Dynamic Cadmium balances in arable soils and grassland soils in the EU: impact of revision of fertiliser regulation on accumulation rates and levels of Cd in soils – *preliminary results as of June 14, 2017*

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Background and Aim

Accumulation of Cadmium (Cd), in arable soils will lead to an increase in the metal content in soil which, in time, can lead to an impact on human health and ecosystem functioning if critical levels in soils are exceeded. According to EFSA (EFSA, 2009, 2012), exposure of children to Cd already exceeds the TDI which is partly due to transfer of Cd from soil into food and subsequent consumption thereof. This would urge the need to reduce Cd levels in soil but at present, an approach to quantify regionally explicit metal accumulation rates and subsequent changes of Cd in soil to evaluate measures that reduce Cd inputs to soil at the European scale is, however, lacking. Therefore a mass balance model operating at a 1x1 km scale was developed considering inputs to soil from inorganic fertilisers, atmospheric deposition, animal manure, compost, sludge as well as outputs including leaching and crop uptake. Inputs via fertiliser, biosolids and manure are based on down-scaled regional or national data. Leaching and crop uptake were calculated at NCU level correcting for differences in soil metal content, pH, organic matter, and clay content using transfer models taking into account regional differences in water fluxes and crop type. The aim of this model approach is to present current metal balances at a regional, national an EU level as well to assess to what extent actual policy revisions, notably those addressing the maximum levels of contaminants in fertilisers (EU2003/2003), affect accumulation rates of Cd in arable and pasture soils. Here we present preliminary model results on the impact of different Cd levels in fertilisers, i.e. 20, 40 and 60 mg Cd kg^{-1} P_2O_5 as proposed. In addition the proposed limit of 80 mg Cd kg^{-1} P_2O_5 is included as well even though this is, at present not part of the current proposal of the EU. Both changes in the Cd load to soil and the resulting changes of Cd in soil after 100 years are discussed.

Results

Data in table 1 show that, at present, there is a net depletion of Cd in grassland soils whereas Cd still accumulates in arable soils even though differences between countries can be significant.

Current Cadmium balances at country and EU level

Table 1 *Overview of current Cd balances in grassland, arable land and total at country level and surface weighted EU average (in g Cd ha^{-1} yr^{-1})*

		Inputs					Outputs		Balance
		Manure	**Fertiliser**	**Compost**	**Sludge**	**Atm. Dep.**	**Uptake**	**Leaching**	
GRASS	Min[1]	0.01	0.00	0.00	0.00	0.17	0.06	0.19	-3.16
	Median[1]	0.10	0.17	0.00	0.00	0.39	0.18	0.94	-0.61
	Max[1]	0.52	1.75	0.00	0.00	1.04	0.69	3.85	1.70
	EU average[2]	0.18	0.38	0.00	0.00	0.43	0.27	1.33	-0.61
ARABLE	Minimum	0.08	0.01	0.00	0.00	0.16	0.06	0.08	-1.08
	Med	0.25	0.45	0.00	0.03	0.42	0.18	0.69	0.35
	Maximum	0.85	1.07	0.25	0.49	0.91	1.52	2.51	1.34
	EU average	0.26	0.64	0.02	0.06	0.42	0.26	0.55	0.58
TOTAL	Minimum	0.08	0.01	0.00	0.00	0.17	0.06	0.11	-2.36
	Med	0.24	0.42	0.00	0.01	0.42	0.18	0.88	0.06
	Maximum	0.74	1.16	0.16	0.42	0.91	1.23	3.11	1.27
	EU average	0.24	0.59	0.02	0.05	0.42	0.26	0.69	0.36

[1] min., median and max of all 26 countries included in the assessment

[2] average balance at EU level in all spatial units (corrected for surface area)

At present the use of P fertilisers is, in arable soils the main source of Cd (0.59 g Cd ha^{-1} yr^{-1} at EU level, ranging from almost zero to 1.2 g Cd ha^{-1} yr^{-1}). Leaching is both in arable soils and grassland soils the main output of Cd with leaching losses being particularly high in counties where low pH soils dominate in combination with high rainfall. The distribution of the balances at country level is illustrated in figure 2.

Crop uptake is quantitatively less important compared to leaching losses even though uptake can vary significantly between crops with higher levels of Cd taken up by (leafy) vegetables compared to for example potato. Due to the higher yields of crops like potato however, the total removal rate can be higher for such crops.

