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A comprehensive dataset demonstrating the within-field variability of soil properties and crop growth conditions in northwestern Germany

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Abstract: A four-year (1999-2002) multivariable dataset for one specific cropland field located in North Rhine-Westphalia is documented in detail. The dataset focusses on the small-scale heterogeneity of soil properties varying in the spatial and temporal dimension. Initial soil sampling was conducted at altogether 80 sampling points arranged in a regular and a nested grid along the 20 ha large field. Information about the soil inventory (soil texture, soil organic carbon) exists for three subsequent soil layers to a total depth of 90 cm and for every sampling point. Subsequently, the same points and layers were examined for the soil variables soil moisture and soil mineral nitrogen biannually. Additional information about crop rotation, tillage, site-specific fertilization, yield performance and weather variables complete the dataset that was used for model inter-comparison within the crop modelling part (CropM) of the international FACCE JPI MACSUR2 project.

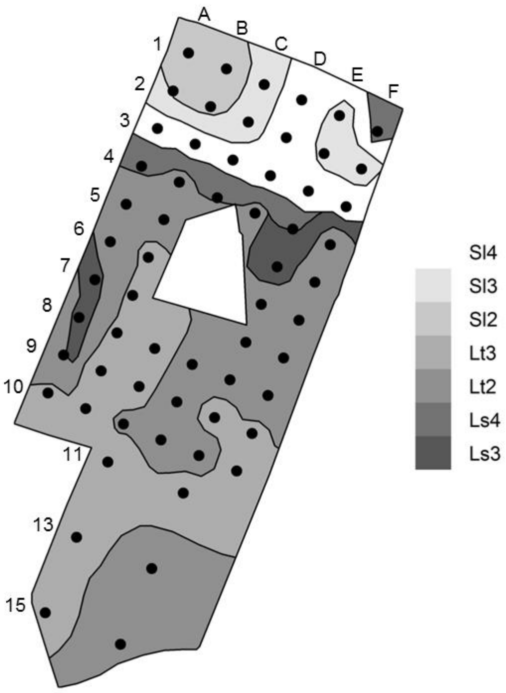
Keywords: spatial variability, soil texture, water and nitrogen supply, site-specific fertilization, Beckum (Germany)

1 INTRODUCTION: Soils play a relevant role for crop production and determine significantly the impact of climate change on crop growth (Kersebaum and Nendel, 2014). Spatial aggregation of soils can have a dominant influence on the outcome of regional yield simulations (Hoffmann et al. 2016). The variability of soil properties within a field often represents most of the variability of a whole landscape (De Wit and van Keulen, 1987) since processes of soil development vary according to almost every spatial and temporal scale. Hence, chemical, physical, and biological soil properties differ greatly even in their small-sale distribution (Pätzold et al., 2008; Selige et al., 2006; Kersebaum et al. 2002; Moore et al., 1993). With respect to agricultural land-use, soil states which influence crop growth conditions and yield are heterogeneously distributed in vertical and horizontal dimensions within the field (Gebbers and Adamchuk, 2010; Geesing et al., 2014; Pätzold et al., 2008; Stafford et al., 1999). For example, provision of mineral nitrogen and water from the soil strongly depends on soil texture, soil organic matter content and composition but also on fertilization and irrigation strategy. From environmental aspects, the water and nutrient holding capacity of individual soils varies and, hence, the risk of resource losses and contamination of adjacent ecosystems is site-specific (Kersebaum et al. 2005). In consequence, unadjusted nitrogen fertilization mainly contributes to the global input of reactive nitrogen to terrestrial ecosystems, drainage water and the atmosphere (Fowler et al., 2013; Liu et al., 2010; Galloway et al., 2003). Although the development of precision agriculture is basing on the knowledge of spatial variability of soils and crop yields, the precise estimation of soil properties and their spatial and temporal distribution is limited and resource-consuming (Schmidhalter et al., 2008; Adamchuk et al., 2004). Advances in the field of proximal soil-sensing contribute to a practical solution (Wallor et al., 2017; Gebbers and Schirrmann, 2015; Rudolph et al., 2015; Lawes and Bramley, 2012; Brevik, 2012). As soon as knowledge about the soil inventory of any agricultural field is available, the application of process-based crop models enables for site-specific management recommendations considering for example nitrogen fertilization (Kersebaum et al., 2005). Moreover, the sensitivity of models to site-specific soil characteristics is an essential precondition to successfully simulate the interaction of processes in the soil-plant-atmosphere system for an integrated impact assessment, e.g. for climate change impacts. This is not always assured and requires additional adaptation and validation (Martre et al., 2015). Therefore, we provide a dataset which can be used to test the response of crop growth models to spatially variable soil properties at the field scale and their consistency across different soil and crop output variables. With respect to the large within-field heterogeneity of soil properties and the high temporal and spatial density of the sampling design the presented dataset is unique and provides the link between spatial yield variability and soil states.

