9. Pricing opportunity costs to meet soil quality concepts in matters of heavy metal inputs into agricultural soils

Wolfgang Reiher, Bernd Weinmann, Rolf-Alexander Düring and Stefan Gäth
(Corresponding author: W. Reiher, email: wolfgang.reiher@agrar.uni-giessen.de)

Abstract

There is reasonable concern that agricultural management restrictions may be imposed, when fertiliser application will lead to failure of heavy metal sustainability criteria. Any management restriction reduces a sites land rent compared to the maximal achievable land rent. A methodology is presented that calculates site-specific opportunity costs when sustainability criteria of heavy metals will be exceeded using the models ProLand and ATOMIS of the model network ITE²M. The methodology enables the economic comparison of different sustainability criteria. The importance of permissible additional heavy metal loads in case of the German soil protection legislation is demonstrated.

Key words
Heavy metals, integrated modelling, land use modelling, opportunity costs, sustainability criteria

9.1 Introduction

Agriculture has intensified dramatically in many regions in Europe during the last decades, leading to a revolutionary change in economic, social, ecological, and political concerns. There is now a need for concepts that address all these aspects of developing culture and support stakeholders, politicians, and decision makers. As an overall assessment of every parameter in a social-economic-ecological system is not possible, especially on regional areas, there is a need for indicator parameters which incorporate protection of ecological resources while maintaining an acceptable level of local economy and achieving satisfactory social conditions (Jessel, 2005) especially when non-sustainability is a slow process and adverse effects are likely unnoticeable, but nearly irreversible such as large-area soil degradation.

With the ITE²M model network (Integrated Tool for Ecological and Economical Modelling) the Collaborative Research Centre 'Land Use Options for Peripheral Regions' develops an integrated methodology towards the achievement and appraisal of economic an ecological sustainable options for regional land use which are site-specific and economically differentiated (Frede, 2005). The spatially explicit approach of ITE²M allows a detailed view on different parts of a region. Areas can be identified where any ecological quality criteria is affected due to non-sustainable agricultural management practice. Methods are developed to estimate costs for a sustainable practice.

This work shows a methodology for pricing opportunity costs to meet soil quality concepts in matters of heavy metal inputs into agricultural soils and therefore focuses on the interrelationship of the two models ProLand (Prognosis of Land Use) and ATOMIS (Assessment Tool for Metals in Soils). Scenarios are developed demonstrating the calculation of opportunity costs from site-specific land-rent estimation for a region and testing the precautionary concept of the German soil legislation.

9.2 Background

Considering ecological aspects of sustainability several environmental laws and conventions appoint requirements and sanctions on agricultural management. One example is the application of organic wastes, which is prohibited in Germany when certain reference values for heavy metals in soils are exceeded (BioAbfV, 1998). Thus, ecological criteria, regulated by law, may have influence on land use and management options.

The German Federal Soil Protection and Contaminated Sites Ordinance (BBodSchV, 1999) states so-called precautionary values which, if exceeded, shall normally mean there is reason that concern for a harmful soil change exists (BBodSchG, 1998). For the inorganic pollutants Ni, Cu, Zn, Cd, and Pb the precautionary values are the same as the above mentioned reference values in the German Ordinance on the Utilisation of Organic Wastes on Agricultural, Forest and Horticultural Used Soils (BioAbfV, 1998). Precautionary values are deliberately low compared to trigger and action values, which emphasises their importance as indicators for multifunctionality. They are particularly suited to protect integratively the different ecological pathways soil – plant, soil – soil organisms, and soil – ground water (BBodSchV, 1999). If exceeded there is a reasonable concern that sustainability and therefore multifunctionality is harmed. Table 9.1 provides an overview on the texture- and pH-differentiated precautionary values. Because precautionary values can be easily exceeded by geogenic reason in some areas, permissible additional heavy-metal loads have been added to the precautionary values. These additional loads are permissible when the precautionary values are exceeded on a site by geogenic reason.

