Deliverable D 3.3
Context Dependency of the Implementation of the Practices and Systems

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Responsible/Author:	Mieke Katharina Jürgens, ZALF Sonoko Bellingrath-Kimura, ZALF
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1. Executive Summary

This deliverable (D3.3) of the AGROWISE project examines why the efficiency of Integrated Pest Management (IPM) and agroecology-based practices varies across regions in Europe. The analysis focuses on biophysical and agronomic factors at site level — including climate, soil, landscape, biodiversity, pest dynamics, and legacy effects. Socioeconomic conditions and policy contexts are excluded, as Task 3.4 aims to isolate ecological drivers of variability. To date, no comparable framework has systematically assessed these drivers, making this deliverable a first step towards filling this gap.

The work builds on a structured literature scan that identified recurrent site-specific factors influencing IPM efficiency. These were synthesised into six context dependency indicators: 1) climate and weather, 2) soil characteristics and hydrology, 3) landscape structure and topography, 4) biodiversity and ecosystem functions, 5) pest pressure and biotic risk, and 6) temporal or legacy effects. This framework formed the basis for a systematic review of European studies, analysing the frequency of each indicator, how indicators co-occur and identifying major remaining knowledge gaps.

A scoring system was then developed to classify the degree of context dependency (0–3 scale) for IPM practices. This integrates the six indicators with the ASP metrics from WP2, which measure agronomic service provision (ASP) and improvement relative to current practice. Combining context dependency with efficiency enables transparent assessment of whether practices are suitable for binding rules or require local adaptation.

The methodology was applied to three case studies: codling moth management in apple orchards, powdery mildew control in vineyards, and weed management in cereals. Practices were mapped within the harmonised taxonomy of WP 2.1 (AGROWISE), scored for context dependency, and interpreted in relation to their efficiency.

Across all cases, climate and pest pressure emerged as the most influential indicators, while soil and biodiversity generally scored lowest. Temporal/legacy effects and landscape factors showed system-specific importance, particularly in cereals (rotation history, management legacies) and perennial crops (habitat management, surrounding land use). At sub-factor level, spatial pest variability, climatic conditions, and seasonal dynamics were most often linked to IPM performance.

The results provide a first overview of how site-specific factors are represented in the evidence base and demonstrate how context dependency can be quantified for regulatory decision making. For policy, the findings suggest that binding rules should focus on practices with low context dependency and stable agronomic benefits, while practices shaped by high ecological variability (e.g. climate, landscape, legacy effects) should remain optional or be supported through flexible guidelines and local adaptation. **The findings also suggest that effectiveness (ASP) and context sensitivity are partly independent dimensions and need to be jointly considered when deriving recommendations (e.g., binding vs. optional implementation).** This differentiation allows EU pesticide reduction strategies to combine effectiveness with fairness across diverse farming systems.

This deliverable offers the first structured approach to classify the context dependency of IPM practices and link these assessments with agronomic performance. It lays the groundwork for

transparent, science-based decisions in future crop- and site-specific pesticide reduction strategies under the Farm to Fork framework.

2. Abbreviations and Acronyms

Abbreviation / Acronym	Description
AGROWISE	Guidelines for farm specific or crop specific rules for mitigating pesticide impacts while ensuring sustainable agriculture
ASP	Agronomic Service Provided
IASP	Improvement of Agronomic Service Provided
IPM	Integrated Pest Management
PLP	Strategic Integrated Project
SUD	Sustainable Use of Pesticides Directive
SUR	Sustainable Use of Pesticides Regulation
WoS	Web of Science
WP	Work Package
ZALF	Leibniz Centre for Agricultural Landscape Research

3. Background

The present document constitutes Deliverable D3.3 “Context dependency of the implementation of the practices and systems” in the framework of the AGROWISE project (*Guidelines for farm-specific or crop-specific rules for mitigating pesticide impacts while ensuring sustainable agriculture*). AGROWISE is funded under the LIFE 2023 Strategic Integrated Project (PLP) program of the European Union, with Grant Agreement number 101148740. The project runs for 18 months (01 May 2024 – 31 October 2025) and is coordinated by a consortium of research institutions across Europe. Deliverable D3.3 is produced within Work Package 3 (Current state of implementation of IPM-based practices/systems) and led by Leibniz Centre for Agricultural Landscape Research (ZALF).

AGROWISE supports the objectives of the EU Farm to Fork Strategy, which calls for a 50% reduction in the use and risk of chemical pesticides by 2030 and builds on the Sustainable Use of Pesticides Directive (2009/128/EC). A revision of this directive into a Sustainable Use of Pesticides Regulation (SUR) was proposed by the European Commission in June 2022 to establish binding reduction targets. However, the proposal was rejected by the European Parliament in November 2023 and formally withdrawn by the Commission in February–May 2024 due to lack of political agreement. As a result, the regulatory framework for pesticide reduction remains in transition, which increases the need for practical, evidence-based approaches to guide future legislative efforts.

Within this policy landscape, IPM is recognised as the cornerstone for achieving pesticide reduction targets, yet its practical implementation varies widely across Europe. The variability in IPM performance is strongly influenced by local environmental conditions: identical practices can produce markedly different outcomes depending on climate, soil characteristics, pest pressure, or other ecological factors. Understanding these context dependencies is therefore essential for designing effective and fair regulations: practices that perform consistently well across diverse conditions could be made binding, whereas those with highly variable performance may require flexibility or local adaptation.

Task 3.4, led by ZALF, specifically addresses the identification of site-specific biophysical factors that explain differences in IPM practice efficiency. It develops a conceptual framework grouping these factors into six high level indicators —1) climate and weather, 2) soil and hydrology, 3) landscape and topography, 4) biodiversity and ecosystem functions, 5) pest pressure, and 6) temporal or legacy effects — and applies this framework to literature mapping, scoring development, and case study analysis. These results will later feed into integration with the harmonised taxonomy of IPM practices (WP2.1) and the efficiency metrics ASP/IASP (WP2.3), forming the basis for rule setting and policy guidance.

4. Objective/Aim

The aim of this deliverable is to establish a framework and methodology for understanding and quantifying the context dependency of IPM and agroecology-based practices across European farming systems. By focusing exclusively on site-specific and biophysical parameters — including climate, soil, landscape structure, biodiversity, pest dynamics and legacy effects — this work isolates the ecological drivers that explain why the same practice can perform differently from one region to another.

Within the AGROWISE project, this deliverable contributes directly to the development of farm and site-specific rules that support EU pesticide reduction targets under the Farm to Fork Strategy and the Sustainable Use of Pesticides framework. The framework developed in Task 3.4 provides the scientific basis for identifying:

1. **Which context parameters influence IPM efficiency most strongly** and how these can be grouped into six indicators for systematic assessment.
2. **How to measure context dependency** using a classification scale (0–3) that can be applied consistently across practices and regions.
3. **How to combine context dependency with efficiency metrics (ASP/IASP)** from WP2.3 to evaluate when practices are suitable for **binding rules** and when they should remain **optional or locally adapted**.
4. **How the framework links to adoption and scalability** of IPM measures by highlighting where local conditions facilitate or hinder implementation.

The deliverable therefore bridges ecological analysis and regulatory application, enabling transparent decision making on IPM practice deployment in future pesticide reduction strategies.

5. Context Dependency of IPM Practices and Systems

This chapter presents the main results of Task 3.4, which examines the context dependency of IPM and agroecology-based practices. It introduces the conceptual framework of six site-specific indicators, summarises how these indicators are represented in the scientific literature, and describes the scoring methodology developed to quantify context dependency. The framework is then applied to three case studies and integrated with existing AGROWISE outputs (IPM taxonomy and ASP/IASP metrics) to inform rule setting for pesticide reduction strategies.

5.1. Definition of Context Dependency

Context, in its broadest sense, refers to the surrounding conditions and circumstances that give meaning to a phenomenon. As defined by Greenhalgh und Manzano (2022), context is the set of conditions that influence how mechanisms are triggered and how outcomes are produced. In everyday language, context explains why an event or action may have different outcomes depending on where, when, or how it occurs. Applied to plant protection, context dependency describes how the performance or efficiency of IPM or agroecological practices changes according to local environmental, agronomic, socio-economic, and policy conditions. Studies in agricultural ecology (Deguine et al. 2021; Stenberg 2017; Wyckhuys et al. 2024) emphasise that variations not only in biophysical factors such as climate, soil quality, and biodiversity but also in farm management, market access, and regulatory frameworks can lead to markedly different levels of pest pressure and biological control. These authors stress that understanding this multidimensional variability is essential to tailor IPM strategies to specific sites and to design robust systems that can function effectively across diverse ecological and institutional settings.

The efficiency of agroecosystems — including yield stability, pesticide use reduction, and resilience to pests — is therefore strongly shaped by context at multiple levels. Without explicitly accounting for these factors, no uniform assessment of IPM practice performance can be achieved. Recognising and categorising this variability is the foundational step for developing a systematic framework capable of guiding policy and farm-level decisions.

In the broader literature, four layers of context are often distinguished and described in more detail:

Biophysical context: This includes climatic conditions, soil properties, landscape structure, biodiversity, pest dynamics, and legacy effects. It addresses the ecological and physical environment in which farming systems operate and directly influences pest development, crop health, and the effectiveness of any control measures (Duru et al. 2015; Petit et al. 2020).

Agronomic context: Refers to crop types, rotations, tillage regimes, specific farm management practices and farm size. These determine the agronomic background in which IPM measures are implemented, affecting factors like nutrient cycling and crop susceptibility (Lechenet et al. 2017; Brévault und Clouvel 2019).

Socio-economic context: Includes labour availability, market conditions, and economic constraints. This context shapes the feasibility and adoption of IPM practices by influencing resource availability, investment capacity, and farmer decision-making (Holland et al. 2016; Alexandridis et al. 2021).

Policy context: Encompasses regulations, incentives, and institutional frameworks that can promote or hinder certain IPM strategies. Examples include pesticide-use directives, agri-environmental schemes, and subsidy structures that affect the attractiveness and uptake of ecological measures (Cardim Ferreira Lima et al. 2020; Wyckhuys et al. 2024).

For this deliverable, **only biophysical and some agronomic factors are considered**, while policy context and socio-economic layers are deliberately excluded to isolate ecological drivers of variability in IPM performance. This focus reflects both the scope of Task 3.4 and the data availability within AGROWISE: by concentrating on ecological parameters, the framework can be consistently applied across Member States and later complemented with socio-economic insights from other research efforts.

Context dependency can be understood at two levels:

Practice-level context dependency: the performance of individual measures (e.g., pheromone traps, cover crops) varies according to specific site parameters such as temperature, soil type, or pest populations.

System-level context dependency: integrated strategies that combine multiple measures (e.g., crop rotation combined with habitat management and biological control) may exhibit emergent dependencies, resulting from **interactions and cumulative effects** across several parameters. This system-level view is essential for agroecological approaches that aim to redesign production systems rather than optimise single practices.

5.2. Relevance of Context Dependency for IPM and Policy

The EU's Farm to Fork Strategy aims to cut the use and risk of chemical pesticides by 50% by 2030. Achieving this requires science-based tools that support fair guidelines across diverse Member States. The current SUD and the proposed SUR, withdrawn in 2024, highlight IPM as central to sustainable crop protection but lack a systematic way to address context variability.

Without such a framework, regulations risk being too general—ignoring local conditions—or too prescriptive, making them hard to implement. A clear method for assessing context dependency can bridge this gap by ensuring harmonised guidance, feasible and adaptable across Europe's varied farming landscapes.

For farmers, context dependency is crucial to adoption and scalability. They often face uncertainty about when and where a practice will work, yet they carry most of the implementation risk. A framework that clarifies these conditions can reduce this uncertainty, improve trust in IPM guidelines, and highlight knowledge gaps where further research or monitoring is needed.

By showing which practices are robust across sites and which are highly site-specific, the framework supports transparent decisions on binding rules versus optional or flexible measures. This helps align policy objectives with the realities of on farm decision making.

5.3. Development of the Context Dependency Indicator Framework

The aim of Task 3.4 in AGROWISE was to develop a framework that can systematically capture and compare how IPM and agroecological practices perform under different regional conditions. By translating site-specific factors into a structured indicator system, this framework will enable consistent cross-regional comparisons and support policy and research needs in reducing pesticide risks under the Farm-to-Fork and Biodiversity strategies.

5.3.1. Existing Frameworks and their Scope

A literature review (Scopus and Web of Science, 2005–2025) identified several frameworks addressing aspects of context dependency in agriculture and ecology (Table 7). Principle-based IPM approaches, such as Barzman et al. (2015) or Stenberg (2017), provide overarching guidance for pest management integration but remain qualitative and lack tools to assess site-specific context. Agroecological transition frameworks, like Deguine et al. (2021) or Cassart et al. (2025) adopt a systemic perspective that combines biodiversity and social learning, yet they are not aligned with the IPM taxonomy (WP2) and lack quantitative scoring. Some indicator-driven studies, such as Finger et al. (2024) or Ryalls et al. (2024), introduce quantitative elements like adoption metrics or pest guild responses, but they focus on specific crops or omit socio-economic and policy dimensions. Conceptual contributions by Han et al. (2024) on multi-pest dynamics and Stastny et al. 2025) on regional IPM adaptation provide useful insights but are not operational for broad agricultural use.

5.3.2. Reference Mapping for Context Dependency Parameters in IPM

None of the frameworks reviewed address the core challenge of explaining why the efficiency of IPM practices varies between sites. Quantitative scoring approaches are rare, and none link context assessment to the IPM taxonomy needed for harmonised European approaches. Existing studies are either principle-based with little operational detail, highly specific to single crops or pests, or focused on broad agroecological transitions without quantifying performance differences across locations. This reveals a major knowledge gap: there is no structured way to assess how local environmental and agronomic conditions determine the success of IPM strategies.

A detailed comparison of nine reviewed frameworks is presented in the Appendix (Table 7). This table summarises their context dimensions, scaling methods, levels of application and relevance for AGROWISE, thereby providing the evidence base for developing a new indicator framework.

5.3.3. Overview of the Context Dependency Indicators

The review of the nine previously mentioned frameworks and of additional empirical studies and literature highlights how site-specific environmental and agronomic conditions shape the performance of IPM practices. All parameters found were organised into a new framework of six biophysical indicator groups.

5.3.3.1. Climate & Weather

Frameworks such as Cassart et al. (2025) and Deguine et al. (2021), as well as modelling studies like Tonnang et al. (2017), consistently highlight the impact of climatic variables — including temperature, rainfall, seasonal shifts, and extreme events. For example, Cassart’s heuristic framework explicitly lists climate as a contextual factor shaping agroecological transitions, while Deguine’s agroecological crop protection paradigm links seasonal variability to the timing and efficacy of preventive IPM measures. Additional studies (e.g., Simić et al. 2024)) show that weather–rotation interactions can alter herbicide performance and pest dynamics in maize. Extreme weather and erosion processes are less frequently quantified but are mentioned as influencing field stability and pest habitat quality (Cassart et al. 2025; Fernandes und Gontijo 2020)

5.3.3.2. Soil Characteristics & Hydrology

Soil parameters emerge in both Cassart et al. (2025) and Finger et al. (2024) as part of the environmental context that influences adoption and performance of IPM practices. Soil texture, structure, pH, and organic matter are identified as drivers of crop resilience and pest–pathogen complexes. Empirical evidence from Lechenet et al. (2017) and Brévault & Clouvel (2019) links reduced-input systems and soil fertility management to improved natural regulation, showing that soil quality modulates pest outbreaks and the effectiveness of biological control. Hydrological aspects — drainage, waterlogging, soil moisture — are mentioned in both framework and empirical sources (e.g., Han et al. 2024 on multi-pest dynamics across soil–crop–pest interfaces).

5.3.3.3. Landscape Structure & Topography

Landscape-scale drivers are central in several frameworks, particularly Cassart et al. (2025) and Deguine et al. (2021), which integrate semi-natural habitats, hedgerows, and field mosaics as determinants of natural enemy populations and pest dispersal. Holland et al. (2016) and Petit et al. (2020) provide extensive evidence that non-crop habitats and topographic variation mediate biological control at landscape scales, though effects can be context-dependent and sometimes inconsistent. Wyckhuys et al. (2024) emphasise global restoration of functional landscapes for pest control, reinforcing the importance of multi-scale habitat management.

5.3.3.4. Biodiversity & Ecosystem Functions

Biodiversity — particularly functional biodiversity of natural enemies and pollinators — is a cornerstone of agroecological IPM frameworks such as Deguine et al. (2021) and Cassart et al. (2025). Both highlight the role of predators, parasitoids, and decomposers in delivering ecosystem services crucial for pest suppression. Duru et al. (2015) and Alexandridis et al. (2021) provide modelling and empirical insights into biodiversity–pest control relationships, stressing context sensitivity: benefits of biodiversity for pest regulation vary with landscape configuration and management intensity. Ryalls et al. (2024) further demonstrate pest guild-specific responses in orchards, showing that biodiversity-driven control can reduce some pests while having neutral or mixed effects on others.

5.3.3.5. Pest Pressure & Biotic Risk Context

Variability in pest populations and resistance profiles is central in multiple frameworks: Ryalls et al. (2024) document how IPM outcomes differ across pest feeding guilds, while Alkema et al. (2019) reveal behavioural context dependence (e.g., push–pull efficacy varying with pest life stage and environmental cues). Stastny et al. (2025) extends this to regional adaptation of IPM for invasive pests, emphasizing that pest ecology and local biotic communities must be assessed before transferring control strategies. Complementary studies like Cardim Ferreira Lima et al. (2020) and Preti et al. (2020) highlight the role of automated monitoring and pathogen–pest complexes in understanding local biotic risk.

5.3.3.6. Temporal & Legacy Effects

Historical management and crop rotations are recurrent in Cassart et al. (2025) and Stastny et al. (2025) as key context dimensions — legacy effects shape current pest communities and system resilience. Simić et al. (2024) provides empirical evidence: diversified rotations in maize reduce weed and pest pressures and mitigate herbicide dependence over time. Duru et al. (2015) similarly note that long-term agroecological management builds soil and habitat conditions that enhance natural control, creating “system memory” that influences future pest dynamics.

Collectively, these frameworks and studies provide a rich qualitative mapping of context parameters relevant for IPM but lack a unified quantitative scoring approach. Climate, soil, and biodiversity factors are consistently represented, while erosion, decomposer communities, and invasive pest emergence are less systematically covered. This mapping confirms the need for

AGROWISE Task 3.4 to develop an integrated indicator framework: one that links these parameters, quantifies their influence on IPM performance, and supports cross-regional comparison and policy harmonisation. A detailed overview of all six indicator groups, their parameters, and associated literature sources is provided in the supplementary reference table (see Appendices Table 8).

5.3.4. Interdependencies, Feedback Loops, and Cascading Effects between Indicators

IPM does not operate through isolated parameters but within a complex network of interdependent processes. As shown in Figure 1 each of the six indicator groups is connected to several others, meaning that changes in one parameter rarely remain confined but often cascade throughout the system. This network was developed within WP3.4 of the AGROWISE project, drawing on the taxonomy established in WP2.1 (SLU 2024), the evidence from the systematic literature review (Section 5.3.3) and the context dependency scoring in the three case studies (Section 5.6). It represents an interpretative framework that integrates the project team's synthesis and expert judgement, rather than a direct reproduction of published evidence. While it is informed by insights from the literature (e.g. Duru et al., 2015; Petit et al., 2020; Wyckhuys et al., 2024), the relationships shown were identified through the analytical process in WP3.4 and therefore constitute an original contribution of this deliverable.

Cascading effects are particularly visible for the indicator group Climate & weather. A single climatic event, such as extreme rainfall, may accelerate erosion processes, thereby reducing soil fertility and destabilising soil structure. Weakened soils subsequently alter biodiversity composition, reduce habitat suitability for beneficial organisms, and increase the vulnerability of crops to pests. This chain of effects ultimately converges on higher pest pressure, which in turn influences pesticide use and feeds into long-term legacy effects. Thus, a single climatic disturbance propagates through multiple system components, creating long-lasting impacts on IPM effectiveness. Across all interactions, pest pressure emerges as the most strongly affected indicator, acting as the central outcome where multiple pathways converge.

The presence of feedback loops further amplifies these dynamics. Positive feedback, such as improved soil organic matter enhancing biological control, can initiate virtuous cycles that reinforce IPM effectiveness. Negative feedback, such as pesticide overuse reducing biodiversity and thereby increasing pest outbreaks, can trap systems in degrading trajectories. Recognising and managing these loops is crucial for effective regulation.

Policy implications are clear: regulatory frameworks for IPM must be adaptive and long-term in perspective. Setting fixed short-term targets risks overlooking delayed benefits or hidden trade-offs. Instead, policies should account for system-level dynamics, time lags, and cumulative effects. This means that evaluation frameworks need to capture both immediate outcomes (e.g. reduced pesticide applications in a single season) and gradual changes in ecosystem properties (e.g. soil health, biodiversity, resilience). Only by acknowledging interdependencies and cascading effects can regulation fully support the transition towards sustainable pest management.

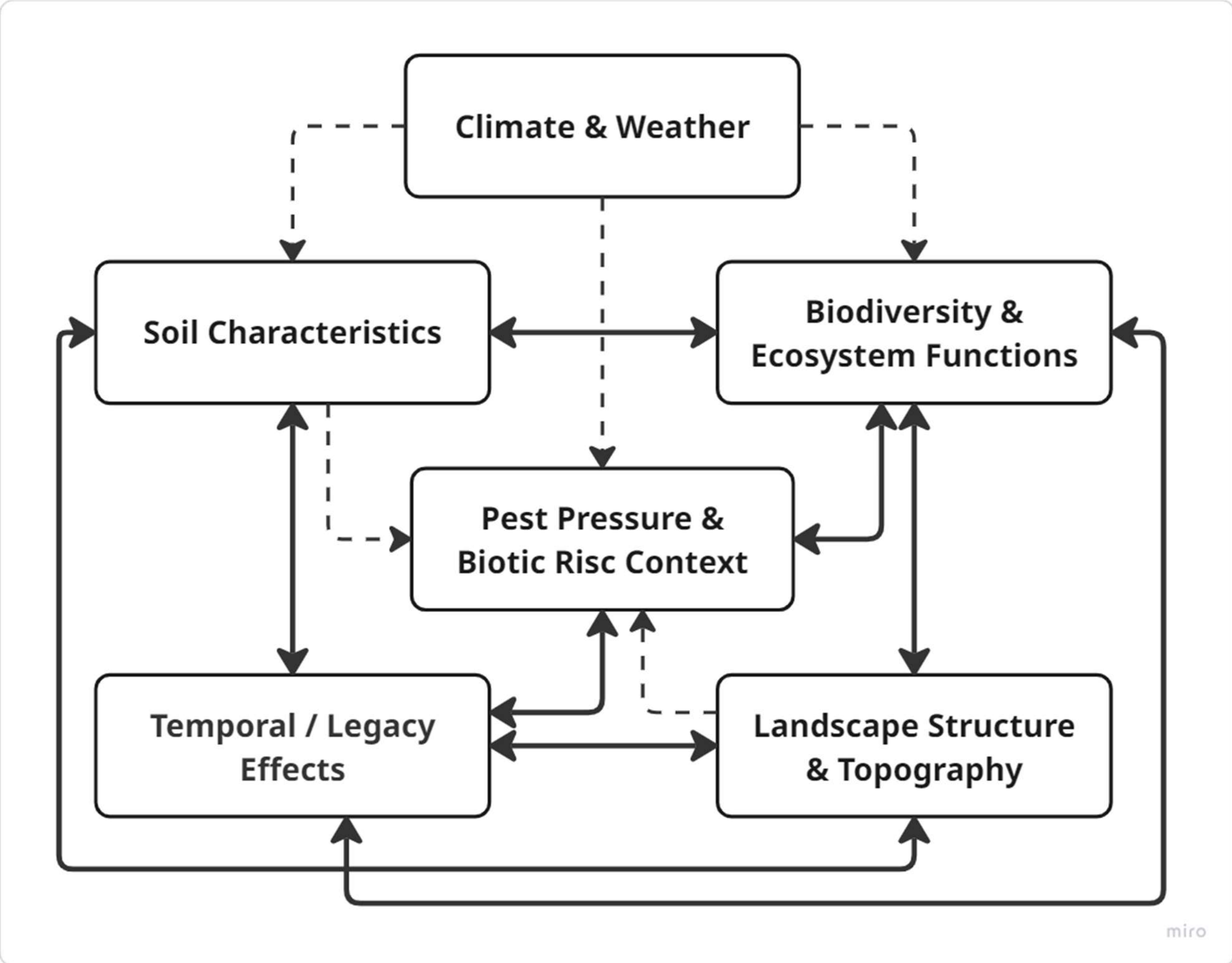

Figure 1: Network of interlinked context indicators shaping IPM effectiveness. Solid bold arrows indicate strong two-way interactions between indicators, while thinner dashed arrows represent one-way influences Developed by the AGROWISE consortium (WP3.4) based on literature synthesis and case study analysis, and should be understood as a heuristic framework rather than a quantitative model.

5.3.5. Which Parameters Can Be Influenced – and How Fast?

To assess the practical relevance of context parameters for IPM implementation, it is essential to determine how far each indicator group can be influenced—either through farm-level management or through policy-level intervention. The answer to this question depends on the response time of the associated subfactors. Parameters that respond quickly (short- to mid-term) can often be addressed by farmers themselves, while those with long-term dynamics typically require policy change or collective action.

The classification of subfactors according to response time (short-term, mid-term, long-term, or not changeable) provides the basis for this analysis and is summarised in Table 1.

1. **Climate & Weather Conditions**

These parameters (e.g. temperature, rainfall, extreme events) are slightly changeable on a long-term and landscape scale and form the static environmental background of IPM systems. They cannot be influenced on a human lifetime-scale by farmers and must be accounted for when adapting practices to local conditions.

2. **Landscape Structure & Topography**

Certain subfactors such as field configuration or the presence of non-crop habitats (e.g. hedgerows, buffer strips) can be influenced mid- to long-term, with limited options for individual farmers. Effective changes typically require policy support or collective actions (e.g. landscape planning, agri-environmental schemes). Other subfactors, like topography and surroundings, are hardly changeable.

3. **Temporal & Legacy Effects**

These include past land use, management legacies, and system memory effects, which are slow-changing or permanent. While some adjustments (e.g. crop rotation) can be initiated by farmers, their effects are long-term. Substantial change requires long-term strategies and policy intervention, as farmers alone cannot alter historical trajectories.

4. **Soil Characteristics**

Most soil parameters (e.g. physical structure, chemical properties, biological activity) are mid-term modifiable via farm-level practices such as fertilisation, organic amendments, or tillage management. Some subfactors like surface erosion require long-term efforts and may need policy support for effective mitigation (e.g. erosion control programs).

5. **Biodiversity & Ecosystem Functions**

Natural enemy populations, pollinators, and decomposers can be enhanced mid-term through on-farm habitat measures (e.g. flower strips, reduced pesticide use). In contrast, functional diversity and ecosystem interactions develop over the long term, requiring landscape-level coordination and supportive policies to be effective.

6. **Pest Pressure & Biotic Risk Context**

Certain subfactors (e.g. spatial variability of pests, seasonal pest dynamics) are short-term responsive and can be managed by farmers through monitoring, thresholds, and biological control. More complex subfactors (e.g. resistance status, pathogen complexes) are mid-term modifiable but may require advisory support. The emergence of invasive species, however, is not controllable at the farm level.

The majority of subfactors in soil, biodiversity, and pest pressure are short- to mid-term responsive and can be actively influenced by farmers through well-designed IPM strategies. In contrast, landscape structure and legacy effects are largely long-term and require policy-level instruments for meaningful change. These findings underscore the importance of matching interventions to response time:

- **Farmers' actions should target indicators with short to mid-term potential,**
- **Policy must focus on enabling change for long-term dependent indicators at a landscape level.**

A detailed overview of subfactor response times and their associated influence level is provided in Table 1.
Each indicator group receives a score between 0 (no influence) and 3 (strong influence). This is not a simple average of subfactor scores. Instead, the overall score reflects how many subfactors are involved and how strongly they affect the practice.

Example: If soil water availability is critical and biodiversity has a minor effect, the overall score for soil may still be set to high (3), because the practice strongly depends on soil conditions.

Table 1: Subfactors of context parameters, classified by response time.

