Winter wheat yield dataset from N-fertilization experiments in Germany between 1958 and 2015

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Abstract
Here, a dataset of winter wheat (*Triticum aestivum L.*) yields from various nitrogen fertilization experiments (1-6 years duration), which were conducted between 1958 and 2015 at 43 locations across Germany is described in detail. Additionally, agronomic factors (previous crop, seed density, soil management, used cultivar, year of release of the appropriate cultivar, dry matter content of the grain), geographical information (latitude, longitude, altitude), and other site specific information of the experimental sites (soil type, soil yield potential, mean annual temperature, mean annual precipitation, mean annual climatic water balance, soil climate region, cultivation region) were included in the dataset in order to provide information for further analysis. The dataset is available via the Bonares Data Centre at ZALF Müncheberg, Germany. The dataset was used to analyse the impact of changing agronomic and climatic factors on winter wheat yield development in Germany within the project "Data-Meta analysis of productivity development of cultivated plants".

Key words
Winter wheat, yields, N-fertilization experiments, yield-fertilization-soil dataset

Introduction
Crop production during the growing season is affected by many environmental and agronomic factors, which influence the quality and quantity of grain yields. However, agronomic and climatic factors with impact on the yield potential changes over time and although breeding progress and the use of nitrogen fertilizers are supposed to grant for higher grain yields, many studies have underlined that the steady growth of crop yields during the second half of the 20th century has been slowing down in regions of major global wheat production (Brisson et al. 2010; Calderini and Slafer 1998; Chen et al. 2015; Grassini 2010; Laidig et al. 2014). In many West European high-yield countries, winter wheat yields reached a plateau at about 7 to 8.5 t ha^{-1} during the 1990s (Grassini et al. 2013; Brisson et al. 2010). Many reasons have been put forward for grain yield levelling including genetic, agronomic, economic (world market price for wheat grain and for production factors), social (expansion of organic production systems; legal limitations to fertilization) and climatic reasons (Brisson et al. 2010; Grassini et al. 2013; Olesen et al. 2012). In particular under high temperatures losses in grain yield quantities are expected to occur due to reduced photosynthesis rate, increased respiration, accelerated leaf senescence and increased evapotranspiration (Porter and Gawith 1999; Wollenweber et al. 2003; Wheeler et al. 1996; Reyer et al. 2013). Attempting to identify the reasons behind this phenomenon, most of the studies about the impact of agronomic and environmental changes on yield development use annual averaged yield data as provided in national of global yield databases (Lobell and Field 2007; Calderini and Slafer 1998; Hafner 2003; Brisson et al. 2010). The average yield is then defined as the yield achieved by farmers in a defined geographical region (on regional, national or global scale) representing most and widely used agronomic practices, e.g. sowing date, cultivar choice, and fertilization or irrigation management (Evans 1996; van Ittersum et al. 2013). Thus, national statistical data reflect not only genetic and climate trends, but also changes in agronomic practice like nitrogen fertilization levels.
However, N fertilization is a factor of central relevance to yield and quality traits in winter wheat production. The design of N fertilization regimes that approximate the optimal demand for a maximum yield is therefore of major interest not merely economically, but also to avoid negative environmental impacts. In particular, nitrate leaching to the ground water or gaseous losses to the atmosphere are issues accompanying excessive N application to crops (Heumann et al. 2013; Sieling et al. 1997; Lebender et al. 2014). Thus, nitrogen uptake by the crop is strongly influenced by the local weather and soil conditions,

by the health status of the crop and varies in the course of its ontogenetic development (Whitfield and Smith 1992; Delogu et al. 1998). Given a non-limiting soil water status throughout the growth period, the N uptake of wheat increases from the start of spring growth over the stem elongation to the ear emergence phase (van Ittersum and Rabbinge 1997; van Ittersum et al. 2013). For this reason, the effectiveness of splitting the full amount of N fertilization into several application amounts as well as finding the optimal N demand has extensively been investigated (Maidl et al. 1996; Raun et al. 2002; Schulz et al. 2015; Basso et al. 2011). Following this concept, we generated a dataset (Table 1) based on literature data from nitrogen fertilization experiments with the major values of interest: grain yields and their corresponding quantity of the applied mineral nitrogen fertilizer. Additionally, we included agronomical and environmental factors as either found in the respective literature or obtained from other sources: the previous crop, seed density, soil management, used cultivar, dry matter content of the grain, the year of release for the cultivars used in the experiments as well as additional site specific information comprising latitude, longitude, altitude, soil type, soil yield potential, mean annual temperature, mean annual precipitation, mean annual climatic water balance, soil climate region, and cultivation region. A dataset like this has the advantage to overcome certain restrictions, such as the limited number of years, locations and genotypes or can be used to split yield dependent factors into certain components that are either attributable to genetic, environmental and agronomic conditions. Nevertheless, this dataset may also face some limitations, because many varieties are outdated after a few years or used only at particular sites and other varieties appear more often over time and/or at various locations. However, this dataset is now available via the portal of the Bonares Research Centre at the Leibniz Centre for Agricultural Landscape Research (DOI comes here).

