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PRELIMINARY STUDY ON PESTICIDE CONTAMINATION IN ALBANIAN AGRICULTURAL SOILS: CHALLENGES, RISK, AND SUSTAINABLE MANAGEMENT STRATEGIES

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Abstract

Pesticides are widely used in modern agriculture to safeguard crops against pests, weeds, and diseases. Their extensive and often indiscriminate application has raised serious environmental concerns in Albania. Agricultural soils act as reservoirs for pesticide residues, which pose risks of leaching into groundwater, contaminating water sources, and entering the food chain, potentially endangering human health. This study examines the presence of pesticide residues in agricultural soils from various regions in Albania, providing insights into contamination levels and associated environmental risks.

A systematic soil sampling procedure was conducted on farms dedicated to vegetable cultivation. Following extraction and cleanup using the multiresidue QuEChERS method, samples were analyzed according to European Normative EN 15662. High-sensitivity techniques, including gas and liquid chromatography coupled with triple quadrupole mass spectrometry detection (Agilent 7000D GC-MS/MS, Agilent 6460 LC-MS/MS), were employed for quantification. The pesticide classes examined in this study included organochlorines, organophosphates, and carbamates.

Variability found in pesticide concentrations across different agricultural areas reflects differences in pesticide application practices among farms. The assessment includes contamination thresholds, bioaccumulation in crops, and the impact on soil microorganisms.

The study emphasizes the importance of stricter regulatory enforcement to ensure compliance with pesticide usage guidelines and residue limits. Additionally, educating farmers on sustainable pest management, integrated pest control, and the safe handling and disposal of pesticides is essential for reducing environmental and health risks.

Key words: *Pesticide residues, Agricultural soil, Albania, Sustainable pest management.*

1. Introduction

Pesticides remain a crucial tool in agriculture for safeguarding crops against pests and diseases, thereby ensuring the sustainability of food production. Since 1945, synthetic organic pesticides such as DDT, 2,4-D, and HCH have replaced natural and inorganic ones, marking the beginning of widespread chemical pesticide use to boost agricultural productivity. Initially dominated by insecticides like carbamates, organophosphates, and organochlorines, pesticide development later expanded to include herbicides and fungicides, with the use of herbicides expected to increase over time [1]. However, long-term and intensive application has raised environmental concerns, particularly due to the persistence of pesticide residues in agricultural soils. These residues may alter the composition and activity of soil microbial communities, serving as sources of diffuse pollution to surrounding water systems. Given these risks, implementing accurate and sensitive residue monitoring methods is critical for sustainable land management and environmental protection [2]. Agricultural soils can accumulate persistent organic pollutants over time, acting as reservoirs that may re-release contaminants into the environment under changing conditions [3].

Albania became a party to the Stockholm Convention in 2004, committing to eliminate major Persistent Organic Pollutants (POPs), restrict the use of DDT, and implement a national plan to meet these obligations [4]. The regulatory framework governing pesticide use in Albania remains underdeveloped, with significant data gaps concerning pesticide residues in soils, which hinders effective environmental risk assessment and management. Research on pesticide residues in Albanian soil is sporadic and largely confined to localised environmental hotspots, such as former storage sites or industrial zones. Recent studies in Albania have revealed the continued presence of persistent pesticide residues in agricultural soils. Studies conducted in regions such as Shkodra, Lezha, Durrës, and Belsh have shown detectable levels of organochlorine pesticides, particularly DDT and its metabolites, indicating either historical misuse or poor management of obsolete stockpiles [5, 6]. These findings highlight the role of soil as a long-term reservoir for persistent pollutants and underscore the need for systematic monitoring and sustainable pesticide practices.

A comprehensive national survey evaluating the extent of pesticide contamination in agricultural soils and water resources is still lacking, highlighting a significant data gap in environmental monitoring and risk assessment.

This study aimed to assess the presence and distribution of pesticide residues in agricultural soils across selected regions of Albania. The objective was to evaluate the extent of environmental contamination resulting from the long-term use of plant protection products in different farming zones. By analysing soil samples from multiple geographic areas, the study sought to identify potential environmental risks and inform sustainable pesticide management practices. An additional goal was to contribute baseline data for national monitoring efforts and support future regulatory and remediation strategies.