Response Time	Short-Term (0-1 year)	Mid-Term (1-5 years)	Long-Term (5-20 years)	Not changeable
Climate and Weather				**Macro- and microclimatic variables** (e.g. temperature, rainfall, seasonal shifts)
				Frequency and intensity of **extreme weather events**
				Seasonal variability
Landscape Structure & Topography			**Field configuration** (e.g. field size, shape, orientation)	
		Presence of non-crop habitats (e.g. hedgerows, buffer strips, flower strips)		
				Topographical variation (e.g. slopes, elevation differences)
				Surroundings (neighbour farms, drifts etc.)
Temporal & Legacy Effects				**Past land use**
			Crop rotation history	
			Management legacies (e.g. past pesticide/fertiliser use, tillage practices)	
				System memory effects (long-term ecological or structural impacts)
Soil Characteristics		**Physical soil properties** (e.g. texture, structure, compaction)		
		Chemical properties (e.g. pH, nutrient availability, salinity)		

		Biological activity (e.g. soil biota, microbial life)		
		Water dynamics (e.g. drainage capacity, soil moisture levels, waterlogging)		
			Surface erosion processes	
Biodiversity & Ecosystem Functions		**Presence of natural enemies** (e.g. predators, parasitoids)		
		Pollinator abundance and diversity		
		Decomposer communities		
			Functional diversity within the agroecosystem	
			Ecosystem service interactions	
Pest Pressure & Biotic Risk Context	**Spatial variability of pest populations**			
	Temporal dynamics (e.g. seasonal patterns, outbreak cycles)			
		Pathogen and pest complexes		
		Resistance status of pests to control measures		
		Invasiveness or emergence of new pest species		

5.4. Systematic Review: Coverage of Indicators in the Literature

5.4.1. Objective of the Review

The purpose of this systematic review is to analyse how the six biophysical context indicators identified in Task 3.4 are represented in the scientific literature on IPM and agroecology within Europe. Specifically, the review aims to:

- **Quantify the coverage of each indicator** by mapping how frequently the different indicators are addressed in peer-reviewed studies relevant to European cropping systems.
- **Identify research imbalances** by highlighting which indicators are comparatively well studied and which remain underexplored. This assessment will clarify where robust evidence already exists to inform regulatory decision-making and where future research investment is required.
- **Examine cooccurrence patterns** among indicators, for example whether climate and soil factors are commonly assessed together, or whether biodiversity is treated in isolation from pest pressure dynamics. Understanding such interlinkages supports the development of multifactorial frameworks rather than single-parameter assessments.
- **Provide a knowledge baseline** for prioritising future research and for detecting gaps that may undermine the transferability of IPM and agroecological practices across Europe's diverse biogeographic regions.

By systematically mapping indicator coverage, the review establishes the empirical foundation needed to judge the robustness and generalisability of current evidence on site-specific drivers of IPM efficiency.

5.4.2. Methodology

A systematic literature search was conducted in **Scopus** and **Web of Science** to identify European studies addressing context dependency of IPM and agroecological practices. The search string combined three concept blocks (Table 2:) –

1. IPM/agroecological terms
2. performance/efficiency terms
3. context-dependency terms

– and was limited to peer-reviewed articles and reviews (2010–2025) in English from European countries (EU Member States, UK, Norway, Switzerland). Subject areas included agronomy, plant sciences, and environmental sciences (Appendices 8.2.4).

After merging the search results, duplicates were removed, and studies were screened in two steps (title/abstract; full text where necessary). Each study was coded for the presence of the six previously defined context indicators; multiple indicators per study were possible, and cooccurrence patterns were recorded. Quantitative synthesis included counts per indicator and analysis of frequent indicator combinations. This provides the basis for identifying well covered versus under-represented context factors in the literature.

Table 2: Overview of search string structure (keywords grouped by concept block). The asterisk (*) indicates the use of a truncation symbol in the search string, allowing retrieval of all word variants with the same root (e.g. "agroeco" covers "agroecological" and "agroecology").

Concept block	Example keywords used in search*
IPM / agroecological	integrated, biological, agroecological, agroeco*, cultural, mechanical, IPM, IWM, IDM, resistance management
Performance / efficiency	effectiveness, efficiency, performance, evaluation, assessment
Context dependency	context dependenc*, sitespecific, locationspecific, systemspecific, region*, transferab*

5.4.3. Quantitative Coverage Results

A total of 1,313 studies were identified through the systematic database search (Scopus and Web of Science) after duplicate removal. The subsequent screening process applied strict inclusion criteria: studies had to (i) be conducted in a European context, (ii) address IPM practices or agroecological control measures, and (iii) explicitly describe at least one of the six predefined context indicators (climate, soil, landscape, biodiversity, pest pressure, temporal/legacy effects) that potentially influence the efficiency of the practice.

Following these criteria, 70 studies (5.3% of screened records) were retained for quantitative analysis.

5.4.3.1. Qualitative Patterns

The quantitative coverage analysis reveals notable variation in how frequently the different context indicators are addressed within the retained studies. Climate and weather conditions—the root drivers of cascading effects in the indicator network (Figure 1), hardly changeable—were most frequently represented, occurring in 38 studies (54%). They were followed by pest pressure & biotic risk context (19 studies; 27%), located at the bottom end of the cascade but often changeable in the short term, and by soil characteristics (18 studies; 25%), which are typically changeable at the farm scale over mid-term. Landscape structure and topography appeared also in 18 studies (25%). In contrast, temporal &legacy effects (6 studies; 8%) and biodiversity and ecosystem functions (4 studies; 6%) were least represented. The accompanying bar chart illustrates the absolute frequency of each indicator, allowing direct comparison of their coverage across the literature (Figure 2).

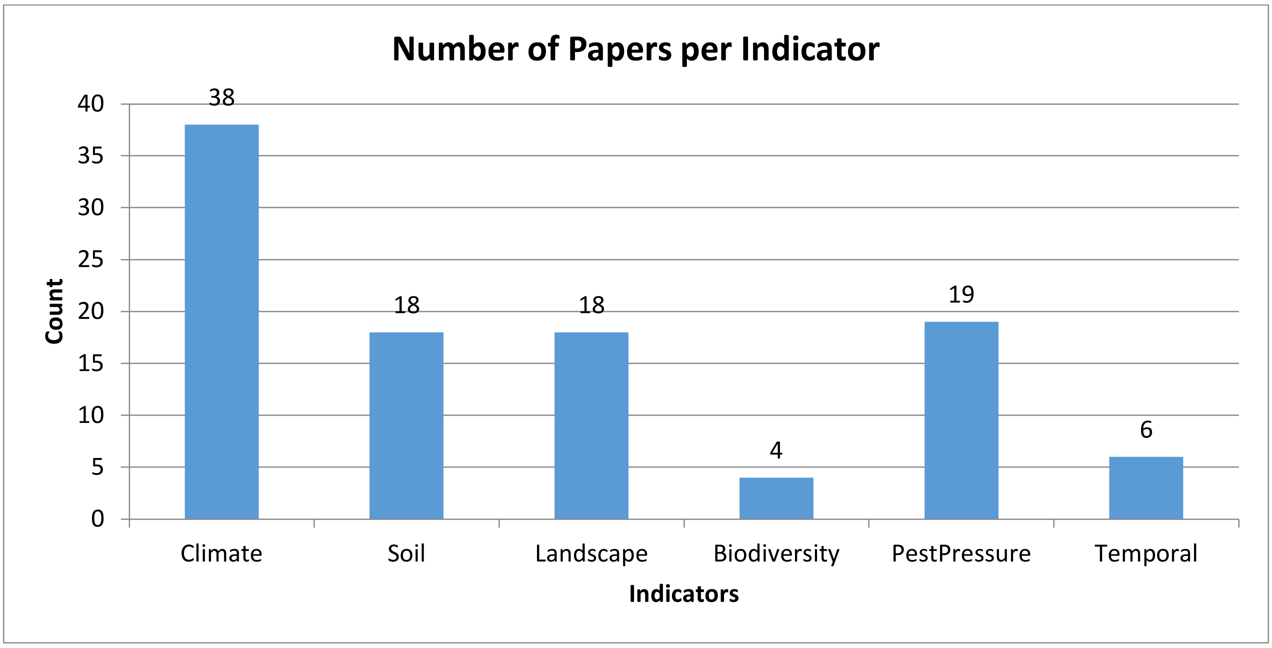

Figure 2: Results of the systematic review – absolute frequency of context indicators across the 70 relevant studies.

In contrast, the pie chart depicts the relative proportions of the indicators, highlighting the dominance of climate-related and soil-related factors compared to biodiversity and temporal aspects Figure 3.

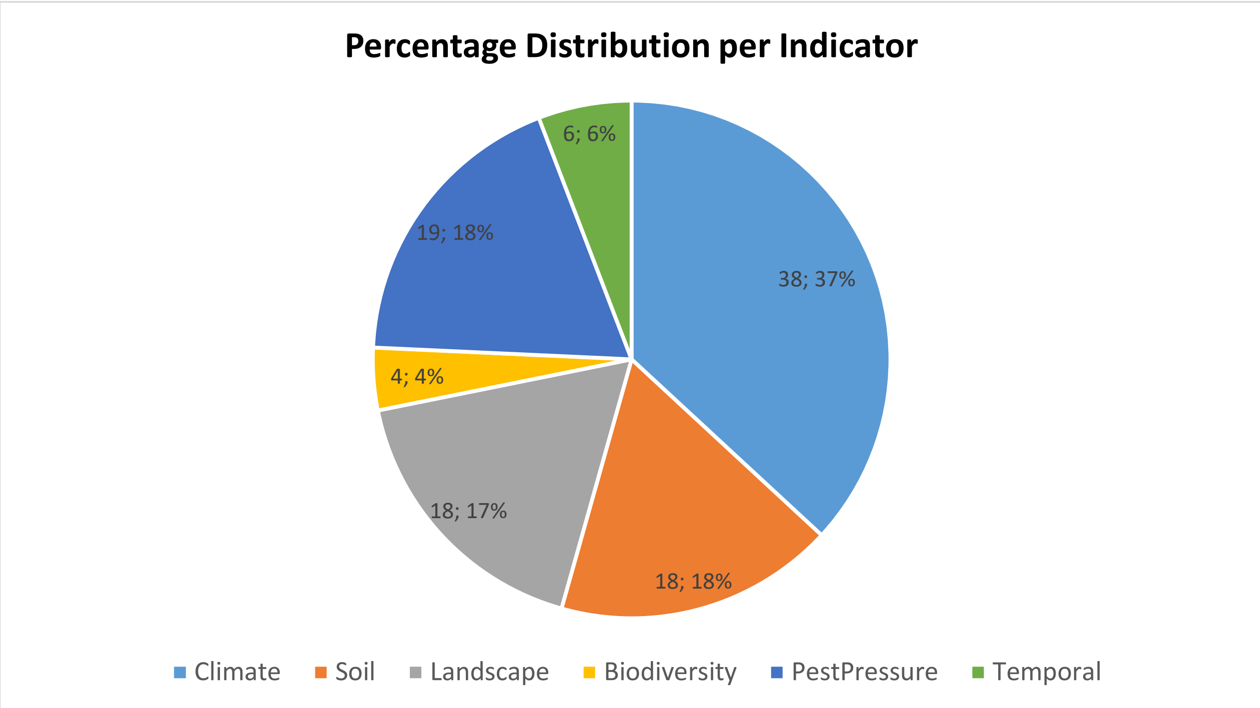

Figure 3: Results of the systematic review – relative proportion of context indicators across the 70 relevant studies with 103 indicator counts in total.

Beyond the frequency of individual indicators, we assessed how many context indicators each study simultaneously addressed. The majority of relevant studies (45 out of 70; 64%) focused on a single indicator, while 16 studies (23%) considered two indicators and five studies (7%) included three indicators. Only two studies (3%) addressed a very broad context, covering five or even all six indicators. This distribution

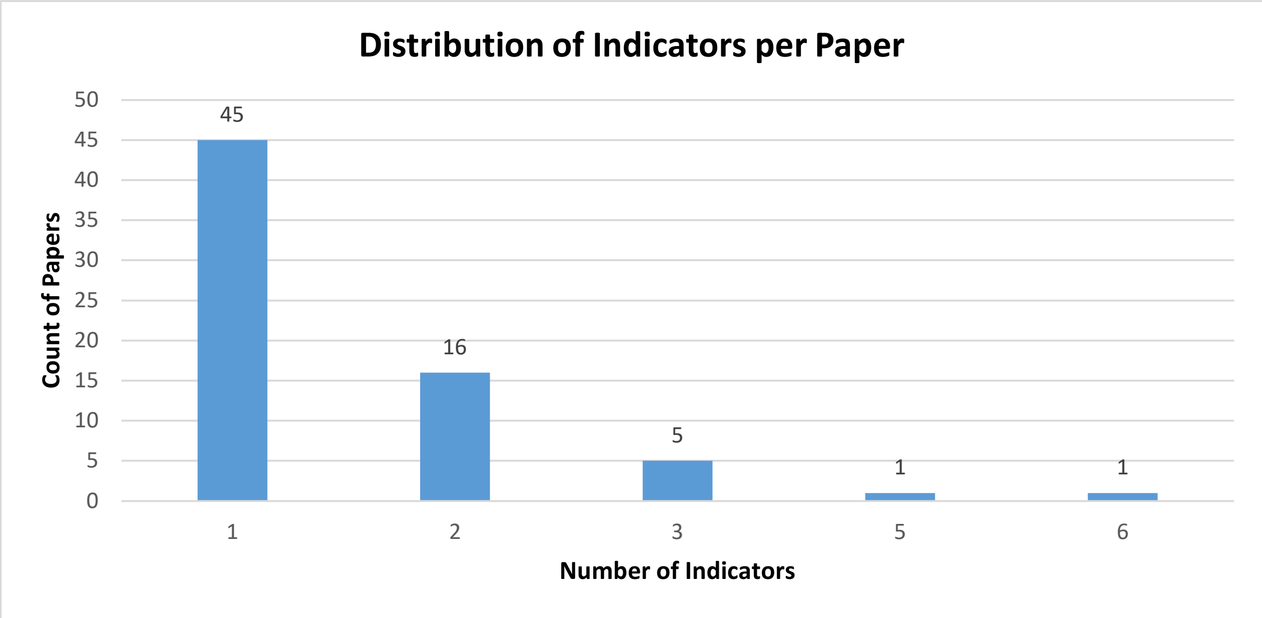

Figure 4) highlights that most of the existing literature provides a narrow, single-factor analysis of IPM practice efficiency, whereas integrative multi-factor approaches are rare.

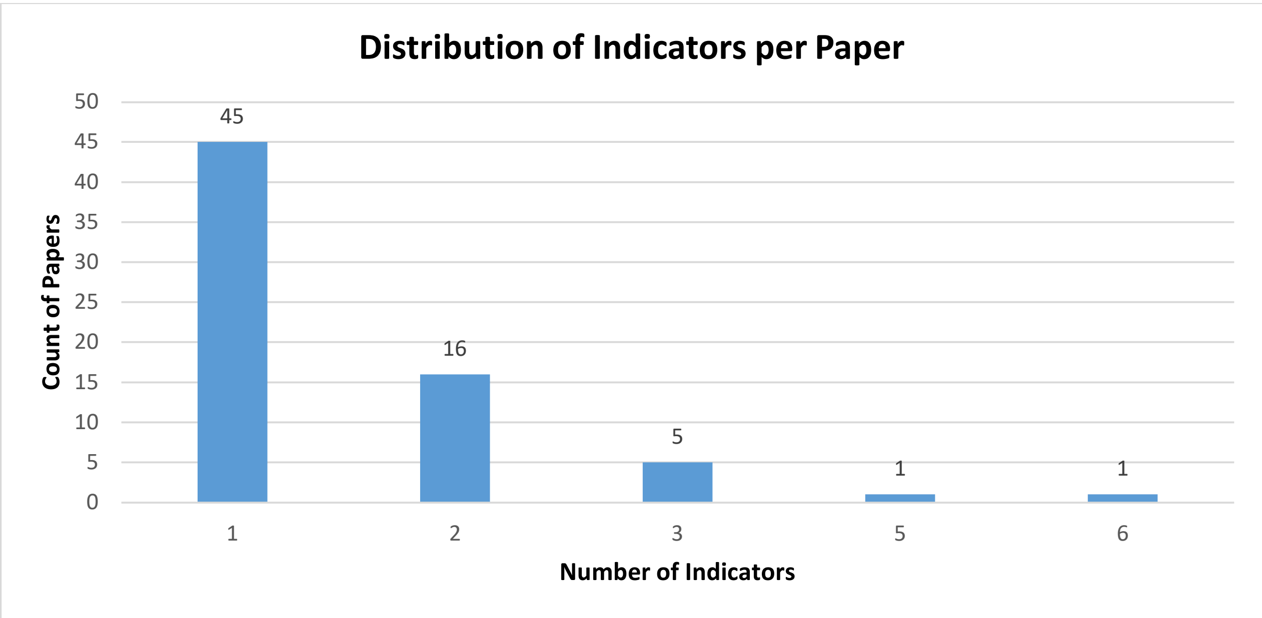

Figure 4: Results of the systematic review – number of context indicators simultaneously addressed per study.

5.4.4. Co-Occurrence Analysis

The symmetric co-occurrence matrix (Figure 5) highlights overlapping factors, showing that combinations of climate and soil (12 studies) and climate and landscape (8 studies) occur most frequently. In contrast, biodiversity-related factors show very low co-occurrence with other indicators. This pattern suggests that abiotic factors (climate, soil, landscape) are far more commonly integrated into assessments of IPM efficiency than biotic interactions (biodiversity) or long-term legacy effects (temporal factors).

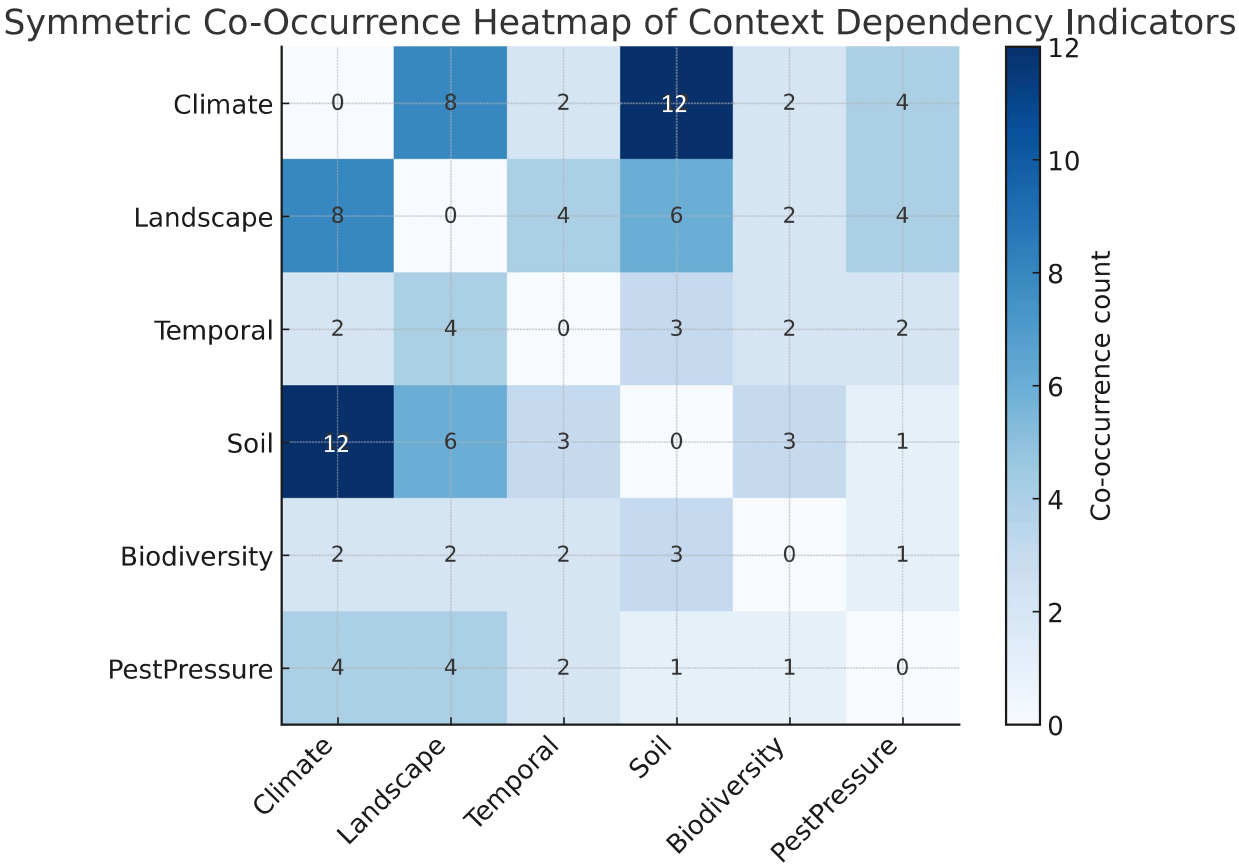

Figure 5: Symmetric co-occurrence matrix of context indicators derived from the systematic review. The heatmap visualises how often pairs of context indicators co-occurred across the 70 relevant studies. The matrix is symmetrized, meaning that relationships are undirected (e.g., "Climate–Soil" equals "Soil–Climate"). Darker shades indicate higher co-occurrence frequencies, highlighting which indicators are most frequently studied in combination (e.g., Climate–Soil and Climate–Landscape), while lighter shades reveal underexplored indicator pairings.

5.4.5. Knowledge Gaps

The systematic review revealed several critical knowledge gaps in the current evidence base regarding context-dependent efficiency of IPM and agroecological practices:

Underrepresented indicators: Biodiversity and temporal & legacy effects are rarely addressed in the reviewed studies (≤6% and ≤8% of studies, respectively). This underrepresentation limits understanding of how ecosystem services and historical land-use dynamics influence practice performance.

Limited integration of multiple indicators: Most studies focus on single contextual factors (64% of relevant studies), with very few addressing more than three indicators simultaneously. As a result, multi-factor interactions — e.g., how climate variability and soil properties jointly affect pest dynamics — remain poorly studied.

Bias towards abiotic factors: The evidence base is dominated by abiotic indicators (climate, soil, landscape), while biotic interactions (biodiversity, pest–predator dynamics) are comparatively neglected. This imbalance constrains the ability to design IPM strategies that leverage ecological processes such as natural pest regulation.

Weak evidence on cross-scale interactions: Interactions between field-level and landscape-level drivers are seldom explored, even though they are crucial for understanding transferability of IPM outcomes across regions and farming systems.

These gaps highlight the need for more integrative research designs that combine abiotic and biotic factors, consider legacy effects, and evaluate practice efficiency across spatial and temporal scales.

5.5. Context-Dependency-Scoring

5.5.1. Classification Scale (0–3) and Measurement Approach

The classification scale has been developed to systematically evaluate the degree of context dependency of IPM and agroecological practices across European farming systems (Table 3). Context dependency in this framework refers to the extent to which the efficiency of a practice — in terms of pest control, pesticide reduction, and yield stability — is shaped by site-specific biophysical and agronomic conditions such as climate, soil characteristics, landscape configuration, biodiversity, pest pressure, or legacy effects.

Table 3: Context-Dependency-Scoring (0-3) for assessing context dependency of IPM practices across six biophysical indicator groups. The scale describes how strongly a practice's performance depends on each parameter group.

Score	Label	Definition	Interpretation for a parameter group
0	Non-dependent	Practice performance is unaffected by this parameter group.	No relevant influence (works independently of factor).
1	Low dependency	Parameters have limited influence on effectiveness.	Works reasonably across most sites; minor adjustments may help.
2	Medium dependency	Parameter moderately affects performance or feasibility.	Effectiveness requires adjustment or calibration to site conditions.
3	High dependency	Parameter strongly influences practice outcome.	Success only under specific local conditions; high risk of failure otherwise.

This scale fulfils several complementary purposes:

Transparency: It establishes a uniform scoring scheme that can be applied consistently to diverse crops, farming systems, and regions. By using the same 0–3 classification for all practices and all six context indicators, it allows stakeholders — from researchers to policy makers — to trace why a given practice is classified as binding, optional, or conditional.

Compatibility with efficiency metrics (ASP/IASP): The scale is fully aligned with the efficiency assessment developed in WP2.3. By combining context dependency (0–3) with Agronomic Service

Provided (ASP) and Improvement of ASP (IASP) scores, practices can be jointly evaluated for both effectiveness and context sensitivity.

Comparability and cross-case learning: The classification makes it possible to compare results across different crops and regions and to synthesise findings from the case studies (apple orchards, vineyards, cereals). Such cross-case analysis will highlight patterns — for example, whether pest pressure or biodiversity is a dominant driver of variability — and guide future data collection or modelling efforts.

5.5.2. Scoring Methodology

Step 1: Assess sub-factors within each indicator group:
Each of the six main context indicators (climate, soil, landscape, biodiversity, pest pressure, legacy effects) is divided into several sub-factors (e.g., for soil: texture, structure, fertility, water dynamics, biological activity). During scoring, all sub-factors that show any influence on a practice's performance are marked, regardless of whether this influence is strong or weak.

We consider only limiting effects. Positive context effects are not included, unless a normally expected benefit is suppressed by local conditions—in which case, context dependency is rated higher.

Step 2: Determine indicator level score (0–3):
Each indicator group receives a score between 0 (no influence) and 3 (strong influence). This is not a simple average of subfactor scores. Instead, the overall score reflects how many subfactors are involved and how strongly they affect the practice.

Example: If soil water availability is critical and biodiversity has a minor effect, the overall score for soil may still be set to high (3), because the practice strongly depends on soil conditions.

Step 3: Calculate overall context dependency score for the practice:
For each practice, the scores (0–3) from all six indicator groups are summed and divided by six to obtain the mean context dependency score (Equation 1):

Equation 1: ***Context Dependency Score (CD-Score)***

$$Context\ Dependency\ Score = \frac{CD_{climate} + CD_{soil} + CD_{landscape} + CD_{biodiversity} + CD_{pest\ pressure} + CD_{legacy}}{\mathrm{N}}$$

With N = number of context indicator group

5.6. Case Study Insights

The following section presents the main results of the context dependency analysis for each of the three case studies. For apples (codling moth), vineyards (powdery mildew), and cereals (weed management), individual practices were mapped within the harmonised taxonomy, scored across the six indicator groups, and linked to their ASP efficiency values. These case-specific insights highlight both common patterns and system-specific differences, providing the empirical foundation for the cross-case synthesis in the subsequent section.

5.6.1. Selection of Case Studies

The context dependency framework developed in WP3.4 is applied to **three representative case**

studies:

1. **Apple orchards – codling moth** (Cydia pomonella)
2. **Vineyards – powdery mildew** (*Erysiphe necator*)
3. **Cereals – weeds**

These case studies were not newly defined within WP3.4 but originate from the work conducted in WP2.4 (Efficiency assessment – ASP/IASP)**.** In WP2.4, the consortium selected these crop–pest combinations to serve as reference systems for evaluating the efficiency of IPM and agroecological practices. The selection criteria included:

- **Relevance to major EU crops:** high pesticide uses and economic importance.
- **Diversity of pest types:** insect (codling moth), fungal (powdery mildew), and weed complexes (in cereals).
- **Representation of contrasting production systems:** permanent (apple, vineyard) versus arable (cereals).

By building on the same case studies, WP3.4 ensures consistency between efficiency (ASP/IASP) and context dependency assessments. This alignment facilitates direct comparison and later integration of results in the decision matrix for binding vs. optional classification.

5.6.2. Methodology for Case Study Application

For the case studies, WP3.4 builds on the groundwork of WP2.1 (SLU, 2024), which developed the harmonised taxonomy of IPM practices. This taxonomy was structured around the eight IPM principles defined in Directive 2009/128/EC (European Parliament and Council 2009) and further elaborated by Barzman et al. (2015). To ensure comparability and harmonisation across systems, WP2.1 organised practices into four hierarchical layers: (i) the **management target** (e.g. crop choice, physical control), (ii) the **IPM strategy** (e.g. enhancing beneficial organisms, reducing pesticide inputs), (iii) the **specific practice** (e.g. crop rotation, pheromone traps), and (iv) **options within practices** (e.g. types of barriers, specific biocontrol agents). This multi-level structure allows consistent mapping of practices from tactical (short-term) to strategic (longer-term) interventions and facilitates their use for both scientific analysis and policy design (Heinen et al. 2024).

Building on this, WP2.4 designed and documented the case studies, assigning each practice to the WP2.1 taxonomy and evaluating its Agronomic Service Provided (ASP), efficiency score, and time of anticipation (Appendices: Table 10, Table 11, Table 12). WP3.4 then takes these case studies as its starting point: the same set of practices was used to assess context dependency, ensuring full consistency between efficiency evaluation (WP2.4) and context sensitivity analysis (WP3.4).

Before discussing principle-specific differences, it is important to recall that Integrated Pest Management in the EU is structured around eight core principles, which were introduced in the Sustainable Use of Pesticides Directive (2009/128/EC) and further elaborated by Barzman et al. (2015). These principles provide the overarching framework for reducing reliance on chemical pesticides and promoting sustainable crop protection.