Data set generation

Data were obtained from the following sources: (a) articles published in international peer-reviewed journals, which were collected by searching the Web of Knowledge using the terms “wheat”, “fertil*”, “nitrogen” and by manually selecting publications on experiments conducted in Germany, (b) dissertations and habilitation theses, which were gathered by searching the catalogued of university libraries and library associations, (c) reports on N fertilization trials conducted by the states’ chambers of agriculture or the federal offices of agriculture, which were gathered by searching the ISIP database of reports on agronomic studies provided by the governmental bodies, (d) conference papers, which were found by manually searching the proceedings of relevant crop science and crop nutrition conferences, and (e) further non-peer-reviewed publications, which were found by consulting the bibliography of relevant articles. The following criteria on trial setup and data presentation were applied to decide on inclusion in the data set for meta-analysis:

Trial setup: (i) data were generated within a field trial, (ii) at least three levels of the total rate of N fertilization (sum of all applications within one growing season) were implemented, (iii) N was provided in form of mineral fertilizer, (iv) plant protection in the trial was carried out in a way to prevent relevant yield losses due to biotic stress, and (v) the trial was not irrigated.

Data presentation: (i) grain yield values are given for the individual levels of N fertilization, (ii) each data point stems from an individual site, (iii) data represent single-year yields, (iv) grain moisture content is given, (v) the location of the trial site is given. Data from static N fertilization experiments were not included because of the accumulation of fertilizer effects in the individual treatments (e. g., Kübler and Hobelsberger 1984). Information on the cultivar(s) used and on further management practices, such as pre-crop, tillage system, sowing density, or on soil were retrieved from the publications as available. In the case the variety was not mentioned, fields were labelled as ‘not specified’

N-fertilization experiments that report data on grain yield of winter wheat in N fertilization trials according to the criteria listed above were found on a total of 34 publications (Table 2). Moreover, source specific meta-data are listed in Table 3. The data given in these publications were obtained from experiments conducted between 1958 and 2015 and represent 43 individual experimental sites and a total of 59 individual cultivars. In this respect ‘experimental site’ refers to a field trial location of an individual research institution or university research station, which hence features comparatively homogenous weather conditions. Data coverage for individual years varied strongly, and so did coverage for individual trial sites. Location was considered as factor in 13 publications with a maximum of 7 sites in 2 publications. The median number of trials per year was 5 (with trial referring to one individual experimental year and one level of any experimental factor apart from N fertilization); however, for the time before 1980, it was < 10, whereas it was > 10 for some years in the 1980s, 2000s, 2010s and > 20 for some years in the early 1990s. The median number of trials per site was 4. At 7 sites it was > 10 and > 30 at 2 sites. Used varieties were documented in 25 sources and considered as a treatment factor in 12 publications. Further management factors varied were tillage (3 publications), seed density (3 publications) and pre-crop (6 publications). For agronomic management not implemented as a treatment factor in the experiment description of the management operations was very heterogeneous; in some cases it was limited to a general statement on plant protection (e. g., according to local practice) and irrigation. Moreover to mention, field experimental data from 1999 onward were only available for sites in South Germany.

Maximum Yields

N-fertilization experiments provide the opportunity to estimate the yield maxima (Y_{max}) for each experiment, which then represent the environmental and agronomic limits in an experimental year and of a region. Y_{max} can then be used to compare the yield variation between different locations and years. To derive potential grain yields under non-N-limited conditions for each experimental year, site and cultivar, data on dry matter grain yield at individual N fertilization levels was used to calculate Y_{max} and the corresponding maximum N fertilization level (N_{max}). Most trials implemented sub-optimal, close to optimal and supra-optimal N-levels in equal quantity steps (e.g. 50, 100, 150 kg N ha^{-1}). We fitted a quadratic yield response function

$$Y = a + bN + cN^2 \quad (1)$$

to the data of each individual N-fertilization response trial, where N is the applied N-level and Y is the observed yield (Equation 1, **Figure 1**), using the statistical software R (R Development Core Team 2008). Values of Y_{max} and N_{max} were obtained from the coefficients of these functions by setting their first derivatives to 0 and solving for *N*:

$$N_{max} = -b/2c \quad (2)$$
$$Y_{max} = a + bN_{max} + cN_{max}{}^2 \quad (3)$$

where a, b, and c are the model parameters.

