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Implications of pesticide use regulation on soil sustainability in Uganda

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ABSTRACT

Reducing pesticide use has become a goal shared by several countries, Uganda inclusive and a major issue in public policies since the adverse impacts of pesticides on environmental media such as soil and on human health have been clearly demonstrated. The main environmental concerns related to pesticides are soil, water pollution and damage to non-target organisms including plants, birds, wildlife, fish and crops. On one hand, pesticides can control pests and diseases, and increase agricultural productivity, which is essential for food security and economic development. However, the positive effects have proven to be short-lived. Moreover, the indiscriminate and injudicious use of pesticides without proper regulation and awareness, more so by small-scale farmers, can lead to detrimental effects on soil health and long-term sustainability. The challenge is exacerbated by pesticides that can persist in the environment and accumulate in the soil over time, leading to soil degradation. Accordingly, regulation of pesticide use then becomes more critical if the adverse effects of pesticide use are to be mitigated. Indeed, Uganda recognizes the importance of sustainable agricultural practices and the need to regulate pesticide use to protect soil health and ensure long-term agricultural productivity. This is manifested in the existing regulatory framework on pesticide use, although challenges and threats to soil sustainability still abound especially from the highly fragmented and sectoral-based approaches. This paper examines the implications of pesticide use regulation on soil sustainability in Uganda, a country heavily reliant on agriculture for food security and economic growth. Suggestions are proffered on some interventions that align with soil sustainability.

1. Introduction

Pest and disease control is an important component of agriculture, with most farmers relying on multiple pest management practices, including insecticides, fungicides, and herbicides (Angole et al., 2023). Most of the available chemical, biological, and genetic crop protection solutions maximize short-term benefits by avoiding pest damage within a season without targeting long-term soil sustainability outcomes creating inadvertent compromises and stressing the need for innovation. In Uganda, like in many other countries, pesticides are widely used in agriculture, forestry, and horticulture to control pests and enhance crop production(The Uganda Environment Performance Index Report, 2020). However, the excessive use and improper management of pesticides can have significant negative impacts on soil sustainability (Sánchez-Bayo, 2011). Pesticides are used to control or eliminate pests such as insects, weeds, and diseases that can cause significant damage to crops. The most common pesticides that have been in use by the agriculture sector in Uganda include: organophosphates Bromophos, Diazinon, Dursban, Dimethoate, Malathion, Parathion), organochlorines among others (Kateregga, 2012). At the same time, there is scientific evidence to illustrate that the use of pesticides has severe adverse effects on the environment (Beketov et al., 2013; Larsen et al., 2017; Stehle and Schulz, 2015).

As the upper layer of the Earth's crust, soil plays a crucial role in food production, biodiversity conservation, and ecosystem services. Unfortunately, pesticide contamination poses a serious threat to soil health given that the chemicals in pesticides can persist in the soil for extended periods, leading to the accumulation of toxic residues and reducing the nutritional value of food (OHCHR, 2021). The chemical residues can harm soil organisms, including beneficial bacteria, fungi, earthworms, and other microorganisms that contribute to soil fertility and nutrient cycling. The loss of such organisms can disrupt the natural balance of the soil ecosystem and degrade its overall health. Continuous use of pesticides without effective governance systems and policy frameworks can have negative impacts on people, the planet, and prosperity, all of which are central to sustainable development (United Nations, 2015).

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Soil degradation resulting from pesticide use has various consequences. First, it can lead to a decline in soil fertility, as essential nutrients are depleted or become imbalanced. This can negatively impact crop yields and reduce the nutritional quality of food produced. Second, soil degradation reduces the soil's ability to retain water, leading to increased erosion, decreased water infiltration, and higher risks of flooding and drought. Third, pesticide contamination can affect the biodiversity of soil ecosystems by harming or killing beneficial insects, and other organisms that contribute to ecosystem balance and resilience (Fu et al., 2022; Wuepper et al., 2023). By polluting soil, injudicious pesticide use endangers farmers at work, local communities as well as the ecosystem services derived from healthy soils (Tambo et al., 2020; Angole et al., 2023). According to the International Center for Soil Fertility and Agriculture Development, there is substantial soil decline in every major region of sub-Saharan Africa with the largest rates of depletion being in Uganda, Guinea, Congo, Angola, Rwanda, and Burundi (Tully et al., 2015).

The Revised World Soil Charter (2015) recognised that careful soil management is one essential element of sustainable agriculture and also provides a valuable lever for climate regulation and a pathway for safeguarding ecosystem services and biodiversity. Soil degradation inherently reduces or eliminates soil functions and their ability to support ecosystem services essential for human well-being (The Revised World Soil Charter, 2015, p 4). Minimizing or eliminating significant soil pollution is essential to maintain the services provided by all soils and is substantially more cost-effective than rehabilitating soils after degradation has occurred (The Revised World Soil Charter, 2015, p 5). One pathway is the regulation of pesticides which are known to contain elements that can harm soil organisms.

Recognizing the importance of soil sustainability, Uganda has established legislative and policy frameworks for environmental protection, including pesticide use. Both pesticide regulation and soil sustainability are partly anchored on international, regional and national legal and policy infrastructure needed to manage chemicals throughout their life cycle. However, its effectiveness depends on the envisaged coordinated and holistic enforcement and compliance, monitoring, and awareness of all stakeholders, including farmers, which is not functioning as such, but rather sectoral based.