They include:

1. **Prevention and suppression** (e.g. crop rotation, resistant varieties, hygiene).
2. **Monitoring** (regular observation of pests, weeds, and diseases).

3. **Decision-making** (use of thresholds and decision support systems).
4. **Non-chemical methods** (mechanical, biological, and cultural control).
5. **Pesticide selection** (preference for products with lowest risk).
6. **Reduced pesticide use** (optimising dose, timing, and application).
7. **Anti-resistance strategies** (rotations and combinations of modes of action).
8. **Evaluation** (assessment of practice effectiveness and continuous improvement).

Together, these principles represent the normative baseline against which IPM practices and systems are assessed in this deliverable.

The context dependency was then scored for the six indicator groups (climate, soil, landscape, biodiversity, pest pressure, legacy) using the 0–3 scale introduced in Section 5.5.1. Subfactors from Table 1 guided the scoring, and the six indicator scores were averaged to obtain an overall context dependency value for each practice. Finally, these results are analysed together with the ASP score and time of anticipation to explore relationships between efficiency, response time, and context sensitivity. Visual outputs (radar charts and summary tables) allow comparison across practices and case studies and provide the evidence base for the policy discussion in Chapter 6.

5.6.3. Apple-Codling Moth

The apple–codling moth system represents a key perennial crop–pest interaction in Europe. Codling moth (*Cydia pomonella*) is one of the most significant pests in pome fruit orchards, with high economic relevance due to fruit damage and market losses. Intensive pesticide use remains common in many regions, making it a priority system for implementing IPM measures to achieve pesticide reduction targets under the EU Farm to Fork Strategy. Within this case study, a total of 19 IPM practices were analysed, covering six of the eight IPM principles (Appendices: Table 10). The distribution was uneven: while only single practices were assigned to Principle 6 (Reduced pesticide use) and Principle 7 (Resistance management), the majority fell under Principle 4 (Non-chemical solutions), followed by Principles 1 (Prevention and suppression) and 2 (Monitoring).

5.6.3.1. Results of Context Dependency Analysis

The radar chart (Figure 6) illustrates that climate and pest pressure are the dominant drivers of variability, while soil has the lowest influence. Landscape and temporal effects contribute moderately, and biodiversity shows intermediate sensitivity.

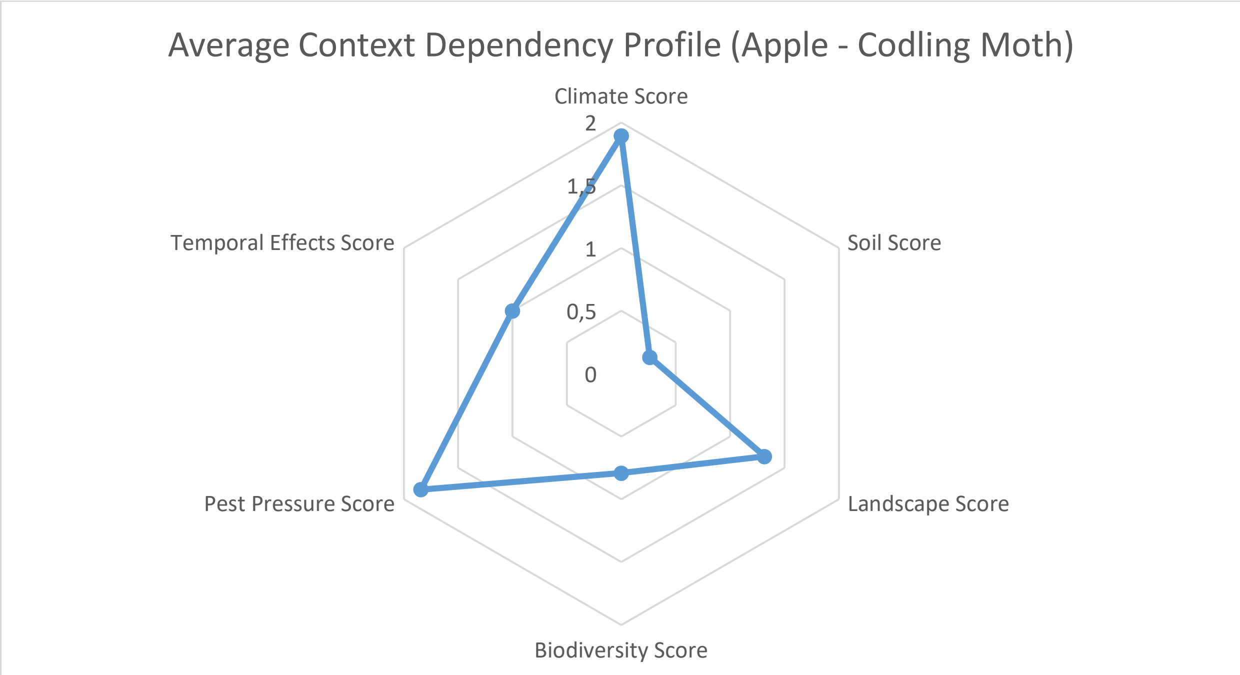

Figure 6: Average context dependency profile (radar chart) for the apple–codling moth case study. The chart shows mean scores (0–3) across six biophysical indicators.

The bar chart (Figure 7) complements this profile by showing the average context dependency scores for each indicator group across all practices. It confirms that climate- and pest-related factors consistently score highest (near 2), while soil remains negligible (<0.5).

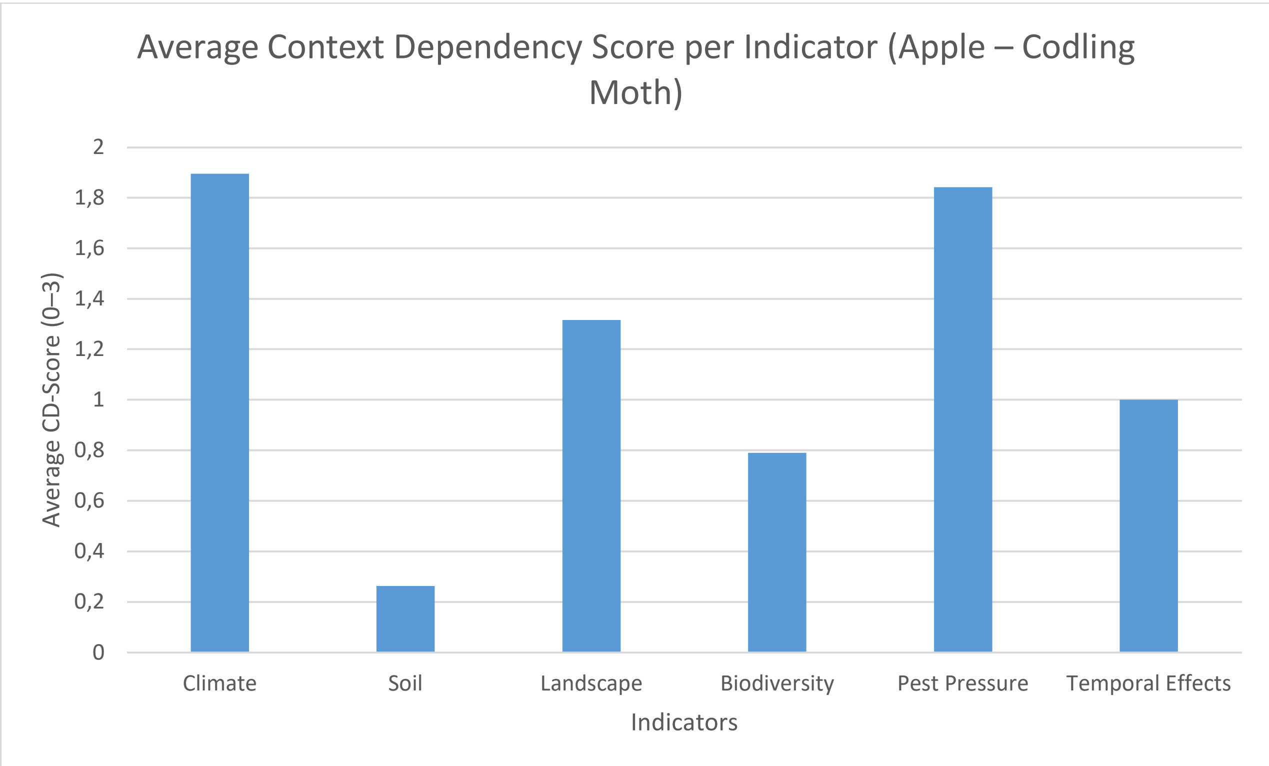

Figure 7: Average context dependency scores per indicator (bar chart) for the apple–codling moth case study.

5.6.3.2. ASP Score vs. Context Dependency

The relationship between ASP efficiency scores and context dependency scores is visualised in Figure 8. Each bubble represents a single IPM practice; bubble size indicates the frequency of identical score combinations. Most practices cluster in the medium efficiency (ASP ~2) and medium context dependency (~1–2) range. Practices under non-chemical solutions (principle 4) frequently show higher ASP scores but also increased context dependency, reflecting their ecological reliance on local conditions (e.g., mating disruption, natural enemy conservation). Conversely, monitoring practices (principle 2) display lower context sensitivity with moderate ASP values, indicating broader applicability across regions.

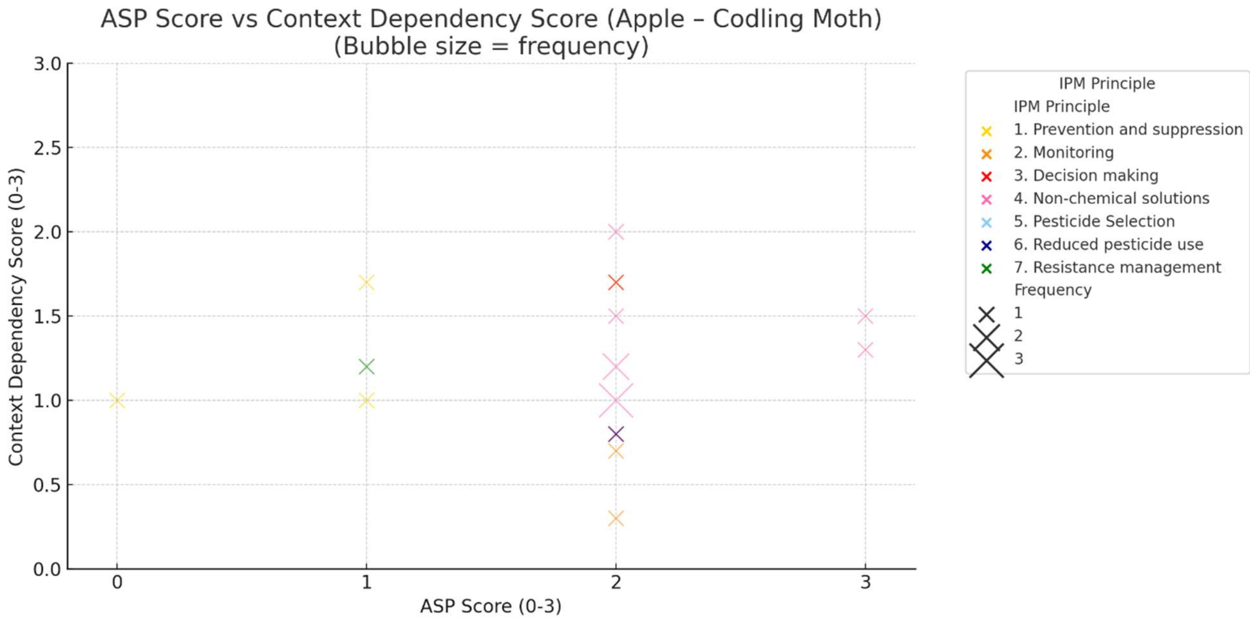

Figure 8: Relationship between ASP efficiency scores (0–3) and context dependency scores (0–3) for IPM practices in the apple–codling moth case study. Bubble size indicates frequency of identical score combinations; colours denote IPM principles.

5.6.3.3. Time of Anticipation vs. Context Dependency

The relationship between time of anticipation (1 = day to 5 = multi-year) and context dependency scores is shown in Figure 9. Bubble size represents the frequency of identical score combinations, and the colour gradient (yellow to red) reflects increasing anticipation time.

Most practices fall within anticipation levels 3–4 (month to year), with context dependency scores clustering between 1–2. Short-term practices (anticipation level 1–2) are rare and generally exhibit low context dependency, indicating quick-response measures that can be implemented broadly. In contrast, long-term practices (anticipation level 4–5) tend to show slightly higher context dependency, reflecting their dependence on sustained ecological processes or landscape modifications (e.g., habitat management for natural enemies).

This pattern highlights that time of anticipation and context dependency are moderately linked even if measures requiring long preparation or multi-year implementation are often those most influenced by local conditions. These insights are crucial when assessing transition timelines and advisory support for future policy measures (further discussed in the synthesis section).

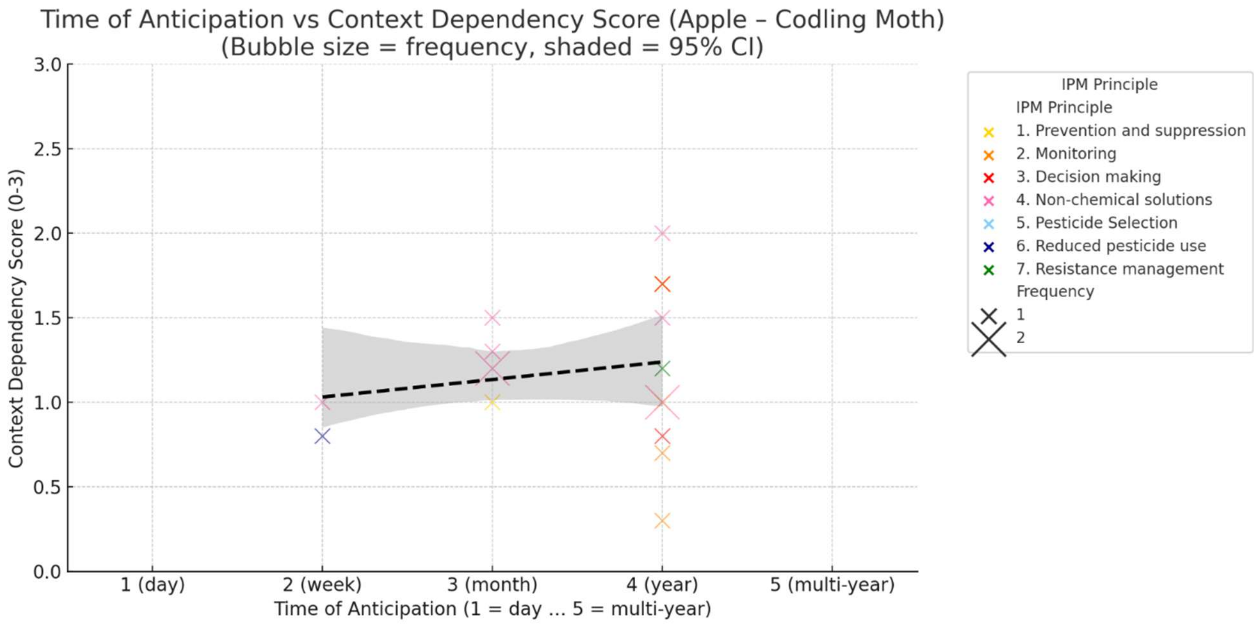

Figure 9: Relationship between time of anticipation (1 = day to 5 = multi-year) and context dependency scores (0–3) for IPM practices in the apple–codling moth case study. Bubble size indicates frequency of identical score combinations; colour gradient denotes anticipation level.

5.6.3.4. Context Dependency by IPM Principle – Link to Taxonomy

The distribution of context dependency scores across the seven (out of eight) IPM principles is shown in Figure 10. The boxplot highlights distinct patterns:

- Non-chemical solutions (Principle 4) and Decision making (Principle 3) display the highest median context dependency (≈ 1.3–1.5), with a moderate spread. This reflects their strong reliance on ecological interactions and local conditions (e.g., natural enemy populations, pest thresholds).
- Prevention and suppression (Principle 1) and Monitoring (Principle 2) have lower median scores (≈ 1.0) and narrower variability, indicating that these practices are more widely applicable across regions.
- Reduced pesticide use (Principle 6) and Resistance management (Principle 7) are represented by only one practice each in this case study. Consequently, their median values (≈ 0.8–1.2) should be interpreted with caution, as they do not capture the variability seen in other principles.

These results illustrate that principle-based differences in context sensitivity exist; however, the limited number of practices for certain principles restrict robust conclusions for this single case study. A more comprehensive synthesis across all three case studies is therefore needed to confirm this trend.

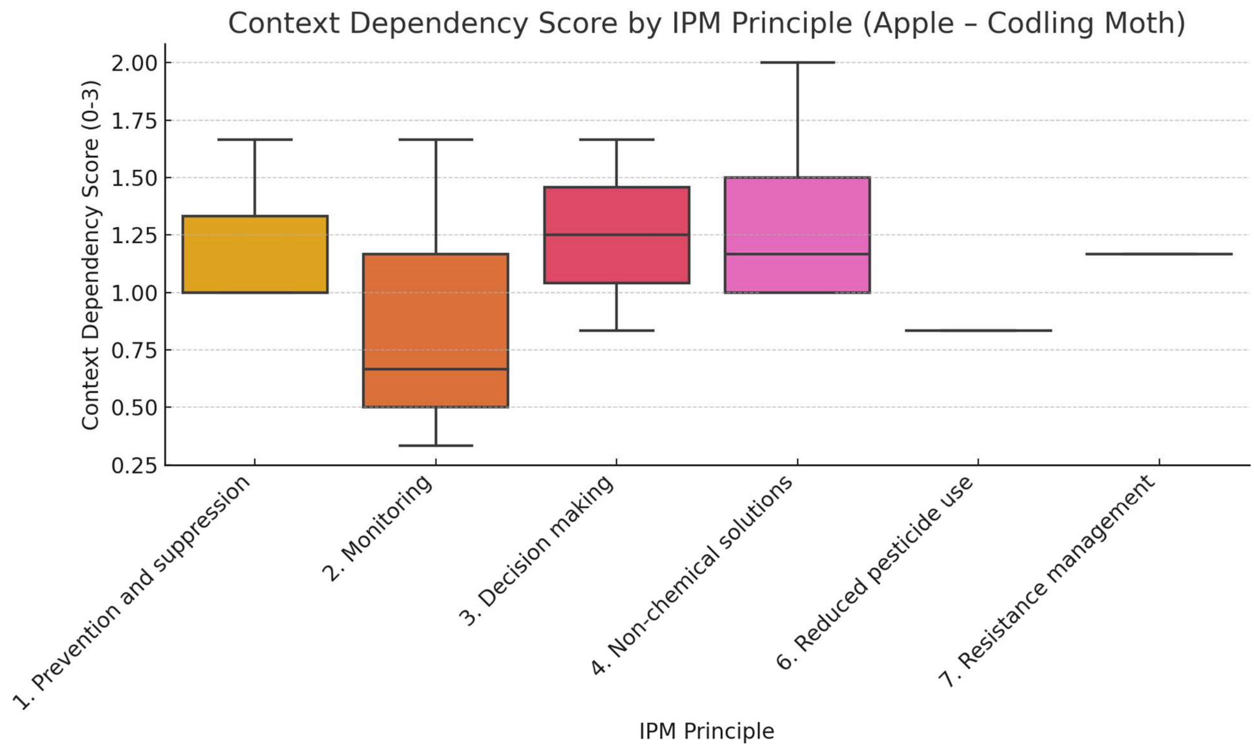

Figure 10: Boxplot of context dependency scores (0–3) across IPM principles for the apple–codling moth case study. Higher median scores indicate greater sensitivity of practices to local biophysical conditions.

5.6.4. Grapevine-Powdery Mildew

The grapevine–powdery mildew system is a key perennial crop–disease interaction in European viticulture. Powdery mildew (*Erysiphe necator*) is among the most damaging fungal diseases of grapevine, causing significant yield and quality losses, especially in warm and dry regions where epidemics develop rapidly. Control strategies rely heavily on frequent fungicide applications, often 8–12 sprays per season, making this system a central focus for pesticide reduction targets under the EU Farm to Fork Strategy. Within this case study, a total of 22 IPM practices were analysed, spanning all eight IPM principles except Principle 8 (Evaluation) (Appendices: Table 11). The distribution was uneven: most practices were linked to Principles 1 (Prevention and suppression) and 4 (non-chemical solutions), while Principles 5 (Pesticide selection), 3 (Decision making), and 7 (Resistance management) were represented by single practices. Four practices addressed Principle 6 (Reduced pesticide use), highlighting operational adjustments as an important pathway for pesticide reduction in viticulture.

5.6.4.1. Results of Context Dependency Analysis

The context dependency analysis of the grape–powdery mildew system shows a moderate to high overall dependency (average scores between 1 and 2 on a 0–3 scale). The radar chart (Figure 12) highlights that climate is the most influential factor, followed by pest pressure and, to a lesser extent, temporal effects. In contrast, soil and biodiversity exhibit the lowest influence, while landscape structure contributes moderately to the overall profile.

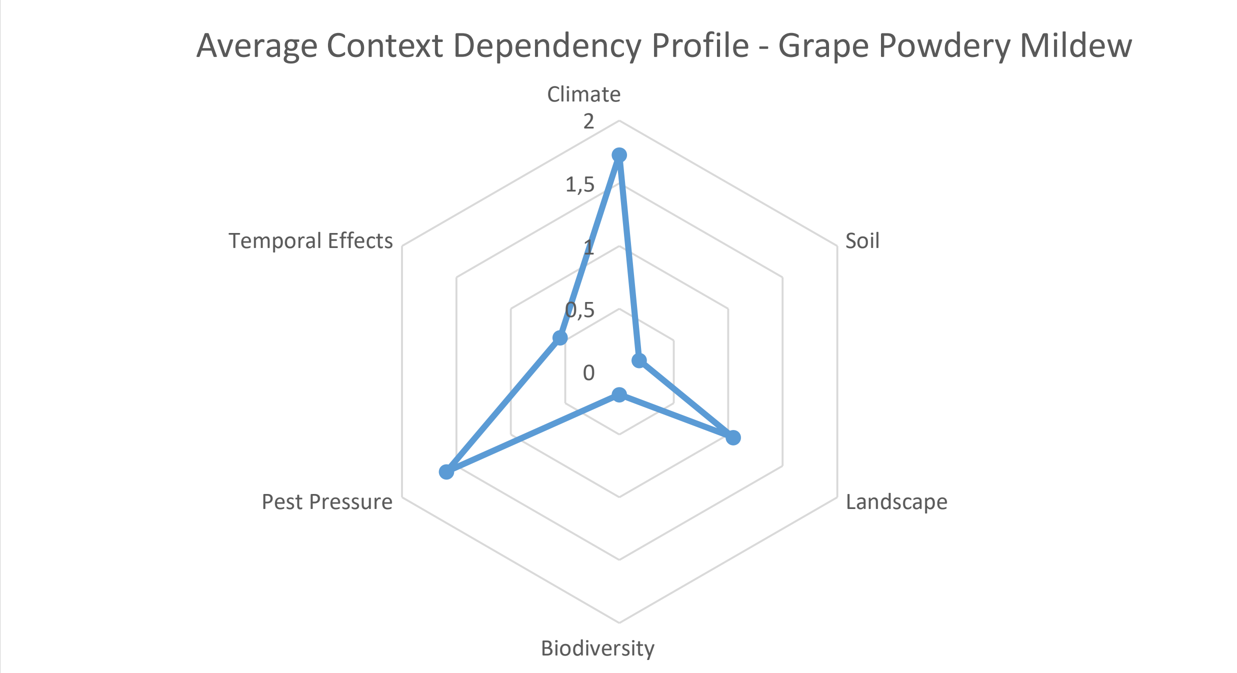

Figure 11: Average context dependency profile (radar chart) for the Grape-Powdery Mildew case study. The chart shows mean scores (0–3) across six biophysical indicators.

The bar chart (Figure 13) provides a complementary perspective by displaying the average scores per indicator group. It confirms the strong relevance of climate- and pest-related factors, which both reach the highest scores (around 2), while soil and biodiversity remain low (<0.5).

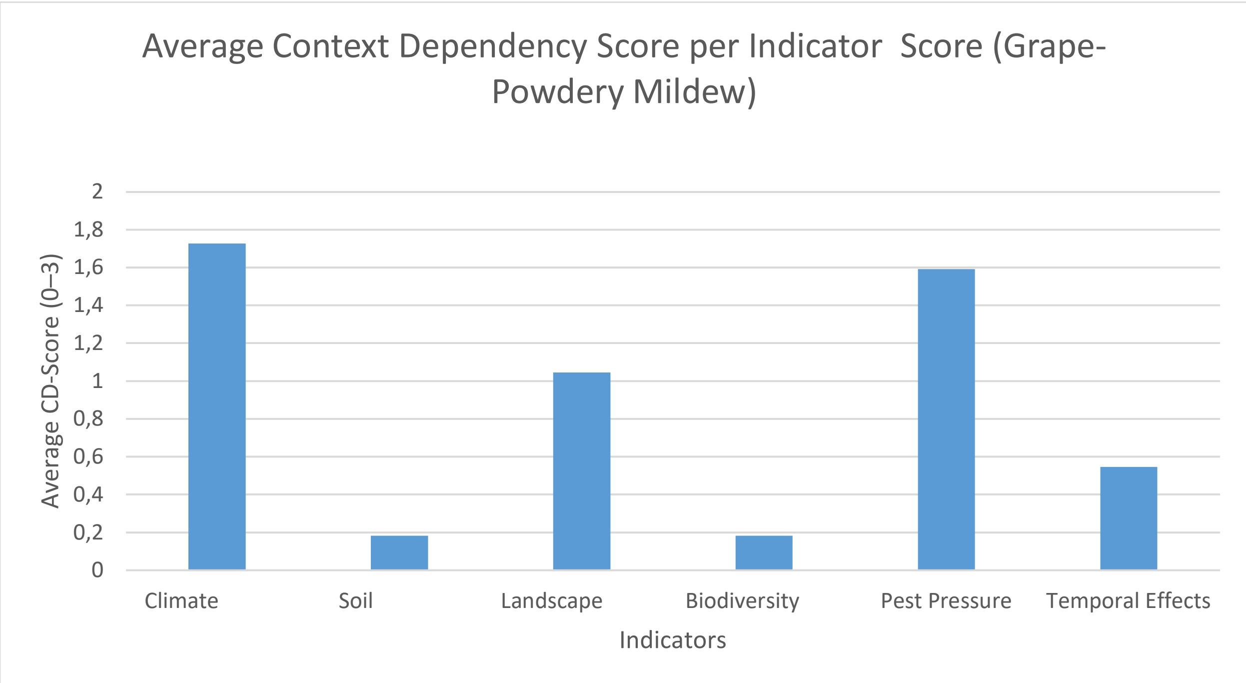

Figure 12: Average context dependency scores per indicator (bar chart) for the Grape Powdery Mildew case study.

5.6.4.2. ASP Score vs. Context Dependency

The results show that most practices cluster around moderate ASP scores (1–2) combined with low to moderate context dependency (0.5–1.5). Only a few practices reach high ASP scores (3), which are mainly linked to non-chemical solutions and prevention strategies. Practices with low ASP scores (1) are often associated with decision-making or resistance management principles and tend to have low context dependency (Figure 13).

