Dear,

Finally back in my office, I wanted to thank you warmly for your comprehensive and very useful information which I read carefully! As you wrote it, it’s particularly clear that the EU proposal and the Phosagro objectives point in the same direction, even if the intentions stem from different background.

Now, I don’t see any possibility for the ESP to support directly the EU regulation proposal. Some time ago, we discussed a similar issue in the steering committee and we decided as a matter of principle that we do not want to provide letters of support for specific applications/projects and I believe that in this rather sensitive subject we cannot speak for the ESP and its members.

Best regards,

De:
Envoyé : mercredi 6 septembre 2017 18:11
À : 1
Cc :
Objet : RE: New EU fertilizer regulation

Dear,

Thank you very much for consulting us and for the valuable information, especially the preliminary findings of the study by Wageningen Environmental Research which we were unaware of.

First a bit more context and additional information on the revision of the fertiliser regulation:
- In March 2016, as part of the Circular Economy Package, the Commission launched a proposal for a new regulation on fertilising products that should replace the existing one. The proposal is currently being discussed in the Council of the EU and in the European Parliament. The opinion of the lead committee (Internal Market and Consumer Protection) was adopted on 13 July; the plenary debate and the subsequent vote on the report is expected to take place in the September or October session. The letter of Phosagro should be seen as an effort to influence these parliamentary discussions.
- The proposal defines safety, quality and labelling requirements that all fertilising products need to comply with to be traded freely across the EU. It eases the access of organic and waste-based fertilisers to the single market, and brings them on the same level as traditional, non-organic fertilisers, thus reducing waste, energy consumption and environmental damage.
- The most controversial part of the Commission's proposal is the introduction of limits for the content of cadmium in fertilisers. Cadmium is a contaminant present in fertilisers produced from phosphate rock and is of no benefit to plants. It is a toxic chemical that may have serious and often irreversible effects on human health and the environment (factsheet added). The Commission proposes a stepwise approach to reduce Cd in fertilisers: first a limit of 60 mg/kg after the implementation of the
regulation, followed by a limit of 40 mg/kg after 3 years, and a maximum of 20 mg/kg after 12 years. This should allow producers enough time to adapt their manufacturing process to comply with the requirements of the regulation.

The cadmium debate has a geopolitical dimension because phosphate rock with higher contaminant content is to be found in mines in e.g. Morocco, Senegal, Tunisia, whereas cleaner phosphate comes from e.g. Finland, South Africa, Jordan or Russia. Some member states and MEP’s argue that the cadmium limits will make us more dependent from Russia, induce a shift in longstanding commercial relations and increase the production costs of fertilisers leading to higher market prices for farmers (because of the extra costs of decadmiation of phosphate rock).

It is clear that Phosagro’s request is driven by its commercial interest from the introduction of strict cadmium limits. As one of the world’s leading producers of low cadmium phosphate fertilisers, their market position could be expected to benefit from the adoption of the Cd limits in the proposal. While the intentions of Phosagro and the Commission are very different, the outcome is in accordance with the objectives of the proposal: less cadmium in European soils and a better protection of the environment and the health of European citizens.

We leave it to your and the ESP member’s discretion if and how the European Soil Partnership should react on this request from Phosagro, but of course we could welcome any support in favour of the Commission’s proposal.

Please don’t hesitate if you would need further assistance or information on this subject.

Best regards,

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From:  
Sent: Tuesday, August 29, 2017 6:26 PM  
To:  
Cc:  
Subject: RE: New EU fertilizer regulation  

Hello  
I hope this email finds you well – my colleague will provide some explanation - please note that your colleague probably refers to the proposal of the Commission which is been discussed in the European Parliament and the European Council, the final text has not yet been approved.

From:  
On Behalf Of  
Sent: Tuesday, August 29, 2017 6:16 PM  
To:  
Subject: TR: New EU fertilizer regulation  

Dear colleagues,

My former colleague (was in charge of the soil protection with the Federal Office for Agriculture in Switzerland, phosphor specialist) asked me if the ESP would be willing to support the new EU fertilizer regulation (see below and joint documents).

I don't have a clear understanding of this regulation and I wonder if (and how) the ESP should support it.

May I ask you to comment on it?

Thank you in advance,

De: ____________________________
Envoyé: mercredi 9 août 2017 14:07
À: 
Objet: New EU fertilizer regulation

Dear

I am writing to you today to explain our efforts and concerns regarding the new EU fertilizer regulation, and kindly request ESP support. Please find the relevant documents attached.

PhosAgro is a Russia-based company and one of the world’s leading phosphate-based fertilizers producers. We offer exceptional, high-quality phosphate raw material and fertilizers from apatite-nepheline that is being mined on the Kola Peninsula, in north-western Russia. Our igneous ore contains low to no hazardous heavy metals compared to nearly any other phosphate raw material in the world. We are Europe’s largest producer of phosphate-based fertilisers, the world’s largest producer of high-grade phosphate rock and the world’s second largest producer of MAP and DAP. Our products are distributed in Russia and globally.

Thank you for your consideration.

Kind regards

Head of Government Affairs & Compliance
PhosAgro Trading SA
Baarerstrasse 63, 6300 Zug (CH)
mob. +41 79 240 72 67

www.phosagro.com

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If you are not the intended recipient you are notified that disclosing, copying, distributing or taking any action in reliance on the contents of this information is strictly prohibited.
Dear colleagues,

My former colleague (was in charge of the soil protection with the Federal Office for Agriculture in Switzerland, phosphor specialist) asked me if the ESP would be willing to support the new EU fertilizer regulation (see below and joint documents). I don’t have a clear understanding of this regulation and I wonder if (and how) the ESP should support it. May I ask you to comment on it? Thank you in advance,

De: 

On Behalf

Sent: Tuesday. August 29. 2017 6:16 PM
To: 
Subject: TR: New EU fertilizer regulation

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Thank you for your consideration.