This paper analyses the implications of pesticide use regulation on soil sustainability in Uganda and proposes interventions that would also align with and contribute to society's broader vision for sustainability across sectors, which is outlined in international policies and initiatives.

2. Pesticide use by small scale farmers

Small-scale farmers play a substantial role in ensuring food security worldwide (Lowder et al., 2014). They support between 70 and 80% of the rural population and therefore, are critical in enhancing rural dietary supply, eradicating poverty, and hence contributing towards the Sustainable Development Goals (SDG) Agenda (Lowder et al., 2014). It is worth noting that agricultural systems in Africa are largely traditional—characterized by a large number of smallholdings of no more than one hectare per household (Nielson, 2020; Abate et al., 2000, p 631). The same situation is present in Uganda where agricultural production is dominated by smallholder subsistence farmers engaged in the production of food and cash crops, horticulture, among others, contributing 75 - 80% of the total agricultural output and marketed agricultural produce (MAAIF, 2020, p 1). The majority of the small-scale farmers own less than 2.5 hectares of land (MAAIF, 2020, p 5).

Due to the limited arable land, and the constant threats posed by pests, diseases and weeds, there has been increased use of agricultural inputs like chemical pesticides to boost productivity on the existing lands. Excessive use of pesticides contaminates soil and water sources, causing loss of biodiversity, destroying the natural enemies of pests, and reducing the nutritional value of food (OHCHR, 2021). Moreover, small farmers often lack the financial and technical resources or the knowledge to use pesticides appropriately (Nielson, 2020; Ssemugabo et al., 2022). The lack of knowledge among farmers to interpret labels, handle, apply, and dispose of pesticide waste exacerbates soil degradation. With the increasing push towards higher use of pesticides to boost productivity, effort is needed to reduce the associated negative impacts on soil quality (FAO, 2015).

3. Soil sustainability

Soil is the upper layer of the Earth's crust transformed by weathering and physical, chemical and biological processes. It is composed of mineral particles, organic matter, water, air and living organisms organized in genetic soil horizons (FAO, 2015, p 250). Sustainability rests on the principle that the present generation must meet its own needs without compromising the ability of future generations to meet their own needs (Mubiru et al., 2017, p 6). Soils host the majority of the world's biodiversity and healthy soils are essential to securing food and fiber production.

Soil plays a crucial role in supporting various ecosystem functions and services, including food production, water regulation, biodiversity conservation, and a significant regulating factor in mitigation of climate change through carbon sequestration (Desai and Sidhu, 2016, p 38). The specific functions provided by soil are governed, in large part, by the suite of chemical, biological, and physical properties present in that soil (The Revised World Soil Charter, 2015). Knowledge of the actual state of those properties, their role in soil functions, and the effect of change both natural and human-induced on them is essential to achieve sustainability (The Revised World Soil Charter, 2015). Soil sustainability embraces activities that maintain or enhance the supporting, provisioning, regulating and cultural services provided by soils without significantly impairing either the soil functions that enable those services or biodiversity (The Revised World Soil Charter, 2015). Some of the practices include the application of manure, moderating or increasing fertilizer use, control of dryland salinity, and implementing zoning systems to protect the best agricultural soils. However, unsustainable soil management practices including excessive use of chemicals, poor regulation of pesticide use, overuse of fertilizers, and poor farming methods, have led to soil pollution and attendant effects (FAO, 2015 (p 31), FAO, 2021). This can have cascading outcomes on soil health and ecosystem functioning.

The challenge of nutrient-deficient soils is particularly serious for smallholder farmers who form the majority living in Africa, where the land is incredibly diverse, very depleted, and supports some of the highest populations in the world (Lowder et al., 2014; Haler et al., 2020). In Uganda, soils have been depleted as a result of poor farming methods and other malpractices such as the overuse of chemicals and pesticides (Food Security Centre, 2019). Soil contamination is responsible for decreasing the soil biodiversity and fertility and hence, decreasing soil health, making it difficult to sustain agricultural productivity. By implementing sustainable soil management practices, we can ensure that current and future generations can meet their needs while preserving this precious natural resource.

4. The nexus between pesticide use and soil sustainability

The nexus between pesticide use and soil sustainability is complex, a delicate balance and can have both positive and negative impacts on soil health. While pesticides can provide short-term benefits in crop protection and yield improvement, their misuse or overuse can lead to negative consequences for soil health and long-term sustainability. In Uganda, agriculture is a significant sector of the economy, and pesticide use is common in agricultural practices. Some of these chemicals under the OCP are being used for vector control and crop production in spite of the bans and restrictions issued in 1970 (Ben et al., 2021). Indeed, as part of the strategy to increase agricultural production and improve food security and farmer income, between 2015 and 2020, the Agriculture

Sector Strategic Plan (ASSP) of the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) focused on pests, vectors and disease control, especially for the priority and strategic commodities (Annual Agricultural Survey (AAS) Report, 2022 p 81).

