



Changes in land management and nitrogen balance at different scales in the Weiße Elster river basin, Germany

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Received 23 September 2009; Accepted 11 February 2010

ABSTRACT

Sound river basin and environmental management depend on accurate data for land use and management. To date, the appropriate sources of agricultural land management data for different planning levels have not been determined. Hence, our study investigated the use of three different information sources of land management: (i) statistical data, (ii) postal surveys, and (iii) interviews. For different aggregation levels, comprising (i) district/community level, (ii and iii) farm level, a detailed analysis was conducted to identify the information about land management and its impact on the nitrogen balance. Land management data are used as the basis for calculation of nutrient balances. Therefore, the analysis included the use of the nutrient balance model REPRO (Reproduction of the soil organic matter) on the small scale for the years 1999–2003. The benefits and limitations of the three information sources were assessed using the example of the “Weiße Elster” river basin in Central Germany. Statistical data are suitable for an overview and first classification, but information about fertilizer application is not available. Postal surveys are suitable for the generation of questionnaires that give specific information about the topic. However, although the low rate of return gives information on land management distribution, it does not provide area-wide information. Interviews are appropriate for smaller areas, and there is a higher response than compared to postal surveys, however interviews are very time consuming. We detected remarkable changes in land management due to the structural changes in the agricultural sector since German unification in 1990. The three different information sources all showed that there has been a marked decrease of livestock densities and land management intensity since German unification. The high resolution data for the “Parthe” sub-basin of the “Weiße Elster” river basin showed that nitrogen balances are significantly influenced by the weather conditions: both very dry and wet conditions led to lower crop yields, and consequently to higher nitrogen balances.

Keywords: EU-Water framework directive (WFD); Land management; Nitrogen balance; River basin; REPRO model; Weiße Elster

1. Introduction

The EU-Water Framework Directive (WFD) requires a good chemical status of rivers. Despite

this goal, many European rivers are highly polluted, including the 4th order “Weiße Elster” river basin (5200 km²), within the large sub-catchment of the Saale basin in Germany [1]. According to investigations by the German federal states, 73% of the area of the “Weiße Elster” river basin will probably not

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achieve the water quality status required by 2015 [2]. Existing agricultural management practices are one of the main reasons for pollution in the basin, and changes could probably help to improve the water quality. Additionally, the high cattle density has an impact to the release of methane gas to the atmosphere, and has hence has an important impact on climate change.

Land management-related measures to reduce nutrient pollution need to be implemented on different scales, such as that of water bodies, sub-catchments, and river basins. However, there is little information about the suitability of different data collection methods, and of using data with different spatial and temporal resolution, for the different planning levels. This lack of knowledge limits development of sound management options.

To address these needs, and to provide a basis for achieving the water quality objectives, we have carried out a study which contributes to a more efficient use of land management information on different aggregation levels.

Our present study started with a detailed analysis of three different methods and levels of gathering spatial data on land management intensities. These data are used as the basis for the calculation of nutrient balances. We also investigated the structural change in agricultural use since German unification in 1990, in order to assess its effects on the development of the agricultural structure in the “Weiße Elster” river basin. Furthermore, nitrogen balances were calculated on a high disaggregated level with the model REPRO, for the sub-basin of the “Weiße Elster” called the “Parthe” for 1999 to 2003, based on personal interviews. This was done to show the effects of different factors such as climate or crops on nitrogen balances.

Hence, we aimed to answer the following questions:

1. Which information about agricultural management practices can be obtained, at which scale?
2. Which are the benefits and limitations of the different types of land management data?
3. Which results derived from calculation of nutrient balances are additional to the data about agricultural management practices derived from management data on field scale?

2. Study area

The “Weiße Elster” study area (5200 km²) lies in the southern part of Central Germany. It is classified as a river basin district according to the WFD. Land use is dominated by arable land (44%), forest (20%) and

Table 1

Land use in the “Weiße Elster” river basin (database: biotope type and land use mapping of Saxony, Saxony-Anhalt and Thuringia).

