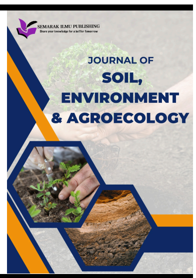
SEMARAK ILMU PUBLISHING
202103268166(003316878-P)

Journal of Soil, Environment & Agroecology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/sea/index
ISSN: 3030-5497



The Application and Challenges of Essential Oils as Natural Pesticides

Aishah Mohd Marsin[1,2], Ida Idayu Muhamad[1,3], Siti Nor Syairah Anis[1,5], Liew Wen Ching[1], Noer Hartini Dolhaji[4], Nurul Asmak Md Lazim[1]

1 Department of Bioprocess and Polymer Engineering, Faculty of Chemical and Energy Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310 UTM, Johor Bahru, Johor, Malaysia
2 Program Pemprosesan dana Kawalan Mutu Makanan, Kolej Komuniti Pasir Salak, Jalan Lebuh Paduka, Changkat Lada, 36800, Kampung Gajah, Perak, Malaysia
3 IJN-UTM Cardiovasular Engineering Centre, Institute of Human Centered Engineering (iHumEn), Universiti Teknologi Malaysia, 81310 UTM, Johor Bahru, Johor, Malaysia
4 Faculty of Plantation and Agrotechnology, Universiti Teknologi MARA, 77300 UiTM, Jasin, Melaka, Malaysia
5. School of Biological Sciences, Universiti Sains Malaysia, Pulau Pinang, Malaysia

ARTICLE INFO

Article history:
Received 16 May 2024
Received in revised form 25 June 2024
Accepted 15 July 2024
Available online 26 August 2024

Keywords:

Essential oil; natural pesticides; side effect; soil quality

ABSTRACT

Throughout nowadays era, humans and the environment have been exposed to various chemicals from high-technology systems. Among those, the substances that could affect human health, disrupt the environment, and soil quality are pesticides. Pesticides are used to protect crops and livestock from pest infestations. However, improper usage or higher dosages used to kill insects might also pose potential risks to food safety, living creatures, soil performance, and humans. Essential oils (EO) were known as natural pesticides without the addition of dangerous chemicals. However, the issue arises when it involves human health and environmental risks with the wrong dosage of EO and concentration used in pesticides. Therefore, this article aims to elaborate on the nature of essential oils as natural pesticides, their classification, the potential risks of EO, and future perspectives on the usage of EO as natural pesticides. It is also suggested for biopesticides in the future.

1. Introduction

According to the Food and Agricultural Organization of the United Nations and the United States Environmental Protection Agency (EPA), pesticides are regulated as substances or a mixture of substances utilized to repel, prevent, control, kill, or mitigate any damaging pest. Pesticides are also denoted as plant regulators, defoliants, and desiccants, along with nitrogen stabilizers. Therefore, pesticides refer to a wide array of natural and chemical agents, including fungicides, germicides, insecticides, herbicides, fumigants, and toxicants. In the light of global modernization and the robust population growth that drives agricultural transformation, pesticide use has intensified significantly in agriculture, aquaculture, horticulture, and households [1-3]. Annually, approximately 2 million tons of pesticides were utilized, with China being the leading country with the highest consumption and taking up about 90.3% of consumption [4-5]. Furthermore, the market size of global home and gardenpesticides were valued at USD 6.8 billion in 2018 and was expected to grow at a 3.8% compound annual growth rate (CAGR) from 2019 to 2025 [6].

Notably, pesticide applications have provided enormous benefits to society, mainly enhancing the yield and quality of crops to produce safer food. As reported by OECD [7], 26% to 40% of the world's potential crop was lost annually without the use of pesticides to prevent pests, weeds, and diseases. Pesticidal applications also reduced the labor-intensive activity of removing unwanted plants. All these advantages paved the way for the greater use of pesticides. However, exposure to pesticides, especially occupational exposure, was still an arising issue, as it was claimed to have potential risks to food safety, human health, and the environment if improperly handled. Pesticide exposure primarily occurs through diets such as drinking water or eating food, while substantial exposure occurs in or around the home [8]. Improper usage of pesticides could cause acute and chronic health effects and environmental pollution. Hence, the evaluation of pesticide toxicity and safety becomes an essential part of ensuring a safe environment for humans.

Several researchers had reviewed the occurrence, application, and potential risks of some pesticides, especially chemical pesticides [9-13] but not much was focused on natural pesticides. The demand for natural pesticides is higher than that for chemical pesticides owing to their eco-friendliness, lower toxicity, and higher degradation rate [9]. Therefore, this paper aims to provide an overview of pesticides based on their synthetic and natural classifications. Particular attention was paid to the nature of essential oils as pesticides, including their origin, dosage, application form, targeted pests, and effectiveness. Their potential risks and adverse effects on human health and the environment were assessed, and it is imperative to minimize their negative impact. Finally, a brief overview of the current practices of essential oil (EO) and future perspectives has been provided that can be important in the context of safer pesticide applications for a sustainable environment.

2. Types of Pesticides

Pesticides are meant to control any animal or plant that is harmful to humans or has human concerns [14]. Pesticides can be grouped by their application, chemical nature, toxicity, target organisms, or according to the types of pests they kill. The most common pesticides and their target pests are classified into six groups, as shown in Fig. 1.

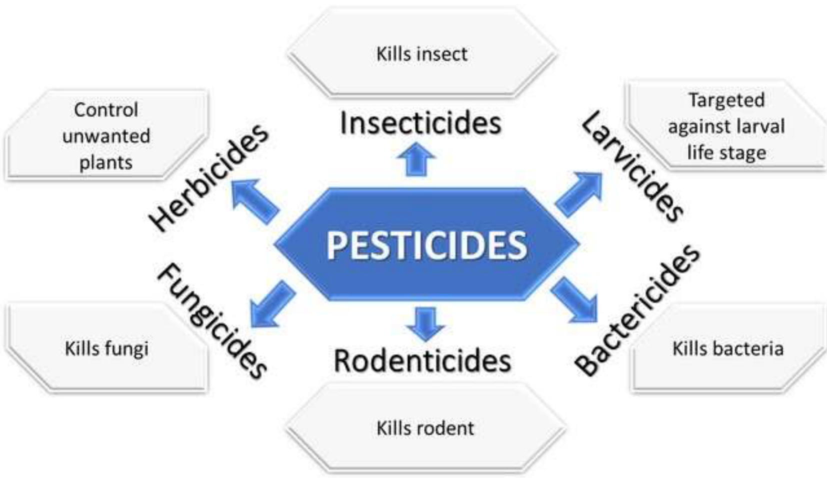


Fig. 1. General classification of pesticides

However, all these groups of pesticides can also be classified based on their derivation, such as synthetic or natural synthesis. Synthetic pesticides are produced through chemical alteration, while natural pesticides refer to products derived strictly from sources in nature with little to no chemical alteration [15–16]. Natural pesticides refer to products derived strictly from sources in nature with little to no chemical alteration [17]. The overall classification of pesticides is illustrated in Fig. 2, based on their source of origin.