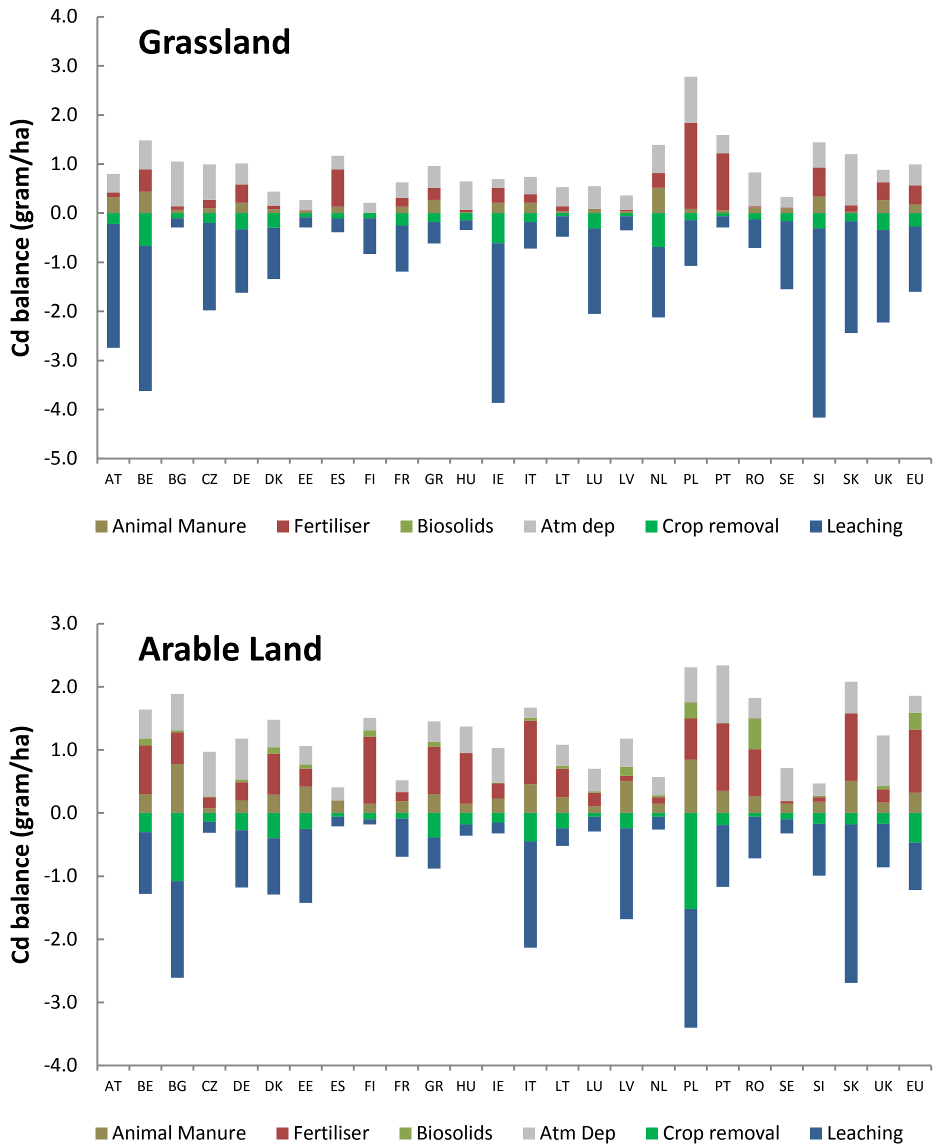
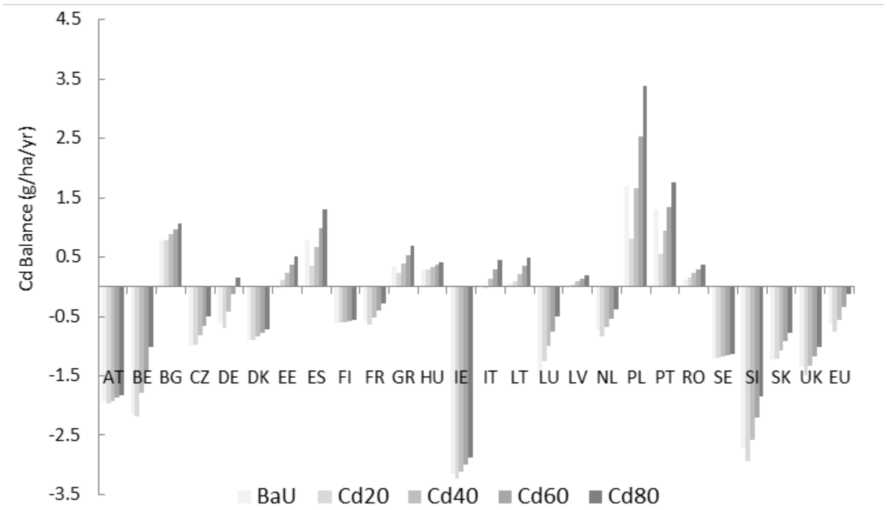