According to numerous studies, pollution in agricultural soils has become a growing concern in most developed and developing nations due to enhanced industrialization and urbanization (Haler et al., 2020). Farmers, through the search for control mechanisms for pests and the re-establishment of the production potential of land, have responded by using agrochemicals and pesticides. The dangers of this rapidly increasing use of pesticides have been acknowledged by the Food and Agriculture Organization (FAO), where it was broadly concluded that there was an urgent need to introduce sustainable and sound agricultural practices that reduce human health and environmental risks associated with the use of pesticides (Carvalho, 2017; FAO, 2021).While pesticides play an important role in sustaining food supply, they may also be hazardous to human health and the environment if not used as intended (Pesticides Control Board, 2018). This is particularly so when a vast majority handle or use pesticides without appropriate protective gear, with limited knowledge about chemicals, and without means of safely washing equipment or disposing of empty containers. Thus, Mengistie et al. rightly posit that many small scale farmers have adopted pesticides without the support necessary to minimize the many risks and adverse effects (Mengistie et al., 2017). It is, therefore, not surprising that most literature does not point to pesticide use as a problem *per se* but rather, the improper use of such chemicals largely caused by inadequate knowledge by the users.

Aliyeva et al. (2013) indicate that contaminated soils in agricultural areas in and around obsolete pesticide stocks still represent 'hotspots' of pesticide emission to the environment. A more recent study by Elina and Elliner shows that the use of synthetic pesticides to treat crop pests is a practice that has recently increased considerably among Paya farmers in Uganda (Andersson and Isgren, 2021). Notably, this finding stands in stark contrast to the much lower figures reported in the official data on pesticide use for Uganda, which are derived from macro-level statistics and therefore prone to issues of data reliability. A recent Uganda National Panel Survey (2015/2016) reports pesticide use frequency on beans, maize and plantain at only 6,5; 8,7; and 5,7%, respectively. These findings on the increase in the use of agrochemicals on pesticide use frequency resonate well with other recent studies by Oesterlund et al. (2014) that contain primary survey data, which report pesticide use in the range of 96–100%. This contrasts the commonly held notion that pesticide use in Uganda is the reserve for commercial farming such as horticulture. Other studies in Uganda also indicate that smallholder farmers use pesticides on numerous staple crops, including potato (Okonya and Kroschel, 2016), sweet potato, cowpeas and maize (Ashour et al., 2019).

A World Health Organization (WHO) report Indicates that the widespread use of pesticides and fertilisers in agriculture is among the main drivers of toxic pollution in developing countries like Uganda (WHO, 2015). Semalulu et al. (2015, p 162) illustrate that pesticides "can be a concern even at low national rates of application if they are used inappropriately." For example, Uganda officially has some of the continent's lowest pesticide application rates (Loha et al., 2018). Yet the European Union recently issued warnings to Uganda over chemical residues in agricultural imports (The Independent Newspaper, 2019, (Ssemugabo et al., 2022). Implementing sustainable pest management practices, reducing reliance on chemical pesticides, and adopting approaches like Integrated Pest Management and organic farming can help mitigate the potential adverse effects on soil sustainability. The long-term well-being of agricultural land depends on good quality soil, water, air, and other ecosystems. In order to preserve these resources good farming practices needs to include protection of the environment. Although pesticides can be of help to the environment, indiscriminate use of pesticides, however, raises a number of environmental and health concerns including soil and water pollution. Evidence of pesticide poisoning, unsafe pesticide-handling practices, polluted ground water and chemical-laden food crops in local markets have been reported among farmers of various crops in Uganda (Ssemugabo et al., 2022; Karungi et al., 2011).

5. Soil pollution

Soil being a universal sink bears the greatest burden of environmental pollution. Therefore, soil pollution has become a major threat to food safety, human health and ecological safety and is a common concern around the world (FAO, 2015). Pollution may be defined as an undesirable change in the physical, chemical, and biological characteristics of air, water, and soil which affect human life, the lives of other useful living plants and animals, industrial progress, living conditions, and cultural assets (Ashraf et al., 2014). Osman defines soil pollution as the accumulation of a substance, native or introduced, in the soil at a level harmful to the growth and health of organisms, including micro-organisms, plants, and animals (Osman, 2014). Toxic substances find their way to the soil from anthropogenic activities, especially domestic, agriculture and industry. Similarly, the National State of Environment of Uganda 2016/2017 report recognises soil pollution as one of the key environmental challenges that Uganda faces. It further attributes the pollution to poor farming practices including pesticide use.

Otitoloju *et al.* rightly observe that soil pollution is a source of danger to the health of people and ecosystems worldwide (Aliyeva et al., 2013; Otitoloju et al., 2009). The increased and injudicious use of pesticides exerts substantial stress on soil health by affecting soil biota responsible for preserving soil functions (Ssemugabo et al., 2022; Tang and Maggi, 2021). Several laboratory studies recount a change in soil microbial community and a drop in microbial growth and enzymatic activities as a result of exposure to single pesticides (Singh et al., 2002,). Various studies and reports have attempted to examine the pesticide residues in soil in the different parts of Uganda. Regarding pesticide residue, when pesticides are applied in the soils, there are continuing processes, in which they are lost in the soils, for example, through leaching, runoff and evaporation, the remnants after application are known as the residue (Diop et al., 2022; Zhang et al., 2020). Some pesticides such as Persistent Organic Pollutants (POPs) or Highly Hazardous Pesticides (HHPs) have a longer period of residual activity and because of that, persist in the environment, while others have a shorter period of time for residual activity, they therefore, do not persist from the environment or results into low residue concentration. Ssebugere et al. (2010), advance that such contamination of soil is connected to the injudicious use of pesticides as well as use of banned chemicals comprising POPs.