Kind regards
Subject: Review of the EU fertilizer regulation

Zug, 09.08.2017

Dear

I am writing to you in support for the new EU fertilizer regulation, which we believe is an important component in caring for EU soils and human health.

In 2015, the European Commission adopted the Circular Economy Package. This includes a proposal for a new fertilizer regulation aiming to incentivise recycling of plant nutrients. It is argued that this would not only help limit waste (from runoff), but it would also reduce the EU’s dependence on imported materials. As this proposal would effectively create a new fertilizer product category (i.e. recycled fertilizer), the proposal includes limit values for As, Cd, and Pb in fertilizers.

In May 2017, the Committee on the Environment, Public Health and Food Safety (ENVI) voted in support of introducing limits for the aforementioned heavy metals. In the case of Cd, the proposed limit is progressive. An initial limit of 60 mg Cd/kg P₂O₅ would be revised to 40 mg/kg P₂O₅ after three years, and then to a final 20 mg/kg P₂O₅ after 9 years. This level is equal to the Cd limit value in mineral fertilizers in Switzerland, which has been in place since 1986. In July 2017, the Internal Market and Consumer Protection Committee (IMCO) supported a voluntary green label for products containing less than 5 ppm of Cd, As, Pb, Cr (VI), and Hg. Both recommendations will be taken into account for the vote in the European Parliament, which is expected in October 2017.

PhosAgro has been following developments in Brussels with interest and has paid special attention to concerns the European Parliament and Member States have regarding the environment, human health and supply security of mineral fertilizers with low amounts of heavy metals.

Fertilizers emit some pollutants. Along with emissions from other sources, this can affect soil quality, and potentially human health via the food chain. Based on LUCAS soil data, Toth et al. (2016) recently found soil Cd concentrations above the investigation threshold throughout the EU and called for strict measures to prevent further Cd increase. Sources with high emission levels, such as some mineral fertilizers, can have a disproportionate impact. The Cd limit values in fertilizers are designed to protect local soil quality, maintain healthy soils, and reduce exposure via ingestion of contaminated food.

Exposure to Cd and other heavy metals has been linked with a range of serious health effects. Repeatedly, limit values have been found to be the measure of choice in order to effectively reduce environmental and health risk.

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addition, recent findings by Römkens et al. (2017)² from Wageningen Environmental Research predict an increase of Cd content in EU soils within 100 years unless measures are taken to address the issue. The study has found that under current conditions change in soil Cd will be higher than proposed by Smolders (2017)³. To achieve stand-still in average EU soils, the acceptable level of Cd content in fertilizers is suggested to be, by Römkens et al. (2017), at 14 mg Cd/kg P₂O₅. In comparison, Smolders (2017) calculated 73 mg Cd/kg P₂O₅.

Fertilizers with low amounts of impurities (like those supplied by PhosAgro⁴) will help farmers maintain soil health for generations and prevent toxic elements making their way through the food chain, potentially harming animal and human health. PhosAgro’s activities are in line with the global fertilizer industry’s Product Stewardship Initiative, striving for zero-harm and adverse environmental impact, and the UN Sustainable Development Goals, amongst global food security and sustainable agriculture.

PhosAgro recently came to learn of a moral hazard which could hamper rational decision making in October. Not only is scientific knowledge being challenged, but industry knowledge – arguably not always readily available to the public – is being denied.

The scientific health debate can no longer be ignored. ENVI supports to help consumers by setting safety standards and demanding limit values in fertilizers. IMCO, in addition, supports voluntary labelling. Clearly, low and no-heavy metal choices need to be offered in the future, but this can be better achieved through obligatory labelling, requiring producers to state the amount of heavy metal their product contains. To blame farmers is not fair, because they are not given the information they need to try and make a good choice for soil health.

As an industry stakeholder, we refute persisting concerns about the availability of low-heavy metal phosphate rock. Numerous producers across various countries are capable of supplying product, e.g. by adopting measures such as blending or decadmiation. More importantly though, countries such as Jordan, South Africa, Canada, and Russia are standing ready to respond to the market demands for low-heavy metal phosphate rock. In addition, the progressive introduction of limits (i.e. a 9-year horizon for the 20 mg Cd/kg P₂O₅ limit), provides adequate time for EU-based nutrient recycling companies to develop further and enter the market. As the EU rapporteur Ildikó Gál-Pelcz (EPP, HU)⁵ has underlined, the proposed limit values are a business case for sustainable development in agricultural fertilizer production, including nutrient reuse.

What is missing, however, is a statement from those stakeholders that are, by their mandate, capable to reintroduce some balance into the scientific debate.

We would appreciate if the European Soil Partnership (ESP) could act and bring to the attention of the members of the European Parliament their support. We consider ESP as an important player in EU-wide efforts to maintain or improve soil health. It therefore is well positioned to make a case for sensitive policy measures that value soil and food safety as well as social welfare and transparency over policies that benefit individual groups, maintain status

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⁴ PhosAgro products comply with the proposed EU regulation. We offer, e.g. < 0.2 mg Cd/kg P₂O₅, < 3.1 mg Pb/kg P₂O₅, < 0.64 mg As/kg P₂O₅, making them some of the purest to the global market.
⁵ http://bit.ly/2C1iKN3
quo and thus hamper development towards more sustainable practices. Your science-based voice carries weight, yet is unheard on this important topic and in this key period.

Please do not hesitate to contact me directly should you have any questions about this request.

Thank you for your consideration and please know, we are grateful for your leadership.

