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Discussion

One Health approach: Addressing data challenges and unresolved questions in agriculture

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ABSTRACT

The *One Health* approach, which seeks to balance the health of people, animals, and ecosystems, is gaining increasing recognition. Although in 2022 the One Health High-Level Expert Panel refined its definition to explicitly include plant health, concrete integration of crop health into *One Health* strategies remains underdeveloped. As a result, the agricultural domain's contributions to the environmental chemical load are still insufficiently addressed. In addition, there is a general lack of studies aimed at estimating the relative contribution of each different *One Health* domain (*i.e.*, the human, the animal, and the plant one) to this phenomenon. This discussion paper examines the current availability of data on main chemical outputs across these domains, specifically focusing on agrochemical and drug/medicine use in agriculture, animal, and human health. However, data collection proved challenging due to inconsistencies and gaps across sectors, making direct comparisons of environmental burdens difficult to establish. Instead, this study provides an indication of trends while primarily highlighting severe gaps in data availability and the unanswered research questions that arise from them. It also emphasizes the necessity of interdisciplinary collaboration across all three domains. In particular, the integration of scholars, professionals, and experts in agriculture, forestry, livestock and environmental sciences is crucial to optimizing future *One Health* initiatives, especially in the context of crop and plant health.

1. Introduction

Pollution from multiple sources, including agriculture, livestock, wildlife, and human activities, poses a global threat thereby necessitating large-scale interventions (Rizzo et al., 2021). Implementing a systemic approach involving input from all the sectors involved is therefore essential. In this respect, the *One Health* approach is gaining increasing recognition worldwide and within the European Union (Coli and Schebesta, 2023). Mentioned in the EU Green Deal package and the Zero Pollution strategy, it is defined by Adisasmito et al. (2022) as *an integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals, and ecosystems*. This definition includes a nuanced role for plants, linking plant health with the environment, and traces back to Schwabe's original concept of One Medicine in 1984, initially focused on zoonoses, then broadened over time to include plant, environmental, and ecosystem health. With respect specifically to plants, while they are integral to the environment, the environment typically encompasses the entire system. Moreover, plants serve multiple roles, including food, feed, medicine, shelter, and energy sources (Destoumieux-Garzón et al., 2018). For this reason, plant health is closely linked to human and animal health, directly or indirectly influencing nearly every environmental factor, especially when crops are considered. However, despite its fundamental role, plant health has historically been underrepresented in *One Health* research and policy, creating gaps in understanding its environmental impact. In this respect, it should be noted that in 2022, the One Health High-Level Expert Panel (OHHLEP) further refined the definition to explicitly include plant health, recognizing its pivotal role in linking environmental, human,

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and animal health (Adisasmito et al., 2022). However, despite this formal inclusion, there is still a lack of integrated assessments that evaluate how agriculture, veterinary, and human agrochemical/medicine/drug inputs contribute to the whole chemical load into the environment. Concrete steps to integrate agriculture and crop health into *One Health* strategies remain underdeveloped (Sengupta et al., 2024), leaving a significant gap in addressing agricultural contributions to chemical pollution and their mitigation. At the same time, agrochemicals are not the sole contributors, medicine/drugs residues from human and animal health sectors also play a crucial role in environmental chemical load, highlighting the need for a cross-sectoral assessment. Furthermore, while existing studies have analysed the environmental impact of individual sectors, such as human pharmaceutical/medicine/drugs, veterinary medicines/drugs, and agrochemicals (Caban and Stepnowski, 2021; Shao et al., 2021; Zhou et al., 2024), there is still a lack of a systematic, cross-sectoral analysis quantifying the relative contribution of each *One Health* domain (human, animal, and plant) to the environmental chemical pollution. This gap is particularly relevant given that all three domains interact within shared ecosystems, meaning that chemical pollutants do not remain confined to their sector of origin but can influence the broader environmental and biological networks. It should be highlighted that the absence of standardized methodologies and comparable datasets hinders the ability to assess sector-specific pollution sources and design targeted mitigation strategies under the *One Health* framework. In fact, integrated models that combine environmental, epidemiological, and agricultural data, ensure a clearer picture of pollution dynamics and enable evidence-based policymaking for any effective action aimed at achieving sustainable and public health objectives. However, every initiative and activity must be grounded in a deep understanding of the application domain (crop/plant, animal, human one), as well as the use and fate of the various chemical products within these contexts. In fact, a holistic and interdisciplinary approach is fundamental to fully capture the complexity of environmental chemical load pollution across *One Health* context.