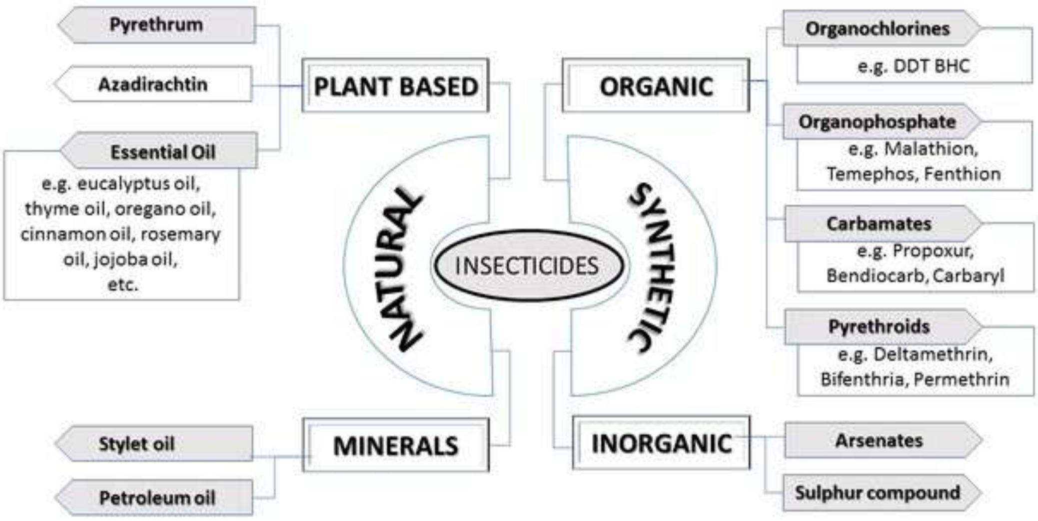


Fig. 2. Overall classification of pesticides based on source of origin and their active ingredients

2.1 Synthetic Pesticides

Synthetic pesticides were first deployed during World War II to kill pests and parasites. They were claimed to have harmful effects on the soil ecosystem and humankind, such as affecting biological molecules, tissues, and organs and resulting in acute and chronic disorders. They were also claimed to affect humans of all ages, including prenatal. These pollutants, when discharged into the water bodies, affect the aquatic system. In the long term, the water molecules in the river are affected by the accumulation of these toxic contaminants with their alkali pH and heavy metals, which could adversely affect the health of flora and fauna [9].

Synthetic pesticides can be further classified into two leading groups: organic and inorganic pesticides. Organic pesticides are categorized into four different groups: organochlorines, organophosphorus, carbamates, and pyrethroids. Organochlorines are organic molecules with chlorine in their structure and are applied for agricultural, industrial, and household purposes. Organophosphorus are organic molecules with phosphorus that are primarily utilized as an alternative pest control to chlorinated hydrocarbons that persist in the environment. Meanwhile, carbamates are insecticides containing carbaryl, methomyl, and carbofuran, which are rapidly detoxified and eliminated from animal tissues. Compared to organochlorines, organophosphorus, and carbamates, pyrethroids that commonly consist of permethrin are generally harmless to humans as commercial and household insecticides.

On the other hand, inorganic pesticides are deemed to be pesticides that are derived from non-living natural sources. They do not contain carbon in their chemical structure, which differentiates them from carbon-containing organic pesticides. Another significant differentiation between organic and inorganic pesticides is their source of extraction, where inorganic pesticides are mined and extracted from the earth. The promising minerals commonly applied in inorganic pesticides are borates, sulfates, silicates, and heavy metals such as mercury, arsenic, cyanide, silver, and copper [18]. In contrast to organic pesticides, inorganic pesticides are more persistent and toxic to humans; therefore, they have limited application in modern agriculture.

2.2 Natural Pesticides

Natural pesticides are generally derived from plants and mineral oils. Plant-derived pesticides include EO, plant extracts (e.g., Azadirachtin), and leftover oilseed cakes. EO is commonly obtained from non-woody parts, particularly foliage that consists of complex mixtures such as terpenoids. The presence of these mixtures constitutes an effective replacement for synthetic pesticides since EO is greener and exhibited a broad spectrum of deterring activity, specifically against insects and selected arthropods [19–20]. Azadirachtin is an extract of seeds from the Neem tree that is native to India. It is commercially applied to regulate insect growth and has proven to be effective against more than 200 insect species. Another natural pesticide is pyrethrum, which is naturally made from the dried flower heads of Chrysanthemum with its active ingredient, pyrethrin. With its pyrethrin and aphid alarm pheromone, pyrethrum is commonly utilized as a companion plant to repel pets from desired crops. All plant-derived natural pesticides are more attractive than synthetic pesticides on account of their low mammalian toxicity and chemical complexity, which do not develop resistance in pests [21]. They have short environmental persistence as well, thus presenting less risk to the environment than synthetic pesticides, aligning with public opinion and influential scientific papers [15].

Mineral oil is defined as a highly refined and paraffinic oil that is most effective against soft-bodied insects and mites. One of the most recognizable mineral oils is petroleum oil, also known as crude oil. It has active ingredients, which are petroleum distillates or "horticultural oil," to control the pests physically by blocking the pests' air holes. It also acts as poison to disrupt pests' eating behavior, thereby killing pests for starvation. Stylet oil is another foliar treatment to manage insect-vectored plant viruses. It helps reduce the ability of aphids (greenfly, blackfly) to acquire the virus from infected plants and transmit the virus to healthy plants. As reported by Jorgensen and Wright [22–23], stylet oil demonstrated strong repellent, anti-feeding, and egg-laying effects on female tomato potato psyllids (TPP) in order to reduce TPP eggs and nymphs. Regardless of the source or type, the application of mineral oil-derived pesticides is limited by their low residual activity and thus must be applied directly to pests. Furthermore, not all the pests are susceptible to mineral oils; hence, they are highly selective in their application. However, researchers reported that mineral oil pesticides can be easily applied with existing pesticides to enhance pest control performance [24].