2. Materials and Methods

2.1 Study area and site description

The study was conducted in two key agricultural regions of Albania, Korça and Berat, both renowned for intensive farming and among the regions with the largest agricultural areas in the country. The monitored sites comprised 12 croplands, characterised by diverse crop rotation practices, all managed under conventional agricultural practices. In Korça, soil samples were collected from open-field vegetable production areas, while in Berat, sampling focused on greenhouse production zones in villages such as Lapardha, Drenovicë, Kutalli, and Pobrat.

Korça has a continental Mediterranean climate characterised by colder winters and greater temperature variations due to its higher altitude, whereas Berat experiences a milder Mediterranean climate with warmer winters and hotter, drier summers. The differing climatic conditions in Korça and Berat influence soil characteristics and agricultural practices, resulting in soil samples that reflect the effects of open-field cultivation under cooler, more variable temperatures versus greenhouse production in warmer, more stable environments.

For this study, fields were selected in Korça, where onions and potatoes are predominantly cultivated. In Berat, the focus was on agricultural areas producing tomatoes, peppers, and cucumbers, which represent the highest cultivated area.

2.2 Sampling strategy

The presence and the concentration of multiple pesticide residues were analysed in 12 topsoil samples. Sampling in the open field was performed before planting to guarantee that the collected samples represent residual contamination unaffected by recent treatments. Soil samples were collected in greenhouses 7-14 days after pesticide application, as provided by the farmer.

The selection of the topsoil sample involves identifying homogeneous areas with consistent soil characteristics and collecting samples from the upper soil layer, typically the top 0-20 cm. The sampling process involved dividing the study area into homogeneous sub-zones based on similar soil characteristics. Using a spatula, soil was collected at the required depth from multiple points within each sub-zone. To obtain a representative composite sample, 5 to 10 individual subsamples were taken within a 10 × 10 m sampling grid, thoroughly mixed, and reduced to a final sample of approximately 0.5-1 kg for analysis. The samples were encoded and transported to the laboratory.

2.3 Sample preparation and analysis

Soil samples of 0.5-1 kg were thoroughly mixed to prepare representative ones, and then dried in a thermostat at 70 ^{0}C until they reached a constant weight. The QuEChERS method was selected for sample preparation due to its well-documented efficiency in extracting a wide range of pesticide residues, including organochlorines, organophosphates, pyrethroids, neonicotinoids, carbamates, and other structurally diverse compounds [7]. The procedure was conducted in accordance with the EN 15662 Standard Method for pesticide residue analysis. A 10 g portion of homogenised soil, prepared through mechanical grinding and sieving to a particle size of ≤ 2 mm, was

used for extraction with acetonitrile (1 g : 1 mL), a salt mixture containing 4 g $MgSO_4$; 1 g NaCL; 500 mg Disodium Hydrogencitrate Sesquilhydrate (Na_2H-citrate x 1.5 H_2O); 1g Trisodium Citrate Dihydrate (Na_3 - citrate x 2 H_2O) was added to facilitate partitioning. Sample clean-up is a critical step in pesticide residue analysis, as it minimises co-extracted matrix components that may impair instrument functionality and negatively affect the sensitivity and accuracy of analyte detection and quantification. Following the clean-up procedure with anhydrous $MgSO_4$ and primary secondary amine (PSA), pesticide residues were quantified using the Agilent 7000D GC-MS/MS and Agilent 6460 LC-MS/MS instruments. The instrumental conditions are reported in Table 1.

Table 1. Instrumental parameters used for pesticide determination using GC-MS/MS and LC-MS/MS techniques

GC–MS/MS Conditions	LC–MS/MS Conditions
Column: Agilent J&W DB-5ms Ultra Inert capillary column (30 m × 0.25 mm i.d., 0.25 µm)	Column: Agilent HD C18 (1.8 µm, 50 × 2.1 mm)
Injection volume: 3 µL (pulsed splitless)	Injection volume: 10 µL
Oven program: Multi-step ramp from 70 ^{0}C to 340 ^{0}C	Flow rate: 0.4 mL/min
Injector 260 ^{0}C, transfer line 330 ^{0}C, ion source 250 ^{0}C	Mobile phase A: 0.1% formic acid, 5 mM ammonium formate in Water
Flow rate: Constant at 1.1 mL/min.	Mobile phase B: 0.1% formic acid, 5 mM ammonium formate in Methanol
Total runtime: 41 minutes	Mobile phase gradient: 95%A / 5%B at 0.5 min 60%A / 40%B at 3.0 min 0%A / 100%B at 17.0 min, held to 19.01 min, re-equilibrated to 95%A / 5%B at 19.10 min