2 THE DATASET

2.1 LOCATION AND EXPERIMENTAL DESIGN: The 20 ha large study site Beckum is located in the Münster region, North Rhine-Westphalia (51.750096°N, 7.993412°E) and was managed conventionally by a local farmer. Soil texture varies considerably in the vertical and horizontal dimension ranging from slightly loamy sand in the north to silty and clayey loam in the south of the field. In addition, stone content increases with depth and the underlying calcareous marl reaches the rooting zone in the southbound direction at a soil depth of 60 to 90 cm. Soil investigation was conducted at three soil layers (0 to 30 cm, 30 to 60 cm, 60 to 90 cm) of altogether 80 grid points. A regular grid of 50 to 50 m in the northern part and 100 to 100 m in the southern part, respectively, consisted of 60 sampling points (Figure 1). The remaining 20 points were arranged in a narrow grid covering two areas in the north, each containing ten grid points with a maximum distance of 2 m. The latter sampling design allows the identification of small-scale variations of selected soil-related properties. The extension of the grid in the southern part is due to the soil conditions, which made the sampling much more difficult (marl, stone content). A recurrent sampling of the three soil layers at every grid point was realized during the investigation period from September 1999 to August 2002 to determine soil mineral nitrogen and soil water content. Based on initial sampling results the amount of applied nitrogen fertilization was adapted by defining homogenous areas at the field. The area-specific fertilization rate was simulated with the agro-ecosystem model HERMES (Kersebaum et al., 2005). However, only on the east side of the field fertilizer was applied site specifically, while on the west side an average amount was applied. All other management activities were executed on field scale. The long-term average precipitation of 800 mm per year was exceeded in two of the three observation years but a period with negative water balance occurred during every growing season. The average water balance of the whole observation period was positive and resulted in a surplus of 300 mm yr^{-1} while the mean temperature was 11.3°C.

Figure 1. Interpolated soil texture after the German Soil Taxonomy (AG Boden, 2005) averaged over a soil depth of 0 to 90 cm based on the regular grid (n = 60) consisting of transects A to F (e.g. Sl2 = slightly loamy sand; Ls3 = moderate sandy loam; Lt3 = moderate clayey loam).