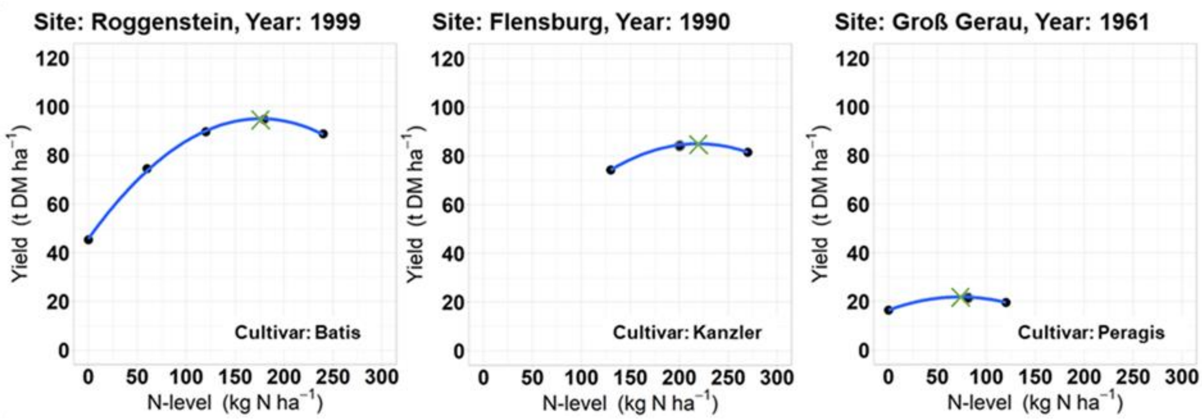

Figure 1. Examples for the yield response curves to nitrogen fertilizer level and derived maximum yields and corresponding nitrogen values of three fertilization experiments. The green crosses mark the maximum achievable winter wheat yields as derived from a quadratic linear function and its corresponding nitrogen level.

When fitting quadratic functions to the trial data, several scenarios need to be considered for interpreting the derived yield as Y_{max} under the given site and climatic conditions: The derived Y_{max} value may lie (i) beyond the highest observed N-level, and (ii) it may be higher or lower than a measured Y_{max} value. To deal with these issues, certain thresholds were set: When the derived Y_{max} was not reached within the observed range of N-levels, an upper threshold was set for acceptance of a study. Specifically, we determined the mean width of the N-level increments. The threshold was computed as the largest N-level tested in the study, plus the mean increment. A study was accepted only if Y_{max} was estimated to occur at an N-level below that threshold. For instance, in an 80-120-160 kg N ha^{-1} trial, the mean increment of the N-fertilization levels is 40 kg N ha^{-1} and when Y_{max} was estimated at 210 kg N ha^{-1}, the trial was then excluded from the dataset, whereas when Y_{max} was derived below or equal to 200 kg N ha^{-1}, the trial was included. Moreover, Y_{max} values below 50 kg N ha^{-1} were excluded from further analysis and considered as unrealistic under conditions present in Germany. When the derived Y_{max} value was below the highest yield measured by more than 5%, the measured yield was taken as Y_{max}. Yet, when the derived Y_{max} was greater than 5% of the highest measured yield, the derived Y_{max} was chosen to reflect the maximum yield achievable. In any case, experiments outside these defined thresholds were excluded from the dataset. 11.2% of the data were removed from further analysis due to decreasing yield functions and coefficients of determination below 0.5. Following these plausibility tests, 324 out of 331 individual trials remained within the dataset. The correlations between Y_{max} and the corresponding

N_{max}, the intercept, and the linear coefficient of the quadratic regression model were 0.51, 0.62, and 0.33, respectively. Correlations between N_{max}, the intercept, and the slope factors of the quadratic regression model ranged between -0.1 and 0.52.

Cultivars

Cultivar information added to the dataset was the year of release (YOR) in terms of registration with the Federal Plant Variety Office. This information was retrieved from databases of the Federal Plant Variety Office and from GRIS (Genetic Resources Information System for Wheat and Triticale, CIMMYT (http://wheatpedigree.net/).