Notably, there is no clear trend of increasing context dependency with higher ASP scores; instead, practices with both high and low ASP scores can show similar dependency ranges. **This suggests that effectiveness (ASP) and context sensitivity are partly independent dimensions and need to be jointly considered when deriving recommendations (e.g., binding vs. optional implementation).**

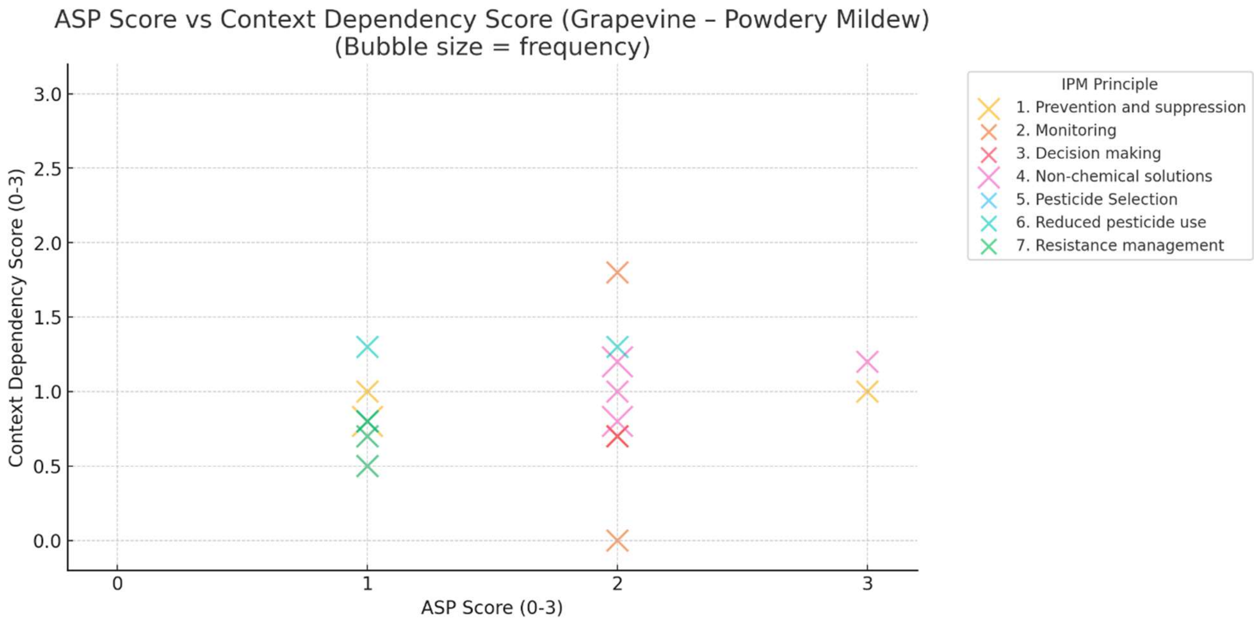

Figure 13: Relationship between ASP efficiency scores (0–3) and context dependency scores (0–3) for IPM practices in the Grape-Powdery Mildew case study. Bubble size indicates frequency of identical score combinations; colours denote IPM principles.

5.6.4.3. Time of Anticipation vs. Context Dependency

Most practices are concentrated at short to medium anticipation horizons (levels 1–3), covering measures that can be applied within days to months. These practices exhibit context dependency scores below 1.5, suggesting moderate sensitivity to local conditions. A smaller subset of practices with longer anticipation horizons (levels 4–5) appears, often linked to structural or landscape-level interventions; these show a slight tendency toward lower context dependency in this dataset (Figure 14).

The overall trend line in the figure shows only a weak negative relationship between anticipation time and context dependency, indicating that for grapevine–powdery mildew, implementation times do not strongly predict site-specific performance.

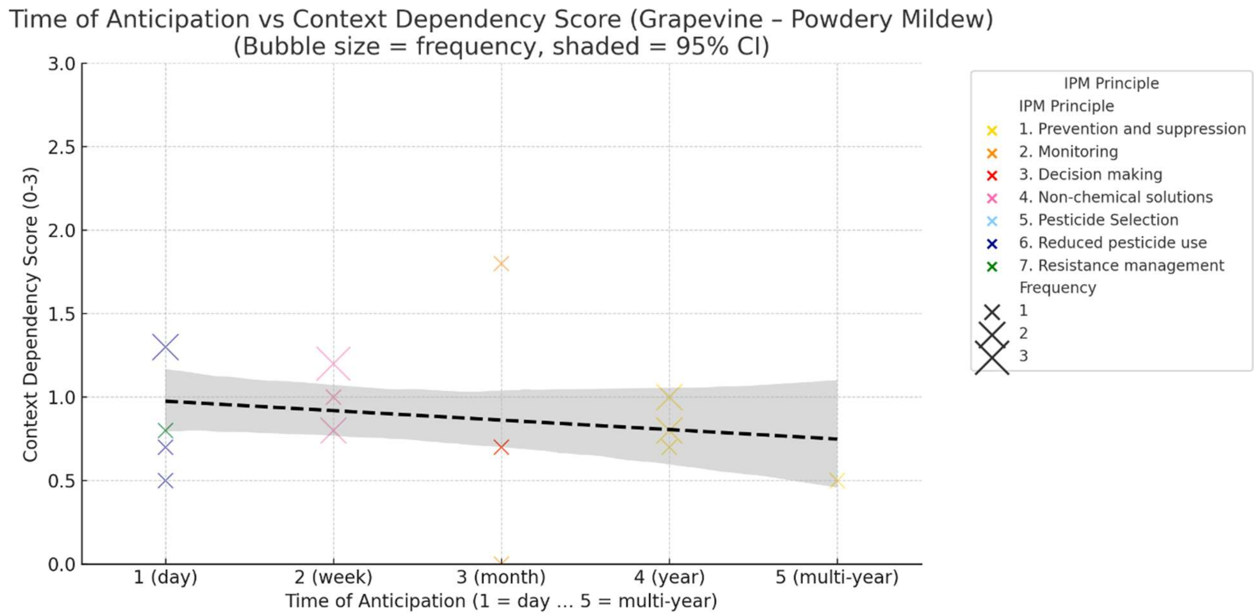

Figure 14: Relationship between time of anticipation (1 = day to 5 = multi-year) and context dependency scores (0–3) for IPM practices in the Grape-Powdery Mildew case study. Bubble size indicates frequency of identical score combinations; colour gradient denotes anticipation level.

5.6.4.4. Context Dependency by IPM Principle – Link to Taxonomy

Prevention and suppression (principle 1) shows relatively low and stable context dependency (median ≈ 0.8), suggesting broad applicability across vineyard contexts. Monitoring (principle 2) displays the widest spread of scores (0–1.8), indicating that some monitoring practices are highly context-sensitive (e.g., location-specific trap thresholds), while others are more universal (Figure 15).

Non-chemical solutions (principle 4) and reduced pesticide use (principle 6) exhibit median context dependencies around 1.0–1.2, with moderate variability, reflecting their dependence on vineyard structure and management history. Other principles, such as decision making (principle 3) and pesticide selection (principle 5), are represented by fewer practices, limiting robust interpretation but suggesting generally low to moderate context dependence.

This distribution highlights that context sensitivity in grapevine IPM is not uniform across principles: monitoring measures are particularly variable, while preventive approaches remain comparatively stable.

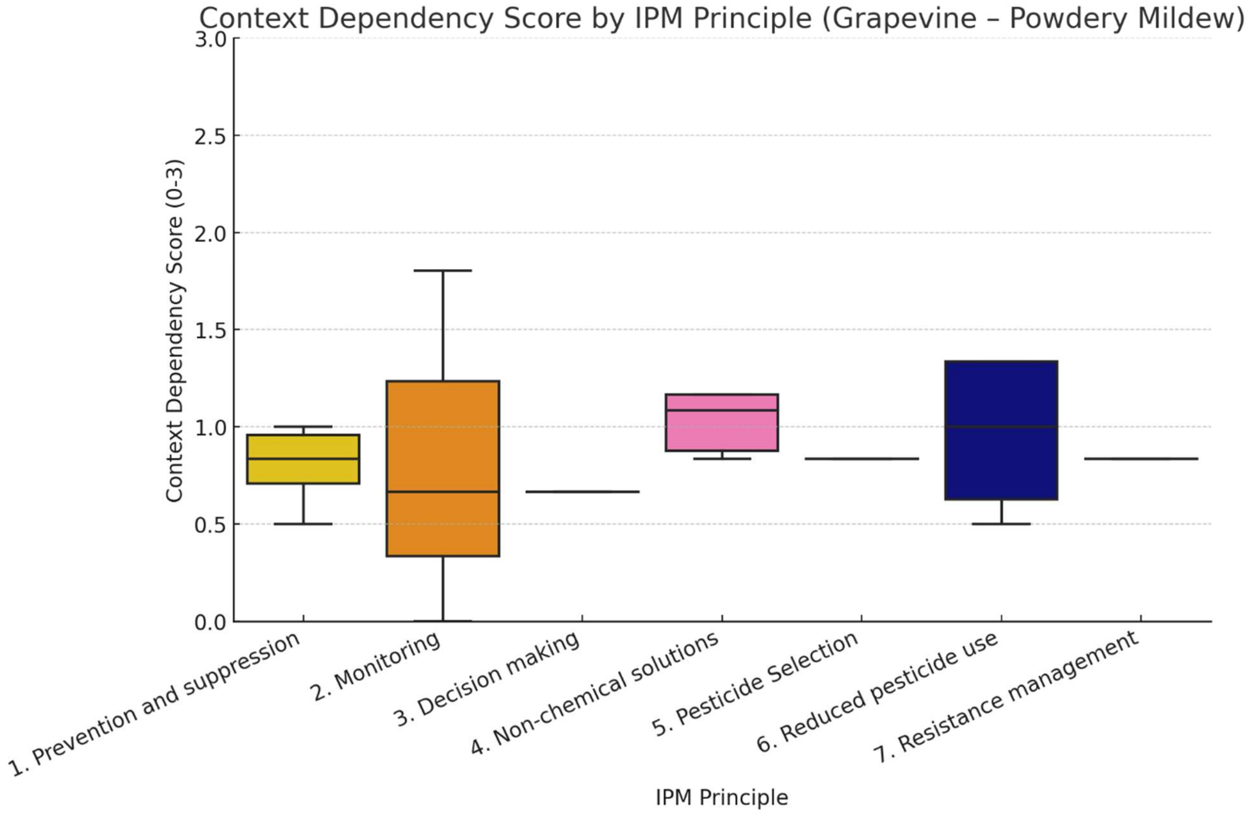

Figure 15: Boxplot of context dependency scores (0–3) across IPM principles for the Grape-Powdery Mildew case study. Higher median scores indicate greater sensitivity of practices to local biophysical conditions.

5.6.5. Cereals-Weeds

The Cereals–Weeds case study focuses on weed management in temperate arable cereal production systems, where herbicide use is among the highest contributors to pesticide load in European cropping. Weeds represent a chronic and widespread pest category, with multiple species exhibiting varying levels of competitiveness, adaptability, and herbicide resistance. The selected practices cover both preventive and curative approaches – from crop rotation and cover cropping to mechanical weeding and precision herbicide application – and were drawn from the harmonised IPM taxonomy in WP2 Table 12. In total, 45 IPM practices were analysed, spanning seven of the eight IPM principles (all except Principle 8, Evaluation). The majority were classified under Principle 1 (Prevention and suppression), reflecting the central importance of crop rotation, sowing strategies, soil management, and cover crops in weed control. Principle 6 (Reduced pesticide use) was also relatively well represented (seven practices), particularly focusing on precision technologies and optimisation of spray applications. In contrast, monitoring (Principle 2), decision-making tools (Principle 3), pesticide selection (Principle 5), non-chemical methods (Principle 4), and resistance management (Principle 7) were represented by only a few individual practices. This distribution underlines that cereal weed management is still dominated by preventive measures, while innovative technologies for reduced pesticide use are emerging but less numerous.

5.6.5.1. Results of Context Dependency Analysis

In the Cereals–Weeds case study, 45 practices from the harmonised IPM taxonomy were assessed for context dependency using the six biophysical indicators. The average scores per indicator (0–3 scale) show a clear dominance of **pest pressure** (1.67) and **climate & weather conditions** (1.44) as the most influential factors determining practice performance (Figure 16). These high values reflect the strong influence of seasonal weed emergence patterns, species composition, and climatic variability on the success of both preventive and curative measures in cereal production systems.

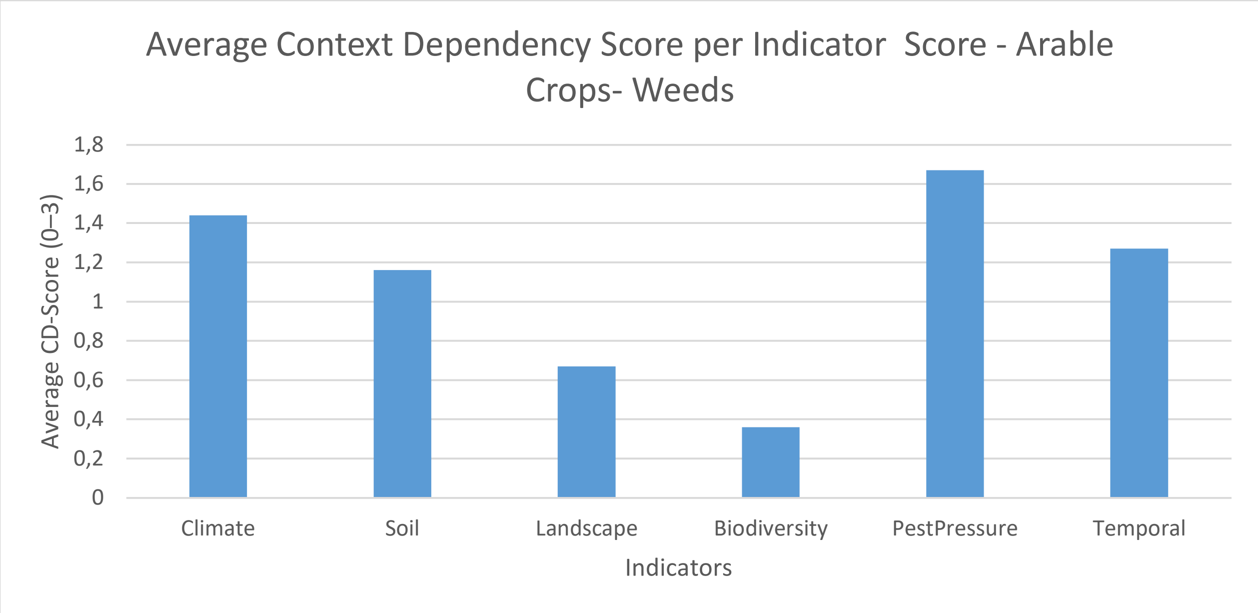

Figure 16: Average context dependency scores per indicator for the Cereals–Weeds case study. Bars represent mean scores (0–3 scale) across all 45 evaluated practices.

Temporal/legacy Effects (1.27) and soil characteristics & hydrology (1.16) received intermediate scores, underlining their role in shaping weed pressure through soil properties, moisture regimes, and rotation history. In contrast, landscape structure & topography (0.67) and biodiversity & ecosystem functions (0.36) were scored substantially lower. This suggests that landscape-scale weed suppression effects and biodiversity-driven regulation are less frequently integrated or empirically documented in current cereal–weed management practices.

The radar chart (Figure 17) illustrates the relative profile of the six indicators, showing pronounced peaks for pest pressure and climate, with intermediate values for temporal and soil, and a steep decline towards landscape and biodiversity. This pattern aligns with the literature review findings, where arable weed management studies most often address abiotic drivers and direct pest-related factors, while biodiversity and landscape influences remain underrepresented. The shape of the radar profile also indicates that in cereals–weed contexts, high-scoring abiotic indicators frequently combine, reinforcing the need for site-specific adaptation in selecting IPM practices.

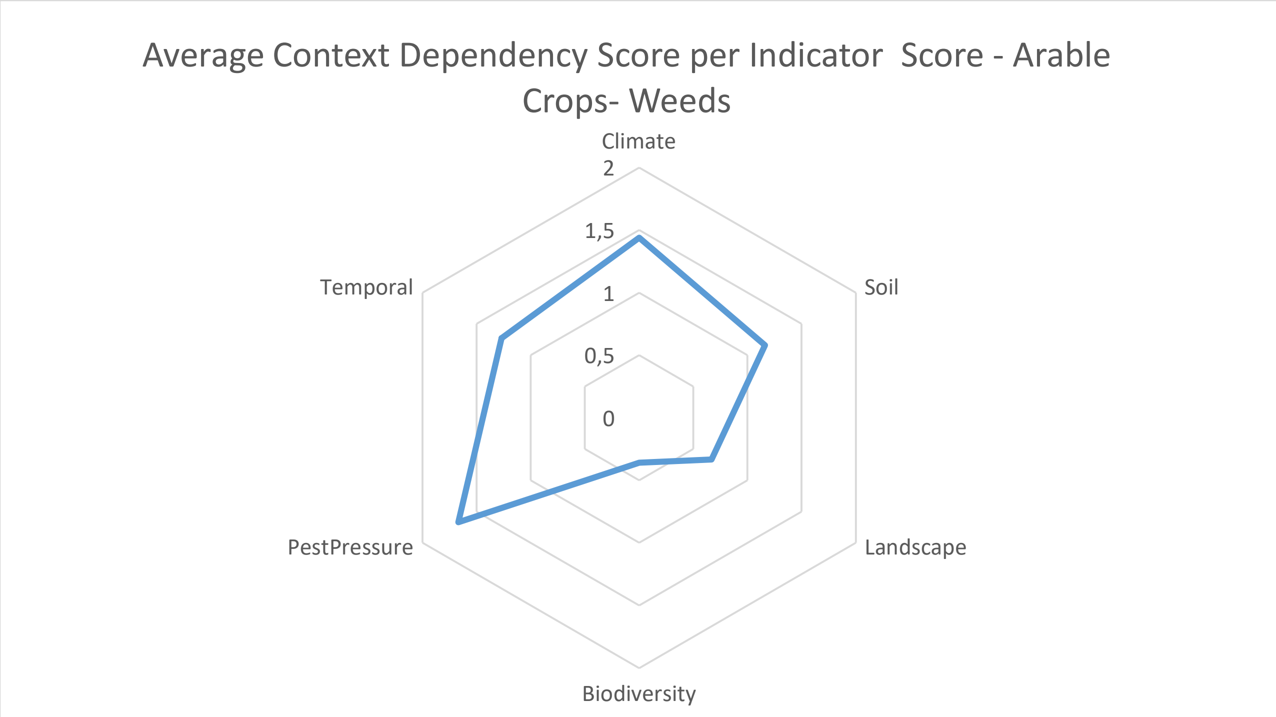

Figure 17: Radar chart of average context dependency scores for the Cereals–Weeds case study.

5.6.5.2. ASP Score vs. Context Dependency

The distribution of practices across the ASP score (0–3) and context dependency score (0–3) space for the Cereals–Weeds case study reveals a concentration of practices with medium to high agronomic service provision (ASP scores 2–3) and low to medium context dependency (Figure 18). Most of these belong to IPM Principle 1 – Prevention and Suppression, which dominates the upper ASP classes, indicating that preventive weed management measures (e.g. crop rotation, stale seedbed techniques, mulching) deliver consistently high service levels but vary in their susceptibility to site-specific constraints.

A smaller cluster of practices appears in the ASP 1 category, typically with low to moderate context dependency. These include mechanical weeding operations and targeted herbicide use, which are effective but may be limited in scope or context flexibility. Practices scoring low on both ASP and context dependency are rare, suggesting that even less impactful measures are generally shaped by at least one significant site-specific factor.

Only a few practices with very high ASP (score 3) combine this with equally high context dependency scores (>2.0). These tend to be measures whose performance is strongly dependent on local climatic or weed population dynamics, such as specific cover crop sequences for weed suppression. The overall distribution indicates that for cereals–weed management, high service provision is achievable without universally high context dependency, offering scope for identifying binding rules for robust preventive measures while keeping more location-sensitive practices as optional.

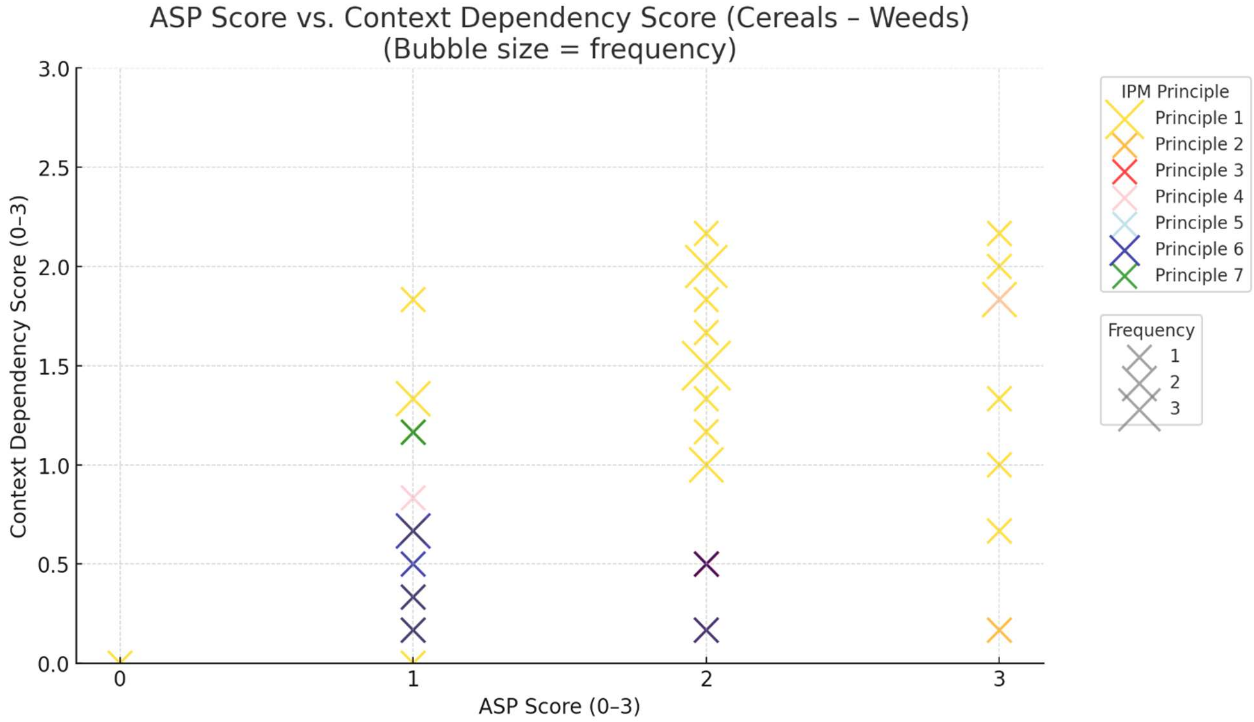

Figure 18: Relationship between ASP score and context dependency score for the Cereals–Weeds case study. Each marker represents an IPM practice, colour-coded by IPM principle (see legend) and scaled by frequency.

5.6.5.3. Time of Anticipation vs Context Dependency

In the Cereals–Weeds case study, context dependency scores show a slight increase with longer anticipation periods (

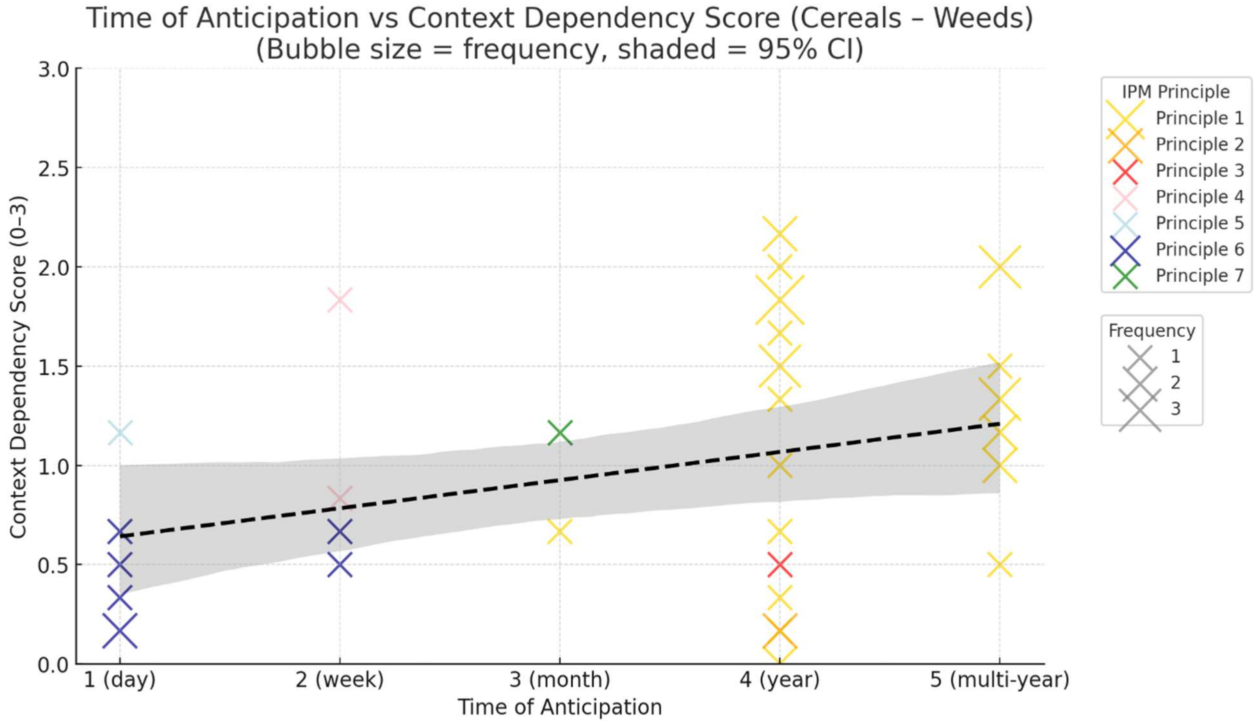

Figure **19**). Short-term measures (1 day to 1 week), such as mechanical weeding or targeted herbicide use, generally have low context dependency, while multi-year interventions – e.g. rotational designs or long-term cover cropping – tend to score higher due to cumulative climatic, soil, and weed population influences. Medium-term measures (months to one year) occupy an intermediate range. Although the trend is modest, it mirrors the other case studies: long-term, system-based measures are typically more sensitive to local conditions because they combine several high-scoring indicators (e.g. climate, pest pressure, temporal effects).

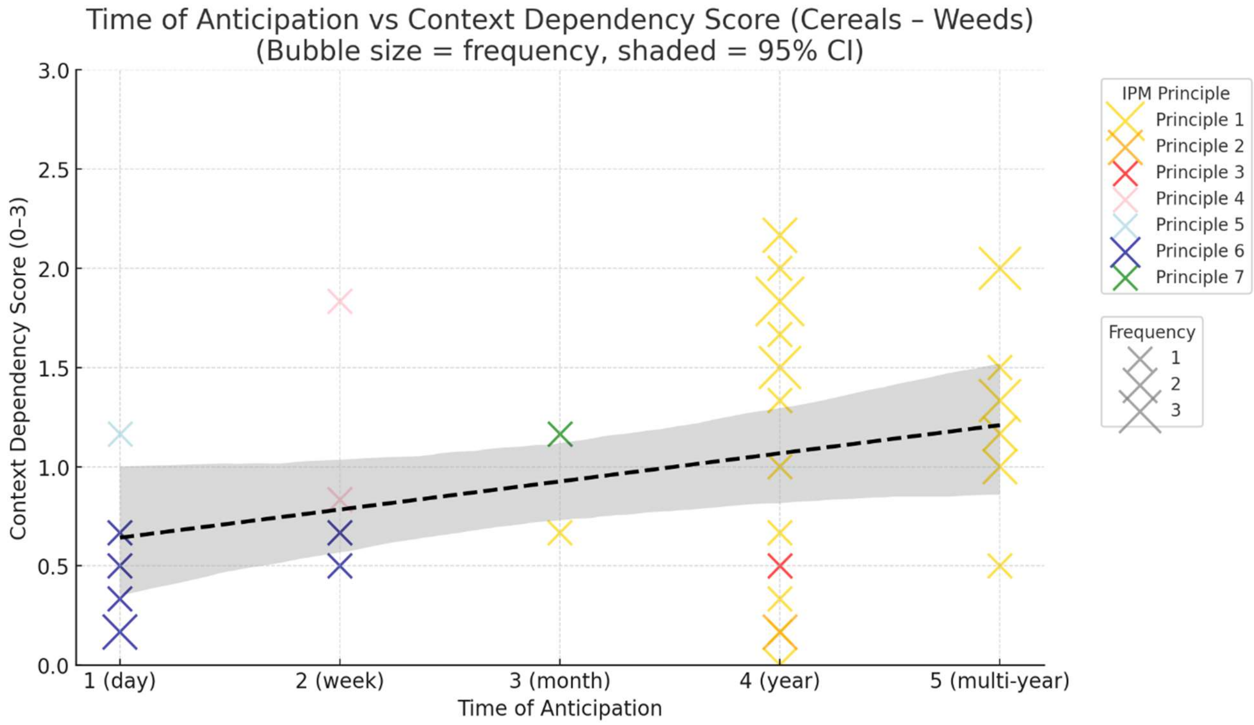

Figure 19: Relationship between time of anticipation and context dependency score for the Cereals–Weeds case study. Each marker represents an IPM practice, colour-coded by IPM principle (see legend) and scaled by frequency. The dashed line indicates the trend, with shaded

areas representing the 95% confidence interval.

5.6.5.4. Context Dependency by IPM Principle

For the Cereals–Weeds case study, Prevention and Suppression (Principle 1) has the highest median context dependency score (≈ 1.33) and shows the greatest variation among practices, reflecting the influence of climatic, soil, and weed population factors on measures such as crop rotation, cover cropping, and mulching.

Non-Chemical Solutions (Principle 4) and Pesticide Selection (Principle 5) also have relatively high median scores (~1.17–1.83), indicating that their effectiveness depends on weed species composition, resistance status, and local suitability of mechanical or selective chemical tools.