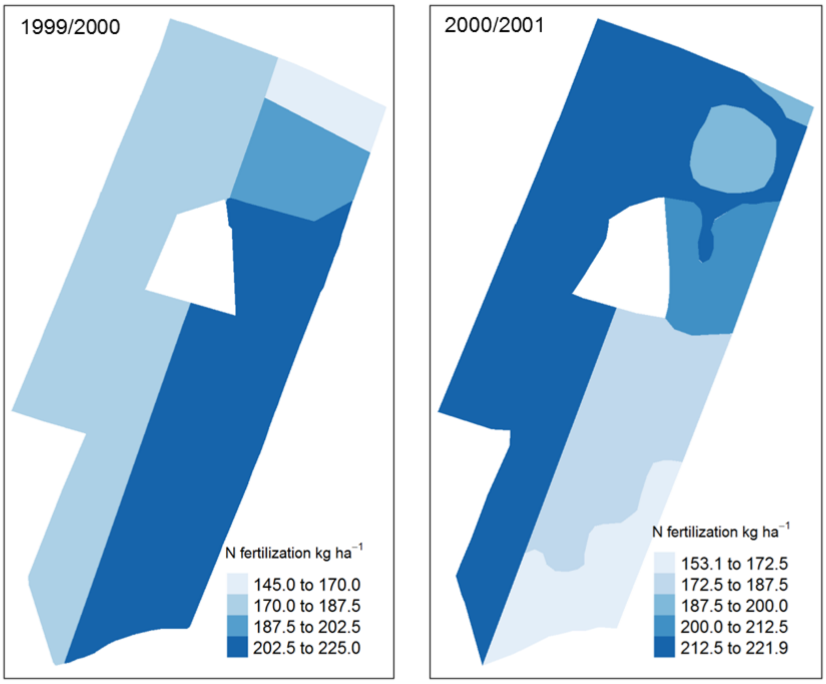


2.2 MANAGEMENT: As outlined before all management activities except the amount of applied nitrogen fertilization were conducted at field scale. Crop cultivation started with winter wheat (*Triticum aestivum L.*) after winter rape (*Brasica napus*) in 1999 followed by another growing season (2000/2001) of *Triticum aestivum L.* and sowing of *Triticale* for the growing season 2001/2002 (Table 1). Soil tillage did not exceed 16 cm soil depth and the soil was ploughed with a moulboard shallowly at the beginning of the observation period. The amount of nitrogen fertilization was calculated for every growing season according to the mineral nitrogen reserves of the soil up to a depth of 90 cm in early spring and the crop-specific demand. Application of nitrogen fertilizer was divided into four to five doses per each growing season, while the highest amount of about 50% was applied in spring. The total annual site-specific amount of nitrogen from fertilization is exemplarily shown in Figure 2 for the growing seasons 1999/2000 and 2000/2001.

Table 1. Management activities at the field Beckum during the observation period 1999 to 2002 (Lorenz, 2005)

Date	Management (Amount of N-fertilization variable/uniform)
20.08.1999	harvest winter rape
17.09.1999	shallow tillage (8 cm depth, plowing)
19.09.1999	sowing winter wheat (variety: Batis)
22.03.2000	nitrogen fertilization (ammonium urea solution), 30 to 55 kg N ha^{-1}
14.04.2000	nitrogen fertilization (ammonium urea solution), 50 to 60 kg N ha^{-1}
16.05.2000	nitrogen fertilization (ammonium urea solution), 35 to 60 kg N ha^{-1}
27.05.2000	nitrogen fertilization (ammonium urea solution), 40 kg N ha^{-1}
09.08.2000	harvest winter wheat
23.08.2000	seedbed preparation (16 cm depth, no plowing)
23.08.2000	nitrogen fertilization (poultry manure), 57 kg N ha^{-1}
24.09.2000	sowing winter wheat (variety: Batis)
20.03.2001	nitrogen fertilization (ammonium urea solution), 60 to 70 kg N ha^{-1}
24.04.2001	nitrogen fertilization (ammonium urea solution), 40 to 70 kg N ha^{-1}
19.05.2001	nitrogen fertilization (ammonium urea solution), 60 to 80 kg N ha^{-1}
23.07.2001	harvest winter wheat
13.08.2001	nitrogen fertilization (poultry manure), 171 kg N ha^{-1}
14.08.2001	seedbed preparation (16 cm depth, no plowing)
29.09.2001	sowing *Triticale* (variety: Lamberto)
11.03.2002	nitrogen fertilization (ammonium urea solution), 65 kg N ha^{-1}
28.03.2002	nitrogen fertilization (ammonium urea solution), 10 kg N ha^{-1}
24.04.2002	nitrogen fertilization (ammonium urea solution), 50 to 85 kg N ha^{-1}
28.07.2002	harvest *Triticale*