Organochlorine Pesticides were found in South western Uganda soils (Ssebugere et al., 2010. p 1250), and in residues on the Ugandan segment of Lake Victoria (Wasswa et al., 2011 p 133). Nanyonga et al. (2013), similarly point to Organochlorine Pesticides (OCPs) residues in carrots from Mukono and Kampala markets. While Wasswa et.al., 2010, found Aldrin, sulfate, Endosulfan, and dieldrin commonly detected Persistent Organic Pollutants (POPs) pesticide residues in vegetables. Soils from the study site at the Mabira Forest Reserve showed frequencies of p,p0 -DDT and p,p0 -DDE of 5% and 9%, respectively, which exhibited residue levels between 2 and 9 lg kg (Isgren and Andersson 2021 and UBOS Statistical Abstract, 2018). The residue ratio of p,p0 -DDE/p,p0 -DDT in Mabira was 0.4. The presence of p,p0 -DDT and p,p0 -DDE residues in Mabira, the reference of this study, may be attributed to atmospheric transport from other places where it had been used, probably from Lugazi tea estates located near the natural forest. Kameri-Mbote, 2020 p 12, reveals that contamination with POPs pesticides in terrestrial and aquatic ecosystems has been recognized as an eminent environmental health concern due to the slow or non-biodegradation of POP pesticides and the tendency to accumulate in soils, plants and animal tissues, which ultimately end in the food chain and may result in human health problems.

Damage to the soil on which all life depends, threatens not only human life but that of other species. A 2017 UNEP report further highlights the effects of toxic soil pollution including, significant losses of income, as well as impacts on food security and direct hazards to human health (UNEP, 2017). However, detailed statistical data on soil pollution and pesticide residues in Uganda is still limited and therefore, not conclusive.

6. Theoretical underpinning for soil sustainability and pesticide use regulation

6.1. Systems theory

The Systems Theory is a framework by which one can investigate and/or describe any group of objects that work together to produce some result (Whitchurch and Constantine, 2009). This could be a single organism, any organization or society, or governance framework. The Systems Theory looks at soil as an open system that interacts with various elements and processes. It is expected that soil is subjected to environmentally sustainable management practices, and the governance of substances such as pesticides that get in contact with the soil system then becomes critical. The governance tools for sound pesticide regulation inevitably affect the soil system – and whether the effect is negative or positive, depends on the interactions, interdependence, complexity, inputs, throughput and feedback.

The Systems Theory has been applied in various fields such as biology, ecology, economics, business management, and land use planning, among others (Whitchurch and Constantine, 2009). The uniqueness of this approach is that it requires a conceptual and practical effort agreed upon by all or majority stakeholders including decision-makers, politicians, researchers, professionals, civil society, citizens, among others (Bai et al., 2016). As pointed out by Forrester, problems confronting modern governments are so complex, profound, and interdependent that only a systems-based paradigm can begin to comprehend them (Forrester, 1993). Problems such as ecological degradation, pollution, and national or regional economic performance have been cited as examples of problems that citizens expect governments to act upon, but which are difficult to tackle within normal policy modes.

6.2. Soil as an open system

The concept of soil as an open system implies that its functioning is determined by the interaction among its subsystem and the surrounding systems (Rasmussen et al., 2011). This interaction is affected by the flows that permeate it such as pesticides. An understanding of soil as an open system, to which substances can be added or removed, was first proposed by Jenny (Nicolodi and Gianello, 2014). According to this author, soil is the result of the interactions among climate, organisms, landscape, rock matrix, and formation time.

Like other scholars, Huggett has also argued that the soil system has a very complex hierarchical organization and comprises a network of relationships among its subsystems (Huggett, 1975). It is part of the many large systems comprising the upper portion of the lithosphere, the lower portion of the atmosphere, and a considerable portion of the biosphere, and substances can be added to and removed from it. The flows of matter and energy through the subsystems of the soil system interfere with its pedogenesis. Thus, its formation is an irreversible process. This process explains the efforts, especially by pedologists, to understand the soil based on Bertalanffy's General Systems Theory (Huggett, 1975). However, when applying this theory to the study of soil sustainability, it can no longer be analysed through the action of an isolated factor but as a component of a larger system comprising other parts including laws and policies across sectors.

6.3. Systems thinking

Systems thinking as an analytical tool is highly relevant in the context of pesticide use regulation and soil sustainability. It enables a holistic understanding of the complex interactions and interdependencies within agricultural systems, highlighting the need to consider the broader impacts of pesticide use on soil health, ecosystems, and human well-being (Zhang et al., 2018). Systems thinking recognizes that agricultural systems are intricate webs of interconnected elements, including soil, water, plants, pests, and human activities. Pesticide use affects not only the targeted pests but also non-target organisms, such as beneficial insects, soil microorganisms, and wildlife (Ssemugabo et al., 2022; FAO, 2021). By adopting a systems thinking approach, regulators can better comprehend these interconnections and anticipate unintended consequences, hence creating policies that minimize negative impacts and promote sustainable soil management practices like integrated pest management (IPM) strategies, crop rotation, and diversified farming systems to break the cycle of dependency on pesticides. This could bring about approaches that balance pest management with soil health, ecological resilience, and human well-being.