Figure 1. *Average Cd balance (current, in g Cd ha^{-1} yr^{-1}) and individual balance posts at country level for Grassland soils (top) and Arable land (bottom)*

At present the Cd load to soils depends on both the use of P fertilisers and the average Cd level in P fertilisers which varies between countries. On average the Cd-P ratio equals approx. 32 mg Cd kg^{-1} P_2O_5 at EU level (Smolders, 2017) but this can vary between almost zero in countries using rock phosphate (a.o. Estonia, Finland and Sweden) to 50 – 60 mg Cd mg Cd kg^{-1} P_2O_5 in Portugal and Spain. Also the use of animal manure in countries like Belgium, Denmark and the Netherlands limits the actual use of mineral P fertilisers since a large part of the P requirements are covered by manure applied to the soil.

Dynamics of Cadmium in soil in view of revisions of the fertiliser regulation

The proposed limits of Cd in fertiliser will affect Cd loads to soil and eventually the Cd level in soil as well. Here we simulate the dynamics of Cd in soil assuming 4 different levels of Cd in P fertilisers and compare these to the impact of the current situation (BaU: Business as Usual). In figure 2 the impact of these scenarios are shown illustrating the impact of the Cd level in fertiliser on the Cd balance at country levels and the EU as a whole. Clearly increased levels of Cd will lead to an increase in the load even though the impact depends on the level of the current quality used at country levels and the amount of fertilisers. In most countries the use of P fertilisers at the lowest proposed level (20 mg Cd kg-1 P_2O_5) will reduce the net balance. In grassland soils, the average balance will remain negative but approaches a stand still situation in case of the 80 mg Cd kg-1 P_2O_5 scenario. In arable soils however, accumulation will increase substantially at both the 60 and 80 mg Cd kg-1 P_2O_5 scenario compared to the current (BaU) and 20 or 40 mg Cd kg-1 P_2O_5 scenarios. This is also illustrated in figure 3 where results at the most detailed spatial level (NCU) are shown. This spatial level consists of approx. 1200 units and hence presents a combination realistic combination of Cd in soil, land use, climate conditions and cd inputs.



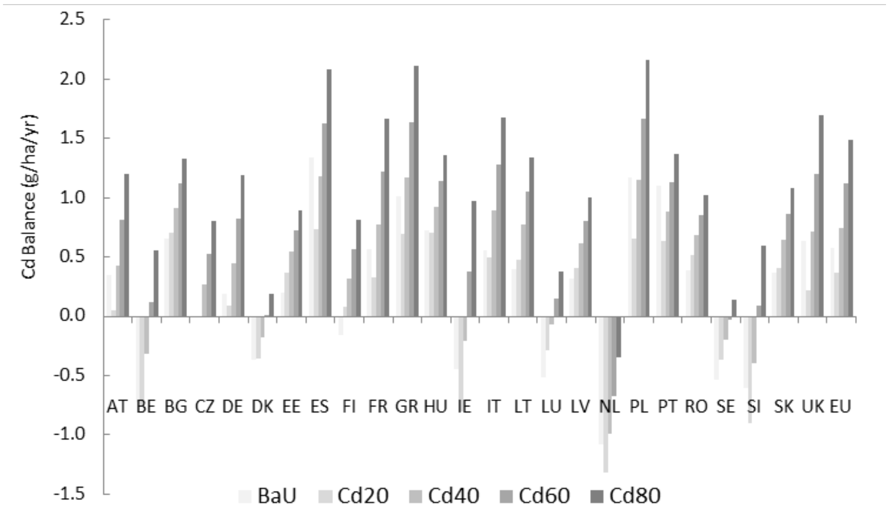


Figure 2. *Impact of EU2003/2003 scenarios on Cd balance (in g Cd ha^{-1} yr^{-1} at country level for grassland (top) and arable land (bottom)*