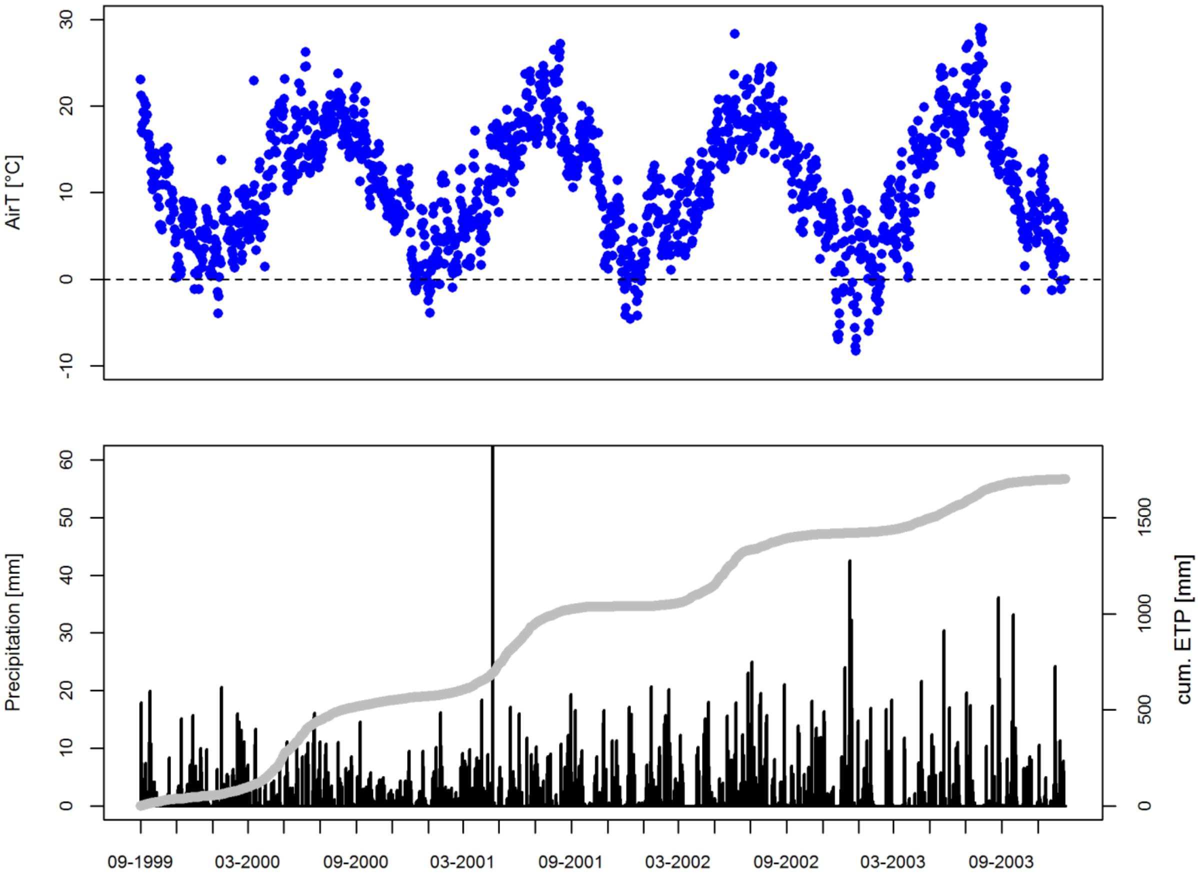
Figure 2. Total annual site-specific fertilizer application at the field Beckum during the observation years 2000 and 2001.



2.3 MEASUREMENTS

2.3.1 WEATHER DATA: A weather station was established at 100 m linear distance from the field. Essential variables as solar radiation, minimum and maximum air temperature, precipitation, wind speed and relative humidity were measured and were provided in daily time steps (Figure 3). Strong precipitation occurred on May 3rd 2001 (97.5 mm) which is outside the scale of Figure 3. From the precipitation distribution it becomes obvious that especially during the growing season 1999/2000 the water supply was restricted due to lower rainfall compared to the other years.