Resistance Management (Principle 7) shows a moderate score (1.17). In contrast, Reduced Pesticide Use (Principle 6) has low median values (≈ 0.5), while Monitoring (Principle 2) and Decision Making (Principle 3) score lowest (≤ 0.5), suggesting these measures are less affected by site-specific biophysical conditions (Figure 20).

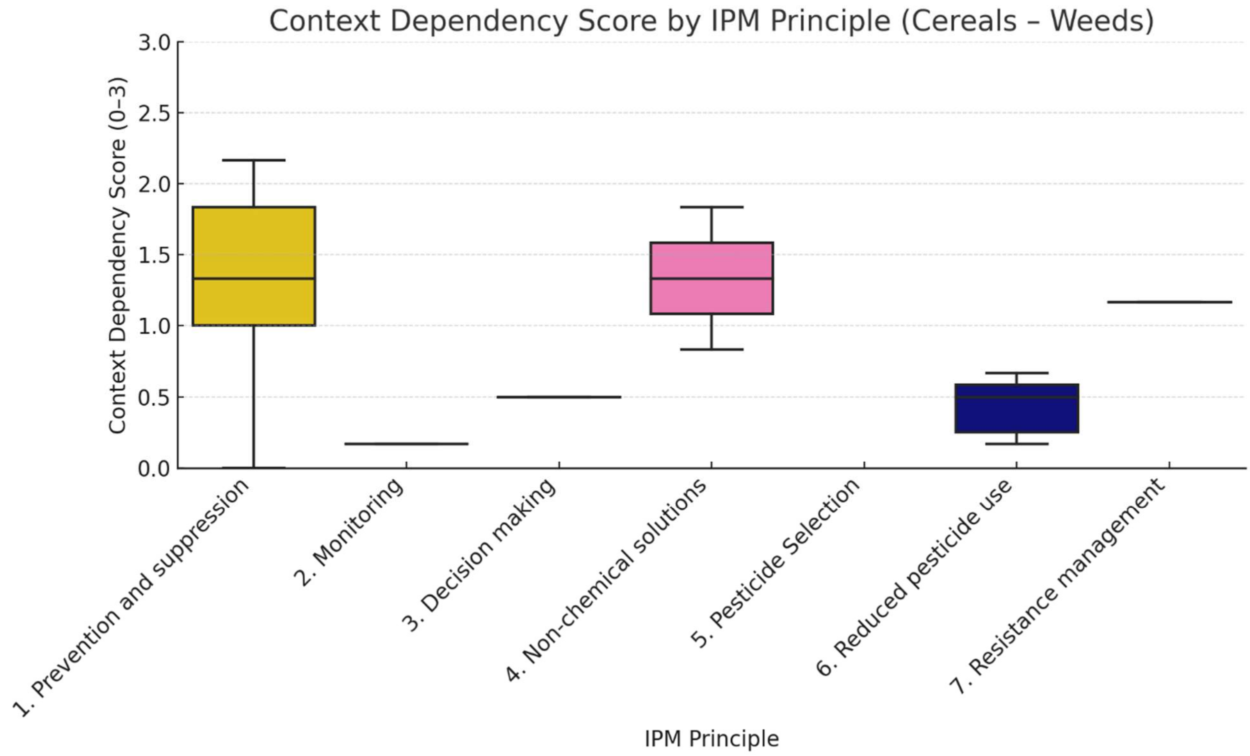

Figure 20: Context dependency scores by IPM principle for the Cereals–Weeds case study. Boxplots show median, interquartile range, and outliers for each principle.

5.6.6. Cross-Case Synthesis

In the following section, the results of the three case studies – *apple - codling moth control*, *grapevine - powdery mildew control*, and *cereal cropping systems - weed management*– are brought together in a cross-case analysis. This synthesis aims to identify common patterns as well as system-specific differences in the performance of IPM practices with respect to their ASP, time of anticipation, taxonomy and context dependency.

Beyond the separate evaluations for each production system, the cross-case approach allows us to explore whether certain IPM principles consistently achieve high agronomic benefits across systems, and under which circumstances their efficiency is more context-dependent. In addition, average scores aggregated across all case studies are used to highlight broader trends relevant to the guiding questions of the AGROWISE project.

The three case studies differ substantially in their **cropping systems, pest pressures, and management contexts**. Apple and grapevine represent perennial fruit production systems with long-term plant–pest interactions, but differ in canopy structure, disease versus insect pest focus, and the role of preventive versus curative interventions. Cereal–based systems, in contrast, are annual arable crops, characterised by shorter crop cycles, higher crop rotation flexibility, and a stronger focus on weed competition and herbicide reduction. These intrinsic differences influence both the feasible range of IPM practices and the expected time horizon for measurable effects.

By integrating these distinct systems into a common analytical framework, the cross-case analysis supports the identification of **practices with robust efficiency across contexts** as well as those **requiring specific environmental, agronomic, or socio-economic conditions** to be effective. This forms the basis for deriving recommendations on the potential for binding versus optional implementation of IPM practices in different Member States.

5.6.6.1. Results of Context Dependency Analysis

In this section, the analysis of context dependency is expanded from the indicator level to the sub-factor level, allowing for a more detailed examination of the specific environmental, agronomic, and structural parameters that influence the efficiency of IPM practices. While the individual case study evaluations focused on the six overarching indicators (e.g. pest pressure & biotic risk, soil characteristics & hydrology), the cross-case synthesis presented here introduces, for the first time, a breakdown into sub-factors. This enables the identification of parameters that are consistently important across systems, as well as those that are highly specific to certain cropping systems.

The aggregated results across all three case studies (Figure 21) are based on a total of 86 IPM practices analysed – 19 in apple–codling moth, 22 in grapevine–powdery mildew, and 45 in cereals–weed management. Across these practices, a total of 727 individual sub-factor assignments were made. The data show that a relatively small number of sub-factors account for a large share of all recorded context dependencies. For example, spatial variability of pest populations was linked to 67 cases – almost 80 % of all practices – while macro- and microclimatic variables (62 cases) and temporal dynamics of pest populations (60 cases) also appeared in over two-thirds of the analysed practices. These parameters appear to be central determinants of IPM efficiency, as they are relevant in all three production systems. In contrast, factors such as functional diversity within the agroecosystem (8 cases) or invasiveness of new pest species (5 cases) were rarely associated with the performance of IPM practices and tend to be system- or situation-specific.

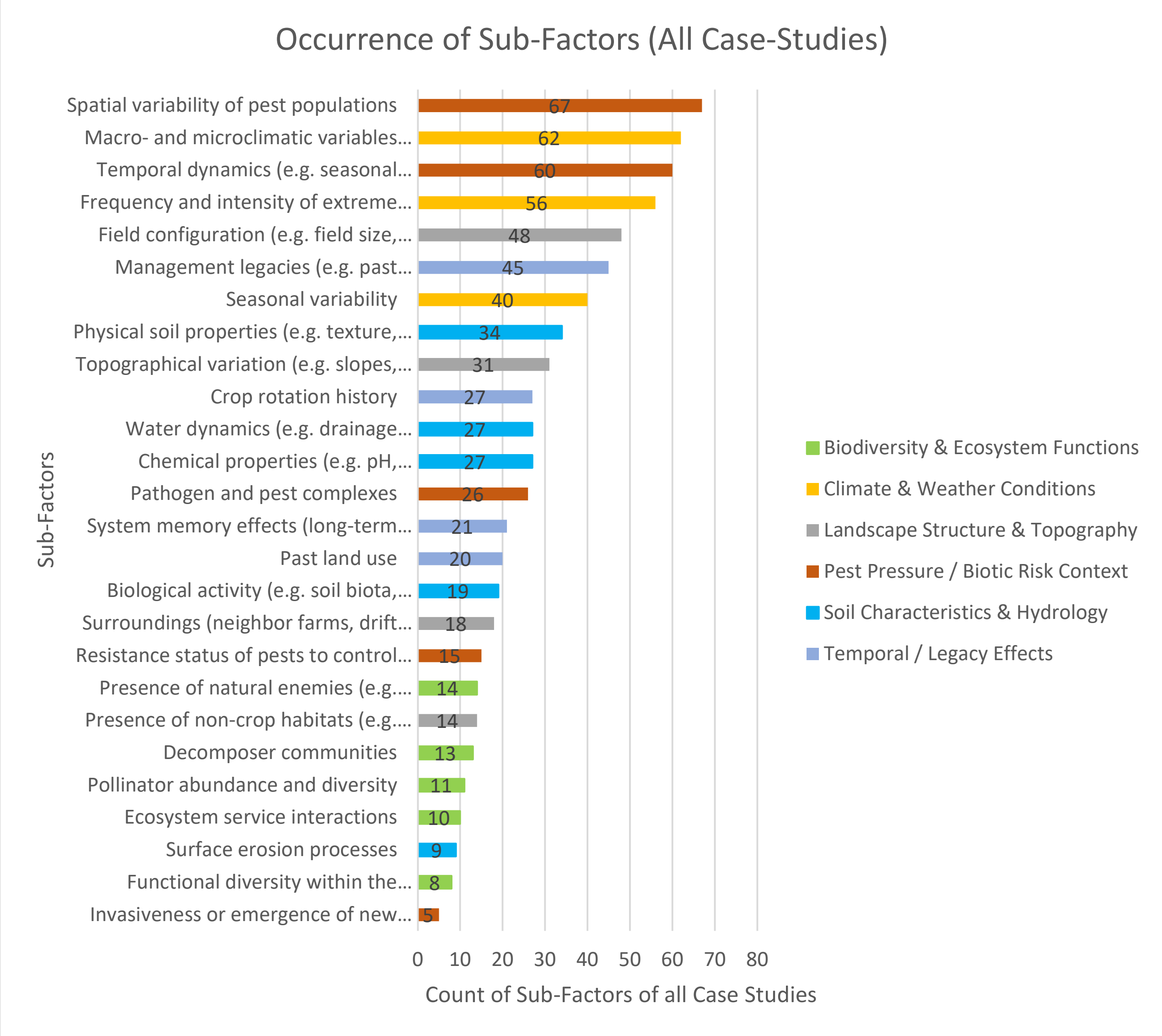

Figure 21: Aggregated occurrence of context dependency sub-factors across all three case studies.

When comparing the relative weight of the six main indicators across the three production systems (Figure 22), clear differences emerge. In cereals–weeds management, soil characteristics & hydrology and temporal & legacy effects play a larger role, reflecting the importance of rotation history, soil fertility, and management legacies in annual cropping systems. In perennial fruit systems, landscape structure & topography and biodiversity & ecosystem functions are more prominent, particularly due to the relevance of habitat management, surrounding land use, and natural enemy presence in pest regulation. The perennial systems also exhibit higher scores for pest pressure & biotic risk context, linked to the continuous presence of host plants and longer pest life cycles.

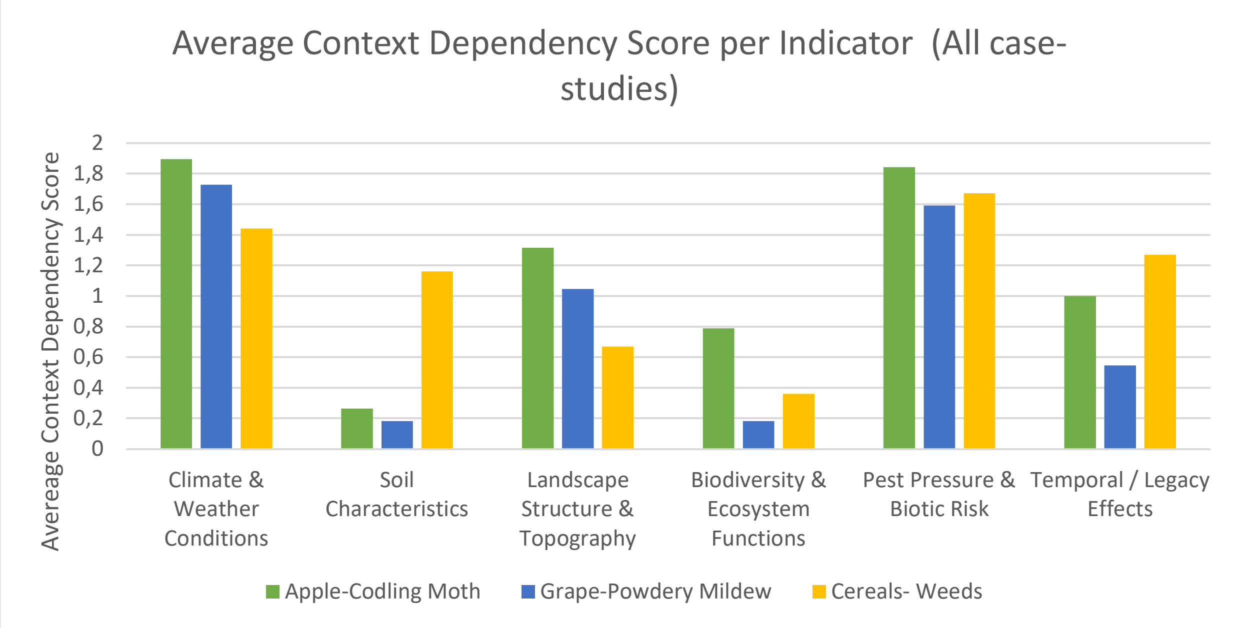

Figure 22: Average context dependency scores per main indicator for apple–codling moth, grapevine–powdery mildew, and cereals–weeds management systems.

The radar chart (Figure 23) summarises these differences by visualising the distinct context dependency profiles of each system. While apple–codling moth and grapevine–powdery mildew shares similar patterns in pest pressure and climate and weather conditions, cereals display a more balanced distribution across indicators, with comparatively lower dependency on climatic parameters and higher emphasis on soil and management-related factors.

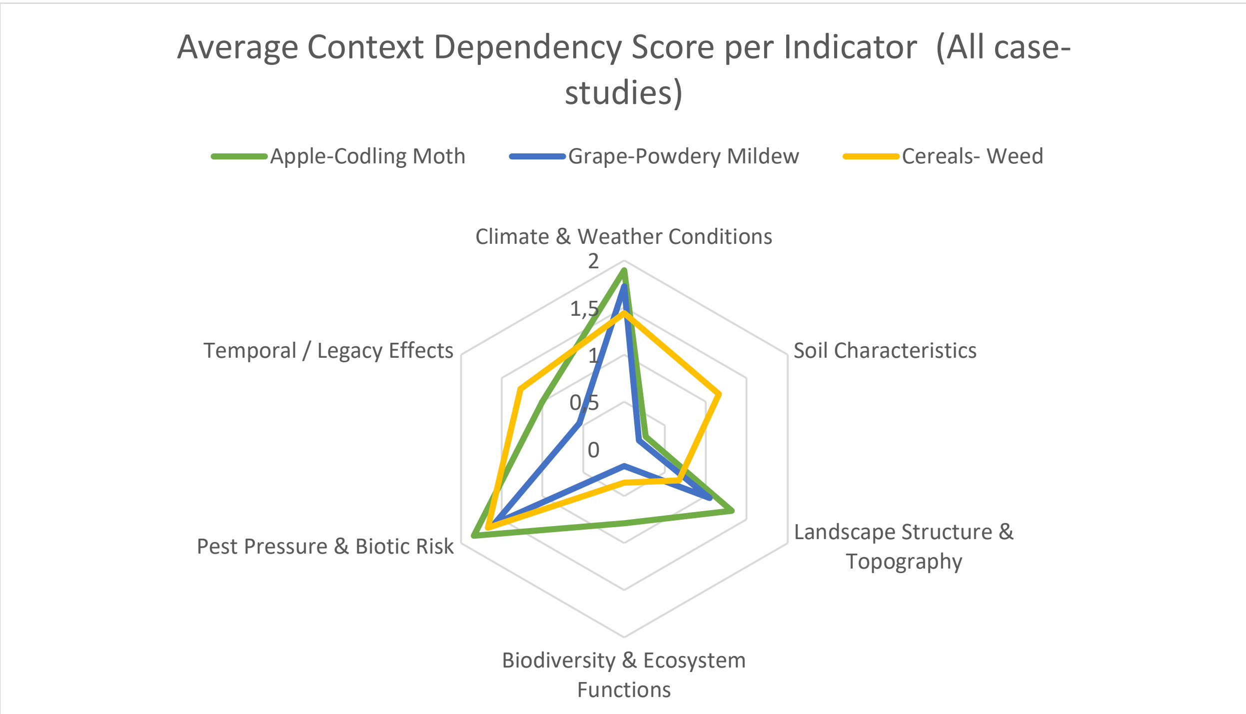

Figure 23: Radar chart illustrating the relative context dependency profiles across the six main indicator categories for the three case studies.

Overall, this sub-factor analysis confirms that while certain parameters are universally relevant for

IPM performance, others are strongly tied to the biological and management realities of specific cropping systems.

5.6.6.2. ASP Score vs. Context Dependency

Figure 24 visualises the relationship between the ASP and the degree of context dependency for all 86 IPM practices assessed across the three case studies. Each point represents one practice, coloured according to the corresponding IPM principle and scaled in size according to its frequency across the cases.

The scatterplot is divided into four quadrants, allowing a classification into:

1. **Low dependency / Low ASP**
2. **Low dependency / High ASP**
3. **High dependency / Low ASP**
4. **High dependency / High ASP**

In the present dataset, no strong clustering pattern across the quadrants emerges. Practices from different IPM principles are scattered throughout the plot, indicating that both high and low ASP values can occur across the full range of context dependency scores. The primary purpose of this visualisation is therefore to facilitate the subsequent categorisation of practices into the four groups above, which form the basis for further evaluation in later sections.

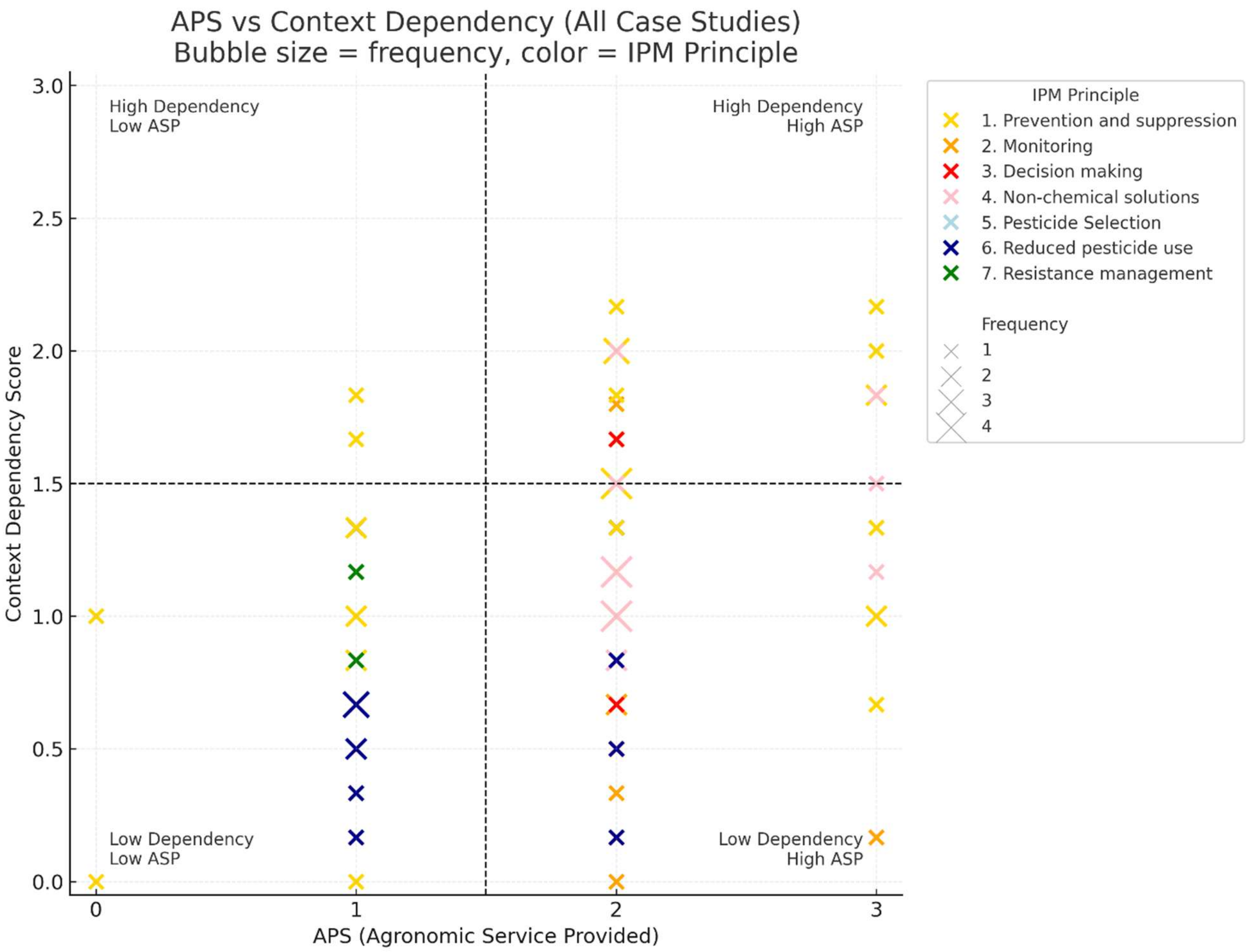

Figure 24: Relationship between agronomic service provided (ASP) and context dependency for all 86 IPM practices across apple–codling moth, grapevine–powdery mildew, and cereals–weeds

management case studies. Each point represents one practice, with bubble size indicating its frequency across the case studies and colour denoting the corresponding IPM principle. Dashed lines indicate the thresholds used for categorisation into four quadrants: (1) low dependency / low ASP, (2) low dependency / high ASP, (3) high dependency / low ASP, and (4) high dependency / high ASP.

5.6.6.3. Time of Anticipation vs Context Dependency

Figure 25 explores the relationship between the time of anticipation required for implementing an IPM practice and its context dependency score across all 86 practices from the three case studies. Time of anticipation refers to the lead time needed before the effects of a measure can be realised, ranging from immediate (1 day) to multi-year time frames.

A clear differentiation by IPM principle can be observed:

- **Principle 1 – Prevention & suppression** and **Principle 2 – Monitoring** is predominantly located at anticipation levels **4–5** (year to multi-year), reflecting their reliance on long-term or continuous implementation (e.g. habitat establishment, multi-season pest monitoring networks).
- **Principle 3 – Decision making** clusters mainly at **levels 3–4** (month to year), consistent with seasonal model calibration and iterative learning.
- **Principle 4 – Non-chemical solutions** is concentrated at **level 2** (week), indicating short preparation times before effects are visible.
- **Principle 5 – Pesticide selection** (only two practices in the dataset) appears exclusively at **level 1** (day), consistent with immediate effect upon application change.
- **Principle 6 – Reduced pesticide use** is also concentrated at **levels 1–2** (day to week), reflecting direct and rapid outcomes from adjustments in dose or spray technology.
- **Principle 7 – Anti-resistance strategies** (three practices) appears once each at **levels 1, 3, and 4**, showing no discernible trend in anticipation time.
- **Principle 8 – Evaluation** (no specific action in those case studies

While there is a slight trend towards higher context dependency with increasing anticipation time, the variation within each anticipation class is substantial. This confirms that anticipation time alone is not a reliable predictor of context sensitivity and that both parameters should be considered jointly when assessing the suitability of practices for binding versus optional implementation.

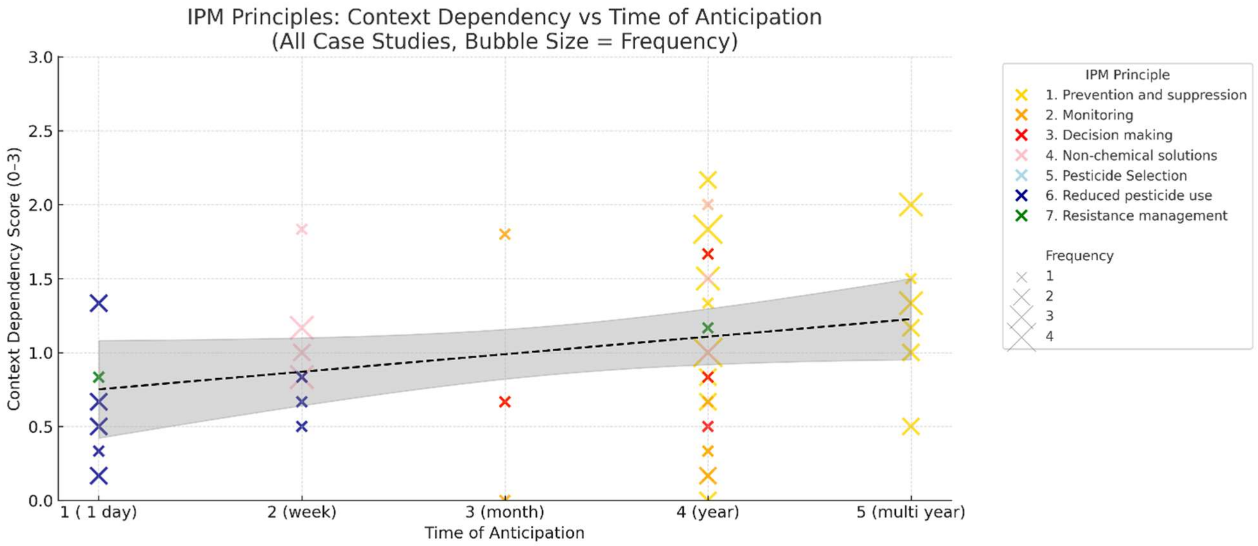

Figure 25: Relationship between Time of Anticipation and context dependency score for all 86 IPM practices across apple–codling moth, grapevine–powdery mildew, and cereals–weeds management case studies. Time of Anticipation is categorised from 1 (1 day) to 5 (multi-year). Bubble size indicates the frequency of the practice across case studies, and colour denotes the corresponding IPM principle. The dashed regression line with shaded confidence interval illustrates the slight positive trend between anticipation time and context dependency.

5.6.6.4. Context Dependency by IPM Principle

The aggregated view (Figure 26, Figure 27) confirms these patterns at the level of overall averages across all case studies. Principles 1, 4, and 7 display the highest mean dependency, while Principle 2 ranks lowest due to the very low value in cereals. This suggests that some principles are consistently more sensitive to non-changeable factors—such as climate, pest biology, and landscape structure—while others are linked primarily to changeable operational parameters, making them easier to implement broadly.

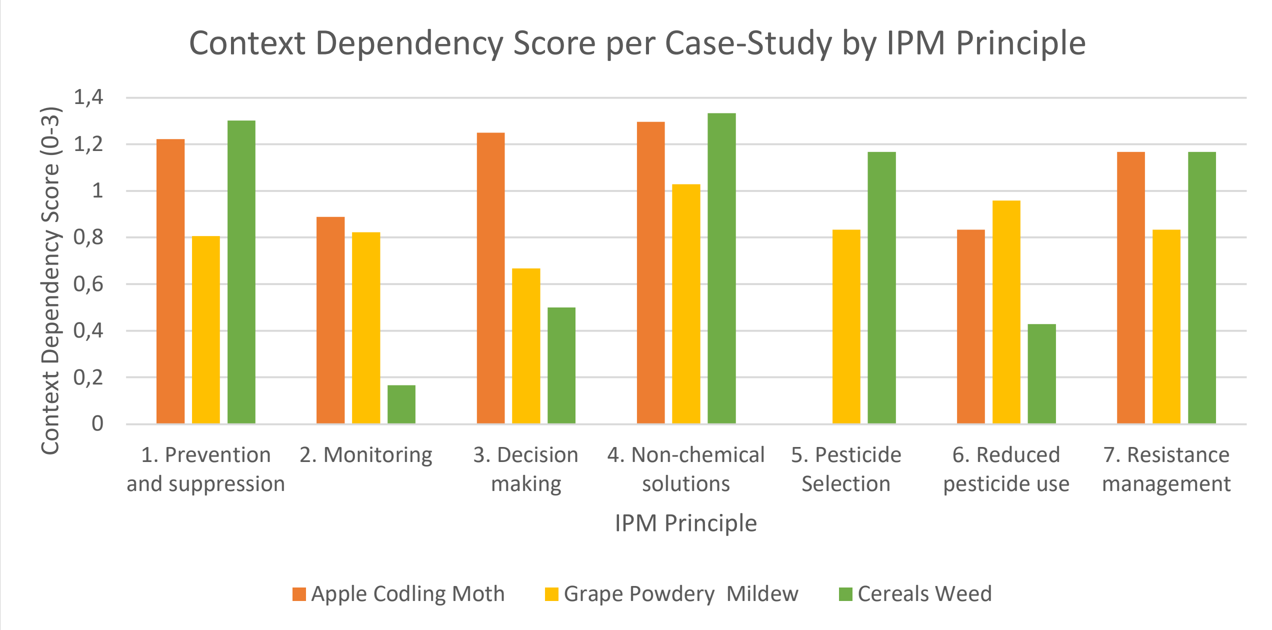

Figure 26: Context dependency scores (0–3) for each IPM principle across three case studies (apple–codling moth, grapevine–powdery mildew, cereals–weeds management). Bars represent mean values per case study, highlighting variation in principle sensitivity to local conditions.