Phenological data

None of the publications from which yield data were retrieved provided precise information about phenological stages and phases. Therefore, data on the beginning of the individual phenological stages of winter wheat were retrieved from the phenological observation database on arable cropping systems (ftp://ftp-cdc.dwd.de/pub/CDC/observations_germany/phenology/) from the German Weather Service (Deutscher Wetterdienst, DWD). Phenological dates were recorded from voluntary observers within a radius of 1.5-2 km and not more than 50 m in altitude from the mean altitude of the observation site covering a period from 1951 to 2015 (as at November 2017). Cultivars used in the fertilization experiments may differ from those underlying the phenological records of the DWD. For this study, the beginning of sowing, emergence, stem elongation, heading, hard dough, and harvest were recorded on an annual basis for all sites where experiments were conducted. In order to estimate the start dates of the aforementioned phenological stages, all DWD observation sites within a radius of 30 km of each experiment site were selected using the ArcGIS Desktop software by Esri (version 10.5.1). To eliminate errors and incorrectly recorded single values, data records were processed by an automated selection process. As suggested in Menzel (2003), only observation sites with relatively complete data records of more than 20 or 30 years should be considered as meaningful for reliable predictions because trend analysis strongly depends on the number of years included in the linear regression. In this study, 30 years was set as minimum record length to ensure a certain degree of temporal stability of the resulting trends. Even then, a small uncertainty remained because part of the variation in trends might be caused by differing start and end years. In respect of topography and altitude (m a. s. l.), all stations with more than 50 m difference in altitude from the experimental sites were removed to avoid misinterpretation due to vertical thermal differences and their influence on stage initiation. Mean values and standard deviation for each year of the stage beginning dates were calculated and potential outliers removed when they fell outside the range of the mean value ± two times the standard deviation as suggested in Siebert & Ewert (2012). After applying the filtering process, the total number of observations obtained for the 43 sites across the study regions was 15238. Moreover, the duration of the whole growing season (GS), the generative phase (GP) and the vegetative phase (VP) was calculated, and in addition VP was subdivided into the leaf development and tillering phase (LP) and the stem elongation and booting phase (SP). As shown in Figure 3, the length of the vegetative phase was defined as the time between emergence and heading and the generative phase as the time between heading and hard dough. The LP and SP were separated by the beginning of the stem elongation.

Site specific conditions and classifications

Climate data

Climate or weather data that would have allowed characterising site specific conditions of each trial site were scarcely provided within the publications. For this reason we obtained climate data from the hydrological raster (HYRAS) database (5 x 5 km²) of the DWD available for the period 1951 to 2006 on a daily basis (Frick et al. 2014) of the German Weather Service (DWD). The interpolation of the gridded HYRAS dataset is based on a combination of multiple linear regression and inverse distance weights and described in detail by Rauthe et al. (2013). Hence, the long-term mean annual temperature, precipitation, and climatic water balance was calculated based on the 30 year reference period 1961-1990 and a distribution of these site characteristics are shown in Figure 2a, b, c, respectively. Mean annual temperature ranged from 7.8 to 10.6 °C and mean of 8.9 °C at the sites in this study. The median was at 8.8 °C. Mean annual precipitation at the sites varied between 580 and 1110 mm. The average was 774 mm and the median 744 mm. As for the mean annual CWB, the minimum was 198 mm, the maximum 822 mm, the average 465 mm, and the median was at 431 mm.

Soil type

For 32 out of the 43 experimental locations documented in the publications the soil type could be retrieved at the level of the soil type group according to the German soil classification system - KA5 (Adhoc-AG Boden 2005). When the missing soil type of a publication could not be obtained from other publications with the same experimental site (3 locations), the soil texture was determined from the soil type classification map of the Federal Institute for Geosciences and Natural Resources in Germany. This map is based on more than 16,000 quality-assured soil profiles of the national survey database and extrapolated based on the land use stratified soil map of Germany 1:1,000,000 (BUEK1000N V2.3) and the land use dataset CORINE Landcover 2006 (Düwel et al. 2007). Four main soil type groups where extracted for the experimental sites in this dataset: 8 loamy sands, 12 sandy loams, 13 loams, and 10 clayey silts.