Land use in %	Portion of the catchment area in %
Arable land	34.77
Grassland	16.11
Forest	19.79
Grove, bosk	1.49
Urbane settlement, traffic	13.64
Special zone	3.27
Water surface area	1.36
Other	0.54
total	100

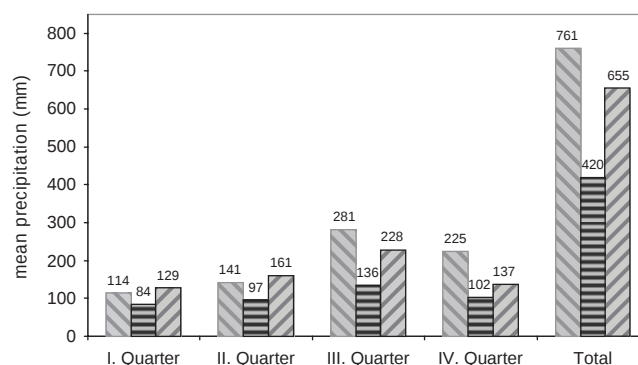


Fig. 1. Mean precipitation (mm) per quarters in 2002 (red), 2003 (pink) and mean values (green) in the federal state of Saxony [9].

grassland (16%) (Table 1). Mean precipitation varies from under 500 mm yr⁻¹ in the north-west, to more than 1000 mm yr⁻¹ in the south-east. The investigated period from 1999 to 2003, includes two years of extreme climatic conditions. In 2002, precipitation was very high, while in 2003 precipitation was very low, compared to the annual mean value (Fig. 1). The northern part of the catchment is dominated by parabrown and tschernosem soils on loess substrate. In the central part of the catchment, mainly pseudogleys are present on a shallow loess substrate over loamy sediments, while in the southern part mainly brown soils occur on bedrock.

To assess land management in detail, we choose the representative sub-basin of the river “Parthe” (403 km²) which lies in the north-east of the “Weiße Elster” river basin. The land use in the “Parthe” sub-basin is dominated by arable land (58%) and grassland (10%). Precipitation varies between 550 and 650 mm yr⁻¹, and there are mainly brown and stagnant soils on sandy and loamy substrates.

3. Methods

Three different approaches were used to gain information about land use and management [3]. (i) We obtained statistical data from the State authorities for an overview of land management intensities. Survey data for 1995, 1999, 2001 and 2003, was available for crops, livestock and yields, for administrative districts (the level between federal state and community) and for some communities. Comparable data for 1985–1989 (before German unification) for this area of the former German Democratic Republic (GDR) were obtained from [4]. (ii) A postal survey was sent to approximately 300 farmers to get more detailed information on a disaggregated level. The questionnaire was divided into general questions about size and kind of the farm. Questions included the development of cattle stock for the years 1989, 1995, 1999, 2003, and for the future, an open question about the cause of this development; the use of organic fertilizer, and participation in support programs. (iii) Personal interviews with farmers were conducted in the sub-basin of the “Parthe” river. Data was obtained at the level of individual fields, for the field crops, organic and mineral fertilizer application, and crop yields. The position of the fields was digitized for presentation in Geographical Information Systems (GIS).

To derive a summary of the impact of the agricultural use on ground and surface water quality, we used nitrogen balances at the individual field level. The latter is a key indicator for the impact of agricultural use on water quality. The personal interviews were used as a basis for the application of the REPRO model (Reproduction of the soil organic matter). This “black-box” model was developed at the Martin Luther University in Halle (Germany) to calculate the internal cycle of humus- and nutrient balances at the farming level [5,6] in a qualita-

tive and quantitative way. Key elements of the model are crop production, livestock breeding, and analysis of the whole matter balances on farm level.

The model works in a modular fashion. The user can choose between the modules according to the particular question. The acquisition of crop data is carried out on field level. For the calculation of nutrient balances, data for crops, yields, organic and inorganic fertilizer, are necessary. Using this data set and internal coefficients, for example for nutrient emissions of different animals (derived from field experiments and literature surveys), the nutrient-, humus- and energy balances can be calculated, which are given as results for the field level and the whole farm. REPRO is suitable for areas of several hundred or thousand hectares.