In conclusion, systems thinking provides a valuable framework for understanding and addressing the complex challenges associated with pesticide use regulation and soil sustainability in Uganda, and beyond. Such an approach could lead to cross-sectoral, integrated agricultural solutions that achieve agronomic, environmental, and economic goals.

7. Regulation of pesticide use in Uganda

The regulatory framework for pesticide use in Uganda is embedded in multiple pieces of national legislation and international instruments.

7.1. The Constitution of the Republic of Uganda, 1995

The Constitution of Uganda 1995 obligates the State to "promote sustainable development and public awareness of the need to manage land, air, and water resources in a balanced and sustainable manner for the present and future generations of all Ugandans (Objective XXVII)." The State is particularly enjoined to take all possible measures to prevent or minimize damage and destruction to land, air and water resources the foundation to protect and preserve the environment from abuse, pollution, and degradation (Objective XXVII, Constitution of Uganda, 1995). The Constitution provides the overall framework for promoting sustainable development and the need to manage natural resources in a balanced and sustainable manner for the present and future generations. Article 39 guarantees a right to a clean and healthy environment which affects several rights, both social and economic. Closely associated with the right to a clean and healthy environment is the right to water.

However, the Constitution does not specifically provide for the preservation of soil health or rights that would be violated by chemically polluted soils. There is an attempt to cure this gap in the National Environment Act which broadly provides for the Rights of nature (Section 4). It enjoins the State to apply precaution and restriction measures in all activities that can lead to the extinction of species, the destruction of ecosystems or the permanent alteration of the natural cycles (Section 4 (3)). This calls for enhanced protection of soil health, which can be achieved in part by improved pesticide use regulation.

7.2. The National Environment Act, 2019

The National Environment Act, 2019 is the principal environmental law. It mandates the National Environment Management Authority (NEMA) with the agency role of regulating, monitoring, supervising and coordinating all activities relating to the environment. Part VI of the Act provides for sound management of chemicals, product control and all chemicals listed under Schedule 8. Schedule 5 to the Act lists projects for which environmental and social impact assessment (ESIA) is mandatory and this includes large-scale application of agrochemicals for disease and pest control, their manufacture, formulation and re-packaging. However, the Act is silent on small scale application of agrochemicals.

Section 107 of the Act provides for soil quality standards. It requires NEMA to establish the criteria and procedure for the measurement and determination of soil quality, including sampling methods and soil analysis, and prescribe minimum standards for the management of the quality of the soil. It further requires NEMA to collaborate with lead agencies to issue guidelines that prescribe measures for the disposal of any substance in the soil; the identification of various soils; the optimum utilization of any soil; the practices that will conserve soil;; the prohibition of practices that degrade soil; and clean-up and restoration of contaminated soil. This provision is important to safeguard soil health from hazardous pesticides.

This National Environment Act has several regulations made under it, including the ESIA Regulations 2020, Waste Management Regulations 2020, Management of Ozone Depleting Substances and Product Regulations 2020, and Environmental Audit Regulations 2020. These regulations are crucial in the regulation of pesticides through the different phases. More regulation on soil quality is under the National Environment (Minimum Standards for Management of Soil Quality) Regulations, 2001 that were made under the repealed National Environment Act Cap 153 but are yet to be revoked. These established and prescribed minimum standards for soil quality, minimum standards for the management quality of soil intended for agricultural use, among others.

7.3. The Agricultural Chemicals (Control) Act 2006

The Agricultural Chemicals (Control) Act 2006 is the key legislation governing pesticide use in Uganda. This law regulates the importation, exportation, distribution, sale, and use of agricultural chemicals, including pesticides. It aims to ensure the safe and responsible use of pesticides to protect human health, the environment, and agricultural produce. Section 2 defines agricultural chemicals to include among others plant protection chemicals, fungicides, insecticides, nematicides, herbicides, bio-pesticides and bio-fertilisers.The Act establishes the Agricultural Chemicals Board under Section 5. It is mandated to, among others, ensure that agricultural chemicals are duly registered and used in a manner consistent with the Act.

Also established under the Act is the office of a designated inspector of agricultural chemicals who has powers to enter upon any place or premises in which he or she reasonably believes an agricultural chemical is stored, sold or used; examine the agricultural chemical; take samples; seize and detain the agricultural chemicals. The Act plays a big role of controlling agricultural chemicals in promoting soil health. The Act is however not comprehensive and there are no new regulations to enforce it, other than the Control of Agricultural Chemicals (Registration and Control) Regulations SI 29-1 that were made under the repealed Control of Agricultural Chemicals Act. The Act does not provide minimum standards for chemical waste disposal which in the end contributes to soil contamination.

The Control of Agricultural Chemicals (Registration and Control) Regulations SI 29-1 regulate the manufacture, importation, exportation, storage, use, distribution and any dealing in agricultural chemicals in Uganda. Regulation 4 requires all agricultural chemicals to be duly registered in the register of agricultural chemicals and a certificate is issued in respect of it prior to any usage, storage, or distribution. The regulations detail the procedure for registration of agricultural chemicals, fumigators and commercial applicators, and premises.