The guidance document SANTE/11312/2021 was used for evaluating analytical method performance and validation in pesticide residue analysis [8]. A calibration curve of matrix-matched standards at concentrations of 0.01, 0.02, 0.05, 0.1, and 0.2 mg/kg was injected at the start and end of the sample sequence. The calibration curves presented satisfactory linearity of response versus concentration, with correlation coefficients ranging from 0.95 to 0.99, and residuals of response lower than ± 20%. A soil sample that did not contain any of the target analytes was used as a blank during method development. This blank sample was fortified with a mixture of reference standard solutions at the lowest calibration level (0.01 mg/kg), which corresponds to the limit of quantification (LOQ) and is consistent across all analytes. Recoveries measured in the spiked soil sample, for all analytes, fell within the range of 70% to 120%.

Each of the 248 analytes was confirmed by matching retention times and peak shapes to standards, while verifying ion ratios within ± 30% of the calibration averages. The concentration of the analytes was calculated using bracketing calibration with a matrix-matched calibration standard.

The list of target pesticide residues was compiled based on the active ingredients most commonly applied to the selected crops, the quantity and frequency of application, and analytical determinability [9]. The selection included compounds from diverse chemical classes, such as organochlorines, organophosphates, carbamates, and pyrethroids, to ensure broad coverage. Priority was given to analytes characterised by high environmental persistence and potential toxicity [10]. The final list consisted of 248 target analytes. Figure 1 illustrates the percentage distribution of selected analytes based on their target organisms.

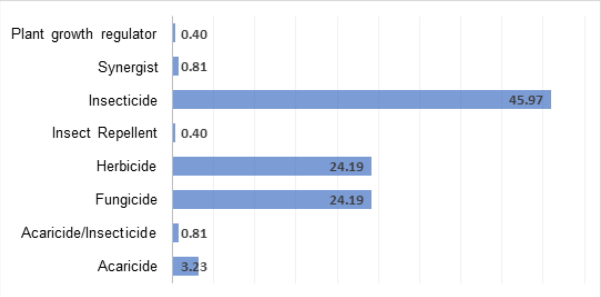


Figure 1. Distribution (in %) of the target analytes by their function

The analytical data were processed using Microsoft Excel, utilizing its functions for data organization, calculation, and interpretation.

3. Results and Discussion

3.1 Detected pesticide residues

Pesticide residues were detected in all tested agricultural topsoil samples, indicating that none of the sampled soils was free from pesticide contamination**.** The detected analytes include 10 insecticides: Chlorfenapyr, Chlorpyrifos, Chlorantraniliprole, Cyhalothrin-λ, DDTs (sum of p,p'-DDT, o,p'-DDT, p,p'-DDE and p,p'-DDD), Flonicamid, Imidacloprid, Pirimiphos-methyl, Pyriproxyfen, and Tefluthrin; 10 fungicides: Azoxystrobin, Boscalid, Cymoxanil, Cyprodinil, Difenoconazole, Mandipropamid, Metalaxyl, Metrafenon, Pyraclostrobin, Tebuconazole; 2 insecticides and acaricides: Hexythiazox and Tebufenpyrad and 2 herbicides: Nicosulfuron and Pendimethalin. The most frequently detected

pesticides across the analysed samples are illustrated in Figure 2.

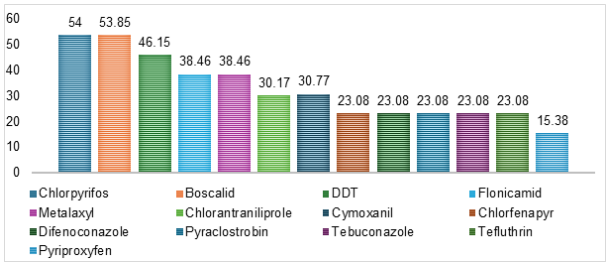


Figure 2. Frequency (in %) of detected analytes

Elevated concentrations of certain substances at specific sites indicate potential localized sources. The data are illustrated in Figure 3. This table outlines the highest measured concentrations of analytes and the plant species designated for cultivation on the respective plots.

