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A System Designed to Identify the Reasons for Pesticide Detections in Organic Crops, Using Examples from Organic Apple, Raspberry, and Strawberry Cultivation in Poland

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Abstract

A multivariate analysis system for assessing the causes of pesticide residues in organic fruit crops was developed for research on organic agriculture conducted in 2016–2017. During the project, a total of 66 organic fruit crops were examined and subjected to detailed multivariate analysis, including 25 apple, 29 raspberry, and 12 strawberry crops from various regions of Poland. Pesticide residue analysis included soil, leaves, and fruit. Pesticide residues were detected in 81.8% of the crops tested, representing 44.4% of all samples. Residues of one compound were detected in 34.8% of the crops, two compounds in 16.7%, three compounds in 18.2%, and four or more compounds in 12.1%. No residues were detected in 18.2% of the crops. The highest residue detection rate was found in soil (75.8% of crops), and the most frequently detected compounds were dichlorodiphenyltrichloroethane (DDT) isomers. Pesticide residues in leaves were found in 36.4% of crops, and in fruit in 3% of crops (2.4% of the total number of fruit samples). A total of 40 pesticide residues were detected across all samples from organic crops, including 16 fungicides and one fungicide degradation product, nine herbicides, 13 insecticides, and one synthetic repellent. Among the detected compounds, eight were withdrawn from use during the study period, and eight were not approved for use in conventional apple, raspberry, and strawberry crops. Multivariate analysis showed that in 74.2% of the crops studied, the detections concerned so-called historical compounds, in 12.1% of cases, contamination from neighbouring conventional crops, and in 39.4% of cases, the intentional use of pesticides not permitted in the organic system. Multivariate analysis indicated that the cause was deliberate use not only in the years when the samples were collected, but also in the period preceding those years. The proposed system should be regarded as a rule-based, multifactorial inference framework that integrates standard analytical methods with structured contextual information, rather than as a purely statistical multivariate model. Its conceptual structure is designed to support causal interpretation of residue findings at the crop level and could be adapted to different regulatory and geographic contexts.

Keywords: organic fruit; pesticide residues; multivariate analysis

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1. Introduction

Modern agriculture faces the challenge of maintaining high productivity while simultaneously reducing pesticide use [1]. To minimise the negative impacts of conventional agriculture on the environment and human health, production systems that reduce pesticide use are increasingly being promoted. Several such food production systems have been developed and implemented, including integrated cropping systems, zero-residue systems, and organic farming. In all these production systems, the emphasis is on the use of biopesticides based on natural substances [2–5]. In this context, organic farming is considered one of the key alternatives to conventional agriculture [6]. This system is based on the principle of using natural biological processes and sustainable development while maintaining soil fertility and biodiversity [6–8]. In Europe, the principles of organic food production are strictly defined by EU legislation [9]. Every food production system is subject to specific control processes, and organic farming is no exception. In Poland, organic production processes are overseen by certification bodies, which are supervised by the Agricultural and Food Quality Inspection [10]. Every organic farm must undergo at least one inspection per year [9], during which the risk of accidental contamination is assessed, among other things [11]. Based on the risk analysis, the inspection body may collect soil, raw materials, or product samples and forward them to selected accredited laboratories [10]. Up to several hundred extended inspections for pesticide residues are conducted annually, and their results are typically published in aggregated form. Reports containing data on inspections and detected prohibited substances are published without specifying the specific reasons for their occurrence on organic farms and products [12,13]. A similar situation occurs in the EU, where, as in Poland, reports do not provide an in-depth analysis of the causes of pesticide residues [14–16]. Organisations promoting organic farming and some members of the scientific community call for the development of a unified procedure for assessing pesticide residue detections on organic farms [16,17], pointing out that the procedures developed so far, based on strictly defined analytical methods that do not include the distribution of detections, are insufficient [18].

This paper presents an attempt to develop a structured control framework and outlines methodological assumptions for determining the causes of residues of substances prohibited in organic farming. The model was tested during inspections of organic apple, raspberry, and strawberry crops in Poland.

Current control systems at both national and EU levels primarily focus on verifying non-compliance with a given production system, such as exceedances of residue levels or the presence of substances not authorised for use in plant products. At present, cases of pesticide residue detection are generally assessed through individual investigations. Practical guidelines for inspectors emphasise the importance of risk-based sampling, evaluation of potential contamination pathways specific to the farm, and verification of documented preventive measures. These elements form the starting point for determining whether detected residues indicate non-compliance or unavoidable environmental exposure.

The developed system for identifying the causes of residue occurrence is based on the integration of multiple sources of information using commonly applied analytical methods. By structuring the collection of specific contextual data and introducing the principle of coordinated sampling of soil, plant material, and fruit from the same location, the system supports causal interpretation of residue findings at the level of individual crops. As a multifactorial assessment framework, the system represents a conceptual evaluation pathway. It can be adapted to other regulatory and geographic contexts and may serve as a component of more standardised procedures. The present study was based on inspections of organic farms conducted in Poland within a specific legal and agronomic context. The study was carried out as part of research projects dedicated

to organic agriculture. Consequently, the evaluation of the proposed framework under real inspection conditions reflects circumstances typical of organic production systems in Central Europe and the associated control procedures. Although the conceptual structure of the system was designed to be adaptable, its direct application in other geographic regions or different regulatory environments would require consideration of local agronomic practices, climatic conditions, and inspection procedures. The findings should therefore be interpreted as a validation of the approach within a defined context rather than as evidence of its universal applicability.

2. Materials and Methods

The system for assessing the causes of pesticide residues in organic crops was based on a two-track analytical pathway with a detailed description of selected stages. The developed system distinguished the Laboratory-Analytical Process (L-AP) and the Information-Analytical Process (I-AP). The Laboratory-Analytical Process involved collecting soil and plant material samples according to established, detailed procedures, conducting laboratory analyses, and processing the results. The Information-Analytical Process involved gathering information and detailed data, then analysing them. The final step was to combine the analytical results with the collected and processed information to identify interactions (Figure 1).

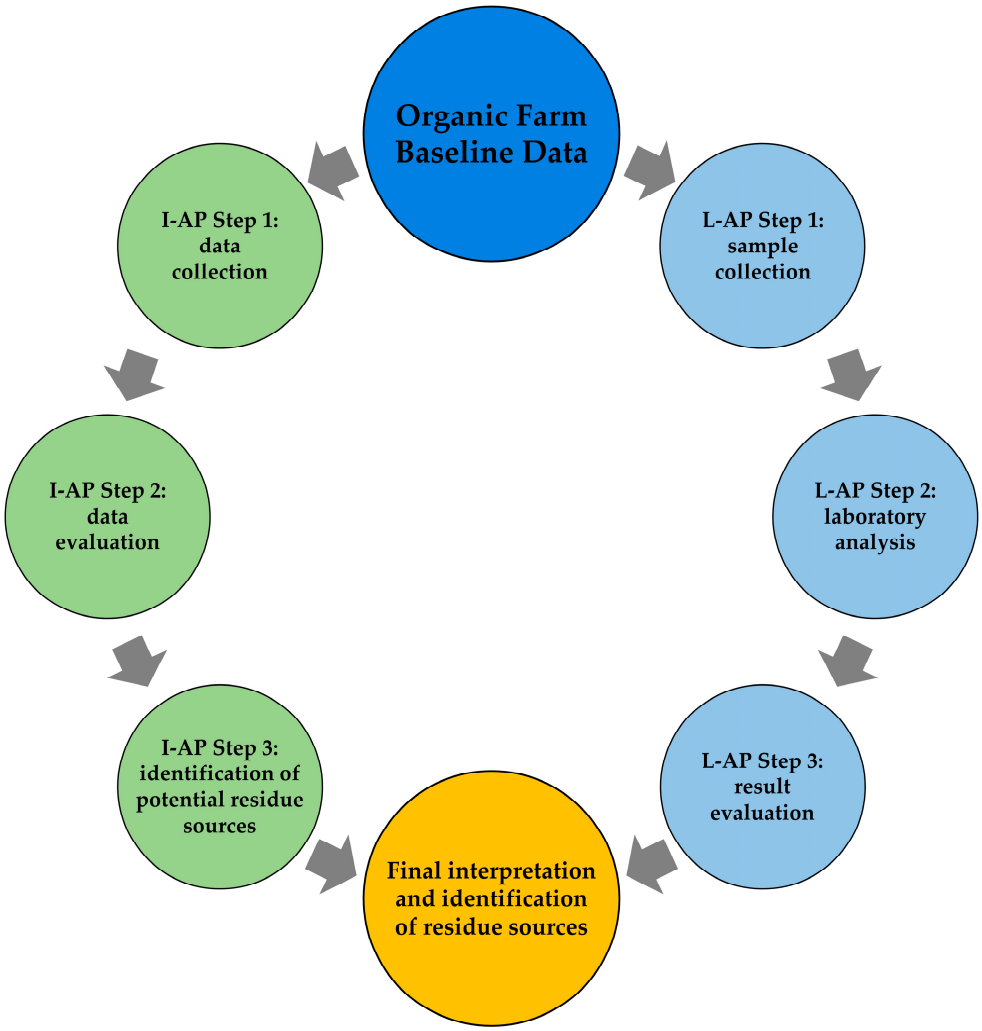

Figure 1. Diagram showing the two-phase analysis process used to identify the causes of pesticide residues in organic crops.

To reduce subjectivity, the information–analytical process was conducted according to a predefined and structured assessment pathway applied consistently across all investigated cases. The evaluation of potential contamination pathways, crop history, and environmental context followed a standardised checklist developed prior to the analysis. This approach ensured that similar cases were assessed using the same sequence of criteria and decision steps, thereby limiting the influence of purely individual judgement.

The assessment was performed by a team of researchers with expertise in pesticide residue analysis, plant protection, and agronomy. The decision-making process followed predefined interpretative rules based on the sequence of analytical results, crop history, and environmental context. Where necessary, individual case evaluations were discussed collectively to ensure consistency of interpretation. The structured assessment pathway and the use of documented decision criteria allowed similar cases to be evaluated in a comparable manner, thereby supporting the reproducibility and transparency of the conclusions.

Because the studies were conducted in a research setting rather than an official one, the investigators considered the information regarding the absence of prohibited pesticides in the tested crops unreliable. The developed analysis and inference system provides high confidence in determining the potential cause of pesticide residues.