Both synthetic and natural pesticides have different sources of origin, and their advantages and disadvantages are compared in Table 1. Yet both synthetic and natural pesticides share the same mutual goal, which is to control or kill the damaging pests in order to maximize crop production. Therefore, the active ingredients and application of both synthetic and natural pesticides must comply with federal and state regulations for commercialization and disposal. This is crucial to ensuring the sustainability of the environment and ecosystem. It is advisable for consumers to handle, apply, and dispose of the pesticides carefully, also by following the instructions strictly. It is a great effort to reduce the potential risk of humans and animals' exposure to pesticides while demanding safer and greener pesticides.

Table 1
Advantages and Disadvantages of Synthetic and Natural Synthesis of Pesticides [25]

	Advantages	Disadvantages
Synthetic Synthesis Pesticides	less expensive cost-effective as lesser total volume of pesticide is required to get desired outcome time saving as less frequent to apply pesticide more persistent and more extended periods of protection less selective so can protect against more types of pests readily available and have a longer shelf life relieve the grower of the necessity of relying on time-sensitive purchases and applications of pesticides	not environmentally friendly as will not breakdown in environment quickly can cause environmental concerns or have harvest restrictions broad-spectrum and may harm beneficial insects lead to secondary explosions of other pests, making further control measures necessary
Natural Synthesis Pesticides	environmentally friendly biodegradable since will breakdown in the environment leaving no residual activity after a relatively short time effective and selective in controlling pests support populations of beneficial organisms less harmful to human	less persistent may require a greater total volume of pesticide to get a more persistent outcome. more selective as not all pests are susceptible may not provide the desired outcome if multiple pest species are present require accurate pest identification and knowledge of the pest lifecycle to be effective require special handling (skill and timing) to be effective more expensive less accessible to consumers in market

3. Essential Oil as Natural Pesticides

Among all the EOs, Eucalyptus is the most promising commercialized pesticide owing to its desirable pest management properties and ease of extraction [56]. Eucalyptus has a variety of species and a genus's name for some types of gum trees. There are more than 800 species of Eucalyptus, origin in Australia. A few species can also be found between New Guinea and Indonesia. A part of them is also found in some regions of the Philippines. However, the species listed in Table 2 have been utilized in many countries nowadays [26];

Table 2
Essential Oil and Its Origin

Species	Type	Origin
E. globulus Labill	Tasmanian blue gum	the People's Republic of China, Portugal, Spain, India, Brazil, Chile, Bolivia, Uruguay and Paraguay
E. smithii	gully gum	South Africa, Swaziland and Zimbabwe
E. polybractea	blumallee	Australia
E. exserta	Queensland peppermint	People's Republic of China
E. radiate	narrow-leaved peppermint	South Africa and Australia
E. dives	broaded-leaved peppermint	Australia
E. camaldulensis	river red gum	Nepal

E. cinerea	medical purposes	
E. cineorifolia	medical purposes	
E. macarthurtii	perfumery industry	
E. citrodora	lemon-scented gum	
E. staigeriana	lemon-scented ironbark	People's Republic of China, Brazil, and India

3.1 Efficacy of Eucalyptus Oil

In the lab scale, the efficacy of eucalyptus oil was tested. At 100 ppm of concentration, E. cintrodora can kill nematode (Meloidogyne incognita) larvae after 48 hours of usage. Meanwhile, E. rudis can eliminate the hatching of eggs of Meloidogyne javanica at all dilution ratios, such as 1:0, 1:1, and 1:2, respectively. Nevertheless, E. globulus can effectively remove the same animals at a lower concentration of 1:2 upon usage. Based on previous research, 2480 mg/kg of 1,8-cineole, 2680 mg/kg of eugenol, 1800 mg/kg of thymol, and 3180 mg/kg of menthol can kill rats and mice through oral LD50, respectively [27]. Another study by Maciel et al [28] reported that at concentrations of 20, 10, 5, 2.5, and 1.2 mg/mL (E. staigeriana) and 40, 20, 10, 5, and 2.5 mg/mL (E. citrodora and E. globulus), it could eliminate the eggs, larvae, and adults of Lutzomyia longipalpis through in vitro testing [28].

However, the list of commodities for which European legislation has established maximum residue limits (MRLs) does not include EO. The Environmental Protection Agency (EPA) in the USA has only made decisions regarding derivatives of citrus. Nonetheless, it is indisputable that good agricultural practices (GAP) and MRL setup are tightly related. Given the many extraction processes and manufacturing modes used throughout the world, establishing MRLs for EO is a highly dubious approach. Actually, the concentration element is crucial in identifying any possible adverse effects [57].

3.2 Rate and Effectiveness of Natural Pesticides to Insects

Table 3 shows the amount of pesticides required to affect the insect life cycle in agriculture. There are different resources of EO highlighted in the table with the addition of active ingredients in the formulations. The effects of different ingredients resulted in different activities, together with different methods applied in order to get effective functional formulations to combat unwanted insects on the farm.

Table 3
The amount of pesticides and their effect on insects

Source of EO/ Plant origin	Active ingredient	Activity	Application method	References
Apiaceae *A. graveolens*	α-phellandrene (59%)	*Culex pipiens* L. larvae of 3rd and early 4^{th} instars (mosquito)	Bioassay	[29]
Acorus calamus A. calamus	s acorenone, β-gyrjunene, Isoshyobunine, β-asarone, Calamendiol, α-selinene, α-calacorene, Calamusenone,	The scale insects were also controlled by the same systematic method by using 0.5% dilution to the infected cotton plants. The control of mealy bugs on cotton, brinjal and Abutilon indicum was achieved by spray method using 0.5% solution	spraying	[30]

fennel mint and sweet orange (*Citrus sinensis*)	Camphene and Shyobunone	stored product pest, grain borer *Rhyzopetha dominica* Habituation in *Rhyzopertha dominica* adults after repeated exposure was evaluated. The decline of *R. dominica* responsiveness was attributable to learning process.	Nano emulsion	[31]
Mentha is a genus from the family Lamiaceae 'spearmint'	pulegone, menthon, menthol, carvone, 1, 8-cineole, limonene and β-caryophyllene	80% mortality of *Ephestia kuehniella* (Zeller) and *Plodia interpunctella* (Hubner) at 2.5 ml/l dose and 2 h of exposure times	Bioassay	[32]
M. spicata subsp. Tomentosa And M.spicatavar.for masa essential oils		100% mortality of *S. granaries* was achieved by *M.spicata* subsp. *Tomentosa* and *M. spicata* var. *formasa* essential oils at 1 µl/l air and the exposure periods of 36 and 48 h and potent mortality of adults at 0.5 µl/l air and an exposure period of 48 h		[33]