1.1. The role of agriculture in One Health: crop production and health

In the *One Health* framework agriculture plays a central role, particularly in relation to crop production and plant health, which are crucial for food security and safety (a central goal of the UN's 2030 Agenda - United Nations, 2015). However, various stressors, both abiotic (such as drought, soil salinity, heat, and cold) and biotic (including pests, weeds, and diseases) (Boyer, 1982; Kopecká et al., 2023; FAO, 2024), threaten crop productivity, leading to yield losses of up to 25–40 % depending on the crops (Kinhal, 2024). Phytopathogenic fungi, bacteria, and oomycetes contribute to nearly 30 % of global crop yield loss (Dong et al., 2021), with the highest impact in food-insecure regions with dense populations (Savary et al., 2019). Historical instances demonstrate the pivotal role of plant diseases in food insecurity, sometimes resulting in starvation and death (Al-Sadi, 2017). Safeguarding crop productivity against biotic stressors is thus crucial. To mitigate these threats, a range of disease control strategies exist, including agronomic, biological, regulatory, genomic, physical, and chemical approaches. Among them, chemical control, which involves the use of agrochemicals like insecticides, herbicides, fungicides, acaricides, and inducers of plant resistance, remains highly effective in agricultural practices (Reddy et al., 2022) and the most widely used in agricultural practices. However, precise application of agrochemicals, including targeting specific crops, timing, dosage, and localized spraying, as well as the use of antidotes and synergistic compounds, is crucial to maximize effectiveness and prevent undesired effects on non-target crops/plants. In addition, it is well known that an agrochemical, effective for one crop may have adverse effects on another one, making it unsuitable for this latter (Aloo et al., 2021). Such phenomena are quite frequent in agriculture, where the variety of available chemicals for defense plans is essential to protect the crops and to maintain their productivity. It is interesting to note that, from a broader point of view, in healthcare for animals or humans, drugs/medicines may exhibit similar inter-species implications, affecting both animals' and humans' health.

From the pollution point of view the issue arises when these agrochemicals, once used for crop protection, enter the environment through runoff, leaching, volatilization, production residues, and/or waste disposal. In the environment, including soil, water bodies, and vegetation, these chemicals undergo decomposition through physical, chemical, and biological reactions (Tudi et al., 2021; Bhanse et al., 2022; Parven et al., 2024). However, certain chemicals like Cu-based fungicides may not decompose, leading to metal accumulation into environments like vineyard soils (Brunetto et al., 2016; Cesco et al., 2021a, b), thus causing significant environmental harm. There is rising concern about agricultural chemicals in the environment, in particular due to public sensitivity towards human health, that is perfectly exemplified by the ongoing debate about glyphosate usage (Rivas-Garcia et al., 2022), similar to past controversies over DDT (see at this respect Carson's [1962] book "Silent Spring"). Interestingly, a recent study suggests that glyphosate presence in wastewater in Europe is not only due to agricultural activities but also to urban applications and, even more interestingly, to aminopolyphosphonates in laundry detergents (Schwientek et al., 2024).

1.2. Animal and human health contributions to environmental pollution

Beyond crop production, also the human and animal health sectors significantly contribute to chemical inputs into the environment. Modern medicine and veterinary care rely heavily on medicines/drugs (*i.e.*, pharmaceuticals, antiparasitic agents, and disinfectants), which, while critical for disease prevention and treatment, have far-reaching environmental consequences (Anadón, 2016). Indeed, in 2023, the global pharmaceutical market was valued at approximately 1.48 trillion USD, highlighting its extensive impact on human health (Statista, 2024). Similarly, the veterinary pharmaceutical market was valued at 43.55 billion USD in 2022, underscoring the crucial role in animal healthcare (Grand View Research, 2024).

Like agrochemicals, drugs/medicines for animals and humans, depending on the specific toxicokinetic and toxicodynamic, once used for their specific purpose, can enter the environment through excretion (urine and faeces) and improper disposal (Hanamoto et al., 2023). Once released, they accumulate in soil and water, posing significant risks due to their presence and potential interkingdom implications on organisms and ecosystems (Falkenberg et al., 2022; Fusi et al., 2016; Ferrari et al., 2011). For instance, painkillers and opioid derivatives detected in aquifers can affect horticultural crops irrigated with contaminated water, posing risks to biodiversity and food safety (de Santiago-Martín et al., 2020). In addition, it has been widely demonstrated that various chemicals released in the environment can bioaccumulate and biomagnify through the trophic chain, potentially leading to food-borne risk for human consumers (Zenker et al., 2014). These concerns raise questions about the environment's ability to handle increasing chemical loads without compromising its health.

1.3. Research objectives

Considered the complex interplay between agricultural, veterinary, and human chemical inputs, this study aims to evaluate and compare their respective contributions to environmental pollution. Specifically, this study: (i) examines publicly available data on agrochemical and medicine/drug use in five European countries (Netherlands, Italy, France, Spain, and Germany), selected for their significant agricultural output, population size, and data accessibility; (ii) identifies key data challenges and methodological limitations, highlighting inconsistencies in reporting, data aggregation, and measurement units across *One Health* domains, (iii) discusses future challenges and policy implications, emphasizing the need for standardized data collection, regulatory harmonization, and cross-sectoral collaboration. The findings provide insights into how harmonized datasets and an integrated *One Health* framework can enhance evidence-based policy decisions. Moreover, this paper underlines the need for professional expertise in the agricultural domain to develop effective mitigation strategies that balance food production, environmental sustainability, and public health.