2.1. Crop Selection

The study on organic farms used random sampling. Crop eligibility for the study was based on two basic conditions. The first was the owners' consent, which included full access to crop documentation detailing the applied fertilisation and plant protection programs, as well as to field cultivation for the collection of research samples and the acquisition of field data. The second condition was the cultivation of the crop under an organic system for at least one year after the conversion period, as confirmed by a certificate of compliance issued by an organic certification body. A necessary condition was that the researchers do not disclose any data on the studied crop that would allow third parties to identify it.

The study included 66 organic farms: 25 apple farms, 29 raspberry farms, and 12 strawberry farms. The farms were located throughout Poland (Figure 2). For analytical purposes, a total of 81 soil samples, 80 leaf samples, 72 fruit samples, and 7 water samples were collected from the studied farms, along with an additional 21 leaf, soil, and fruit samples from neighbouring farms as comparative material. The number of farms was limited by the amount of funding available for laboratory analysis of the collected research material. Therefore, efforts were made to collect material from regions with varying climatic and terrain conditions and varying densities of fruit crops. The plantations qualified for the study were part of farms of varying sizes and crop types. For the purposes of the analytical framework, the terms "small-scale cultivation" and "large-scale cultivation", as used in the decision schemes, refer to relatively smaller or larger cultivation units within the studied farms and do not correspond to formal farm size categories defined by strict area thresholds.

2.2. Research Material and Sampling System

Material for laboratory analysis was collected using a standardised soil and plant sampling system. This system ensured the best possible representation of the studied crops and accounted for basic parameters such as planting structure, crop size, and proximity. The sampling technique followed the Regulation of the Minister of Agriculture and Rural Development [19] regulating the collection of research material intended for pesticide residue analysis. Guidelines for soil, leaf, and fruit sampling methods developed by the National Institute of Horticultural Research [20,21] were also used. Fruit and leaf samples were collected manually, while soil samples were collected from the 0–30 cm layer of the

soil profile using an Egner stick or an auger with adjustable sampling depth. An additional requirement was that soil and plant material samples be collected from the exact locations.



Figure 2. Approximate location of the studied crops in Poland.

To obtain the best possible representation of the basic parameters of crops and their vicinity, an original scheme for collecting research material was developed and tested (Figure 3), in which several types of samples were distinguished:

- ST1 (Sample Type 1)—random sample representative of the studied cultivation;
- ST1A (Sample Type 1A)—Includes the representative random sample of the studied cultivation and, optionally, additional samples from neighbouring organic crops;
- ST2 (Sample Type 2)—Includes the representative random sample of the studied cultivation plus additional samples from neighbouring conventional crops;
- ST3 (Sample Type 3)—Includes samples collected from the edges of the studied cultivation adjacent to conventional crops, one sample from the central part of the field, and samples from each neighbouring conventional crop. For large-scale fields, the number of samples should be increased to maintain representativeness.

For information and analytical material, a unified data collection system was also adopted, covering all available information on the examined crop and dividing it into five main groups (Figure 4). Group 1: detailed cultivation information: number of years under organic farming system, age, species, and cultivar of the crop at the time of sampling, organic crops preceding the current cultivation. Group 2: detailed layout cultivation plan, including: neighbouring crops within the farm, neighbouring crops outside the farm, production systems of adjacent crops, distribution of farm buildings and other infrastructure,

location of public roads, location of wastelands, rivers, ponds and similar features, identification of the presence or absence of buffer zones or other means of separation between the studied cultivation and neighbouring fields. Group 3: information on crops preceding the organic cultivation, specifying the cultivated species and their management systems. Group 4: information regarding plant protection and fertilisation programs applied in the studied cultivation. Group 5: information on pest and disease issues observed in the studied cultivation.

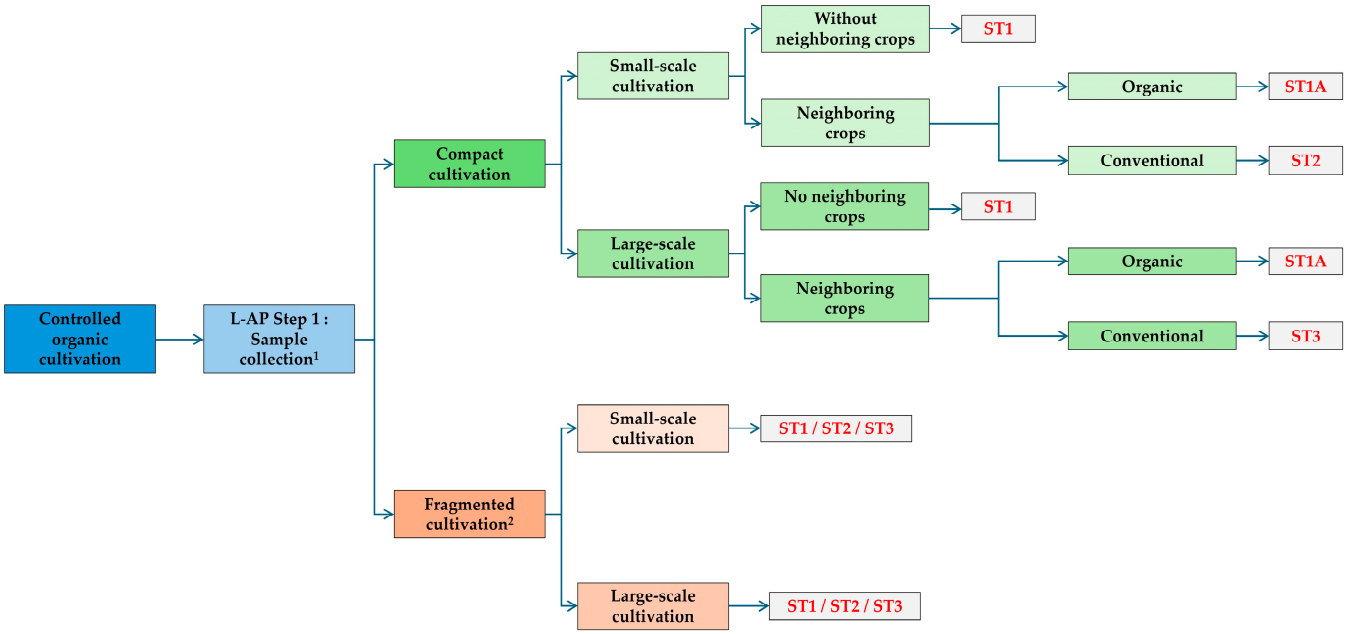

Figure 3. Scheme for soil and plant material sampling based on crop size. [1] Soil, leaf, and fruit samples, and optionally mulch materials, were collected from the same area, ensuring the best possible overlap between soil, leaf, and fruit sampling sites, [2] In the case of spatially dispersed fields belonging to the same farm, plantings of the same crop species separated by at least several hundred meters were treated as distinct cultivation units.

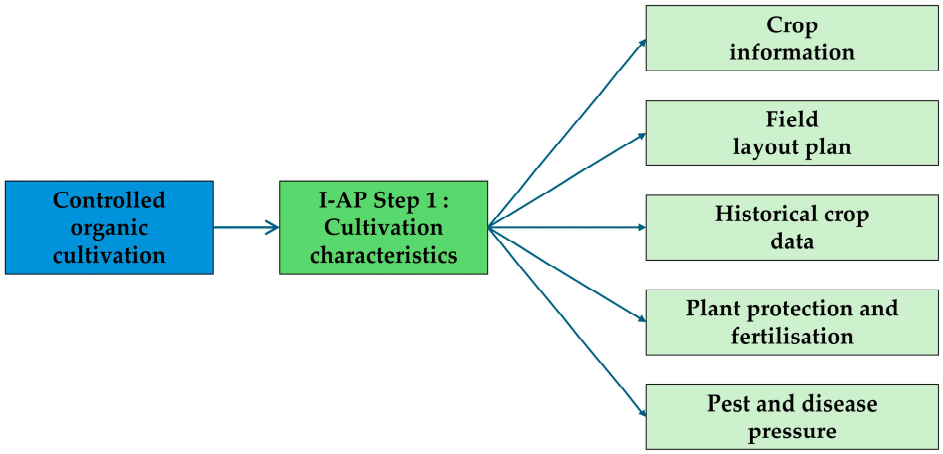

Figure 4. Information and analytical material–scope and division into main groups.

2.3. Laboratory Analysis of Pesticide Residues

Soil and plant material samples were analysed at the accredited Food Safety Laboratory at the National Institute of Horticultural Research in Skierniewice, Poland, where pesticide residues were determined. The analyses utilised a multi-residue method based on Polish standards [22,23], which involved QuEChERS extraction using acetonitrile and

purification of the extracts using dispersive solid-phase extraction (d-SPE). The extracts were then analysed using liquid chromatography (LC-MS/MS) and gas chromatography (GC-MS/MS) coupled with tandem mass spectrometry. For the determination of acidic herbicide residues, a modified method described in the Polish standard [22] was used, which included an alkaline hydrolysis step during QuEChERS extraction. The obtained extracts were analysed using liquid chromatography coupled with tandem mass spectrometry (LC-MS/MS). Other methods were used to determine the residues of polar pesticides that are not susceptible to QuEChERS extraction. For AMPA, ethephon, glyphosate, and trimethylsulfonium cation, extraction with an aqueous solution of potassium dihydrogen phosphate was used, followed by analysis of the extracts using liquid chromatography coupled with tandem mass spectrometry (LC-MS/MS) [24]. Phosphonic acid and fosestyl aluminium were analysed using ammonium buffer extraction and, as with other polar pesticides, LC-MS/MS analysis [25]. Analyses of soil and plant material included a total of 554 active substances of plant protection products and their metabolites, as well as dithiocarbamate fungicides, grouped as carbon disulfide (CS_2) content. Agilent MassHunter Quantitative software (version 12.1 Update 2 (Build 12.1.938.22 for GC-MS/MS and version 12.0, Networked Workstation Version: 3.6.0.538 for LC-MS/MS), included with the chromatographs, was used to calculate the amounts of determined pesticide residues, and the results were presented in mg kg^{-1} (Table 1).

Table 1. Analytical methods used for pesticide residue determination and the number of target compounds.