Figure 3. Essential climatic variables at Beckum according to the observation period; cumulative potential evapotranspiration (cum. ETP) was simulated using the model HERMES (Kersebaum, 2007).



2.3.2 SOIL DATA: Initial soil sampling was conducted on the 15th of September 1999 for every grid point and every soil layer (see above) including the nested grid points. Samples were analyzed for the long-term stable parameters total carbon content, total nitrogen content and organic carbon content following international standard (ISO 10694 and ISO 13878). The components of soil texture were determined according to the German Soil Taxonomy (AG Boden, 2005). The stone content was roughly estimated by visual assessment of the coarse fraction per depth as described by the AG Boden (2005). In addition, the soil moisture was estimated from disturbed samples using thermogravimetric method and volumetric moisture was afterwards calculated by multiplication with bulk density. Undisturbed samples for bulk density determination were taken in three replicates according to soil depth and homogenous soil area (Figure 1). The range of selected analytical results is visualized by regressions based on the estimated clay content as explanatory variable (Figure 4). Simultaneously, the status of soil mineral nitrogen (N_{min} = NO_3-N+NH_4-N) was determined after ISO 14256 for every soil layer and grid point. Periodical soil sampling was conducted as described above in spring and after harvest of each growing season. Samples were analyzed for N_{min} and soil moisture in order to examine the spatial and temporal variability of these variables in the course of the year. In Figure 5 this heterogeneity is visualized for the two sampling dates of the year 2000 and the entire soil profile (0 to 90 cm) according to the sampled transects. The partly appearing wide range of observed values per each transect demonstrates the variability of mineral nitrogen and water supply that is directly or indirectly influenced by soil properties, which to some extent have an impact on crop growth and, hence, on nitrogen uptake by plants (Kersebaum, 2000). Precise information about the applied methods for soil analysis is provided in the attached metadata file.

Figure 4. Relation between clay content and soil organic carbon content as well as soil water content of the uppermost examined soil layer 0 to 30 cm.