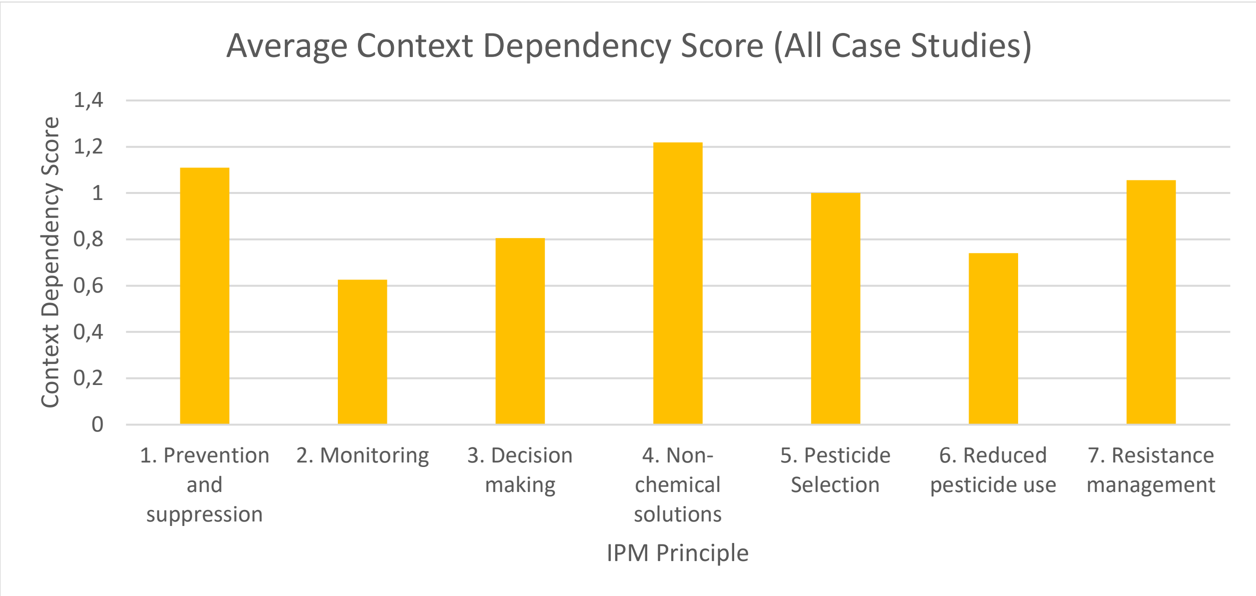

Figure 27: Average context dependency score for each IPM principle aggregated across all case studies. Higher scores indicate greater reliance on non-changeable factors, lower scores indicate dependence on changeable factors, enabling faster and broader implementation.

6. Discussion

6.1 Key Patterns in Context Dependency - Which Context Parameters Influence IPM Efficiency most Strongly?

The analysis of context dependency across systems integrates three complementary evidence sources:

1. results from the literature review on IPM performance factors,
2. aggregated findings from the three case studies (apple – codling moth, grapevine – powdery mildew, cereal systems – weed management), and
3. the sub-factor level assessment linking sub-factor frequency to the system response time.

6.1.1. Dominant and Underrepresented Indicators from Literature and Case Studies

Across both literature and case study datasets, pest pressure & biotic risk context and climate & weather conditions consistently emerge as key determinants of IPM efficiency (Section 5.4, 5.6.6, Figure 22, Figure 23). In all three production systems, spatial variability of pest populations and temporal dynamics were among the most frequently selected parameters (Section 5.6.6.1, Figure 21). The convergence between case study results and the literature is clear: both sources highlight pest population dynamics and climatic variability as primary drivers of control success and failure.

There is also overlap for landscape structure & topography and temporal & legacy effects, but with system-specific nuances:

- In the case studies, landscape structure & topography (particularly field configuration) scored higher in perennial fruit systems than in cereals, likely due to its direct influence on pest dispersal and natural enemy movement in orchards and vineyards (Section 5.6.6.1, Figure 22).
- Temporal & legacy effects (especially management legacies) were more prominent in cereal systems, reflecting the importance of soil seedbank dynamics and past herbicide use in weed management (Section 5.6.6.1, Figure 22).

Some divergences also emerge. biodiversity & ecosystem functions, for instance, is often emphasised in conceptual and narrative literature as a cornerstone of long-term natural pest regulation. However, our systematic review revealed that it was in fact the least represented indicator across empirical European studies (≤ 6 % of reviewed papers). This matches the case study results, where biodiversity was also rarely selected as a dominant factor. **The discrepancy highlights a clear evidence gap: while biodiversity is widely acknowledged as a key principle for sustainable IPM, robust quantitative assessments of its context dependency and short- to mid-term influence on practice efficiency remain scarce.**

6.2. Sub-Factor Analysis and Integration with System Response Time

To add resolution beyond indicator group level, we linked each sub-factor to its system response time category as defined in Table 1. Figure 28 plots the frequency with which each sub-factor was selected in the case studies (y-axis, as percentage of the 86 assessed practices) against its system response time category (x-axis). A higher percentage indicates greater context dependency – i.e., the efficiency of a practice is more sensitive to that sub-factor.

The sub-factor level reveals how broad indicator groups break down into highly specific drivers of IPM performance (Appendices Table 13). For example:

- Pest pressure & biotic risk context → Spatial variability of pest populations (short-term, >75 % share) and temporal dynamics (short-term, ~70 %) dominate; both are highly context-dependent yet can be influenced within a single season through monitoring and tactical interventions.
- Climate & weather conditions → Macro-/microclimatic variables and frequency of extreme weather events show high context dependency but are "not changeable," meaning adaptation, not direct manipulation, is required.
- Soil characteristics & hydrology → several low-to-moderate share sub-factors (e.g., physical and chemical properties, biological activity, water dynamics) are mid-term and more manageable, linking directly to binding policy potential.

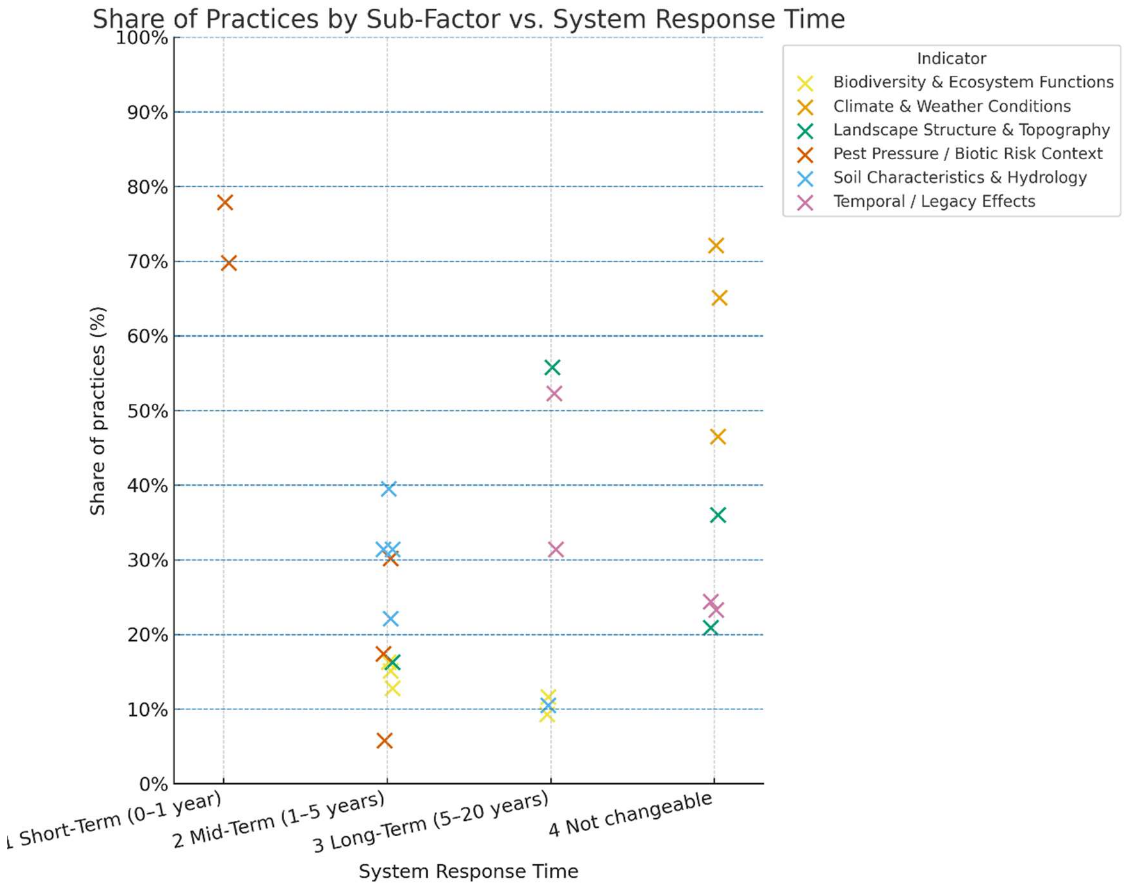

Figure 28 Share of practices (%) for each sub-factor (y-axis) plotted against its System Response Time category (x-axis), based on the classification from Table 1: Subfactors of context parameters, classified by response time. Colours represent the six context indicator groups.

6.3. Implications for Policy Design

Figure 24, together with the classification in Table 4 highlights four main quadrants defined by context dependency (share %) and changeability (System Response Time). From a policy perspective, the most actionable group are short- and mid-term sub-factors with lower context dependency (0–50 %). These can be influenced relatively easily through targeted management, have a shorter adaptation horizon, and are therefore strong candidates for binding implementation. Examples include soil physical and chemical properties, biological activity, water dynamics, the presence of non-crop habitats, beneficial organisms, and certain pest and pathogen characteristics.

Two further categories are better suited for optional implementation:

- Short-/mid-term sub-factors with high context dependency (50–100%), which require more adaptive, site-specific management.
- Long-term sub-factors with low context dependency (0–50%) (excluding “not changeable”), which need longer timeframes to realise benefits.

Parameters in the “not changeable” category, regardless of context dependency, cannot be directly influenced and thus fall outside the scope of binding regulation, though they remain critical for adaptation strategies and resilience planning.

Table 4: Sub-factors grouped by System Response Time (Short-Term, Mid-Term, Long-Term, Not changeable) and context dependency level (low: 0–50 %; high: 50–100 %). This classification links sub-factor frequency from the case study scoring to their temporal responsiveness. Colours indicate levels of policy relevance: green = suitable for binding implementation (short–mid-term, low context dependency), orange = conditional/optional implementation (high dependency or longer anticipation), and red = unsuitable for binding regulation (long-term or not-changeable factors)

		System Response Time			
		Short-Term	**Mid-Term**	**Long-Term**	**Not Changeable**
Share of Percentage of context dependency	**0-25%**		Biological activity	Surface erosion processes	Surroundings
			Presence of non-crop habitats	Functional diversity	Past land use
			Pollinator abundance and diversity	Ecosystem service interactions	System memory effects
			Resistance status of pests		
			Invasiveness of new pest species		
	25-50%		Physical soil properties	Crop rotation history	Seasonal variability
			Chemical properties		Topographical variation
			Water dynamics		

			Decomposer communities		
			Pathogen and pest complexes		
	50-75%	Temporal dynamics		Field configuration	Macro- and microclimatic variables (e.g. temperature, rainfall, seasonal shifts)
				Management legacies	Frequency and intensity of extreme weather events
	75-100%	Spatial variability of pest populations			

6.4. Synthesis and Link to Broader Evidence

By combining evidence from literature, case studies, and sub-factor analysis, a clearer picture emerges of which parameters are both universally relevant and operationally manageable**. Pest population metrics, certain soil properties, and habitat-related features offer the strongest combination of influence, feasibility, and potential for harmonised implementation across Member States.** Climate-driven parameters, while highly relevant, require flexible, adaptive frameworks rather than prescriptive rules. **Biodiversity parameters, though less frequently cited in the case studies, remain strategically important for long-term sustainability and merit further integration into IPM support policies.**

While the cross-case synthesis highlights the most influential context parameters and their general implications for policy and practice, it does not capture the specificities of each production system. The following section examines system-specific differences in context dependency, focusing on how indicator groups and sub-factors vary in relevance across apple, grapevine, and cereal-based systems. This differentiation is essential for understanding why certain IPM practices perform better under specific agronomic, climatic, or structural conditions, and for identifying where tailored implementation strategies may be required.

6.5. System-Specific Differences

While the cross-case synthesis identifies parameters that are generally relevant across IPM systems, their relative importance and the underlying drivers vary between production systems. These system-specific differences are shaped by biological characteristics of the target pest or weed, crop phenology, management cycles, and structural factors such as landscape context and infrastructure. The following comparison details how context dependency patterns diverge between the apple–codling moth, grapevine–powdery mildew, and cereal–weeds systems, and explains these differences considering system-specific constraints and opportunities.

6.5.1. Apple – Codling moth

In the apple–codling moth system, context dependency is dominated by pest pressure & biotic risk context (especially spatial variability and temporal dynamics of pest populations) and climate & weather conditions (macro- and microclimatic variability) (Section 5.6.3.1, Figure 7). Landscape structure & topography also plays a significant role, with factors such as field configuration and surrounding land use influencing pest migration and habitat availability for natural enemies.

Overall, the system shows medium context dependency scores (average 1–1.5), with a clear influence of climatic and phenological processes on the timing and success of control measures. Biodiversity indicators, particularly the presence of natural enemies, have an intermediate role, mainly supporting non-chemical solutions. Compared to the other systems, landscape effects are more prominent in apple than in cereals, and climate influence appears stronger than in grapevine due to the codling moth's temperature-dependent phenology.

6.5.2. Grapevine – Powdery Mildew

The grapevine–powdery mildew system also ranks climate & weather conditions and pest pressure as its most influential indicators, but here the focus lies on microclimatic conditions within the canopy and seasonal disease dynamics (Section 5.6.4.1, Figure 12). Disease complexes are more prominent than in apple, reflecting the interaction of powdery mildew with other fungal pathogens.

Average context dependency is moderate to high (1–2), and canopy microclimate emerges as a decisive factor for disease development. Biodiversity scored low in the case study data, despite the literature emphasising its long-term role in pest regulation – **likely reflecting the indirect and multi-year nature of these effects.** Monitoring practices show the widest spread in context dependency, with some measures being highly site-specific (e.g. trap thresholds) and others more universal. Landscape is moderately important, less so than in apple but more than in cereals.

6.5.3. Cereals – Weeds

In cereals–weed management, pest pressure remains a top indicator, but temporal / legacy Effects (management legacies, crop rotation history) and soil characteristics & hydrology are far more prominent than in perennial systems (Section 5.6.5.1, Figure 16). These factors directly shape weed population dynamics through crop sequencing, soil fertility, and water management.

Climate plays a smaller role compared to apple and grapevine, reflecting the flexibility of annual cropping cycles. Landscape and biodiversity indicators score very low, suggesting that landscape-scale weed suppression and biodiversity-driven control are not widely integrated into current cereal weed management strategies. Monitoring practices display very low context dependency, indicating high robustness across sites. The system is characterised by stronger control through changeable management parameters rather than fixed environmental constraints. Table 5 provides a comparative overview of the three systems, highlighting the top context dependency indicators, unique system drivers, and key policy levers.

Table 5: System-specific differences in context dependency of IPM practices across the three case studies. The table summarises the most influential indicators, unique system drivers, and

corresponding policy levers for apple–codling moth, grapevine–powdery mildew, and cereals–weed management.

System	Top Indicators (highest context dependency)	Unique Drivers	Key Policy Levers
Apple – codling moth	• Climate & Weather Conditions • Pest Pressure / Biotic Risk Context (spatial variability, temporal dynamics) • Landscape Structure & Topography	• Temperature-dependent pest phenology • strong influence of surrounding land use, • relevance of natural enemy habitats	• Landscape management (buffer strips, habitat provision) • climate-adapted timing of control • targeted monitoring
Grapevine – powdery mildew	• Climate & Weather Conditions (microclimate, seasonal variability) • Pest Pressure (temporal dynamics, disease complexes)	• Canopy microclimate effects • interaction with other fungal pathogens • variable monitoring sensitivity	• Canopy management (leaf removal, pruning) • microclimate monitoring • disease forecasting
Cereals – weeds	• Pest Pressure (weed species composition, emergence) • Temporal / Legacy Effects (rotation history, management legacies) • Soil Characteristics & Hydrology	• Crop sequencing impact • soil fertility and moisture regime • low landscape/ biodiversity influence	• Crop rotation planning • soil health management • weed population monitoring

6.5.4. Comparative interpretation

Perennial systems (apple and grapevine) share a strong dependency on climate and pest pressure due to the continuous presence of host plants and multi-year pest or disease cycles. However, apple management is more influenced by landscape structure, while grapevine performance is more sensitive to microclimatic variation within the canopy and specific disease complexes.

In contrast, the annual cereal system relies more on management history and rotation-based weed suppression, with comparatively low influence from climate and landscape variables. This greater reliance on changeable parameters provides more flexibility for uniform implementation but also requires consistent crop management planning.

6.6. Principle-Specific Differences

The aggregated analysis across all three case studies reveals that context dependency is not evenly distributed across IPM principles (Figure 27). Principles 1 (Prevention & Suppression), 4 (Non-chemical Solutions), and 7 (Resistance Management) show the highest average dependency scores, indicating a stronger reliance on local biophysical and structural factors such as climate variability, pest biology, and landscape configuration. These factors are only partly changeable in the short term and therefore require more site-specific adaptation for effective implementation.

In contrast, Principle 2 (Monitoring) consistently records the lowest context dependency scores, driven by its very low value in the cereals–weeds case study. Monitoring measures are generally linked to changeable parameters—such as trap placement, frequency of scouting, and threshold calibration—that can be implemented broadly and adjusted quickly without being constrained by non-changeable environmental conditions.

Principle 3 (Decision-making) holds an intermediate position. The empirical averages show relatively high dependency on climate (2.0), while other indicators remain low (soil 0.25, biodiversity 0.25, temporal 1.0). This indicates that decision-making is partly constrained by non-changeable factors but is still largely shaped by controllable elements such as the availability and quality of local data, decision support systems, and advisory capacity. As such, this principle can be rolled out broadly but may require regional calibration in areas with strong climatic constraints.

Principle 5 (Pesticide selection) displays heterogeneous results. Soil and climate dependencies are negligible, yet pest pressure scores are consistently very high (2–3). Because pest dynamics are only partly controllable, pesticide selection cannot be considered fully dependent on changeable parameters. Instead, its effectiveness hinges on careful adaptation to local pest complexes. This suggests that Principle 5 is suitable for conditional implementation, with flexibility required in regions of high or unpredictable pest pressure.

Principle 6 (Reduced pesticide use) shows low context dependency overall. Soil, biodiversity, and temporal dependencies remain very low (<0.5), with slightly higher values for pest pressure (1.5). Since these factors are largely controllable through operational adjustments such as spray timing or application technique, this principle is well suited for binding implementation in most contexts.

Linking these findings to the **“changeable vs. not changeable”** framework Table 1 confirms that:

- Principles 2 and 6 are predominantly dependent on changeable parameters, making them suitable candidates for binding implementation across contexts. Their low context dependency means that they can be rolled out broadly with minimal adaptation.
- Principle 3 is intermediate: although partly influenced by non-changeable climatic conditions, it remains largely responsive to controllable parameters and thus can be implemented widely but should allow for regional calibration.
- Principle 5 depends strongly on pest pressure, which is only partly controllable. It is therefore best considered a conditional candidate for binding implementation, with adaptation required in pest-intensive regions.
- Principles 1, 4, and 7 are more often influenced by non-changeable or long-term ecological factors, suggesting that they may require a regionalised or optional implementation approach. This would allow adaptation to specific climatic zones, pest complexes, and landscape configurations while still promoting uptake where conditions are favourable.

From a policy design perspective, these principle-level differences complement the system-specific analysis presented above**. Together, they highlight that robust regulation will require a dual lens: one focusing on the inherent responsiveness of practices within each production**

system, and another on the degree to which entire IPM principles are shaped by changeable versus fixed context factors.

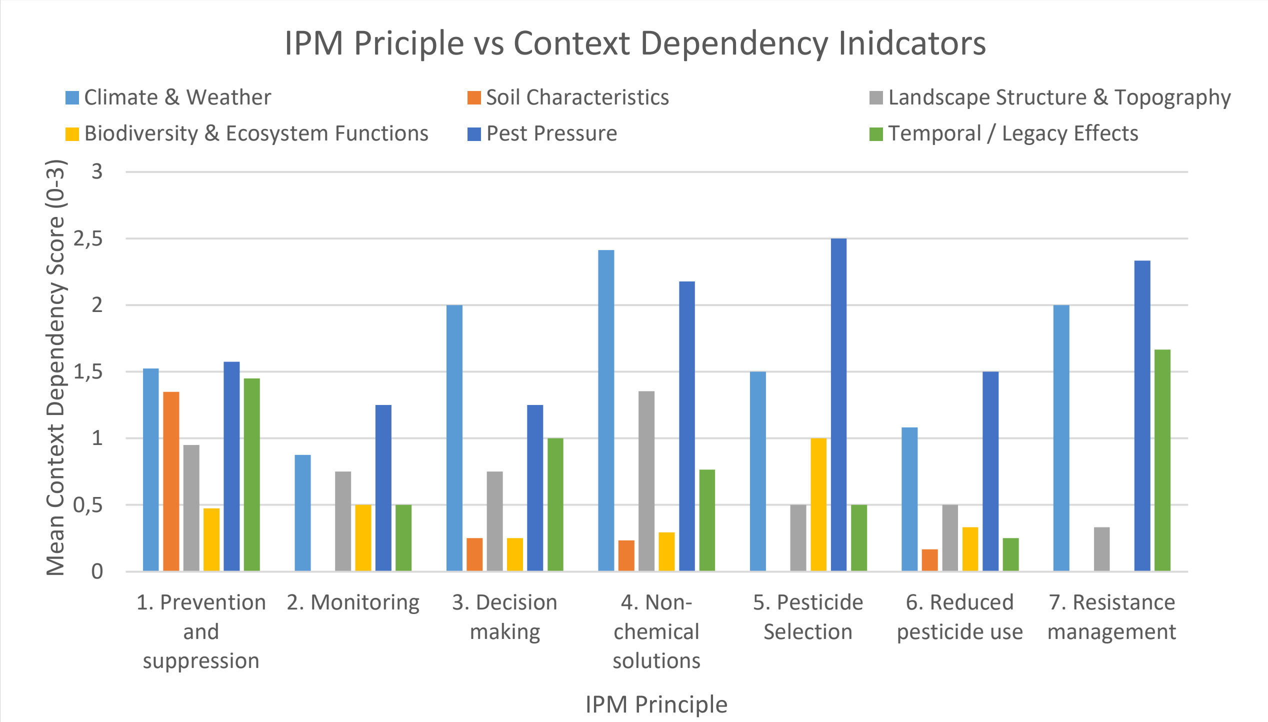

Figure 29: Average context dependency scores per IPM principle across the six context indicator groups

6.7. Integration with Agronomic Service Provided (ASP)

Building on the quadrant classification of ASP versus context dependency (Figure 24) and the anticipation patterns by IPM principle (Figure 25), the analysis positions each practice within a framework that considers both technical performance and practical rollout horizons. This combined perspective allows for a targeted policy approach, distinguishing between practices suitable for immediate binding rules and those better suited to optional or region-specific uptake.

Category 1 – Low dependency / Low ASP

- Low agronomic benefit and minimal context sensitivity make these practices of low strategic importance. They should remain optional and be promoted only as complementary actions or for niche objectives.

Category 2 – Low dependency / High ASP

- Short–mid-term anticipation: Practices in this group deliver high agronomic benefits with predictable performance across a wide range of contexts. They are strong candidates for binding implementation without the need for extensive adaptation.
- Long-term anticipation: Still suitable for binding rules, but benefits will accrue over several years. A phased introduction is recommended to align expectations with realistic implementation timelines.

Category 3 – High dependency / Low ASP

- These measures combine limited agronomic benefits with high context dependency, making them the least suitable for broad regulation. They should be avoided in EU-wide frameworks, except in very specific local conditions where they have proven effectiveness.

Category 4 – High dependency / High ASP

- Short–mid-term anticipation: High-benefit practices that depend strongly on local conditions. Suitable for targeted binding only in regions where enabling conditions are known and present.
- Long-term anticipation: Performance is highly variable, and uptake requires adaptive management and supportive infrastructure. These measures should remain optional, supported through eco-schemes, incentives, and advisory services.

Table 6: Policy-Matrix: ASP–Context Dependency Categories and Time of Anticipation. Thresholds applied: ASP (low = 0–1.49, high = 1.50–3.00), context dependency (low = 0–1.49, high = 1.50–3.00), anticipation horizon (short-term = 1–2, mid-term = 3–4, long-term = 5). Example practices are drawn from the apple–codling moth, grapevine–powdery mildew, and cereals–weeds case studies. Practices are referenced by their corresponding IPM principle: P1 = Prevention & suppression, P2 = Monitoring, P3 = Decision making, P4 = Non-chemical solutions, P5 = Pesticide selection, P6 = Reduced pesticide use, P7 = Resistance management.

Category	Anticipation Horizon	Policy Implication	Example Practices (Case Study, Principle)
Category 2 – Low dependency / High ASP	Short–Mid-term	Binding implementation	Apple: Mating disruption (P4); Grapevine: Disease prediction model (Vitimeteo) (P3); Cereals: Field observations (P2), Precision spraying equipment (P6)
	Long-term	Binding (phased introduction)	Grapevine: Resistant cultivars (P1); Apple: Insect-proof nets (P4); Cereals: Crop rotation sequences (P1, phased impact)
Category 4 – High dependency / High ASP	Short–Mid-term	Targeted binding in suitable regions	Apple: Pest & disease prediction models (P3); Cereals: Mechanical weeding (P4)
	Long-term	Optional with support via incentives	Cereals: Intercropping (species mixtures) (P1); Apple: Sterile insect technique (SIT) (P4); Cereals: Crop rotation history (P1)
Category 1 – Low dependency / Low ASP	Any	Optional / voluntary uptake	Apple: Removal of dropped fruit (P1); Grapevine: Spray placement efficiency (P6); Cereals: Seed treatment – steeping (P1)
Category 3 – High dependency / Low ASP	Any	Not recommended except in specific niches	Apple: Alternation of actives (P7); Cereals: Weed-specific pesticide selection (P5)

This integrated classification supports the core AGROWISE objective of aligning IPM policy design with both effectiveness and feasibility. By jointly considering agronomic performance, context sensitivity, and time to impact, policymakers can prioritise measures that are both impactful and realistically implementable across the diversity of EU farming systems.

7. Conclusions

This deliverable (D3.3) aimed to develop and apply a robust framework for quantifying the biophysical and agronomic context dependency of IPM and agroecology-based practices across contrasting European farming systems. In doing so, it responds to the urgent policy need for science-based criteria to determine which practices can be made binding under EU pesticide reduction targets, and which require flexibility or adaptation to local conditions. The analysis explicitly focused on six biophysical and agronomic drivers — 1) climate and weather, 2) soil characteristics and hydrology, 3) landscape structure and topography, 4) biodiversity and ecosystem functions, 5) pest pressure and biotic risk, and 6) temporal or legacy Effects—while deliberately excluding socio-economic and institutional factors to isolate the ecological dimension of variability.

Methodological approach

The framework was built on a systematic literature review and structured into the six main indicator groups, each further broken down into sub-factors. A standardised 0–3 scoring scale was developed to assess how strongly each indicator influences the performance of a given practice. This scale was applied to three case studies — apple–codling moth, grapevine–powdery mildew, and cereals–weeds — selected from the harmonised IPM taxonomy and efficiency assessments in WP2. For each practice, scores were assigned across all six indicators, averaged to obtain an overall context dependency score, and combined with the ASP metrics and Time of Anticipation. This allowed for cross-case synthesis and the classification of practices into four ASP–dependency categories, providing the basis for binding vs. optional rule considerations.