4. Risk of Essential Oil Residue Pesticides

Most of the pesticides using EO can be lethal to certain insects. All commonly used EO are considered safe after being regulated by the US Food and Agricultural Administration (FDA) and known to be "Generally Regarded As Safe" (GRAS). However, pesticide usage from EO also posed possible side effects to non-target organisms and human health through inhalation, ingestion, and skin contact, as shown in Table 4. Overdose usage of EO might cause a potential side effect in formulating the pesticides, using non-diluted EO, or applying high-photosensitivity EO to the pesticides without any concern from a clinical trial, professional therapist, or knowledgeable healthcare provider. The worst could happen when the use of EO as a pesticide affects infants and pregnant women too. It is also inferred that the side effect could occur in humans based on several factors, including the age of the person, an underlying health issue, and ongoing medication or supplementation [53].

The side effects of EO in the usage of pesticides are considered when considering the chemical compositions of the respective EO, the method of pesticide usage, the duration use, and the dosage of EO used in the pesticides. Since pesticides are primarily used to kill and repel insects, they are supposed to be aware of the possible side effects on other issues, primarily involving human health in the long term. Some EOs are considered safe if inhaled, yet they may irritate if applied to the skin in concentrations as low as 3-5%. Thyme, oregano, clove, and cinnamon bark essential oils are examples of this. Several of the citrus oils, such as bergamot, lemon, lime, orange, and angelica, can cause phototoxicity, which is severe burns or skin cancer, if there is exposure to natural sunlight or sun-bed radiation following skin applications, whereas this would not result from inhalation [54].

EO with the wrong doses or too much concentration has been found to contribute to tumor development and other harmful changes in the body during animal and laboratory studies. Some EO can even be damaging to the skin, liver, and other organs if misused. Many essential oils are FDA-approved as ingredients in food and fragrances and are labeled GRAS. However, some oils can be toxic and should only be ingested under medical supervision [55]. Up to the authors knowledge, there are no reports on the side effects of pesticides from EO on human health, whether long- or short-term. However, a study by Lee *et al.*, [58] concluded that it demonstrates a strong correlation between the use of essential oils and detrimental cardiac effects, such as elevated heart rate and blood pressure, and a drop in the percentage of anticipated peak expiratory flow rate (PEFR) in those who use them heavily. Among individuals who did not use essential oils or who used them sparingly (less than an hour per day), there was no discernible correlation between the use of essential oils and harmful cardiopulmonary consequences. A study concluded that among individuals who used essential oils for more than an hour a day, exposure to indoor air pollution linked to essential oils experienced negative cardiopulmonary effects [58].

Table 4
Potential Side Effect of Essential Oil

Essential oil	Route of Exposure	Side effects	Reference
Anise	Ingestion	Affect the central nervous system through high intake of drugs	[34]
Bergamot	Skin	Skin sensitivity and burn	[35]
Cinnamon	High concentration	Mucus membrane irritation, dermatitis, facial flushing, double vision, nausea, vomiting	[36]
Cinnamon	Ingestion	Precaution to pregnant woman	[37]
Eucalyptus	Ingestion	Seizures or asthma attack	[38]
Clary oil	Inhalation	Precaution for pregnant woman	[39]
Lemon verbena	Skin contact	Photosensitivity and may result in burning	[35]
Nutmeg	Skin contact	Rash or burn	[40]
Nutmeg	Overdose ingestion	Hallucination and even coma	[41]
Peppermint	Skin contact	Rash and irritations	[42]
Peppermint	Ingestion	Hurtburn	[43]
Tea tree	Skin contact	Rash or concentration	
Tea tree	Ingestion	Loss of muscle coordination and confusion	[44]
Clove oil	Skin contact	Irritation	[45]
Citronella	Skin contact	Irritation	[46]
Lemongrass	Skin contact	Irritation	[47]
Oregano	Skin contact	Irritation	[48]
Thyme	Skin contact	Irritation	[49]
Carvacrol	Skin contact	Irritation	[48]

5. Soil Quality after Pesticide Consumption

In general, after every pesticide application, there is a report on changes in soil parameters. It is crucial to keep in mind that the effects of any given pesticide in a series are probably going to be impacted by prior applications of other substances; thus, making a list that assigns particular effects to individual pesticides or mixes won't be valid. However, a study by the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture in China mentioned several soil quality effects after applying the pesticides in general [59].

Even when sprayed on a growing crop, a portion of the pesticide treatment normally reaches the soil, where it may impact soil-dwelling creatures. It is crucial to research how particular practices could affect the characteristics of the soil. This is especially concerning in cases where pesticides are used heavily, regularly, and for extended periods of time, as is the case with crops like corn and cotton, which frequently have many pesticide treatments given to them in a single growing season. Numerous micro- and macroorganisms, such as bacteria, actinomycetes, fungus, nematodes, arthropods, crustaceans, and earthworms, make up the dynamic living system that is soil. They are primarily responsible for the nitrification, nitrogen fixation, and release of nutrients from soil minerals, as well as for the breakdown of organic matter such as plant and animal wastes. Anything that has an impact on their operations may also have an impact on how well soils perform in the global carbon and nitrogen cycles, in agricultural production, and in the removal of various environmental pollutants. Thus, there may be dire repercussions [59]. In short, the soil quality concern is based on different situations, as depicted in Fig. 3.