Agricultural management practices such as fertilisation are the major inputs of heavy metals into topsoils beside atmospheric deposition (Nicholson *et al*., 2003). Liming has a main influence on heavy metal solubility and bioavailability by steering soil pH-value, usually the most important factor for heavy metal sorption (Alloway, 1995). The type of fertilisers has a main influence on the heavy metal load and which specific elements may put a risk to the soil. On the one hand potentially high Cd concentrations in mineral P-fertilisers is a well known problem. On the other hand even organic fertilisers from animal husbandry may exhibit high contents of Cu and Zn (Thiele and Leinweber, 2001; Nicholson *et al*., 2003). There is reasonable concern that agricultural management constraints may be imposed on particular sites, when precautionary values are exceeded in the future, to accomplish sustainability criteria.

9.3 Methodology

9.3.1 ProLand

The bio-economic simulation model ProLand is a comparative static model predicting the explicit spatial allocation of land use systems (Kuhlmann *et al*., 2002). The main assumption is that the land use pattern is a function of the natural, economic, and social conditions and therefore the focus of the model is to analyse the consequences on the allocation of agricultural and forestry systems as these general conditions change (Möller *et al*., 2002). The basic behavioural function of ProLand is maximisation of land rent. It is assumed that land users will maximise the land rent under the precondition that the opportunity costs of capital and labour would reach a certain minimum level, set by spatially variant realistic values for the region (Kuhlmann *et al*., 2002; Weinmann *et al*., 2006).

Calculating the land rent takes several steps (Weinmann, 2002). The first step is estimating the site-specific maximum realisable yield). Therefore specific conditions like soil type, accumulated temperature, and precipitation in growing season are used as inputs to determine this yield. The second step is the calculation of the production costs adjusted to natural and site conditions such as slope or field size. For this reason a calculative approach is applied to reproduce the influence of the local characteristics on several elements of costs (KTBL, 2002). The land rent maximisation is carried out for every decision unit, in this case the grid units of a grid map. The output of ProLand includes land rent, land use and in particular management information (e.g. crop rotation or fertiliser application) for each site.

9.3.2 ATOMIS

The Assessment Tool for Metals in Soils (Reiher *et al*., 2004) prognoses site-specific potential Ni, Cu, Zn, Cd, and Pb long-term accumulation. The heavy metal sorption is calculated using general purpose Freundlich isotherms according to van der Zee and van Riemsdijk (1987) and Horn (2003). These sorption equations are parameterised by soil sorption characteristics like pH-value, clay-content, content of soil organic carbon, and heavy metal content of the soil. They estimate the element concentration in soil solution which can be removed from the topsoil by leaching and plant uptake. Predicted total concentrations in topsoils are compared to the sustainability criteria at each yearly time step and the time to precautionary value exceedance is calculated. In this study a land use and management system is considered to be sustainable, when simulated heavy metal concentration in topsoils do not exceed these legal values within 100 years. Assumed pH-target-values vary between 5.8 and 6.8 for arable land and 4.9 and 5.8 for grassland depending on clay content; beside soil texture, they determine the effective precautionary value. Beside atmospheric deposition (HLUG, 2001), heavy metal input is calculated by ProLand information on the amount of P-fertilisation. The amount of P-fertilisation is equal to the amount of P-removal by harvested plant parts.

9.3.3 Backcoupling of ATOMIS and ProLand

In case ATOMIS prognoses exceedance of any precautionary value within 100 years on a specific site, it reduces the amount of P-input onto that site iteratively during repeated simulations to an amount which ensures that there will be no exceedance within this period of time. This sustainable P-input is a new input parameter in ProLand to calculate a new, sustainable land use and management under the new restriction of a maximum tolerable P-input. The new scenario option has its own land rent, which is either equal or lower than the land rent in the base scenario, which was considered to deliver the site-specific maximum land rent in the region. The first case means that no change in land use is necessary and there will occur no reduction of land rent on any sites. The second case means that a change of land use is possible and a land rent reduction will occur. The opportunity costs are the difference of original and sustainable P-input.

TABLE 9.1. Precautionary values and permissible additional heavy metal loads according to German soil legislation (BBodSchV, 1999) for Ni, Cu, Zn, Cd, and Pb.