4. Results

4.1. Statistical data

After German unification, a large percentage of the agricultural area (90%) was cultivated by the small percentage of farms (20%) which were larger than 100 ha (Fig. 2). This in balance is due to the agricultural production policy of the former East Germany (GDR), which led to farms of an average size of 200 ha. In contrast, in the former West Germany, farms were much smaller, with an average size of 32 ha [7]. In 2001, organic farming was rare; however there was a marked increase (325%) in the next two years, with 5% of the area devoted to organic farming in 2003.

Arable land and permanent crops are generally mainly situated in the northern part of the catchment, due to the high fertility of the loess soils. Grassland is mainly in the southern part of the catchment, due to less fertile soils and steeper slopes.

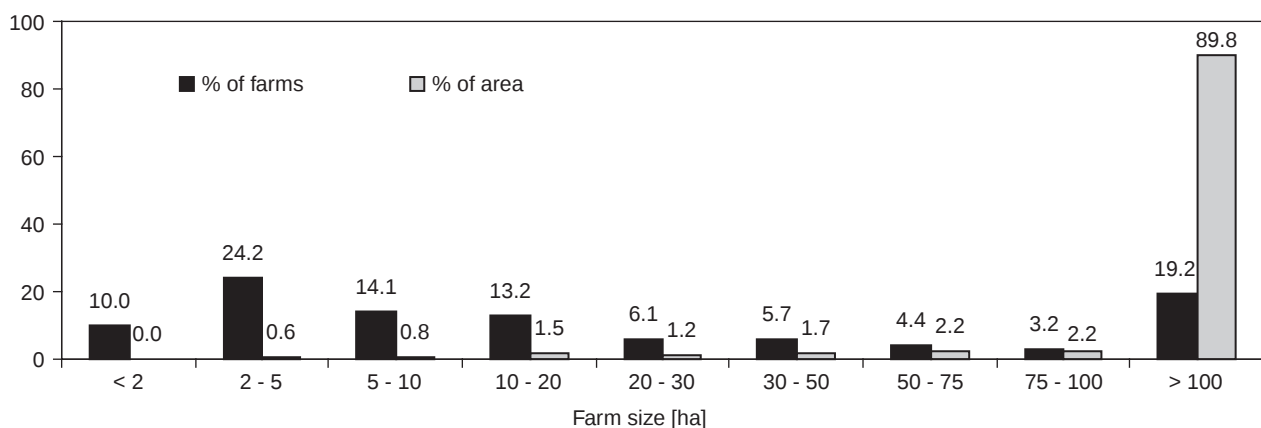


Fig. 2. Farm size in the “Weiße Elster” river basin.

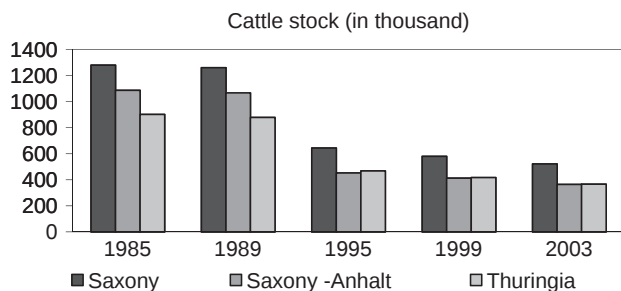


Fig. 3. Changes in cattle stock in the federal states of Saxony, Saxony-Anhalt and Thuringia 1985–2003.

The percentages of land used for different crops changed markedly when comparing 1986–1989 with 2003. Arable land increased from 80% to 86%, while the expense of grassland decreased. On arable land forage crops decreased from 26% to 10% [3]. Other changes of note were for cereal which increased from 53% to 60% of the arable land, and winter rape which increased from 2% to 17%; in contrast, root crops decreased from 15% to 4%. Between 1982–1986 and 2003, there was a marked reduction of 62% in cattle stock in the federal states of Saxony, Saxony-Anhalt and Thuringia which lie in the “Weiße Elster” river basin, due to structural changes in the farming systems in the area of the former GDR after German unification (Fig. 3). During the same period, milk yield per cow doubled, from approximately 4000 kg yr⁻¹ to approximately 8000 kg yr⁻¹.