Analytical Method	Analytical Technique	Number of Target Compounds
Multiresidue method	LC-MS/MS, GC-MS/MS	494
Sub-method 1	LC-MS/MS	6
Sub-method 2 (acid herbicides)	LC-MS/MS	34
Dithiocarbamates (as CS_2)	GC-MS	9
QuPPe-PO (polar pesticides)	LC-MS/MS	11
Total		554

In total, 554 active substances of plant protection products and their metabolites were included in the analytical scope. The majority of compounds (494) were determined using the multi-residue QuEChERS-based method, while additional targeted methods were applied for acidic herbicides, dithiocarbamates and polar pesticides. A detailed list of compounds covered by each analytical method is provided in Tables S2–S5 in the Supplementary Materials. Overall quality-control procedures, including the use of solvent and matrix blanks, fortified samples at LOQ and 10 × LOQ levels, internal standards, routine performance monitoring, and proficiency testing, are described in detail in the Supplementary Materials.

2.4. Analysis of Information Obtained on Farms

Information gathered during field visits was compiled and organised according to a detailed diagram (Figure 5). For each crop, a simplified diagram of field conditions was developed, showing the location of each crop within the farm's immediate vicinity. Particular attention was paid to the proximity of other crops, including their management practices. The most critical threats, diseases, and pest problems in the crop were identified based on owner information and crop inspections, with varietal composition taken into account.

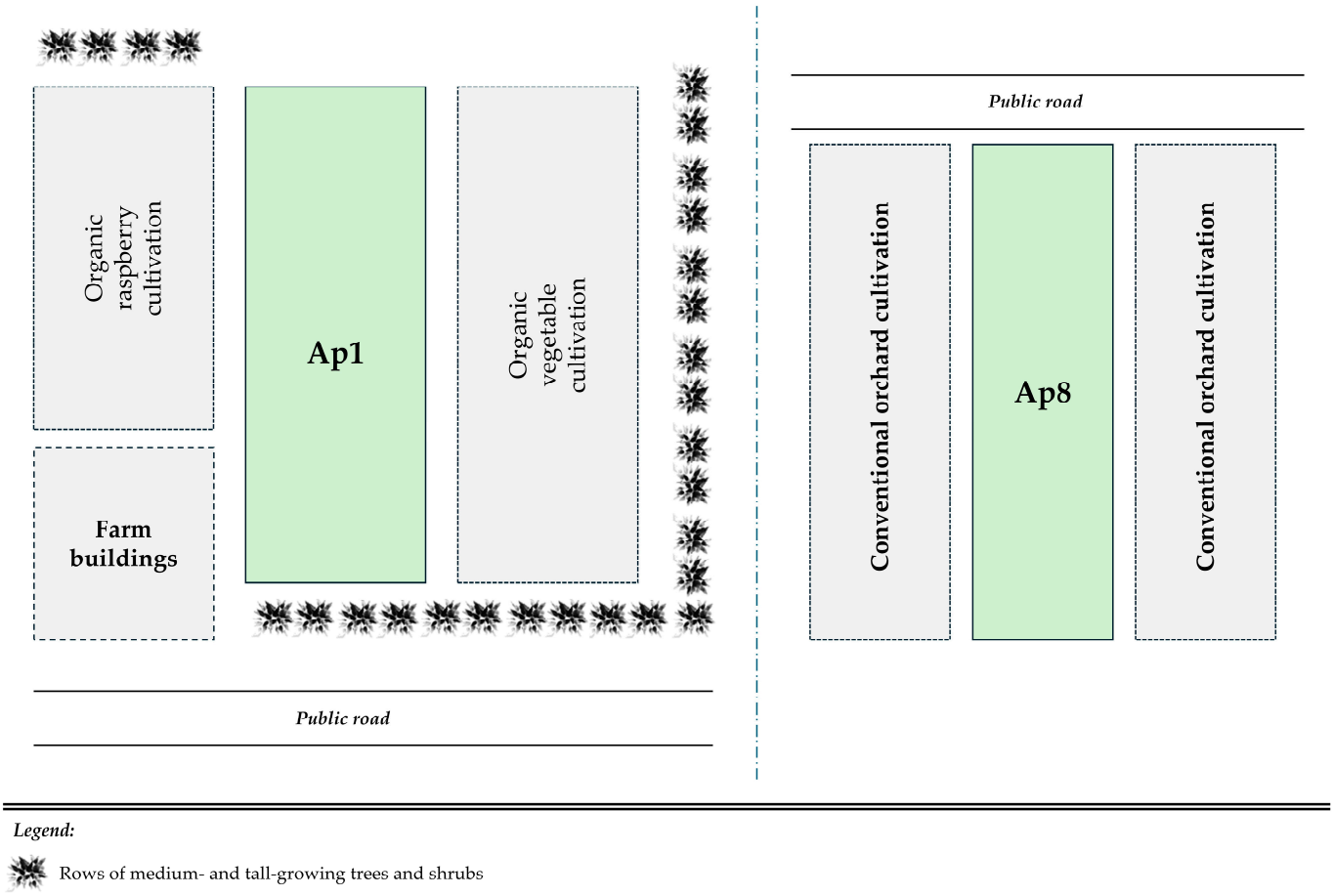

Figure 5. Example of a schematic plan of the tested crops: Ap 1 and Ap 8.

2.5. Identifying the Sources of Pesticide Residues

The conclusion to determine the hypothetical cause of the presence of pesticide residues was based on the following workflow:

- No residue detected: conclusion of the conclusion process
- Detection of pesticide residues:
  - detection of only DDT in the soil: conclusion of the process, identifying the cause as the previous cultivation system. For clarity, residues attributed to pesticide use prior to the conversion of the farm to organic management are referred to in this study as residues originating from previous (pre-conversion) use, hereafter termed "historical residues"
  - detection of other compounds:
    - spinosad and azadirachtin: conclusion of the process, determining compliance with the organic system
    - in the case of other compounds, initiation of the information and analytical process:
      - Determination of whether the detected compound may be of natural origin or used as a pesticide: possibility of conclusion of the process, identifying the natural cause of its occurrence, or further conclusions
      - Referencing the analytical results to the proximity of other crops, including organic crops. A comparison of the compounds detected in the tested crop and neighbouring crops, along with their amounts, could end with a determination of intentional use or pesticide drift.

- Determining the potential use of detected compounds in specific crop types: orchard trees, orchard berry plants, crops, vegetable crops, nurseries, and forestry: the process could end with a determination of intentional use or pesticide drift.
- The theoretical estimation of the degradation of detected pesticides, calculated from the hypothetical date of their introduction into the investigated crop, aimed to determine whether the presence of a given pesticide could be linked to crops cultivated prior to the conversion to the organic production system. In subsequent stages of the inference process, additional information obtained for the specific crop was incorporated, depending on the outcome of the calculations. The estimations were performed using the minimum and maximum dissipation half-life (DT_{50}) values available in the literature.
  When applying theoretical calculations within a real-world inference framework, it must be recognised that pesticide degradation in soil is strongly influenced by site-specific environmental conditions. The rate of pesticide degradation depends particularly on soil temperature, moisture, and microbial activity, which affect both the biological and chemical degradation pathways of active substances [26,27]. Another important factor is soil pH and organic matter content, which influence pesticide sorption and their availability to soil microorganisms. Soil microorganisms are capable of using certain pesticides as an energy source by utilising carbon atoms contained in these compounds and incorporating them into their own metabolic pathways [28,29]. For these reasons, the calculations should be regarded as indicative only, and their results constitute a supplementary element of the evidence considered when determining the cause of residue occurrence. They were therefore interpreted in conjunction with field observations, crop history, and other contextual information within the overall inference framework. The time required for a pesticide residue to reach a reference concentration of 1.2 mg kg^{-1} was estimated assuming first-order degradation kinetics. The backward time was calculated using the following equation:

$$t = \frac{DT_{50}}{30.44} \times \left| \log_2 \left(\frac{C_{detected}}{1.2} \right) \right|$$

  where t—estimated time in months prior to sampling, DT_{50}—pesticide half-life in days, $C_{detected}$—measured pesticide concentration in the sample (mg kg^{-1}), 30.44—average number of days per month, | |—absolute value ensuring a positive time estimate.
- Consideration of the varietal and species composition of the studied crops and issues related to disease and pest pressure. This information was used when the previous stages of the inference process did not allow for a clear explanation of the cause of the residues: the process could end with a determination of intentional use or pesticide drift.
- In cases where none of the steps in the inference flowchart yielded results, the cause was designated as undetermined.

Cases suggesting intentional application were identified on the basis of multiple independent indicators, including residue concentrations, estimated degradation periods,

crop management history, and the absence of plausible environmental transfer pathways. Such determinations do not constitute direct proof of deliberate misuse, but represent the most probable explanation within the applied inference framework. Therefore, the conclusions were expressed in terms of likelihood rather than absolute certainty.

2.6. Decision Framework for Identifying the Origin of Pesticide Residues

The decision framework presented in Figure 6 describes a structured, stepwise procedure used to identify the most probable origin of pesticide residues detected in organic crops. The assessment is initiated only when at least one residue is detected in soil, leaf, or fruit samples collected from the studied crop. In the absence of any detections, the assessment is terminated and the crop is classified as compliant with organic farming requirements (COFR).