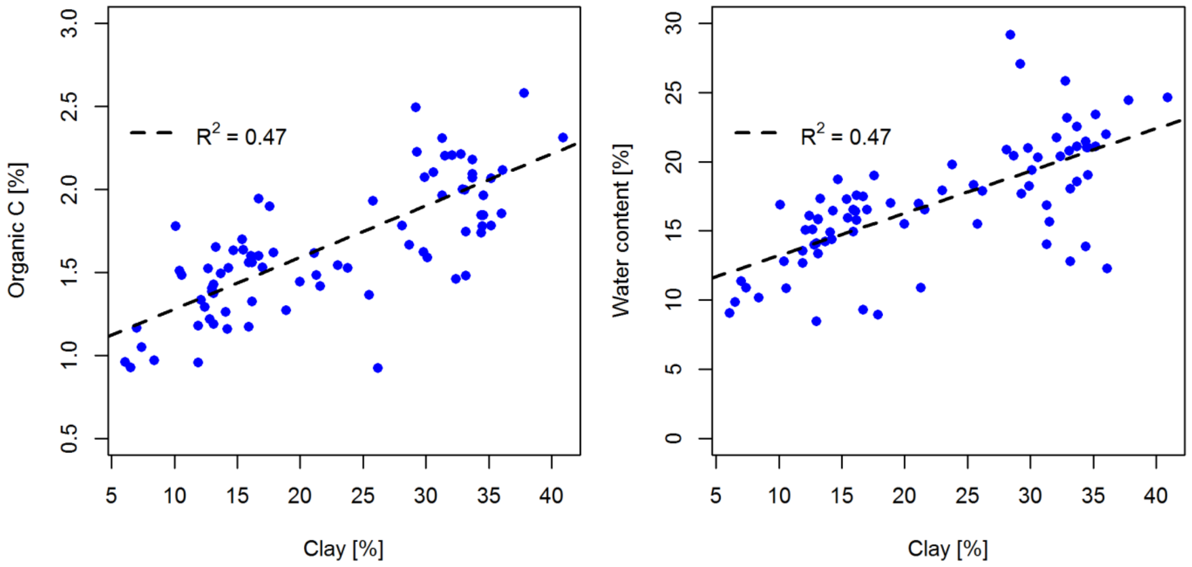
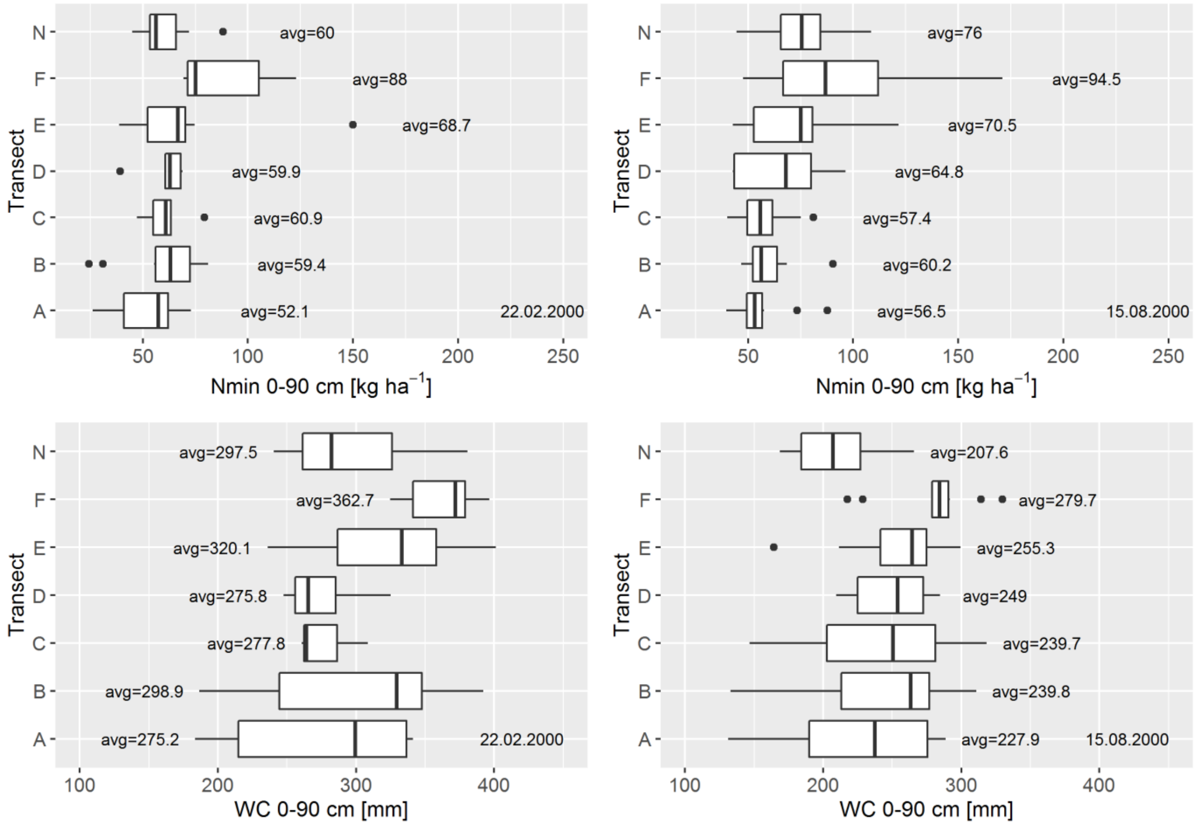


Figure 5. Distribution of observational parameters mineral nitrogen and soil water content for the entire soil profile 0 to 90 cm along examined transects on 20th, 2000 and August 15th, 2000; N = sampling points of the nested grids.