Kind regards,

______________________________
Irina Evstigneeva
PJSC PhosAgro
Director for Marketing and Development
Moscow
Ievstigneeva@phosagro.ru

______________________________
Dr. Andrea Ulrich
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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

Paul Römkens, Wim de Vries and Hans Kros – Wageningen Environmental Research (Alterra)

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\(_2\)O\(_5\) as proposed. In addition the proposed limit of 80 mg Cd kg\(^{-1}\) P\(_2\)O\(_5\) 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\(^{-1}\))

<table>
<thead>
<tr>
<th></th>
<th>Inputs</th>
<th>Outputs</th>
<th>Balance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Manure</td>
<td>Fertiliser</td>
<td>Compost</td>
</tr>
<tr>
<td>GRASS Min(^1)</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Median(^1)</td>
<td>0.10</td>
<td>0.17</td>
<td>0.00</td>
</tr>
<tr>
<td>Max(^1)</td>
<td>0.52</td>
<td>1.75</td>
<td>0.00</td>
</tr>
<tr>
<td>EU average(^2)</td>
<td>0.18</td>
<td>0.38</td>
<td>0.00</td>
</tr>
<tr>
<td>ARABLE Minimum</td>
<td>0.08</td>
<td>0.01</td>
<td>0.00</td>
</tr>
<tr>
<td>Med</td>
<td>0.25</td>
<td>0.45</td>
<td>0.00</td>
</tr>
<tr>
<td>Maximum</td>
<td>0.85</td>
<td>1.07</td>
<td>0.25</td>
</tr>
<tr>
<td>EU average(^2)</td>
<td>0.26</td>
<td>0.64</td>
<td>0.02</td>
</tr>
<tr>
<td>TOTAL Minimum</td>
<td>0.08</td>
<td>0.01</td>
<td>0.00</td>
</tr>
<tr>
<td>Med</td>
<td>0.24</td>
<td>0.42</td>
<td>0.00</td>
</tr>
<tr>
<td>Maximum</td>
<td>0.74</td>
<td>1.16</td>
<td>0.16</td>
</tr>
<tr>
<td>EU average(^2)</td>
<td>0.24</td>
<td>0.59</td>
<td>0.02</td>
</tr>
</tbody>
</table>

\(^1\) 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\(_{2}O_{5}\) 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 kg\(^{-1}\) P\(_{2}O_{5}\) 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\(_2\)O\(_5\)) 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\(_2\)O\(_5\) scenario. In arable soils however, accumulation will increase substantially at both the 60 and 80 mg Cd kg\(^{-1}\) P\(_2\)O\(_5\) scenario compared to the current (BaU) and 20 or 40 mg Cd kg\(^{-1}\) P\(_2\)O\(_5\) 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.
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\(_2\)O\(_5\)
- 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\(_2\)O\(_5\) 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

The model development and scenario analyses as described in this paper was partially financed by EEA and PhosAgro. The content of this paper is based on preliminary findings and as such will be verified at a later stage pending peer review. We also acknowledge the feedback and input from Prof. E. Smolders.

References

EFSA 2009. European Food Safety Authority. Cadmium in food - Scientific opinion of the Panel on Contaminants in the Food Chain. EFSA Journal, 7, n/a-n/a.

EFSA 2012. European Food Safety Authority. Cadmium dietary exposure in the European population. EFSA Journal, 10, n/a-n/a.


Background data

Figure B1. Overview of soil properties used in the model calculations
Heavy metals in agricultural soils of the European Union with implications for food safety

G. Tóth a,*, T. Hermann b, M.R. Da Silva c, L. Montanarella a

a European Commission, Joint Research Centre, Institute for Environment and Sustainability, 21027 Ispra, Via E. Fermi 2749, Italy
b University of Pannonia, Geogkon Faculty, Department of Crop Production and Soil Science, Hungary
c Food and Agricultural Organization of the United Nations, Italy

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ABSTRACT

Soil plays a central role in food safety as it determines the possible composition of food and feed at the root of the food chain. However, the quality of soil resources as defined by their potential impact on human health by propagation of harmful elements through the food chain has been poorly studied in Europe due to the lack of data of adequate detail and reliability. The European Union’s first harmonized topsoil sampling and coherent analytical procedure produced trace element measurements from approximately 22,000 locations. This unique collection of information enables a reliable overview of the concentration of heavy metals, also referred to as metal(loids) including As, Cd, Cr, Cu, Hg, Pb, Zn, Sb, Co, and Ni. In this article we propose that in some cases (e.g. Hg and Cd) the high concentrations of soil heavy metal attributed to human activity can be detected at a regional level. While the immense majority of European agricultural land can be considered adequately safe for food production, an estimated 6.24% or 137,000 km² needs local assessment and eventual remediation action.

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1. Introduction

The heavy metal (HM, also referred to in scientific literature as metalloid) contamination of soil is one of the most pressing concerns in the debate about food security and food safety in Europe (CEC, 2006a) and globally (Kong, 2014). A recent review by Peralta-Videa et al. (2009) summarizes the impact of heavy metal from food origin on human health as well as the mechanism of uptake, transformation and bioaccumulation of heavy metals by plants.

The number of contaminated sites in the European Union (van Liedekerke et al., 2014) and the area affected by different kinds of pollution, of which the remediation would cost €17.3 billion annually (CEC, 2006b) underlines the extent of the problem in the continent. Apart from soil contamination which may lead to the degradation of water quality and a series of negative impacts on the environment (Mulligan et al., 2001; Rattan et al., 2005), the propagation of heavy metals throughout the food chain have serious consequences for human health (Järup, 2003). Despite of the importance of HM contamination, so far there has been no sufficient data to provide a reliable view on the real extent of the problem in Europe and worldwide. FOREGS data produced by the EuroGeoSurvey (Salminen, 2005) and the derived continuous map sheet (Lado et al., 2008) have been the most comprehensive source of information to date. However, the low sampling density (1 site/5000 km²) of the FOREGS study (Demetriades et al., 2010) allows only limited interpretation apart from the provision of a continental-scale overview without the possibility of comparing the concentrations by land use type.