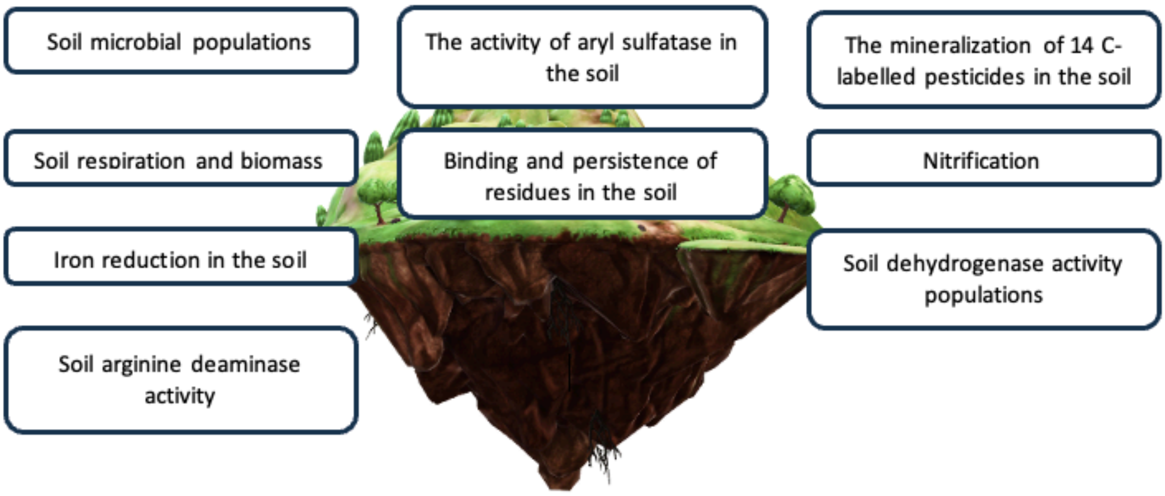


Fig. 3. The effect of pesticides on soil quality

6. Safety Considerations for the use of EO Pesticides (Labeling, Storage, and Disposal)

Pesticides have become an indispensable part of modern agriculture nowadays to meet the demands of an ever-growing population, speedy urbanization, and worldwide industrialization. Therefore, it is crucial to practice proper handling of pesticides since occupational hazards are unavoidable for crop producers. First and foremost, EO pesticide registration must be done according to EU legislation. The scientific and legal registration pathways described by Damalas *et al.*, [8] are: (i) research on pesticides by the manufacturer; (ii) submission for registration to an authority; (iii) data revision by the authority by conducting toxicological testing; and (iv) a decision on registration based on the compliance of the product. All these processes must be provided with clear guidelines and transparency, enabling manufacturers to refer. The manufacturers are required to submit detailed information about EO pesticides, including the properties of active ingredients, production method, efficacy and its intended application, toxicological testing results, label, waste disposal method, and safety label data sheet according to WHO specifications, to make sure they meet the regulatory standards. Several assessments, such as hazardous and ecological risk assessments, will be determined consistently by the registration authority prior to approval.

After the registration, the EO pesticides will be industrialized and marketed with complete labels to avoid misuse. To minimize the potential risk of EO pesticide exposure, it is advisable for crop producers to wear personal protective equipment (PPE), which includes protective goggles, gloves, a mask, a respirator, a protective cloth, a hat, and boots. Different PPE is applicable to different pesticides, so crop producers have to study the safety precautions carefully while choosing the PPE. The effectiveness of PPE can be decreased when it is improperly used, incorrectly fitted, and improperly maintained. Therefore, to some extent, it is difficult to achieve maximum protection and to assess the actual protection level [50]. If the spraying equipment is applied, crop producers need to ensure it is in good working condition without leaking. After every EO pesticide application, crop producers must thoroughly clean their bodies with soap to wash off the pesticides' residues. The remaining EO pesticides need to be stored properly in their original containers as instructed by the labels and checked for leakage registration authority prior to approval.

Waste disposal of EO pesticides is another issue worth noting. According to FAO, remaining pesticides that are diluted are mandatory to do triple rinsing, while their empty containers need to be completely cleaned. The containers must be punctured to prevent reusing them for other purposes. Dry pesticides should be fully utilized before disposal, and their containers are required to be cleaned as well as the liquid pesticides. FAO also emphasizes that the burial of pesticide waste is strictly prohibited worldwide. This is because burying pesticides may cause residual pesticides to leak, which further pollutes the water and soil. The same concern exists for the burning of pesticides, which may release toxic gases, thereby polluting the air and environment. Needless to mention, the disposal of pesticide waste directly into drains or rivers causes water pollution [51]. Furthermore, if the crop producers do not have a proper facility to dispose of the waste, FAO suggests that pesticide manufacturing firms should provide the disposal service. Crop producers need to inform the participating authorities about their used pesticides in order to arrange proper disposal management according to the legislation and norms of the country without delaying [52].

In short, safety precautions for EO pesticides need to be taken in manufacturing, labeling, storing, applying, and disposing to minimize their potential adverse effects. Before proceeding with the production, the manufacturer or supplier must register and label their products (pesticides) to ensure that the next step will not be harmful to the user. The registration must follow legit regulation and proper standard production in order to minimize the side effects of pesticides in the future. It is also recommended by the WHO, the biggest organization worldwide.

7. Future Perspectives

Although there are some international conventions to provide means for countries to protect their populations from pesticide exposure, there is a lack of valuable information about the incidence, circumstances, and health impact of EO pesticide exposure in many countries. Therefore, more comprehensive research should be done in other countries, especially those with high pesticide consumption, to provide valuable insights. Furthermore, a more reliable and standard assessment method should be introduced to evaluate the potential hazards of EO pesticides more accurately and minimize their unfavorable effects. This is important to determine the safety limit of EO pesticide dosage in future applications. The discovery of novel, safer EO pesticides with good label indication is encouraged as well to commercialize them and make them more accessible to the public. Lastly, the implementation of an alternative agricultural system that is more environmentally friendly could be a pivotal measure to reduce the dependency on EO pesticides, which could probably have adverse effects if applied improperly.

8. Conclusion

This article highlighted the essential oil pesticides on three important components of the ecosystem (soil, plants, and humans). The harmful effects of essential oil pesticides were comprehensively discussed in terms of long-term side effects and others. In addition, their implications on human health were also observed. Pesticides in general are mobile in the soil and consequently affect the essential microorganisms and disturb the soil's organic matter, as well as other processes in the soil. Soil pH and sorption capacity can be negatively affected by the pesticide's accumulation. Moreover, some pesticides have a harmful effect on soil microbial groups, such as rhizobiales. There is a considerable rule to produce pesticides before reaching the users. However, there are also some suggestions for biopesticides. Biopesticides are growing faster than synthetic pesticides and can provide advantages, including resistance to pests and residue control, in addition to low hazards to beneficial insects and other non-target groups when used in integrated pest management programs. Because labor is less expensive in developing nations than in industrialized ones, production can be more affordable, and wild flora is frequently extremely abundant, developing nations have a great deal of potential for using biopesticides.