	Ni		Cu	Zn		Cd		Pb	
pH	**≥6**	**<6**		**≥6**	**<6**	**≥6**	**<6**	**≥5**	**<5**
clay [mg kg^{-1}]	70	50	60	200	150	1.5	1.0	100	70
loam/silt [mg kg^{-1}]	50	15	40	150	60	1.0	0.4	70	40
sand [mg kg^{-1}]	15		20	60		0.4		40	
permissible additional loads [g ha^{-1} a^{-1}]	100		360	1,200		6		400	

9.3.4 Scenario description

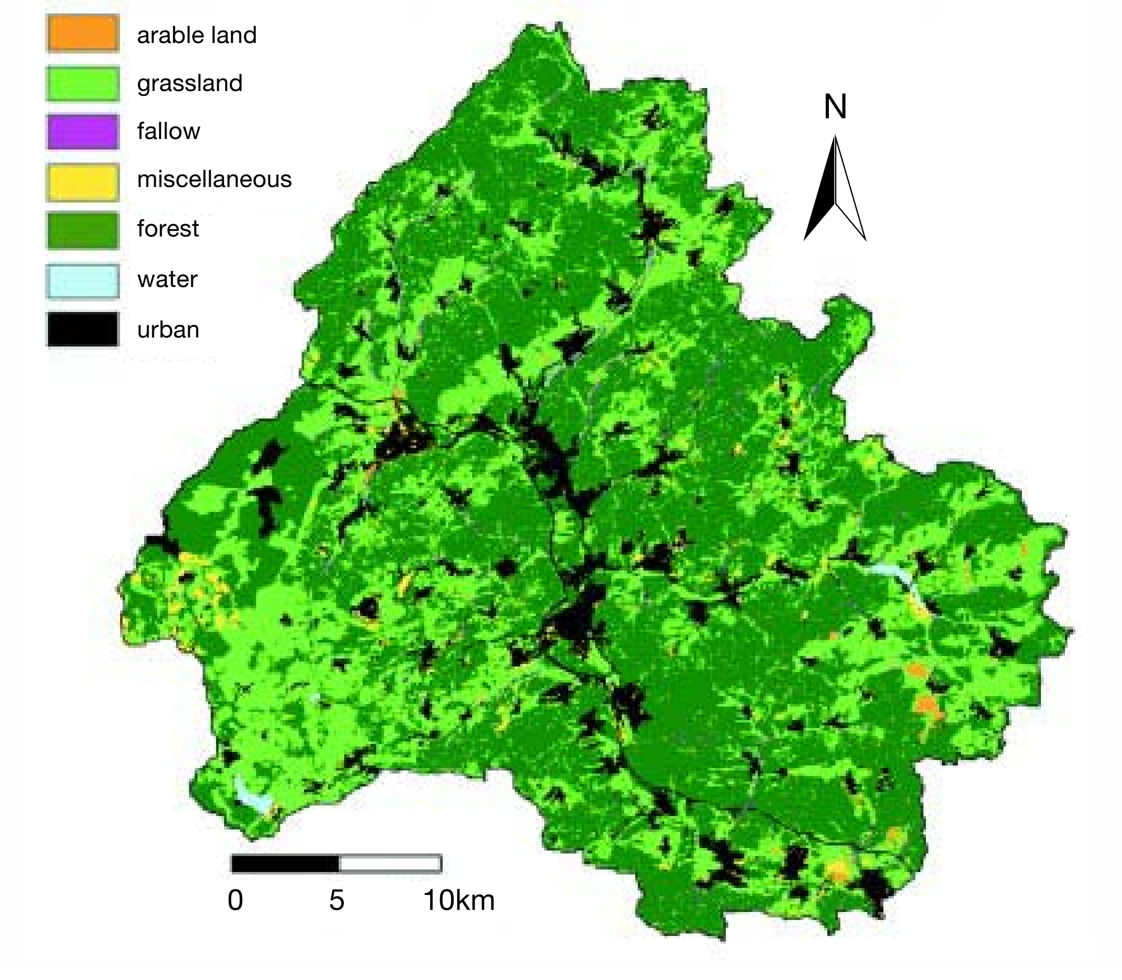
The study was done using the basic conditions of the 2003 reform of the Common European Agricultural Policy (CAP), described by Weinmann *et al*. (2006). It was assumed that area payments for grass- and arable land are equal, as it will be the case by the year 2013. The area of interest was the low mountainous Dill river catchment (693 km^2, Hesse, Germany) (Figure 9.1) as it is the region where all ITE^{2}M-models have been developed. Only cattle manure and mineral NPK-fertiliser were possible fertiliser types in the presented methodological study, because pig husbandry and sewage sludge or organic waste application was not taken into account by ProLand for the CAP-scenario. Cattle manure was assumed to be only applied to sites which produce fodder for cattle husbandry. As sustainability criteria the concept of the German soil protection legislation was tested (scenario A) with the above mentioned precautionary values and permissible additional loads (Table 9.1 page 63). To demonstrate the methodology and the effect of the permissible additional loads on the land rent, two more scenarios where computed. In scenario B the permissible loads were reduced by 50% and by 100% in scenario C.