2. Methodology

2.1. Data sources

To assess the contribution of the plant, animal, and human health domains to chemical load into the environment, publicly available datasets from international organization and regulatory bodies were analysed. The following data sources were used:

- Agrochemicals (*pesticides*): Data were obtained from FAO[1] (model-based estimates) and EUROSTAT[2] (sales data, except when classified as confidential).
- Veterinary medicines/drugs: The ESVAC[3] database reports antimicrobial use, but data on non-antimicrobial veterinary drugs are not publicly available due to commercial confidentiality. To address this, ESVAC data were combined with Animal Health Europe reports (2012–2020) on veterinary pharmaceutical sales.
- Human medicines/drugs: OECDSTAT[4] data were used, reporting human medicine consumption in Defined Daily Dose (DDD) per 1000 inhabitants per day. However, this dataset excludes over-the-counter (OTC) drugs, except for France.

Each of these sources provides the most comprehensive publicly datasets available, though limitations exist regarding reporting completeness, aggregation levels, and national regulatory differences, necessitating additional processing stage.

2.2. Data processing

To ensure comparability across *One Health* domains, data were standardized as follows:

- FAO pesticide estimates were cross-checked against EUROSTAT sales data to adjust for national reporting inconsistencies.
- veterinary medicine/drug use was estimated by integrating ESVAC antimicrobial data with Animal Health Europe's total sales figures. However, due to the absence of specific breakdowns in industry-reported data, estimations of total veterinary medicine/drug use remain approximate.
- human medicines/drugs consumption, originally expressed in DDD, was converted into kilograms of active substances using the methodology proposed by RIVM (Moermond et al., 2020).

The primary challenges encountered were:

- time restrictions: most datasets only cover up to 2020, limiting the long-term analysis.
- confidentiality constraints: animal medicine/drug consumption data remain partially inaccessible, requiring indirect estimations.
- measurement inconsistencies: different reporting units (*e.g.*, DDD for human medicines *vs* kg of active substance for agrochemicals and veterinary drugs) complicated direct comparisons.

To address these challenges, all data were standardized into kilograms of active substance, ensuring cross-domain comparability and enabling a more accurate assessment of environmental impact.

2.3. Analytical approach

To account for differences in land use and exposure risk, chemical usage data were normalized as follows:

- pesticides and veterinary medicines/drugs were normalized per unit of utilized agricultural area (UAA) to reflect their environmental burden relative to land use.
- human medicines/drugs were normalized per unit of service and residential area (SRA), where wastewater treatment plants primarily process these compounds.

This approach ensured that comparisons were made based on actual exposure risk, avoiding distortions caused by including areas with minimal chemical interaction, such as forests or protected natural zones.

To assess country-level differences in chemical inputs, data were compared across the five study countries. Key factors influencing cross-country differences in chemical inputs include:

- agricultural intensity and crop types, which affect pesticide application rates.
- livestock production systems, influencing veterinary medicine/drug use.
- national regulations and prescription practices, impacting human medicine/drug consumption.
- healthcare system structures and consumer preferences, affecting overall medication use.

For instance, countries with intensive agricultural systems and high-density livestock production exhibited higher agrochemical and veterinary medicine/drug use, whereas stricter environmental policies correlated with lower recorded chemical inputs. However, lower reported usage does not necessarily indicate lower environmental impact, as unreported or diffuse sources of chemical inputs may still contribute to contamination.

A summary of the main data sources, data processing steps, normalization procedures, and key limitations is provided in Table 1.

3. Results

3.1. Environmental chemical load datasets and limitations

The datasets utilized in this study represent the most comprehensive publicly available sources for estimating agrochemicals and medicines/drugs contribution to environmental chemical load within a *One Health* framework. FAO and EUROSTAT data provided pesticide estimates and sales figures, while ESVAC and Animal Health Europe offered insight into veterinary antimicrobial and broader veterinary pharmaceutical consumption. OECDSTAT reports human medicine/drug use in DDD, which required conversion to kilograms for comparability across domains.

Despite leveraging these established sources, several challenges emerged in constructing a harmonized dataset. Data availability was a key issue, as many datasets were incomplete or reported only aggregated

[1] https://www.fao.org/faostat/en/#data/RP.

[2] https://ec.europa.eu/eurostat/cache/metadata/en/aei_fm_salpest09_esms.htm.

[3] https://www.ema.europa.eu/en/veterinary-regulatory-overview/antimicrobial-resistance-veterinary-medicine/european-surveillance-veterinary-antimicrobial-consumption-esvac-2009-2023#:~:text=ESVAC%202022%20report,antimicrobials%20in%20food%2Dproducing%20animals.