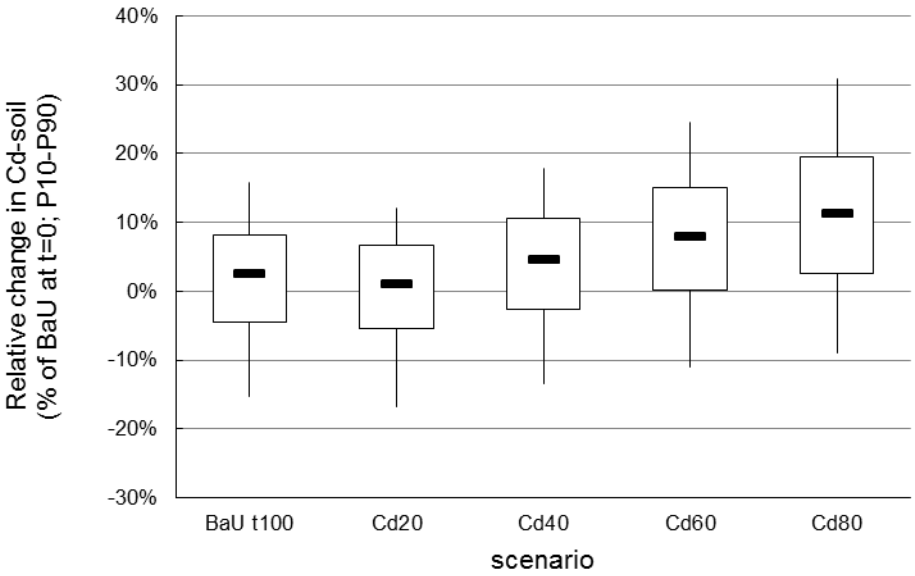


Figure 3. *Predicted relative changes in soil Cd levels at NUTS3 levels (grassland and arable land) for all scenarios at t=100 compared to t=0 (top: all data; middle: P5-P95; bottom: P10-P90)*

Results in figure 3 indicate that Cd levels in soils will, on average increase in all scenarios but this increase is close to zero (+1% change compared to current levels in soil) in case of the 20 mg Cd kg^{-1} P_2O_5 scenario. All other scenarios, result in an average increase in soil Cd ranging from +5% to +11% (median of all units) depending on the level of Cd in P fertilisers. As such this trend is similar to the one presented recently (Smolders, 2017), that is, the differences between the scenarios used here (ranging from BaU to Cd-80) is comparable. The main difference however is that the absolute level of the change is slightly higher, i.e. the average relative change in the Cd levels in soils using the Integrator model is higher than the ones calculated by Smolders who predicts that average changes in Cd levels in soils range from -21% om case of the Cd-20 scenario to +3% for the Cd-80 scenario. The main reason for the current difference in model outcome is related to differences in the models used to predict leaching from the soil. As stated by Six and Smolders (2014), leaching is not only the dominant output in the metal balance but also rather poorly defined (quantitatively) due to a combination of model uncertainty, lack of reliable data of leaching from the topsoil and inherent differences between models as such. For example, the model by Smolders based on a linear Kd model predicts, on average a net leaching loss of 2 g Cd ha^{-1} yr^{-1} whereas the non-linear Kd model used in Integrator estimates leaching losses at, on average, 0.7 g Cd ha^{-1} yr^{-1}. Such differences alone could explain the differences in the final balances as given by Smolders (2017) and the current ones described here.

The impact of such regional variation in Cd levels in soil after 100 years is also shown in figure 4 at the most detailed spatial scale used here (NCU level).

Figure 4 illustrates the substantial differences in long term changes of Cd in soil with small changes or even a depletion in countries in the (north) western part of Europe that either use low Cd P fertilisers or are characterised by high leaching rates. On the other hand accumulation is substantial in countries with high consumption rates of mineral fertiliser and/or an above average level of Cd in fertilisers (Spain, Poland).