9.4 Results

Cu (Figure 9.2a) and other heavy metal concentrations are mainly differentiated by geologic reason, even after 100 years which is due to no fertiliser application (forest) or relatively low P-application because of poor site conditions that result in a low P-demand by plants (Figure 9.3a).

Arable land covers only a very small part of the area (1.5% of agricultural area). The dominating crop rotation system is silage-maize/silage-maize/winter-wheat. With the exception of little fallow land intensively and extensively used grassland (91.8% of agricultural area) dominated the agricultural usable sites. All agricultural sites producing cattle fodder show accumulation of Cu and Zn (data not presented for Zn), originating from enriched Cu and Zn contents in livestock manure. Figure 9.2b demonstrates the modelled exceedance of Cu precautionary values over a period of 500 years. This long period was chosen due to the relatively extensive fertilising management, which causes a slow accumulation rate, to demonstrate site specific differences in heavy metal accumulation. The differentiation by time is due to site differentiated agricultural management practise. This holds true also for

FIGURE 9.1. By ProLand simulated land use for CAP-scenario in Dill river catchment results.



Ni, Zn, and Pb. An exception is Cd. Its sorption behaviour is relatively low compared to other heavy metals, the Cd input is relatively low due to low P-fertiliser application (Figure 9.3a) and Cd concentration is low in cattle manure, which is the dominating fertiliser in this scenario because grassland and silage-maize is used as cattle fodder (Figure 9.1). A wide area shows precautionary value exceedance for Cu within the first hundred years and most of these sites appear to show exceedance from the beginning due to geologic reason. Other heavy metals show comparable behaviour so that nearly each site shows an exceedance of precautionary values for at least one heavy metal. For Cu the permissible additional load is stated to 360 mg ha^{-1} a^{-1}. Because of low amounts of applied fertiliser (Figure 9.3a) the effective heavy metal loads are everywhere clearly below this value. For Cu the maximum annual load to a site is calculated as 173 mg ha^{-1} a^{-1} (Figure 9.2c). Thus, scenario A proves to be sustainable under the assumed model input parameters for the Dill river catchment in terms of heavy metals in agricultural topsoils in the next 100 years according to the German soil quality protection concept. The annual accumulated land rent is 15.8 mio. €.

Reducing permissible additional loads for all considered heavy metals by 50% leads to a distinct reduction of sustainable P-input on sites which get more than 19 kg P ha^{-1} a^{-1} in scenario A (Figure 9.3b). As there is no reduction to less than 7 kg P ha^{-1} a^{-1}, no additional forest area was simulated so that there is no reduction of agricultural used land. The area's total land rent is reduced by 73% to 4.3 mio. €, so that the opportunity costs of halved permissible additional loads can be calculated to 11.5 mio. € when P-fertiliser reduction is assumed to be the management restriction on regarded sites. In scenario C the effect of no permissible additional heavy metal loads is demonstrated. Here the sole sustainability criteria are the precautionary values. As there are some geologic classes in the Dill river catchment with relatively high contents of heavy metals,

FIGURE 9.2. ATOMIS-results for scenario A. A: Cu-concentration after 100 years. B: Time to exceedance of precautionary value of Cu. C: Annual Cu loads onto agricultural used soils.