Soil yield potential

The suitability of a site under agricultural land use and its estimated yield potential was retrieved for all sites in this study based on the Muencheberg Soil Quality Rating (MSQR). This method was developed by the Leibniz Centre for Agricultural Landscape Research (ZALF) and provided in a map that shows the MSQR for cropland in Germany based on the land use stratified soil map of Germany at scale 1:1,000,000 (Mueller et al. 2010). This method estimates the yield potential on a set of soil describing properties (e.g. the substrate, rooting depth, topsoil structure, or soil compaction) and evaluates yield effecting hazardous factors, such as drought risk, soil depth above solid rock, flooding, or extreme water logging regimes. Evaluation points range from 0 to 102. The MSQR for the 43 sites in this dataset ranges from 31 to 99.

Table content and data structure

Table 1: Overview of the main table

Field name	Data type	Unit	Description
STID	Integer		Number of the data source and trial
Site	Character		Name of the experimental site
State	Character		Abbreviation of the state name
Lat	Double	°N	Northing coordinates in decimal degree (6 digit accurateness)
Lon	Double	°E	Easting coordinates in decimal degree (6 digit accurateness)
Alt	Long integer	m a.s.l.	Elevation of the experimental site
Year	Long integer		Year of harvest of the displayed data (yyyy)
Cultivar	Character		Name of the variety as used in the experiments
YOR	Long integer		Authorization year (yyyy) of the corresponding winter wheat cultivar as provided by the Federal Plant Variety Office and from GRIS (Genetic Resources Information System for Wheat and Triticale, CIMMYT, http://wheatpedigree.net/)
N_fert	Double	kg N ha^{-1}	Optimal nitrogen amount of the fertilizer applied in the experiment.
Yield_max	Double	dt DM ha^{-1} y^{-1}	Grain yield as derived from yield response curves based on N-fertilization experiments
Soil	Character		Acronym of the soil type class as found in literature - missing data were filled from BODENEIGENSCHAFTEN V1.0, (c) BGR, Hannover, 2017. (https://produktcenter.bgr.de/terraCatalog/DetailResult.do?fileIdentifier=3fd88c18-b23b-47ca-aa36-f86c72c906c3). Names of the soil type abbreviations are shown in Table 4 and a distribution of the sites and their soil type in (Figure 2d).
SQ	Double		Evaluation of the soil yiel potential (soil quality, SQ) based on the Müncheberger Soil

			Quality Rating (MSQR) with numbers between 0 and 102. (https://produktcenter.bgr.de/terraCatalog/DetailResult.do?fileIdentifier=3DBC11EE-81E9-41A2-916E-1281DDD6C7A8)
MAT	Double	°C	Mean annual temperature for each experimental site based on calculations with the HYRAS database and the reference period 1961 and 1990 (Figure 2a).
MAP	Double	mm	Mean annual precipitation amount for each experimental site based on calculations with the HYRAS database and the reference period 1961 and 1990 (Figure 2b).
MACWB	Double	mm	Mean annual climatic water balance defined as the difference between the precipitation height and the amount of the ETP [mm] for each experimental site based on calculations with the HYRAS database and the reference period 1961 and 1990. The potential evapotranspiration (ETP, mm) was calculated using the Haude approach (Haude, 1954) (Figure 2c).
Climate data	double		Calculated climatic situation within a certain phenological phase of winter wheat crop growth (Bönecke et al. 2020)

Table 2: References of the sources of the yield and fertilization data

Source	Literature
1	Blankenau, Klaus; Kuhlmann, Hermann (1998): Evaluation of different harvesting methods in field experiments with cereals and consequence for the calculation of fertilizer N uptake. In Agribiological Research 51 (4), pp. 309–318.
2	Czauderna, Rudi (1992): Ertragsbildung und Ertragsstruktur von Winterweizensorten unter besonderer Berücksichtigung des Stickstoffhaushaltes und der Nährstoffaneignung. Dissertation. Christian-Albrechts-Universität Kiel, Kiel.
3	Müller, Rüdiger; Dennert, Johann (1988): Vergleichende Untersuchungen von Stickstoffdüngung und Bodennitratgehalt in Hinblick auf Ertrag und Kornqualität von Winterweizen. In G. Geisler, Wolfgang Diepenbrock (Eds.): 32. Jahrestagung am 6. und 7. Oktober 1988
4	Retzer, Franz (1995): Untersuchungen zur Stickstoffverwertung von Weizenbeständen. Dissertation. Technische Universität München (Technische Hochschule München), Freising-Weihenstephan. Lehrstuhl für Pflanzenbau und Pflanzenzüchtung.
5	Diekmann, Florian; Fischbeck, Gerhard (2005): Differences in Wheat Cultivar Response to N Supply. I: Differences in Grain Yield Formation. In Journal of Agronomy and Crop Science 191, pp. 351–361
6	Schächtl, Josef (2004): Sensorgestützte Bonitur von Aufwuchs und Stickstoffversorgung bei Weizen- und Kartoffelbeständen. Dissertation. Technische Universität München (Technische Hochschule München), Freising-Weihenstephan. Lehrstuhl für Pflanzenbau und P
7	Fischbeck, Gerhard; Dennert, Johann; Müller, Rüdiger (1990): N-Dynamik des Bodens, Ertragsbildung und Stickstoffentzug von Winterweizen bei unterschiedlicher Höhe und Verteilung der mineralischen N-Düngung. In Journal of Agronomy and Crop Science 164, pp.
8	Kleiber, Erik (2000): Untersuchungen über die Reaktion von Winterweizensorten auf extensive und intensive Anbaubedingungen. Dissertation. Justus Liebig-Universität Gießen, Gießen. Institut für Pflanzenbau und Pflanzenzüchtung.