The LUCAS Topsoil Survey, with its 1 site/200 km² sampling density opened new prospect in this regard. The survey represents the first effort to build a consistent spatial database of soil properties for environmental assessments ranging from regional to continental scale on all major land use types across Europe (Tóth et al., 2013). As the inputs of HM to soils are accumulated in the topsoil (Hou et al., 2014) and crop and meadow grass nutrient uptake also takes place predominantly from this zone (Kismányoky and Tóth, 2010), the LUCAS Topsoil Survey presents an adequate information base to assess the HM load to the environment and its potentials to enter the food chain. The standard sampling and analytical procedures of the Survey – with the analysis of all soil samples being carried out in a single laboratory – provides a basis for an EU wide harmonized soil monitoring scheme as well.

In this paper a detailed analysis of the HM content in agricultural topsoils of the European Union is delivered. The analysis covers the main potentially toxic elements, namely As, Cd, Cr, Cu, Hg, Pb, Zn, Sb, Co and Ni. Soil heavy metal content was assessed against element-specific thresholds of contamination and remediation needs. While delivering a new insight into the level of soil HM contamination and highlighting the needs to intensify monitoring or taking remediation actions to eliminate risks to human health in specific regions, the study does not cover aspects like the bioavailability of elements by various pathways.
plant species or the potential differentiated impact of elemental speciation to ecological conditions or human health.

2. Materials and methods

2.1. Soil sampling

With the scope of creating the first harmonized and comparable data on soil at European level to support policymaking, Eurostat together with the European Commission’s Directorates-General for Environment (DG ENV) and the Joint Research Centre (JRC) designed a topsoil assessment component (‘LUCAS-Topsoil’) within the 2009 and 2012 LUCAS surveys (Tóth et al., 2013; Tóth et al., 2015). The LUCAS Programme itself assesses the land use and land cover parameters that are deemed relevant for agricultural policy. Since 2006 the sampling design is based on the intersection of a regular grid covering the territory of the EU (Eurostat, 2015a). Around 220,000 points are periodically visited as control points for the survey. The LUCAS 2009 and 2012 surveys included topsoil sampling at around 10% of those points, which were visited for land use and land cover assessment in 27 EU Member States (all current EU countries excluding Croatia, which joined the EU in 2014). As a result, topsoil samples were collected from some 22,000 points using a standardized sampling procedure. In order to secure the most reliable overview of soil properties in European regions, a multi-stage stratified random sampling approach (McKenzie et al., 2008) was chosen. Attributes, slope, aspect (orientation of the slope), slope curvature and land use were considered for the stratification of the survey points. It is worth noting that the geographical coordinates of some samples (<5% of the collection) were not fully recorded, or the records had low reliability. These samples were not considered in our analysis. Regions with inadequate sample size (less than 5 samples from agricultural land) were omitted from the current study as well.

Samples were collected from the designated locations by a process of composite sampling. Five soil subsamples were taken and mixed together at each sampling. These composite soil samples, weighting about 0.5 kg each, were dispatched to a central laboratory for physical and chemical analyses.

2.2. Methods of laboratory analysis

The laboratory analysis of the soil samples for the basic soil parameters followed standard procedures (Tóth et al., 2013). After the analysis of the basic soil parameters which project concluded in 2012 – soil tests for heavy metal content, including As, Cd, Co, Cr, Cu, Ni, Pb, Sb and Zn were carried out. Elements were analyzed by inductively coupled plasma–optical emission spectrometry. Two certified reference materials (BCR 141R, Calcareous Loam Soil, and NIST 2711, Montana Soil) were used to compare the accuracies of the two digestion procedures. In the first phase of the HM analysis comparative tests were performed using two digestion methods on a subset of 500 samples (Comero et al., 2015). The standard method (ISO, 1995) using aqua regia as an extracting agent was matched with one using microwave-assisted acid digestion (ECS, 2010) and the same detection methods, employing ICP-OES (inductively coupled plasma optical emission spectrometer) for the above listed elements. Based on the reliable correspondence between the measured concentrations by the two methods and considering the advantages of the microwave assisted approach (Comero et al., 2015), all samples were analyzed using the prEN16174 (ECS, 2010) procedure. The unit of measurement was mg/kg for As, Cd, Cr, Cu, Pb, Zn, Sb, Co and Ni, with detection limits 2.84, 0.07, 0.32, 0.26, 1.16, 2.12, 0.81, 0.15 and 0.27 mg/kg respectively. As a result of the analytical procedure we obtained the concentrations of the studied elements. These are expressed by their elemental weight in milligram per 1 kg of soil. No elemental speciation was measured.

In order to enable a full spatial analysis of the results, samples with concentrations below the detection limit were characterized with a value equal to the half of the detection limit. Although this approach might be misleading when mapping the presence of the elements in soil and might cause bias in other applications as well, it seemed to be a sufficient solution for our purposes. The fact that the detection limits are an order of magnitude smaller concentrations than what is considered to have any ecological or health risk (Table 1) confirms the adequacy of the approach.