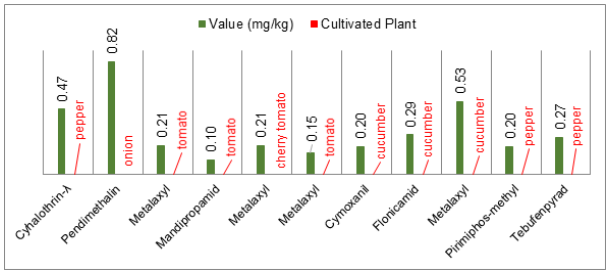


Figure 3. The highest concentrations of analytes measured

3.2 Geographic variability

Significant differences in pesticide contamination patterns were observed between greenhouse and open-field systems, with greenhouses generally exhibiting higher residue loads. This may be attributed to differences in microclimatic conditions, more frequent pesticide applications, or reduced photodegradation. The number of pesticide residues also varied significantly across regions and between cropping systems. Soils from greenhouses contained substantially higher levels of pesticide residues than those from open fields. In greenhouses, the number of detected pesticides per field ranged from 2 to 10. In contrast, open-field soils, apart from the notable concentration of the herbicide Pendimethalin, exhibited low levels of other analytes, often detected only as traces or in the form of degradation products such as p,p'-DDE.

3.3 Environmental risk indicators

Soil contamination indicators revealed the presence and distribution of pesticide residues, highlighting potential environmental and health risks. The occurrence of Boscalid and Tebuconazole in soils aligns with their classification as persistent or moderately persistent fungicides, widely approved for agricultural use. The most prevalent contaminant combination in the soil samples, detected in 46.15% of the analysed cases, included the organochlorine compound p,p'-DDE. Due to its chemical stability, p,p'-DDE exhibits long-term persistence in the environment and is known for its tendency to bind to particles, facilitating environmental mobility. As a degradation product of DDT, it shares the parent compound's persistence, potential for bioaccumulation in adipose tissues, and capacity for long-range atmospheric transport. DDT has been linked to adverse health and environmental effects, including carcinogenicity, and has therefore been banned in the United States since 1972 and in the European Union since 1986, recognized as a substance that could pose a cancer risk to humans [11]. Pesticide residues such as p,p'-DDE can adversely affect soil health by reducing microbial diversity and enzymatic activity, while also compromising crop safety through residue accumulation and the induction of physiological stress in plants.

3.4 Sustainable management strategies

To reduce the environmental footprint of pesticide use and ensure food safety, we propose an integrated monitoring and regulatory framework aligned with EU directives, including routine soil and crop residue testing, strict enforcement of Maximum Residue Limits (MRLs), and the promotion of sustainable alternatives such as Integrated Pest Management (IPM) and low-risk plant protection products, in line with Regulation (EC) No 1107/2009 and the Farm to Fork Strategy [12, 13].

4. Conclusions

- This study reveals that the widespread presence of various pesticide residues in Albanian agricultural soils may pose significant long-term threats to soil biodiversity and ecological functions. Findings indicate a strong need to adopt more responsible and sustainable pesticide practices.
- Additionally, the results suggest that the prevalence of both banned and currently used pesticides may be underestimated. Chlorpyrifos, banned in the EU, was detected in 50% of the analysed soil samples.
- Furthermore, residues of other substances such as Pirimiphos-methyl and Imidacloprid were also identified. Both present significant ecotoxicological risks to aquatic organisms and pollinators, underscoring the ongoing environmental concerns related to pesticide contamination.
- Further studies are needed to assess the extent to which pesticide residues affect soil organisms, and consequently, soil processes and functions. Strengthening institutional frameworks, coupled

with targeted capacity-building efforts at all levels of governance, is essential for the effective and sustainable implementation of related policies. Regulatory enforcement should not focus solely on pesticide authorisation and reduction of use; it must also include regular monitoring of pesticide residues and their profiles in soils. Establishing clear, science-based soil quality standards is crucial to support this process and ensure environmental and agricultural sustainability.

- To minimise pesticide use and mitigate further environmental contamination, the adoption of more sustainable agronomic approaches, including Integrated Pest Management (IPM), is strongly recommended. All relevant stakeholders, including farmers, regulatory authorities, researchers, and industry representatives, should strengthen their focus on the responsible use of pesticides to safeguard soil health and promote environmental sustainability.

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