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11	Weber, E. A.; Graeff, S.; Koller, W.-D.; Hermann, W.; Merkt, N.; Claupein, W. (2008): Impact of nitrogen amount and timing on the potential of acrylamide formation in winter wheat (Triticum aestivum L.). In Field Crops Research 106 (1), pp. 44–52. DOI: 10
12	Kuhlmann, Josef (1988): Ertragsbildung und Krankheitsbefall von unterschiedlich anfälligen Winterweizensorten unter der Einfluß differenzierter Stickstoff-, Fungizid- und Herbizidanwendungen und deren Bedeutung für den integrieren Pflanzenschutz. Disserta
13	Wendland, M.; Offenberger, Konrad; Euba, M.; Heigl, L.; Schmidt, M.: N-Düngung zu Winterweizen anhand verschiedener Düngesysteme (DSN, N-Sensor und N-Simulation) mit und ohne organischer Düngung. Edited by Bayerische Landesanstalt für Landwirtschaft
14	Wendland, M.; Offenberger, Konrad; Schmidt, M.: N-Düngungsversuch zu Winterweizen (Sensortechnik). 2001 bis 2005. Edited by Bayerische Landesanstalt für Landwirtschaft (Versuchsergebnisse aus Bayern)
15	Wendland, M.; Offenberger, Konrad; Heigl, L.; Schmidt, M.: N-Düngung bei Winterweizen (Düngerform, stabilisierte Dünger, Injektion) 2012 bis 2015. 2012 bis 2015. Edited by Bayerische Landesanstalt für Landwirtschaft (Versuchsergebnisse aus Bayern)
16	Weipert, Dorian (1964): Einfluß der Stickstoffdüngung auf Entwicklung, Ertragsbildung und Backeigenschaften einiger Winter- und Sommerweizensorten. Dissertation. Justus Liebig-Universität Gießen, Gießen. Institut für Pflanzenbau und Pföanzenzüchtung.
17	Hanna, Loius Philipp (1967): Der Einfluß der Stickstoffdüngung auf Ertrag, Ertragsaufbau und bäckereitechnologische Qualitätseigenschaften einiger Sommer- und Winterweizensorten. Dissertation. Justus Liebig-Universität Gießen, Gießen. Institut für Pflanze
18	May, Heinrich (1970): Über müllerei- und bäckereitechnologische sowie einige ernährungssphysiologische Qualitätseigenschaften bei Weizen unter dem Einfluß von Sorte und Stickstoff-Spätdüngung. Dissertation. Justus Liebig-Universität Gießen, Gießen. Instit
19	von Schutzbar genannt Milchling, Kraft (1972): Über den Einfluß von Standort, Witterung, Sorte und Stickstoffdüngung auf Rohproteingehalt und -zusammensetzung bei Weizen, Gerste und Hafer. Dissertation. Justus Liebig-Universität Gießen, Gießen.
20	Springer, Bernd (1985): Einfluss des Einsatzes von Herbiziden unterhalb und oberhalb der Schadensschwellen auf die Ertragsentwicklung von Winterweizen in Abhängigkeit von Stickstoffdüngung und Fungiziden. Dissertation. Georg-August-Universität Göttingen,
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22	Dennert, Johann (2007): N-Spätdüngung in Winterweizen, um das Ertragspotential auszuschöpfen und die geforderte Qualität zu erreichen. Optimierung von Termin und Menge. Technische Universität München. München
23	Kwast, Anke (1996): Vorstellung des Internationalen Organischen Stickstoff-Dauerdüngungsveruschs (IOSDV) Dülmen und Auswertung der Erträge und N-Entzüge. In Archiv für Acker- und Pflanzenbau und Bodenkunde 40, pp. 133–143
24	Wendland, M.; Offenberger, Konrad; Euba, M.: Einfluss der Stickstoffdüngung auf den Winterweizenertrag in Trockengebieten
25	Wendland, M.; Offenberger, Konrad; Aigner, K.: Internationaler organischer Stickstoffdauerversuch. Versuchsergebnisse aus Bayern 1985 bis 2009. Edited by Bayerische Landesanstalt für Landwirtschaft
26	Wendland, M.; Offenberger, Konrad; Aigner, K.: Internationaler organischer Stickstoffdauerversuch. Versuchsergebnisse aus Bayern 1985 bis 2012. Edited by Bayerische Landesanstalt für Landwirtschaft