2.3. Assessment of soil heavy metal contamination and remediation needs

European countries have a number of approaches to define risk levels associated with different concentrations of heavy metal in soil (Carlon et al., 2007; Ferguson, 1999). After investigating the options presented by the various approaches and thresholds applied by them, we chose the standards set in the Finnish legislation for contaminated soil (Ministry of the Environment — MEF, Finland, 2007). The Finnish standard values represent a good approximation of the mean values of different national systems in Europe (Carlon et al., 2007) and India (Awasthi, 2000) and they have been applied in an international context for agricultural soils as well (UNEP, 2013). The Finnish legislation sets concentration levels by each hazardous element to identify soil contamination and remediation needs. It sets lower and higher concentration levels indicating the need for different actions if exceeded. Higher concentration levels are defined by major land uses, i.e. for industrial or transport sites and for other land uses. The so-called “threshold value” is equally applicable for all sites and it indicates the need for further assessment of the area. In areas where background concentration is higher than the threshold value, background concentration is regarded as the assessment threshold. The second concentration level is the so-called “guideline value”. If this is exceeded, the area has a contamination level which presents ecological or health risks. Different guideline values are set for industrial and transport areas (higher guideline value) and for all other land uses (lower guideline value). With the aim to characterize the soil contamination statuses of European soils, we classified the LUCAS topsoil samples by their heavy metal concentration values by elements using the threshold value and guideline value standards of the Ministry of Environment of Finland (2007) into four categories. Soil samples in the first category have no detectable content or the concentration is below the threshold value set by the MEF. The concentration of the investigated element in the second category is above the threshold value, but below the lower guideline value. The third category includes samples in which the concentration of one or more element exceeds the lower guideline value but is below the higher guideline value while the fourth category includes samples having concentrations above the higher guideline value. For assessing agricultural land we applied the threshold and lower guideline values for samples

<table>
<thead>
<tr>
<th>Substance (symbol)</th>
<th>Threshold value mg/kg</th>
<th>Lower guideline value mg/kg</th>
<th>Higher guideline value mg/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antimony (Sb) (p)</td>
<td>2</td>
<td>10 (t)</td>
<td>50 (e)</td>
</tr>
<tr>
<td>Arsenic (As) (p)</td>
<td>5</td>
<td>50 (e)</td>
<td>100 (e)</td>
</tr>
<tr>
<td>Mercury (Hg)</td>
<td>0.5</td>
<td>2 (e)</td>
<td>5 (e)</td>
</tr>
<tr>
<td>Cadmium (Cd)</td>
<td>1</td>
<td>10 (e)</td>
<td>20 (e)</td>
</tr>
<tr>
<td>Cobalt (Co) (p)</td>
<td>20</td>
<td>100 (e)</td>
<td>250 (e)</td>
</tr>
<tr>
<td>Chrome (Cr)</td>
<td>100</td>
<td>200 (e)</td>
<td>300 (e)</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>150</td>
<td>150 (e)</td>
<td>200 (e)</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>60</td>
<td>200 (t)</td>
<td>750 (e)</td>
</tr>
<tr>
<td>Nickel (Ni)</td>
<td>50</td>
<td>100 (e)</td>
<td>150 (e)</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>200</td>
<td>250 (e)</td>
<td>400 (e)</td>
</tr>
<tr>
<td>Vanadium (V)</td>
<td>100</td>
<td>150 (e)</td>
<td>250 (e)</td>
</tr>
</tbody>
</table>

The guideline values have been defined on the basis of either ecological risks (e) or health risks (t). If the risk of groundwater contamination is higher than normal in concentrations below the lower guideline value, the substances are marked with the letter p.
originating from agricultural areas and the threshold values and higher guideline values for all samples.

2.4. Comparison of HM concentrations across regions and land use types

The LUCAS topsoil database provides a range of opportunities to compare HM concentrations across land use types and management practices, countries, regions, climatic and geological factors and other variables, including socioeconomic data. The primary aim of our current study was to perform a reconnaissance in the soils of the European Union in general and in agricultural soils in particular. Therefore we analyzed agricultural land use types in comparison with all land uses with regards to HM concentrations.

The LUCAS dataset was subsampled to extract samples from agricultural land use types, namely cropland and grassland. All remaining samples were regarded as from "other land uses". A series of descriptive statistics and multiple comparison tests were performed to assess the topsoil data from agricultural land use and other land uses in different climatic regions and countries of the EU. One-way ANOVA tests were also performed in specific cases to assess if there were significant differences between larger geographical regions (i.e. Eastern and Western Europe) or land use types concerning their soil HM concentration, on a 0.05 confidence level.

For the regional analysis in the EU the so-called basic regions for the application of regional policies (NUTS2; Eurostat, 2015b) were used. The spatial dataset of the NUTS2 units was accessed from the Eurostat website. As the area of the NUTS2 regions in Europe differ greatly and not all statistical regions had sufficient number of samples to draw reliable conclusions from, we analyzed only those regions from which at least five soil samples were taken in the LUCAS survey. Heavy metals in the topsoil of 248 regions were studied.

3. Results and discussion

3.1. Overview of heavy metals' concentrations in the soils of the European Union

The soil heavy metal assessment in the European Union shows a quite diverse pattern both for geographic variability and the distribution of samples by the different concentrations of various heavy metals (Fig. 1).

Results of the analyses of all heavy metals for each soil sample were combined to see, which samples have concentrations above threshold or guideline values of any one or more elements. Figs. 2–5 display the percentage of samples having high concentration of any heavy metals, by NUTS2 regions of the EU. Most regions in the EU have very high percentages of samples which have concentrations above the investigation thresholds, both on their entire land area (Fig. 2) and on their agricultural land (Fig. 3). Regional differences can be observed in the continental overview. North-eastern Europe and Eastern-Central Europe is less affected by high concentrations of heavy metals, while most soil samples in Western-Europe and the Mediterranean have concentration above the investigation threshold of least one kind of heavy metal. This alarming figure urges for the establishment of detailed monitoring of soil throughout the EU.

Summary statistics (Table 2) also show that agricultural land of the EU has higher percentage of samples with concentration above the threshold value, than other land uses. This figure probably reflects the fact that forest land, which provides the second most LUCAS samples after agricultural areas, are less affected by heavy metal contamination.