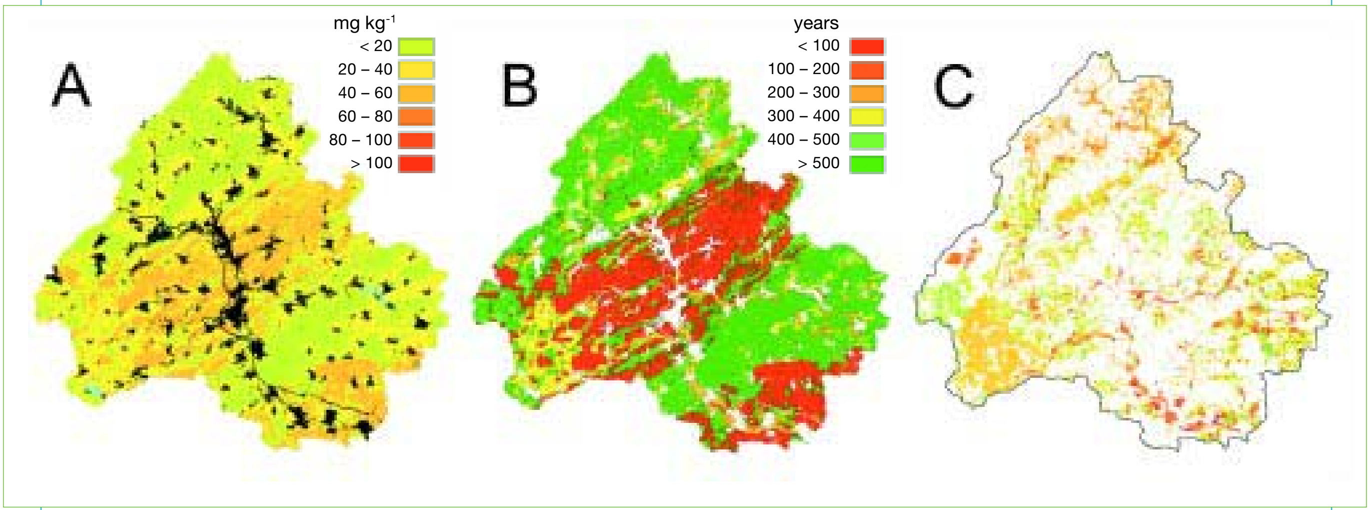
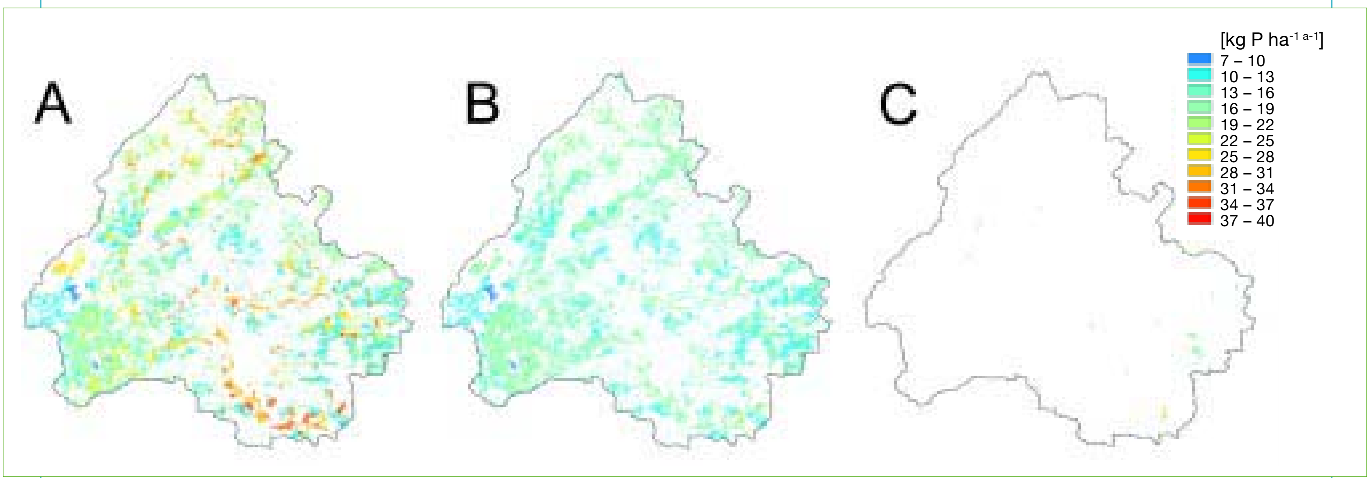