In the “Weiße Elster” river basin, livestock units ha⁻¹ dropped from 1.1 in 1983–1986 [1], to 0.64 in 1992 and to 0.42 in 2003. In 2003, no district exceeded the 0.5 livestock unit ha⁻¹, which is considered to be the threshold for sustainable agricultural land use.

The number of livestock units ha⁻¹ of agricultural area in 2003 is shown in Fig. 4. In the northern part of the river basin, livestock density was low (< 0.5 livestock unit ha⁻¹ of agricultural area), due good soil conditions leading to preferable use as arable land. In contrast, in the more hilly southern part of the river basin, the livestock density reached 0.8 units ha⁻¹ of agricultural land, with less preferable soils.

4.2. Postal survey

The postal survey yielded a 23% return rate, (which is above the expected rate of 20% [8], and gave us detailed information about 68 farms in the “Weiße Elster” river basin.

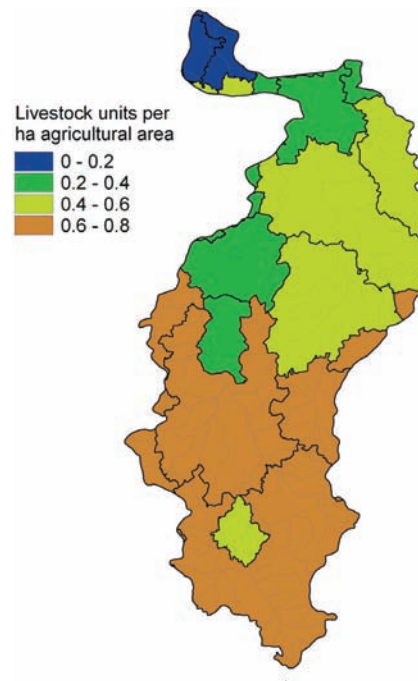


Fig. 4. Livestock units per ha agricultural area for 2003 (based on official statistics at the county level) in the “Weiße Elster” river basin.

The results at this disaggregated level were different from the statistical data at the district or community level, especially for the number of farms with livestock units of the desired density of < 0.5 ha⁻¹. The 68 participating farms reported livestock densities ranging from 0.02 to 14 livestock units ha⁻¹, which includes much higher values than we derived from the statistical data at the district level. A density of livestock > 1 livestock unit ha⁻¹ was present in 18 of the 68 farms.

Between 1995 and 2003, 50% of the farms reduced their cattle stock, and 36% increased their cattle stock; most farmers expected a constant cattle stock in the future. For 32% of the farms which had increased cattle stock, a subsequent decrease was expected due to increased milk production per cow, constant milk quotas, and the current low milk prices. Increasing cattle stock was mainly reported from farms with low cattle stock, due to the need for specialisation because of falling milk prices and the potential use of quotas.

The use of organic fertilizer was also examined at this disaggregated level. Organic fertilizer such as slurry, liquid manure, and stall manure were mainly applied to the farmers own fields, only three farms with livestock units > 1 ha⁻¹ sold the organic fertilizer.

The correlation coefficient between the livestock units and the amount of applied organic fertilizer was 0.76.

4.3. Assessment of personal interviews

Nine farms, varying from 66 to 4780 hectares, provided input data for the REPRO model. Data was available for 317 fields, covering 12,880 hectares, some 8300 hectares of which were in the “Parthe” catchment, and accounted for approximately 40% of the agricultural area in the catchment.

The land cultivated by the farms was 91% arable, and 9% grassland. The crops were mainly winter wheat, winter barley, rape (mainly used for its oil), maize and rye. Seven farms were farmed partly or completely with intercropping (crops cultivated in winter between two main crops used as forage, or to green manures to regenerate the soil). Eight farms used mulch on parts of their fields. Seven of the nine farmers were participating in support programs in order to balance the economic losses through these measures, and to get a secure source of income. Crop rotation was mainly determined by the agro-economic situation (market prices, availability of support programs, and contingencies for special crops), rather than by scientific reasons.