The relatively high percentage (6.24%) of samples with any kinds of heavy metal concentration above the guideline value set for agricultural land suggest that an estimated 137,000 km² of agricultural land is affected to a certain degree (Fig. 4). Furthermore, 2.56% of the samples
from agricultural land contained heavy metal in concentration which would require remediation also if these were from industrial or transport areas (Fig. 5), based on the applied guideline values.

3.2. Arsenic in topsoils of the European Union

Arsenic in soil is generally considered to be mainly of geological origin, with higher background concentration in clayey soils. However anthropogenic arsenic pollution is quite widespread, as release of arsenic from anthropogenic sources far exceeds those of natural origin (ATSDR, 1999). A previous study by Ursitti et al. (2004) revealed that arsenic does not migrate laterally and its vertical movement is also limited in soils. Our results confirm the dominance of geological reasons behind arsenic concentrations in topsoil on a continental scale, as the main border line between regions with high and low concentration coincides with that of the last glaciation (Fig. SIA, B). Areas of quaternary origin in the north show significantly lower concentrations than most of other regions in Europe. Our findings also suggest that the geomorphology-based explanation of topsoil arsenic is less relevant. A detailed analysis of samples from the north European region with recent soils developed after the last glaciation showed no significant influence of soil texture on As concentration, either. However, south-eastern Europe, including Hungary, Romania and to some extent Slovakia, Bulgaria and Greece have generally lower levels of arsenic in their topsoil. More than half of the EU statistical regions have samples with As concentration above the investigation threshold concentrations in the majority of the soil samples. With regards to agricultural land, 15% of the regions had more than 1% of their samples with As concentration above the lower guideline value (Table 1), in 7 regions the number of such samples was above 5% and in 3 regions it reached or exceeded 10% (Fig. S1C, D). Only two regions had more than 10% of their samples above the lower guideline value, but these regions had few sampling points, among which 1 and 2 samples were found to be affected. Similar figures were obtained for samples from all major land uses with regards to higher guideline values (Fig. S1E). Furthermore, some agricultural areas, mainly in the Mediterranean countries, have higher As content than allowed by the higher guideline value (Fig. S1F). This fact urges for thorough investigation of the arsenic problem in particular in
France, Italy and Spain. The sporadic distribution of samples with high concentration indicates that Arsenic pollution can be a continent-wide problem but only on a small percentage (0.8%) of agricultural areas and in other land uses.

15% of the regions had more than 1% of their samples with As concentrations above the guideline value (Table 1), in 7 regions the number of such samples was above 5% and in 3 regions it reached or exceeded 10%.

3.3. Cadmium concentrations in topsoils of the European Union

Cadmium concentrations show a diverse pattern in soils across the European Union (Fig. S2B). Most samples (72.6%) of Europe did not display detectable concentrations of Cd and only 5.5% of the samples have concentrations above the threshold value. However, with the exception of Estonia and Hungary, whose samples did not display any detectable cadmium contamination, soil samples with Cd concentration above the investigation threshold were found throughout the EU (Fig. S2A). Regions with some of the highest mean cadmium concentration can be found in Ireland and Greece. Nevertheless, we can declare that agricultural areas in Europe are safe from cadmium contamination at the present (Fig. S2D, F). Only isolated cases in France and Spain provided soil samples with concentrations above the guideline values set for land for food production. In some regions the generally higher concentrations – which are still below food safety considerations – might correspond to natural Cd concentrations. However, the LUCAS data call for strict measures to prevent further increase of Cd in soil in many European regions. According to EFSA (2012a) the European population has an average daily Cd intake of 35% the recommended maximum, which intake can be up to 135–208% in some groups of the population.
As most of this Cd enters the human body through the food materials, which accumulate Cd from the soil, soil protection measures are needed to maintain or improve the current situation by preventing any further Cd contamination e.g. by controlling Cd in phosphorus fertilizers.

Detailed statistical analysis also revealed the significant difference between Cd concentration in agricultural land of Eastern and Western Europe. Data shows higher concentrations of Cd in the agricultural soils of Western Europe (EU15) compared to those in the new member states (EU12). There was no such difference in the data when also assessed against the concentrations of LUCAS samples from forest areas, which suggests a higher concentration of anthropogenic impact on agricultural land in Western Europe. This may be caused by the phosphorus fertilizers, which are historically of different origins in the western and eastern parts of the continent. While the Russian magmatic Kola phosphate rock, the main source of P fertilizers in Eastern Europe, is practically free of Cd, that from Morocco, the main source of P fertilizer in Western Europe, contains Cd (Csillag et al., 2006).

3.4. Cobalt concentrations in topsoils of the European Union

Cobalt is an element which is essential to human health (e.g. it is part of vitamin B12), but which in excess amounts can cause serious effects to lungs and heart (ATSDR, 2004a). It is worth noting that the transfer potential from soil to the edible parts of plants is rather low (Luo et al., 2010). The assessment of European soils revealed that excess cobalt is a real risk only in a few regions in Europe (Fig. S3B–D). While samples with concentration above the threshold value can be found in most European regions (Fig. S3A), these concentrations exceed the guideline.
Fig. 4. Percentage of samples with concentrations above the lower guideline value in LUCAS samples from agricultural land.

values only in a few cases, both for agricultural and other land uses. One region in France and four smaller regions in Greece were found to have samples with cobalt concentrations above the guideline values for agricultural land (Fig. S3E). These samples represent a small percentage of the regions' total. However, while 4.5% of the samples from agricultural lands have cobalt concentrations above the investigation threshold, the guideline values are exceeded in 0.38% of the samples. This means that an estimated 668,000 ha of land are affected, which is five times the total agricultural land area of Luxembourg. Although cobalt is essential to life in a small amount and its deficiency has a negative effect on the human neurological system, exposure to higher doses of it can hamper lung functions. Thus a European policy should be adopted to monitor cobalt in soils.