FIGURE 9.3. Sustainable P-input for scenarios A, B, and C.



e.g. Ni (median of 121 samples of basaltic topsoils under arable land: 207 mg kg^{-1}, LABO (2003)), and, as the dominating land use class is grassland, large agricultural used areas have a pH-value below the Ni-, Zn-, and Cd-threshold pH-value of 6, which decreases the valid precautionary value (Table 9.1 page 63), 98.7% of agricultural land in scenario A converts to fallow land or forest in scenario C. Figure 9.3c shows the allowed amount of P-fertiliser on the remaining agricultural land for this criterion of 'sustainability'. The opportunity costs are calculated to 12.5 mio. €, which is a reduction of total land rent of 79%. The remaining 3.3 mio. €, compared to the land rent in scenario A, consist of land rent of forestry, EU-subsidies for fallow land, and the land rent of the remaining agricultural land, which is mostly arable land. Arable land has usually higher pH-value and therefore rarer failure of precautionary values.

9.5 Discussion

Keller *et al*. (2002), who presented a comparable study, calculated the expected costs associated with the probability of failure of Swiss guide values for Zn after an accumulation period of 200 years to 22 mio. € for 36 km^2. This order of magnitude may indicate the agricultural intensity in the investigated Sundgau region (Switzerland). As Keller *et al*. (2002) had no exact information on land rent, they assumed for each site a decrease from 30 to 10 € per m^2 without further differentiation, if the critical value was exceeded. The here presented approach of coupling ProLand and ATOMIS shows that a more detailed estimation of opportunity costs is possible, even though we demonstrate the methodology of developing sustainable management due to heavy metals in topsoils only on the option of fertiliser reduction. In the current state it is useful for estimating the order of magnitude of opportunity costs, but it can only be a rough estimation as long as there are no other management options included. Possible other options are e.g. enduring and increased liming to keep a sites pH-value above the threshold pH-value of the problem elements so that a higher precautionary value is valid. Obviously, liming increases the heavy metal accumulation, so that at any time in the future of such a site when the application of lime can not be guaranteed any more by any reason, the soils will acidify and a higher content of heavy metals will become potentially bioavailable and leachable. As pig husbandry is not included in ProLand so far, which leads to underestimation especially of Cu and Zn in soils, the used types of fertiliser are limited for the recent state of ProLand development. To include pig husbandry will be the major challenge in the near future. A third critical point may be the way of distributing the fertiliser. One may argue that 'problematic' sites could be treated with unproblematic fertilisers, which have low heavy metal concentrations, and vice versa. This is of cause a thinkable way of assuring the right supply of fertiliser application and accomplishing sustainability criteria, but such individual behaviour can not be included in the presented model approach, that shall be transferable to other regions.

9.6 Conclusion

The site-specific calculation of land rent is an encouraging approach for estimating land use options, which depend on each site's natural characteristics. When site conditions are well known for differentiation of management options, their ecological effects on each site can be calculated. In case environmental quality criteria are violated, sustainability can be assessed and an adjustment of management options can happen. For the developed sustainable land use and management options the land rent and thus the opportunity costs can be estimated. Further possible management options like pig husbandry or a more sophisticated liming strategy have to be taken into account in the future.

Under the assumed basic conditions, the CAP-scenario proved to be sustainable on all sites in the Dill river catchment in matters of heavy metal contents of topsoils during the next 100 years. This is mainly the reason, because German soil protection legislation has introduced the instrument of permissible additional heavy metal loads on sites where precautionary values are exceeded by geogenic reason. As it could be demonstrated the value of these loads is a sensitive parameter in terms of economic and therefore potentially social sustainability.

Acknowledgement

This work is part of the Collaborative Research Centre 'Land Use Options for Peripheral Regions' (SFB 299) supported by the German Research Foundation (DFG).

References

Alloway, B.J. 1995. Soil processes and the behaviour of heavy metals. In: Alloway, B.J. (ed.). *Heavy metals in soils.* 2nd edition. Blackie Academic and Professional, Glasgow.