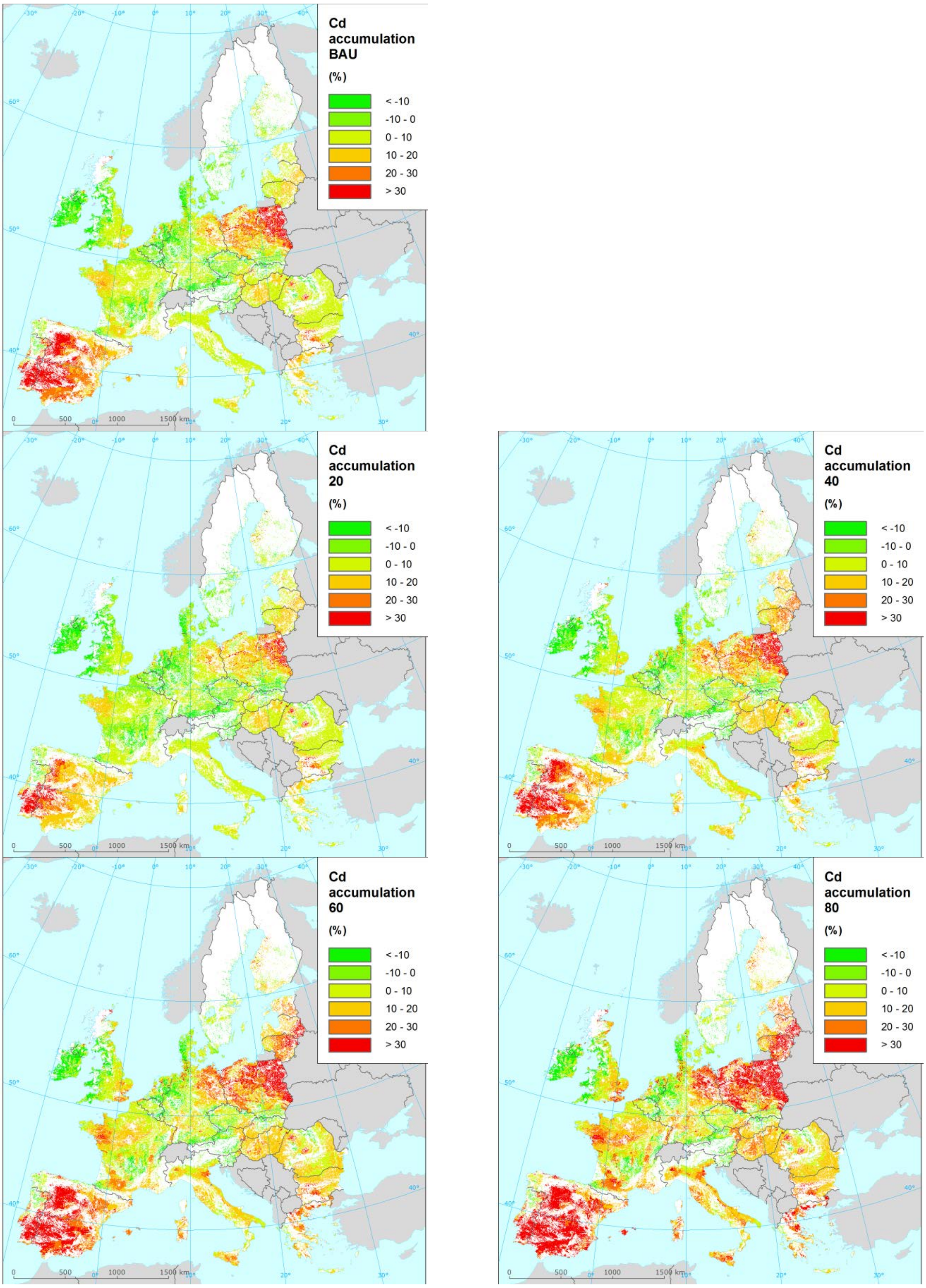


Figure 4. *Spatial distribution of the relative changes (in %) in the soil Cd content at t=100 compared to current levels in soil for the Business as usual scenario and the Cd20, Cd40, Cd60 and Cd80 scenario.*

Conclusions

- At present, Cd balances as calculated with a spatially explicit approach are, on average, negative in grassland soils and positive in arable soils even though differences between countries can be large;
- Depletion is most pronounced in grassland soils in countries with high rainfall, low pH soils and accumulation is largest in Mediterranean areas and countries that use P fertilisers with, on average, higher levels of Cd.
- Accumulation in arable soils will continue to occur at the BaU scenario and will become more pronounced at Cd levels in P fertilisers higher than 20 mg Cd kg^{-1} P_2O_5
- Predicted changes in Cd levels in soil after 100 years however are small compared to current levels even though Cd levels in soil in specific spatial units (with high pH and high Cd loads) are calculated to increase up to 200% compared to current levels.
- On average the predicted increase in Cd levels in soils ranges from +3% (Business as Usual) to +11% (80 mg Cd kg^{-1} P_2O_5 scenario) relative to the current level in soils
- The level of such relative changes is higher compared to recent estimates by Smolders (2017) but the difference is likely to be related to differences in model concepts used to calculate leaching. This aspect will be assessed in more detail through a quantitative comparison of model results from both models.
- Both differences in model approach (linear versus non-linear models used to calculate leaching losses or plant uptake) and data selection (solution data versus extracts) have a clear impact on the ultimate model results which calls for a more harmonized approach to characterize leaching losses so as to avoid unjustified conclusions based on either model approach.