[4] https://www.oecd-ilibrary.org/social-issues-migration-health/data/oecd-health-statistics/oecd-health-data-pharmaceutical-market_data-00545-en?parentId=http%3A%2F%2Finstance.metastore.ingenta.com%2Fcontent%2Fcollection%2Fhealth-data-en.

Table 1
Data sources.

Area	Source of data	Type of data	Normalization/standardization procedure	Limitations
Pesticides	FAO[a]	Combination of data covering sales and use of pesticides.	//	Estimated data (FAO database).
Animal Drugs/ Medicines	ESVAC[b]	Antimicrobial animal medicine use	Extension to all animal drugs/medicines based on the proportion of antimicrobial on total drugs/medicines.	Normalization procedure may introduce a bias.
Human medicines	OECDSTAT[c]	Human medicines sales (DDD per day per 1000 inhabitants)	DDD to kg of active substance	Over-the-counter (OTC) drugs not included. Personal care products not included.

[a] https://www.fao.org/faostat/en/#data/RP.
[b] https://www.ema.europa.eu/en/veterinary-regulatory-overview/antimicrobial-resistance-veterinary-medicine/european-surveillance-veterinary-antimicrobial-consumption-esvac-2009-2023#:~:text=ESVAC%202022%20report,antimicrobials%20in%20food%2Dproducing%20animals.
[c] https://www.oecd-ilibrary.org/social-issues-migration-health/data/oecd-health-statistics/oecd-health-data-pharmaceutical-market_data-00545-en?parentId=http%3A%2F%2Finstance.metastore.ingenta.com%2Fcontent%2Fcollection%2Fhealth-data-en.

figures, reducing granularity and precision in estimating total chemical inputs. For example, while antimicrobial use in veterinary medicine is systematically recorded, other classes of veterinary medicines/drugs are not consistently documented due to commercial confidentiality, necessitating indirect estimations. Additionally, inconsistencies in measurement units presented a challenge, with pesticides reported in kilograms of active ingredient while human medicines/drugs were measured in DDD per 1000 inhabitants per day. Standardization was required to enable meaningful cross-sectoral comparisons. Another limitation was the timeframe constraint, as most available data covered only up to 2020, limiting the ability to analyze long-term trends or assess the impact of recent regulatory changes. Furthermore, differences in national regulatory frameworks and reporting practices introduced inconsistencies across countries, complicating direct comparisons. Nevertheless, despite these limitations, it was possible to define a dataset that, although approximate, provides a representative overview of the environmental chemical load across the *One Health* domains, allowing for a comparative assessment of domain contributions. These challenges highlight the complexities involved in compiling comprehensive and harmonized datasets to assess environmental chemical load in a *One Health* context.

3.2. General trends in chemical use across countries

Results reported in Table 2 highlight significant variability in chemical inputs across countries. Among the five nations examined, the Netherlands exhibits the highest values across all categories, with 6.17 $kg^*UAA^{-1}*year^{-1}$ for pesticides, 0.89 $kg^*UAA^{-1}*year^{-1}$ for animal medicines/drugs, and 2.75 $kg^*SRA^{-1}*year^{-1}$ for human medicines/drugs. This reflects the country's intensive agricultural and livestock production systems. Italy follows, with 4.87 $kg^*UAA^{-1}*year^{-1}$ for pesticides and 0.67 $kg^*UAA^{-1}*year^{-1}$ for animal medicines/drugs, while Spain presents similar trends, particularly in veterinary medicine/drug use (0.58 $kg^*UAA^{-1}*year^{-1}$). In contrast, Germany and France report lower levels of agrochemicals and veterinary medicine/drug use, with France having the lowest value for the veterinary ones (0.15 $kg^*UAA^{-1}*year^{-1}$), likely due to differences in livestock management and stricter regulatory restrictions. Regarding human medicines/drugs, the variation among countries is less pronounced, ranging from 1.85 $kg^*SRA^{-1}*year^{-1}$ (France) to 2.75 $kg^*SRA^{-1}*year^{-1}$ (Netherlands), suggesting more standardized medicines/drugs consumption patterns across Europe. In this context, the impact of the agricultural sector emerged as the most significant contributor to chemical inputs, although potential underestimations in the animal and human domains remain due to limited data on OTC drug use and the estimation approach for veterinary medicines/drugs. These findings highlight the need for tailored mitigation strategies that consider national agricultural intensity, regulatory frameworks, and healthcare practices.

The normalized data (per UAA or SRA) reported in Table 3 display similar trends.

4. Discussion

Assessing the environmental chemical load within a *One Health* framework presents multiple challenges, requiring a structured approach to identifying key obstacles and developing practical solutions. The key issues addressed in this discussion paper include data availability and standardization, interdisciplinary collaboration, new knowledge and engagement for the agricultural domain and its professionals, targeted regulation of agrochemical use, regulatory coordination and policy adaptation, and international cooperation. By following this structured approach, the discussion progresses from identifying fundamental challenges to outlining actionable solutions that support evidence-based policymaking and sustainable environmental management.