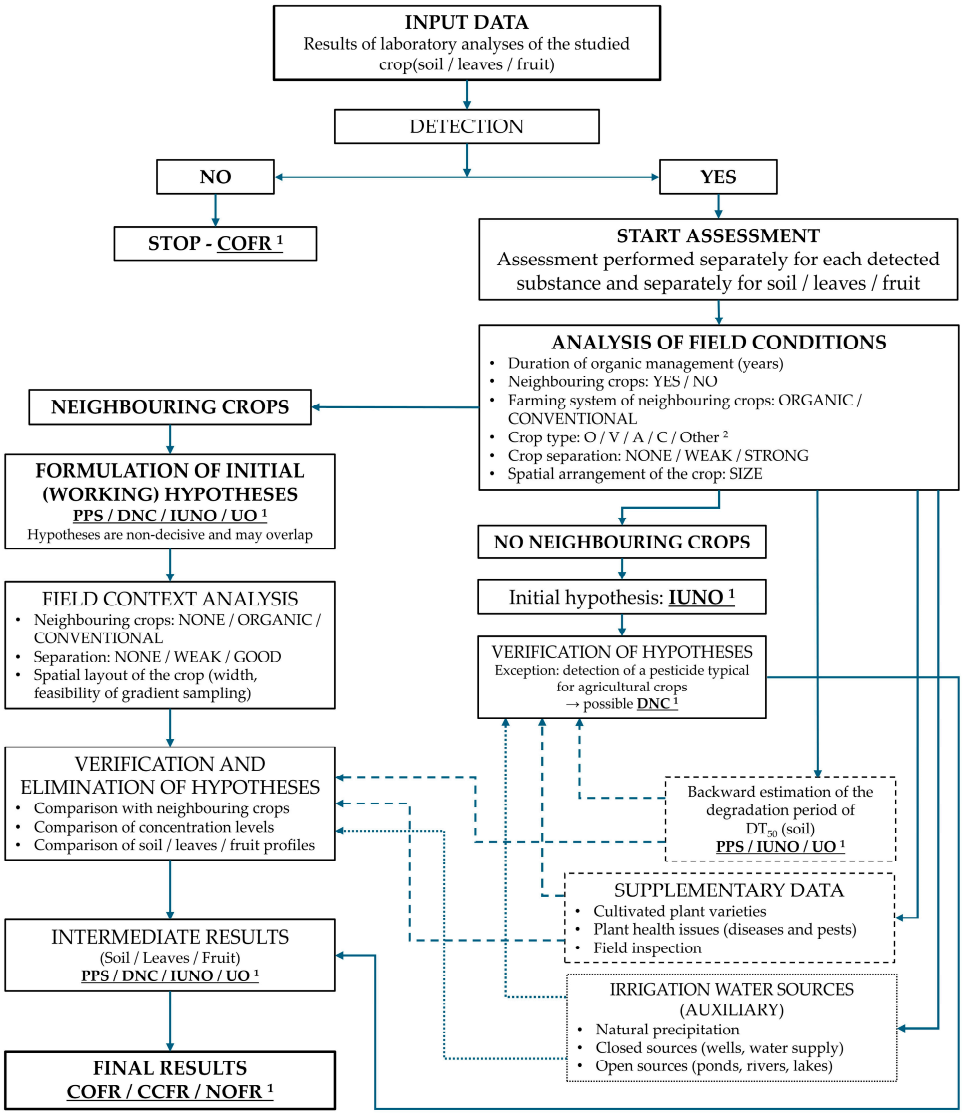

Figure 6. Decision framework for identifying the most probable origin of pesticide residues detected in organic crops and for determining the final compliance status with organic farming requirements. [1] COFR—Compliance with Organic Farming Requirements, CCFR—Conditional Compliance with Organic Farming Requirements, NOFR—Non-compliance with Organic Farming Requirements, PPS—Previous Production System, DNC—pesticide drift from neighbouring crops, IUNO—Intentional Use Considered the Most Probable Explanation, UO—Unknown Origin, [2] O—Orchard crops; V—Vegetable crops; A—Agricultural crops; C—Cereal crops.

When residues are detected, the assessment is conducted separately for each detected substance and independently for each material type (soil, leaves, fruit). The first stage involves the formulation of initial (working) hypotheses regarding the possible origin of the detected residue. These hypotheses include residues originating from the previous production system (PPS), pesticide drift from neighbouring crops (DNC), intentional use considered the most probable explanation (IUNO), or an unknown origin (UO). At this stage, the hypotheses are non-decisive and may coexist.

Subsequently, an analysis of field and landscape conditions is performed. This analysis includes the presence or absence of neighbouring crops, the farming system applied in adjacent fields (organic or conventional), the general crop category of neighbouring production systems, the degree of separation between fields, and the spatial configuration of the studied crop, including field size and the feasibility of gradient-based sampling.

If no neighbouring crops are present, the working hypothesis is set to IUNO. An exception is made when the detected substance is a pesticide typically associated with agricultural crops, in which case pesticide drift remains a plausible explanation.

In cases where neighbouring crops are present or where the situation remains ambiguous, supplementary data are collected. These include analytical results from neighbouring crops, additional samples collected within the studied crop, and an evaluation of the spatial distribution of residues, particularly the presence of concentration gradients or decay patterns. Where necessary, a retrospective assessment based on soil dissipation half-life values (DT_{50}) is applied as supportive evidence only, to assess whether detected residue levels are temporally consistent with historical land use.

The formulated hypotheses are subsequently verified and progressively eliminated based on comparisons with neighbouring crops, concentration levels, residue profiles across soil, leaves, and fruit, and consistency with agronomic and spatial evidence. This process results in an intermediate classification for each material type.

Finally, the final compliance status at the crop level is determined by aggregating the intermediate results. The final classification distinguishes between Compliance with Organic Farming Requirements, Conditional Compliance with Organic Farming Requirements—requiring the implementation of effective mitigation measures to prevent pesticide drift- and Non-compliance with Organic Farming Requirements in accordance with the rules illustrated in Figure 6.

3. Results

3.1. General Information Regarding the Crops Tested

The crops qualified for the study reflected the general structural profile of horticultural farms in Poland. The plantations assessed were part of 46 small, medium, and large farms, ranging in size from approximately four hectares to over 100 hectares. Most of the farms studied had a dispersed structure, meaning individual crops were located far apart, with some even located in different municipalities. Only a small number of farms had a compact structure, with all crops situated adjacent to each other. Many farms cultivated a wide variety of crops. A small number of farms practised parallel cultivation in organic, integrated, or conventional systems. Some plantations were part of producer groups. The information obtained indicates that of the 46 farms, 28 used fertilisers intended for organic farming, cattle or chicken manure, and on-farm-produced liquid manure. Plant protection against diseases and pests was provided on only 11 farms, while the remaining producers reported no protection.

During site visits, the most common problems reported by producers were high disease and pest pressure and insufficient plant protection products available in organic

farming. A large group of producers expressed concerns about the immediate proximity of conventional crops.

On the surveyed farms, organic crops most often preceded conventional fruit and cereal crops and, significantly less frequently, conventional arable and vegetable crops. In several cases, organic crops were established on previously fallow land or on meadows and pastures. In many instances, organic crops preceded extensive vegetable and fruit crops, and in one case, conventional herb cultivation.

3.2. Detection of Pesticide Residues

In the study, a total of 233 soil and plant samples from organic farms and 21 from neighbouring farms were analysed for pesticide residues. In 2016, an additional seven water samples used to irrigate the studied crops were collected.

Pesticide residues were not detected in 18.2% of the crops, including six apple crops and six raspberry crops. Pesticide residues were detected in the remaining 81.8% of the crops tested, with detections accounting for 44.4% of the total sample. Residues of one compound were detected in 34.8% of the crops, two in 16.7%, three in 18.2%, and four or more in 12.1%.

A total of 40 pesticide residues were detected in all samples from organic crops, including 16 fungicides and 1 fungicide degradation product, 9 herbicides, 13 insecticides, and 1 synthetic repellent. Among the detected compounds, 8 were withdrawn from use during the study period, and 8 were not approved for use in conventional apple, raspberry, and strawberry crops. The most frequently detected compounds in the samples were: DDT (44 detections), chlorpyrifos (11), captan and anthraquinone (8 each), carbendazim (5), and glyphosate (4) (Table 2). Only a few substances were detected multiple times, with the dominant compounds being the p,p′-DDE, p,p′-DDT, and p,p′-DDD isomers. In contrast, the remaining compounds were detected sporadically, 18 were detected only individually, and their complete list is presented in the Appendix A (Tables A1–A3).

Table 2. Quantity of detections of pesticide active substance residues.

Substance/Group	Number of Detections	Apple	Raspberry	Strawberry	Occurrence Pattern
DDT sum of isomers	44	✓	✓	✓	dominant substance
Chlorpyrifos	11	✓	✓	✓	frequent detections
Captan	8	✓	✓	–	moderate frequency
Anthraquinone	8	✓	✓	–	moderate frequency
Carbendazim	5	✓	✓	✓	sporadic detections
Glyphosate	4	✓	✓	✓	sporadic detections
Quizalofop-P-ethyl	4	✓	✓	–	sporadic detections
MCPA	4	✓	✓	–	sporadic detections
Bifenthrin	3	✓	–	–	sporadic detections
Spinosad	3	✓	✓	–	sporadic detections
Tetraconazole	3	✓	–	–	sporadic detections
Other substances were detected only once	18	✓	✓	✓	single, sporadic occurrences
Total detected substances	40				

Substances classified as “Other substances detected only once” were recorded sporadically across all crop types. The complete list of these compounds is provided in the Appendix A (Tables A1–A3).

A total of three compounds were detected in soil from the studied apple orchards, 23 in leaves, but none in fruit. In the studied raspberry plantations, a total of 11 compounds were detected in soil, seven in leaves, and one in fruit. In samples from strawberry plantations, nine compounds were detected in soil, seven in leaves, and one in fruit. A complete list of detected compounds is included in Tables A1–A3 in Appendix A. Pesticide residues were detected in two water samples: quizalofop-P-ethyl and proquinazid, as well as quizalofop-P-ethyl.

3.3. Predicting the Decay Period of Pesticides Detected in Soil

Because pesticide residues were most often detected in soil, a need arose to determine whether the detected substances could have been present in the soil before the establishment or conversion of an existing crop to an organic system. To this end, an attempt was made to estimate their degradation time. DDT was excluded from the theoretical calculations due to its half-life of several decades, as was anthraquinone, which may be of natural origin, but also due to the lack of literature data regarding its DT_{50}. Estimates of this degradation, based on literature data regarding DT_{50} (Table 3), were made for 12 compounds: 2.4-D, quizalofop-ethyl, chlorpyrifos, fluazifop-P-butyl, glyphosate, carbendazim, MCPA, methoxychlor, napropamide, oxyfluorfen, procymidone, and tetraconazole. The purpose of calculating the decay estimate was to assess whether the estimated degradation period was temporally consistent with the crop's management history and to compare it with the operational period of a given plantation in an ecological system

Table 3. Time ranges of persistence (DT50) of pesticide active substances detected in soil samples.