Acknowledgements

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Background data

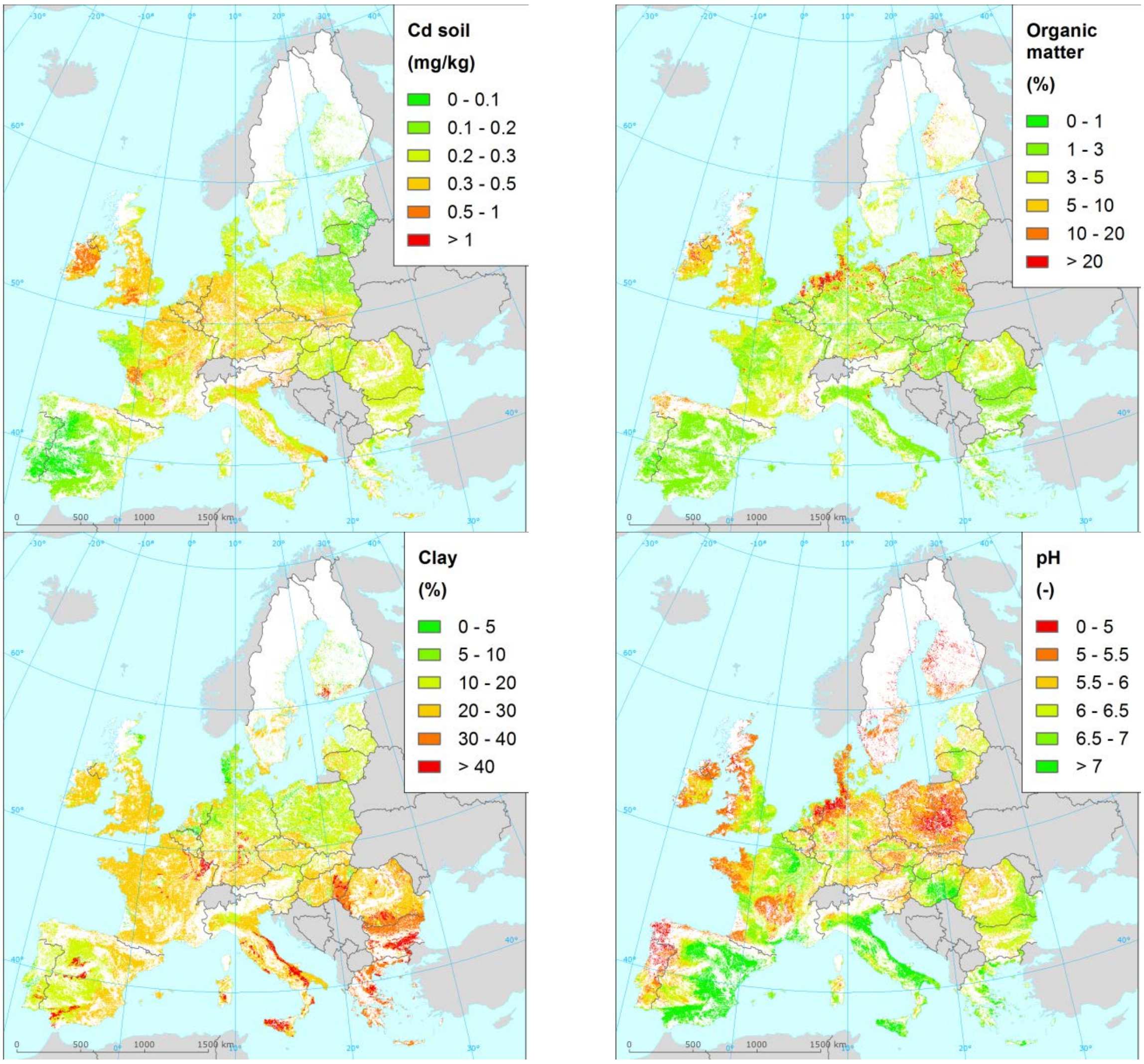

Figure B1. Overview of soil properties used in the model calculations