3.5. Chromium concentrations in topsoils of the European Union

Chromium is quite abundant in most soils and 4.4% of all samples were above the threshold value. Although this figure is seemingly low, samples with concentrations above the threshold can be found in nearly half of the EU's NUTS2 regions (Fig. S4A). What is more noticeable, if we look at agricultural land is that 2.7% are above the threshold and 1.1% of the samples were above the guideline value (Fig. S4B, D). This figure shows that some 2 million ha agricultural land is at an ecological risk from high concentrations of chromium in soil. Our analysis shows that especially Piemonte, Lorraine-Alsace, Western-Macedonia and Central Greece are affected. As long term exposure to high Cr doses may cause adverse effects in the liver and the kidney and in situ remediation of
soils affected by high concentration of chromium can be quite com­pli­cated (Palmer and Wittbrod, 1991; Pagilla and Canter, 1999), it would be especially important to take measures (e.g. controlling industrial sources) to prevent any further increase of Cr in the soil. Our study re­vealed the spread of chromium in agricultural land based on its elemen­tal measures. However, it is worth noting that the highest risk arising from soil chromium is associated to its hexavalent form and trivalent Cr is relatively immobile in soil, thus present lower risk (McLean and Bledsoe, 1992).

3.6. Cu concentrations in topsoils of the European Union

Copper belongs to the substances which are essential for human health, e.g. by being part of enzymes involved in specific metabolic pro­cesses. However, it may be harmful in higher doses by causing gastrointestinal distress, damage to liver, the immune system, neuro­logical system and reproductive ability (ATSDR, 2004b).

Accumulation of copper in soils is mainly due to anthropogenic ori­gin, such as mining or industrial activities. Agricultural use of products containing copper is also common, especially in pesticides applied in vineyards and orchards (Fishel, 2014). This might be a reason, why soil samples with high Cu concentrations can be found in the countries of the Mediterranean (Fig.S5A–F) where these land uses are common. Agricultural land is affected mostly in France, Italy, Portugal and Romania. Although the share of samples with Cu concentrations above the guideline value is rather low among all of the samples, its proportion exceeding 2% in some regions in France and Italy indicates a potential problem for food production. This is especially true, if we consider the higher proportion of samples with concentrations above the threshold value, which already indicates the presence of copper in a concentration...
Table 2
Share of soil samples from the LUCAS survey with high concentrations of heavy metals.

<table>
<thead>
<tr>
<th>Samples from agricultural land (n = 14,865)</th>
<th>Samples with concentrations above the threshold value</th>
<th>Samples with concentrations above the lower guideline value</th>
<th>Samples with concentrations above the higher guideline value</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>8632</td>
<td>928</td>
<td>380</td>
</tr>
<tr>
<td>%</td>
<td>58.07%</td>
<td>6.24%</td>
<td>2.59%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Samples from all land uses (n = 21,980)</th>
<th>Samples with concentrations above the threshold value</th>
<th>Samples with concentrations above the lower guideline value</th>
<th>Samples with concentrations above the higher guideline value</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>11,718</td>
<td>n.a.</td>
<td>523</td>
</tr>
<tr>
<td>%</td>
<td>53.31%</td>
<td>n.a.</td>
<td>2.38%</td>
</tr>
</tbody>
</table>

that requires precautionary thinking. Although most crops take up and accumulate Cu in small quantities only, continuous exposure to Cu in food may cause negative health effects in humans.

3.7. Hg concentrations in topsoils of the European Union

Mercury – either in inorganic forms or in its methyl compounds – may pose threat to kidney, liver the nervous-, and reproductive systems, as well as to the immune system. However, methylmercury species have higher bioavailability and toxicity. A recent study of the EFSA (2012b) suggests that inorganic mercury from the diet does not exceed the tolerable intake in Europe. Assessment of the LUCAS data confirms the very low risk posed by lead in agricultural soil in Europe. In fact, lead concentrations were found to exceed the threshold and the guideline values in a very small proportion (in 25 and 16 samples, respectively) of the samples from agricultural land. The affected samples originate from a few regions only. Historically, mining for gold and mercury leads to high Hg concentrations in mine areas. The latter may be the reason for the high Hg concentrations in some samples from Central Italy, North-West England and Eastern Slovakia (Fig. S6). Although these represent isolated cases only, the fact that some soil samples with Hg above the higher guideline values were still found on agricultural land of France, Germany, Italy and Spain calls for stricter control of Hg in all parts of the food chain, including soil. As mercury from human activities is the main source of Hg contamination (ATSDR, 1999; Steinnes, 1995) of soil today, contamination sources should also be under strict control.

3.8. Ni concentrations in topsoils of the European Union

Nickel in soil, like most other heavy metals may be of either natural or anthropogenic origin. While industrial activity may also be responsible for soil contamination in parts of Europe (Cempel and Nikel, 2006) according to the LUCAS survey there are also considerable differences between climatic regions regarding higher concentrations of Nickel in soil (Fig. S7). This fact suggests that soil Ni can be attributed to natural factors to a great extent. Our assessment suggests that the whole of the EU is affected by Ni contamination to some degree, but land under the influence of the last glaciation e.g. Germany, Poland and the Scandinavian countries are less prone to it. With the exception of the southern Apennine peninsula and most of Spain, samples with high concentrations of Ni can be found in considerable percentage of the samples from the Mediterranean region of Europe. The density of samples with Ni concentrations above the higher guideline value is the highest in Greece, where in some regions, more than half of the samples have Ni in higher concentrations (Fig. S7E, F). As excess amount of nickel may adversely affect the immune system as well as the reproductive system (ATSDR, 2005), our findings urges for more detailed analysis of soil nickel in the Mediterranean, even if the mobility and the potential bioavailability of nickel is one of the lowest among heavy metals (Ma and Rao, 1997).