Pesticide Name	DT_{50} [Days]	Bibliographic Source of the Information
2.4-D	10	[30]
Antrachinon	-	No data available
DDT	7300	[31]
Chlorpyrifos	20–120	[32]
Quizalofop-ethyl	15–21	[33,34]
Fluazifop-P-butyl	8–24	[35]
Glyphosate	4–197	[36]
Carbendazim	12–366	[37]
MCPA	1.5–16	[38]
Methoxychlor	7–56	[39]
Napropamide	57–152	[30,40]
Oxyfluorfen	75–150	[41]
Procymidone	14–24	[42]
Tetraconazole	67–86	[43]

For the initial assessment, the average pesticide degradation time was used (indicated in Tables 4–6 as AV). The use of the average degradation time was motivated by practical considerations. Under field conditions, circumstances that favour the fastest possible degradation of pesticides are rarely encountered, similarly, extremely unfavourable conditions are also uncommon. In cases of uncertainty, the minimum and maximum degradation periods were considered.

Table 4. Following the detection of pesticide residues in apple crops, a backward estimation of the degradation period, based on theoretical calculations, was conducted to determine the minimum and maximum time interval between potential application and detection.

Crop No.	Soil Sampling Month	Duration of Organic Farming System [Months]	Detected Compound	Estimated Time from Potential Pesticide Application to Detection [Months]		
				Min	Max	Av
Ap 8	August	126	Carbendazim	Min 2.8	Max 86.1	42.3

Table 5. Following the detection of pesticide residues in raspberry crops, a backward estimation of the degradation period, based on theoretical calculations, was conducted to determine the minimum and maximum time interval between potential application and detection.

Crop No.	Soil Sampling Month	Duration of Organic Farming System [Months]	Detected Compound	Estimated Time from Potential Pesticide Application to Detection [Months]		
				Min	Max	AV
Rs 1	August	48	2,4-D Glyphosate	1.4 0.4	1.4 20.3	1.4 9.3
Rs 2	July	144	Procymidone	3.2	5.5	4.6
Rs 5	September	192	Quizalofop-P-ethyl Glyphosate	3.8 0.6	5.4 29.1	4.6 13.3
Rs 6	September	192	Quizalofop-P-ethyl	4.1	5.7	4.9
Rs 9	August	12	MCPA	0.3	3.3	2.0
Rs 19	September	144	Quizalofop-P-ethyl Fluazifop-P-butyl MCPA	0.4 3.8 2.3	4.4 5.3 7.0	2.8 4.5 4.4
Rs 20	September	144	Quizalofop-P-ethyl Fluazifop-P-butyl	4.8 2.3	6.7 6.8	5.8 4.3
Rs 24	July	12	Tetraconazole	15.9	20.4	16.6
Rs 28	September	96	Oxyfluorfen	18.3	36.6	29.3
Rs 29	September	12	Chlorpyrifos	5.0	30.1	15.1

Table 6. Following the detection of pesticide residues in strawberry crops, a backward estimation of the degradation period, based on theoretical calculations, was conducted to determine the minimum and maximum time interval between potential application and detection.

Crop No.	Soil Sampling Month	Duration of Organic Farming System [Months]	Detected Compound	Estimated Time from Potential Pesticide Application to Detection [Months]		
				Min	Max	AV
St 1	September	72	2,4-D Glyphosate	2.0 0.5	2.0 25.5	2.0 11.7
St 2	July	120	Tetraconazole	15.0	19.3	13.5
St 3	July	48	Chlorpyrifos	4.2	25.5	12.7
St 5	July	84	2,4-D MCPA	3.3 0.5	3.3 5.1	3.3 3.2
St 8	September	24	MCPA	0.5	5.2	3.2
St 9	September	24	Carbendazim Napropamide	11.7 3.8	31.3 116.0	12.3 57.0
St 10	June	168	Methoxychlor	1.7	13.3	7.1

Estimating pesticide degradation for 16 crops and comparing the results with the crops' periods of operation in the organic system revealed that, in 15 cases, pesticides were present during their organic management. For the Rs 24 crop, the degradation period of the detected pesticide was significantly longer than the operational period in the organic system. A similar case was observed in the crop designated St 9, where carbendazim residues were detected. In this crop, the second detected pesticide appeared during its operation in the organic system (Tables 4–6).

When the average degradation period of detected pesticides in the soil was shorter than the cultivation period in the organic system, further analysis was performed, accounting for other variables in accordance with the system's assumptions. The proximity of other crops, particularly conventional crops, and information on pest and disease problems occurring in the soil were taken into account.

3.4. Residues in Plant Material

Pesticide residues detected in leaves and fruit were considered prohibited in all cases. The exception was the presence of spinosad residues. If residues were detected in plant material, additional samples were collected from the tested crop and neighbouring crops. The starting material was the results of analyses of the research material collected from neighbouring crops, which were compared with those obtained from the organic material. When pesticide drift from neighbouring crops was suspected, additional samples were collected from the tested crops. Sample sites were evenly distributed at varying distances from the crop, where pesticide drift could have occurred. The results of these analyses showed that pesticide levels declined, depending on their source. During analysis of the collected material, the crop location and the presence of natural or artificial crop separators were also considered. Additional supplementary material included information on the plant species studied and their susceptibility to fungal diseases and pest infestations. Attention was paid to the occurrence of soil pests such as black vine weevil (*Otiorhynchus sulcatus*), wireworm (*Agriotes* spp.) or larvae of *Melolontha melolontha* in the case of strawberry and, less frequently, raspberry crops, pests damaging shoots and fruits such as codling moth (*Cydia pomonella*) and rosy apple aphid (*Dysaphis plantaginea*) in apple crops, and fungal diseases such as gray mold (*Botrytis cinerea*), powdery mildew of strawberry (*Podosphaera aphanis*), strawberry anthracnose (*Colletotrichum* spp.), Fusarium wilt of strawberry (*Fusarium* spp.), Phytophthora root rot (*Phytophthora cactorum*) in strawberry crops, gray mold (*Botrytis cinerea*), cane blight (*Didymella applanata* syn. *Didymella rubi*), powdery mildew of Raspberry (*Podosphaera macularis*), Phytophthora root rot of raspberry (*Phytophthora rubi*) in mali crops, apple scab (*Venturia inaequalis*), powdery mildew of apple (*Podosphaera leucotricha*), and brown rot of pome fruit (*Monilinia fructigena*) in apple crops. The compilation of all collected data enabled the proper determination of the most probable cause of the detected pesticides.

3.5. Examples of Multifactorial Analysis

A thorough multifactorial analysis, including field conditions, laboratory analyses of the tested and neighbouring crops, and the presence of pests, allows us to determine the cause of pesticide residues. For example, in a strawberry crop designated as St 3, chlorpyrifos residues were detected in the soil, and acetamiprid was detected in the leaves. After assessing chlorpyrifos degradation, it was determined that it was detected in the crop during organic farming. After comparing the results with additional samples from neighbouring crops that showed no residues, intentional use was considered the most probable explanation. This conclusion is further supported by the very high incidence of *Melolontha melolontha* larvae in the years preceding the study (Table 7).

Table 7. Pesticide residues in soil and plant material from plot St 3 and adjacent crops [mg kg^{-1} DM].

Adjacent Crop (Lupin)	Sample 1	St 3 Sample 2		Sample 3		Adjacent Crop (Oilseed Rape)
Soil						
ND	ND	Chlorpyrifos DDT	0.006 0.041	Chlorpyrifos DDT	0.014 0.023	ND
Plant material						
ND	ND	Acetamiprid	0.004	ND		ND

In the cases of Ap 7 and Ap 8 crops, determining the causes of occurrence was achieved by simply comparing the results of laboratory analyses of samples from the tested crops and neighbouring crops. In Ap 7, two substances were found at higher levels than in neighbouring crops (Table 8). Crop Ap 8 is a unique case in the entire study cycle. Plant material collected from the tested crop contained four compounds not present in the neighbouring crop, and two others were present in higher amounts (Table 9). A significant piece of information illustrating the non-compliance with basic principles is the use of substances in apple crops that were not omitted from these crops (Tables 8 and 9). In these two crops, field analysis revealed a lack of separation between organic and conventional crops, resulting in pesticide drift onto neighbouring crops. When pesticides decompose on leaves, it is essential to remember that this process is influenced by several factors, including environmental conditions, the type of soil in which the plants are growing, weather conditions, the use of microbiological preparations, and the plant species on which the pesticide was applied. During a comparative assessment of the detected residue levels in both conventional and organic crops, higher values were observed in organic crops. Although minor differences between these residues were observed, they were detected within the same species growing under the same environmental conditions. In these specific cases, there is also a high probability that microbiological preparations were used in organic crops.

Table 8. Pesticide residues in leaves from plot Ap 7 and adjacent crops [mg kg^{-1} DM].

Adjacent Crop (Apple)		Ap 7		Adjacent Crop (Apple)	
Pesticides detected in the studied crop and adjacent crops					
Bifenthrin *	0.31	Bifenthrin *	0.011	Bifenthrin *	0.027
		Chlorpyrifos	0.037	Chlorpyrifos	0.012
Cyprodinil	0.008	Cyprodinil	0.009	Cyprodinil	0.006
Captan	12.0	Captan	1.8	Captan	41.9
Tetraconazole	0.015	Tetraconazole	0.016	Tetraconazole	0.64
Pesticides were detected only in adjacent crops					
Acetamiprid	0.003			2,4-D	0.004
Bupirimate	0.046			Cyflufenamid	0.006
Difenoconazole	0.031			Bupirimate	0.012
Ethirimol	0.011			Difenoconazole	0.081
Fluopyram	0.017			Fluopyram	0.021
Folpet *	0.14			Folpet *	0.36
Phosmet	0.114			Phosmet	0.14
Methoxyfenozide	0.752			Propiconazole	0.1
Tebuconazole	0.059			Proquinazid	0.072
				Methoxyfenozide	2.49
				Tebuconazole	0.05

* A compound not authorised for use in apple cultivation.

Table 9. Pesticide residues in soil and plant material from plot Ap 8 and adjacent crop [mg kg^{-1} DM].