27	Wendland, M.; Offenberger, Konrad; Aigner, K.: Internationaler organischer Stickstoffdauerversuch. Versuchsergebnisse aus Bayern 1985 bis 2015. Edited by Bayerische Landesanstalt für Landwirtschaft
28	Durst, Leonhard (1986): Wirkung verschiedener Blatt-Vorfrüchte sowie differenzierter Primärbodenbearbeitung und N-Düngung auf Ertrag und Ertragsbildung von Winterweizen (Sorte Vuka). Dissertation. Universität Hohenheim, Hohenheim. Institut für Pflanzenbau
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30	Boguslawski, Eduard von (1971): Die Stickstoffdüngung bei Weizen, Gerste und Hafer. In Getreide und Mehl 21, pp. 73–82
31	Knittel, H.; Zerulla, W. (1987): Einfluß der N-Düngung auf die Ertragsentwicklung landwirtschaftlicher Kulturen und Veränderungen des mineralischen N-Gehaltes im Boden bei achtjährigen Dauerversuchen. Journal of Agronomy and Crop Science 159, pp. 251–2
32	Wendland, M.; Offenberger, Konrad; Schmidt, M.: N-Spätdüngungsversuch zu Winterweizen. 2004 bis 2006. Edited by Bayerische Landesanstalt für Landwirtschaft (Versuchsergebnisse aus Bayern)
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Table 3: Overview of the documentation criteria and other meta-information.

Source	Documentation type	Data visualisation in the source	Language	Checked date
1	journal	table	English	07 Jul 2016
2	dissertation	table	German	01 Aug 2016
3	conference proceeding	table	German	20 Jun 2016
4	dissertation	table	German	21 Aug 2016
5	journal	table	English	20 Nov 2015
6	dissertation	table	German	21 Aug 2016
7	journal	diagram and table	German	20 Jan 2016
8	dissertation	table	German	01 Aug 2016
9	journal	diagram	English	01 Aug 2016
10	dissertation	table	German	20 Jun 2016
11	journal	table	English	21 Aug 2016
12	dissertation	table	German	21 Jul 2016
13	internet document	table	German	12 Jul 2016
14	internet document	table	German	06 Jul 2016
15	internet document	table	German	12 Jul 2016
16	dissertation	table	German	25 Jul 2016
17	dissertation	table	German	01 Mar 2016
18	dissertation	table	German	20 Jun 2016
19	dissertation	table	German	03 Aug 2016
20	dissertation	table	German	14 Jul 2016

21	dissertation	table	German	21 Jul 2016
22	internet document	diagram	German	04 Mar 2016
23	journal	table	German	08 Feb 2016
24	internet document	table	German	15 Feb 2016
25	internet document	table	German	27 Jul 2016
26	internet document	table	German	27 Jul 2016
27	internet document	table	German	27 Jul 2016
28	dissertation	diagram	German	07 Jul 2016
29	dissertation	table	German	20 Jun 2016
30	journal	diagram	German	03 Aug 2016
31	journal	table	German	04 Aug 2016
32	internet document	table	German	08 Aug 2016
33	internet document	table	German	08 Aug 2016
34	journal	table	German	08 Jan 2016

Table 4: Overview of soil types in this dataset according to the German soil classification system - KA5 (Ad-hoc-AG Boden 2005).