7.4. International and regional conventions and agreements related to the management and use of pesticides

Uganda is a signatory to several international and regional conventions and agreements related to the management and use of pesticides. Uganda ratified the Basel Convention on the Control of Trans-boundary Movements of Hazardous Wastes, 1992 on March 11 1999. The Basel Convention, 1992 aims at protecting human health and the environment from risks posed by hazardous wastes and their transboundary movement. Uganda implements it through the East African Community (EAC) Customs Management Act which in Schedule 2 Part A, Para (11) lists Agricultural Chemicals that are prohibited from importation across EAC Partner states borders, the National Environment Act and the Agricultural Chemicals (Control) Act.

On August 18 2008, Uganda acceded to the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade, 1998. The Rotterdam Convention has the objective to promote shared responsibility and cooperative efforts among Parties in the international trade of certain hazardous chemicals to protect human health and the environment from potential harm. Article 2 of the Convention defines chemicals to inter alia consist of a pesticide including severely hazardous pesticide formulations. Annex III lists pesticides and industrial chemicals that are subject to the Convention's prior informed consent procedure. It requires information exchange and dissemination among Parties concerning the covered chemicals.

Uganda also acceded to the Stockholm Convention on Persistent Organic Pollutants, 2004 on July 20, 2004. The Stockholm Convention has the objective to protect human health and the environment from the adverse effects of Persistent Organic Pollutants (POPs). The Convention currently lists 12 chemicals or groups of chemicals and these include pesticides. The main obligations of the Parties to the Convention are to eliminate intentionally or intentionally produced POPs, stockpiles and wastes. Uganda's National Environment Act 2019 lists the prohibited and restricted chemicals under the Convention (Schedule 8). The EAC Customs Management Act 2004 regulates the management and administration of customs in the EAC. Section 18 provides for prohibited goods which are listed under Second Schedule Part A and paragraph 11 lists prohibited Agricultural chemicals. The Act facilitates the importation of certified pesticides for agricultural use and the prohibition of hazardous pesticides in Uganda.

Related to hard law, is the International Code of Conduct on Pesticide Management, 2014 which is a non-binding instrument developed by FAO. It is a framework on pesticide management for all public and private entities engaged in, or associated with production, regulation and management of pesticides. Article 3.1 of the code provides that Governments have the overall responsibility for regulating the availability, distribution and use of pesticides in their countries and should ensure the allocation of adequate resources for this mandate. The Code is important in safeguarding agricultural soils because registration of biochemical pesticides is required if a product is applied to the soil and can accumulate in the soil (International Code of Conduct on the Distribution and Use of Pesticides 1985 revised 2002, Annex C).

The Sustainable Development Goals (SDGs) adopted by the UN in 2015 as a universal call to action to end poverty and protect the planet also provider the roadmap and critical guidelines relevant to environmentally sound management of chemicals (UN General Assembly, 2015). Particularly, goal 3.9 aims to substantially reduce the number of deaths and illnesses from soil pollution and contamination by 2030. Failure to comply with such principles and national legal procedures could result in environmental pollution liability by the project or product proponent.

7.5. Institutional framework

In terms of regulatory institutions, the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) is responsible for policy formulation, planning, and setting standards of agricultural inputs including pesticides. The Ministry of Water and Environment has the overall responsibility for development, management, and regulation of water and environment resources in Uganda. The National Environment Management Authority (NEMA) is the principal agency in Uganda for regulating, monitoring, supervising and coordinating all activities relating to the environment including chemical use and soil quality.

The Agricultural Chemical Board (ACB) is the statutory body established under the Agricultural Chemical (Control) Act 2006 and charged with overseeing, deciding or advising the Minster responsible for agriculture on the registration and control of agricultural chemicals and exercising responsibility for all policy matters affecting agricultural chemicals. The Agriculture Chemicals Board is in charge of the national legal, institutional, administrative, and technical infrastructure for agricultural chemicals management. ACB administers the Act and considers applications for registration of agricultural chemicals, manufacturers, of agricultural chemicals, certified commercial applicators and fumigators, and issues licenses. The Uganda National Bureau of Standards (UNBS) does not directly oversee the management of agricultural chemicals but has a significant role to play at points of entry of chemicals into the country.

Regulation and enforcement of pesticide use, along with promoting sustainable agriculture practices and providing education and awareness, are essential for mitigating the negative impacts and ensuring long-term soil sustainability in Uganda. Unfortunately, challenges abound the realization of pesticide use regulation requisite for soil sustainability.

8. Implications of pesticide regulation on soil sustainability

Regulations regarding pesticide use and soil management are indeed crucial for mitigating the harmful effects of pesticides on soil and the environment. The World Soil Charter emphasizes the need for governments to establish and implement regulations that limit the accumulation of contaminants beyond acceptable levels. These regulations are aimed at safeguarding human health, preserving the well-being of plants and animals, and facilitating the remediation of contaminated soils when necessary.