Adjacent Crop (Apple)		Ap 8	
Soil			
DDT	1.2	DDT	0.2
Chlorantraniliprole	0.0069		
		Carbendazim	0.0084
Plant material			
Pesticides were detected in the studied crop and the adjacent crop			
Bifenthrin *	0.009	Bifenthrin *	0.011
Boscalid	0.007	Boscalid	0.016
Chlorantraniliprole	0.68	Chlorantraniliprole	0.014
Cyflufenamid	0.008	Cyflufenamid	0.011
Cyprodinil	0.056	Cyprodinil	0.034
Difenoconazole	0.071	Difenoconazole	0.015
Folpet *	1.2	Folpet *	0.018
Indoxacarb	0.013	Indoxacarb	0.013
Captan	385.0	Captan	0.68
Spirotetramat	0.118	Spirotetramat	0.007
Pesticides were detected only in the studied crop or the adjacent crop			
Acetamiprid	0.0019	Chlorpyrifos	0.018
Diflubenzuron	0.014	Fluopyram	0.012
Methoxyfenozide	0.005	Tebuconazole	0.011
		Trifloxystrobin	0.014

* A substance not authorised for use in apple cultivation.

For the St 2 crop, additional factor analyses were performed, including comparisons with a neighbouring crop and field analyses. During the on-site inspection, no separation of crops was observed, and further comparison of plant material sample results indicated pesticide drift from the neighbouring crop. Additionally, the use of a withdrawn substance was detected in the conventional crop (Table 10).

Table 10. Pesticide residues in leaves from plot St 2 and adjacent crop [mg kg^{-1} DM].

Adjacent Crop (Strawberry)		Ap 8			
		Sample 1		Sample 2	Sample 3
Pesticides were detected in the studied crop and the adjacent crop					
Boscalid	0.041	Boscalid	0.008		
Clothianidin *	0.012	Clothianidin *	0.016		
Pesticides were detected only in the adjacent crop					
Chlorpyrifos	0.387				
Fluazifop-P-butyl	4.21				
Flutriafol	0.034				
Carbendazim	2.68				
Napropamide	0.159				
Thiamethoxam	0.104				
Thiophanate-methyl	1.998				

* A substance withdrawn from use.

Another example is the Ap 1 and Rs 4 crops, which were part of the same organic farm along with other organic vegetable crops. The entire farm was located far from other conventional crops, with meadows and pastures in the immediate vicinity. Furthermore, the farm was very well separated from the surrounding area by tall trees. Among other substances, a popular fungicide commonly used to combat apple scab (Captan) and carbendazim, a popular pesticide used in previous years but now withdrawn from use, were detected in leaves sampled from apple and raspberry trees. The presence of the detected pesticides suggests that deliberate use is the most probable explanation, especially in apple cultivation, where varieties susceptible to apple scab were grown. The presence of the fungicide in raspberry cultivation is puzzling, especially since the 'Polana' variety growing on it is less susceptible to fungal diseases.

3.6. Reasons for Residue Occurrence

The result of multivariate analyses conducted in accordance with the system's theoretical assumptions is the determination of whether a given crop has been intentionally used. No cases were determined to most probably result from intentional application in 40 of the examined crops, while intentional use was considered the most probable explanation in 26 cases. In cases of crops with cases where intentional application was considered the most probable explanation, the analysis revealed their use not only in the year of the study but also up to several years prior. In 12 crops, no residues were detected, and in 21, residues originating from previous (pre-conversion) use were detected. These crops met the requirements of the organic fruit production system. In five cases, residues from the last system cultivation were detected, along with residues from neighbouring crops, whereas in two cases, residues originated only from neighbouring crops. In these 7 cases, solutions to reduce pesticide drift from conventional crops should be implemented. A detailed description of the causes of pesticide residues, taking into account the sample type, and a summary assessment of compliance with the organic system requirements are presented in Tables 11–13.

Table 11. Results of multifactorial analyses determining the causes of pesticide residue occurrence in the studied apple crops (OF—Final compliance classification).

Crop No./OF		Soil Detection of Pesticide Residues	Leaves	Fruits	Crop No./OF		Soil Detection of Pesticide Residues	Leaves	Fruits
Ap 1	NOFR	PPS	IUNO	-	Ap 14	COFR	PPS	-	-
Ap 2	COFR	-	-	-	Ap 15	COFR	-	-	-
Ap 3	CCFR	PPS	DNC	-	Ap 16	NOFR	PPS	IUNO	-
Ap 4	CCFR	PPS	DNC	-	Ap 17	COFR	PPS	-	-
Ap 1	NOFR	PPS	IUNO	-	Ap 18	COFR	PPS	-	-
Ap 5	NOFR	-	IUNO	-	Ap 19	COFR	-	-	-
Ap 6	COFR	PPS	-	-	Ap 20	COFR	PPS	-	-
Ap 7	NOFR	PPS	IUNO	-	Ap 21	CCFR	PPS	DNC	-
Ap 8	NOFR	IUNO	IUNO	-	Ap 22	COFR	-	-	-
Ap 9	CCFR	PPS	DNC	-	Ap 23	COFR	-	-	-
Ap 10	COFR	PPS	-	-	Ap 24	NOFR	PPS	IUNO	-
Ap 11	COFR	PPS	-	-	Ap 25	NOFR	PPS	IUNO	-
Ap 12	COFR	-	-	-	Ap 14	COFR	PPS	-	-
Ap 13	COFR	PPS	-	-					

Table 12. Results of multifactorial analyses determining the causes of pesticide residue occurrence in the studied raspberry crops.

Crop No./OF		Soil Detection of Pesticide	Leaves Residues	Fruits	Crop No./OF		Soil Detection of Pesticide	Leaves Residues	Fruits
Rs 1	NOFR	IUNO	-	-	Rs 16	COFR	PPS	-	-
Rs 2	NOFR	IUNO	PPS	-	Rs 17	COFR	PPS	-	-
Rs 3	COFR	-	-	-	Rs 18	COFR	PPS	-	-
Rs 4	NOFR	PPS	IUNO	-	Rs 19	NOFR	IUNO	UO	-
Rs 5	NOFR	IUNO	-	-	Rs 20	NOFR	IUNO	-	-
Rs 6	NOFR	IUNO	-	-	Rs 21	NOFR	-	IUNO	-
Rs 7	COFR	PPS	-	-	Rs 22	NOFR	-	IUNO	-
Rs 8	COFR	PPS	-	-	Rs 23	CCFR	PPS	DNC	-
Rs 9	NOFR	IUNO	IUNO	IUNO	Rs 24	NOFR	IUNO	-	-
Rs 10	COFR	PPS	PPS	-	Rs 25	COFR	-	-	-
Rs 11	COFR	-	-	-	Rs 26	COFR	PPS	-	-
Rs 12	COFR	-	-	-	Rs 27	COFR	-	-	-
Rs 13	COFR	PPS	-	-	Rs 28	NOFR	IUNO	-	-
Rs 14	COFR	-	-	-	Rs 29	CCFR	DNC	DNC	-
Rs 15	COFR	PPS	-	-					

Table 13. Results of multifactorial analyses determining the causes of pesticide residue occurrence in the studied strawberry crops.

Crop No./OF		Soil Detection of Pesticide	Leaves Residues	Fruits	Crop No./OF		Soil Detection of Pesticide	Leaves Residues	Fruits
St 1	NOFR	IUNO	-	-	St 7	COFR	PPS	-	-
St 2	CCFR	DNC	DNC	-	St 8	NOFR	IUNO	-	-
St 3	NOFR	IUNO	IUNO	-	St 9	NOFR	IUNO	-	-
St 4	COFR	PPS	-	-	St 10	NOFR	IUNO	IUNO	DNC
St 5	NOFR	IUNO	-	-	St 11	NOFR	-	IUNO	-
St 6	COFR	PPS	-	-	St 12	COFR	PPS	-	-

4. Discussion

Published research on pesticide presence in organic farming primarily focuses on food and rarely considers residues in soil or plant material. This pattern holds for data from both the EU and other parts of the world. Furthermore, data from markets outside Europe is often difficult to access or limited in scope. Such information is often reported in aggregate across a wide range of fruits and vegetables, including both organic and conventional products. Available information indicates that detecting pesticide residues in organic products is a concern worldwide, wherever organic farming is practised. Current national and EU control systems primarily focus on verifying compliance with production standards, such as exceedances of maximum residue levels or the presence of substances not authorised for use in organic farming. In practice, cases of pesticide residue detection are usually assessed through individual investigations that consider farm-specific risk factors, potential contamination pathways, and documented preventive measures. The framework proposed in this study builds on these principles by integrating multiple information sources using commonly applied analytical methods, while introducing a structured approach to data collection and interpretation. In particular, the coordinated sampling of soil, plant material, and fruit from the same location supports a more consistent causal interpretation of residue findings at the crop level. In this sense, the system represents a conceptual assessment pathway that may complement existing procedures and could be adapted to other regulatory and geographic contexts. It should be noted that the framework does not incorporate

quantitative modelling of environmental and spatial variability, such as detailed soil parameters, microclimatic conditions, terrain exposure, or spatial patterns of pesticide drift and deposition. These factors may significantly influence pesticide persistence and distribution under field conditions. However, the purpose of the proposed system was not to simulate environmental processes, but to support a structured interpretation of residue findings using available inspection and contextual data. Consequently, environmental and spatial factors were considered qualitatively within the inference process, rather than through formal modelling approaches. In a meta-analysis of reports on pesticide detections in organic food from 1993 to 2021 in the UK, Germany, Sweden, France, Spain, Italy, Poland, the USA, Australia, and other countries, the frequency of pesticide residues was approximately 4 times lower in organic crops than in conventional crops [44]. In Asia, studies in Hong Kong found residues in 37% of organic vegetable samples, with a few maximum residue level (MRL) exceedances [45], in China (Shanghai), in 29.2% of organic vegetable samples [46], in India in 2017–2018, in 22.8% of organic vegetables, of which 1.6% exceeded the MRL and 15.4% contained residues of pesticides not approved for use [47] and in 2022–2025, in 2.8% of fruit and vegetable samples [48]. A similar pattern is observed for organic products from the African market in international trade, particularly from Egypt, where information on pesticide presence is regularly reported [49,50]. In the EU, the system for monitoring pesticide residues in food is well developed and has been in operation for many years. Long-term results indicate that organic food has a significantly lower frequency of detected pesticide residues than conventional food. Overall, European Food Safety Authority (EFSA) reports that 6.5% of organic food samples contain pesticide residues [15,51,52], whereas in Switzerland this figure is 9% [53]. In Poland, in addition to official tests for pesticide residues in organic food, several scientific studies are conducted. For example, control tests of organic crops conducted between 2007 and 2010, covering apples, strawberries, and raspberries, found pesticide residues in 4.4% of samples [54]. Between 2008 and 2014, pesticide residues in organic berries were detected at levels below 10% [55,56]. In other studies conducted between 2016 and 2018, covering organic fruit and vegetables available in retail chains, 7.3% of samples contained at least one active substance [57]. The results of this study confirm the general trend of sporadic residue detection in organic fruit. The presence of pesticide residues in 2.4% of the fruit samples is lower than the average reported in the literature. The study also confirms the general conclusions of Glibowski [58], namely that organic products exhibit a significantly lower frequency of pesticide residues than conventional products, while maintaining a low percentage of samples with detections. It should also be acknowledged that the distribution of sampled farms and crops was not uniform, and the study was not designed to provide a statistically representative picture of organic production at the national level. The selection of farms was random within predefined crop profiles (apple, raspberry and strawberry), and the number of farms was limited due to financial and logistical constraints. Nevertheless, efforts were made to include holdings located in different regions of the country and representing a broad diversity of production structures. The study therefore covered small, medium, and large farms, holdings specialised in a single crop as well as those cultivating multiple crop species, farms focused exclusively on orchard production as well as those combining fruit production with vegetable or cereal cultivation and both compact and spatially dispersed field structures.