Main findings

Across literature and case study evidence, pest pressure / biotic risk context and climate and weather conditions consistently emerged as the most influential indicators of IPM performance. Sub-factors such as *spatial variability of pest populations*, *temporal pest dynamics*, and *macro- and microclimatic variables* were repeatedly linked to high context dependency across systems. In cereals, soil characteristics & hydrology and temporal / legacy effects played a larger role, while perennial fruit systems (apple and grapevine) showed higher relevance of landscape structure & topography and, to a lesser extent, biodiversity & ecosystem functions.

The relationship between ASP and context dependency was generally weak, confirming that both dimensions must be considered jointly. High agronomic benefits can occur in both low- and high-dependency contexts, and conversely, low ASP practices may be either broadly robust or highly site-specific. Time of Anticipation showed only a modest trend toward higher context dependency with longer implementation horizons, with substantial variability within each anticipation class.

Policy-relevant synthesis

By combining ASP, context dependency, and anticipation time, four policy-relevant categories emerged:

- **Category 1 – Low dependency / Low ASP**: Low strategic priority; remain optional or complementary.
- **Category 2 – Low dependency / High ASP**: Immediate candidates for **binding implementation**, especially for short–mid-term measures where high performance is consistently achievable across contexts. Long-term measures in this category remain binding but may require phased roll-out.
- **Category 3 – High dependency / Low ASP**: Least suitable for EU-wide regulation; only recommended under specific local conditions.
- **Category 4 – High dependency / High ASP**: High-value practices, but context-sensitive. Binding only where enabling conditions are met; otherwise supported through optional schemes and targeted advice.

This classification provides a transparent, evidence-based logic for deciding where binding rules are justified and where optional or conditional uptake is more appropriate. It also highlights the importance of anticipation time as a practical constraint — short–mid-term, low-dependency practices are easier to scale quickly, whereas long-term, high-dependency measures require sustained policy support and adaptive frameworks.

Limitations

The analysis focused solely on biophysical parameters and did not capture socio-economic or policy-related barriers to implementation. While this isolation was intentional to ensure comparability across Member States, it limits the ability to fully predict adoption feasibility.

Furthermore, some IPM principles and cropping systems were under-represented in the dataset, constraining the statistical robustness of certain comparisons. In addition, context dependency was assessed at a single point in time; seasonal and interannual variability may further influence these relationships.

Future Work

Building on this biophysical framework, the next step is to integrate socio-economic and institutional dimensions—including labour requirements, cost-effectiveness, and market access—into the classification of practices. Expanding the dataset to include more diverse cropping systems, pest complexes, and geographic regions will improve the representativeness of results. Refinement of sub-factor scoring, coupled with long-term monitoring, will help capture dynamic shifts in context dependency under climate change and evolving pest pressures. Ultimately, linking this framework to practical advisory tools and financial incentives under the CAP—including eco-schemes, agri-environmental commitments, investment supports, and risk management instruments—can ensure that binding rules are both ambitious and realistic, aligning EU pesticide reduction targets with the realities of European farming.

Policy Context

The results of this deliverable align directly with the EU's Farm to Fork Strategy, which sets the objective of a 50 % reduction in the use and risk of chemical pesticides by 2030, and with the Sustainable Use of Pesticides framework (SUD/SUR), which provides the legislative basis for achieving these goals. They highlight the need for crop- and site-specific rules to be embedded within the broader framework of the Common Agricultural Policy (CAP)—through eco-schemes, agri-environmental commitments, investment supports, and other financial instruments—as well as in National Action Plans, ensuring that practices are implemented where they are most effective. At the same time, they point to the challenge of balancing harmonisation—necessary for fairness and comparability across Member States—with the flexibility required to adapt to diverse agronomic and ecological conditions. Addressing this balance will be key to designing effective, equitable IPM regulation in Europe.

8. Appendices

8.1. Framework Analysis

Table 7: This table summarises nine key frameworks addressing context dependency in IPM and agroecological practices. Context factors are categorised into environmental, agronomic, socio-economic, and policy/institutional domains, providing a detailed view for integration into AGROWISE Task 3.4.

Framework / Source	Context factors (environmental, agronomic, socio-economic, policy)	Scaling	Level	Relevance / Gaps for AGROWISE
Barzman et al. 2015 – Eight IPM Principles	Environmental: Indirect climate factors (e.g., weather influencing pest thresholds), biodiversity (natural enemies), soil conditions (crop rotation impacts). Agronomic: Cropping system design, crop rotation, prevention tactics, pest monitoring and thresholds, reduced pesticide use strategies. Socio-economic: Farmer advisory services, information exchange, market incentives influencing adoption. Policy/institutional: Core EU IPM directive (2009/128/EC), mandatory adoption of eight principles, risk-reduction policies.	Qualitative; high-level principles, no measurable scoring system	Field + System (EU policy framework)	Provides baseline EU IPM guidance; lacks explicit parameter-level context differentiation; no quantitative scoring.
Deguine et al. 2021 – Agroecological Crop Protection (ACP)	Environmental: Climate variability, biodiversity enhancement, landscape-scale habitat management. Agronomic: Emphasis on agroecological redesign, multi-pest prevention strategies, crop diversification. Socio-economic: Participatory approaches, farmer knowledge integration, community-led innovation. Policy/institutional: Highlights gaps in conventional IPM policy; advocates systemic change beyond current EU frameworks.	Qualitative; systemic paradigm with no explicit metric	Field + Landscape + Social (transition processes)	Strong conceptual orientation; excellent for integrating ecological and social context; requires translation into quantitative indicators and IPM taxonomy.

Stenberg 2017 – Conceptual IPM Science	Environmental: Biodiversity interactions (plant resistance, natural enemies). Agronomic: Integration of multiple pest management tactics (e.g., biological control + resistant varieties). Socio-economic: Limited focus; indirectly assumes farmer uptake of integrated methods. Policy/institutional: Not explicitly addressed; framework is research-oriented and method-agnostic.	Qualitative; focuses on synergies among tactics, not context per se	Field/System	Conceptual foundation for integrating tactics; lacks context granularity and policy/socio-economic linkage.
Finger et al. 2024 – Sustainable Crop Protection Framework	Environmental: Climate and soil variability influencing pest pressure and IPM effectiveness. Agronomic: Bundles of practices; indicator-based measurement of IPM intensity and outcomes. Socio-economic: Farmer behaviour, adoption costs/benefits, market forces, advisory networks. Policy/institutional: Explicit link to EU pesticide reduction targets; supports context-adjusted policy indicators.	Quantitative; proposes context-adjusted indicators for adoption and effectiveness	System + Policy (EU-wide analysis)	Provides robust quantitative method; highly relevant to design measurable context scoring (0–3) for AGROWISE.
Cassart et al. 2025 – Heuristic Framework for Agroecological Transition	Environmental: Covers all six bio-physical dimensions (climate, soil, landscape, biodiversity, pest pressure, legacy). Agronomic: Farming system characterisation, crop rotations, management practices in conservation agriculture. Socio-economic: Knowledge networks, farmer collaboration, market conditions, social capital. Policy/institutional: Governance structures, policy incentives, institutional barriers and levers for agroecological transition.	Qualitative; heuristic checklist covering context, actors, barriers/levers	Field + Network + Policy	Comprehensive context mapping; excellent for scoping; lacks quantitative scaling, needs integration with indicator frameworks like Finger 2024.
Han et al. 2024 – 3MP Framework	Environmental: Seasonal climate dynamics, biodiversity (natural enemies), pest interactions across temporal scales.	Conceptual; integrates spatial and temporal	Field/System (spatial-temporal integration)	Adds dynamic (time-space) dimension; valuable for complex pest scenarios;

(Multi-Dimensional IPM)	Agronomic: Multi-pest management tactics, integration of soil–crop–pest–natural enemy networks. Socio-economic: Limited (focuses on ecological rather than social drivers). Policy/institutional: Not explicitly addressed; primarily ecological framework.	dynamics, no fixed scale		lacks policy and socio-economic context, needs operationalisation.
Ryalls et al. 2024 – Meta-analysis Apple IPM	Environmental: Pest guild-specific responses (tissue-chewing vs. sap-sucking), biodiversity impacts. Agronomic: IPM adoption intensity scoring (number of IPM facets used); cultural, biological, chemical tactics. Socio-economic: Not explicitly considered; meta-analysis across diverse study contexts. Policy/institutional: Indirect – draws from global literature; not tied to EU frameworks.	Quantitative; meta-analysis uses effect sizes and IPM adoption levels (1–4 facets)	Field (study-level synthesis)	Strong empirical evidence of context dependence; crop-specific but methodology adaptable; missing explicit socio-economic and policy layers.
Alkema et al. 2019 – Push–Pull Context Dependence	Environmental: Behavioural response to infochemicals varies with climate (diurnal/seasonal), biodiversity (natural enemies). Agronomic: Push–pull tactics in fruit systems (trap crops, repellents/attractants). Socio-economic: Not addressed; focuses on pest–environment interactions. Policy/institutional: Not covered; tactic-specific framework without governance perspective.	Qualitative; micro-ecological (behavioural) focus, no general scoring	Field (tactic-specific)	Relevant for fine-scale pest control behaviour; not generalisable for full IPM systems or policy decisions.
Stastny et al. 2025 – Regional Adaptation of IPM (Forestry)	Environmental: Climate zones, host tree/pest interactions, biodiversity differences across regions. Agronomic: Transfer of IPM tactics across forestry systems; scaling to new crop/host types. Socio-economic: Cultural practices, institutional capacity, stakeholder engagement. Policy/institutional: Regional regulations, cross-border knowledge transfer, adaptive management policies.	Qualitative; structured evaluation for transferring IPM programs between regions	Regional / Landscape	Excellent template for context transfer; needs adaptation for agricultural IPM and quantitative scaling to fit AGROWISE framework.

Table 8: A detailed overview of all six context dependency indicator groups and their references

Indicator Group	Parameter	Sources (frameworks + additional literature)
Climate & Weather	Macro- and microclimatic variables (temperature, rainfall, seasonal shifts)	Deguine et al. 2021; Simić et al. 2024; Tonnang et al. 2017
	Frequency and intensity of extreme weather events	Tonnang et al. 2017
	Seasonal variability	Deguine et al. 2021; Simić et al. 2024
Soil Characteristics & Hydrology	Physical soil properties (texture, structure, compaction)	Lechenet et al. 2017; Brévault & Clouvel 2019
	Chemical properties (pH, nutrient availability, salinity)	Lechenet et al. 2017
	Biological activity (soil biota, microbial life)	Brévault & Clouvel 2019; Duru et al. 2015
	Water dynamics (drainage, soil moisture, waterlogging)	Lechenet et al. 2017
	Surface erosion processes (impact on soil structure, pest habitat, runoff)	Fernandes et al. 2020
Landscape Structure & Topography	Field configuration (size, shape, orientation)	Holland et al. 2016; Petit et al. 2020
	Non-crop habitats (hedgerows, buffer strips, flower strips)	Holland et al. 2016; Wyckhuys et al. 2024
	Topographical variation (slopes, elevation differences)	Petit et al. 2020
	Surroundings (neighbor farms, drift)	Holland et al. 2016
Biodiversity & Ecosystem Functions	Natural enemies (predators, parasitoids)	Duru et al. 2015; Alexandridis et al. 2021
	Pollinator abundance and diversity	Duru et al. 2015
	Decomposer communities (soil fauna, fungi, bacteria)	Duru et al. 2015
	Functional diversity of agroecosystems	Alexandridis et al. 2021
	Ecosystem service interactions	Duru et al. 2015
Pest Pressure & Biotic Risk Context	Spatial variability of pest populations	Cardim Ferreira Lima et al. 2020; Preti et al. 2020
	Temporal dynamics (seasonal patterns, outbreak cycles)	Cardim Ferreira Lima et al. 2020
	Pathogen and pest complexes	Preti et al. 2020
	Resistance status of pests	Cardim Ferreira Lima et al. 2020
	Invasiveness or emergence of new pest species	Wyckhuys et al. 2024
Temporal / Legacy Effects	Past land use	Simić et al. 2024
	Crop rotation history	Simić et al. 2024
	Management legacies (past pesticide/fertiliser use, tillage practices)	Duru et al. 2015

	System memory effects (long-term ecological impacts)	Duru et al. 2015

8.2. Literature Search Strategy

8.2.1. Scopus Search String

```
TITLE-ABS-KEY(
 (
  (
   ("integrated"
   OR "biological"
   OR "agroecological"
   OR "agro-eco*"
   OR "cultural"
   OR "mechanical"
   OR "alternative"
   OR "ecologic*")
   AND ("pest" OR "weed" OR "disease")
   AND ("management" OR "control")
  )
  OR IPM
  OR IWM
  OR IDM
  OR "resistance manegement"
  OR "economic threshold*"
 )
 AND
 (
  "effectiveness" OR "efficiency" OR "performance" OR "evaluation" OR "assessment"
 )
 AND
 (
  "context dependenc*" OR "context-dependent" OR "context dependent" OR
  "site-specific" OR "site specific" OR
  "location-specific" OR "location specific" OR
  "system-specific" OR "system specific" OR
  region* OR transferab*
 )
)
AND PUBYEAR > 2009 AND PUBYEAR < 2026
AND (
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  LIMIT-TO (AFFILCOUNTRY, "Italy") OR
  LIMIT-TO (AFFILCOUNTRY, "Spain") OR
  LIMIT-TO (AFFILCOUNTRY, "Germany") OR
  LIMIT-TO (AFFILCOUNTRY, "France") OR
  LIMIT-TO (AFFILCOUNTRY, "Netherlands") OR
  LIMIT-TO (AFFILCOUNTRY, "Switzerland") OR
  LIMIT-TO (AFFILCOUNTRY, "Sweden") OR
  LIMIT-TO (AFFILCOUNTRY, "Belgium") OR
  LIMIT-TO (AFFILCOUNTRY, "Greece") OR
```

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   LIMIT-TO (AFFILCOUNTRY, "Denmark") OR
   LIMIT-TO (AFFILCOUNTRY, "Poland") OR
   LIMIT-TO (AFFILCOUNTRY, "Austria") OR
   LIMIT-TO (AFFILCOUNTRY, "Finland") OR
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   LIMIT-TO (AFFILCOUNTRY, "Czech Republic") OR
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   LIMIT-TO (AFFILCOUNTRY, "Romania") OR
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   LIMIT-TO (AFFILCOUNTRY, "Slovenia") OR
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   LIMIT-TO (AFFILCOUNTRY, "Slovakia") OR
   LIMIT-TO (AFFILCOUNTRY, "Albania") OR
   LIMIT-TO (AFFILCOUNTRY, "Luxembourg")
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   LIMIT-TO (SUBJAREA, "ENVI")
)
AND (
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   LIMIT-TO (DOCTYPE, "re")
)
AND LIMIT-TO (LANGUAGE, "English")
```

8.2.2. Web of Science Search String

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   OR "cultural"
   OR "mechanical"
   OR "alternative"
   OR "ecologic*")
   AND ("pest" OR "weed" OR "disease")
   AND ("management" OR "control")
  )
  OR "IPM"
  OR "IWM"
  OR "IDM"
  OR "resistance manegement"
  OR "economic threshold*"
 )
```

```
 AND
 (
  "effectiveness" OR "efficiency" OR "performance" OR "evaluation" OR "assessment"
 )
 AND
 (
  "context dependenc*" OR "context-dependent" OR "context dependent" OR
  "site-specific" OR "site specific" OR
  "location-specific" OR "location specific" OR
  "system-specific" OR "system specific" OR
  region* OR transferab*
 )
)
```

8.2.3. Filters Applied

- **Publication years:** 2010–2025
- **Document types:** Article OR Review Article
- **Countries/Regions:** England, Italy, Germany, Spain, France, Netherlands, Switzerland, Belgium, Sweden, Denmark, Austria, Portugal, Greece, Scotland, Poland, Czech Republic, Finland, Norway, Ireland, Luxembourg, Slovakia, Romania, Croatia, Wales, Slovenia, Hungary
- **Web of Science Categories:** Agronomy, Entomology, Environmental Sciences, Ecology, Plant Sciences, Parasitology, Biodiversity Conservation, Biotechnology

8.2.4. Results from the Literature Analysis

Table 9: Positive Results from the Systemic Literature Analysis

Author	Year	Title	DOI	Dataset	Climate & Weather	Soil Conditions	Landscape Structure & Topography	Biodiversity & Ecosystem Functions	Pest Pressure / Biotic Risk Context	Temporal / Legacy Effects
Abad J.; Marín D.; Santesteban L.G.; Cibriain J.F.; Sagüés A.	2020	Under-vine cover crops: Impact on weed development, yield and grape composition	10.20870/OENO-ONE.2020.54.4.4149	Both	Yes	Yes	no	no	no	no
Adrakey H.K.; Malembic-Maher S.; Rusch A.; Ay J.-S.; Riley L.; Ramalanjaona L.; Fabre F.	2022	Field and Landscape Risk Factors Impacting Flavescence Dorée Infection: Insights from Spatial Bayesian Modeling in the Bordeaux Vineyards	10.1094/PHYTO-10-21-0449-R	Both	no	no	yes	no	yes	no
Antoniou P.P.; Gizi D.; Tjamos S.E.; Tjamos E.C.	2020	Recent achievements in the application of soil solarization against soilborne pathogens in outdoor and covered organic or IPM vegetable crops in Greece	10.17660/ActaHortic.2020.1270.16	Scopus	yes	no	no	no	no	no
Anzalone A.; Ramírez-	2011	Mulch evaluation for weed control on		Both	Yes	no	no	no	no	no

Guerrero H.; Lugo J.; Cirujeda A.; Zaragoza C.; Aibar J.		integrated tomato production; [Evaluación de cubiertas de suelo para el control demalezas en la producción integrada de tomate]								
Athanassiou C.G.; Kavallieratos N.G.; Vayias B.J.; Tomanović Ž.; Petrović A.; Rozman V.; Adler C.; Korunic Z.; Milovanović D.	2011	Laboratory evaluation of diatomaceous earth deposits mined from several locations in central and southeastern Europe as potential protectants against coleopteran grain pests	10.1016/j.cropro.2010.10.004	Scopus	yes	no	no	no	no	no
Bangemann L.-W.; Westphal A.; Zwerger P.; Sieling K.; Kage H.	2014	Copper reducing strategies for late blight (Phytophthora infestans) control in organic potato (Solanum tuberosum) production	10.1007/BF03356498	Scopus	yes	no	no	no	yes	no
Benelli G.; Ricciardi R.; Cosci F.; Iodice A.; Ladurner E.; Savino F.; Lucchi A.	2023	Sex Pheromone Aerosol Emitters for Lobesia botrana Mating Disruption in Italian Vineyards	10.3390/insects14030270	Both	no	no	yes	no	no	no
Beris, E; Papachristos, D; Ponchon, M; Caca, D;	2024	The effects of temperature on pathogenicity of entomopathogenic	10.1016/j.cropro.2023.106542	WoS	yes	no	no	no	no	no

Kontodimas, D; Reineke, A		fungi for controlling larval populations of the European grapevine moth (Lobesia botrana) (Lepidoptera: Tortricidae)								
Bousselin X.; Lorin M.; Valantin-Morison M.; Fustec J.; Cassagne N.; Baux A.	2024	Determinants of oilseed rape-service plant intercropping performance variability across a farmers' fields network in Western Switzerland	10.1007/s13593-024-00972-6	Both	yes	no	no	no	no	no
Boutagayout A.; Bouiamrine E.H.; Synowiec A.; Oihabi K.E.; Romero P.; Rhioui W.; Nassiri L.; Belmalha S.	2025	Agroecological practices for sustainable weed management in Mediterranean farming landscapes	10.1007/s10668-023-04286-7	Both	yes	yes	yes	yes	yes	yes
Bregaglio S.; Savian F.; Raparelli E.; Morelli D.; Epifani R.; Pietrangeli F.; Nigro C.; Bugiani R.; Pini S.; Culatti P.; Tognetti D.; Spanna F.; Gerardi M.; Delillo I.;	2022	A public decision support system for the assessment of plant disease infection risk shared by Italian regions	10.1016/j.jenvman.2022.115365	Both	yes	no	no	no	no	no

Bajocco S.; Fanchini D.; Fila G.; Ginaldi F.; Manici L.M.										
Brooker R.W.; Bennett A.E.; Cong W.-F.; Daniell T.J.; George T.S.; Hallett P.D.; Hawes C.; Iannetta P.P.M.; Jones H.G.; Karley A.J.; Li L.; Mckenzie B.M.; Pakeman R.J.; Paterson E.; Schöb C.; Shen J.; Squire G.; Watson C.A.; Zhang C.; Zhang F.; Zhang J.; White P.J.	2015	Improving intercropping: A synthesis of research in agronomy, plant physiology and ecology	10.1111/nph.13132	Both	yes	no	yes	no	no	no
Caruso G.; Carputo D.; Conti S.; Borrelli C.; Maddaluno P.; Frusciante L.	2013	Effect of mulching and plant density on out-of-season organic potato growth, yield and quality		Scopus	yes	ja	no	no	yes	no
Cayuela L.; Hernández R.; Hódar J.A.;	2014	Tree damage and population density relationships for the	10.1016/j.foreco.2014.05.051	Scopus	yes	no	no	no	no	no

Sánchez G.; Zamora R.		pine processionary moth: Prospects for ecological research and pest management								
Cayuela L.; Hódar J.A.; Zamora R.	2011	Is insecticide spraying a viable and cost-efficient management practice to control pine processionary moth in Mediterranean woodlands?	10.1016/j.foreco.2011.01.022	Scopus	no	no	no	no	yes	no
Christina M.; Negrier A.; Marnotte P.; Viaud P.; Mansuy A.; Auzoux S.; Techer P.; Hoarau E.; Chabanne A.	2021	A trait-based analysis to assess the ability of cover crops to control weeds in a tropical island	10.1016/j.eja.2021.126316	Scopus	yes	no	no	no	no	no
Ciaccia C.; Kristensen H.L.; Campanelli G.; Xie Y.; Testani E.; Leteo F.; Canali S.	2017	Living mulch for weed management in organic vegetable cropping systems under Mediterranean and North European conditions	10.1017/S1742170516000016	Scopus	no	no	no	no	yes	no
Colbach N.; Schneider A.; Ballot R.; Vivier C.	2010	Diversifying cereal-based rotations to improve weed control. Evaluation with the AlomySys model quantifying the effect of cropping systems on a	10.1684/ocl.2010.0331	Scopus	no	no	no	no	no	yes

		grass weed								
Cotes B.; Rämert B.; Nilsson U.	2018	A first approach to pest management strategies using trap crops in organic carrot fields	10.1016/j.cropro.2018.05.025	Both	no	no	no	no	yes	no
Cotes, B; Campos, M; Pascual, F; Ruano, F	2010	The Ladybeetle Community (Coleoptera: Coccinellidae) in Southern Olive Agroecosystems of Spain	10.1603/EN09160	WoS	no	no	yes	no	no	no
Di Ilio, V; Cristofaro, M	2021	Polyphenolic extracts from the olive mill wastewater as a source of biopesticides and their effects on the life cycle of the Mediterranean fruit flyCeratitis capitata(Diptera, Tephriditae)	10.1007/s42690-020-00224-6	WoS	no	no	no	no	yes	no
Didelot F.; Caffier V.; Orain G.; Lemarquand A.; Parisi L.	2016	Sustainable management of scab control through the integration of apple resistant cultivars in a low-fungicide input system	10.1016/j.agee.2015.10.023	Both	no	no	no	no	yes	no
Djian-Caporalino, C; Navarrete, M; Fazari, A; Baily-Bechet, M;	2019	Design and assessment of innovative Mediterranean vegetable cropping systems to manage		WoS	no	yes	no	yes	no	no

Marteu, N; Dufils, A; Tchamitchian, M; Lefèvre, A; Pares, L; Mateille, T; Tavoillot, J; Palloix, A; Sage-Palloix, AM; Védie, H; Goillon, C; Castagnone-Sereno, P		root-knot nematodes								
Dugan I.; Pereira P.; Defterdarovic J.; Filipovic L.; Filipovic V.; Bogunovic I.	2023	Straw Mulch Application Enhanced Soil Properties and Reduced Diffuse Pollution at a Steep Vineyard in Istria (Croatia)	10.3390/land12091691	Both	yes	yes	yes	no	no	no
Dvořák P.; Tomášek J.; Kuchtová P.; Hamouz K.; Hajšlová J.; Schulzová V.	2012	Effect of mulching materials on potato production in different soil-climatic conditions		Both	yes	yes	yes	no	no	no
Etxebeste, I; Sanchez-Husillos, E; Alvarez, G; Gisbert, HMI; Pajares, J	2016	Dispersal of Monochamus galloprovincialis (Col.: Cerambycidae) as recorded by mark-release-recapture using pheromone traps	10.1111/jen.12278	WoS	no	no	yes	no	no	no
Farinós G.P.; De La Poza M.;	2012	Susceptibility to the Cry1F Toxin of Field	10.1603/EC11213	Scopus	yes	yes	yes	no	no	no

Ortego F.; Castañera P.		Populations of Sesamia nonagrioides (Lepidoptera: Noctuidae) in Mediterranean Maize Cultivation Regions								
Fogliatto S.; Zafferoni G.; Zefelippo M.; De Palo F.; Airoldi G.; Dinuccio E.; Vidotto F.	2024	Feasibility of mechanical rice transplanting in organic Italian rice system	10.1017/S1742170524000188	Scopus	no	yes	no	no	no	no
Freckleton R.P.; Hicks H.L.; Comont D.; Crook L.; Hull R.; Neve P.; Childs D.Z.	2018	Measuring the effectiveness of management interventions at regional scales by integrating ecological monitoring and modelling	10.1002/ps.4759	Both	no	no	yes	no	yes	no
Furlan, L; Vasileiadis, VP; Chiarini, F; Huiting, H; Leskovsek, R; Razinger, J; Holb, IJ; Sartori, E; Urek, G; Verschwele, A; Benvegnù, I; Sattin, M	2017	Risk assessment of soil-pest damage to grain maize in Europe within the framework of Integrated Pest Management	10.1016/j.cropro.2016.11.029	WoS	no	yes	yes	no	no	yes
Ganz M.;	2025	Context dependency	10.1016/j.agee.20	Both	no	no	yes	no	no	no

Ghazoul J.; Jeanneret P.		and differential arthropod responses belie simple agro-ecological management solutions	25.109771							
García-Feced C.; Weissteiner C.J.; Baraldi A.; Paracchini M.L.; Maes J.; Zulian G.; Kempen M.; Elbersen B.; Pérez-Soba M.	2015	Semi-natural vegetation in agricultural land: European map and links to ecosystem service supply	10.1007/s13593-014-0238-1	Both	no	no	no	no	no	no
Gummert A.; Ladewig E.; Bürcky K.; Märländer B.	2015	Variety resistance to Cercospora leaf spot and fungicide application as tools of integrated pest management in sugar beet cultivation - A German case study	10.1016/j.cropro.2015.02.024	Both	no	no	no	no	yes	no
Hausmann J.; Heimbach U.; Gabriel D.; Brandes M.	2024	Effects of regional crop rotations on autumn insect pests in winter oilseed rape	10.1002/ps.7716	Both	no	no	yes	no	no	yes
Hyatt-Twynam S.R.; Parnell S.; Stutt R.O.J.H.; Gottwald T.R.; Gilligan C.A.; Cunniffe N.J.	2017	Risk-based management of invading plant disease	10.1111/nph.14488	Scopus	no	no	no	no	yes	yes
Jaffuel G.; Blanco-Pérez	2018	The evaluation of entomopathogenic	10.1016/j.agee.2018.04.008	Scopus	yes	yes	no	no	no	no

R.; Hug A.-S.; Chiriboga X.; Meuli R.G.; Mascher F.; Turlings T.C.J.; Campos-Herrera R.		nematode soil food web assemblages across Switzerland reveals major differences among agricultural, grassland and forest ecosystems								
Jakubowska M.; Bocianowski J.; Nowosad K.	2018	Seasonal fluctuation of agriotes lineatus, A. Obscurus and A. sputator click beetles caught using pheromone traps in Poland	10.17221/39/2016-PPS	Both	yes	no	no	no	no	no
Koźbiał W.; Lewandowski M.	2025	Hymenopteran Parasitoids of Drosophila suzukii (Diptera: Drosophilidae)	10.1007/s12595-025-00565-5	Scopus	no	no	no	yes	no	no
Lamichhane J.R.; Bischoff-Schaefer M.; Bluemel S.; Dachbrodt-Saaydeh S.; Dreux L.; Jansen J.-P.; Kiss J.; Köhl J.; Kudsk P.; Malausa T.; Messéan A.; Nicot P.C.; Ricci P.; Thibierge J.; Villeneuve F.	2017	Identifying obstacles and ranking common biological control research priorities for Europe to manage most economically important pests in arable, vegetable and perennial crops	10.1002/ps.4423	Both	yes	no	no	no	no	no
Lamichhane	2022	Biological seed	10.1007/s13593-	Both	yes	no	no	no	no	no