The implications of pesticide use regulation on soil sustainability in Uganda are multi fold. Firstly, regulatory measures promote the use of environmentally friendly and less toxic pesticides, reducing the risk of soil contamination (Ssemugabo et al., 2022, Chemutai, 2022). By encouraging the adoption of IPM practices, which emphasize pest prevention and non-chemical pest control methods, soil health can be preserved, and the overall ecosystem balance can be maintained (Turyahikayo, 2013; Kansiime et al., 2016). Secondly, pesticide use regulation encourages proper application techniques, dosage, and timing, minimizing the potential for excessive pesticide residues in the soil. This helps to maintain the soil's natural microbial activity and nutrient cycling processes, preserving soil fertility and reducing the need for synthetic fertilizers (Ashour et al., 2019). Thirdly, regulations on pesticide use promote farmer education and awareness programs, empowering farmers with knowledge of sustainable pest management practices. Through training and extension services, farmers gain insights into alternative pest control methods such as crop rotation, intercropping, and biological control, which reduce the reliance on pesticides and contribute to soil sustainability.

However, challenges remain in implementing and enforcing pesticide regulations effectively. Limited resources, inadequate infrastructure, and lack of awareness among farmers and pesticide retailers pose obstacles to achieving optimal soil sustainability outcomes. Strengthening institutional capacity, investing in agricultural research and extension services, and promoting farmer education are crucial for overcoming these challenges.

9. Challenges

While the policy and legal framework for quality control, sale and distribution of pesticides in Uganda is to be regarded as "satisfactory" according to a recent assessment report, the capacity for monitoring and enforcement of regulatory systems is largely inadequate (Kansiime et al., 2016). A survey by Nalwanga et al. revealed that in Uganda, pesticide usage remains relatively unregulated and the use of counterfeit products inhibits monitoring as chemicals are frequently mislabelled (Nalwanga and Ssempebwa, 2011). The FAO Code of Conduct for Pesticide Use is most of the time not adhered to in many developing countries (FAO, 2002). Kumar et al. further illustrate that in developing countries, where chemicals used for agricultural purposes are often not effectively regulated, safely used, or environmentally disposed of, the human population continues to face grave toxic risks through the chemical pollution of water, soil, and food (Thi et al., 2015).

Healy and Gunningham illustrate that the potential of the regulatory framework for pesticides to promote safety practices is constrained by four factors: the fragmentation and complexity of the regulatory framework and institutional arrangements; the inappropriateness of the current regulatory model to agriculture; the widespread reliance on relatively ineffective information and training strategies to encourage farmers' compliance with safety standards; and the lack of regulatory incentives for compliance (Healy and Gunningham, 2004). As Lockie puts it, there are both cultural and financial reasons for the unsustainable use of agrochemicals. Most farmers' first priority is to maintain the economic viability of their farm, often under increasingly difficult economic circumstances (particularly in the case of small farms) (Lockie, 1997; Ssemugabo et al., 2022; Haler et al., 2020). For the majority of farmers, despite some anxiety about the health and environmental impacts of pesticides, their use to maintain productivity represents good farming practices.

Regarding the aspect of national capacities to adequately monitor and document pesticide use and disposal especially among small scale farmers, literature points to lack of documentation, inspection and monitoring by State agencies in most Sub Saharan countries like Kenya, Uganda and Nigeria (Route to Food, 2019). As suggested by Okonya, monitoring retailers and banning certain products, as well as their application by farmers entails strict enforcement of pesticide legislation that needs a costly inspection process (Okonya and Kroschel, 2016). This may prove unaffordable to the governments. However, such government regulatory efforts could be augmented by research and academic efforts but unfortunately, scholarship on chemicals pollution is scarce in the continent as pointed out by Gwenzi and Chaukura (2018).

Small-scale farmers have limited knowledge to understand the complexity and the information. The levels of illiteracy are high yet the labeling is done in English. Consequently, there is a lot of misuse and misapplication that interferes with the quality of soils. There are also few trained and certified commercial applicators and fumigators with the technical knowledge of the chemistry, toxicology, efficacy, safety and general use of the chemical being handled. Thus, farmers rely on available family labor to spray or apply pesticides in their gardens.

The poverty levels among SSFs exacerbate the difficulty in compliance with pesticide use regulations and soil quality standards. They cannot afford certified applicators, standard and well-packed pesticides on the market, application equipment and protective gear. This contributes to leakages and spillage during transportation and application which contaminates the soils beyond the intended plant.

Uganda's regulatory framework on pesticide use has inadequacies in terms of provisions requiring training of pesticide dealers and farmers, it prescribes weak penalties for non-compliance and limited incentives. The Agricultural Chemicals Act and the regulations are outdated and do not provide for the promotion of organic approaches or techniques which are soil friendly than pesticides. There is a broad institutional framework for pesticide regulation and soil management led by MAAIF, Ministry of Water and Environment, NEMA, Uganda National Bureau of Standards, and the Agriculture Chemical Board but these are faced with limited financial and human resource capacity, limited institutional coordination, limited laboratory equipment for pesticide certification and soil testing.

Inadequate soil data is a big setback to soil sustainability. Particularly, data that links soil to pesticide use and attendant pollution. There is limited research and scientifically analyzed information on the soils that can inform the regulators and farmers of the fertility, acidity, nutritional content, minerals, living organisms and other essential contents of the soil that favor plant growth and reduce agrochemical reliance (Nadudu, 2015).