4.1. Data availability and standardization challenges

From a general point of view, it is well acknowledged that pollution in all its forms (*e.g.*, atmospheric, water, soil, acoustic, thermal, light, electromagnetic) and types (*e.g.*, chemical, physical, biological), poses a significant threat to ecosystems and planetary health. Legislative measures, such as those enacted in response to asbestos contaminations (Peña-Castro et al., 2023), are urgently needed to mitigate these effects. Moreover, climate change is likely to exacerbate these challenges by increasing reliance on agrochemicals, veterinary and human drugs/medicines to manage stressor affecting plant, animal, and human health. These interconnections highlight the urgent need for integrated, cross-sectoral strategies to address chemical pollution and safeguard both ecological and human health. This reinforces the need for reliable, standardized, and accessible data to better understand the scale and impact of chemical pollution across the *One Health* context.

Currently, more than 350,000 chemicals are indeed registered for production and use, many of which enter the environment during their lifecycle. Among these, emerging contaminants (ECs), such as active pharmaceutical ingredients, personal care products (PCPs), endocrine-disrupting compounds (EDCs), polyfluoroalkyl substances (PFAS), *etc.*, are frequently detected in the environment, raising concerns about their persistence, bioaccumulation, and toxicity (Chen et al., 2024). Despite international regulatory initiatives, significant gaps in data availability and monitoring persist, limiting effective risk assessments. The Stockholm Convention (www.pops.in), which aims to eliminate or reduce the use of Persistent Organic Pollutants (POPs), and the Minamata Convention (www.minamataconvention.org), which specifically targets mercury (a potent neurotoxin that affects ecosystems and human health globally), serve as important global frameworks for managing chemical pollutants. However, many contaminants remain underregulated or insufficiently monitored, particularly PFAS, which despite their environmental persistence and widespread industrial use, are not yet fully covered by international treaties. In this context, the findings of this discussion paper reinforce the urgent issue of fragmented and

Table 2
Pesticides, animal medicines and human medicines per total country surface.

Average 2010–2020		France	Germany	Italy	Netherlands	Spain
Pesticides	kg*ha of total surface^{-1}*year^{-1}	1.23	1.30	2.03	3.44	1.06
Animal drugs/medicines	kg*ha of total surface^{-1}*year^{-1}	0.08	0.21	0.28	0.46	0.28
Human medicines	kg*ha of total surface^{-1}*year^{-1}	0.18	0.36	0.24	0.64	0.13

Table 3
Pesticides, animal medicines and human medicines per UAA or SRA.

Average 2010–2020		France	Germany	Italy	Netherlands	Spain
Pesticides	kg*UAA^{-1}*year^{-1}	2.40	2.69	4.87	6.17	2.11
Animal medicines	kg*UAA^{-1}*year^{-1}	0.15	0.43	0.67	0.89	0.58
Human medicines	kg*SRA^{-1}*year^{-1}	1.85	2.68	2.51	2.75	2.53

inconsistent data, particularly concerning agrochemical use and medicine/drug consumption patterns. Without comprehensive datasets, it is challenging to quantify the true environmental impact of chemical inputs and implement effective mitigation strategies. For example, global agrochemical data remain incomplete and vary significantly between nations, with usage underestimation reaching up to 30 % in some regions (Shattuck et al., 2023). Similarly, monitoring of emerging contaminants, such as EDCs and PFAS, remains limited with many programs lacking spatial and temporal coverage (Puri et al., 2023). These limitations hinder accurate trend assessment and the implementation of effective mitigation strategies. Addressing this challenge requires improved reporting mechanisms and harmonized international data collection efforts, ensuring comparability across *One Health* domains. To achieve this, enhancing data transparency, comparability, and integration across domains is clearly crucial. Expanding global chemical monitoring initiatives, such as the FAO-WHO Codex Alimentarius for food safety,[5] the Global Monitoring Plan under the Stockholm Convention,[6] and the OECD Environmental Performance Reviews,[7] could facilitate a more structured and coordinated approach to tracking environmental chemical pollution, thereby supporting more informed and effective policy decisions.

4.2. Interdisciplinary collaborations

Given the complexity of environmental contamination, tackling environmental chemical loads under the *One Health* framework requires coordinated, cross-domain engagement, involving policymakers, scientists from various domains, industry professionals, civil society, and agricultural professionals/experts. Each of these actors plays a crucial role. Policymakers are pivotal in formulating evidence-based regulations and ensuring their enforcement, while scientists provide critical data, predictive models, and technical expertise to support decision-making. Industry professionals are responsible for innovating sustainable practices and ensuring compliance with regulatory standards. Civil society raises awareness, monitors compliance, and provides feedback. Meanwhile, agricultural professionals/experts are instrumental in promoting sustainable crop and soil management, precision agriculture, and agroecological practices that reduce reliance on harmful chemicals while maintaining agricultural productivity. It is interesting to highlight that this collaborative approach has also been recommended for managing climate-related agricultural emergencies (Cesco et al., 2024), further emphasizing its relevance in environmental sustainability.