BBodSchG, 1998. Gesetz zum Schutz des Bodens vor schädlichen Bodenveränderungen und zur Sanierung von Altlasten. BGBl. I, 502.

BBodSchV, 1999. Bundes-Bodenschutz- und Altlastenverordnung. BGBl. I, 502.

BioAbfV, 1998. Verordnung über die Verwertung von Bioabfällen auf landwirtschaftlich, forstlich und gärtnerisch genutzten Böden. BGBl. I, 2955.

Frede, H.-G. 2005. Introduction to the Conference 'Multifunctionality of Landscapes'. Conference Abstracts for the International Conference 'Multifunctionality of Landscapes', University of Giessen, 1.

HLUG [Hrsg.], 2001. Staubnierderschlagsmess-programm Hessen - Messbericht für das Jahr 2001, Staubniederschlag und Schwermetalle im Staubniederschlag. Hessisches Landesamt für Umwelt und Geologie, Wiesbaden.

Horn, A. 2003. Beiträge zur Parametrisierung und Validierung erweiterter Freundlich-Isothermen für die Beschreibung der Sorption von Cd, Zn, Ni und Cu im Boden. Ph.D. Thesis, Justus-Liebig-University Gießen (Germany), 188 p.

Keller, A., Abbaspour, K.C. and Schulin, R. 2002. Assessment of uncertainty and risk in modeling regional heavy-metal accumulation in agricultural soils. *J. Environ. Qual.* 31, 175–187.

KTBL (Kuratorium für Technik und Bauwesen in der Landwirtschaft e.V., Eds.), 2002. Datensammlung Betriebsplanung Landwirtschaft 2002/2003. Darmstadt.

Kuhlmann, F., Möller, D. and Weinmann, B. 2002. Modellierung der Landnutzung: Regionshöfe oder Raster-Landschaft? Berichte über Landwirtschaft 80, 3, 351–392.

Jessel, B. 2005. Indicators and Assessment of Multifunctionality. In: Mühle, H., Meyer, B.C. and Eisert, S., *Sustainable Land Use in Intensively Used Agricultural Regions*. – Conference proceedings for the conference on 'Sustainable Land Use in Intensively Used Agricultural Regions', UFZ Centre for Environmental Research, Leipzig, September 20–23, 2005. – Published in September 2005, p.14.

LABO - Bund-Länder-Arbeitsgemeinschaft Bodenschutz, 2003. Hintergrundwerte für anorganische Stoffe in Böden. Available at: http://www.labo-deutschland.de/LABO-HGW-Anhang.pdf

Möller, D., Fohrer, N. and Steiner, N. 2002. Quantifizierung regionaler Multifunktionalität land- und forstwirtschaftlicher Nutzungssysteme. Berichte über Landwirtschaft 80, 3, 393–418.

Nicholson, F.A., Smith, S.R. and Alloway, B.J. Carlton-Smith, C., Chambers, B.J., 2003. An inventory of heavy metals inputs to agricultural soils in England and Wales. *Sci. Total Environ*. 311, 205 – 219.

Reiher, W., Düring, R.-A. and Gäth, S. 2004. Development of Heavy Metal Contents in Soils According to Land Use and Management Systems – A Heavy Metal Balance Approach (10 pp.). Proceedings of the EUROSOIL 2004, Freiburg.

Thiele, S. and Leinweber, P. 2001. Parameterization of Freundlich adsorption isotherms for heavy metals in soils from an area with intensive livestock production. *J. Plant Nutr. Soil Sci*. 164, 623–629.

van der Zee, S.E.A.T.M. and van Riemsdijk, W.H. 1987. Transport of reactive solute in spatially variable soil systems, Water Resour. Res. 23, 2059–2069.

Weinmann, B. 2002. Mathematische Konzeption und Implementierung eines Modells zur Simulation regionaler Landnutzungsprogramme. Dissertation, Agrarwirtschaft Sonderheft 174, Agrimedia.

Weinmann, B., Schroers, J.O. and Sheridan, P. 2006. Simulating the effects of decoupled transfer payments using the land use model ProLand. Agrarwirtschaft special issue. (in press).