf der Hochmoorkulturen	Bremen	45	3	Fertilization
189	Königsmoor/Nordheide	Bremen	45	3	Fertilization
198	Versuch 250 (Nährstoffmangelversuch)	Ihinger Hof	46	4	Fertilization
199	Versuch 251	Ihinger Hof	46	4	Fertilization

(Wechseldüngungsversuch)

Institutional addresses:

1 Landwirtschaftskammer Rheinland-Pfalz, Referat 21 Pflanzenbau, Burgenlandstr. 7, 55543 Bad Kreuznach

2 Helmholtz-Zentrum für Umweltforschung, Versuchsstation Bad Lauchstädt, Hallesche Straße 44, 06246 Bad Lauchstädt

3 Thüringer Landesamt für Landwirtschaft und Ländlichen Raum, Postfach 100 262, 07702 Jena

4 Humboldt-Universität zu Berlin, Lehr- und Forschungsstation, Bereich Pflanzenbauwissenschaften, Albrecht-Thaer-Weg 5, 14195 Berlin

5 Hochschule Anhalt, Fachbereich Landwirtschaft, Strenzfelder Allee 28, 06406 Bernburg

6 Landesanstalt für Landwirtschaft und Gartenbau, Strenzfelder Allee 22, 06406 Bernburg

7 Universität Bonn, Institut für Nutzpflanzenwissenschaften und Ressourcenschutz, Karlrobert-Kreiten-Str. 13, 53115 Bonn

8 Julius Kühn-Institut, Bundesforschungsinstitut für Kulturpflanzen, Messeweg 11/12, 38104 Braunschweig

9 Stabsstelle Boden des Thünen-Instituts, Bundesallee 50, 38116 Braunschweig

10 Julius Kühn-Institut, Bundesforschungsinstitut für Kulturpflanzen, Stahnsdorfer Damm 81, 14532 Kleinmachnow

11 Forschungsring e.V., Brandschneise 5, 64295 Darmstadt

12 YARA GmbH & Co. KG, Hanninghof 35, 48249 Dülmen

13 Martin-Luther-Universität Halle-Wittenberg, Allgemeiner Pflanzenbau / Ökologischer Landbau, Betty-Heimann-Str. 5, 06120 Halle

14 Technische Universität München, Lehrstuhl für Pflanzenernährung, Emil-Ramann-Straße 2, 85354 Freising

15 Institut für Zuckerrübenforschung an der Georg-August-Universität Göttingen, Holtenser Landstr. 77, 37079 Göttingen

16 Justus-Liebig-Universität Gießen, Institut für Pflanzenbau und Pflanzenzüchtung I, Biomedizinisches Forschungszentrum Seltersberg, Schubertstraße 81, 35392 Gießen

17 Justus-Liebig-Universität Gießen, Lehr- und Versuchsbetrieb für ökologischen Landbau, 65606 Villmar

18 Georg-August-Universität Göttingen, Abteilung Pflanzenbau, Von-Siebold-Str.8, 37075 Göttingen

19 Georg-August-Universität Göttingen, Fakultät für Agrarwissenschaften, Carl-Sprengel-Weg 1, 37075 Göttingen

20 Leibniz-Institut für Gemüse- und Zierpflanzenbau, Theodor-Echtermeyer-Weg 1, 14979 Großbeeren

21 Landesamt für Verbraucherschutz, Landwirtschaft und Flurneuordnung, Referat Ackerbau und Grünland, Berliner Straße, 14532 Stahnsdorf, OT Güterfelde

22 Julius Kühn-Institut, Bundesforschungsinstitut für Kulturpflanzen, Rudolf-Schick-Platz 3a, OT Groß Lüsewitz, 18190 Sanitz

23 Martin-Luther-Universität Halle-Wittenberg, Naturwissenschaftliche Fakultät III, Institut für Agrar- und Ernährungswissenschaften, Lehr- und Versuchsanstalt Halle, 06099 Halle (Saale)

24 Universität Hohenheim, Versuchsstation Agrarwissenschaften, Standort Ihinger Hof (403), 71272 Renningen

25 Christian-Albrechts-Universität zu Kiel, Abteilung Acker- und Pflanzenbau, Institut für Pflanzenbau und Pflanzenzüchtung, Hermann-Rodewald-Str. 9, 24118 Kiel

26 Agrarzentrum Limburgerhof, Speyerer Str. 2, 67117 Limburgerhof

27 Sächsisches Staatsministerium für Energie, Klimaschutz, Umwelt und Landwirtschaft, Abteilung 7, Referat 72, Wilhelm-Buck-Straße 2, 01097 Dresden

28 Leibniz-Zentrum für Agrarlandschaftsforschung, Eberswalder Str. 84, 15374 Müncheberg

29 Landwirtschaftskammer Niedersachsen, Bezirksstelle Hannover, Wunstorfer Landstr. 11, 30453 Hannover

30 unbekannt

31 Landesanstalt für Landwirtschaft, Institut für Ökologischen Landbau, Bodenkultur und Ressourcenschutz, Lange Point 6, 85351 Freising

32 Versuchsstation Klostergut Scheyern, 85298 Scheyern

33 Landwirtschaftliche Untersuchungs- und Forschungsanstalt Speyer, Obere Langgasse 40, 67346 Speyer

34 Humboldt-Universität zu Berlin, Lehr- und Forschungsstation Pflanzenbauwissenschaften, Thyrower Dorfstraße 9, 14959 Trebbin, OT Thyrow

35 Universität Hohenheim, Kleinhohenheim 1, 70599 Stuttgart-Schönberg

36 FEhS-Institut für Baustoff-Forschung e.V. (Forschungsgemeinschaft Eisenhüttenschlacken), Bliersheimer Straße 62, 47229 Duisburg

37 Universität Rostock, Agrar- und Umweltwissenschaftliche Fakultät, Justus-von_Liebig-Weg 6, 18059 Rostock

38 Staatliche Höhere Landbauschule Rotthalmünster, Franz-Gerauer-Straße 22-24, 94094 Rotthalmünster

39 SKW Stickstoffwerke Piesteritz GmbH, Möllensdorfer Straße 13, 06886 Lutherstadt Wittenberg

40 Landesamt für Ländliche Entwicklung, Landwirtschaft und Flurneuordnung, Neue Chaussee 3A, 14550 Groß Kreutz (Havel)

41 Landesforschungsanstalt für Landwirtschaft und Fischerei Mecklenburg-Vorpommern, Dorfplatz 1 / OT Gülzow, 18276 Gülzow-Prüzen

42 Technische Hochschule Bingen, Team Landwirtschaft und Umwelt, Berlinstraße 109, 55411 Bingen am Rhein

43 Technische Universität München, Lehrstuhl für Grünlandlehre, Alte Akademie 12, 85354 Freising

44 Thüringer Landesamt für Landwirtschaft und Ländlichen Raum, Naumburger Str. 98, 07743 Jena

45 Landesamt für Bergbau, Energie und Geologie, Stilleweg 2, 30655 Hannover

46 Universität Hohenheim, Fachgebiet Nachwachsende Rohstoffe in der Bioökonomie (340b), Fruwirthstraße 23, 70599 Stuttgart