3.9. Pb concentrations in topsoils of the European Union

According to the data of the WHO (2015) the European population is the least prone to dietary lead intake. Exposure to lead from food materials in Europe is commonly much below the tolerable weekly intake, as the study of EFSA (2012c) reports. Exposure to lead occurs mainly through the food chain, although ingestion of soil and dust can also be an important contributor (EFSA, 2012c). Relatively low lead exposure can impair brain and nervous system – especially those of children – and elevated blood pressure, chronic kidney disease and probably cancer can be also caused by lead, even at relatively low blood lead levels (ATSDR, 2007a; IARC, 2006). Therefore a detailed assessment of the risk associated with lead in topsoil is required. Based on our regional assessment, Central Italy, France Germany and the UK display the highest share of samples with relatively high concentrations of Pb in soils (Fig. S8A, B). Samples from the Baltic states, Finland and Hungary did not display detectable traces of lead contamination on agricultural land (Fig. S8B). The highest percentage of samples with Pb concentrations above the threshold value is found in Lazio province in Central Italy, probably due to the abundance of tertiary volcanic material in this region. However, none of these samples display a concentration above the guideline value for agricultural land. Such samples are very rare: only a few cases around Europe were found among the over twenty thousand samples, indicating that currently lead is not a problem for food safety. Nevertheless, the widespread occurrence of samples with concentrations above the threshold value, even if in small shares among the total number of samples, indicates the need for strict control of lead in agricultural land and – eventually – in the food chain.

3.10. Sb concentrations in topsoils of the European Union

Antimony may alter pulmonary function and may cause respiratory, neurological cardiovascular, gastrointestinal and hematological effects, as reported mostly based on data on exposure to airborne antimony dust (ATSDR, 1992). However, a study by Hammel et al. (2000) found correlation between the mobile fraction of antimony in the soils and antimony in leaves of spinach, proving that high concentration in soil can result accumulation of antimony in plants. The LUCAS data shows that antimony is quite abundant in the topsoils in the European Union, with the highest density of samples with concentrations above the threshold value (both for agricultural areas and for all land use types) in Southern and Western Europe; Greece and Ireland, in particular (Figs. 1 and S9A, B). However, based on the application of the lower guideline value on the LUCAS soil samples, we can observe a much lower proportion of problematic samples and also with smaller areal coverage (Figs. S9C–F). In fact, while Greece and Ireland display antimony in most of their soil samples, the concentration of this element remains below the contamination threshold. Nevertheless, most of their areas require the assessment of their soil contamination and remediation need, just as most of Austria, Bulgaria, Catalonia, Northern Italy and Southern France. While precautionary measures seem to be necessary in these regions, and especially in Austria, France, Germany, Italy, Poland and Spain, where samples above the lower guideline values were found also on agricultural land, just a few samples were found in the whole EU with concentration above the higher guideline value. Although this result suggests that food of European origin is safe from Sb contamination, any further Sb load should be avoided, especially in some regions indicated above.

3.11. Zn concentrations in topsoils of the European Union

Zinc is an essential element for both plants and humans, but it is toxic in excess amounts (Swartjes, 2011). Therefore it is crucial to
control its right amount in agricultural soils. It may have direct toxic effects and, among others, may cause gastrointestinal and immunologic problems. In the same time, high amounts of Zinc probably also inhibit copper absorption, thus resulting copper deficiency symptoms. Zinc is transported throughout the food chain by bioaccumulation resulting in higher concentrations in meat products than in vegetables and fruits (ATSDR 2007b). While zinc deficiency can be attributed to soil factors like high pH, high Ca and CaCO₃ concentrations (Alloway, 2008), its excess in soil might be either of geological or anthropogenic origin. The LUCAS data shows that excess zinc appears in agricultural land in more than 20% of the NUTS regions in Europe by showing concentrations above the threshold concentration (Fig. S10A, B). However, the percentage of these samples in the total is less than half of 1% (0.004500/0). The number of samples in which the concentration exceeds the higher guideline value is just above a dozen out of the more than twenty thousand in total. We can state that zinc pollution exists only in isolated cases in the agriculture of the EU. Consequently, this metal presently does not hold any risk to food safety on a continental scale. However, it is worth noting that different zinc species are absorbed at different rates, which may result different risk of toxicity depending on the local conditions.

4. Conclusions

Data from the LUCAS Topsoil Survey shows that the immense majority of European agricultural land can be considered adequately safe for food production. However, based on the continent-wide survey the high share of samples with HM concentrations above the assessment threshold indicate large areas where precautionary measures are needed. At the same time, an estimated 62.4% of the agricultural land needs local assessment and eventual remedial action, based on the guideline concentrations applied in our study. Although at first sight this percentage of land with soils of relatively high concentrations of heavy metals does not seem to be alarming high, the real area coverage of this low percentage share can total 137,000 km² of agricultural land in the European Union. The survey-based evidence on the areal extent of this problem should lead to relevant policy action on the remediation and management of soil resources across Europe. Preventive measures applied at the critical lands to exclude harmful substances from the food chain can include the control of bioavailability of the elements (e.g. by liming or applying other methods for demobilizing heavy metals), but also production of materials other than foodstuff on affected land, and eventually also remediation actions.

The results of the assessment based on the soil samples from the LUCAS survey also highlight the need for spatially intensified and thematically broadened monitoring of soil resources in the European Union. We also suggest to establish harmonized screening values for soil contamination in the EU, to gain better understanding of the magnitude and details of the problem associated with heavy metals in soil. Such, harmonized system could provide multiple benefits for planning the sustainable utilization of land resources in the European Union.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.envint.2015.12.017.

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