Several initiatives already illustrate the success of interdisciplinary collaboration. The EU-funded Horizon 2020 'NEREUS' project (New and Emerging Risks in Water Reuse) brought together policymakers, environmental scientists, industry leaders, and local stakeholders to tackle the risks associated with emerging contaminants in water reuse systems. Similarly, the One Health European Joint Program[8] (OHEJP) integrates expertise from multiple disciplines to address issues such as food safety, antimicrobial resistance, and environmental health through joint research and risk assessments. At a global scale, organizations such as the International Panel on Chemical Pollution[9] (IPCP) and the UN Global Framework on Chemicals[10] provide platforms for cross-sectoral engagement, highlighting the need for binding international agreements. Developing legally enforceable conventions, similar to the Minamata Convention, but focusing on specific high-risk chemicals, could play a pivotal role in strengthening global chemical governance. However, to ensure the success of such initiatives, it is vital to strengthen engagement of key stakeholders, particularly those in the agricultural sector, who directly manage chemical inputs and their environmental fate.

4.3. Enhancing knowledge and engagement of agricultural domain professionals

Within the *One Health* framework, the agricultural sector plays a crucial role in shaping both environmental contamination and sustainable management strategies. However, its effective integration requires the active involvement of domain-specific professionals, who possess the expertise necessary to develop balanced, science-based interventions. It should be noted that the use of pesticides in agriculture is primarily crop-dependent, making the engagement of experts in agriculture, forestry, and animal production sectors essential in all *One Health*-related activities, from policy formulation to on-field application. This is particularly crucial when addressing potential trade-offs between seemingly competing interests, such as plant health *versus* human health. This need is further emphasized by the increasing adoption of new technologies, such as smart farming (*e.g.*, based on cyber-physical systems, the Internet of Things, artificial intelligence, big data) and biotechnologies (*e.g.*, competing microorganisms and/or the use of more resilient crop varieties obtained *via* new breeding technologies) (Cesco et al., 2021b, 2023; Thomas et al., 2023; Pii et al., 2024). As these technologies evolve, ensuring their correct implementation requires specialized knowledge to fully exploit their benefits, including the potential to reduced chemical inputs and improved resource efficiency. In this evolving landscape, agricultural professionals serve as a bridge between scientific research and practical implementation, ensuring that

5 https://www.fao.org/fao-who-codexalimentarius/codex-texts/list-standards/en/.

6 https://chm.pops.int/Implementation/GlobalMonitoringPlan/Overview/tabid/83/Default.aspx.

7 https://www.oecd.org/en/publications/oecd-environmental-performance-reviews_19900090.html.

8 https://onehealthejp.eu/.

9 https://www.ipcp.ch/.

10 https://www.chemicalsframework.org/.

innovations are implemented in ways that both reduce environmental impact and sustain food production. These advancements signify an important transformation of the primary production system towards a more sustainable use of natural resources, potentially reducing the reliance on agrochemicals in agriculture. Thus, ensuring the systematic involvement of these professionals is essential to effective implementation of *One Health* policies and initiatives.

A critical consideration in chemical management is that access to drugs/medicines for animals and humans typically necessitates a medical or veterinary prescription, unlike agrochemicals. Introducing a similar oversight mechanism for agrochemical, involving agronomists and other domain-specific professionals in their prescription and use, could promote more responsible use and sustainable application. Furthermore, a *One Health* approach that encourages the interdisciplinary collaboration among various professionals within their specific domains, such as medical doctors and veterinarians for human health, veterinarians and animal production doctors for animal health, agronomists and foresters for plant/crop health, is crucial for a long-term perspective.

Beyond technical expertise, recognizing the role of agricultural professionals in balancing environmental protection with rural sustainability is particularly relevant. Their presence in agricultural areas is essential to maintaining viable farming systems, preventing land abandonment, and ensuring that rural communities can continue to steward the landscape effectively. Without their engagement, increased conservation efforts could shift costs to society while weakening environmental management.

Ensuring the effective engagement of agricultural professionals is not only vital for sustainable farming but also for optimizing chemical pollution reduction strategies without compromising food security. For instance, identifying chemical pollution hotspots would help policymakers prioritize regions for intensive monitoring and remediation, while longitudinal chemical concentration data could be used to track the effectiveness of environmental measures over time. Thus, a robust environmental monitoring system and risk-based legislation are essential to ensuring that pollution reduction efforts align with broader sustainability goals. This would directly support the Sustainable Development Goals (SDGs), including Goal 6 (Clean Water and Sanitation), Goal 13 (Climate Action), and Goal 15 (Life on Land).