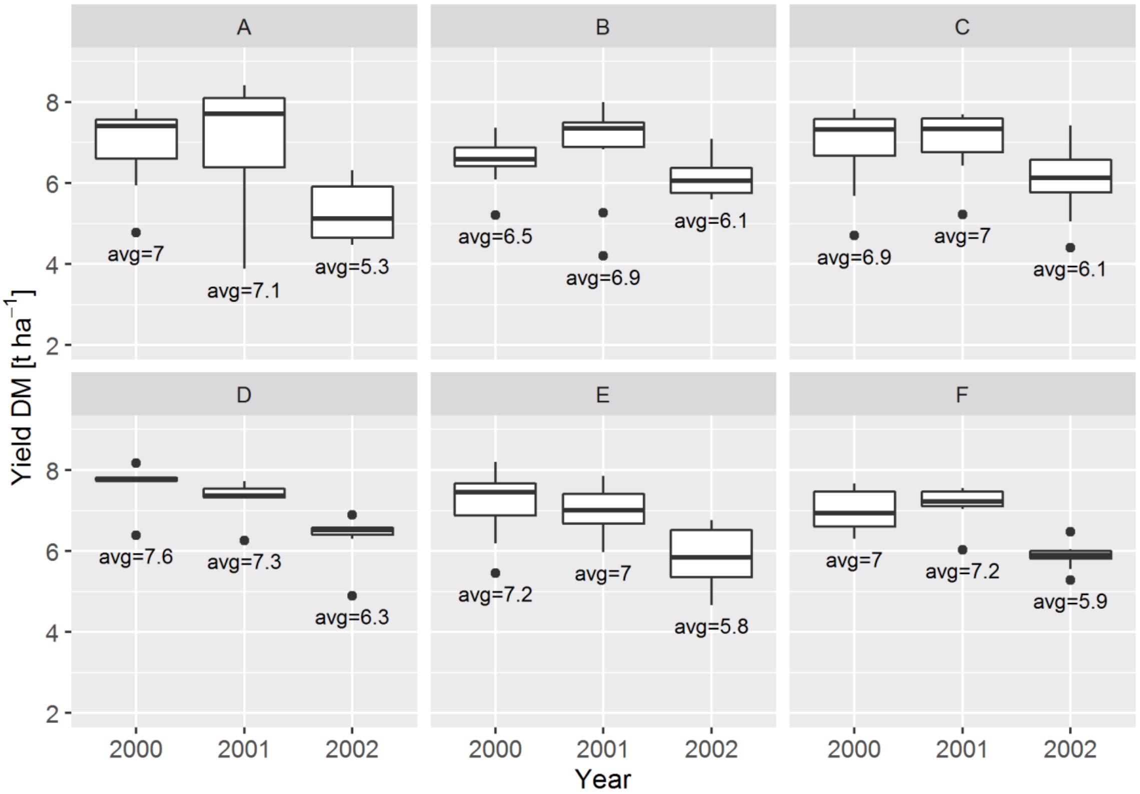


2.3.3 CROP DATA: The provided crop information focuses on estimated dry matter yields per each grid point and year of harvest starting with the year 2000 and ending in 2002. Dry matter yields were measured on the go during harvest using a yield monitor on the combine harvester. Following Jürschik et al. (1999) all measured yields that exceeded or deceeded the twofold standard deviation were excluded from the dataset. The average observed value within a radius of 25 m around each grid point was assigned to the point. In addition, the standard error of all observations within the defined radius was calculated. The annual yield performance per each transect is presented in Figure 6. Grid points of the nested grids were excluded from the procedure due to the reduced distance between the points. Additional details about crop development according to the investigated growing seasons are given in Table 2 following the BBCH-scale.

Table 2. Phenology according to growing season derived from the DWD Climate Data Center (CDC) (www.dwd.de) for neighboring locations

Crop	Date 3 leaves unfolded (BBCH 13)	 booting (BBCH 41)	 ripening: hard dough (BBCH 87)
Winter wheat	-	23.05.2000	10.01.2000
Winter wheat	01.11.2000	30.05.2001	19.07.2001
Triticale	-	04.06.2002	21.07.2002

Figure 6. Distribution of yields at Beckum according to the year of harvest and examined transects.