4.4. Results of the REPRO model

The mean nitrogen (N) balances on the field level were calculated with the REPRO model for 1999 to 2003

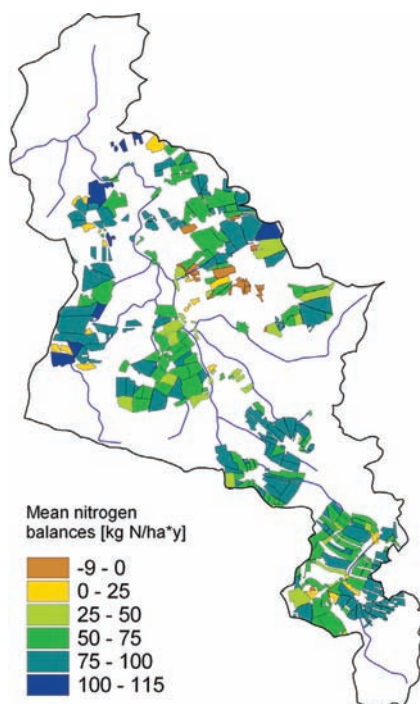


Fig. 5. Mean nitrogen balances (1999–2003) in the “Parthe” catchment, REPRO models results on the field level [3].

(Fig. 5, Table 2). Nitrogen balances on the field level for a single year describe the direct influence of the crops and fertilization within the same year, the input of which can be compensated for in the following cropping sequence. The values for mean nitrogen balances on the field level ranged from -9 to $+115$ kg N ha⁻¹ yr⁻¹, taking into account the effect of growing different crops with different nutrient balances in subsequent years.

The nitrogen balances on the farm level varied among the 9 farms from 53 to 90 kg N ha⁻¹ yr⁻¹ (see Table 2). These 1999–2003 values are much lower than those for the 1980s, when the mean nitrogen balance was 98 kg N ha⁻¹ yr⁻¹ [4]. This reduction was due to structural changes due to German unification; particularly reduction of livestock densities and the abandonment of intensive farming systems (see Section 4.1 and Fig. 4).

In 2001, high crop yields resulted in nitrogen balances that were the lowest of the five years studied. The maximal yearly nitrogen balance on a single field was 127 kg N ha⁻¹ yr⁻¹, on a field with winter rye, and the minimal yearly balance was -23 kg N ha⁻¹ yr⁻¹ on a meadow with several cuttings a year. In 2002, the catastrophic flood in the Elbe River also influenced the tributary rivers, including the “Parthe” river. Due to high rainfall (Fig. 1), crop yields were reduced, and/or their quality was reduced. Compared to 2001, this led to 30% higher nitrogen balances (16 kg N ha⁻¹ yr⁻¹) in 2002. In 2003, precipitation was very low (Fig. 1), which led to significantly lower crop yields in Saxony (20% below the mean yields) [9]. The dry weather prevented sufficient fertilizer uptake by the crops, and consequently nitrogen balances increased to a value that was 47% higher than in 2001. These results show that nitrogen balances were significantly influenced by climatic conditions, especially in 2002 and 2003. The climate as an unpredictable element can lead to high nitrogen balances, even if farming practices conform to good agricultural standards, and when “best management practices” are applied. Despite such climate-induced variations, improving agro-environmental standards lead to a significant decline in mean nitrogen balances after some years [10,11].

Table 2

Mean nitrogen balances (kg N ha⁻¹ yr⁻¹) on the farm level for 9 farms for 1999 to 2003 (REPRO-results).

	1999	2000	2001	2002	2003
Mean N-balance	62.7	73.1	55.4	71.8	81.6
Min	52.7	61.7	42.2	59.4	71.0
Max	71.2	85.5	66.3	93.0	90.3

Table 3

Advantages and disadvantages of three different methods of data collection [3].