Given the vast quantity of plant stock needed for the manufacturing of biopesticides, large-scale plant cultivation employed in their production may be carried out on marginal territory unsuitable for agricultural crops in order to minimize the risk of competition with food crops. To reduce manufacturing costs and issues with waste landfilling, low-cost solvent processing and the extraction of biopesticides should be taken into account. The biopesticide products should thus be easily affordable for small farmers, allowing them to further introduce effective anti-pest control agents.

Considering that biopesticides biodegrade easily, further research is still required to create solutions that have an extended shelf life without sacrificing their intended efficacy. It is important to carry out more research on the endurance of botanical pesticides, especially in outdoor settings. Thus far, a number of products have been found, extracted, and described that may eventually be turned into biopesticides. To be sure that the efforts made to date to identify and isolate these products have not been in vain, more study is necessary. Even while research on these biopesticides continue, obstacles to the effectiveness of some items have been found and need to be solved. Collaboration among stakeholders is still essential; therefore, biopesticide researchers must collaborate closely with business executives, farmers, legislators, public servants, and other relevant stakeholders.

References

[1] Alavanja, Michael CR. "Introduction: Pesticides use and exposure, extensive worldwide." *Reviews on environmental health* 24, no. 4 (2009): 303-310. https://doi.org/10.1515/REVEH.2009.24.4.303

[2] Meftaul, Islam Md, Kadiyala Venkateswarlu, Rajarathnam Dharmarajan, Prasath Annamalai, and Mallavarapu Megharaj. "Pesticides in the urban environment: A potential threat that knocks at the door." *Science of the Total Environment* 711 (2020): 134612. https://doi.org/10.1016/j.scitotenv.2019.134612

[3] van de Merwe, Jason P., Peta A. Neale, Steven D. Melvin, and Frederic DL Leusch. "In vitro bioassays reveal that additives are significant contributors to the toxicity of commercial household pesticides." *Aquatic Toxicology* 199 (2018): 263-268. https://doi.org/10.1016/j.aquatox.2018.03.033

[4] Pariona, A. (2017). Top Pesticide Using Contries. *Worldatlas*

[5] Sharma, Anket, Vinod Kumar, Babar Shahzad, Mohsin Tanveer, Gagan Preet Singh Sidhu, Neha Handa, Sukhmeen Kaur Kohli et al. "Worldwide pesticide usage and its impacts on ecosystem." *SN Applied Sciences* 1 (2019): 1-16. https://doi.org/10.1007/s42452-019-1485-1

[6] Research, G. V. (2019). *Home & Garden Pesticides Market Size, Share & Trends Analysis Report By Type (Herbicides, Insecticides, Fungicides, Fumigants), By Application (Garden, Household), By Region, And Segment Forecasts, 2019 – 2025*.

[7] OECD, Food, & of the United Nations, A. O. (2012). *OECD-FAO Agricultural Outlook 2012*. https://doi.org/https://doi.org/https://doi.org/10.1787/agr_outlook-2012-en

[8] Damalas, Christos A., and Ilias G. Eleftherohorinos. "Pesticide exposure, safety issues, and risk assessment indicators." *International journal of environmental research and public health* 8, no. 5 (2011): 1402-1419. https://doi.org/10.3390/ijerph8051402

[9] Rajmohan, K. S., Ramya Chandrasekaran, and Sunita Varjani. "A review on occurrence of pesticides in environment and current technologies for their remediation and management." *Indian journal of microbiology* 60, no. 2 (2020): 125-138. https://doi.org/10.1007/s12088-019-00841-x

[10] Rani, Lata, Komal Thapa, Neha Kanojia, Neelam Sharma, Sukhbir Singh, Ajmer Singh Grewal, Arun Lal Srivastav, and Jyotsna Kaushal. "An extensive review on the consequences of chemical pesticides on human health and environment." *Journal of cleaner production* 283 (2021): 124657.https://doi.org/10.1016/j.jclepro.2020.124657

[11] Van Maele-Fabry, Genevieve, Laurence Gamet-Payrastre, and Dominique Lison. "Residential exposure to pesticides as risk factor for childhood and young adult brain tumors: A systematic review and meta analysis." *Environment international* 106 (2017): 69-90.https://doi.org/10.1016/j.envint.2017.05.018

[12] Van Maele-Fabry, Genevieve, Laurence Gamet-Payrastre, and Dominique Lison. "Household exposure to pesticides and risk of leukemia in children and adolescents: Updated systematic review and meta-analysis." *International journal of hygiene and environmental health* 222, no. 1 (2019): 49-67. https://doi.org/10.1016/j.ijheh.2018.08.004

[13] VoPham, Trang, Kimberly A. Bertrand, Jaime E. Hart, Francine Laden, Maria M. Brooks, Jian-Min Yuan, Evelyn O. Talbott, Darren Ruddell, Chung-Chou H. Chang, and Joel L. Weissfeld. "Pesticide exposure and liver cancer: a review." *Cancer Causes & Control* 28 (2017): 177-190. https://doi.org/10.1007/s10552-017-0854-6

[14] Yadav, Ishwar Chandra, and NINGOMBAM LINTHOINGAMBI Devi. "Pesticides classification and its impact on human and environment." *Environmental science and engineering* 6, no. 7 (2017): 140-158.

[15] Bahlai, Christine A., Yingen Xue, Cara M. McCreary, Arthur W. Schaafsma, and Rebecca H. Hallett. "Choosing organic pesticides over synthetic pesticides may not effectively mitigate environmental risk in soybeans." *PloS one* 5, no. 6 (2010): e11250. https://doi.org/10.1371/journal.pone.0011250

[16] Yadav, Ishwar Chandra, and NINGOMBAM LINTHOINGAMBI Devi. "Pesticides classification and its impact on human and environment." *Environmental science and engineering* 6, no. 7 (2017): 140-158.