Soil type	**Name**
sl	Sandy loam
ls	Loamy sand
tu	Clayey silts
ll	Normal loams

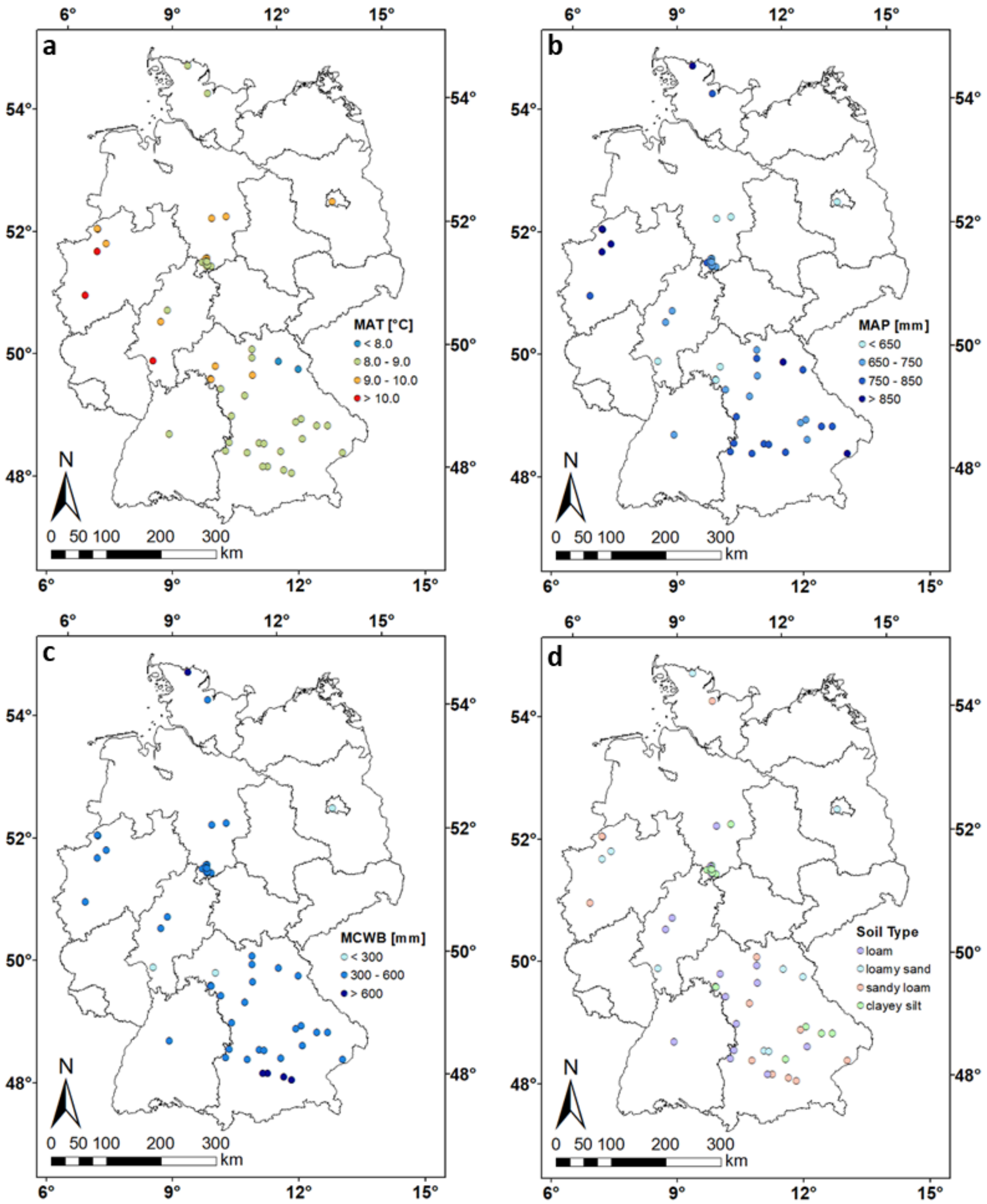

Figure 2: Spatial distribution of the locations in this study and their long term (1977-2006) climatic and soil conditions. a, Mean annual temperature (MAT). **b**, Mean annual precipitation (MAP). **c**, Mean annual climatic water balance (MCWB). **d**, Soil types after Ad-hoc-AG Boden (2005)

Author Contributions

E. Bönecke and L. Breitsameter collected the data. E. Bönecke created the database and prepared it for the repository of the Bonares Data Centre and wrote the major part of the manuscript. L. Breitsameter contributed to the writings. All authors contributed to the content of the manuscript, discussed the data set and commented on the manuscript.

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