Furthermore, the estimations presented in this study (Tables 2 and 3) confirm that that agrochemicals, veterinary, and human medicines all contribute significantly to the overall environmental chemical load. While agriculture plays a crucial role in chemical input into the environment, human and veterinary pharmaceuticals must also be considered in regulatory frameworks to ensure a comprehensive approach. However, decision-making in this area has largely relied on limited data. Policies such as the *Farm to Fork Strategy* (European Commission, 2020), while well-intended, have been developed with data constraints that may compromise their effectiveness in balancing food production with environmental protection. Gaps in transparency further hinder the evaluation of policy outcomes, limiting the ability to refine and adapt strategies effectively. To address these challenges, enhancing public data availability and investing in further research activities to quantify chemical inputs across the *One Health* domains is crucial. Improved data access would bridge existing knowledge gaps, fostering a more transparent and participatory policymaking process. By involving professionals from diverse sectors (agriculture, veterinary medicine, environmental science, and public health), data-driven, cross-sectoral strategies can be developed to ensure long-term sustainability. Collaborative and data-driven approaches are particularly vital for achieving sustainable agriculture (Goal 2 – Zero Hunger) while ensuring environmental protection (Goal 12 – Responsible Consumption and Production), thereby fostering sustainability at the intersection of food security, rural community livelihoods, and ecosystem health. Additionally, considering not only the quantity but also the subgroups of agrochemicals and drugs is important due to the scale of the problem. This detailed approach would allow targeted regulation adjustments where they are most needed. In fact, differentiating chemical classes based on their toxicity, persistence, and bio-accumulative potential would enable more precise, risk-based regulatory adjustments, ensuring that mitigation measures are targeted where they are most needed.

4.4. Targeted regulation of agrochemical use

While reducing agrochemical use is a central goal in environmental policies, regulatory strategies must consider the specific needs of agricultural production. The current use of agrochemicals sparks intense debate and criticism (Uddin, 2018). It is notable that the European Union is actively working to reduce agrochemical use. Albeit not legally binding, the *Farm to Fork and Biodiversity Strategy*, for instance, has set ambitious targets: to reduce by 50 % the use and risk of chemical pesticides and the use of more hazardous pesticides by 2030. However, while such initiative is essential for minimizing environmental impact and, therefore, easily understandable and acceptable, any restrictions must consider agronomic realities. For instance, unlike human medicines/drugs, pesticides are mainly used preventively to avoid pathogen development, highlighting the importance of not equating these two classes of compounds in terms of use strategy and consumption. Moreover, agricultural systems are highly diverse, and a one-size-fits-all reduction policy may disproportionately impact certain crops or regions. When revising legislation, such as towards *one substance, one assessment* initiative, it is essential to consider this difference to ensure that food security is not compromised. Addressing this requires recognizing the diminishing availability and quality of natural resources (such as land, water, soil, and air), particularly in an era of accelerating climate change. Recognizing the challenges faced by the agricultural sector is crucial to ensuring sustainable food production (SDG 2 – Zero Hunger) while protecting biodiversity and natural resources (SDG 15 – Life on Land). Rather than applying uniform restrictions, regulations should prioritize precision agriculture approaches that optimize agrochemical application while ensuring productivity and minimizing environmental risks.

4.5. Regulatory coordination and policy implications

Regulatory frameworks governing chemical inputs into the environment must be designed to ensure consistency, transparency, and enforceability across sectors and regions. Better data availability on chemical release into the environment would support improved resource management and inform climate change mitigation strategies, ensuring long-term sustainability. For instance, tracking chemical sources and their regional impacts would enable targeted remediation strategies while strengthening climate resilience efforts. For regulations to be effective within *One health* dimension, they must be based on high-quality data and through analysis. Several key policy considerations emerge from this study: i) strengthening targeted regulations for agrochemical, balancing reduction efforts with agricultural sustainability; ii) enhancing interdisciplinary and international regulatory alignment, preventing regulatory loopholes that allow pollution displacement; iii) expanding interdisciplinary collaboration, ensuring professionals across health, agriculture, and environmental sciences contribute to policymaking and implementation.