J.R.; Corrales D.C.; Soltani E.		treatments promote crop establishment and yield: a global meta-analysis	022-00761-z							
Laurent A.; Makowski D.; Aveline N.; Dupin S.; Miguez F.E.	2021	On-Farm Trials Reveal Significant but Uncertain Control of Botrytis cinerea by Aureobasidium pullulans and Potassium Bicarbonate in Organic Grapevines	10.3389/fpls.2021.620786	Both	no	no	no	no	yes	no
Linhart L.; Moretti B.; Herrera J.C.; Forneck A.	2023	Maximum stomatal conductance rather than stomatal sensitivity to drought differentiates the PIWI grapevine cultivar Souvignier gris from Muscaris and Donauriesling	10.20870/oeno-one.2023.57.2.7307	Scopus	yes	yes	no	no	no	no
Lux S.A.	2014	PESTonFARM - stochastic model of on-farm insect behaviour and their response to IPM interventions	10.1111/jen.12083	Scopus	no	no	no	no	no	no
Lô-Pelzer E.; Aubertot J.N.; Bousset L.; Salam M.U.; Jeuffroy M.H.	2010	SIPPOM-WOSR: A Simulator for Integrated Pathogen POpulation Management of phoma stem canker on Winter OilSeed Rape. II. Sensitivity analysis	10.1016/j.fcr.2010.04.006	Both	yes	yes	yes	yes	no	yes
Lô-Pelzer E.;	2010	SIPPOM-WOSR: A	10.1016/j.fcr.201	Scopus	no	no	no	no	no	no

Bousset L.; Jeuffroy M.H.; Salam M.U.; Pinochet X.; Boillot M.; Aubertot J.N.		Simulator for Integrated Pathogen POpulation Management of phoma stem canker on Winter OilSeed Rape. I. Description of the model	0.04.007							
Mastore, M; Quadroni, S; Rezzonico, A; Brivio, MF	2023	The Influence of Daily Temperature Fluctuation on the Efficacy of Bioinsecticides on Spotted Wing Drosophila Larvae	10.3390/insects14010043	WoS	yes	no	no	no	no	no
Meno L.; Escuredo O.; Rodríguez-Flores M.S.; Seijo M.C.	2021	Looking for a sustainable potato crop. Field assessment of early blight management	10.1016/j.agrformet.2021.108617	Both	yes	no	no	no	yes	no
Merot A.; Smits N.	2024	Explaining yield dynamics during vineyard conversion to organic farming	10.1016/j.eja.2023.127068	Both	no	yes	no	no	no	no
Merz U.; Lees A.K.; Sullivan L.; Schwärzel R.; Hebeisen T.; Kirk H.G.; Bouchek-Mechiche K.; Hofferbert H.R.	2012	Powdery scab resistance in Solanum tuberosum: An assessment of cultivar×environment effect	10.1111/j.1365-3059.2011.02489.x	Both	no	no	no	no	no	no
Pavli O.I.; Stevanato P.; Biancardi E.;	2011	Achievements and prospects in breeding for rhizomania	10.1016/j.fcr.2011.03.019	Scopus	no	no	no	no	yes	no

Skaracis G.N.		resistance in sugar beet								
Paz Luna A.; Bintanel H.; Viñuela J.; Villanúa D.	2020	Nest-boxes for raptors as a biological control system of vole pests: High local success with moderate negative consequences for non-target species	10.1016/j.biocontrol.2020.104267	Both	no	no	no	no	yes	no
Pinke G.; Giczi Z.; Vona V.; Dunai É.; Vámos O.; Kulmány I.; Koltai G.; Varga Z.; Kalocsai R.; Botta-dukát Z.; Czúcz B.; Bede-fazekas Á.	2022	Weed Composition in Hungarian Phacelia (Phacelia tanacetifolia Benth.) Seed Production: Could Tine Harrow Take Over Chemical Management?	10.3390/agronomy12040891	Both	yes	yes	no	no	no	no
Pisante M.; Stagnari F.; Grant C.A.	2012	Agricultural innovations for sustainable crop production intensification	10.4081/ija.2012.e40	Scopus	no	no	no	no	no	no
Plećaš M.; Gagić V.; Janković M.; Petrović-Obradović O.; Kavallieratos N.G.; Tomanović T.; Thies C.; Tscharntke T.; Ćetković A.	2014	Landscape composition and configuration influence cereal aphid-parasitoid-hyperparasitoid interactions and biological control differentially across years	10.1016/j.agee.2013.10.016	Both	no	no	yes	no	no	no
Price C.S.V.;	2024	Spatial Aggregations of	10.3390/insects1	Both	yes	yes	no	no	no	no

Harris W.E.; Forbes E.; Walters K.F.A.		the Grey Field Slug Deroceras reticulatum Are Unstable Under Abnormally High Soil Moisture Conditions	5100819							
Razinger J.; Vasileiadis V.P.; Giraud M.; van Dijk W.; Modic S.; Sattin M.; Urek G.	2016	On-farm evaluation of inundative biological control of Ostrinia nubilalis (Lepidoptera: Crambidae) by Trichogramma brassicae (Hymenoptera: Trichogrammatidae) in three European maize-producing regions	10.1002/ps.4054	Both	yes	no	no	no	no	no
Reimer, M; Ringselle, B; Bergkvist, G; Westaway, S; Wittwer, R; Baresel, JP; van der Heijden, MGA; Mangerud, K; Finckh, MR; Brandsæter, LO	2019	Interactive Effects of Subsidiary Crops and Weed Pressure in the Transition Period to Non-Inversion Tillage, A Case Study of Six Sites Across Northern and Central Europe	10.3390/agronomy9090495	WoS	no	no	no	no	yes	no
Reis A.R.; Ferreira L.; Tomé M.; Araujo C.; Branco M.	2012	Efficiency of biological control of Gonipterus platensis (Coleoptera: Curculionidae) by Anaphes nitens (Hymenoptera: Mymaridae) in cold	10.1016/j.foreco.2012.01.038	Scopus	yes	no	no	no	no	no

		areas of the Iberian Peninsula: Implications for defoliation and wood production in Eucalyptus globulus								
Royo-Esnal A.; Recasens J.; Garrido J.; Torra J.	2018	Rigput Brome (Bromus diandrus Roth.) Management in a No-Till Field in Spain	10.3390/agronomy8110251	Both	yes	no	no	no	no	no
Rubio-Cabetasa M.J.	2012	Present and future trends in peach rootstock breeding worldwide		Scopus	no	yes	no	no	no	no
Runia W.T.; Molendijk L.P.G.; Van Den Berg W.; Stevens L.H.; Schilder M.T.; Postma J.	2014	Inundation as tool for management of Globodera pallida and Verticillium dahlia	10.17660/ActaHortic.2014.1044.22	Scopus	no	yes	no	no	no	no
Schmidt F.; Böhm H.; Piepho H.-P.; Urbatzka P.; Wachendorf M.; Graß R.	2023	Yield stability of silage maize double cropping systems across nine German environments	10.3389/fagro.2023.1235034	Scopus	yes	yes	no	no	no	no
Seid A.M.; Fredensborg B.L.; Steinwender B.M.; Meyling N.V.	2019	Temperature-dependent germination, growth and co-infection of Beauveria spp. isolates from different climatic regions	10.1080/09583157.2018.1564812	Scopus	yes	no	no	no	no	no
Skelsey P.; Rossing	2010	Invasion of Phytophthora infestans	10.1094/PHYTO-06-09-0148	Scopus	yes	no	yes	no	no	no

W.A.H.; Kessel G.J.T.; Van Der Werf W.		at the landscape level: How do spatial scale and weather modulate the consequences of spatial heterogeneity in host resistance?								
Soane B.D.; Ball B.C.; Arvidsson J.; Basch G.; Moreno F.; Roger-Estrade J.	2012	No-till in northern, western and south-western Europe: A review of problems and opportunities for crop production and the environment	10.1016/j.still.2011.10.015	Scopus	yes	no	no	no	no	no
Travlos I.S.; Lysandrou M.; Apostolidis V.	2014	Efficacy of the herbicide GF-2581 (penoxsulam + florasulam) against broadleaf weeds in olives		Scopus	yes	no	no	no	no	no
Uesugi R.; Köneke A.; Sekine T.; Tabuchi K.; Herz A.; Yoshimura H.; Böckmann E.; Shimoda T.; Nagasaka K.	2024	Intercropping and flower strips to enhance natural enemies and control aphids: a comparative study in cabbage fields of Japan and Germany	10.1007/s13355-024-00867-8	Both	yes	no	yes	no	yes	no
Vacas S.; Alfaro C.; Zarzo M.; Navarro-Llopis V.; Primo J.	2011	Effect of sex pheromone emission on the attraction of Lobesia botrana	10.1111/j.1570-7458.2011.01124.x	Scopus	yes	no	no	no	no	no
Vasileiadis V.P.; Dachbrodt-	2017	Sustainability of European winter wheat- and maize-based	10.1016/j.cropro.2016.11.002	Both	yes	no	no	no	no	no

Saaydeh S.; Kudsk P.; Colnenne-David C.; Leprince F.; Holb I.J.; Kierzek R.; Furlan L.; Loddo D.; Melander B.; Jørgensen L.N.; Newton A.C.; Toque C.; van Dijk W.; Lefebvre M.; Benezit M.; Sattin M.		cropping systems: Economic, environmental and social ex-post assessment of conventional and IPM-based systems								
Vasileiadis V.P.; van Dijk W.; Verschwele A.; Holb I.J.; Vámos A.; Urek G.; Leskovšek R.; Furlan L.; Sattin M.	2016	Farm-scale evaluation of herbicide band application integrated with inter-row mechanical weeding for maize production in four European regions	10.1111/wre.12210	Both	yes	yes	no	no	no	no

8.3. Case Study Analysis

Table 10: Apple- Codling Moth Data

IPM Practice	IPM Principle	ASP Score	Time of Anticipation	Climate Score	Soil Score	Landscape Score	Biodiversity Score	Pest Pressure Score	Temporal Effects Score	Context Dependency Score
1.5.1 Management of ecological infrastructure (Promote the impact of naturally occurring beneficial insects such as earwigs and Anthocorids)	1. Prevention and suppression	1	4 (year)	2	1	3	2	1	1	1,666667
1.6.2.2 Removal of infested plant parts - Collecting infested apple fruits (removing / destroying dropped fruit as a reservoir)	1. Prevention and suppression	1	3 (moth)	0	0	2	0	1	3	1
1.6.2.3 Suppression of Pest and Disease Reservoirs (Proximity of potential pest reservoirs (Apple, Pear, crab apple, neighboring orchards, ornamental planting) that can support pests	1. Prevention and suppression	0	4 (year)	0	0	0	3	3	0	1
2.1.1.2 Field observations – oviposition marks on fruits from May on (depending on region)	2. Monitoring	2	4 (year)	0	0	0	0	2	0	0,333333
2.1.1.4 Monitoring with traps / Smart traps	2. Monitoring	2	4 (year)	2	0	1	0	1	0	0,666667
2.1.2.2 Advisory service	2. Monitoring	2	4 (year)	2	0	2	2	2	2	1,666667
3.1.1.1 Use of pest and	3. Decision	2	4 (year)	3	1	1	1	2	2	1,666667

disease prediction models	making									
3.1.3. Thresholds	3. Decision making	2	4 (year)	3	0	0	0	2	0	0,833333
4.1.1 Supplemental Release of Live Beneficials - Cydia pomonella Granulovirus - CpGV	4. Non-chemical solutions	2	3 (moth)	3	0	0	0	3	3	1,5
4.1.1 Supplemental Release of Live Beneficials- Steinernema carpocapse, Steinernema feltiae	4. Non-chemical solutions	2	4 (year)	3	3	1	1	2	2	2
4.1.1. Supplemental release of live beneficials – Trichogramma species	4. Non-chemical solutions	2	2 (week)	3	0	1	0	2	0	1
4.2.2.1 Use of Pheromone Traps - Mating disruption (Pheromone dispensers for insect confusion)	4. Non-chemical solutions	3	3 (moth)	3	0	3	0	2	0	1,333333
4.2.2.1 Use of Pheromone traps – Mass trapping	4. Non-chemical solutions	2	3 (moth)	3	0	3	0	1	0	1,166667
4.2.4.1 Sterilised insect pest or organism – SIT	4. Non-chemical solutions	3	4 (year)	3	0	3	0	2	1	1,5
4.3.1.2 Barriers: Other Physical – Nets - Insect proof nets mesh size (2.4 x 4.8 mm) used to protect orchards from hail	4. Non-chemical solutions	2	4 (year)	0	0	2	2	1	1	1
4.3.1.2 Barriers - cardboard banning (belts) - Cardboard banding applied to the trunks of host trees, works as a trap for codling moth larvae	4. Non-chemical solutions	2	4 (year)	1	0	0	2	2	1	1

4.4.1.2 Biopesticides/Botanical pesticides	4. Non-chemical solutions	2	3 (moth)	2	0	2	0	3	0	1,166667
6.1.1.1 Equipment/pesticide application techniques/machineries – nozzle selection and calibration/ spray drift control technologies - recycling sprayer	6. Reduced pesticide use	2	2 (week)	2	0	1	2	0	0	0,833333
7.1.1.3 Pesticide replacement/rotation – alternation of active ingredients	7. Resistance management	1	4 (year)	1	0	0	0	3	3	1,166667

Table 11: Grape- Powdery Mildew Data

IPM Practice	IPM Principle	ASP Score	Time of Anticipation	Climate	Soil	Landscape	Biodiversity	Pest Pressure	Temporal Effects	Overall Context Score
1.1.1.1. Cultivar and Rootstock Diversity -> Use Resistant And/or Tolerant Cultivars	1. Prevention and suppression	3	4 (year)	1	1	0	0	3	1	1
1.3.2.1. Pruning - Improve air circulation in the canopy to reduce humidity	1. Prevention and suppression	1	4 (year)	2	0	1	0	1	1	0,833333
1.3.2.1. Pruning - reduce shading in the canopy	1. Prevention and suppression	1	4 (year)	2	0	1	0	1	1	0,833333
1.3.2.1. Pruning - Removing	1.	1	4 (year)	2	0	1	0	1	2	1

flag shoots early in the season	Prevention and suppression									
1.3.2.1 Pruning - Partial defoliation of the grape zone for better deposition of fungicides	1. Prevention and suppression	1	4 (year)	2	0	1	0	1	0	0,666667
1.1.3 Crop Selection -> Adaptation to Site Conditions - Slope of the terrain recommended	1. Prevention and suppression	1	5 (multi year)	1	1	1	0	0	0	0,5
2.1.2.2 Assessment -> Advisory Service	2. Monitoring	2	3 (month)	1	0	2	2	2	2	1,8
2.1.1 Monitoring -> Monitoring - First monitoring of the underside of the leaf	2. Monitoring	2	3 (month)	1	0	1	0	2	0	0,666667
2.1.1 Monitoring -> Monitoring - Early monitoring with lab analysis for powdery mildew presence	2. Monitoring	2	3 (month)	0	0	0	0	0	0	0
3.1.1.1. Use of disease prediction models - Decision support system e.g. Vitimeteo Oidium (DE)	3. Decision making	2	3 (month)	1	0	2	0	1	0	0,666667
4.4.1.1 Essential Oils and Plant Extracts - Sweet orange	4. Non-chemical solutions	2	2 (week)	3	0	1	0	1	0	0,833333
4.4.1.1. Essential Oils and Plant Extracts	4. Non-chemical solutions	2	2 (week)	3	0	1	0	2	1	1,166667
4.4.1.2. Natural substances: Biopesticides:	4. Non-chemical	2	2 (week)	3	0	1	0	3	0	1,166667

Fungal extracts of Penicillium chrysogenum and Saccharomyces	solutions									
4.4.1.2. Natural substances: Bio-Pesticides/Botanical Pesticides - Sulfur	4. Non-chemical solutions	3	2 (week)	3	0	1	0	3	0	1,166667
4.4.1.2. Natural substances: Bio-Pesticides/Botanical Pesticides - Bicarbonate	4. Non-chemical solutions	2	2 (week)	2	0	1	0	2	1	1
4.4.1.2. Natural substances: Bio-Pesticides/Botanical Pesticides - Chitosan	4. Non-chemical solutions	2	2 (week)	2	0	1	0	2	0	0,833333
5.1.1. Pesticide selection	5. Pesticide Selection	1	1 (1 day)	2	0	1	0	2	0	0,833333
6.1.2.1 Spray Application - Pesticide dosage – reduced application in resistant varieties	6. Reduced pesticide use	2	1 (1 day)	0	2	2	0	3	1	1,333333
6.1.2.2 Pesticide timing – application start in critical situations from the 3-leaf stage, otherwise from the 5-leaf stage	6. Reduced pesticide use	1	1 (1 day)	2	0	1	0	1	0	0,666667
6.1.2.3 Pesticide Frequency - application intervals adapted to crop growth and weather conditions	6. Reduced pesticide use	1	1 (1 day)	2	0	1	2	2	1	1,333333
6.1.2.4. Spray application: Pesticide and adjuvants placement: Improving spray application efficiency	6. Reduced pesticide use	1	1 (1 day)	1	0	1	0	1	0	0,5

and spray distribution in the canopy										
7.1.1.3. Timing of pesticide application: A treatment of liquid lime sulfur before rainfall in winter	7. Resistance managemen t	1	1 (1 day)	2	0	1	0	1	1	0,833333

Table 12: Cereals- Weed Data

IPM Practice	**IPM Principle**	**ASP Score**	**Time of Anticipatio n**	**Climate**	**Soil**	**Landscap e**	**Biodiversit y**	**Pest Pressure**	**Temporal Effects**	**CD-Score**
1.1.1.1.2 Use Resistant And/or Tolerant Cultivars -> Cultivar monoculture / cultivar mixtures	1. Prevention and suppression	1 - Low	4 (year)	1	1	1	0	3	2	**1,333333**
1.1.2.1.1 Crop Rotation -> Crop sequences	1. Prevention and suppression	3 - Major	4 (year)	3	3	2	1	2	2	**2,166667**
1.1.2.1.2 Crop Rotation -> Relay cropping	1. Prevention and suppression	2 - Moderate	4 (year)	3	3	2	1	2	2	**2,166667**
1.1.2.1. Crop rotation -> service/cover crop (sequential)	1. Prevention and suppression	2 - Moderate	5 (multi year)	3	3	1	1	2	2	**2**
1.1.2.1.4 Crop Rotation -> Fallow (pest suppression through fallow)	1. Prevention and suppression	3 - Major	4 (year)	1	1	0	0	1	1	**0,666667**
1.1.2.2.1 Intercropping -> Crop species mixtures	1. Prevention and suppression	3 - Major	4 (year)	3	3	1	0	2	2	**1,833333**

1.1.2.2.2 Intercropping -> Service/cover crop (spatial)	1. Prevention and suppression	2 - Moderate	4 (year)	3	3	1	0	2	2	**1,833333**
1.1.3 Crop Selection -> Adaptation to Site Conditions	1. Prevention and suppression	1 - Low	4 (year)	3	3	1	0	1	3	**1,833333**
1.1.4.1.2 Use of certified seed -> Physiological value (quick emergence)	1. Prevention and suppression	1 - Low	4 (year)	0	0	0	0	0	0	**0**
1.1.4.1.3 Use of Certified Seed -> Phytosanitary quality (absence of pathogens and weed seeds)	1. Prevention and suppression	0 - Insufficient	4 (year)	0	0	0	0	0	0	**0**
1.1.4.3.1 Seed treatment -> Microbial inoculants	1. Prevention and suppression	1 - Low	4 (year)	0	1	0	0	0	1	**0,333333**
1.1.4.3.2 Seed Treatment -> Steeping / Seed clusters	1. Prevention and suppression	1 - Low	4 (year)	0	0	0	0	0	1	**0,166667**
1.2.1.1 Sowing -> Delay sowing	1. Prevention and suppression	3 - Major	4 (year)	3	2	2	0	2	2	**1,833333**
1.2.1.2 Sowing -> Seeding Depth	1. Prevention and suppression	2 - Moderate	4 (year)	3	2	1	0	2	2	**1,666667**
1.2.1.3.2 Seed Density -> High density (weed prevention)	1. Prevention and suppression	2 - Moderate	4 (year)	3	2	0	0	2	2	**1,5**
1.2.1.4.2 Sown plant spatial arrangement -> Sowing three densified rows	1. Prevention and suppression	2 - Moderate	4 (year)	3	2	0	0	2	2	**1,5**

1.2.1.4.3 Sown plant spatial arrangement -> Sowing positioned on the row and perpendicularity	1. Prevention and suppression	2 - Moderate	4 (year)	0	2	2	0	3	2	**1,5**
1.3.1.1 Soil Cultivation -> Reduced Tillage (Non-Inversion)	1. Prevention and suppression	3 - Major	5 (multi year)	1	3	0	1	1	2	**1,333333**
1.3.1.2 Soil cultivation -> Direct Seed/ Direct Sowing	1. Prevention and suppression	1 - Low	5 (multi year)	2	3	0	1	1	1	**1,333333**
1.3.1.3 Soil Cultivation -> Plough (Inversion)	1. Prevention and suppression	2 - Moderate	4 (year)	1	1	0	0	3	1	**1**
1.3.1.4 Soil Cultivation -> Stale Seed Bed	1. Prevention and suppression	3 - Major	4 (year)	3	3	1	0	3	2	**2**
1.3.2.2.1 Crop topping -> Mechanical Topping	1. Prevention and suppression	2 - Moderate	5 (multi year)	1	1	2	0	1	2	**1,166667**
1.3.2.2.2 Crop topping -> Topping with Flail Mowers or Mulchers	1. Prevention and suppression	2 - Moderate	5 (multi year)	1	0	2	0	1	2	**1**
1.3.3.1.1 Advanced Harvest Technology -> Seed destruction	1. Prevention and suppression	2 - Moderate	5 (multi year)	0	0	0	1	2	0	**0,5**
1.4.1.1. Mulching -> Living Mulch (e.g., cover crops or ground cover)	1. Prevention and suppression	2 - Moderate	5 (multi year)	2	2	0	1	2	2	**1,5**
1.4.2.1.1 Organic Fertilisation -> Compost (animal and plant)	1. Prevention and suppression	1 - Low	5 (multi year)	1	0	0	2	2	2	**1,166667**
1.4.2.2 Balanced	1. Prevention	3 - Major	5 (multi	0	1	0	0	3	2	**1**

fertilisation -> Balanced Mineral Fertilisation	and suppression		year)							
1.4.4 Amendments -> Water Management	1. Prevention and suppression	2 - Moderate	5 (multi year)	3	2	2	1	3	1	**2**
1.5.1.1.3 Creation or Restauration of Habitat for Beneficial Organisms Outside the Production Area -> Field margins	1. Prevention and suppression	2 - Moderate	5 (multi year)	1	1	3	3	3	1	**2**
1.6.2.2.1 Removal of Inoculum Sources -> Removal of plant debris	1. Prevention and suppression	2 - Moderate	5 (multi year)	1	1	3	1	0	2	**1,333333**
1.6.3 Hygiene measures and biosecurity -> Soil Disinfection	1. Prevention and suppression	1 - Low	3 (moth)	0	2	1	0	0	1	**0,666667**
2.1.1.1.1 Monitoring -> Drone-Based Crop and Pest Monitoring	2. Monitoring	2 - Moderate	4 (year)	1	0	0	0	0	0	**0,166667**
2.1.1.2 Monitoring -> Field Observations	2. Monitoring	3 - Major	4 (year)	0	0	0	0	1	0	**0,166667**
3.1 Decision making -> Decision Support Systems & Thresholds (e.g. IPMwise) or Apps & Thresholds	3. Decision making	2 - Moderate	4 (year)	1	0	0	0	0	2	**0,5**
4.3.3.1 Mechanical removal of pests -> Mechanical Weeding	4. Non-chemical solutions	3 - Major	2 (week)	2	1	2	0	3	3	**1,833333**
4.4.1.1 Natural Substances -> Essential Oils and Plant Extracts	4. Non-chemical solutions	1 - Low	2 (week)	2	0	0	0	3	0	**0,833333**
5.1.1 Pesticide	5. Pestice	1 - Low	1 (1 day)	1	0	0	2	3	1	**1,166667**

selection - depending on the weed species, development stage and the temperature requirements of the herbicides	Selection									
6.1.1.1 Adapting Spraying Technology -> Equipment/pesticide application techniques/machineries	6. Reduced pesticide use	2 - Moderate	1 (1 day)	0	0	0	0	1	0	**0,166667**
6.1.1.2 Adapting Spraying Technology -> Mode of Application / Precision Application	6. Reduced pesticide use	1 - Low	1 (1 day)	0	0	0	0	1	0	**0,166667**
6.1.1.3. Precision application	6. Reduced pesticide use	1 - Low	1 (1 day)	0	0	0	0	2	0	**0,333333**
6.1.2.1 Spray Application -> Pesticide Dosage	6. Reduced pesticide use	1 - Low	1 (1 day)	1	0	0	0	2	1	**0,666667**
6.1.2.2 Pesticide timing – adapted to weather conditions, crop growth stage, season	6. Reduced pesticide use	1 - Low	2 (week)	2	0	0	0	2	0	**0,666667**
6.1.2.3 Pesticide dose rates - application rates adapted to the size of the weeds	6. Reduced pesticide use	2 - Moderate	1 (1 day)	1	0	0	0	2	0	**0,5**
6.1.2.4. Pesticide and adjuvants placement	6. Reduced pesticide use	1 - Low	2 (week)	2	0	0	0	1	0	**0,5**
7.1.1.3 Choice of active substances and control agent -> Pesticide	7. Resistance management	1 - Low	3 (moth)	3	0	0	0	3	1	**1,166667**

Replacement/Rotation - sufficient range of active ingredients, active ingredients should be alternated regularly										

Table 13: Sub-Factor Count with Response time and % of total practices

Indicator	**Sub-Factor**	**Response Time**	**Sum**	**% of total practices**
Climate & Weather Conditions	Macro- and microclimatic variables (e.g. temperature, rainfall, seasonal shifts)	4	62	72.1 %
Climate & Weather Conditions	Frequency and intensity of extreme weather events	4	56	65.1 %
Climate & Weather Conditions	Seasonal variability	4	40	46.5 %
Soil Characteristics & Hydrology	Physical soil properties (e.g. texture, structure, compaction)	2	34	39.5 %
Soil Characteristics & Hydrology	Chemical properties (e.g. pH, nutrient availability, salinity)	2	27	31.4 %
Soil Characteristics & Hydrology	Biological activity (e.g. soil biota, microbial life)	2	19	22.1 %
Soil Characteristics & Hydrology	Water dynamics (e.g. drainage capacity, soil moisture levels, waterlogging)	2	27	31.4 %
Soil Characteristics & Hydrology	Surface erosion processes	3	9	10.5 %
Landscape Structure & Topography	Field configuration (e.g. field size, shape, orientation)	3	48	55.8 %
Landscape Structure & Topography	Presence of non-crop habitats (e.g. hedgerows, buffer strips, flower strips)	2	14	16.3 %
Landscape Structure & Topography	Topographical variation (e.g. slopes, elevation differences)	4	31	36.0 %
Landscape Structure & Topography	Surroundings (neighbor farms, drift etc.)	4	18	20.9 %
Biodiversity & Ecosystem Functions	Presence of natural enemies (e.g. predators, parasitoids)	2	14	16.3 %
Biodiversity & Ecosystem Functions	Pollinator abundance and diversity	2	11	12.8 %
Biodiversity & Ecosystem Functions	Decomposer communities	2	13	15.1 %
Biodiversity & Ecosystem Functions	Functional diversity within the agroecosystem	3	8	9.3 %

Biodiversity & Ecosystem Functions	Ecosystem service interactions	3	10	11.6 %
Pest Pressure / Biotic Risk Context	Spatial variability of pest populations	1	67	77.9 %
Pest Pressure / Biotic Risk Context	Temporal dynamics (e.g. seasonal patterns, outbreak cycles)	1	60	69.8 %
Pest Pressure / Biotic Risk Context	Pathogen and pest complexes	2	26	30.2 %
Pest Pressure / Biotic Risk Context	Resistance status of pests to control measures	2	15	17.4 %
Pest Pressure / Biotic Risk Context	Invasiveness or emergence of new pest species	2	5	5.8 %
Temporal / Legacy Effects	Past land use	4	20	23.3 %
Temporal / Legacy Effects	Crop rotation history	3	27	31.4 %
Temporal / Legacy Effects	Management legacies (e.g. past pesticide/fertilizer use, tillage practices)	3	45	52.3 %
Temporal / Legacy Effects	System memory effects (long-term ecological or structural impacts)	4	21	24.4 %

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