[17] Tripathi, Rahul, and Brahmeshwar Mishra. "Development and evaluation of sodium alginate–polyacrylamide graft–co-polymer-based stomach targeted hydrogels of famotidine." *Aaps Pharmscitech* 13 (2012): 1091-1102. https://doi.org/10.1208/s12249-012-9824-1

[18] Karuppuchamy, P., and Sheela Venugopal. "Integrated pest management." In *Ecofriendly pest management for food security*, pp. 651-684. Academic Press, 2016. https://doi.org/10.1016/B978-0-12-803265-7.00021-X

[19] Batish, Daizy R., Harminder Pal Singh, Ravinder Kumar Kohli, and Shalinder Kaur. "Eucalyptus essential oil as a natural pesticide." *Forest ecology and management* 256, no. 12 (2008): 2166-2174. https://doi.org/10.1016/j.foreco.2008.08.008

[20] Koul, Opender, Suresh Walia, and G. S. Dhaliwal. "Essential oils as green pesticides: potential and constraints." *Biopesticides international* 4, no. 1 (2008): 63-84. https://doi.org/10.1303/aez.32.437

[21] Abubakar, Y., H. Tijjani, C. Egbuna, C. O. Adetunji, and K. C. Patrick-Iwuanyanwu. "Pesticides, History, and Classification. Natural Remedies for Pest, Disease and Weed Control, 29-42." (2020). https://doi.org/10.1016/B978-0-12-819304-4.00003-8

[22] Jorgensen, N., R. C. Butler, and J. Vereijssen. "Biorational insecticides for control of the tomato potato psyllid." *New Zealand Plant Protection* 66 (2013): 333-340. https://doi.org/10.30843/nzpp.2013.66.5708

[23] Wright, Peter J., Graham P. Walker, Frances H. MacDonald, Robin Gardner-Gee, and Duncan I. Hedderley. "Mineral oil foliar applications in combination with insecticides affect tomato potato psyllid (Bactericera cockerelli) and beneficial insects in potato crops." *New Zealand Journal of Crop and Horticultural Science* 45, no. 4 (2017): 263-276. https://doi.org/10.1080/01140671.2017.1323764

[24] Cranshaw, Whitney, and B. Baxendale. *Insect control: Horticultural oils*. Colorado State University Extension Service, 2005.

[25] McCoy, Tim, and Daniel Frank. "Organic vs. conventional (synthetic) pesticides: advantages and disadvantages." (2020).

[26] Rathore, Hamir Singh, and Leo ML Nollet. "Eucalyptus oil: ExtraCtion, analysis, and properties for use in pest control." In *Green Pesticides Handbook*, pp. 43-58. CRC Press, 2017.

[27] Khodeir, I. A., T. N. El-Dakhakhni, and A. E. Youssef. "Effect of Garlic and Eucalyptus oils in comparison to Organophosphatinsecticides against some Piercing-Sucking Faba bean insect Pests and natural enemies populations." *Egyptian Academic Journal of Biological Sciences, F. Toxicology & Pest Control* 5, no. 2 (2013): 21-27.

[28] Maciel, M. V., S. M. Morais, C. M. L. Bevilaqua, R. A. Silva, R. S. Barros, R. N. Sousa, L. C. Sousa, E. S. Brito, and M. A. Souza-Neto. "Chemical composition of E ucalyptus spp. essential oils and their insecticidal effects on

Lutzomyia longipalpis." *Veterinary parasitology* 167, no. 1 (2010): 1-7. https://doi.org/10.1016/j.vetpar.2009.09.053

[29] Evergetis, Epameinondas, A. N. Michaelakis, and Serkos A. Haroutounian. "Essential oils of Umbelliferae (Apiaceae) family taxa as emerging potent agents for mosquito control." InTech, 2012. DOI: 10.1016/j.indcrop.2012.04.058

[30] Tariq, Rajput Muhammed, S. NAIMUL-HASAN Naqvi, Muhammad Iqbal Choudhary, and Ahmed Abbas. "Importance and implementation of essential oil of Pakistanian Acorus calamus Linn., as a biopesticide." *Pak. J. Bot* 42, no. 3 (2010): 2043-2050.

[31] Giunti, Giulia, Orlando Campolo, Francesca Laudani, Lucia Zappalà, and Vincenzo Palmeri. "Bioactivity of essential oil-based nano-biopesticides toward Rhyzopertha dominica (Coleoptera: Bostrichidae)." *Industrial crops and products* 162 (2021): 113257. https://doi.org/10.1016/j.indcrop.2021.113257

[32] Singh, Pooja, and Abhay K. Pandey. "Prospective of essential oils of the genus Mentha as biopesticides: A review." *Frontiers in plant science* 9 (2018): 1295. doi: 10.3389/fpls.2018.01295

[33] Aslan, Irfan, Isa Telci, Oender Calmasur, and Halit Cam. "Toxicity of essential oil vapours obtained from several plants species against the granary weevil, Sitophilus granarius (L.)." *Fresenius Environ. Bull* 18 (2009): 1717-1722.

[34] Mukunda, Archana, Meera K. Pynadath, Neethu Kadar, and Arun Mohan. "Cytotoxic effect of anise seed (Pimpinella anisum) extract on KB cell line-a comparative study with CISPLATIN." *Oral & Maxillofacial Pathology Journal* 11, no. 1 (2020).

[35] Dosoky, Noura S., and William N. Setzer. "Biological activities and safety of Citrus spp. essential oils." *International journal of molecular sciences* 19, no. 7 (2018): 1966.

[36] Ackermann, Leena, Kristiina Aalto-Korte, Riitta Jolanki, and Kristiina Alanko. "Occupational allergic contact dermatitis from cinnamon including one case from airborne exposure." *Contact dermatitis* 60, no. 2 (2009): 96-99.

[37] Ulbricht, Catherine, Erica Seamon, Regina C. Windsor, Nicole Armbruester, J. Kathryn Bryan, Dawn Costa, Nicole Giese et al. "An evidence-based systematic review of cinnamon (Cinnamomum spp.) by the Natural Standard Research Collaboration." *Journal of dietary supplements* 8, no. 4 (2011): 378-454. https://doi.org/10.3109/19390211.2011.627783

[38] Waldman, Neil. "Seizure caused by dermal application of over-the-counter eucalyptus oil head lice preparation." *Clinical Toxicology* 49, no. 8 (2011): 750-751. https://doi.org/10.3109/15563650.2011.602084

[39] Tadokoro, Yuriko, Shigeko Horiuchi, Kaori Takahata, Takuya Shuo, Erika Sawano, and Kazuyuki Shinohara. "Changes in salivary oxytocin after inhalation of clary sage essential oil scent in term-pregnant women: a feasibility pilot study." *BMC research notes* 10 (2017): 1-7. https://doi.org/10.1186/s13104-017-3053-3

[40] Zhang, Wei Kevin, Shan-Shan Tao, Ting-Ting Li, Yu-Sang Li, Xiao-Jun Li, He-Bin Tang, Ren-Huai Cong, Fang-Li Ma, and Chu-Jun Wan. "Nutmeg oil alleviates chronic inflammatory pain through inhibition of COX-2 expression and substance P release in vivo." *Food & nutrition research* 60, no. 1 (2016): 30849. https://doi.org/10.3402/fnr.v60.30849

[41] Agbogidi, *, & Azagbaekwe, O. M. (2013). Scientia Agriculturae. In *Sci. Agri* (Vol. 1, Issue 2).