4.6. Interdisciplinary and international regulatory alignment for agrochemical use

At an international level, regulatory harmonization is necessary to prevent unintended consequences, such as shifting chemical-intensive agricultural production to regions with weaker regulations. Stricter policies in one country must not lead to increased chemicals' load in others due to trade imbalances (Fuchs et al., 2020). International cooperation is key to avoiding such regulatory loopholes. Therefore, closer collaboration among EU agencies, national governments, and international organizations is essential for fully leveraging the *One Health* approach to address planetary health threats. This approach requires participation from various scientific fields, including veterinarians, medicine doctors, agriculture, forestry, livestock and environmental scholars/professionals (in an interdisciplinary environment). The term *One Health* is increasingly used in policy and literature, emphasizing the need for alignment with its knowledge, competences and skills. Consistency in defining *One Health* is essential to avoid its misuse as a buzzword and maintain its effectiveness. Social sciences play a vital role in clarifying definitions and setting guidelines for *One Health* activities, ensuring interdisciplinary integration. At this juncture, the opportunity should be taken to stress the role of water and soil health in environmental health, necessitating strong regulation. The Proposal for the Soil Monitoring Directive can form the basis for integrative regulation between water and soil. This potential integration is particularly promising if the Soil Directive aligns with the Water Framework Directive (WFD), facilitating collaborative efforts between river basin districts and the proposed soil districts, fostering a more cohesive and effective regulatory approach to environmental management. Ultimately, achieving meaningful reductions in environmental contamination will require a combination of strengthened regulations, scientific collaboration, and engagement with stakeholders across all *One Health* domains.

5. Conclusions and future perspectives

This discussion paper highlights the urgent need for a more comprehensive assessment of the environmental chemical load from the human, animal, and plant health domains within the *One Health* framework. The lack of standardized, cross-sectoral data integration limits a comprehensive understanding of the issue and weakens the effectiveness of regulatory and mitigation strategies. Our findings indicate that while agriculture represents a significant contributor to chemical inputs in the environment, the human and animal health domains also play a substantial role. Thus, achieving effective regulatory oversight requires a holistic perspective that recognizes the complex interplay between these three domains, particularly considering the crucial role of agriculture in ensuring food production, rural sustainability, and ecosystem health. This is even more evident if the *Farm to Fork and Biodiversity Strategy* is considered.

A key outcome of this study is the recognition that fragmentation of reporting systems complicates comparisons across *One Health* domains, making it difficult to quantify their respective contributions to environmental pollution. To bridge this gap, regulatory frameworks should prioritize harmonized methodologies and standardized data-sharing mechanisms at both national and international levels. In the agricultural sector, where chemical inputs are closely tied to crop-specific needs, soil conditions, and climate variability, improving monitoring and reporting systems is particularly critical for designing effective, evidence-based policies that balance environmental sustainability with food security.

To enhance the effectiveness of One Health-based environmental policies, three main recommendations emerge from this study: i) strengthening cross-sectoral data integration through standardized reporting practices and expanding environmental monitoring programs, such as the Global Monitoring Plan under the Stockholm Convention; ii) enhancing regulatory coordination by aligning international risk assessment frameworks and policy mechanisms to ensure consistency in chemical management and prevent pollution displacement across regions; iii) fostering interdisciplinary collaboration among policymakers, scientists, industry professionals, and agricultural domain professionals to support the development of more sustainable chemical management strategies.

Furthermore, the involvement of qualified professionals of the agricultural domain at every stage of the process is crucial to improving policy implementation, particularly in the agricultural, forestry, livestock, and environmental sectors. Experts in these fields, along with agricultural and environmental scholars, play a pivotal role in addressing interdisciplinary challenges and ensuring alignment with the One Health principles embedded in the UN's 17 SDGs, ensuring both environmental protection and food security. The role of agronomists, farmers, and rural communities in managing sustainable agricultural practices is not only a matter of environmental responsibility but also a fundamental pillar of rural livelihood preservation. Without their engagement, the effectiveness of environmental policies may be undermined, and the depopulation of rural areas would increase, leading to additional costs for land management and environmental protection, ultimately burdening the broader society.

Finally, strengthening international cooperation through a holistic One Health approach is essential for tackling the broader challenge of chemical pollution and ensuring a sustainable balance between food security, public health, and environmental sustainability. In the agricultural sector, international efforts should focus on promoting precision agriculture, integrated pest management, and sustainable fertilization techniques to minimize environmental contamination without compromising productivity. Future research should focus on developing predictive models that integrate environmental, epidemiological, and agricultural data, as well as exploring more sustainable agricultural practices and biotechnological advancements that could help mitigate chemical contamination while maintaining productivity. By placing greater emphasis on sustainable agriculture and the role of professionals in the field, advancing data-driven policies, fostering interdisciplinary research, and enhancing regulatory harmonization, the *One Health* framework can evolve into a truly effective tool for addressing global environmental challenges.

CRediT authorship contribution statement

Julia Vos: Writing – original draft, Formal analysis, Data curation. **Mirta Alessandrini:** Writing – review & editing, Supervision. **Marco Trevisan:** Writing – review & editing, Supervision, Conceptualization. **Youry Pii:** Writing – review & editing, Writing – original draft. **Fabrizio Mazzetto:** Writing – review & editing, Conceptualization. **Guido Orzes:** Writing – review & editing, Writing – original draft, Supervision, Formal analysis. **Stefano Cesco:** Writing – review & editing, Writing – original draft, Supervision, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Youry Pii, Fabrizio Mazzetto, and Stefano Cesco reports financial support was provided by European Union Next-Generation EU. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Publicly available data are used in the study. Their references are mentioned in the paper.

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