The investigated cases thus reflect situations encountered during targeted inspections and research activities rather than the results of a statistically designed survey of organic farms. Consequently, the findings should be interpreted as illustrating typical diagnostic and interpretative scenarios rather than as quantitative estimates of the frequency of particular causes of pesticide residue occurrence. On the other hand, the results of the latest

tests commissioned by certification bodies for organic farming in Poland in 2023 are much more alarming. Pesticide residues were detected in 16.3% of samples of fruit, vegetables, and cereals from organic farming. However, in the case of control tests commissioned by companies marketing organic products from the domestic or imported market, this percentage reached a significant 31.8% [59]. This discrepancy between the latest reports and the results of the present study may indicate an increase in the frequency of pesticide residue detections in organic products in recent years. A separate issue is whether the plant protection and fertilisation practices used for crops are consistent with an organic production system. According to the principles of the organic system, it is treated as a binary system. This means that unauthorised pesticides cannot be present in this production system. Most scientific studies and reports do not address this issue in detail. The availability of information on the detection of pesticide residues in soil or in leaves from organic crops is limited. Among the few published sources providing such data are the studies by Miszczak et al. [59] and Ukalska-Jaruga et al. [60]. In the study, multivariate analysis, conducted in accordance with the assessment system's assumptions, revealed residues originating from previous (pre-conversion) use in 74.2% of the crops. The most frequently detected compound in the soil classified as a historical residue was DDT isomers. The high frequency of historical residues is consistent with available literature [61,62]. In addition to DDT isomers, residues of 13 other pesticides were detected during the study, and their concentrations did not exceed the permissible values for agricultural soils [63]. In most cases, multivariate analysis identified situations in which intentional application was considered the most probable explanation. The presence of low pesticide concentrations in the soil partially supports the conclusions of other authors who report low levels of pesticides in the soil of organic crops in Europe [64–66]. The research results, when compared with the findings of the multivariate analysis, also support the thesis put forward by Miszczak et al. [59] that the soils selected for organic plantations in Poland are not heavily contaminated with residues originating from previous (pre-conversion) use. During the multivariate analyses, the origin of the anthraquinone, which is often detected in soil, could not be clearly determined. These cases were determined to have an undetermined source of residues because the literature reports the natural occurrence of this compound [67]. An additional factor supporting this classification was information about the potential production of this compound by certain fungi [68]. Another factor was the lack of information in the literature on this compound's half-life. Multivariate analysis highlighted pesticide drift from neighbouring crops as a relevant factor affecting organic production. In the crops analysed in the present study, this issue was identified in 12.1% of the samples.

DDT residues in soil may represent a potential source of contamination of organic products. The literature indicates that some plant species can accumulate (bind) DDT. Examples include crops from the Cucurbitaceae family [69,70], carrot (*Daucus carota*) [71], radish (*Raphanus sativus* var. *sativus*) and spinach (*Spinacia oleracea*) [72], as well as tomato (*Solanum lycopersicum*), sunflower (*Helianthus annuus*), soybean (*Glycine max*), and alfalfa (*Medicago sativa*) [73]. A fascinating case regarding the potential transfer of DDT from soil to plants is the raspberry plantation labelled as Rs 10. Only a single occurrence of DDT was detected in plant material, despite frequent detections of DDT in soil samples from raspberry plantations. This observation is consistent with reports of DDT's limited bioavailability due to its strong soil sorption. Previous studies confirmed that DDT may occur within the soil–plant system in orchard crops [74] and that DDT-related compounds can be taken up by cultivated plants grown on orchard soils [75]. Nevertheless, this pathway is generally considered limited, mainly because DDT is highly lipophilic and has limited mobility within plants [76].

The low percentage of crops affected by pesticide drift is generally consistent with findings from other studies. These studies report that the few detections of individual substances were primarily related to environmental factors and proximity to conventional crops [54–56]. An example of drift-related contamination is the detection of dithiocarbamate residues in leaves (e.g., Rs 10). It is difficult to unequivocally determine the causes of their presence because the analytical methods used quantify the decomposition product of these compounds as CS_2. On the one hand, dithiocarbamates occur in pesticides, including dimethyldithiocarbamates (thiram, ziram), ethylenebisdithiocarbamates (mancozeb, maneb, metiram), and propylenebisdithiocarbamates (propineb) [77]. On the other hand, they may have a natural origin in plants such as brassicas and amaryllids, or in specific plant-based preparations containing high levels of sulphur compounds [78]. Due to differences in the metabolism of sulphur-containing compounds, CS_2-based analysis may lead to false-positive results for dithiocarbamate residues of non-natural origin. In this particular case, the source of these residues was classified as pesticide drift from a neighbouring maize crop, where the use of products containing ziram, a dimethyldithiocarbamate, was permitted.

An example of unintended use or an unexplained cause of pesticide residue detection is the single detection of DEET. This compound is widely used in the most common insect repellents.

Another disconcerting finding from the multivariate analysis was the detection of cases where intentional application was considered the most probable explanation in organic crops. This problem affected 39.4% of the studied crops. These cases represent situations where intentional application was considered the most probable explanation, although definitive confirmation is not possible within the limits of field-based residue investigations. This result is much higher than the rates rarely reported in the literature. Miszczak et al. [59] report that, in their study, pesticide residues were detected in leaves of over 8% of organic crops, but they do not clearly specify the cause of their occurrence. Most authors who elaborate on the causes of residues in organic crops state that the most common causes are pesticide drift [62,79,80], accidental contamination [44], environmental factors [63], or sporadic cases where intentional use was considered the most probable explanation [62]. The obtained results generally confirm the conclusions of other authors. It should be noted, however, that the cited authors likely did not conduct thorough analyses of organic crops and instead relied on their own knowledge. The results showed that permitted pesticide use in organic crops exceeds the sporadic use reported by [54,79]. Some authors suggest that the increasing frequency of pesticide residue detections in organic crops may result not only from environmental factors (e.g., pesticide drift or contamination) but also from intentional application of non-authorised pesticides [56,81]. It should be noted, however, that the multivariate analysis performed during the study identified intentional use not only in the study year but also in older cases. Comparing the total number of detections in fruit to those in soil and leaves reveals an alarming phenomenon that raises concerns regarding the integrity of organic production control systems. Unfortunately, the study failed to explain why pesticide residues were not detected in fruit from crops determined to most probably result from intentional use used in the year of sampling, despite pesticide residues being detected in soil and/or leaves. Information available in the literature may partially explain this problem. For example, refs. [82,83] describe the impact of microorganisms: *Bacillus* spp., *Trichoderma* spp., and *Glomus* spp. on reducing pesticide residues in apples, while ref. [84] discusses the degradation of atrazine by algae. Another factor that may explain this is the deliberate use of pesticides early in the growing season of the studied plants. Finally, let us summarise the validity of the finding that, despite constant reports of

pesticide presence in organic farming, the frequency of detections and residue levels are significantly lower than in conventional systems [62,85].

5. Conclusions, Limitations and Recommendations

In the present study, it should be noted that the survey covered only a tiny proportion of all organic orchard crops in Poland. This is, for sure, a limitation of the presented study. However, the farms and plantations included in the study were selected to reflect a cross-section consistent with the structure of organic farms in Poland. Therefore, a direct extrapolation of the results to the entire organic farming sector would not be justified; however, the conclusions may be applicable more broadly. The limitations of this study also stem from the use of data on the probable half-life of individual pesticides, which can only be estimated approximately due to the many factors influencing this period. Therefore, the described system for assessing the likelihood of intentional use of prohibited pesticides in organic orchards should be considered a proposal for further development and improvement.

The proposed framework should be understood as a structured interpretative tool supporting inspection practice rather than as a predictive or statistically generalisable model.

Based on the results obtained, the authors suggest the following recommendations for practise:

- Before establishing a new organic crop or converting an existing conventional crop, producers should carry out routine soil testing for pesticide residues.
- Before entering an organic fruit production system, producers should conduct a detailed risk assessment of pesticide contamination from nearby conventional crops, especially those in the immediate vicinity.
- Organic cultivation should not be undertaken unless effective measures can be implemented to protect crops from contamination originating from neighbouring conventional crops.
- Organic certification bodies should have the authority to prohibit organic cultivation if effective measures cannot be implemented to protect crops from contamination originating from neighbouring conventional crops.
- Varieties that are resistant to, or have low susceptibility to, fungal diseases should be selected for commercial plantings in organic systems.
- During the annual inspection process, selected farms should undergo thorough testing to assess compliance with the principles of organic fruit and vegetable production. This should include sampling of soil and plant material (e.g., leaves, shoots, and edible parts) taken from the same specific locations.
- Crops in which intentional use of unauthorised pesticides is considered the most probable explanation should be excluded from the organic production system.
- Organic producers who consistently experience pesticide drift from neighbouring crops are advised to switch to an alternative cultivation system (e.g., a zero-residue system).
- When problems accumulate under high disease and pest pressure and cannot be controlled effectively, organic producers are advised to switch to an alternative cultivation system (e.g., a zero-residue system).