[42] Stanojevic, Ljiljana P., Jelena S. Stanojevic, Vesna Lj Savic, Dragan J. Cvetkovic, Ana Kolarevic, Zeljka Marjanovic-Balaban, and Ljubisa B. Nikolic. "Peppermint and basil essential oils: chemical composition, in vitro antioxidant activity and in vivo estimation of skin irritation." *Journal of Essential Oil Bearing Plants* 22, no. 4 (2019): 979-993. https://doi.org/10.1080/0972060X.2019.1661793

[43] Liu, Jenn-Hua, Gran-Hum Chen, Hong-Zen Yeh, Chin-Kuen Huang, and Sek-Kwong Poon. "Enteric-coated peppermint-oil capsules in the treatment of irritable bowel syndrome: a prospective, randomized trial." *Journal of gastroenterology* 32 (1997): 765-768. https://doi.org/10.1007/BF02936952

[44] Bischoff, K., and Fessesswork Guale. "Australian tea tree (Melaleuca alternifolia) oil poisoning in three purebred cats." *Journal of Veterinary Diagnostic Investigation* 10, no. 2 (1998): 208-210.https://doi.org/10.1177/104063879801000223

[45] Monton, Chaowalit, Sukanya Settharaksa, Jirapornchai Suksaeree, and Tun Chusut. "The preparation, characterization, and stability evaluation of a microemulsion-based oral spray containing clove oil for the treatment of oral candidiasis." *Journal of Drug Delivery Science and Technology* 57 (2020): 101735. https://doi.org/10.1016/j.jddst.2020.101735

[46] Sharma, Ruchi, Rekha Rao, Sunil Kumar, Sheefali Mahant, and Sarita Khatkar. "Therapeutic potential of citronella essential oil: a review." *Current Drug Discovery Technologies* 16, no. 4 (2019): 330-339. https://doi.org/10.2174/1570163815666180718095041

[47] Lulekal, Ermias, Solomon Tesfaye, Selam Gebrechristos, Kassahun Dires, Tizazu Zenebe, Nigus Zegeye, Gezu Feleke, Abayneh Kassahun, Yoseph Shiferaw, and Awol Mekonnen. "Phytochemical analysis and evaluation of skin irritation, acute and sub-acute toxicity of Cymbopogon citratus essential oil in mice and rabbits." *Toxicology reports* 6 (2019): 1289-1294. https://doi.org/10.1016/j.toxrep.2019.11.002

[48] Reichling, Jürgen, Ulrike Suschke, Jürgen Schneele, and Heinrich Konrad Geiss. "Antibacterial activity and irritation

potential of selected essential oil components–structure-activity relationship." *Natural Product Communications* 1, no.11 (2006): 1934578X0600101116.

[49] Spiewak, R., C. Skorska, and J. Dutkiewicz. "Occupational airborne contact dermatitis caused by thyme dust." *Contact Dermatitis* 44, no. 4 (2001): 235-239. https://doi.org/10.1034/j.1600-0536.2001.044004235.x

[50] Damalas, Christos A., and Spyridon D. Koutroubas. "Farmers' exposure to pesticides: toxicity types and ways of prevention." *Toxics* 4, no. 1 (2016): 1. https://doi.org/10.3390/toxics4010001

[51] WHO, Geneva. "Guidelines for the management of small quantities of unwanted and obsolete pesticides." (1999).

[52] Food And Agriculture Organization Of The United Nations. (2015). The international code of conduct on pesticide management. Food & Agriculture Org.

[53] Sánchez-Gómez, Susana, Rafael Pagán, Roman Pavela, Eugenia Mazzara, Eleonora Spinozzi, Oliviero Marinelli, Laura Zeppa et al. "Lethal and sublethal effects of essential oil-loaded zein nanocapsules on a zoonotic disease vector mosquito, and their non-target impact." *Industrial Crops and Products* 176 (2022): 114413. https://doi.org/10.1016/j.indcrop.2021.114413

[54] Pathak, Vinay Mohan, Vijay K. Verma, Balwant Singh Rawat, Baljinder Kaur, Neelesh Babu, Akansha Sharma, Seeta Dewali et al. "Current status of pesticide effects on environment, human health and it's eco-friendly management as bioremediation: A comprehensive review." *Frontiers in microbiology* 13 (2022): 962619.

[55] Halcón, L. Aromatherapy. Available at https://www.takingcharge.csh.umn.edu/are-essential-oils-safe. Accessed on 17th May 2024

[56] Slimane, Badreddine Ben, Olfa Ezzine, Samir Dhahri, and Mohamed Lahbib Ben Jamaa. "Essential oils from two Eucalyptus from Tunisia and their insecticidal action on Orgyia trigotephras (Lepidotera, Lymantriidae)." *Biological research* 47 (2014): 1-8. doi: 10.1186/0717-6287-47-29

[57] Fillatre, Yoann, Francois-Xavier Gray, and Celine Roy. "Pesticides in essential oils: Occurrence and concentration in organic and conventional orange essential oils from eleven geographical origins." *Analytica chimica acta* 992 (2017): 55-66. https://doi.org/10.1016/j.aca.2017.08.039

[58] Lee, Chien-Yu, Lian-Yu Lin, Hsiao-Chi Chuang, Kin-Fai Ho, and Kai-Jen Chuang. "Long-Term Exposure to Essential Oils and Cardiopulmonary Health from a Population-Based Study." *Atmosphere* 13, no. 4 (2022): 631. https://doi.org/10.3390/atmos13040631

[59] Joint, F. A. O. *Impact of long term pesticide usage on soil properties using radiotracer techniques. Proceedings of a final research coordination meeting*. No. IAEA-TECDOC--1248. Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, 2001.