3 DATA CLASSIFICATION FOR CALIBRATION AND VALIDATION OF AGRO-ECOSYSTEM MODELS: Experimental field data are inter alia fundamental to calibrate, validate and improve agro-ecosystem models. Thereby, the intended use of the data essentially depends on their complexity, quality and quantity. One applicable method to evaluate the consistency and quality of agricultural datasets is provided by Kersebaum et al. (2015) who developed a software tool that considers data requirements for model calibration and validation. The tool classifies a dataset from low to high suitability for the purpose of modelling encompassing the levels “copper”, “silver”, “gold” and “platinum”. Each block of variables essential for model input (meteorological data, agronomic management, soil data, initial values, previous crop, topography) and model testing (phenology, crop growth, soil, surface fluxes, additional observations) were classified. Every block contains variables and/or information that are weighted by relevance and with respect to a defined weighting condition (e.g. number of soil layers, investigated soil depth). By completing information for each variable block a total sum of points is calculated based on available data, relevance and weighting condition classifying each block to one of the mentioned levels. The sum of total points defines the quality rank of the entire dataset. The user is able to specify the number of site variants and treatments that are considered in the dataset which might improve the total estimated ranking by calculating a multiplier (for detailed information see Kersebaum et al. (2015)). The present dataset received in total the rank "gold", while the rank of variable blocks reached from "copper" (phenology) to "platinum" (agronomic management, topography). The variable blocks "initial values" and "weather" were ranked as "gold" and measured crop, soil data and state variables (model testing) as "silver", respectively. A considerable improvement was achieved by the specification of the nitrogen treatment and the site variants which upgraded the classification from "silver" to "gold". Due to site-specific fertilization we defined five treatments of nitrogen application and a number of seven site variants reflecting the areas of homogenous texture classes shown in Figure 1.

4 DATASET STRUCTURE AND ACCESS: The described dataset is structured into seven tables and available via the Open Research Data Portal of the Leibniz Centre for Agricultural Landscape Research. It can be accessed via the doi: 10.4228/ZALF.2003.327. The values in the data tables are comma-separated and the file formats are csv. A brief description of the methods applied during the presented survey together with position information of all grid points are provided additionally.

Table 3. Content of the described dataset Beckum

File name	**Content and comments**
Weather_Bec.csv	climatic variables (global radiation [MJ m^{-2}], air temperature [°C], precipitation [mm], wind velocity [m s^{-1}]) per day measured at Beckum and suitable for process modelling
Management_Bec.txt	management activities at the field Beckum starting with harvest of winter rape (20.08.1999) and ending with harvest of *Triticale* (28.07.2002)
Initial_Parameters_Bec.txt	results of the initial soil sampling on 15.09.1999 including stone content [% per mass], organic carbon [% per mass], total carbon [% per mass], total nitrogen [% per mass], mineral nitrogen (ammonium and nitrate) [mg 100 g^{-1}], soil moisture [vol % and % per mass] and plant available mineral nitrogen [kg ha^{-1}] for every soil layer and grid point
Soil_Texture_Bec.txt	results of the initial soil sampling considering soil texture (coarse, medium, fine and total sand [%]; coarse, medium, fine and total silt [%]; clay [%]) after the German Soil Taxonomy (AG Boden, 2005) and bulk density [g cm^{-3}] for every soil layer and grid point
Soil_Variables_Bec.txt	results of the recurrent soil sampling at six additional dates within the observation period covering soil mineral nitrogen (ammonium and nitrate) [mg 100 g^{-1}], gravimetric [% per mass] and estimated volumetric [vol %] water content and plant available mineral nitrogen [kg ha^{-1}] for every soil layer and grid point
Fertilization_Bec.txt	date of fertilization within the observation period and type and amount of fertilizer [kg ha^{-1}]; the grid points are assigned to the corresponding amount of site-specific fertilization
Yields_Bec.txt	on the go measurements of yield during harvest were spatially assigned to the grid points by calculating the average yield [t ha^{-1}] from all measurements within a radius of 25 m around each point; the standard error resulting from this approach is included in the table.

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