	Statistical data	Postal survey	Personal interviews and REPRO nutrient balance model on farm level
Aggregation level	District/community level	Farm level	Field level
Advantages	• General availability for data on district level • Consistent frame of survey (comparability) • Useful for overview for characteristics of a landscape • Low effort for data collection	• Conception of the questionnaire is variable (adaptable to the relevant questions) • Possibility to query open questions	• High resolution data on field level • High level of information • Consistent basis of calculation • Model-internal calculation of nutrient balances
Disadvantages	• Low disaggregation of data (mainly district level) • Gaps in data due to data protection (mainly on community level) • Data on community level for many federal states not available	• Laborious collection of addresses • Low rate of return without additional measures (e.g. telephone calls) • labour-intensive and without guarantee about the data accuracy • Cost intensive (postal charges, also for reply)	• Many “sensitive” data necessary • High effort to gain the data • Data input for several farms is very time-consuming • No areal information for catchments possible

5. Discussion and conclusions

Depending on the research question and the required spatial scale, different approaches to gathering agricultural management data are appropriate (Table 3). Statistical data provided by the authorities give an overview of agricultural management on an aggregated level; however, information on fertilizer use is missing. It is highly desirable to obtain these data additionally, because of the high impact of fertilizer use on nutrient fluxes. Postal surveys provide information on a disaggregated level for any information requested. However, this method requires a higher effort than working with statistical data, and it is not feasible for a complete area, because this method is dependent on the cooperation of the farmers. Transfer functions would be necessary to gain an area-wide dataset, which introduce an additional error in the investigations. Personal interviews are suitable for smaller areas, and can yield all relevant information on a field scale, enabling further data handling including running models such as REPRO. The interview approach also requires considerable effort, and is only feasible for small areas.

Our comparison shows, with the example of the critical parameter of livestock units ha^{-1} , that the use of data with different spatial resolution can lead to markedly

different results. Results for livestock units on district level which are under the desirable livestock units of $< 0.5 \text{ ha}^{-1}$, showed that in the “Weiße Elster” river basin all districts are below this value and are in sharp contrast to the results for livestock units on community level (which although not available area-wide, exceed the threshold value considerably in many communities). This result was confirmed by the postal survey. The results of this latter method show even higher values for the farm level, of up to 14 livestock units ha^{-1} . This circumstance should be considered with all such investigations.

With the high resolution data collected for the “Parthe” catchment, sound management data can be provided for the field scale. But time-consuming data collecting makes it unfeasible to provide these data for larger areas. However the use of data from the central INVEKOS-database [12] could potentially solve this problem. The database documents financial claims for farm premiums in Germany, and provides all relevant information about agricultural management practices on the farm and field level. However, at present the data is not available for scientific purposes due to data protection laws.

The results from the three different information sources show that since German unification in 1990, there has been a clear decrease of livestock densities and

land management intensity in the study area, which was associated with a decrease of the nitrogen balances. These data show land management changes that are closely related to ground and surface water pollution. For implementing sound river basin management, these data are indispensable. Especially for the implementation of the WFD in national law, it is necessary to find the most effective measures for the particular region. According to different natural, financial and social conditions, variable measure or rather measure packages have to be provided. Therefore, reasonable measures can only be chosen on the basis of sound land use and management data for a region.

Statistical data on the district level are suitable for general measures, for example to optimize the agricultural support from the EU, and for measures concerning cross compliance, or to decrease the levels of organic or inorganic fertilizer as by new national laws. However, lack of data, such as no information about inorganic fertilizer (as would be the case if only statistical data were available), can limit application of the data to the discussed questions and compensation of the lack of data is only possible through assessment of fertilizers used on the particular crops and rating of national statistics.

More detailed data on the community level or a more detailed overview by postal surveys are suitable for regional planning, such as planning measures of the federal states to cope with the differences of national regions. Data on the farm level are suitable for giving farmers input about their nutrient balances, and therefore a better source than data on a more aggregated level to control the environmental input on water and the atmosphere. Financial support from the EU can depend on compliance with distinct agricultural management as a powerful instrument to change to a more sustainable land management effectively.

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