10. Untapped potential

To address the above identified issues and mitigate the negative impacts of pesticide use regulation on soil quality, efforts are needed to promote sustainable agricultural practices. One approach is to adopt new agricultural technologies that rely on organic inputs such as manure, biofertilizers, biopesticides, slow-release fertilizers, and nano-fertilizers (Bisht and Chauhan, 2020).

Promotion of sustainable soil management practices. This includes adopting practices that maintain or enhance soil functions and biodiversity while supporting agricultural production, like reducing chemical inputs through integrated pest management, implementing conservation agriculture techniques, and promoting soil conservation measures like terracing and agroforestry.

Fostering the implementation and further research on IPM and Integrated Management of Pests and Pesticides as a means of improved management of the use of pesticides. There are indigenous conservation practices that can be adapted to particular situations and locations but little research has been undertaken. Furthermore, providing education and training to small-scale farmers on the proper use and management of pesticides, as well as promoting IPM strategies, can help minimize the risks associated with pesticide use. Overall, a shift towards sustainable agricultural practices and the adoption of IPM that emphasizes a combination of biological, cultural, and chemical control methods to manage pests effectively while reducing reliance on pesticides. approaches can help small-scale farmers reduce their reliance on harmful pesticides and mitigate the negative impacts on soil quality.

Regular sensitization and awareness creation among farmers provide another avenue for reduced or judicious pesticide use. Famers need to be informed about the right pesticides to use and their application. Farmer Field Schools (FFS) have proven a viable tool that develops the skills and expertise of farmers, facilitating them to build more efficient and sustainable production systems, and agricultural practices and, thus, contribute to the achievement of the Sustainable Development Goals (SDGs) as a whole and soil sustainability, in particular. This approach is already existent in some parts of Uganda but can be further rolled out and consolidated for better outcomes in respect to environmentally sound use pesticides by small scale farmers.

There are international binding and non-binding instruments that can guide comprehensive national regulation on pesticide use and soil sustainability. For example, the International Code of Conduct on Pesticide Management 2014 established voluntary standards of conduct for all public and private entities engaged in or associated with the management of pesticides, particularly where there is inadequate or no national legislation to regulate pesticides. The latest Global Framework on Chemicals (GFC, 2023) avails another valuable policy framework. Like its predecessor the Strategic Approach to International Chemicals Management (SAICM), the framework provides for inclusive, multi-stakeholder, and multi-sectoral approach. Additionally, there is The Revised World Soil Charter (2015) that sets principles and practices of sustainable soil management necessary to guide policy and legislation at all levels of government. Through the East African Community (EAC), legislation and policy on pesticides and soil quality standards can be harmonised. Prohibition on the importation of hazardous pesticides can easily be managed with the cooperation of Partner States of the EAC.

It is also critical that regular and quality agricultural statistics are provided for evidence-based decision-making and policy development to improve the performance of the sector so that it meets the national food security needs and reduces risks such as soil pollution from injudicious use of pesticides. Comprehensive studies that provide regular and accurate analysis on pesticide residues in soil in Uganda are urgent.

The globalization of information and communication technologies (ICT). Integration of ICT in agricultural activities is crucial for data dissemination among all stakeholders, especially regarding standard or counterfeit pesticides on the market, organic approaches to pest management and soil conservation. There is untapped potential in the provision of incentives to promote sustainable pesticide use and soil conservation. Accordingly, coordinated and multisectoral efforts that minimize the potential for environmental issues by following label directions, storing pesticides safely, and using them properly, as well as their safe disposal can improve pesticide use regulation and enhance soil sustainability.

11. Conclusion

This paper has illustrated a close nexus between pesticide use, its regulation and soil sustainability. Although both facets are embedded in the legal, policy, and institutional frameworks, various challenges exist for optimal results. This is illustrated by the persistent cases of indiscriminate use of pesticides, unsafe pesticide-handling practices, among others. One clear indicator is that the regulatory architecture is fragmented and sectoral-based, losing out on the benefits that come with a multi-sectoral approach. Adopting a multi-sectoral approach based on systems thinking, the nexus between soil sustainability and pesticide use regulation has the potential to unite farmers, researchers, government agencies, non-profit organisations, and the private sector around the possibility that management of agroecosystems can meaningfully contribute to solving major environmental challenges including pollution.

This paper posits that continued efforts in raising awareness, capacity building, and strict enforcement of regulations on pesticide use, and in a more collaborative manner are necessary to ensure the long-term protection of soil resources and ecosystem services. Uganda can safeguard its soil health, preserve fertility, and promote sustainable agriculture practices for the benefit of both present and future generations by promoting the judicious use of pesticides, encouraging alternative pest control methods, and enhancing farmer education. Finally, further research and deliberate legislative processes ought to be undertaken so as to have focused targets going forward. The current European Union pesticide regulation agenda can lend a great guide.

CRediT authorship contribution statement

Hadijah Yahyah: Conceptualization, Data curation, Formal analysis, Writing – original draft, Writing – review & editing, Investigation, Methodology. **Patricia Kameri-Mbote:** Conceptualization, Resources, Supervision, Writing – original draft, Writing – review & editing, Methodology. **Robert Kibugi:** Conceptualization, Formal analysis, Methodology, Resources, Supervision, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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