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/app16041955/s1, Table S1: GC–MS/MS detector parameters used for pesticide residue analysis, including retention times (RT), precursor ions, product ions, collision energies, and ion transitions applied for compound identification and confirmation; Tables S2–S5: Scope of substances analysed and validation parameters of the applied analytical methods. Table S6: Validation parameters of different analytical methods used for the determination of pesticide residues.

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Abbreviations

The following abbreviations are used in this manuscript:

D	Detected
ND	Not detected
DM	Dry matter
FM	Fresh matter
Ap 1–25	Apple crop no. 1–25
Rs 1–29	Raspberry crop no. 1–29
St 1–12	Strawberry crop no. 1–12
DT_{50}	Dissipation half-life
MRL	Maximum residue level
CS_2	Carbon disulfide
OF	Final compliance classification
COFR	Compliance with organic farming requirements
NOFR	Non-compliance with Organic Farming Requirements
PPS	Residue originating from the previous production system
UO	Unknown origin
IUNO	Intentional use considered the most probable explanation and not compliant with organic farming rules
DNC	Pesticide drift from adjacent crops.
O	Orchard crops
V	Vegetable crops
A	Agricultural crops
C	Cereal crops

Appendix A

Tables A1–A3 present detailed results of the analyses of the main samples collected from the studied crops, and additional designations were applied:

- [A] After the conversion period in the sampling year,
- [1] 2016 sampling year,
- [2] 2017 sampling year,
- [3] 2018 sampling year,
- [4] the substance may occur naturally in some plants,

- [5] may also occur as a breakdown product of thiophanate-methyl,
- [6] breakdown products of captan,

Several detected pesticides are listed in abbreviated form:

- DDT—dichlorodiphenyltrichloroethane (sum of isomers),
- 2,4-D—2,4-dichlorophenoxyacetic acid,
- DEET—N,N-Diethyl-m-toluamide,
- MCPA—2-methyl-4-chlorophenoxyacetic acid

Table A1. Pesticide residues in apple (Ap) crops tested in 2016–2018.

Crop No.	Years in the Organic Farming System [A]	Biologically Active Substances					
		Soil	[mg kg^{-1} DM]	Leaf	[mg kg^{-1} DM]	Fruit	[mg kg^{-1} FM]
Ap 1 [1]	15	DDT	0.009	Captan Carbendazim [5]	0.016 0.01	-	-
Ap 2 [1]	24	-	-	-	-	-	-
Ap 3 [1]	12	DDT	0.103	Chlorpyrifos Dithiocarbamates [4] Carbendazim [5] Spinosad	0.014 0.016 0.018 0.009	-	-
Ap 4 [1]	12	DDT	0.082	Glyphosate	0.16	-	-
Ap 5 [2]	5	-	-	Captan Tetrahydrofthalamide [6]	0.02 0.01	-	-
Ap 6 [2]	5	DDT	0.022	-	-	-	-
Ap 7 [2]	5	DDT	0.097	Bifenthrin Chlorpyrifos Cypermethrin Captan Tetraconazole	0.011 0.037 0.009 1.8 0.016	-	-
Ap 8 [2]	10	DDT Carbendazim [5]	0.2 0.008	Bifenthrin Boscalid Chlorantraniliprole Chlorpyrifos Cyflufenamid Cyprodinil Difenoconazole Fluopyram Folpet Indoxacarb Captan Spirotetramat Tebuconazole Trifloxystrobin	0.011 0.002 0.014 0.018 0.01 0.034 0.015 0.012 0.018 0.013 0.68 0.007 0.011 0.014	-	-
Ap 9 [2]	12	DDT	0.006	Chlorpyrifos	0.015	-	
Ap 10 [2]	9	DDT	0.009	-	-	-	
Ap 11 [2]	9	DDT	0.015	-	-	-	
Ap 12 [2]	9	-	-	-	-	-	
Ap 13 [2]	10	DDT	0.058	-	-	-	
Ap 14 [2]	10	DDT	0.009	-	-	-	

Table A1. *Cont.*

Crop No.	Years in the Organic Farming System [A]	Biologically Active Substances					
		Soil	[mg kg^{-1} DM]	Leaf	[mg kg^{-1} DM]	Fruit	[mg kg^{-1} FM]
Ap 15 [3]	5	-	-	-	-	-	
Ap 16 [3]	14	DDT	0.042	Diflubenzuron Captan	0.13 0.076	-	-
Ap 17 [3]	1	Anthraquinone [4]	0.007	-	-	-	
Ap 18 [3]	8	Anthraquinone [4]	0.007	-	-	-	
Ap 19 [3]	14	-	-	-	-	-	
Ap 20 [3]	14	Anthraquinone [4] DDT	0.028 0.08	-	-	-	-
Ap 21 [3]	27	Anthraquinone [4] DDT	0.014 0.028	Fenpropimorph Metazachlor	0.008 0.013	-	-
Ap 22 [3]	10	-	-	-	-	-	-
Ap 23 [3]	1	-	-	-	-	-	-
Ap 24 [3]	8	Anthraquinone [4] DDT	0.035 0.11	Chlorpyrifos	0.025	-	-
Ap 25 [3]	8	Anthraquinone [4] DDT	0.01 0.012	Diflubenzuron	0.026	-	-

Table A2. Pesticide residues in raspberry (Rs) crops tested in 2016–2018.

Crop No.	Years in the Organic Farming System [A]	Biologically Active Substances					
		Soil	[mg kg^{-1} DM]	Leaf	[mg kg^{-1} DM]	Fruit	[mg kg^{-1} FM]
Rs 1 [1]	4	2,4-D DDT Glyphosate	0.069 0.023 0.136	-	-	-	-
Rs 2 [1]	12	Anthraquinone [4] DDT Procymidone	0.012 0.009 0.009	Dithiocarbamates [4]	0.83	-	-
Rs 3 [1]	10	-	-	-	-	-	-
Rs 4 [1]	16	DDT	0.036	Chlorpyrifos Captan	0.014 0.025	-	-
Rs 5 [1]	16	Chizalofop-P-ethyl DDT Glyphosate	0.005 0.013 0.053	-	-	-	-
Rs 6 [1]	16	Chizalofop-P-ethyl DDT	0.004 0.096	-	-	-	-
Rs 7 [1]	16	DDT	0.032	-	-	-	-
Rs 8 [1]	16	DDT	0.083	-	-	-	-
Rs 9 [2]	1	MCPA	0.002	Carbendazim [5]	0.004	Pyrimethanil	0.006
Rs 10 [2]	17	DDT	0.039	DDT	0.012	-	-

Table A2. *Cont.*

Crop No.	Years in the Organic Farming System [A]	Biologically Active Substances					
		Soil	[mg kg^{-1} DM]	Leaf	[mg kg^{-1} DM]	Fruit	[mg kg^{-1} FM]
Rs 11 [2]	17	-	-	-	-	-	-
Rs 12 [2]	7	-	-	-	-	-	-
Rs 13 [2]	7	DDT	0.057	-	-	-	-
Rs 14 [2]	7	-	-	-	-	-	-
Rs 15 [2]	12	DDT	0.042	-	-	-	-
Rs 16 [2]	12	Anthraquinone [4] DDT	0.006 0.087	-	-	-	-
Rs 17 [2]	2	DDT	0.114	-	-	-	-
Rs 18 [2]	2	DDT	0.03	-	-	-	-
Rs 19 [2]	12	Chizalofop-P-ethyl DDT Fluazifop-P-butyl MCPA	0.006 0.001 0.003 0.003	DEET	0.008	-	-
Rs 20 [2]	12	Chizalofop-P-ethyl DDT Fluazifop-P-butyl	0.001 0.055 0.003	-	-	-	-
Rs 21 [2]	11	-	-	Captan	0.014	-	-
Rs 22 [2]	10	-	-	Captan	0.015	-	-
Rs 23 [3]	11	DDT	0.018	Linuron	0.029	-	-
Rs 24 [3]	1	DDT Tetraconeazole	0.017 0.008	-	-	-	-
Rs 25 [3]	14	-	-	-	-	-	-
Rs 26 [3]	14	DDT	0.03	-	-	-	-
Rs 27 [3]	4	-	-	-	-	-	-
Rs 28 [3]	8	Oxyfluorophen	0.007	-	-	-	-
Rs 29 [3]	1	Chlorpyrifos	0.006	Chlorpyrifos	0.005	-	-

Table A3. Pesticide residues in strawberry (St) crops tested in 2016–2018.

Crop No.	Years in the Organic Farming System [A]	Biologically Active Substances					
		Soil	[mg kg^{-1} DM]	Leaf	[mg kg^{-1} DM]	Fruit	[mg kg^{-1} FM]
St 1 [1]	6	2,4-D DDT Glyphosate	0.016 0.295 0.078	-	-	-	-
St 2 [1]	10	DDT Tetraconeazole	0.052 0.011	Boscalid Clotianidin	0.008 0.016	-	-
St 3 [1]	4	Chlorpyrifos DDT	0.014 0.041	Acetamiprid	0.004	-	-
St 4 [1]	4	DDT	0.027	-	-	-	-
St 5 [2]	7	2,4-D MCPA	0.001 0.001	-	-	-	-
St 6 [2]	6	DDT	0.002	-	-	-	-

Table A3. *Cont.*

Crop No.	Years in the Organic Farming System [A]	Biologically Active Substances					
		Soil	[mg kg^{-1} DM]	Leaf	[mg kg^{-1} DM]	Fruit	[mg kg^{-1} FM]
St 7 [2]	6	DDT	0.012	-	-	-	-
St 8 [2]	2	DDT MCPA	0.014 0.001	-	-	-	-
St 9 [2]	2	DDT Carbendazim [5] Napropamide	0.111 0.002 0.016	-	-	-	-
St 10 [3]	14	Methoxychlor	0.008	Chlorpyrifos Dimetoate Spinosad Tetraconeazole	0.120 0.013 0.01 0.072	Dimetoate	0.002
St 11 [3]	1	-	-	Chlorpyrifos Spinosad	0.005 0.018	-	-
St 12 [3]	4	DDT	0.022	-	-	-	-

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